Missile-Warning Augmentation

A Low-Risk Approach

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Recent operational successes with new space-based capabilities offer important reminders of our dedication to a strong space program for national security. Our military and intelligence operational responsibilities worldwide demand timely intelligence, surveillance, reconnaissance, warning, and communications to maximize the effectiveness and efficiency of the force. Investments in research, development, production, and operations have yielded important space-based mission capabilities that differentiate the United States and its allies in the execution of national security objectives.

The dependence of US national security on space continues to grow. A drumbeat of studies, reviews, speeches, articles, and congressional testimony, however, carries a clear message: (1) US national security space systems cost too much and take too long to go from concept refinement to deployment; (2) threats to our space capabilities are significant and increasing—if left unaddressed, our space infrastructure will become more vulnerable, fragile, and indefensible; and (3) the current US financial situation, including potentially draconian defense cuts, challenges the continuation of status quo acquisitions.

This article seeks to realistically address documented risks associated with a rapid transition from baseline space-program architectures if that transition involves immature technology alternatives. It draws on past Government Accountability Office (GAO) reports, studies, and program histories to raise awareness of the significant threats to successful operations and program acquisition when architectural transition decisions rely on unproven design and limited understanding of the ability and cost of production. The article includes direct reference to overhead persistent infrared (OPIR) architectural-transition concepts currently under consideration with the advent of disaggregation approaches by the Space and Missile Center. Initial concepts introduced by the center include changing from the space-based infrared system (SBIRS) to a wide field of view (WFOV) disaggregated approach.[1] This article recommends a judicious, low-risk demonstration and prototyping approach to insert capability, retire risk, and realize enhanced estimation of production and manufacturing costs.

Reinventing Space

Recently, Air Force leaders have made efforts to explore new architectures and acquisition strategies as potential solutions to the perceived high cost of continuing legacy space programs. Today most of the service's constellations consist of a few large, highly capable (typically multimission) spacecraft. Specifically, these new candidate architectures advocate the distribution of mission capabilities onto a variety of platforms—commercial or smaller, purpose-built craft. This concept, termed *disaggregation*, urges the United States to "buy capabilities in smaller capacity increments, distributed across more but smaller satellites or hosted payloads, and migrate ground segments to (shared), modular, open architectures."[2] Interestingly, OPIR already represents a disaggregated architecture that uses multiple, different orbits; free-flying and hosted payloads; and a distributed ground architecture to support a number of mission users. Is the national security community ready to begin such an extensive and, some would say, radical transition to additional new architectural- and capability-procurement approaches—especially when one considers that our current systems are just beginning to demonstrate significantly enhanced performance and functionality beyond expectation?[3]

Although the OPIR mission area has existed for decades as overhead nonimaging infrared with SBIRS and other systems, it is now the new kid on the block, integrating target-signature nuances, time, and place into persistent intelligence and operational products that bring exciting capabilities to the war fighter. The timely, near-seamless integration of observations provides discriminating capabilities. Users, now responding with analytic tools and techniques to best exploit the new capabilities, are only beginning to understand how to utilize the amazing new data. Having recently tested the downloading of OPIR sensor data directly to handheld devices to enhance battlespace awareness, the Army wants to pursue additional experimentation under the proposed Joint Capability Technology Demonstration.[4] Furthermore, the SBIRS Program Office is pursuing use of SBIRS infrared data to support requirements for weather and climate information.[5]

Expanding Overhead Persistent Infrared's Sensor Capabilities

The Alternative Infrared Satellite System (AIRSS), a new program started in the Department of Defense's (DOD) budget for fiscal year 2007, was intended to substitute for the geosynchronous Earth orbit (GEO) satellite segment of the SBIRS High program and produce a replacement for the US Defense Support Program's (DSP) missile-warning satellites.[6] According to a GAO report of 2007, the DOD was not pursuing the AIRSS as a "plan B" program as originally envisioned. Rather than seek to maintain continuity of operations, the program focused on advancing capabilities. Moreover, it did so within highly compressed time frames. DOD stakeholders disagreed regarding the wisdom of this approach, given past experiences with space acquisitions.[7]

The current Commercially Hosted Infrared Payload (CHIRP) experiment derives from the AIRSS program, also known as third-generation infrared surveillance legacy. Upon termination of the latter, the Operationally Responsive Space Office and SBIRS Program Office continued work on the hosted flight demonstration to advance process development of hosted payloads and conduct on-orbit testing of the CHIRP focal plane array at the least cost. Science Applications International Corporation's WFOV sensor is integrated on the SES-2 commercial geosynchronous communications satellite built by Orbital Sciences Corporation to validate missile-warning technologies from GEO in a fast and cost-effective manner. The CHIRP sensor features a fixed telescope that can view one-quarter of the earth from GEO. The infrared sensor will test the potential of its WFOV capabilities for future OPIR missions for the Air Force.

The ongoing WFOV demonstration encompassed by the CHIRP experiment helps to retire risk associated with incorporation of WFOV technology into missile-warning architectures and informs us of issues in the commercial hosting of payloads. However, it represents only a first step toward addressing the many performance, architectural, and manufacturing feasibility risks identified in numerous acquisition reviews. Transitioning from the SBIRS architecture that must meet demands across a number of mission areas—missile warning, missile defense, battlespace awareness, and technical intelligence—to a new, disaggregated architecture that will rely principally on WFOV technology carries significant mission risk at this time.

The CHIRP WFOV missile-warning (evaluation) sensor leveraged limited new-sensor focal-plane-array chip-production capabilities derived from the AIRSS program. A recently completed Burdeshaw Associates study of sensor performance notes that

> these WFOV designs contemplate use of large format staring arrays to provide full earth disk coverage in a series of optical payloads without dynamically adjusting the optical path. The stated, but unproven, advantage to the WFOV design paradigm is in reducing complexity, and therefore cost, through:
>
> - Elimination of an optical path element such as the mirror assembly
> - Elimination of moving mechanisms
> - Elimination of ground tasking software for the moving mechanisms
> - Use of commonly available optics for low(er) cost telescopes.[8]

The expanding missions in OPIR demonstrate the need for precise geolocation performance. Since the performance necessary to meet mission requirements depends upon position knowledge of all payloads so they operate as one, the latter drives integration precision, spacecraft stability, ephemeris, and line-of-sight knowledge. As a consequence of this complexity, these design parameters must also accommodate overlapping of the coverage of independent sensor payloads in order to interleave pixels to meet mission demands for geospatial resolution. Plans for the CHIRP experiment did not include validation for this criterion. The fundamental technology upon which WFOV uniquely depends—large-format, high-pixel-count infrared focal planes with thousands of pixels per side—is still maturing in uniformity and defect rates relative to the stringent target-detection needs of missile warning and the other OPIR missions.

Current WFOV sensor alternatives are under consideration as a payload that can be either hosted by or deployed on a small satellite. The coverage capability expands by integrating a focal plane array that contains 3,000 by 3,000 detectors (3K x 3K focal plane array) in combination with various optics options from four degrees to 14 degrees. By using such options, the focal plane array can observe greater geographic areas. However, the expanded coverage areas result in less geospatial resolution because as coverage increases, resolution suffers, adversely affecting the ability to discriminate individual launches from closely spaced launch locations until sufficient separation of the trajectory occurs. The strategic and theater components of the OPIR missile-warning requirements assess raid-counting accuracy and complete understanding of the boost-phase track as an imperative to quickly warn of and characterize an inbound attack to support responsive decision making. These design trades are important in determining system performance. The Burdeshaw Associates study reveals that

- WFOV is desirable technology, but the remaining design and production challenges preclude near term proven technology availability. The present sensitivity provided by these designs may be insufficient for current upper stage threats and many emerging threats.
- Affordable uniformity and defect rates in large medium wave infrared (MWIR) formats is still a work in progress.
- The wide field coverage combined with available large format focal planes limits the aperture size to those much smaller than SBIRS.

Simply stated, sensitivity requires photons, and the number of photons is a function of aperture size.

- Separation and counting of targets in realistic scenarios is poor and a real concern.

To help improve target discrimination, the WFOV designs have added a moving filter wheel to the optical path to accommodate additional infrared spectral bands. This increases complexity and cost over a CHIRP-like staring array.[9]

Some realities of WFOV payload integration with host vehicles may call for additional technology and engineering. The Burdeshaw Associates study draws from a survey of industrial-base analyses which conclude that

- WFOV may need to add image motion compensation mirrors in the optical path to retain image quality due to spacecraft bus vibrations, stability and drift characteristics that would otherwise spoil the optical image and its registration necessary for the success of imaging processing techniques and geolocation.
- The relatively slender WFOV multi-telescope designs will need a sufficiently stiff integrating structure to transfer attitude reference from telescope to telescope to maintain micro-radian level absolute bore-sight knowledge potentially precluding lower cost commodity bus options.
- An internal self contained line of sight knowledge calibration capability will be an essential part of WFOV payload design maturity.
- A thermal, solar and sun outage protection design must be completed to mature WFOV payload design. This is a special challenge for hosted WFOV payloads where CONOPS [concept of operations] flexibility may be restricted by primary commercial mission priority.[10]

The WFOV designs must address these complexities early in the acquisition to assure a smooth, predictable transition to the new technology.

Staff assessments by the Office of the Secretary of Defense conclude that required functional availability precludes transition from SBIRS prior to procurement of SBIRS spacecraft GEO 6 due to the alternative development timelines. Thus, meeting the need date for SBIRS GEO 7—assuming a new start in fiscal year 2014—involves risk. In today's fiscal climate, the Office of the Secretary of Defense is struggling with simultaneously pursuing a new architecture while completing/sustaining its current missile-warning architecture. Unlike the decision during the 1990s to transition from the DSP—the previous OPIR spacecraft used for missile-warning detection—to SBIRS, no stored DSP or SBIRS spacecraft are available to reduce operational hazards should acquisition delays, performance failures, or launch disasters delay successful new architectural deployments. Comparing the present situation with the one in 1994 is revealing:

- In 1994 the missile-warning architecture was very robust with more than 20 years of sustained DSP operations, spares on orbit, and six more satellites (DSP 18–23) in production, resulting in low operational risk and time to design and develop SBIRS.
- Presently the missile-warning architecture reflects declining health of remaining DSP satellites, a single SBIRS GEO 1 spacecraft on orbit, and SBIRS GEO 2–4 in production, reflecting far less architectural robustness.

Moreover, acquisition history has repeatedly demonstrated that cost assessments of revolutionary alternative architectures are generally quite optimistic due to frequent underestimation of systems engineering, program management, nonrecurring engineering, operational integration, and launch operations. The cost of ground infrastructure is often assumed neutral among alternatives. In this case, however, disaggregated architectures requiring large numbers of sensor hosts will surface new and possibly unexpected problems in management, infrastructure, and data integration.

Possible Profile of a Low-Risk Augmentation Program

Over the last several decades, we have learned many painful lessons concerning space system development (SBIRS, the Transformational Communications Satellite, space-based radar, etc.), probably the most significant of which concerns the critical nature of mature technology. Transitioning new technologies into comprehensive acquisition programs favors diligent early efforts to demonstrate the performance of those technologies and to evolve toward a full prototype prior to commitment to full production programs. This circumstance appears very relevant to OPIR WFOV alternatives.

Consequently, we need a structured approach that reduces the likelihood of both performance problems and schedule delays through judicious, step-by-step demonstration of individual spacecraft development, production, and performance as well as multispacecraft architectural performance and impact. Key elements of that approach should include (1) sustaining the operational mission of foundational capability throughout transition, (2) fully assessing the operational performance of new technology during transition from demonstrator to prototype, (3) validating final operational performance and production costs during prototype development, and (4) understanding architectural implications.

Figure 1 depicts a structured serial approach that minimizes costs through the transition while retiring performance, production, and manufacturing pitfalls. The Burdeshaw Associates study offers an example of the schedule and elements associated with a low-risk maturation program leading to an architectural alternative and/or follow-on. The dark blue and green arrows reflect SBIRS spacecraft already in production; the light blue arrows reflect those spacecraft that need additional funding and the estimated dates for delivery to mitigate operational degradation to the mission. The figure shows the three phases of the alternative augmentation technology program, indicating development and production as clear boxes and on-orbit evaluation timelines as red, yellow, and green boxes. The star represents the study's first estimate of a decision point for moving to a new missile-warning architecture.

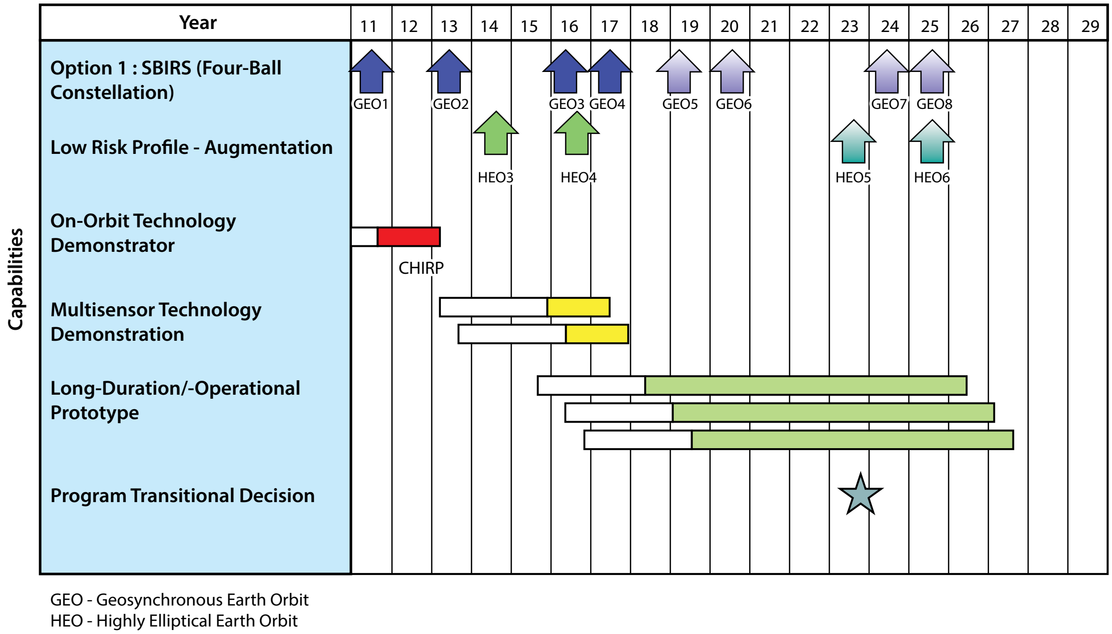

Figure 1. Profile of a low-risk augmentation program

Sustain Operational Mission throughout Transition

Fortunately, SBIRS performance is exceeding expectations. We understand its costs and risks of production; further, with the procurement of SBIRS GEO 7 and 8 and highly elliptical Earth orbit (HEO) 5 and 6, we can expect that sustained capability will support all four mission areas through 2030. This offers the DOD a sustained period during which it can thoroughly evaluate and develop WFOV capabilities and follow a minimal annual investment approach to reduce midterm and long-term risk. By maturing the mission requirements of the WFOV constellation, technical capability, and architectural approach, the department can reach a transition point based upon comprehensive understanding of the cost, performance, and ability to produce and manufacture the new components of the alternative architecture. Steps toward realizing that end begin with fully understanding and certifying across the community of stakeholders the intended set of demands that the proposed WFOV architecture will address.

Fully Assess Operational Performance of New Technology during Transition from Demonstrator to Prototype

The current CHIRP demonstration emphasizes assessing the validity of WFOV-expected simulations conducted during research, development, test, and evaluation (RDT&E) of third-generation infrared surveillance; additionally, it provides a baseline understanding of the basic performance of WFOV and integration of the payload on a commercial host. Evaluating test results over eight months to one year will help determine data accuracy and application of the WFOV sensor for missile-warning augmentation in the future. As discussed before, numerous data acquisition and processing areas need to be addressed as a means of determining whether the data acquisition and accuracies are sufficient to support missile-warning missions, both strategic and tactical. To validate data-accuracy capabilities, we will probably need a follow-on multisensor technology demonstration.

After establishment of performance requirements, sensitivity, WFOV uniformity, and defect rates, technology demonstration can move from validating expected performance of the WFOV technology to design demonstrations that more closely examine the specific mission-performance demands that the DOD assigns to the missile-warning augmentation capability. If augmentation is really intended to concentrate on enhancing resiliency of the most critical OPIR mission needs, then we should direct overall mission performance toward sustaining strategic and theater missile-warning capabilities through any contingency. We must demonstrate performance that supplies sufficiently accurate information to address missile warning through all threat environments across all geospatial areas. The architecture should focus on resiliency sufficient to survive a nuclear environment to the extent that other strategic forces can endure. To enhance the flexibility of the architecture, we must demonstrate WFOV sensor configurations that will extend the area coverage from one-quarter to full coverage of the earth, just as we must stiffen the bus and process multiple arrays together to ensure the accuracies necessary for OPIR missions. Moreover, we must deal with extended on-orbit satellite and sensor-life demonstration since replacement of short-life spacecraft or sensors for large, long-lived constellations significantly increases the life-cycle costs associated with providing the mission capability over time. After the demonstration of design technologies, missile-warning augmentation should move to the expected demonstration of an operational design configuration for the multisatellite prototype.

Validate Final Operational Performance and Production Costs during Prototype Development

Once final design for the missile-warning augmentation capability matures, we should pursue near-final-design prototypes to validate production and manufacturing costs and to develop production-line and supplier-tier organizations, processes, and costs. On-orbit assessment of multisatellite performance against near-standard designs will enable high-confidence understanding of constellation mission capability and substantiate the overall concept of deployment and operations. Additionally, confidence of the broader industrial base in estimates of production cost will assure the sustainment of program expenses throughout longer production runs of numerous satellites. High-confidence estimates of program costs will enable the definition of more realistic life-cycle costs for the entire architecture, thus enabling a better informed transition decision.

Understand the Architectural Implications

Finally, this low-risk approach gives us time to fully understand the entire architectural evolution (including ground) costs associated with transition to a “disaggregated architecture” of numerous individual spacecraft—both free flyers and hosted. Changes in operational concept and force management will have time to adapt to new ways of doing business. Understanding related costs for launch infrastructure, communications upgrades, mission management, mission data processing across many more systems, and mission-processing changes will all mature as the sensor and spacecraft design develops.

Acquisition History Reinforces Concern over Rapid Transitions

A number of reviews of space acquisition conclude that recurring risks continue to plague new starts of space programs and represent acquisition conditions that eventually lead to increases in program cost and unstable program-capability transitions. On 21 March 2012, Cristina T. Chaplain, GAO's director of Acquisition and Sourcing Management, testified before the US Senate Subcommittee on Strategic Forces, Committee on Armed Services, that

> our past work has identified a number of causes of acquisition problems, but several consistently stand out. At a higher level, DOD has tended to start more weapon programs than is affordable, creating a competition for funding that focuses on advocacy at the expense of realism and sound management. DOD has also tended to start its space programs before it has the assurance that the capabilities it is pursuing can be achieved within available resources and time constraints. There is no way to accurately estimate how long it would take to design, develop, and build a satellite system when critical technologies planned for that system are still in relatively early stages of discovery and invention. Finally, programs have historically attempted to satisfy all requirements in a single step, regardless of the design challenges or the maturity of the technologies necessary to achieve the full capability. DOD's preference to make larger, complex satellites that perform a multitude of missions has stretched technology challenges beyond current capabilities in some cases. Figure 2 illustrates the negative influences that can cause programs to fail.[11]

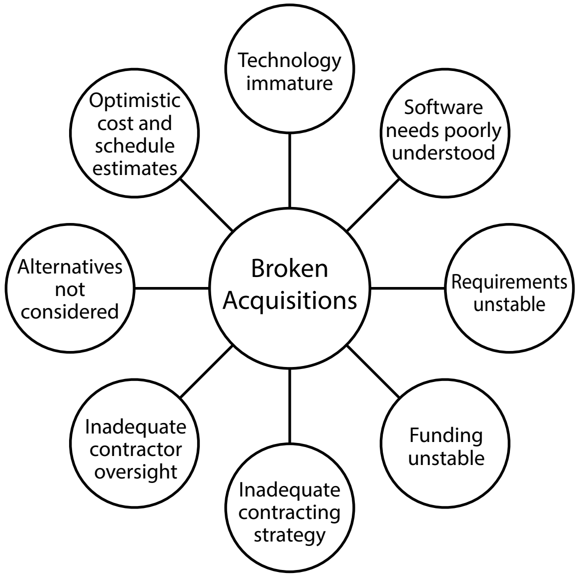

Figure 2. Negative influences that can cause programs to fail

Similarly, in 2011 a National Defense Research Institute analysis of the root causes of recent breaches of the Nunn-McCurdy Amendment, designed to curb cost increases in weapons procurement, led RAND to identify the following lessons learned:

- Production delays increase exposure to changing private sector market conditions, which can result in cost growth.
- Acquisition flexibility (e.g., start-stop programs) comes with a cost.
- Cost estimates should be conducted independently of a program manager.
- Combining remanufactured and new build items causes complexity and can lead to cost growth.
- Greater planning of manufacturing process organization is required.
- Large reductions in procurement quantities can significantly increase per unit cost.
- Sufficient RDT&E is required to ensure the "produce-ability" of a program.
- Greater government oversight of the contractor is required in a technologically complex project.
- More "hedges" against risky elements of program are required.
- Additional collaboration is needed on design specifications and discussion of cost-performance trade-offs.[12]

None of this is new. The scar tissue of experience needs to inform the debate. Some of the proposed technologies under consideration as keystones for attaining disaggregated architectures have only just begun technology demonstrations to evaluate their performance capabilities, architectural implications (e.g., reduction of risk to individual nodes and mission network operation), and manufacturing/product feasibility. When only PowerPoint designs represent the extent of capability understanding, significant hazards remain that call for additional research and development and demonstrations to retire risk areas sufficiently to meet mission assurance needs. Structuring an affordable, time-sequenced approach toward retiring these problems will put into place the "hedges" to assure that we avoid unexpected program costs and realize expected performance within the larger architecture.

The complex DOD acquisition process has numerous stakeholders, complicated interrelationships among players, and inextricably linked, interdependent processes. Unsurprisingly, then, as program proposals transition from RDT&E demonstrations to full development and production, a host of new organizational structures, management processes, new personnel, and facility and equipment investment comes into play. The history of cost estimates made in response to requests for proposals suggests that those based on mature, well-known processes and structures are consistently more accurate than those based on fresh or untried approaches. Any assessment of risk during this transition should pay particular attention to the following areas of concern.

Control Requirements

With respect to OPIR, clear identification of the requirements subset that an augmentation program should provide will preclude confusion during transition to development and production. Clearly, the current demonstrated WFOV capabilities will not satisfy the full set of OPIR needs. Concentrating on the subset of requirements that such systems will augment alleviates requirements creep as the program progresses; it also hedges against the instability of program costs.

Improve Systems Engineering

The slow development of conceptual design by means of progressively more capable demonstrators builds better understanding of performance reliability, architectural integration, and manufacturing/production process costs. Structuring a low production rate allows time to evolve and adapt design and production processes incrementally so that design and production surprises do not result in major increases in program costs and schedule risks driven by operational imperatives.

Similar lessons apply to space systems and the transition from one space architecture to the next. To assure the retirement of similar risks to manufacturing feasibility, we must assure additional evolution from sensor and spacecraft demonstrators to prototypes. In the case of OPIR, the architectural implications of multisensory data integration and interleaving necessitate the testing of multi-WFOV sensors on-orbit to better comprehend the implications for data accuracy and fulfillment of the mission. Until we contend with such demonstrations and prototypes, the alternative architectures remain at high risk for the growth of program costs and possible mission failure.

Recognize Hidden Costs in Using the Commercial Base

The RAND study concluded that

> the broader lesson learned for this [Wideband Gapfiller Satellite] program is that when DoD procurement piggybacks on a commercial base, notably the commercial base of a particular company and its ecosystem, it takes a certain risk. The base may shrink, leaving it with less capacity to cover total overhead costs. Even if the base does not shrink, it will evolve. If DoD requirements do not evolve in parallel—and there is no inherent reason why they should—the divergence between DoD's requirements and the market's requirements means that either the requirements are compromised (admittedly, this may be acceptable in some circumstances) or, eventually, such programs have to stand on their own feet. . . . This suggests that a certain procurement discipline is called for, or DoD will pay the difference. Start-stop programs are costlier than steady-state programs (i.e., when buys are consistent from one year to the next), which, in turn,

> are somewhat more costly than total buy programs (e.g., we want six satellites, deliver them when you finish them). Although DoD cannot necessarily commit to even procurements for a variety of reasons (e.g., changing requirements, risk management, congressional politics), everyone concerned should understand that there are costs entailed in maximizing acquisition flexibility.[13]

Understand Changes in Procurement Quantities

Furthermore, according to the RAND study,

> Changes in quantity are never the primary source of a change in cost. Rather, quantity changes are always driven by some other factor, such as a change in threat or mission, which changes the requirement, or technical problems, which increase costs and therefore affect affordability.
>
> The initial reductions in planned quantities from the 32-ship class originally envisioned for [the] DD-21 [destroyer] to the ten ships included in the Milestone B baseline were due to affordability. As the system design matured and experience was gained with the key technologies and subsystems through the EDMs [engineering design modifications], more realistic (higher) cost estimates were developed, which reduced both the production rate (number of ships approved for construction in a given year) and total quantity.[14]

The current state of Earth coverage by the WFOV focal plane array will likely entail multiple sensors and spacecraft to offer coverage comparable to that of SBIRS. Because of this criterion and the imperative of enlarging constellation size to add a degree of resilience, architectural quantities will increase to 20 or more platforms. Should costs escalate in the transition from demonstration design to system-development decision, the effect on the DD-21 and other programs will likely apply in the missile-warning area as well. This risk again argues for a judicious demonstration and prototyping cycle to allow our understanding of design, performance, architectural, and production costs to mature.

Conclusion

Over the past few decades, Congress has paid particular attention to the DOD's program-acquisition difficulties and has repeatedly directed that both internal DOD reports as well as those by the GAO and various commissions review space and nonspace acquisition programs and practices. Those findings reinforce the need for a judicious development of technology together with incremental improvement and testing of designs prior to production commitment. In today's fiscal climate, setting aside these lessons to once again pursue an architectural transition based upon immature assessments of new technology performance and the ability to produce would be sheer folly. Furthermore, the consequences of delay or cost risks could prove operationally catastrophic for the missile-warning mission because, unlike previous circumstances, we lack a robust backup OPIR mission force structure that can sustain program disruptions. ✪

Notes

1. Lt Gen Ellen Pawlikowski, Doug Loverro, and Col Tom Cristler, "Space: Disruptive Challenges, New Opportunities, and New Strategies," *Strategic Studies Quarterly* 6, no. 1 (Spring 2012): 40–43, 47–48, http://www.au.af.mil/au/ssq/2012/spring/pawlikowski.pdf.
2. Sara M. Langston, "USAF Official: Long Road for Distributed Sats," *Aviation Week*, 31 August 2011, accessed 6 September 2011, http://www.aviationweek.com/avnow/news/channel_space_story.jsp?id=news/asd/20.
3. Director, Operational Test and Evaluation, *FY 2012 Annual Report* (Washington, DC: Director, Operational Test and Evaluation, Office of the Secretary of Defense, 2013), 275–76, http://www.dote.osd.mil/pub/reports/FY2012/pdf/other/2012DOTEAnnualReport.pdf.
4. Briefing, Space and Missile Defense Center, Huntsville, AL, subject: Theater InfraRed Proposed Joint Capability Technology Demonstration, 2011.
5. Air Force Space and Missile Systems Center/ Weather Program Office, Los Angeles AFB, El Segundo, CA, "Defense Weather Satellite Follow-on Industry Briefing," 25 April 2012.
6. SBIRS features a mix of four GEO satellites, two highly elliptical Earth orbit (HEO) payloads, and associated ground hardware and software, with dramatically improved sensor flexibility and sensitivity. Like its predecessor, SBIRS has sensors that cover shortwave infrared, expanded midwave infrared, and see-to-the-ground bands, allowing it to perform a broader set of missions than the DSP's. The HEO sensor configuration includes the following: an infrared payload of about 500 pounds (scanning sensor), three colors (shortwave,

midwave, and see-to-ground), sensor chip assemblies, Short Schmidt telescopes with dual optical pointing, agile precision gimbal pointing and control, passive thermal cooling, 100 Mbps data rate to ground, and strategic and theater surveillance. The GEO spacecraft configuration includes the following: predicted wet weight of about 10,000 pounds at launch; three axes stabilized with 0.05 degrees of pointing accuracy and solar flyer attitude control; RH-32 radiation-hardened, single-board computers with reloadable flight software; approximately 2,800 watts generated by GaAs solar arrays; Global Positioning System receiver with Selected Availability Secure Anti-Spoof Module; infrared payload of about 1,000 pounds (scanning and staring sensors); three colors (shortwave, midwave, and see-to-ground); sensor chip assemblies; Short Schmidt telescopes with dual optical pointing; agile precision pointing and control; passive thermal cooling; and secure communications links for normal, survivable, and endurable operations.

7. Government Accountability Office, *Space Based Infrared System High Program and Its Alternative*, GAO-07-1088 (Washington, DC: Government Accountability Office, 12 September 2007), 3, http://www.gao.gov/assets/100/95166.pdf.

8. Burdeshaw Associates, *Space Architecture Study* (Bethesda, MD: Burdeshaw Associates, March 2013), 181.

9. Ibid., 151n3.

10. Ibid.

11. Senate, *Space Acquisitions: DOD Faces Challenges in Fully Realizing Benefits of Satellite Acquisition Improvements, Statement of Cristina T. Chaplain, Director, Acquisition and Sourcing Management, GAO, Testimony before the Subcommittee on Strategic Forces, Committee on Armed Services*, 112th Cong., 2nd sess., 21 March 2012, 15–16, http://www.gao.gov/assets/590/589487.pdf.

12. Irv Blickstein et al., *Root Cause Analysis of Nunn-McCurdy Breaches*, vol. 1 (Santa Monica, CA: RAND Corporation, 2011), xvi, http://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG1171.1.pdf.

13. Ibid., 84.

14. Ibid., 27.

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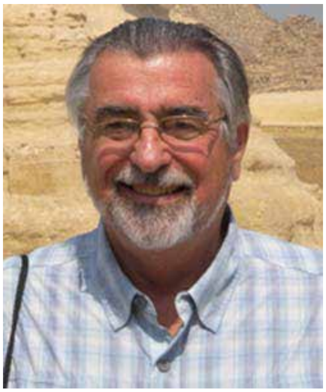
Mr. Harris (BS, Rochester Institute of Technology), the chief executive of JKH Consulting, LLC, has contributed to US national security capabilities in both government and industry where he has fostered new technologies and programs. He retired from Lockheed Martin as a corporate officer and served as president of Lockheed Martin Missiles and Space and of Lockheed Martin Special Programs. He also served as president of Space Imaging, the first company to provide high-resolution satellite imagery and information products for cost-effective solutions to global business needs. Before entering the private sector, Mr. Harris held senior national leadership positions, including assistant secretary of the Air Force for space, director of the National Reconnaissance Office, and associate executive director of the intelligence community. In all of these capacities, he provided direct support to both the secretary of defense and the director of central intelligence.



Gilbert Siegert

Mr. Siegert (BS, University of California–Santa Barbara; MBA, University of Wyoming) possesses more than 41 years of Department of Defense (DOD) and corporate aerospace experience in many of the space operations and systems that emerged during that period. He has 26 years of experience in the US Air Force, retiring as a colonel; 14 years in supporting the Office of the Secretary of Defense; and several years serving as the president of Space Ventures Consulting. During this consulting period, he worked for Burdeshaw Associates on numerous space-related projects. His expertise in space policy and strategy development, space program oversight, US government processes, and commercial space efforts contributed to the evolution of space operations over the last 40 years. While serving as a special assistant for space policy, strategy, and plans in the Office of the Deputy Assistant Secretary of Defense for Space Policy, Mr. Siegert was called upon to lead and participate in numerous congressional reports as well as interagency and DOD studies and analyses that directly resulted in organizational, program, and force-structure changes over the years. His analysis and inputs formed the basis for the space portion of the past several Quadrennial Defense Reviews and both Space Posture Reviews. He contributed to many of the foundational assessments that led to the Global Positioning System, various military satellite communication systems, space-based infrared system, electro-optical reconnaissance system, space-based radar, missile defense systems, Defense Support System program, multiple space launch vehicles, space situational awareness capabilities, and supporting technologies. Mr. Siegert's investigation of future commercial space capabilities such as commercial space launch ventures, space solar power generation technologies, space debris generation and domain consequences, and space traffic management concepts enabled him to contribute to space industry projections and industrial base analyses.

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