CAN THE SPACE SECTOR MEET MILITARY GOALS FOR SPACE?

The Tension Between Transformation and Federal Management Practices

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Military transformation as currently interpreted relies heavily on next-generation satellites to provide U.S. forces with advanced reconnaissance, communications, and navigation. However, the performance of the technology and manufacturing bases supporting production of national-security satellites declined in the years following the collapse of communism. The purpose of this study is to determine whether the technology and manufacturing bases are capable of supporting transformation plans for space.

Satellites built for military and intelligence missions are among the most complex systems ever devised, often requiring 20 years to progress from initial research to full operational status. The technology base for national-security satellites is scattered among a variety of public and private-sector organizations, most notably the major aerospace companies and federally-funded R&D centers. The manufacturing base is concentrated in the private sector. Although key skills are fungible across a range of aerospace activities -- civil, commercial and military -- the workforce engaged in designing, developing and integrating national-security satellites is small, totaling about 100,000 personnel.

The biggest problems facing the national-security space sector are unplanned cost growth, program delays and inability to meet performance goals. These problems are caused mainly by decisions and behavioral characteristics of the federal government, which is the sole source of demand for national-security satellites. Because companies in the sector depend on federal funds for their survival, their operating practices generally reflect the incentives and expectations imposed by the government customer.

Some of the sources of sector problems are structural in nature, and thus beyond the capacity of policymakers to change. These include the government's decentralized decision processes, the mismatch between developmental and political cycles, the uncertainty about future needs, the uniqueness of requirements, and the imposing technology hurdles those requirements present. However, other sources of difficulty are the result of bad policies, which lead to unrealistic cost estimates, excessive performance requirements, schedule slippage, poor management and high workforce turnover. The Bush Administration has moved to correct many of the policy-related problems.

Workforce trends are a perennial concern in the space sector. Some of the factors limiting recruiting and retention of skilled personnel are structural in nature, such as the need for security clearances, the variability of demand, and changing military requirements. But federal policies also impede recruiting and retention, particularly those contributing to destructive competition, uneven program pacing, inadequate compensation and burdensome security procedures. Problems with the private-sector workforce can be largely resolved by addressing these issues, but deficiencies in the public-sector workforce are more deeply rooted.

Despite government efforts to improve the performance of the technology and manufacturing bases, it is not clear that transformation plans can be accomplished in a timely and cost-effective manner. The sense of urgency and discipline that prevailed in Cold War years is largely gone, and there is little continuity or consensus among key federal players concerning goals in space.

Nonetheless, the government could increase the chances of success by developing a better grasp of industrial-base trends, improving workforce incentives, rethinking management assumptions and keeping senior policy positions filled. In addition, Congress should give recent reforms time to work rather than continually changing program plans.

I. CAN THE SPACE SECTOR MEET MILITARY GOALS FOR SPACE?

The armed forces are changing the way they prepare for and wage war, in a complex process called "military transformation." Military transformation has many facets and features, but virtually all of them are linked in some manner to the promise of new technology. Proponents of change argue that by assimilating emerging technologies and linking them to appropriate revisions of doctrine and organization, the military can achieve revolutionary progress in warfighting performance.

Although the concept of military transformation predates Donald Rumsfeld's tenure as defense secretary, he has given the movement for change momentum and focus. One area of particularly heavy emphasis is space. Rumsfeld and his key advisors believe that orbital systems offer unique advantages in providing military forces with timely intelligence, precise targeting, and robust communications.[1]

Few experts would disagree. However, even as ambitious plans to leverage space technology have gained the support of policymakers, a troubling pattern has appeared in the execution of national-security space programs. Every one of the next-generation constellations being developed has encountered unanticipated cost growth, schedule slippage and technical difficulties. The problems are so pervasive that they raise doubts about whether government and industry can successfully execute military plans for space.

Doubts that they can reached a climax in the Spring of 2005, when congressional committees reviewing defense budget requests for the next fiscal year threatened to terminate or drastically scale back several of the Pentagon's most important space initiatives.[2] Among the endangered programs were the nation's next generation of missile-warning satellites, its next generation of photo-reconnaissance satellites, its next generation of secure communications satellites, and its first-ever constellation of space-based radars.

It isn't surprising that such programs face developmental challenges. Not only are they the most technologically complex military systems ever built, but many were burdened with demanding new performance requirements in the aftermath of 9-11 terrorist attacks. Nonetheless, problems have become so widespread and chronic that they threaten to undermine the viability of the entire transformation agenda.

The purpose of this study is to determine the precise character and origin of the difficulties in national-security space. Specifically, it investigates whether the domestic technology and manufacturing base relevant to national-security space programs is adequate to support the goals of military transformation. If it is not, then transformation as currently conceived will have to be rethought. If it is, then policymakers need to understand why the base is performing so poorly. Either way, this study intends to find out what the problem is, and identify remedies.

II. RESEARCH CHALLENGES & ORGANIZATION

The phrase "national-security space" is used to describe federally-funded space activities that support the military and intelligence communities. The systems employed in national-security space missions are usually grouped into three categories: spacecraft (satellites), launch vehicles (rockets), and ground infrastructure. This study is concerned with the technology and manufacturing base supporting production of spacecraft, since that is where most of the development problems are concentrated. While problems sometimes arise in the development of launch vehicles and ground networks, they do not at present pose a challenge to military transformation. Spacecraft problems do.

No complete description of the technology and manufacturing base supporting production of national-security spacecraft is available to the public. The government declines to acknowledge the existence of several so-called "black" space constellations used for electronic eavesdropping, and discloses few details about other satellites used for collecting imagery and relaying intelligence. Even those national-security space systems in the "white" world where programs are officially acknowledged -- such as navigation and missile-warning satellites -- typically have features withheld from the public.

Official secrecy imposes severe limits on what can be discussed in a study such as this one. Government organizations engaged in sensitive work seldom reveal the details of development problems they are facing, and will not participate in private research that could circumvent classification rules. Companies involved in such work operate under similar restrictions, and typically avoid public discussion of issues that might help competitors gain an edge in pursuing government contracts. As a result, it is difficult to characterize precisely the participants in the technology and manufacturing base supporting national-security space, and even harder to dissect the development problems they are encountering.

With so many obstacles to inquiry, there traditionally has been little public discussion of national-security space programs. However, disarray in the sector has now spread to a point where public debate is unavoidable. This study was conceived to contribute constructively to the debate by integrating the content of recent government reports, private research, and numerous interviews with recognized experts. Many of the experts interviewed -- including those on the project's advisory panel -- have held senior posts in government or industry directly relevant to the problems being analyzed.

The study is *not* a complete picture of the technical and managerial challenges national-security space faces, but it contains more detail, more coherently organized, than is common in open-source documents. The main body of the study consists of five sections:

-- A description of the development problems the space sector is encountering, including a discussion of the undesirable consequences those problems could have for military transformation.

-- A delineation of the technology and manufacturing base supporting national-security spacecraft programs, including identification of where the biggest problems seem to be concentrated.

-- An analysis of the budgetary, managerial and technological factors causing the problems, including a forecast of whether the factors are likely to persist (or grow worse) in the future.

-- An assessment of demographic and skill trends within the relevant public and private-sector workforces, including an examination of how government personnel policies contribute to negative patterns.

-- A series of findings concerning the capacity of the space technology and manufacturing bases to achieve the goals of military transformation, including an enumeration of steps the government should take to correct deficiencies.

III. DEFINING THE PROBLEM

The United States has been the dominant force in global space efforts for a generation. It produces most of the world's commercial satellites, sustains the biggest civil exploration program, and spends as much money on national-security activities in space as every other country on earth combined.

The scale and success of U.S. investment in space systems has produced a corresponding dependency on those systems. That is particularly true of the military, which cannot operate effectively in much of the world without continuous access to orbital communications links, reconnaissance sensors and navigation aids. Not only does space offer a unique vantage point from which to support military activities on or near the earth's surface, but orbital systems are far more secure from attack than their terrestrial counterparts.

Operating from space does have drawbacks, starting with the high cost of getting there. But precisely because orbital operations are so expensive and technically challenging, the United States has been able to establish a lead in exploiting space that no other country can pretend to match. When a presidential commission stated in 2001 that the U.S. should aim to field commercial spacecraft a generation more advanced than those of overseas competitors, and national-security spacecraft two generations more advanced, it wasn't merely expressing an aspiration -- it was describing the competitive standing of the U.S. space sector as it then existed.[3]

Space and Military Transformation

Pentagon policymakers and independent experts have long recognized that America's leading role in space confers important military advantages. For example, the 1997 report of the National Defense Panel -- a founding document in the movement for military transformation -- asserted that, "Space power is an integral part of the revolution in military affairs and a key asset in achieving military advantage in information operations." Calling space "the information battle's high ground," the panel argued that, "The United States cannot afford to lose the edge it now holds in military-related space operations."[4]

Donald Rumsfeld shared this view of space's importance when he returned to the Pentagon for a second tour as defense secretary in 2001. Rumsfeld had spent much of the preceding year chairing the Commission to Assess United States National Security Space Management and Organization. The commission's final report, issued just as Rumsfeld was taking office, stated that, "defense and intelligence activities in space will become increasingly important to the pursuit of U.S. national security interests." Noting that the Defense Department and intelligence community were preparing "to replace virtually their entire inventory of satellites and launch vehicles over the next decade or so," the report recommended organizational adjustments aimed at improving management of what promised to be a very ambitious undertaking.[5]

As defense secretary, Rumsfeld implemented most of the commission's recommendations, and repeatedly signaled that he viewed greater use of orbital systems as a core feature of military transformation. The Pentagon's Transformation Planning Guidance issued in April of 2003 identified "enhancing the capability and survivability of space systems and supporting infrastructure" as one of six operational goals of national military strategy.[6] Moreover, space systems played a prominent role in Rumsfeld's framework for pursuing each of the five other goals, from protecting critical bases of operation to countering anti-access strategies to denying enemy sanctuary to conducting information operations to constructing a joint communications and intelligence architecture.

Rumsfeld and his advisors were not content to simply execute the space investment agenda they had inherited from their predecessors. Additional, leap-ahead programs were begun to aggressively develop a constellation of space-based radars that could track the movement of surface vehicles from orbit, and a "transformational communications architecture" that would deliver internet-style information services from space to previously disadvantaged military users. Other new initiatives were funded in the "black" world of space-based intelligence satellites.

By May of 2003, a Defense Science Board task force on the acquisition of national-security space systems could report that every type of national-security satellite constellation except those for signals intelligence and classified communications was "in transition," meaning that next-generation replacements or block upgrades were being developed.[7] This description actually understated the extent of new investment in space, since several different constellations of imagery satellites were being developed simultaneously and the global war on terror had stimulated extensive research into improved electronic eavesdropping from space. Furthermore, all of the new spacecraft families required complex ground segments that could better integrate and exploit the functions of overhead assets.

Signs of Trouble

By the time the Defense Science Board released its report, though, there was evidence that the Pentagon's bold plans for exploiting space were going badly awry. In fact, the report was commissioned precisely because policymakers were concerned about cost growth and schedule slippage in several next-generation space programs. The task force's report found that national security space programs were characterized by excessive technical and schedule risk, unrealistically low cost estimates, and weak government oversight. The report also warned of long-term trends in the space industrial base -- the research and manufacturing capacity supporting space programs -- that could undermine the military's ability to meet its goals for space.[8]

The presidential commission that Secretary Rumsfeld chaired and earlier Defense Science Board task forces had anticipated problems due to poor management practices and fractured organization in the parts of the government charged with developing national-security space systems. However, few experts understood how impaired the space acquisition system had become. In the two years after the Defense Science Board issued its 2003 report, key programs continued to deteriorate, creating a real crisis. By the summer of 2005, several constellations of reconnaissance satellites essential to national-security missions had deployed their last spacecraft, and yet no next-generation satellites were available for placement in orbit. The possibility thus arose that there might be dangerous gaps in missile warning, imagery collection, and other areas.

Congressional observers were particularly concerned that the programs encountering trouble had been inherited from the Clinton years, and thus did not incorporate the more ambitious performance goals established by the Bush Administration in pursuit of military transformation. In their May, 2005 report on the Defense Department's budget request for fiscal 2006, House appropriators asked how the Pentagon could hope to build transformational space systems if it couldn't successfully execute more modest programs that had already been in progress for the better part of a decade. Noting that program performance in national-security space efforts had deteriorated further since the 2003 Defense Science Board report, the appropriators rendered a harsh verdict:

> Rather than slowing down to take stock of the problems, [the Department of Defense] has instead embarked on a path that requires a significant ramp-up in space expenditures over the future year defense plan. Thus, the same space acquisition professionals (both in government and industry) that are struggling to execute the current level of investment will soon face greater challenges managing the additional programmatic content and complexity that comes with the budget ramp-up. Unless DoD takes significant corrective action, the Committee is very concerned that the space acquisition work force may not meet these challenges effectively. In fact, the Committee is concerned whether DoD is in a position to make appropriate choices regarding which programs to pursue given the systemic deficiencies that reduce the availability of good data (cost, technical maturity, acquisition approach, schedule) to senior leadership.[9]

Having concluded that defense decisionmakers might lack the insight to make sound choices, House appropriators recommended drastic cuts in some of the Pentagon's biggest space programs. Similar action was taken by the House armed services and intelligence committees. Their Senate counterparts also moved to reduce the Pentagon request for space, although action by the upper chamber was less severe. Nonetheless, the fiscal 2006 budget cycle was noteworthy for the convergence of views between the two chambers about the seriousness of problems afflicting national-security space. The scale of the difficulties can be grasped by describing three high-priority programs to replace communications, imagery and missile warning constellations.

Advanced EHF System. The Advanced Extremely High Frequency (AEHF) System was conceived during the Clinton years as a successor to the Milstar satellite communications network. Milstar was designed to provide secure, reliable communications to a range of military users around the globe under any circumstances, including nuclear war. It incorporated crosslinks between orbital nodes to minimize the likelihood of interception or jamming, and on-board rerouting of traffic to assure optimum utilization of available bandwidth. AEHF would provide the same security and reliability in satellites with much greater carrying capacity and access. A single AEHF satellite could support thousands of airborne and surface terminals. The Pentagon currently plans to deploy a constellation of three such satellites, although it may buy more.[10]

Following the failure of a launch vehicle in 1999 that stranded a Milstar satellite in a useless orbit, the Defense Department decided to accelerate development of AEHF by 18 months to enable deployment of the first satellite in late 2004. However, the revised acquisition plan made a series of aggressive assumptions about cost and development timetables that proved to be much too optimistic. These mistakes were compounded by the addition of new performance requirements as the system was in development. Within a few years the estimated cost of the program had increased by over a billion dollars while the projected date of launch for the first satellite had slipped 40 months to April of 2008. Delays in developing the AEHF system led congressional oversight bodies to slash funding for the Pentagon's proposed "transformational communications architecture," because they doubted the prudence of pursuing an even more complex system when AEHF was still facing challenges.[11]

Future Imagery Architecture. The Air Force operates two constellations of spacecraft designed to collect imagery of objects on the earth's surface. One constellation consists of satellites collecting imagery in the infrared and visible-light portions of the electromagnetic spectrum. The other consists of satellites generating radar beams whose return signals can be processed into images of lesser resolution. Between them, the two constellations can produce imagery under almost any atmospheric conditions, day or night. But because there are only a handful of satellites in each constellation and they are positioned in low-earth orbit, long periods elapse during which there is no spacecraft within range of important targets. In 1996, the intelligence community conceived a Future Imagery Architecture (FIA) that would replace existing imagery spacecraft with a larger number of smaller satellites offering longer dwell times and faster revisit rates. It would also make greater use of commercial satellite imagery and airborne collectors in an integrated system designed to better serve the needs of diverse consumers.[12]

The Boeing Company won a competition to build the space-based portion of FIA in 1998, displacing Lockheed Martin from its forty-year incumbency as primary supplier of secret imagery satellites. However, Boeing's winning bid proposed very aggressive cost, schedule and performance goals even though it had scant experience with relevant technologies. It soon encountered severe development challenges that resulted in a multiyear delay and the need to add $4 billion to the program's budget. When performance and schedule problems persisted despite a longer development timetable and increased funding, congressional oversight committees began threatening to seek alternatives. Fortunately, the ground network developed to exploit and disseminate imagery from the new satellites is already operational, and enables users to derive greater value from the collections of existing spacecraft.[13]

Space-Based Infrared System. The United States maintains a constellation of missile-warning satellites in geosynchronous orbit called the Defense Support Program (DSP). The satellites monitor most of the earth's surface for bursts of infrared energy that could signal a missile launch, and then relay that information to command centers where it can be correlated with other warning indications. DSP is arguably the most important technical asset in the system of nuclear deterrence, since without it U.S. leaders might be unaware of an attack until it was too late to take the sort of retaliatory measures that deter aggression in the first place. In 1994, members of the military and intelligence communities agreed on a plan to replace DSP with a Space-Based

Infrared System (SBIRS) that would provide improved missile warning while also contributing to missile defense and providing battlefield characterization for tactical users.[14]

The proposed architecture would consist of four primary satellites in geosynchronous orbit plus sensors hosted on eavesdropping satellites in elliptical orbits to cover areas not within range of the primary spacecraft. The geosynchronous satellites would each contain two sensors, one to scan for threats and the other to stare continuously. Legacy satellites only have a scanning capability. But a decade after its inception, SBIRS has encountered a series of setbacks that collectively make it, in the words of the 2003 Defense Science Board report, "a case study for how not to execute a space program." Among other things, the task force found the program to be inadequately funded, poorly managed and burdened with excessive performance requirements. As a result, the projected program cost has nearly tripled from its original estimate of $4 billion and it will be fielded years later than originally intended. Whether it will satisfy its key performance parameters remains to be seen.[15]

It probably is no coincidence that all three of these programs -- AEHF, FIA and SBIRS -- were begun at a time when funding for national-security space efforts was shrinking and the government was experimenting with new acquisition practices. But those days are now long gone, and yet there is little sign of improvement in the system for developing national-security spacecraft. In fact, problems have seemed to grow worse during the Bush Administration, raising doubts about the viability of the technology and manufacturing base supporting national-security space. Because space-based systems play a crucial role in plans for military transformation, the persistence of such problems could undermine the entire agenda for transforming the way America wages war in the future.

Consequences for Transformation

The motive force behind military transformation is a longstanding American belief that new technology can revolutionize human relations. While there is much more to transformation than a single-minded fixation on technology, an examination of the goals advanced by proponents of military change reveals that few could be accomplished without the emergence of new tools for sensing, analyzing, communicating and targeting. Because space offers a unique vantage point from which to apply such breakthroughs, it isn't surprising that the prevailing approach to implementing transformation stresses the value of orbital systems.

Some might argue that this emphasis is arbitrary in that there are other ways to accomplish the missions envisioned for next-generation space systems. For example, unmanned aircraft seem to offer better persistence, precision, flexibility and affordability for most reconnaissance missions than satellites do.[16] However, all of these virtues depend on the ability of unmanned aircraft to transit airspace in hostile or contested areas, a feature that may not be feasible in future conflicts (and that is not feasible in some places today).

Even if access to airspace could be assured, the laws of physics make space-based solutions intrinsically superior to airborne or terrestrial approaches for accomplishing some military missions. Science-fiction writer Arthur C. Clarke saw clearly in 1945 that communications satellites positioned in geosynchronous orbit -- seemingly stationary above a fixed point on the earth's surface -- would have unique properties for relaying communications over vast distances. Because all electromagnetic energy travels at the speed of light (about 300,000 km. per second) in a straight line, Clarke noted, geostationary satellites could convey information instantly to the most remote locations on the earth's surface without encountering the horizon constraints or infrastructure costs of alternatives closer to the ground.[17]

The value of space-based systems is amplified by the emerging concept of network-centric warfare, because the information generation and transmission functions of satellites can be combined with those of other military systems to produce unprecedented synergy. For instance, electro-optical and radar imagery collected by orbital sensors can be combined with imagery from other sources, or correlated with other types of information such as missile-warning indications and signals intelligence, to create a composite picture of a battlespace. The resulting picture can then be made available to military forces anywhere on earth at the speed of light, using communications constellations such as Milstar. The ground segments developed to support the Future Imagery Architecture and the Space-Based Infrared System are designed to fully exploit the potential of networking technology, and both of them are delivering big gains to warfighters even before next-generation spacecraft have been launched.[18]

Unfortunately, the spacecraft associated with those programs aren't faring as well, which raises the question of what it might mean for military transformation if development problems cannot be overcome. Most experts believe that the orbital systems begun during the Clinton era will eventually be deployed, but the spacecraft development experience of recent years doesn't warrant optimism about whether they will offer all the performance features originally planned, or about the prospects for building more transformational follow-on systems. Congress already has terminated an "integrated flight experiment" that was central to the development of space-based lasers, and now is moving to scale back the biggest space initiatives proposed during Secretary Rumsfeld's tenure. It is even threatening to cancel poorly-performing legacy programs.

These trends raise a host of issues for military transformation, given the heavy emphasis that space-based capabilities receive in current plans. First of all, the delays in fielding AEHF and other military communications satellites combined with the unraveling of the Pentagon's proposed transformational communications architecture mean that the military will not have the high-capacity, assured connectivity it was planning for -- at least, not until many years later than expected. Being able to access networks with sufficient bandwidth to carry imagery, video content, and other complex products is a core requirement of information-age warfare. Thus, the defects and delays in current satellite communications programs will severely limit the pace of transformation in the years ahead.

Second, setbacks in the development of intelligence-gathering and reconnaissance satellites inevitably raise doubts about the availability of timely and precise intelligence. Some insiders are complaining about the relatively modest improvement of capability that FIA will deliver, but even that gain is in question given chronic problems in developing spacecraft to host collection sensors. Delays in development of SBIRS will deny tactical units useful reconnaissance about battlefield infrared events such as missile launches and artillery bursts that could be correlated with other types of reconnaissance to form a more complete operational picture. At the strategic level, SBIRS problems potentially undercut both nuclear deterrence and missile defense. Furthermore, the pessimism engendered by faltering performance on these programs has led directly to congressional cuts in the proposed Space Radar, a program central to the Rumsfeld transformation vision because of its revolutionary capacity to track moving targets over vast areas of the earth's surface. Space Radar would also have delivered imagery superior to that generated by FIA radar-imaging satellites.

Third, problems in developing national-security spacecraft potentially undercut the navigational and targeting precision that is a key feature of transformational warfighting. Transformation as currently constructed stresses the importance of finesse over firepower in delivering tailored effects. Not only do such "effects-based" operations enable new concepts of warfare, but they also limit unintended damage that diminishes the political value of employing military force. However, today's highly accurate kinetic and non-kinetic weapons depend on precise positional information and intelligence that is generated from space-based systems. One such system, the Global Positioning System, is increasingly susceptible to jamming by adversaries intent on degrading U.S. accuracy. If the planned GPS III satellite constellation encounters the same development delays seen in some other space programs, that will present a serious problem for military and civilian users counting on its availability.[19]

Fourth, problems in fielding new national-security satellites impede progress on achieving interoperability across the joint force and broader warfighting coalitions. All of the next-generation spacecraft currently experiencing difficulties were conceived to provide support to a wider array of military users than the specialized satellites of Cold War years. For example, the Defense Support Program originally was designed to report missile warning indications only to national command authorities, whereas SBIRS will offer a range of infrared intelligence to many different users. When diverse users rely on the same, versatile system, barriers to awareness and sharing break down in a way that fosters interoperability. Other goals of transformation such as the creation of a common operating picture and the construction of a truly transparent joint logistics network become easier to achieve. So the delay in deploying more capable spacecraft has operational and cultural consequences that transcend the lack of specific functions.

These and other impacts on military transformation underscore the importance of fixing problems in the technology and manufacturing base supporting national-security space. But before the precise sources and solutions for current problems can be identified, it is necessary to define clearly what that base is and how it operates. As the next section demonstrates, the difficulties afflicting national-security space are closely related to the peculiar business relationships and practices prevailing in the sector.

IV. DEFINING THE TECHNOLOGY & MANUFACTURING BASE

The technology and manufacturing base for national-security spacecraft is not big. Although assigning a precise value to its annual revenues is precluded by the secrecy surrounding some programs, it appears to comprise at most about one-tenth of one percent of the gross domestic product, and its workforce claims a similar share of the labor pool -- about 100,000 workers.[20] Most of these personnel are highly skilled employees of a handful of large defense contractors such as Boeing, Lockheed Martin and Northrop Grumman, but many thousands more are scattered across academia, government laboratories, and the specialized companies supplying defense majors.

Although national-security spacecraft are uniquely suited to the needs of the military and intelligence communities, the technologies and skills employed in producing them are not. One of the complexities in defining the relevant technology and manufacturing base is the fungibility of competencies across a variety of potential markets. Companies engaged in developing national-security spacecraft often have related business lines addressing civil and commercial space customers, and it is rare for them to distinguish among programs and customers in reporting financial performance. As a result, it is difficult to determine how the national-security space operations of a particular enterprise are faring from scrutinizing publicly-reported information. A similar problem exists is analyzing federal spending for national-security spacecraft, since funding for "black" intelligence satellites is hidden in unrelated accounts.

The technology and manufacturing base for national-security spacecraft has undergone considerable reorganization since the end of the Cold War. The ranks of "system integrators" capable of producing finished satellites have consolidated into a handful of full-service companies, while the number of companies supplying specialized parts and components to the integrators has shrunk markedly. These trends are mainly a response to declining demand from the government customer following the collapse of communism, but they also reflect the decision of some companies to exit businesses with low margins or growth potential. The customer itself has reorganized during the same period, most notably in the management changes instituted by defense secretary Donald Rumsfeld that vested primary authority for developing national-security spacecraft and launch systems in the Air Force.[21] Rationalization of capacity has unfolded faster in the private sector than in those parts of the public sector engaged in national-security space work, a divergence that creates tensions as government labs and other federal entities encroach on activities traditionally assigned to industry.

The single most important feature of the market for national-security spacecraft is that it is a monopsony dominated by a non-economic customer. The government is the only source of demand for military and intelligence satellites, and it actively discourages contractors from selling related technologies to foreign buyers. The fact that there is only one customer, and that it is not subject to the economic forces shaping private-sector behavior, largely explains the peculiar business dynamics prevailing in the national-security space sector. Other than electing to exit the business, companies have little choice but to conform to whatever structure of incentives the customer presents. They therefore devote considerable effort to trying to influence customer decisions concerning requirements, investment priorities and contract terms. One consequence of this behavior is to exacerbate centrifugal forces already at work within the government, since there are many centers of power in the federal structure and different companies usually want different outcomes.

The decentralized and occasionally capricious behavior of the government customer will be a recurrent theme in the next section, which explains the causes of problems in the technology and manufacturing base. Before performing that analysis though, it is important to understand in greater detail the development stages and business dynamics that shape the space sector.

Technology Thresholds

The most current and complete description of the national-security space sector available in open sources is the *Space Research and Industrial Base Study* produced by Booz Allen Hamilton in 2002 under contract to the Department of Defense. Although that study is already becoming dated due to changes in government spending patterns and the economy, it contains an excellent discussion of the developmental stages involved in producing national-security spacecraft, and how they shape the structure of the sector. The study identifies four "technology horizons" that collectively define the acquisition cycle for military and intelligence satellites:[22]

-- *Basic research* is the initial stage of development, during which thousands of interesting ideas may be investigated to determine their potential applicability to future space systems. At this early stage, government labs, academic institutions and private industry are all engaged in the search for useful concepts and technologies.

-- *Technology development*, or applied research, is the second stage at which more focused development begins, with the number of projects funded shrinking by an order of magnitude -- from thousands to hundreds -- while the amount of money devoted to each surviving project increases significantly. This is the last stage at which academia plays a key role in the acquisition cycle.

-- *Concept demonstration* is the third stage at which the range of ideas being investigated shrinks by another order of magnitude -- from hundreds of projects to mere tens -- but the amount of funding devoted to any given project may become quite sizable. At this point, the main action is concentrated in government labs and industry where complex hardware can be assembled and tested to determine its operational viability.

-- *Fielding systems* is the final stage at which only a handful of the original thousands of ideas have survived, but the decision has been made to deploy operational systems. Each of the surviving spacecraft projects will typically cost in excess of a billion dollars to build, but their projected service life will be sufficiently lengthy to allow repetition of the full acquisition cycle in pursuit of a successor generation.

The authors of the Booz Allen Hamilton study estimated that on average, it would take about five years to complete each of these stages, meaning that the full cycle requires twenty years. Of course, it is quite common to improve fielded systems rather than simply start over, a process that is encouraged by the Bush Administration's emphasis on "spiral" or evolutionary development. Most of the national-security spacecraft constellations currently in service are evolved versions of earlier satellites that have been upgraded to meet new operational requirements or incorporate emerging technologies. However, there is a limit to how much legacy architectures can be improved before they must be replaced to secure all the benefits of new technology, so eventually the acquisition cycle must start over. The Bush Administration's desire to accelerate military transformation has led it to initiate new starts of spacecraft programs before the systems they would replace have even been fielded.

Military transformation as currently constructed may have added a new, fifth stage to the traditional acquisition cycle for spacecraft by requiring that they fit into an overarching, "system-of-systems" architecture.[23] Cold War satellites usually were deployed in stand-alone constellations with minimal links to other military or intelligence systems. In fact, some Cold War constellations weren't even designed to combine the outputs of the individual spacecraft that comprised the constellation. For example, the Defense Support Program had separate and non-convergent downlinks for the missile-warning indications its three satellites generated -- information that only now is being fused through implementation of the ground network for the successor Space Based Infrared System.

But with the advent of "network-centric warfare" -- a core concept in current definitions of military transformation -- all spacecraft will be expected to interface easily with other military systems to form an integrated architecture. Thus, the output of satellites in the Future Imagery Architecture will be combined with imagery from other orbital and airborne collectors through a system called Mission Integration and Development (MIND), and the resulting products in turn will be merged with additional types of intelligence on a network that can be accessed by diverse users.[24] Similarly, Advanced EHF and Wideband Gapfiller communications satellites will be linked into a "global information grid" that assumes the availability of numerous other subsystems to achieve full functionality.

As these examples suggest, the requirements of network-centric warfare add considerably to the challenge of designing and developing next-generation space systems. System engineering and integration skills become even more important than they were in the past, as do software generation and testing capabilities. The complexity of some proposed architectures is so imposing that experts are divided as to whether they can be successfully constructed within existing budgetary and skill constraints. At the very least, emerging warfighting requirements change the composition of the technology base supporting national-security space by putting a premium on competencies relevant to the integration and support of complex networks.

This is a very different set of issues from the concerns that preoccupied policymakers in the decade following the collapse of the Berlin Wall. During the 1990's, the dominant technology concern in national-security space was that declining government demand and sector consolidation would thin the ranks of suppliers for critical technologies such as solar cells and lightweight optics. That concern has not gone away -- the Under Secretary of Defense for Acquisition, Technology & Logistics reiterated it in an interview for this study. However, he argued that erosion in the capacity of domestic sources to supply specialized technology for military and intelligence satellites had less to do with lagging innovation than with policy choices by the government customer.[25]

That assessment is supported by technology data presented in the 2002 Booz Allen Hamilton report. It found the U.S. ahead of foreign competitors in 39 technologies critical to space programs, equal in 13, and lagging in only 3. The report determined that U.S. competitiveness in critical space technologies was closely related to the scale and duration of federal funding for projects requiring such inputs. In other words, the U.S. technology base was robust in areas where the government had invested heavily for many years, and weak in areas where it had invested lightly or sporadically. The technology areas where overseas competitors seemed to be gaining on U.S. providers were those with broad commercial applications such as software generation and photonic signal processing, because in those areas private-sector demand compensated for the lower level of space investment made by foreign governments.[26]

Such findings can hardly be viewed as surprising, since the same report estimated that the federal government provided over 95% of funding for basic research, 85% for technology development, and 70% for concept demonstration in the space sector.[27] Like the big system integrators that assemble finished spacecraft, the small companies, government labs and academic institutions that comprise much of the technology base could not remain active in the sector in the absence of sustained government demand. The health of the technology base for national-security space is thus largely a matter of federal spending priorities (this is especially true given the erosion of demand for commercial spacecraft following the collapse of the telecommunications boom).

Production Capacity

The production base of the national-security space sector overlaps considerably with the technology base. All of the enterprises that integrate finished spacecraft or manufacture major subsystems sustain technical competencies that make them part of the technology base. However, unlike technology activities in the sector, manufacturing activities are concentrated almost entirely in the private sector. In the years since the Cold War ended, the companies comprising the manufacturing base have consolidated vertically and horizontally, acquiring both competitors and suppliers. As a result, there are fewer system integrators left in the sector, but each one has a broad range of competencies.

Initially, merger activity looked likely to reduce the range of choices available to the government customer. When the current decade began, a single company -- Lockheed Martin -- held three-quarters of the market for national-security spacecraft as a result of combining satellite operations from General Electric, Lockheed and Martin Marietta.[28] However, major acquisitions by Boeing and Northrop Grumman strengthened their capacity to compete with Lockheed Martin for new space programs, and they have gradually gained market share at Lockheed Martin's expense. Although Lockheed Martin remains the dominant integrator in the sector today, there is heavy competition among system integrators and the government has a range of capable sources from which to acquire most spacecraft types.

A major consequence of industry consolidation has been to eliminate excess satellite manufacturing capacity. Five years ago, Booz Allen Hamilton estimated that less than half of the existing production capacity for large and medium satellites -- the major weight categories for national-security spacecraft -- was likely to be needed during the period from 2000 to 2015.[29] Today the industry is carrying less unused capacity, which presumably reduces costs to the government customer. On the other hand, consolidation has accelerated the retirement of older workers with decades of experience, and some industry observers think that this trend has been detrimental to quality standards and expertise in the sector. Many older workers participated in a range of programs during the sector's heyday, and thus have insights that more recent hires lack. However, with the mix of skills required for next-generation spacecraft shifting away from those emphasized during the Cold War, the loss of longtime employees isn't necessarily as bad as it seems (workforce issues are addressed in section six below).

The basic structure of the production system for national-security spacecraft resembles the multi-tier supply chain found in other parts of the defense industrial base. System integrators obtain major components and subassemblies from suppliers that specialize in the manufacture of items such as structures, sensors, controls and electrical systems. These "subtier" suppliers in turn acquire pieces and parts that make up their products from other companies further down the supply chain. Experts often refer to this arrangement as a production "pyramid," but that metaphor is misleading since in some cases there are fewer sources of specific components than there are integrators in the sector. While it is true that there are many small technology companies providing specialized inputs to system integrators, the number in any given category of critical input often is only one or two. The narrowness of the subtier supplier base for key items used in spacecraft is a constant source of concern for policymakers.

The production system is in a state of continuous evolution as technology requirements change and companies adjust their business strategies. During the 1990's, system integrators sought to generate more of the inputs to spacecraft internally rather than outsourcing as a way of maintaining revenue levels in the face of declining demand. This practice increased the financial pressures on their suppliers, many of whom elected to exit the sector or be acquired by companies further up in the supply chain. Meanwhile, government laboratories sought to cope with diminished federal spending by growing into areas that traditionally were the preserves of industry, creating additional tension in a shrinking market.

More recently, the growing emphasis on networking and other applications involving information technology has brought an influx of non-traditional suppliers to the manufacturing base. System integrators routinely turn to information-technology powerhouses such as Cisco and Juniper for inputs not available in the traditional supplier community. If the emphasis on network-centric warfare persists, integrators of finished spacecraft will undoubtedly build up more organic capacity to use information technologies as a way of maximizing revenues and maintaining control over markets. That process has already begun, although some observers are skeptical that companies heavily dependent on the government for business can keep up with the pace of innovation in the commercial technology sector.

In the years immediately following the end of the Cold War, policymakers had hoped that a new defense industrial base could be fashioned that relied on dual-use technologies and skills obtained in the commercial world. The space sector was expected to experience rapid growth in demand for commercial spacecraft, enabling users of national-security spacecraft to benefit from faster development cycles, economies of scale, and flexible commercial practices. Most of these hopes have been confounded. Demand for commercial spacecraft collapsed with the dot.com boom, and efforts to apply commercial specifications and practices in national-security space have produced disappointing results.

Policymakers now realize that for the foreseeable future, government will be the dominant source of demand in the space sector. Furthermore, the composition of government demand for spacecraft is likely to be heavily skewed towards national-security missions, given the modest size of the civil space program and the need of the military to deploy a range of new spacecraft. The government customer therefore is making a renewed effort to understand the dynamics of the manufacturing base supporting national-security space, especially in terms of how federal policies help or harm the base. As the next section demonstrates, most of the sector's problems are directly traceable to behavior by the government customer.

V. SOURCES OF DEFICIENT PERFORMANCE IN THE SPACE SECTOR

Having defined the problems facing national-security space and the range of participants comprising the relevant technology and industrial bases, it is now time to ask what the causes of deficient performance are. This section explains why the space sector is chronically afflicted by rising costs, schedule slippage, and technical challenges that threaten the performance of next-generation spacecraft. However, it is not enough to simply identify causes. Since the goal of this study is to determine whether the space sector is capable of executing plans for military transformation, there must also be an assessment of whether the causes can be corrected, and the problems fixed.

The answer, as it turns out, is not so simple. Deficient performance originates in many factors, some of which are beyond the ability of government and industry to change. Others factors can be changed, but the resolve of government and industry to make necessary adjustments is in doubt. The discussion that follows separates the causes of problems into two categories -- "structural" issues that are likely to persist due to the nature of the forces shaping the sector, and "policy" issues that potentially can be resolved by altering the prevailing approach to designing and acquiring spacecraft. The discussion provides an assessment of whether the policy issues influencing sector performance are likely to improve, but treats structural issues as "givens" that simply must be accepted at the present time. A separate section is dedicated to discussing demographic and skill trends in the national-security space workforce.

Although public debate of the problems troubling national-security space often focuses on industry, the analysis here assumes that the underlying causes of most difficulties in the sector are traceable to behavior on the part of the government customer. There are two reasons for taking this approach. First of all, the most important study of the sector's problems conducted in recent times -- that done by the Defense Science Board task force in 2003 -- found no "systemic problems" with the implementation of national-security space programs by industry.[30] While the study identified numerous instances where industry had failed to operate in an optimal fashion, most of these cases were easily explained in terms of requirements and expectations imposed by the federal customer.

A second and related reason for focusing mainly on defects in the customer is the monopsonistic character of the national-security space market discussed in the previous section, which imparts great influence to the customer in driving the practices and performance of its suppliers. Acting Under Secretary of Defense for Acquisition, Technology & Logistics Michael Wynne captured the controlling role of the federal customer in written responses to questions submitted for this study:

> The private sector responds to government and market forces. The space industry is largely driven by the government -- commercial space has played a much smaller role in recent years. Therefore, leadership, continuity, consistency, and stability on the part of the government are primary factors driving the health of the space industrial base. The government needs to understand industry and be a better customer (requirements stability, program stability, personnel stability).

> Similarly the government needs to understand Wall Street's view of the space industry...[31]

Wynne acknowledged important areas where industry needed to improve its performance, such as training strong program managers, embracing best practices, and communicating problems in a timely fashion. But he shared the view of the Defense Science Board that government has considerably more latitude than industry in shaping behavior in the national-security space sector, since it is the sole source of demand and there are multiple potential suppliers for any given type of spacecraft. In other words, companies are so thoroughly the captives of their customer's rules and expectations that even when they appear to be acting purely on their own discretion, the outcome usually can be explained in terms of what they think the government customer wants.

Of course, the government is not all-powerful in the sense that it acts with one mind on any given decision regarding national-security space. Quite the opposite: it often seems divided, uncertain, or dependent on contractor inputs for the decisions it makes. But a serious analysis of why national-security space is in such deep trouble must begin by recognizing that all such weaknesses result from characteristics of the government or policy choices it has made, rather than some power on industry's part to shape outcomes. Industry's behavior is almost entirely a reflection of its efforts to meet investor expectations within a structure of incentives that government has created. Other than its enduring need to generate good rates of return, it will adjust its behavior in whatever manner is required to satisfy the customer. So it is the way that the customer operates that usually explains why things turn out well or poorly in national-security space.

Structural Issues

Some of the underlying causes to deficient performance in the space sector cannot be fixed. They are called structural issues here because they either reflect intrinsic characteristics of government and industry, or are circumstances that originate outside the sector in a manner that is beyond the capacity of policymakers to change. Intrinsic structural issues such as the fragmented nature of decisionmaking in a government of separated powers or the urge of industry to maximize returns will probably never change. They must simply be accepted as inescapable features of the space enterprise. Circumstantial structural issues such as doubts about future military requirements or uncertainties in the development of new technologies will gradually change with the passage of time, but not in a way that policymakers can fundamentally alter.

One of the perennial mistakes that experts make in analyzing the space sector is to propose that such structural issues be corrected. They can't be. Exertions on the part of policymakers may magnify or mitigate the impact of structural factors, but they cannot make them go away. For example, a commonplace complaint among practitioners in the sector is that Congress acts capriciously in funding national-security space programs. There is some truth to the complaint, but Congress isn't likely to abandon its tradition of decentralized decisionmaking simply to improve the efficiency of space programs. Another complaint is that there should be greater stability in performance requirements for space systems, so that spacecraft do not need to be redesigned once they enter advanced development. Greater stability in requirements would certainly help programs to stay on cost and schedule, but how realistic is such a solution at a time when both threats and missions seem to be changing dramatically?

The most policymakers can hope to achieve in coping with structural contributors to sector problems is that the acquisition practices and procedures they put in place will minimize the consequences of such structural influences. But since structural factors cannot be eliminated, they must be recognized as constraints on the performance of the sector -- just as they limit other facets of military and industrial activity. There are at least six such factors currently contributing to difficulties in the sector.

Decentralized decisionmaking. The decentralized organization of Congress and the Executive Branch results in a balkanized, byzantine process for funding and overseeing national-security space programs. On the legislative side, multiple committees in each chamber have major influence in shaping space priorities, and there are few institutional constraints on the behavior of senior members. Individual committees and members often embrace contradictory, idiosyncratic approaches to specific programs that make the formulation of a coherent space agenda nearly impossible. On the executive side, chronic tensions between users with contending needs, and managers with divergent responsibilities, further contribute to the fragmentation of funding and oversight. There is little evidence that the various reorganization plans implemented over the years by the military and intelligence communities have improved the coordination of space efforts. Barring the emergence of an overwhelming and persistent national emergency, the system for funding and overseeing national-security space programs will probably always be a severe drag on sector efficiency.

Mismatched cycles. A second structural issue is the mismatch between political and technology cycles. As noted in the Booz Allen Hamilton study cited in section four above, the product life-cycle for national-security spacecraft consists of a series of technology horizons stretching over decades. It takes many years to design, develop, integrate and deploy satellites as complex as those currently in use by the military and intelligence communities. The migration to network-centric, "system-of-systems" architectures will probably make product cycles even more lengthy. However, the rhythms of the political system are much briefer, usually measured in two or four-year cycles. That means that the senior executives and committee members overseeing a particular satellite program may change many times during the period between basic research and final fielding in orbit. If these influential players have different agendas or priorities than their predecessors, changes may be made to the funding, schedule and performance requirements of the program. Thus, even if the political system was organized to efficiently fund and oversee national-security space programs, the mismatch between political and technology cycles would lead to instability in development efforts.

Industry Goals. Like the previous two issues, the profit motivation of private-sector participants in the space sector is an intrinsic feature of the landscape that probably will never change. Companies must generate returns above cost to remain in business, and their natural inclination is to maximize returns while minimizing risks. When the government customer fashions an effective structure of incentives for its suppliers, the profit motive can be used to drive and discipline their performance. When it fashions a poor structure of incentives, or fails to apply incentives rigorously, the profit motive can lead to undesirable behavior such as excessively optimistic cost estimates or delayed reporting of problems. Either way, it is unrealistic to expect that suppliers will pursue a course of action that reduces returns over the long run unless they have no alternative. Some critiques of industry performance on space programs seem to suggest that industry should be motivated by other considerations, but that view betrays a fundamental misunderstanding of how private enterprises operate in a market economy.

Unique Requirements. A fourth structural constraint on national-security space is the government's apparent inability to achieve economies of scale and other synergies by meeting its needs with products generated in the commercial marketplace. In the years following the end of the Cold War, some policymakers believed that the government would rely on the growing commercial space industry for many of its requirements in the future, and thus avoid the need to sustain a specialized technology and manufacturing base for national-security spacecraft. However, that hope was confounded by a collapse in demand for commercial satellites and a growing realization that national-security needs in space were likely to remain very different from those of the private sector. While the skills and technologies required to build spacecraft are often fungible across market segments, there is little private demand for the kinds of services provided by systems such as Space Radar and the Future Imagery Architecture. In addition, security concerns impede the sharing of technologies and facilities even when there is a confluence of public and private demand, as in the case of the Global Positioning System. So rather than promoting an integrated market for space products, the government has been forced to accept the necessity of a dedicated national-security space sector with unique standards, specifications, system architectures and performance expectations.

Uncertain Requirements. A different kind of structural constraint arises from the unsettled character of the contemporary global security environment. Unlike the preceding structural issues, which reflected intrinsic features of the political, economic and technological landscape, the present uncertainty about future military and intelligence requirements is probably a temporary condition. During the Cold War, requirements changed relatively slowly, and usually in ways that could be anticipated well in advance of when new capabilities were needed. Today, however, there is great doubt among policymakers about the nature of future threats facing the nation, and efforts to construct a "capabilities-based" defense posture that can address diverse dangers have spawned more confusion than clarity. The reason this presents a challenge for the space sector is that new requirements -- or new ideas about requirements -- arise much faster than the space acquisition system is capable of responding. Unfortunately, there is no way of avoiding the resulting instability, because it reflects geopolitical trends at work in the global environment rather than management choices within the purview of policymakers.

Technology Hurdles. A final structural factor contributing to problems in the space sector is the need to assimilate new technologies that may not be mature or fully understood. This challenge has existed since the dawn of the space age, because every new generation of spacecraft incorporates features never attempted before, and space is a uniquely difficult operating environment. But the technology hurdles may be higher in national-security space today, in part due to the profusion of emerging technologies with potential national-security applications and in part due to the very ambitious expectations that policymakers have for future satellites. As noted in the previous section, the performance requirements for some spacecraft linked to military transformation are so imposing that there is debate among experts as to whether they are executable within existing budgetary and skill constraints. They probably are, but the technology hurdles that must be overcome are a continuous issue in keeping programs on schedule and within budget.

Surveying the various structural factors that limit the performance of national-security space programs, it isn't hard to see why such programs periodically present policymakers with unpleasant options. However, many observers believe that policy choices the government has made exacerbate the impact of structural issues, or cause other problems that are wholly avoidable. Since these policy-driven difficulties may ultimately make the difference between meeting and not meeting the goals of military transformation in space, it is important to understand their causes and potential remedies.

Policy Issues

Policy changes are the main remedy available to the government for correcting deficiencies in the technology and manufacturing bases supporting national-security space activities. Since the government is the only source of demand for domestically-produced military and intelligence satellites, the way in which it goes about acquiring such systems potentially has a profound impact on the progress of programs and the behavior of suppliers. To the extent that there are structural constraints on the success of space initiatives, policy choices can magnify or mitigate the consequences of those constraints.

However, it is difficult to sort out how specific policies shape program outcomes, because policy choices do not exist in isolation. Each new regulation concerning bidding procedures, design specifications, testing requirements and the like is assimilated into a pre-existing framework of rules, practices, customs and expectations in a way that may confound predictions of its impact. Furthermore, the lengthy development cycles prevailing in the sector mean that proposed remedies to a problem must be in place for years before their value can be assessed -- during which time additional actions to fix the problem by an impatient political system may thoroughly confuse the question of which remedies are working, and why.

Because of the way that new policies interact with pre-existing rules and conditions, it isn't feasible to track the effects of specific policies through the system. Outcomes will almost always reflect some combination of interrelated causes rather than the impact of a single policy initiative. Recognizing that fact, the analysis here begins by identifying the most frequently-cited defects of the present system, and then describing the cumulative effect of various policies deemed by experts to have contributed to the defects. Five defects are considered: (1) unplanned cost growth, (2) excessive performance requirements, (3) unanticipated schedule slippage, (4) poor program management, and (5) government workforce instability.

Cost Growth. Unanticipated cost growth is a chronic problem in national-security space programs. Virtually every military and intelligence satellite system currently in development has seen cost escalation well beyond planned budgets, and in some cases the increases total billions of dollars. The Government Accountability Office traces the problem to a lack of fiscal discipline on the part of federal managers, stating in a June 2005 report that the Defense Department "starts more programs than it can afford over the long run, forcing programs to underestimate costs and overpromise capability."[32] Similar sentiments were expressed by the Defense Science Board task force on acquisition of national-security space programs in 2003. One of the task force's key findings was that, "The space acquisition system is strongly biased to produce unrealistically low cost estimates throughout the acquisition process." The task force asserted that, "These estimates lead to unrealistic budgets and unexecutable programs."

Such findings imply that there is a collusive relationship between contractors and the government customer, one in which participants to the bidding and budgeting processes know they are understating likely costs. This impression is reinforced by the GAO's assertion in its June 2005 report that, "the practice of breaching cost and schedule objectives to meet difficult requirements would not persist without a customer's cooperation." GAO contends that, "Unlike commercial customers, DOD customers tend to be tolerant of cost overruns and delays in order to get a high-performance weapon system."[33] Obviously, if potential suppliers expect the government to cover cost increases in a program, then they are more likely to bid optimistically in order to win the program. That dynamic was captured in the comment of one senior industry executive interviewed for this study, who stated "The cost-plus structure of a long-term contract bias[es] industry to win and then work the risk." Unrealistic bidding by contractors is referred to in the vernacular of the sector as "priced-to-win," meaning that cost estimates are based less on probable expenses than on an assessment of what price is expected to win a competitive award.

Irresponsible cost estimates probably became more common during the 1990's, because federal acquisition reforms granted more discretion to contractors who were desperate for work in a demand downturn at the same time that the government's organic capacity to analyze programs was being hollowed out. However, the familiar charge of collusion between contractor and customer in weapons programs is much too simplistic to explain the persistent pattern of cost escalation in national-security space programs. Other factors are at work, as analyst John Williams of Booz Allen Hamilton has demonstrated. Williams dissected several major spacecraft programs including AEHF, SBIRS and the Global Positioning System to determine the precise sources of cost increases. He constructed the following breakdown:[34]

-- 21% of cost growth resulted from "requirements generation and translation," meaning difficulties in implementing baseline performance requirements and any further requirements added after a program commences.

-- 21% of cost growth was caused by "budget and funding," meaning cutbacks, delays or constraints on the funding available to programs.

-- 18% of cost growth was attributable to "cost estimation," meaning inaccurate projections of what particular items or processes would cost.

-- 15% of cost growth was a reflection of the "acquisition process," meaning defects or distortions in the way that the government purchased space systems.

-- 13% of cost growth was driven by the "competitive process," meaning the tendency of contractors to be overly optimistic in bidding for contracts because of pressure to win.

-- 10% of cost growth was traceable to "personnel/management," meaning high turnover and inadequate experience within the public and private-sector workforce.

-- 2% of cost growth was caused by "industrial base" considerations, meaning shortages of necessary skills or items.

What the Williams breakdown clearly shows is that cost increases in national-security space programs originate in many different sources, rather than some particular policy or practice. This reality is readily apparent to those who have analyzed the record of specific programs. For example, GAO attributes substantial cost increases in the AEHF orbital communications system to frequent changes in performance requirements, acceleration of the original development schedule, underestimation of technical challenges, a high-risk acquisition strategy, a shortfall in budgetary resources, and manpower shortages in key skill areas.[35]

According to Booz Allen Hamilton, the confluence of all these negative factors produces a funding profile for the typical national-security space program that nearly guarantees cost overruns. The government's initial cost estimate for a program significantly understates its eventual pricetag due to unquantifiable risks, optimistic schedule assumptions, and inadequate estimating techniques. The government then budgets for a cost less than the already optimistic estimate, and industry bids a price below the budgeted amount. The price at time of award is usually above the contractor's bid, but nowhere near the original estimate, which in turn proves to be nowhere near the true baseline cost. Subsequent changes in the program's scope, quantity, funding stream and schedule then lift the actual cost at completion to well above the true baseline cost -- occasionally to several times the amount that contractors bid.[36]

Excessive Requirements. In the parlance of the acquisition community, requirements are performance goals for military systems. The most important such goals are set forth as "key performance parameters," or KPP's. KPP's largely define the capabilities, configuration and complexity of a system. When they are rigorously stated at the outset of a development program, they can serve as a critical point of reference for designers and a metric in measuring progress. When they are loosely crafted or subject to revision, they can lead to endless confusion. Requirements for next-generation military spacecraft tend to be extremely demanding, far exceeding the performance of any operational system.

Some experts think that the requirements for national-security spacecraft may be too demanding, and that in its zeal to "leap ahead" in space, the government is undermining prospects for success. Others think that the problem results less from excessive expectations than from frequent changes in requirements that force costly redesigns. Unfortunately, these maladies are not mutually exclusive -- the current requirements system may be suffering from both excessive expectations *and* excessive instability. That was the verdict of the 2003 Defense Science Board study: "The task force found requirements definition and subsequent control, or lack thereof, to be a dominant driver of cost increases, schedule delays, and incurred mission risk."[37] Booz

Allen Hamilton came to much the same conclusion, identifying "requirements generation and translation" as one of the leading causes of cost growth in space programs. The GAO has repeatedly cited the requirements process as a source of difficulty in keeping weapons programs on budget and on schedule. There is no good mechanism for performing tradeoffs once development has begun and problems arise.

As noted earlier in this section, some features of the requirements dilemma cannot be fixed because they reflect valid national-security needs emerging from a fast-changing global security environment. However, there is abundant evidence that this structural challenge is made worse by a poorly managed requirements process that imposes too many demands at the beginning of programs or continuously revisits requirements in response to transient circumstances. The Defense Science Board study cited the Space-Based Infrared System as a case study in excessive requirements generation, arguing that its 18 key performance parameters were far too numerous to permit timely program execution (it recommended no more than four or five KPP's on a given program).[38] A different sort of requirements problem arose in the AEHF communications system, where a midstream decision to enhance cryptological capabilities led to long delays as the development team waited for the necessary government-furnished equipment to be delivered.[39]

There are at least five policy-related factors contributing to the requirements dilemma. First of all, the growing number of users dependent on orbital systems has spawned a diverse range of requirements for each new constellation. For instance, SBIRS replaces a legacy system designed mainly to provide missile warning indications to national command authorities; but the new constellation will also provide tracking data for national missile defense, battlefield characterization for tactical warfare, and weapons intelligence for the analytical community. Having so many functions and users broadens the political base of a program, but it also makes program execution much more challenging. Both of the major space initiatives begun during Secretary Rumsfeld's tenure -- Space Radar and Transformational Communications -- would serve many different users whose requirements must be reconciled and accommodated.

A second factor extending far beyond the space sector is the tendency of the military acquisition system to embrace requirements long before there has been a rigorous assessment as to their feasibility. This results partly from the way the requirements process is organized, and partly from a lack of technical depth among its participants. GAO described the consequences in its June 2005 report:

> More than 30 organizations within the requirements community may have a hand in determining a weapon system's performance requirements before a contractor with systems engineering expertise can identify the gaps between the requirements and available resources. This process means the "doability" of the requirements is often not known with certainty until well into product development or until a significant percentage of funds planned to develop the system has been invested. By this point in time, customers' expectations have been set, making it difficult to change requirements if gaps between requirements and available resources are found.[40]

A third factor contributing to the requirements dilemma is the fragmentation of authority within the acquisition system. It is challenging enough for designers to cope with the growing diversity of users and needs, but when no one in the system has the power to limit requirements or impose tradeoffs, confusion ensues. Acquisition reforms undertaken in the 1990's had the unintended consequence of further decentralizing the system by giving contractors some responsibilities for requirements definition while weakening the authority of government program managers. The limited capacity of contractors to impose solutions, combined with other aspects of acquisition reform such as the reduced reliance on military specifications, led to mistakes in determining what could realistically be expected from next-generation spacecraft.[41] The government is now moving to strengthen program-manager authority and selectively reinstitute military specifications, but fragmentation of authority remains an impediment to generating reasonable, stable performance requirements for future spacecraft.

A fourth factor contributing to the requirements dilemma is the weak technical credentials of many participants in the process. National-security spacecraft are among the most complex technological systems ever created, and the challenge of grasping their intricacies is magnified by the advent of network-centric operations. Very few government personnel are adequately trained to understand the tradeoffs that spacecraft designers must make, and there are disincentives in both the civil and military personnel systems to acquiring the necessary expertise. In fact, the current training and tenure of government program managers in national-security space is so inadequate that there is reason for concern about what mistakes might result from restoring the lost authority of program managers.

Finally, and in a related vein, there is some doubt about the objectives of national-security space policy given the similarly weak technical credentials of many senior political leaders. The overarching goals that policymakers set for military transformation and network-centric operations influence the generation of key performance parameters for next-generation spacecraft, and yet it is far from clear that political leaders understand the technical challenges of what they are proposing. During the Cold War, the performance requirements of key military systems were driven mainly by what was known about the dominant threat. In a "capabilities-based" planning environment, there is much more latitude for imagination. But if senior decisionmakers lack a grasp of technological realities, then the possibility of unexecutable requirements would exist even in an otherwise optimal acquisition system.

Schedule Slippage. Other than cost increases, schedule delays are probably the most frequently cited defect in the current system for acquiring national-security spacecraft. Most satellite development programs are begun many years before they need to be operational, in recognition of the technological hurdles that must be overcome and various other uncertainties that programs face. Nonetheless, schedule slippage has become so persistent on some programs such as the Future Imagery Architecture and Space Based Infrared System that it potentially endangers national security, because the legacy systems supporting essential missions may cease functioning before their replacements are in orbit.

A case in point is SBIRS, the planned successor to Cold War missile-warning satellites. Timely warning of hostile missile launches is a critical part of nuclear deterrence, and all of the legacy satellites providing such warning have now been launched. In order to avoid a gap in missile-warning capabilities, SBIRS must be on station and operational before the current constellation ceases functioning towards the end of the next decade. But development of geostationary spacecraft at the heart of the SBIRS architecture has been repeatedly delayed since the program began in 1995. In 1996, launch of the first geosynchronous satellite was projected to occur in 2002; in 1999 the launch slipped to 2004; in 2000 it slipped to 2005; in 2002 it slipped to 2006; and in 2003 it slipped to 2007. The Defense Department's best guess today is that the first SBIRS geosynchronous satellite will be launched in 2008, but few observers have much confidence in that prediction. In fact, planners are currently debating major modifications to the design, ten years after the program began.[42]

Most of the factors contributing to program delays have already been noted. Aside from structural constraints such as a serpentine funding process and the inevitable technology challenges, planners routinely underestimate the cost of system development and impose excessive performance requirements on designers. Underestimation of costs results in program development being stretched out as policymakers try to accommodate many different programs within a limited investment budget. Excessive requirements lead to unnecessary complexity, unanticipated technical problems, and other issues that force schedule delays. Acquisition officials usually prefer to accept schedule delays rather than seeking increases in near-term funding or relaxing requirements, because funding requests might be denied and military plans assume the future availability of key performance features. When resources and requirements are fixed, time may be the only variable available for managing risk.

One issue that comes up frequently in studies of why national-security space programs encounter delays is the inveterate optimism of managers in estimating how long it will take to accomplish complex development tasks. According to the Government Accountability Office, "DOD often sets dates for delivering capabilities on the basis of optimism rather than the knowledge that critical technologies would work as intended by those dates."[43] The former director of operational testing at the Pentagon, Philip Coyle, remarked in an article that managers of the SBIRS program "underestimated again and again [the] technical challenges," which implies they learned little from their mistakes.[44] This pattern of continuously confounded optimism undoubtedly reflects the many bureaucratic and budgetary pressures weighing on managers, which encourage them to take risks in developing schedules. It also reflects the uniquely unforgiving design environment for space systems, wherein, as the Defense Science Board put it, "thousands of good engineering decisions can be undone by a single engineering flaw or workmanship error."[45] But beyond managerial pressures and engineering challenges, it seems reasonable to ask whether there is not an issue with the competency of government managers when trying to explain why schedule slippage is so common. That question deserves a separate discussion.

Poor Management. When organizations repeatedly underestimate costs, overrun schedules and fail to establish realistic performance goals, they are usually said to be mismanaged. Thus far, this study of defects in the national-security space acquisition system has focused on the factors that lead capable people to make bad decisions. But there is another cluster of considerations contributing to sector problems -- those reflecting the fact that many of the personnel in the government acquisition system aren't very competent. The question of competency seldom gets raised directly because suppliers fear retribution and politicians prefer to blame industry. But occasionally those who have worked in the sector for many years render a candid assessment of the federal workforce, and the picture that emerges is less than heroic. For example, here is what one senior industry executive said of the Air Force's Space and Missile Systems Center, the lead agency for acquiring most military satellites:

> The uniform military workforce at SMC is heavily weighted to junior officers who don't have enough experience or technical expertise. Career civil servants who have been in position for long periods at SMC tend to be mediocre, because rewards are so poor that the competent people have left for industry. [Most of] the longtime civil-service types at SMC are the ones industry didn't want.

A former intelligence officer now working for a major space-sector supplier offered a similarly discouraging description of the workforce at the National Reconnaissance Office, the other major agency engaged in buying national-security spacecraft:

> The [military officers] we work with in the NRO have very little understanding of the industry (NGA is even worse), and limited experience in program management. Moreover, the risk/reward ratio has moved dramatically against being an acquisition executive -- none are adequately rewarded and all feel the threat of being the focus of a congressional investigation.

These views are not confined to industry. The Government Accountability Office complained in June of 2005 that program managers in national-security space "are often not equipped to understand what is behind a contractor's proposal," and "are not always experienced enough to stand up to contractors when development is being mismanaged." GAO also stated that government managers "may not understand the best ways to incentivize contractors and gain insight into their performance." Although GAO assigned some of the responsibility for management failures to industry for withholding vital information, it conceded that, "there are not enough experienced program managers and/or enough experts in software engineering -- a consequence of starting more programs than DOD can afford and effectively manage." The Defense Science Board came to a similar conclusion in 2003, stating bluntly, "today's government system engineering capabilities are not adequate to support the assessment of requirements, the conduct of tradeoff studies, the development of architectures, the definition of program plans, the oversight of contractor engineering, and the assessment of risk." Describing deteriorating levels of experience and expertise at the Air Force's Space and Missile Systems Center, the DSB said, "Such an unbalanced dependence on an inexperienced staff to execute some of the most vital space programs is a crucial mistake."[46]

The government has taken numerous steps since 2003 to address the management deficiencies noted by the Defense Science Board, some of which are discussed at the end of this section. Unfortunately, standards within the acquisition system had been deteriorating for the better part of a decade before the problem was grasped, and it will take a long time to restore lost capabilities. The nature of demand in the sector has shifted so radically during the intervening period that the government may never fully recover the organic engineering expertise or programming skills it once possessed, because there simply aren't enough programs in early development now to train a new generation of managers. For those who think the Cold War was a golden era of managerial excellence in national-security space -- particularly in the "black" world of reconnaissance satellites -- the future is likely to be a letdown. It may not be feasible for the federal government to sustain a sense of urgency and discipline in the absence of profound danger.

That lesson seems to be embedded in the prevailing explanation for how the problem arose in the first place. During the mid-1990's, as the government was scaling back its military posture in response to the collapse of communism, the acquisition community embraced a management concept called Total System Performance Responsibility (TSPR). TSPR sought to save money by loosening design standards, shifting engineering responsibilities to the private sector, shrinking the acquisition bureaucracy, and relying more on the marketplace for innovation. Reflecting the political ethos and circumstances of the time, the government embraced increased risk as a price to be paid for less investment, hoping that the private sector could deliver solutions that were cheaper and more imaginative. It isn't likely that policymakers would have taken such a chance during the Cold War, and in fact the whole exercise proved tremendously destructive. The Defense Science Board described the outcome in these terms:

> Over the decade of the 1990's the government space acquisition workforce [was] significantly reduced and their authority curtailed. Capable people recognized the diminution of the opportunity for success and left. They continue to leave the acquisition workforce because of a poor work environment, lack of appropriate authority, and poor incentives. This has resulted in widespread shortfalls in the experience level of government acquisition managers, with too many inexperienced individuals and too few seasoned professionals.[47]

As former Acting Under Secretary of Defense for Acquisition, Technology & Logistics Michael Wynne put it in an interview for this study, "Because we became less smart buyers, we were not able to answer questions the contractors had -- we backed away from our responsibilities as a buyer, and turned over too much to industry." Wynne believes that the government must reconstitute "that qualified government acquisition and systems engineering corps" that he says has "disappeared" if the national-security space program is ever to recover its former managerial standards.[48] But the government management culture that Wynne wants to restore took two generations to create during a period when circumstances were a good deal more conducive to success, so it is by no means certain that the levels of competence once seen in the system will one day return.

Workforce Instability. A final policy-related problem that contributes to the deficient performance of the national-security space complex is the high rate of turnover among government program managers and other federal employees. The Defense Science Board task force reported in 2003 that the average tenure for program managers was approximately two years, and opined that, "a program cannot be effectively or successfully managed with such frequent rotations." The Government Accountability Office made a similar finding in 2005, noting that the problem of high turnover existed at all leadership levels in the acquisition system:

> Short tenures for top leadership and program managers within the Air Force and the Office of the Secretary of Defense have lessened the sense of accountability

> for acquisition problems and further encouraged a short-term view of success, according to officials we interviewed. Turnover makes it difficult for upper-level managers to establish effective working relationships with program managers, resulting in less trust when divulging problems.[49]

The propensity of the military promotion system to move key personnel frequently has been noted for generations, and has been blamed for a number of problems ranging from poor combat performance to high divorce rates. In theory, rapid rotation exposes rising officers and enlisted personnel to an array of demands that train and test them for broader responsibility. Within the national-security space community, though, frequent rotations often mean that program managers spend their first year in position learning the job and their second year preparing for a successor. The continuity and experience that comes from extended management of a program are largely lost. The turnover problem is less pronounced among civilian program managers, but as noted earlier, there is a tendency for the best civil servants to leave for industry -- a pattern which contributes to workforce instability.

Among the senior civilian leaders to whom program executives report the turnover problem is even worse, because of the recent trend toward leaving such positions vacant for long stretches of time. For example, during the second quarter of calendar year 2005, the following political positions were either unfilled or occupied by acting (unconfirmed) personnel: Under Secretary of Defense for Acquisition, Technology & Logistics; Principle Deputy Under Secretary of Defense for Acquisition, Technology & Logistics; Secretary of the Air Force; Under Secretary of the Air Force; Assistant Secretary of the Air Force for Acquisition; and Director of the National Reconnaissance Office. The collection of empty positions included most of the senior leadership in the Executive Branch responsible for managing national-security space efforts.

In an interview for this study, former Acting Under Secretary of Defense for Acquisition, Technology & Logistics Michael Wynne remarked that, "leadership, continuity, consistency, and stability on the part of the government are primary factors driving the health of the space industrial base."[50] Wynne should certainly know, having spent much of his career in the space sector. However, Wynne himself never managed to be confirmed for the Under Secretary's job, falling victim to the baroque process governing the selection and confirmation of political appointees. Obviously, if senior positions such as his are frequently vacant or filled by unconfirmed personnel, and managers of key space programs are cycling out of position every two years, then it will be very difficult to fashion a management system characterized by "leadership, continuity, consistency, and stability." Even when competent personnel (such as Wynne) are available to fill jobs, some of the value of their expertise will be lost, and the likelihood of marginal people ending up in key positions will be increased. So high workforce turnover is often cited as an impediment to sector success.

With so many structural and policy-driven obstacles to effective sector performance, it is hardly surprising that Congress has lost patience with the performance of the national-security space community. Skepticism about the capacity of the technology and manufacturing base to support military transformation plans for space certainly seems warranted. Before looking more deeply at workforce trends and policies affecting the sector, it is useful to consider whether any of the negative influences currently at work are likely to change in the near future.

Can The Problems Be Fixed?

When George W. Bush became President in 2001, he assembled a national-security team that fully grasped the importance of space systems for the nation's military and intelligence needs. Less than a year after taking office, defense secretary Donald Rumsfeld issued sweeping guidance to reorganize the national-security space community, in the process implementing many of the recommendations made by the presidential commission that he had chaired.[51] However, few if any senior policymakers in the Bush Administration understood at first how detrimental the trends of the previous decade had been to the health of the space technology and manufacturing bases. Not only had demand in the commercial space industry collapsed, but misguided acquisition reforms in the national-security complex had severely degraded the government's capacity to understand, plan and execute next-generation spacecraft programs.

Partly because of the distraction created by 9-11 and the global war on terror, it was not until 2003 that a determination coalesced among senior decisionmakers to make additional, major changes in national-security space. The report of the Defense Science Board task force on management of national-security space programs played a key role in alerting policymakers to the fact that problems were generalized across the sector, rather than being concentrated in a handful of programs. The task force's final report, issued in May of 2003, offered numerous useful suggestions about how to fix the problems, including restoration of program-manager authority, rebuilding of system-engineering skills within the government, increasing realism in cost estimation and increasing rigor in the formulation of performance requirements. The task force was particularly influential in helping policymakers to understand how the acquisition of spacecraft was different from buying other types of military systems, given the absence of prototyping, compressed production runs and minimal opportunities for post-production repair.

The task force findings and other efforts within the government led to promulgation of National Security Space Acquisition Policy 03-01, which reversed many of the acquisition reforms instituted in the previous decade. As amended in December of 2004, the revised acquisition policy contains the following features:[52]

-- Increased authority for program managers, including the opportunity to present their views directly to senior decisionmakers rather than through a chain of command.

-- Selective reintroduction of military specifications and standards for space systems, to assure that contractors and customers operate within a common design framework.

-- Firm rules for establishing technical baselines before program development can begin, and a more rigorous approach to the formulation of performance requirements.

-- Early testing of components and subsystems to assure that key elements are sufficiently mature for incorporation into system designs in a timely fashion.

-- Independent cost and technical analyses to verify the accuracy of program budgets and requirements as schedules progress toward operational status.

In parallel with these measures, the Air Force has accelerated its efforts to professionalize the training and promotion system for space acquisition managers. As executive agent for most national-security spacecraft, the Air Force plays a central role in manning the space acquisition system. In the past though, it has been accused of understaffing, undertraining, and undervaluing its space acquisition activities. It now acknowledges the need for a better structure of incentives to attract and retain key personnel. It also has increased the duration of tours for program managers from the average of two years cited by the Defense Science Board to four years or longer.

Whether these steps will enable the national-security space sector to recover from its recent difficulties is unclear. There are reasons to doubt it will. First, all of the structural constraints cited earlier in this section -- decentralized decisionmaking, mismatched cycles, uncertain requirements, and the like -- will persist for the foreseeable future. Second, there is little evidence that the sense of urgency and discipline prevailing in Cold War years is returning; despite the importance that military transformation assigns to space systems, the policymaking apparatus seems to be gradually losing its focus with regard to investment priorities. Third, no credible plan has been advanced for restoring the organic system-engineering capabilities of the federal government that once enabled it to assess precisely the feasibility of requirements and the performance of contractors. Fourth, there has been almost no official action regarding one of the most frequently cited sources of workforce turnover, namely the poor rewards and incentive structure for key personnel. Fifth, congressional impatience with cost overruns and delays has led recently to budget cuts that undermine recovery measures, such as the decision to delete funding needed for early testing on the Transformational Communications Satellite. Finally, only two next-generation satellite constellations have actually been begun since new acquisition rules were put in place, the Transformational Communications Satellite and the Mobile User Objective System for narrowband communications; all the other next-generation spacecraft programs were begun under the old system, and their progress (or lack thereof) reflects that fact.

Balanced against these numerous negative factors is one bright positive. Most experts believe that the technology and manufacturing base is capable of meeting key performance objectives for future national-security spacecraft if the government customer can learn to behave differently. The problems seen in the national-security space sector since the collapse of communism are almost entirely a reflection of poor policies and poor management on the part of the federal government, rather than a fundamental deficiency in the capacity of the technology and manufacturing base to satisfy national needs. However, some experts believe that the same government ineptitude that has compromised programs will eventually do irreversible damage to the underlying industrial base -- especially the cadre of uniquely skilled scientists and engineers at the heart of that structure. It is now time to turn to that issue, and see whether such worries are warranted.

VI. RECRUITING & RETENTION OF A SKILLED WORKFORCE

Workforce trends are a perennial concern in the national-security community. Every time the nation suffers a perceived setback in its global standing traceable to the technological achievements of other nations, policymakers and analysts speculate that America may be "losing its edge" in science and engineering. Such worries arose repeatedly during the Cold War period, beginning with Soviet aerospace breakthroughs in the 1950s, and ending with the growth of Japanese economic power in the 1980s. More recently, observers have worried about the aging of the skilled workforce in the defense sector since the collapse of communism, and the rapid expansion of China's industrial economy in response to globalization. Because science and engineering skills are fungible across diverse markets, some analysts see a connection between the two trends and conjecture that China may one day challenge America's prowess in military technology.

Such worries are probably a good thing in that they motivate policymakers to address nascent problems before seriously negative consequences occur. However, there is little evidence that the United States faces a generalized shortage of science and engineering personnel. A study released by the RAND Corporation in 2003 entitled "Is There a Shortage of Scientists and Engineers?" found no basis in employment or earnings data to conclude that the market for technically skilled personnel was getting tighter.[53] The respected science observer Daniel S. Greenberg stated in 2004 that, "There's no shortage of scientists and there's no impending crisis," noting that wages for scientists were depressed by an apparent glut of talent relative to demand, and that the number of foreign students receiving science degrees who elected to remain in America rather than returning home was actually rising.[54] More recently, an analysis of the global market for engineers performed by McKinsey & Company in 2005 estimated that the United States had 540,000 young engineers (seven years of experience or less) with attributes attractive to U.S. employers, more than China, India, Germany, Russia and Poland combined.[55]

Those findings are consistent with trend data, which reveal that the number of full-time undergraduate engineering students enrolled in U.S. universities today is roughly the same as in 1980, rather than exhibiting dramatic shrinkage. While enrollment did show a steady decline following its peak of about 400,000 in the early 1980s, the decline bottomed out in the late 1990s and enrollment began rising again in response to the dot.com boom and the recovery of military technology spending. There has been a discernible shift out of aerospace and electrical engineering into computer and software disciplines, but this pattern undoubtedly reflects demand trends in the broader economy. Thus, the number of degrees -- undergraduate and graduate -- granted in aerospace engineering fell 16% between 1991 (the first year of the "post-Cold War" period) and 2004; the number of degrees granted in computer engineering rose over 200% during the same period. The total number of undergraduate and graduate degrees granted in engineering for all disciplines increased by about a quarter during the same period, which hardly suggests impending shortages. Indeed, the biggest problem facing many engineers is uncertain job prospects and stagnant salaries in their chosen fields.[56]

Unfortunately, these findings do not necessarily signal a benign recruitment and retention environment for national-security space activities. There are so many barriers to the movement of workers between the commercial economy and the national-security complex that labor shortages can exist in the defense sector even when surpluses prevail elsewhere. Furthermore, the skills that the national-security community requires are seldom coterminous with the needs of the broader economy. In some respects they are genuinely unique, and even when the skills are fungible across sectors they may be in far greater demand for defense and intelligence applications than for commercial markets. So special recruiting and training mechanisms are likely to be needed to staff the national-security complex. Some observers believe existing mechanisms are inadequate, as reflected in a December 2000 finding by Booz Allen Hamilton:

> Booz Allen Hamilton research determined that human resources issues are the largest long term problem facing the industry. Even as companies continue to consolidate, the human capital has been declining sharply. The industry faces significant operating risks from lack of human resources at the middle management level as well as lack of interest from college recruits because there is not perceived growth in the industry. This study concluded that the space industry is experiencing the leading edge indicators of a major problem in the next decade.[57]

The alarming tenor of this passage in part reflects the period in which it was written. Military demand for new technology had undergone a prolonged downturn, while many young engineers were migrating to the burgeoning information sector of the commercial economy. Five years later, military demand has recovered while the dot.com boom has collapsed. However, some experts feel that those developments have not fully dispelled the workforce concerns that national-security space faces. They point to the problems cited in the previous section as evidence that there are persistent quantitative and qualitative deficiencies with the relevant workforce -- deficiencies that need to be addressed before they grow worse. This section will examine what the sources of those deficiencies might be, observing the same distinction noted in the preceding section between structural and policy-related issues.

Structural Issues

As noted in section four, the specialized workforce supporting development and production of national-security spacecraft is not large. It currently numbers about 100,000 personnel, and is concentrated primarily in the private sector. Additional personnel are employed by a handful of federally-funded organizations such as the Aerospace Corporation and Sandia National Laboratory. One of the defining characteristics of this workforce is its heavy weighting toward technical skills such as research science and engineering. If laboratory technicians are included, well over 50% of the private-sector workforce can be described as possessing advanced technical skills, and the percentage among federal employees is probably even higher. Only 20% of the private-sector workforce is engaged in actual manufacturing ("touch labor" in the vernacular of the industry), reflecting the fact that production runs for national-security spacecraft are relatively compressed and most acquisition funding is devoted to development activity.[58]

A workforce with these characteristics cannot be sustained unless there is a process for continuously recruiting and retaining highly skilled personnel, especially engineers with expertise in aerospace, electrical, software and systems design. Although the U.S. educational system appears to generate adequate numbers of graduates to meet sector requirements, there are a number of structural constraints impeding the ability of government and industry to attract and retain talent. Four generic factors are cited frequently by experts.

Security Restrictions. The missions and characteristics of some national-security spacecraft are so sensitive that the government doesn't acknowledge they exist. Even when their existence is widely known, spacecraft employed by the military and intelligence communities typically have operational features that must be kept secret from potential enemies. That means the workforce designing and building national-security spacecraft must be carefully selected to avoid security problems. Not only are most individuals of foreign origin denied the necessary clearances, but so are some Americans. This presents a major obstacle to workforce recruitment since nine percent of undergraduate degrees and over half of graduate degrees in engineering conferred by U.S. universities go to foreign nationals. When the high level of foreign enrollments is combined with the relatively small pool of graduates in key disciplines such as software and radio-frequency engineering, there is a danger of labor shortages in some specialties. The limitations on recruitment imposed by security restrictions are magnified by the way in which clearances are currently administered, a subject discussed later in this section.[59]

Demand Cycles. A second structural issue is the wide swings in federal demand for science and engineering talent, driven mainly by changing threat assessments. These swings produce rapid increases or decreases in the ranks of technical personnel employed by the government and its suppliers, which in turn lead to recruiting and retention challenges. The recruiting challenge is that young engineers and scientists are more likely to seek employment in industries where there is relatively stable demand, and thus some measure of job security. The retention challenge is that cyclical fluctuations in demand produce uneven age cohorts across the workforce, so that large numbers of the most experienced personnel retire in relatively brief periods of time. For example, the space industry is concerned today about the imminent retirement of the "Apollo generation" that was hired during the heyday of Cold War aerospace activity, because it is being followed by a smaller cohort of less experienced personnel hired in the post-Apollo era. When large numbers of workers with specialized skills retire in brief spans of time, the challenge of recruiting new employees and retaining old ones to keep organizations adequately staffed is made much harder.[60]

Changing Requirements. A key feature of training in the national-security space sector is the exposure of younger workers to personnel with long experience in managing programs. That process is especially useful when the older employees have had the opportunity to participate in a range of different programs, as the so-called Apollo generation did. However, changing military requirements have placed increased emphasis on skills that were not so common a decade ago in the sector, such as software generation and network design. The requirements shift creates two problems in sustaining the national-security space workforce. First, the sector often must compete against commercial firms for junior employees in the information sciences, and commercial firms sometimes have more flexibility in structuring compensation and benefits. Second, when a new employee is actually recruited, organizations in the space sector may have fewer resources for training the hire to an adequate level of proficiency for developing "network-centric" systems. The traditional mentoring approach of the sector has to some degree been degraded by the growing demand for skills that older employees lack.

Government Culture. In addition to the three aforementioned structural issues -- all of which reflect the federal government's unique role and character -- there is a more generalized cluster of difficulties that arise from the government's peculiar operating culture. Program funding is erratic from year to year due to political influences. Program schedules and performance requirements can shift in unexpected and seemingly capricious ways. Pay scales and incentive systems are hard to adjust because of legislative and regulatory limitations. Paperwork and other distractions from value-added activity are more common than in the commercial world. While some of these practices properly belong in the discussion of policy-related issues rather than structural issues, they highlight the fact that dealing with the government will always be a different experience than dealing with a commercial customer or employer. For at least some skilled personnel, the difference is great enough to deter them from seeking or continuing employment in the sector, and it thus becomes a subtle structural constraint on both recruitment and retention.

Despite these various structural considerations, government and industry have not faced chronic difficulties in meeting their workforce needs. Temporary distortions in the labor market brought on by the dot.com boom have now thoroughly dissipated, and industry executives interviewed for the study say that they are encountering few problems in securing the skills they need. Nonetheless, a number of federal policies or practices seem to make recruitment and retention of qualified personnel harder than it needs to be, potentially contributing to workforce deficiencies.

Policy Issues

In addition to the structural factors cited above, numerous federal policies influence the size, composition, performance and occupational environment of the workforce engaged in designing and building national-security spacecraft. Most of the policies directed explicitly at human resource and workplace concerns are not unique to the space sector -- they apply to all public-sector workers, or to all private-sector workers employed by government contractors. However, some federal policies and practices seem to have unique or especially pronounced consequences for the workforce in the space sector. Here are four examples.

Competitive Awards. Incumbents almost never win competitions to develop a follow-on generation of spacecraft. Federal policies and practices governing such competitions seem to favor challengers. Thus, Lockheed Martin displaced Northrop Grumman from its longstanding role in building missile-warning satellites, and Northrop Grumman displaced Lockheed Martin from its longstanding role in building military weather satellites. While such upsets are often viewed as evidence that merit-based choices are being made by contracting authorities, their long-term effects tend to be destructive -- especially for the workforce. The reason why is that the government pays incumbent contractors billions of dollars to train and sustain a workforce that is uniquely qualified to build particular types of spacecraft, and then squanders that investment by awarding the next generation of satellites to contractors with no similar pool of talent. The incumbent ends up disbanding or reassigning a highly specialized workforce, while the challenger must scramble to assemble a suitably qualified team. The challenger's efforts seldom go well, due in part to the limited availability of arcane skills in labor markets, and in part to the fact that it takes years to build a real team. Having seen this process produce problems over and over again, it should be clear to policymakers that the prevailing approach to competition underestimates the difficulty to maintaining a competent workforce.[61]

Program Pacing. The Defense Science Board task force on management of national-security space programs stated in its 2003 report that, "A continuous flow of new programs -- cautiously selected -- is required to maintain a robust space industry." It went on to say that in the absence of such a steady flow, the workforce would be placed at risk.[62] Previous sections of the present study have described the structural factors that lead to uneven pacing of programs, such as changes in the threat. But even when such unavoidable factors are taken into account, there seems to be excessive unevenness in the pacing of programs. The DSB noted in its 2003 report that every category of national-security spacecraft was "in transition" except for signals intelligence and classified relay satellites, which suggests that planners gave little thought to spacing out development efforts. In contrast, the next ten years look likely to produce almost no new program starts, severely depressing the demand for some skills in the space sector. As the head of strategic planning at one very large space contractor remarked, better pacing of programs would make it easier to sustain a capable workforce: "If the government creates stable demand in national-security space, the workforce will stabilize; we'll attract the young talent we need if the demand is stable."

Workforce Compensation. One of the reasons why the United States does not produce more home-grown scientists and engineers is the relatively modest pay and benefits that personnel in those professions can expect to receive during their careers. Other fields offer superior compensation and job security while demanding considerably less effort. That asymmetry undoubtedly creates challenges for recruiters in the aerospace industry. Judging from the comments of executives and managers interviewed for this study, the challenge facing government recruiters is far worse. Respondents repeatedly cited low pay levels, weak incentive structures, and poor work conditions as factors contributing to the sub-par performance of public-sector employees in the space community. One senior executive stated flatly that the terms of employment are so unappealing in the Air Force's main acquisition organization for space that any civil servant with experience would have long since left for industry if offered a job. That's almost certainly an exaggeration -- the folklore of the sector is full of stories about government managers who saved programs -- but the pervasive perception of inferior compensation for public-sector employees must reflect a real problem. In the absence of better compensation and incentives, it is hard to see how the government can hope to rebuild its internal management and engineering capabilities for space.

Security Reviews. While few doubt the need to control carefully who has access to space technology and plans, the current system for processing security clearances is extravagantly wasteful. According to the National Defense Industrial Association's panel on workforce challenges and solutions, it typically takes a year or longer to grant top-secret clearances -- during which time personnel with scarce skills may be unable to usefully apply their expertise. At least some of the delay could be avoided if the government refrained from over-classifying positions, increased the portability of clearances, and centralized the management of background investigations. A number of legislative measures have been introduced to improve the system, but for the time being it remains a continuous drag on the productivity of the space-sector workforce.[63] It also is an impediment to recruiting qualified personnel, since potential employees with other career options may wish to avoid the aggravation of extended background checks. For example, the Bush Administration's initial candidate to oversee national-security space programs withdrew his name from consideration after a series of protracted background checks -- checks deemed necessary even though he already held several high-level clearances.

Despite the many obstacles to recruiting, training and retaining a competent workforce, sentiment within the space sector is divided as to how serious workforce challenges are. Some insiders say problems are growing worse, and others say they have improved markedly since the low ebb of the dot.com era. One industry executive contends that whatever challenges do exist are more traceable to the attitude of the government customer than to fundamental problems:

> If you looked at the American shipbuilding industry in 1941, you would have gotten the wrong answer as to what was feasible in World War Two. Motorola sure didn't look like a space company before Iridium, but they became one -- and did a great job on Iridium. So there is a huge latent space technology and industrial capacity we could tap... What's missing today is any real sense of urgency about the space base, especially workforce trends.

Much of the research conducted for this study supports that view. Not only are senior policymakers often complacent about the capacity of the technology and manufacturing base to deliver whatever is needed, but they have failed to develop the databases and analytical tools needed to determine whether their complacency is warranted. The government knows remarkably little about the current state of the workforce in the space sector, and the information that is available tends to be dated, fragmentary or poorly organized to answer key questions. It may be that the single most important step policymakers could take toward assuring a robust space technology and manufacturing base would be to develop a better understanding of what the base actually looks like today, starting with the status of the skilled workforce that makes every other facet of America's preeminence in space possible.

VII. FINDINGS & CONCLUSIONS

This section summarizes the findings of the study concerning the capacity of the national-security space technology and manufacturing bases to accomplish the goals of military transformation. It also enumerates several important steps that the federal government must take to remedy deficiencies in the way it manages national-security space programs. The key findings of the study can be distilled down to ten points:

1. Military transformation as currently defined depends heavily on the successful completion of next-generation satellites designed to carry out critical military and intelligence missions. Without such satellites in orbit and operating, important goals in the areas of reconnaissance, communications, navigation and environmental awareness are unattainable.

2. The performance of the national-security space sector has deteriorated in the years since the Cold War ended. Most next-generation satellite programs are over cost and behind schedule; some will never satisfy their original performance objectives. (The performance of satellites already in orbit seems to be superb.)

3. Almost all of the erosion in sector performance is traceable to behavior on the part of the federal government, which is the sole source of domestic demand for military and intelligence satellites. Although private industry is far from blameless, its missteps -- accidental or deliberate -- are usually a reflection of the structure of incentives the federal customer has created.

4. Some undesirable features of federal demand are structural in nature, and thus beyond the capacity of policymakers to change. These include a decentralized decisionmaking process, unique performance requirements, mismatched political and developmental cycles, and imposing technology hurdles.

5. However, many of the most destructive influences at work in the sector result from government policies and practices that could be changed. These influences include unrealistic cost estimates, excessive performance requirements, unduly optimistic program schedules, unprofessional management practices, and high turnover of essential personnel.

6. The government has taken steps to modify some undesirable practices, most notably through the promulgation and revision of National Security Space Acquisition Policy 03-01. However, political and budgetary circumstances today do not favor an early recovery of the sector's lost capabilities, and the overhang of past mistakes will persist for years to come.

7. One area of persistent concern is the small but highly skilled workforce that designs and builds national-security spacecraft. Some of the negative pressures on that workforce are structural (such as the need for security restrictions), but there is much room for improvement in the way the government manages public and private-sector personnel.

8. The most important policy-related factors detrimental to the workforce are a counter-productive emphasis on competition, excessive unevenness in the pacing of programs, poor

pay and benefits, and burdensome security procedures. Addressing these issues would alleviate deficiencies in the private-sector workforce, but defects in the federal workforce run deeper.

9. The biggest challenge national-security space faces today is a lack of focus and expertise among the policymakers and legislators charged with overseeing it. Because the most powerful federal players exhibit only sporadic, superficial concern about fixing the problems government has created, it is possible that drift and deterioration will continue in the sector.

10. Given these findings, it is far from clear that the technology and manufacturing bases can meet military-transformation goals in space. The difficulty resides not in the private sector's capacity to develop and integrate necessary technology, but in the government's seeming inability to tap those skills in a timely and cost-effective manner.

Concerning steps the government should take to remedy deficiencies in its management of national-security space programs, there are obviously many lessons that could be derived from the compendium of misguided policies and managerial mistakes set forth in the preceding pages. Fortunately, the Bush Administration has already recognized many of the key problems and moved to address them. Little purpose would be served here by insisting on the need to increase the training, authority and time in position of program managers when measures have already been adopted to accomplish those ends. The deleterious effects of unrealistic cost estimates and excessive performance requirements are by now universally understood, and recent policy initiatives may well reduce the recurrence of past errors. However, there are at least five important steps that the government has not taken, and each could materially improve the prospects for the sector:

1. The government does not collect enough empirical data on the status of the national-security space technology and manufacturing bases, especially concerning trends in the workforce. Considering the importance of space programs to overall military plans, it should establish some mechanism for precisely and continuously tracking sector trends as a way of determining when corrective steps are needed.

2. It is abundantly clear that the public-sector workforce assigned to national-security space activities does not receive sufficient rewards in the existing federal personnel system to recruit and retain the best people. The Department of Defense should consider how it can establish a better system of incentives, linked to mechanisms for measuring performance and professionalism.

3. As part of its effort to properly organize and reward the public-sector workforce, the Department of Defense should reconsider whether program management of complex space initiatives properly belongs among the core competencies of uniform military personnel. Sector observers complain constantly about the competence of military personnel assigned to space programs; while better training may resolve such complaints, there is a larger question as to why military personnel are managing the programs at all.

4. It is hard to see how the management system for national-security space programs can function properly when the most senior positions are left unfilled for long periods of time. Some method must be found for minimizing the long delays in selecting and confirming political appointees, because their absence from office sometimes leaves the system rudderless at precisely the moment that the biggest decisions need to be made.

5. Finally, Congress needs to contain its impatience and give reforms enough time to demonstrate whether they are working. Policy changes have been put in place to correct many of the most egregious errors of past years, but these changes will take years to bear fruit; if Congress insists on making further adjustments with every new budget cycle, it will perpetuate problems rather than assisting in their resolution.

If this enumeration of necessary steps seems unduly modest after cataloguing so many deficiencies in the space sector, it is only because the Bush Administration has already taken action to correct many problems. As noted repeatedly in the study, national-security space is afflicted by a range of structural limitations beyond the power of policymakers to change. But within the boundaries of what is do-able to bring about constructive change, the Bush Administration has done quite a bit. In discussing the sector's various challenges, one can easily forget that it remains by far the biggest and most capable concentration of space expertise in the world. One reason for pursuing necessary changes expeditiously is that if America does not take the next, bold strides in space, it is unlikely anyone else will.

NOTES

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[2] *National Defense Authorization Act For Fiscal Year 2006*, Report of the Committee on Armed Services, House of Representatives, Washington, D.C.: Government Printing Office, May 20, 2005, pp. 208-209, 213-217; “Problems in DoD Space Programs,” *Department of Defense Appropriations Bill, 2006*, Report of the Committee on Appropriations, House of Representatives, Washington, D.C.: Government Printing Office, June 10, 2005, pp. 205-206.

[3] *Report of the Commission to Assess United States National Security Space Management and Organization*, p.40.

[4] *Transforming Defense: National Security in the 21st Century*, Report of the National Defense Panel, Washington, D.C.: Department of Defense, December 1997, p.38.

[5] *Report of the Commission to Assess United States National Security Space Management and Organization*, pp.15, 79-98.

[6] *Transformation Planning Guidance*, Washington, D.C.: Department of Defense, April 2003, p.11.

[7] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology & Logistics, Department of Defense, May 2003, p.12.

[8] *Ibid*., pp.13-29.

[9] “Problems in DoD Space Programs,” *Department of Defense Appropriations Bill*, 2006, pp.205-206.

[10] Christine Anderson, *Military Satellite Communications: Past*, *Present*, *Future*, briefing charts, MILSATCOM Joint Program Office, Washington , D.C.: Department of Defense, 2003, pp.8-11; Amy Butler, “Tug of War: Contractors, Air Force butting heads over $12-billion satcom system,” *Aviation Week & Space Technology*, March 21, 2005, p.63.

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[13] *Ibid.*

[14] *Ibid.*

[15] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.30; *Defense Acquisitions: Improvements Needed to Optimize Growing Investment in Space*, Washington, D.C.: Government Accountability Office, November 18, 2003, pp.8-9; Jeremy Singer, “Teets: Pentagon Must Launch SBIRS by 2015,” *Space News*, March 25, 2003.

[16] David Fulghum, “NRO Wants UAVs,” *Aviation Week & Space Technology*, September 22, 2003, p.54.

[17] Arthur C. Clarke, “Extra-Terrestrial Relays – Can Rocket Stations Give Worldwide Radio Coverage?,” *Wireless World*, October 1945. (www.lsi.usp.br/~rbianchi/clarke/ACC.ETRelaysFull.html)

[18] See Loren Thompson, “Space-Based Reconnaissance: Great Leaps, On the Ground,” issue brief, Arlington, VA: Lexington Institute, February 27, 2004.

[19] Rich Tuttle, “Next-Gen GPS: Navigation satellites must keep improving to keep U.S. ahead of attempts at jamming,” *Aviation Week & Space Technology*, Mary 19, 2003, p.46.

[20] *Space Research and Development Industrial Base Study*, Phase One Final Report, McLean, VA: Booz Allen Hamilton, February 2002, p.50.

[21] The management changes were detailed in a memorandum entitled “National Security Space Management and Organization” sent by Secretary Rumsfeld to the service secretaries and other interested parties on October 18, 2001.

[22] *Space Research and Development Industrial Base Study*, Phase One Final Report, pp.19-21.

[23] *Space Research and Development Industrial Base Study*, Phase Two Final Report, McLean, VA: Booz Allen Hamilton, August 2002, pp.25-26.

[24] “Future Imagery Architecture’s Mission Integration and Development (MIND) Key Messages,” briefing charts, Washington, D.C.: Raytheon Corporation, February 2004; Loren Thompson, “Space-Based Reconnaissance: Great Leaps, On the Ground.”

[25] Michael Wynne, Acting Under Secretary of Defense for Acquisition, Technology & Logistics, interview at the Pentagon, June 2, 2005.

[26] *Space Research and Development Industrial Base Study*, Phase Two Final Report, pp.27-35.

[27] *Space Research and Development Industrial Base Study*, Phase One Final Report, p.36.

[28] *Space Industrial Base Study*, McLean, VA: Booz Allen Hamilton, December 2000, p.27.

[29] *Ibid*., pp.28-29.

[30] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.26.

[31] Michael Wynne, interview.

[32] *Defense Acquisitions: Incentives and Pressures That Drive Problems Affecting Satellite and Related Acquisitions*, GAO-05-570R, Washington, D.C.: Government Accountability Office, June 24, 2005, p.7.

[33] *Ibid.*, p.9.

[34] John Williams, Senior Associate, Booz Allen Hamilton, interview in McLean, VA, January 14, 2005.

[35] *Military Space Operations: Common Problems and Their Effects on Satellite and Related Acquisitions*, GAO-03-825R, Washington, D.C.: Government Accountability Office, June 2, 2003, p.9.

[36] John Williams, interview.

[37] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.19.

[38] *Ibid.*, p.20.

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[43] *Defense Acquisitions: Incentives and Pressures That Drive Problems Affecting Satellite and Related Acquisitions*, p.4.

[44] Richelson, "The Satellite Gap," p.52.

[45] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.13.

[46] *Ibid.*, p.24; *Defense Acquisitions: Incentives and Pressures That Drive Problems Affecting Satellite and Related Acquisitions*, pp.14-15.

[47] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.23.

[48] Michael Wynne, interview.

[49] *Defense Acquisitions: Incentives and Pressures That Drive Problems Affecting Satellite and Related Acquisitions*, p.13.

[50] Michael Wynne, interview.

[51] The management changes were detailed in a memorandum entitled, "National Security Space Management and Organization," sent by Secretary Rumsfeld to the service secretaries and other interested parties on October 18, 2001.

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[60] *Space Research and Development Industrial Base Study*, Phase One Final Report, pp.51-55.

[61] *Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, p.15.

[62] *Ibid.*, p.IV.

[63] *Summary of Workforce Results*, pp.3, 10, 28-30.