Future Space System Acquisitions

Is the Key "What" or "When"?

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Illustration, Defense Meteorological Satellite Program orbiter. Source: U.S. Air Force Space and Missile Systems Center.

A serious discussion is under way within the defense community on the strategic direction of future space system acquisitions. Among the questions being addressed:

Now that the difficulties with our major, large, aggregated space systems seem to have been overcome, should the United States simply continue and/or improve these systems over time? Or should we go quickly toward small-satellite, platform-focused, distributed-system architectures?

What seems to be missing in the discussion is a basic tenet of good acquisition management: Do not initiate a major acquisition program, either a revolutionary architecture change or an evolutionary one, until the key technologies are mature.

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What We Buy

Certainly, what we buy is very important. Successful space acquisitions depend on many factors. For a military space system to succeed, mission performance requirements must be met; costs must be affordable; the system must be available when needed (resilient); and it must be adaptable to new mission needs. All these factors influence what we decide to buy.

There is an ongoing, low-key debate within the space community on whether to move to proposed small-satellite, distributed architectures or to continue and/or evolve existing aggregated systems. In a recent *Strategic Studies Quarterly* article, "Disruptive Challenges, New Opportunities, and New Strategies," Lt. Gen. Ellen Pawlikowski, Doug Laverro, and Col. Tom Cristler argued that our current and near-future space systems lack the needed resiliency, affordability and adaptability demanded by new international realities. These new realities, or disruptive challenges, include:

- Widespread and growing operational dependence on U.S. space systems.
- Growing threats (e.g., anti-satellite weapons (ASATS), jamming, cyber attacks, etc.) to these systems.
- Poor resiliency of U.S. space systems (i.e., large, expensive satellites; few if any spares; small constellations and easy targets).
- Fragility of U.S. constellations. A loss or delay of a single satellite greatly degrades capabilities.
- Technological stagnation of our systems.
- The shrinking industrial base, especially suppliers in the second and third tier.

In formulating a response to these disruptive changes, the authors argued, "We found the most important elements were not the conditions surrounding what we build, but rather the architectures we choose to build."

They further concluded that many challenges are a direct result of building aggregated, highly integrated, long-lived satellites. The solution presented concentrates on small-satellite, platform-focused, distributed-system architectures. The potential advantages they advocated for this revolutionary architectural approach fall into four important areas:

- Cost and Schedule Improvement
  - — Lower the cost of individual satellites.
  - — Use less costly mission assurance and smaller, less-expensive launch vehicles.
  - — Use executable baselines (cost and schedule).
  - — Create hosting opportunities at reduced cost.
- Industrial Base Strengthening
  - — Use smaller satellites in larger constellations that call for a continuous, multiyear production line, thereby strengthening the industrial base and lowering cost.
- Improved Resiliency
  - — Lower-cost options for adding on orbit spare or redundant systems—and ground reserves for reconstitution.
  - — Increase constellation size, distribute capability and reduce the impact of losing a satellite to render more difficult an attack on the satellites.
- Ease of Technology Insertion
  - — Use less complex satellites to allow for easier, new technology insertion and capability upgrades.

This concept, however, has its critics. We maintain that the transition from mission to architecture focus must be assessed and analyzed carefully. Once requirements are defined, architectural alternatives represent only one metric. Other needs that must be assessed to arrive at a best value program include acquisition strategy, sensor performance, satellite performance, total integrated system performance, launch vehicle requirements, ground station architecture and user equipment.

As to the proposed advantages of a small-satellite, platform-focused, disaggregated architecture, other considerations merit discussion.

Definitive Analysis

There has not yet been a rigorous analytical comparison of using a proposed small-satellite, distributed architecture versus evolving an existing aggregated system for each mission.

Cost and Schedule

Though the costs of the existing aggregated systems are very high, there is no reason to believe the small-satellite, distributed architectures will cost less.

The need for aggregation and complexity is driven by mission performance requirements. Disaggregation may reduce the cost of an individual satellite but not necessarily the cost of the composite architecture needed to fulfill the mission.

Many smaller satellites in an architecture have unique constellation management issues, possible constellation intercommunications requirements, transition considerations, ground infrastructure complexities and user costs that could greatly increase the composite architecture life-cycle costs.

When deciding whether to evolve from the existing aggregated systems (e.g., SBIRS, AEHF, etc.), the impressive technology and performance advances now available in those systems also must be considered and treated carefully.

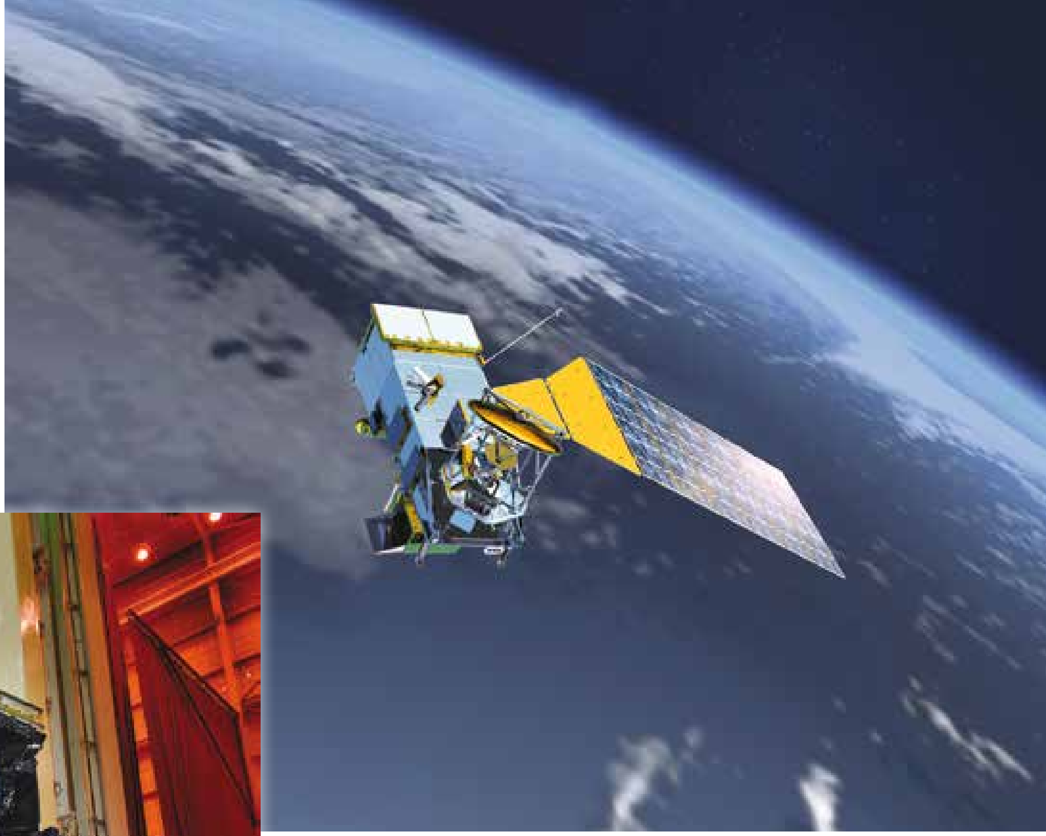
Hosted payloads may have a role, but many unique challenges concerning weight, power, space, communications, and satellite support must be addressed.

Space System Industrial Base

While a small-satellite production line may help, other current factors contribute to the industrial base problem. These include the reduced opportunities for space-related research and development; current fiscal downsizing; budget instability; the inability of primes (until Efficient Space Procurement) to

Right: National Polar-orbiting Operational Environmental Satellite System.
Source: National Oceanic and Atmospheric Administration.

Below: Advanced Extremely High Frequency satellite system.
Source: Lockheed Martin.



block buying satellites; and the prohibition against part and subsystem purchases across a number of individual programs.

Resiliency

There seems to have been none of the needed, detailed studies to assess the relationship between constellation size and resilience and to demonstrate how much disaggregation is enough. Intuitively, more satellites may make it more difficult to attack the capability—but not necessarily by much.

Other space protection measures should factor into our strategy. Examples include international agreements and treaties; satellite self-defense; decoys; counterstrike capability; a clearly stated U.S. policy to retaliate for any such attack; space control capabilities; hardening; and augmentation capabilities from the aerial and ground levels. Proliferation of satellites may be the least cost-efficient path to resiliency.

Technology Insertion

Disaggregation of a satellite system doesn't necessarily mean it is easy to insert new technologies. Complex transition management across several evolutionary generations and configurations of space payloads still could be costly and take considerable time to implement as evidenced by the recent Global Positioning System (GPS) program experience.

It is hoped that this brief treatment of the very complex architectural issues illustrates there are no easy, obvious architecture solutions and that architecture is only one of many space system acquisition issues. One of the most important is when to enter the Defense Acquisition System.

When We Buy

There are some very important lessons in our space history. When we interviewed industry and government executives and asked what space programs they considered successful models and which were troubled, the answers were very consistent. Successful programs included:

- Discoverer/Corona and its successors
- Transit
- Defense Support Program (DSP)
- Defense Satellite Communications System (DSCS)
- Defense Meteorological Satellite Program (DMSP)

Almost as many were considered "troubled" programs, including:

- Future Imagery Architecture (FIA)
- Military Strategic and Tactical Relay (MILSTAR)

- National Polar-orbiting Operational Environmental Satellite System (NPOESS)
- Space Based Infrared System (SBIRS)
- Advanced Extremely High Frequency (AEHF) satellites

We decided to look at these programs broadly to see if we could discern a consistent pattern that would point to the really important differences between successful and troubled programs in the context of our present situation.

Lessons from Successful Programs

Discoverer/Corona

The Discoverer/Corona (KH-1 through KH-5/6) programs produced a series of strategic reconnaissance satellites used from 1963 through 1972. The program, at inception, was truly revolutionary. This is demonstrated by the number of firsts Discoverer/Corona achieved. Among those were the first polar orbiting satellite (Discoverer 1); the first 3-axis stabilized satellite maneuverable from the ground; the first to send a re-entry vehicle back to Earth (Discoverer 2); the first successful recovery of a re-entry vehicle (Discoverer 13/KH-1); and the first successful recovery of image intelligence from space (Discoverer 14/KH-1).

These "firsts" came at a price—11 of the first 12 launches were failures. But as the Corona satellites' technology evolved, performance improved, and, by the end of the program in 1972, the program had launched 144 satellites with 102 successful recoveries of usable photographs.

Transit (also known as NAVSAT)

Transit was the first operational satellite navigation system. It started development in 1959, but the first Transit failed to reach orbit. Transit 1B was launched successfully in 1960. This was followed by 42 more launches, culminating in Transit Oscar-31 in 1988.

Following some difficult initial problems, the Transit proved very reliable. The first production run (Transit Oscar-12 through Oscar-32) of this indestructible satellite was able to keep the constellation operational for more than 32 years, and the constellation still is transmitting as the Navy Ionospheric Monitoring System.

But it wasn't easy at first. Transit went through five experimental satellites, three series of operational prototypes, and 11 short-lived "operational satellites" before the fully successful O-12 (Oscar 12). The design through this period evolved. Navigation accuracy went from 120 meters (1964) down to 3 meters (1980).

Defense Support Program (DSP)

The DSP is one of the most successful U.S. programs. It is a survivable, reliable satellite constellation designed to detect missile and/or spacecraft launches and nuclear explosions. The DSP has undergone five technology upgrades that have taken its weight from 2,100 to 5,250 pounds; its power from 400 watts to over 1,250 watts; its detectors from 2,000 to more than 6,000; and its design life from 1.25 years to more than 5 years. Since its first launch in 1970, DSP has provided 40 years of uninterrupted space-based early warning.

Defense Satellite Communications System (DSCS)

The DSCS program began in 1967 with the launch of three Initial DSCS I satellites. The DSCS I program launched 27 initial DSCS satellites with one failure. The DSCS I satellites weighed 100 pounds and contained a single X-band transponder.

The DSCS II program was approved in 1968, with the first launch in 1971. The DSCS II satellites were a significant upgrade of DSCS I. This 1,150- to 1,350-pound satellite emphasized hardening, anti-jam protection and increased channel capacity. The communication payload included two 20-watt X-band channels. Fifteen DSCS II satellites were launched, with two failures.

The DSCS III, first launched in 1982, remains the workhorse of the U.S. military's super high-frequency communications system. It offers significantly greater capacity, longer life and better-protected communications than its predecessors. It is a 2,580-pound satellite with six channels of X-band communications. Fourteen DSCS III satellites have been launched successfully.

Defense Meteorological Satellite Program (DMSP)

Another of the most successful U.S. space programs, the DMSP was initiated in 1961 at the National Reconnaissance

Office (NRO). Now in its fifth decade of service, the DMSP still provides valuable weather data to the military, civil and scientific communities. The DMSP-5D3 is the latest (11th) version of DMSP satellites. The DMSP has evolved from a 90-pound, spin-stabilized satellite with shutter-style TV cameras to the current 2,640-pound satellite with seven sophisticated instruments. Fifty-one DMSP satellites have been launched with nine failures during its 50-year lifetime.

Lessons from 'Troubled' Programs

Future Imagery Architecture

A book could probably be written about this program—called by the *New York Times* "perhaps the most spectacular and expensive failure in the 50-year history of American spy satellite programs." In summary, NRO decided to develop optical and radar imagery satellites that were smaller, lighter and less expensive than the current satellites. Conceptual architectural studies began in 1996, but it wasn't until 1999 that Boeing was awarded the optical and radar-imaging satellite contracts. Boeing had underbid Lockheed Martin by a billion dollars. It was a very surprising selection since Lockheed Martin had supplied all the then-current imaging spacecraft—optical and radar—and Boeing had never built the kind of satellites the government was seeking. By 2005, an estimated $10 billion had been spent, twice the original estimate of $5 billion. Most analysts believe FIA was destined to fail because the technology needed to meet requirements wasn't mature, there wasn't enough funding, the schedule was unrealistic and the selection criteria and source selection process for the space element of FIA were flawed.

MILSTAR

The MILSTAR program officially started in 1981 to develop a secure, jam-resistant, worldwide communication satellite system. The first launch was scheduled for 1987. Schedule slips and cost overruns started in 1984 and continued. In 1991, DoD restructured the program by reducing constellation size from eight to six, reducing ground stations from 25 to nine, cutting total terminal quantity from 1,721 to 1,467 and eliminating survivability features.

Six satellites were launched between 1994 and 2003, with one failure. These satellites provide jam-proof, UHF and high-data-rate communications. The cost of reaching the redirected capability has been estimated at $22 billion (up from an estimated $9 billion to $10 billion), with each satellite costing about $800 million. The schedule slipped more than 4 years.

The Government Accountability Office identified the following MILSTAR problems:

- Technology was insufficiently mature (concurrency).
- Software needs were poorly understood.
- Requirements were defined inadequately.
- There were myriad requirements and engineering changes.

National Polar-orbiting Operational Environmental Satellite System (NPOESS)

NPOESS, a revolutionary, very complex, next-generation weather satellite system was designed to monitor the Earth's weather, atmosphere, oceans, land and near-space environment. The NPOESS program was managed jointly by the U.S. Air Force, the National Oceanic and Atmospheric Administration (NOAA) and NASA. The program was canceled Feb. 1, 2010, due to cost overruns, schedule slips and technology difficulties.

The NPOESS program was an effort to integrate the capabilities of the NOAA Polar-orbiting Environmental Satellite, the DoD DMSP, and NASA's continuous climate data collection satellite into one satellite. Some of the NPOESS problems centered on technically maturing its large suite of very sophisticated sensors.

This, coupled with many interagency management problems, killed the program.

Space-Based Infrared System (SBIRS)

Like the NPOESS, the SBIRS was conceived in an era when the prevailing wisdom called for combining missions on a single satellite to reduce the number of satellites and launches, saving development and operational costs. The SBIRS satellites were built to satisfy four missions—missile warning, missile defense, technical intelligence and battlespace characterization.

The program encountered significant technical problems (both hardware and software), unclear requirements, unexpected software complexity and unstable funding. As a result, program costs ballooned and the schedule slipped dramatically. The program now faces parts and subsystem obsolescence challenges. If the government decides to purchase GEO 6 and 7, the focal plane array substrate will have to be replaced, as the only company that made the substrate material has gone out of business. This problem largely came about because of the multiyear schedule slippages but also because some of the parts are unique to SBIRS and have only a single supplier or no source.

The recently launched SBIRS GEO and HEO satellites are performing very well and provide significantly improved performance and utility to their users.

Advanced Extremely High Frequency (AEHF) Satellite System

The AEHF is a planned six-satellite constellation to be used to relay service communications for U.S., British, Canadian and Dutch military forces worldwide. Two of the six have been launched and are undergoing tests. AEHF will provide 10 to 12 times the bandwidth and 6 times the data rates and it will support twice as many tactical networks as the MILSTAR II satellites. This means the AEHF will deliver 10 to 12 times the data throughput of MILSTAR so that "for every one link of the

Illustration of a disaggregated satellite system. Source: Defense Advanced Research Projects Agency.

old MILSTAR, the Air Force now has 12 links operating at 4 (to 6) times the speed."

The AEHF had its share of technical problems, including interface control redesigns, delayed delivery of signal-encryption products, disqualified parts, and unplanned component testing. But the program suffered as much, if not more, from as many as six changes in the requirements and number of satellites, from budget fluctuations and from constant program replanning and rebaselining. Two successful AEHF launches have occurred, and testing is under way. The satellites have displayed very impressive performance in these early tests.

Summary

Lessons we might justifiably draw from this brief and broad recap of past satellite programs include:

(1) Virtually all the programs, successful or troubled, that were revolutionary in technology and/or design had significant initial cost, schedule and technical problems (see Discoverer/Corona, Transit, NPOESS, SBIRS and AEHF).

(2) Once the technology matures (e.g., Discoverer/Corona, Transit, MILSTAR, SBIRS, and AEHF), revolutionary systems can further evolve and improve with significantly fewer problems as long as the inserted technology is mature and has a continuing industrial base. For example, to go from the Discover/Corona re-entry capsules to the first real-time imaging satellite, the risk reduction/maturation process took about 5 years and more than $1 billion (in today's dollars).

(3) Technical maturity must be matched by a significant production base for the parts and subsystems used on the satellites. As SBIRS is demonstrating, if there is no production base and no commercial adjunct, the Service would not only bear the cost of developing the system but as sole customer would have to support the manufacturing base at enormous cost over the many years of a typical system life cycle or develop new technology to replace the parts or subsystems.

The most successful programs (DSP, DSCS and DMSP) really were evolutionary programs. That is, the initial versions were challenging technically but didn't require major technological leaps. These programs had some initial problems but these were much less significant than those seen in the more revolutionary programs. Significant upgrades were made, with few major problems, in subsequent versions—when the technology was mature.

It is clear that evolution of a mature technology (be it from the beginning of the full-scale development effort or after the painful maturing of a revolutionary development effort) is the best approach for successful space system acquisition.

One key to successful space system development is to initiate acquisition of the operational space system after the research-and-development effort has matured the technology to be utilized. Maturity can be defined as follows: The technology has been developed, tested on the ground and in orbit; production sources have been identified and costs verified; and performance ranges (i.e., marginal performance vs. cost) have been established. Our bottom line is that the United States should evolve its present systems carefully. Evolutionary changes should be made as the technology matures, and revolutionary architecture changes should be deferred until small-satellite, distributed-system technology has been thoroughly analyzed, developed and tested; costs have been verified; performance ranges established and production sources identified.

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