

# Space

## Disruptive Challenges, New Opportunities, and New Strategies

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FEBRUARY 17, 1864 was a cold night just outside Charleston Harbor. The War of the Rebellion had raged for the prior three years as a bitter struggle of will and staying power. Key to that staying power—or more precisely, to breaking it—was the strategic blockade Union forces had imposed on the South, the so-called Anaconda Plan;<sup>1</sup> and no single point in that blockade was more important than Charleston Harbor. As the site of the Civil War's first real battle and the largest port in the South, it bore both symbolic and strategic significance.

On that night, though, a new strategic dynamic was about to unfold. Beneath the dark, frigid waters of the Atlantic, the *H. L. Hunley* steered toward its target, the USS *Housatonic*. RADM John Dahlgren, the US

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Navy commander of the South Atlantic Blockading Squadron, had heard of the new Confederate vessel—a submersible that could engage ships while under water—and its two previous failed missions;<sup>2</sup> but this knowledge was not able to save his fleet from loss. As alarms rang out above, and with cannons ill adapted to target the low lying vessel, the *Hunley* rammed its 135-pound torpedo into the hull of the *Housatonic*, and in less than five minutes, the *Housatonic* was lowered to its watery grave (along with its attacker just a few hours later). Submarine warfare had begun, and the Union navy, and every subsequent navy, had to either adapt or sink into insignificance.

A century and a half later, “In the predawn darkness of 11 January 2007,”<sup>3</sup> a similar strategic shift was emerging. Symbolically and strategically, the US position in space had been a source of strength and prowess since the dawn of the space age. The space race of the late 1950s and early ’60s was a formative surrogate for the more expansive superpower contest that raged on for the next three decades. The US “victory” in the race for the moon was a defining moment for our nation and for our adversaries. That symbolic victory underscored the strategic import yet to come.

The technological edge that led to this victory had sharpened over the ensuing 50 years. At the close of the last millennium, the United States enjoyed dominance in space power that, while waning, was still head and shoulders beyond its closest competitors. The US reliance on that dominance had not gone unnoticed. Chinese strategists recognized their ability to counter US military capability lay, in part, in the ability to target space.<sup>4</sup> As in the case of the *Hunley*, the US apparently knew of the upcoming Chinese kinetic antisatellite (ASAT) weapon test and its previous failures.<sup>5</sup> But with measures ill adapted to intervene in such a test, all the US could do was observe and take heed. Space warfare had begun anew, and the space community, along with every space-faring nation, was now on notice that they had either to adapt or plummet into insignificance.

*In times of disruptive change your expected future is no longer valid.  
Leaders need to think and act differently in order to chart a new  
course for the enterprise.*

—Doug Berger, *Innovate*, August 2005

Disruptive change is not a new phenomenon. New technologies, unexpected threats, novel tactics and techniques, and altered approaches

can create changes to the strategic environment in which we operate. Those changes can alter the landscape in ways that, if not addressed, can dramatically upset the existing order. They can render effective strategies impotent, change winners into losers, and turn victory into defeat.

Disruptive change has been a decisive force throughout history. The English longbow rendered knights' armor ineffective in the Battle of Crécy and is considered by many historians as the beginning of the end of classical chivalry.\* Assembly line mass production not only dramatically impacted the speed at which manufactured goods could be assembled, but also reset the productivity curve for each worker, significantly increasing their value and wages and precipitously driving down the cost of manufactured goods†—a major step in the growth of the middle class. Today, digital music and file sharing have upset 50 years of unimpeded growth in the record industry, with many predicting its end is near.<sup>6</sup>

Disruptive change rarely involves a single element, nor does it happen abruptly. It has taken over 30 years for the record industry. The introduction of digital music in 1982,<sup>7</sup> along with high-speed Internet, high-capacity digital storage drives, and a change in public focus from high-quality music to readily available music, have all led to the extended downhill slide that leaves many big music labels grasping for how to cope with the threat.

How will disruptive change impact the direction of US space power, and what strategies will be effective in dealing with it? The answer lies in our understanding of the rise of space power and how that led to the conditions of today. This article examines the forces of disruptive change in addition to the ASAT threat, presents a set of possible responses to the challenges, and investigates whether the responses group into logical categories of actions. It then delves into how those actions might be implemented in future architectural states for space systems and if the conditions of the space market are appropriate for those responses. Finally, it asks how we might change the acquisition of space capabilities to better allow these responses and what that might mean in specific mission areas.<sup>8</sup>

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\*Once mounted, knights became vulnerable to common soldiers firing from a distance; the classic use of armored cavalry and hand-to-hand battle became of lesser significance in the outcome of battles.

†For example, wages in the Ford factory doubled while the cost of an individual automobile fell by almost 30 percent.

## **The Growth of Space Power**

The current generation of US satellite systems emerged in an era far removed from today. From the very beginning of the space age to the last days of the Cold War, most space systems were focused on strategic conflict. They were highly classified, with services and information that had little impact on the tactical landscape. Space warfare was viewed as unlikely—just another element of the strategic *détente* between the Soviet Union and the United States. If a war in space were to occur, it would be as a prelude to a strategic contest between the world's two superpowers.

Depending upon one's view, either the United States or the Soviet Union was the preeminent space power during the early days of the Cold War.<sup>9</sup> But by the late 1970s, the US space industrial base—powered by simultaneous investments of Apollo, ICBMs, and SLBMs—was unmatched, robust, and vibrant, with multiple competitive sources of supply at every level of production. Retired general Tom Moorman said, “The 1960s and early 1970s saw the rapid growth of military space technologies, infrastructure and programs. The breadth of space capabilities developed during this time was indeed quite remarkable and in a word—breathtaking.”<sup>10</sup>

In those days technology was king, and experimentation in the military uses of space was expansive. From manned military programs, such as Dyna-Soar and the Manned Orbiting Laboratory (MOL),<sup>11</sup> to unmanned nuclear detection and warning programs and early space reconnaissance programs, failures preceding success were common, if not expected. And failures could be tolerated, because dependence on specific systems for everyday war-fighting was minimal. In fact, due to their highly classified nature, most of the failures were shielded from the kind of scrutiny that other programs endured.<sup>12</sup>

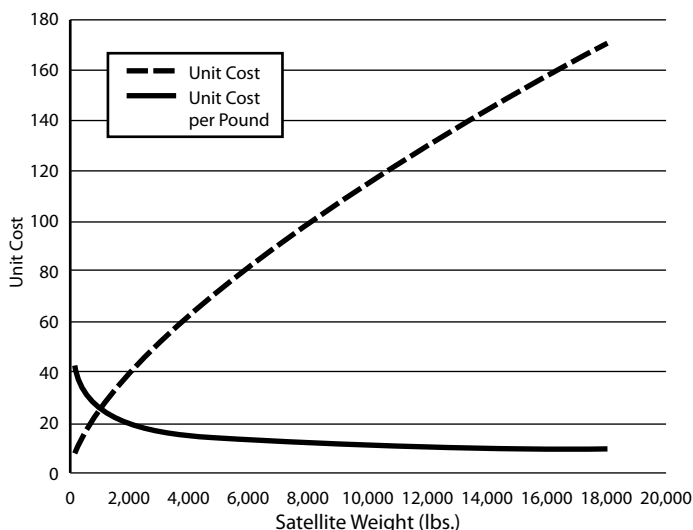
Lastly, the cost of space, while important, was of lesser concern. As part of the superpower contest between the United States and the Soviet Union, most space programs were viewed as vital and nonnegotiable. The price tag for a program was regarded in contrast to its larger strategic purpose rather than as an element of discretionary military spending.

With these conditions as backdrop, the US space program and the systems it developed were aimed at only a few primary ends—pre-conflict intelligence, nuclear attack warning and response,<sup>13</sup> and continuity of nuclear command and control.\* Continuous war-fighting resiliency, short of

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\*It is interesting to note that the GPS system was justified for part of its development, not on the basis of its impact to tactical maneuver warfare, but on the role it played in nuclear attack assessment.

nuclear survivability,<sup>14</sup> was sacrificed for technical capability. There was no “live-fire survivability testing” or requirement that accompanied similar war-fighting systems. Additionally, space was viewed as an extension of strategic *détente*; the same kind of deterrence that prevented nuclear war was relied upon to protect satellite systems.



**Figure 1. Satellite cost versus weight** (Graph generated through the unmanned space cost model, or USCOM.)

These forces had a direct impact on the way space systems were designed. An unchanging dynamic of space systems is that their utility on a per-pound basis tends to increase as their weight increases, with a simultaneous decrease in cost per pound (see fig.1). Similarly, the cost of launch was significant, but once a launch vehicle was determined, it made economic sense to maximize the system weight within the launch vehicle constraints.

In traditional war-fighting systems, the concentration of so much capability onto a single platform might not make military sense; but the lack of a direct threat to the system reduced the consequences of that decision. Plus, given the short lives of space systems (most at that time were planned to last 3–5 years), production runs were relatively large and replacement satellites could be called up in comparatively short time frames.

As the space enterprise matured, this approach continued. The evolution of the defense meteorological satellite program (DMSP) is instructive. The

original (Block 1) satellite launched in the early 1960s weighed about 175 lbs. By the late 1990s, the Block 5 satellites had swelled to over 2,500 lbs. Had it been completed, the replacement national polar orbiting environmental satellite system (NPOESS) would have weighed in at over 5,000 lbs. Even though the cost-per-pound of such a satellite would be about one-third of the initial smaller design, the total cost would have increased by a factor of 10.

## **Space Begins to Blossom**

As the Cold War began to thaw, space was poised for change. Space capabilities during that era had been primarily focused on supporting strategic warning, intelligence, and continuity of operations in the event of nuclear war. In contrast, its role in non-nuclear force enhancement was modest at best.<sup>15</sup> Yet today, US space dominance has become a crucial element of how the United States fights wars. Our use of space capabilities has transformed over the past two decades.

The First Gulf War was labeled by then–Air Force chief of staff Gen Merrill McPeak as “the first space war.”<sup>16</sup> Indeed, the impact of space power on the conduct of Desert Shield/Desert Storm was substantial;<sup>17</sup> substantial enough for both space advocates and non-advocates to take notice. However, the true war-fighting impact was arguable. Precision bombing was still dependent upon laser or electronic designation\* rather than GPS guidance;<sup>18</sup> imagery products, too large for broadcast through existing satellite communication (SATCOM) networks, were delivered to theater by air transport; and while DSP-detected scud launches were useful for warning troops and civilians, the information was neither timely nor accurate enough to allow “scud hunters” to find their targets.<sup>19</sup> Space power was still in its infancy.

These facts were not lost on senior DoD and Air Force leadership. Their sentiment was best expressed by the commander of Desert Storm allied air forces and future commander of US Space Command, Gen Chuck Horner: “What we have to do is change our [space] emphasis from strategic war to theater war. We have to get over the Cold War and make sure

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\*For example, in the 1991 Gulf War, 92 percent of the bombs were unguided and 8 percent were laser guided. By contrast, nearly 60 percent of the bombs dropped on Afghanistan in 2001 and 2002 were either laser or GPS guided.

that we're equipping and training and organizing to fight the kind of war that's probably going to be thrust upon us."<sup>20</sup> And from his perch at US Space Command, he had the wherewithal to make it happen. Over the next 10 years, the integration of space and theater tactical forces expanded beyond expectations. While these capabilities exercised their adolescence in Kosovo, they reached true adulthood in Operations Enduring Freedom and Iraqi Freedom.

Today, the direct combat support role of space is inarguable.<sup>21</sup> Without exaggeration, the combat effects we have come to expect from our smaller, more mobile force structure would not be possible without space capabilities.<sup>22</sup> The impact of GPS alone has fundamentally shifted the way US forces locate and destroy targets, plan operations, control both material and war-fighting assets, synchronize effects, and guide both troops and remotely piloted aircraft (RPA) home. Beyond GPS, the impact of SATCOM (RPA control, direct broadcast of real-time imagery), space imagery (target location and identification), space weather (route and operations planning), and overhead persistent infrared reconnaissance (missile warning, missile defense, and battlespace awareness) have had wide-ranging impact on every element of war.

### **Compounding Changes—Disruptive Forces**

As stated by then–Deputy Secretary of Defense Bill Lynn, “In less than a generation, space has fundamentally and irrevocably changed. . . . Without [space capabilities], many of our most important military advantages evaporate.”<sup>23</sup> In Clausewitzian terms, space has become a US center of gravity,<sup>24</sup> a fact as apparent to our adversaries as to our own defense establishment. Thus, borrowing from their own military philosophy, “What is of supreme importance is to attack the enemy’s strategy,”<sup>25</sup> Chinese planners set out upon an ambitious effort to hold US space systems at risk; an effort that culminated with the events of January 2007 described in the prologue above.

China is not the only nation capable of threatening US space capabilities. The technological capability to jam satellites is fairly simple and can be easily assembled by either individuals or nations for a fairly modest investment. Multiple reports of both state and nonstate groups jamming satellites have been seen over the last decade. GPS jammers are well known and offered openly for sale on the Internet. Satellite transit times are available from several websites and can be downloaded onto smart phones.<sup>26</sup> While none

of these threats rise to the level of an in-space ASAT test, they demonstrate how technologies once reserved for only advanced space-faring nations are now the purview of smaller states and individuals alike. The days of space chivalry are clearly numbered.

These fundamental changes—the growth of space as a tactically vital resource and the demonstration by adversaries of their intent to make space a target in both a nuclear and conventional contest—are two of the critical disruptive forces sweeping over US space strategy today. However, there are others.

Space technological strength is no longer a monopoly for American industry; multiple nations now boast a fully developed space industrial base, from satellite technologies to launch. By 2011, over 50 countries had at least one satellite in orbit;<sup>27</sup> they, and multiple consortia, vie for orbit positions and expansion of capabilities and can buy those capabilities from an increasing number of companies that provide space technology to the world.

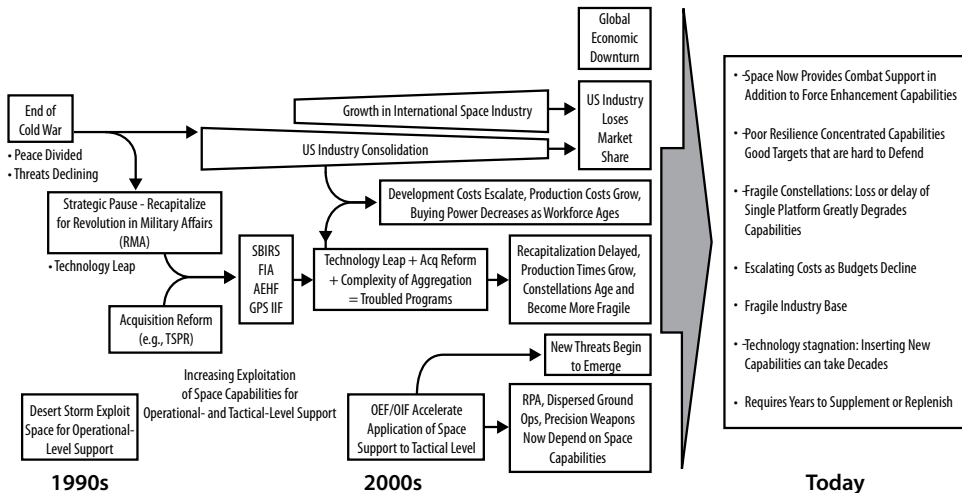
The expansion of space industrial capability beyond the shores of the United States or Russia coincided with the “peace dividend” in the early 1990s; both led to a rapid consolidation of industry within the United States. The robust industrial base of the ICBM and Apollo eras that had empowered growth and competition in the space industry during the Cold War was disappearing. US suppliers, especially those in the second and third tiers, came at risk due to inconsistent acquisition and production rates, long development cycles, consolidation of suppliers under first-tier prime contractors, and a more competitive foreign market.<sup>28</sup>

At the same time industrial competitiveness waned, costs began to grow, and delivery times began to stretch. Since the mid-1990s, we have seen some of the longest delivery times for major space systems since the beginning of the space age.<sup>29</sup> The causes are multifaceted—higher spacecraft complexity, fewer sources of space-qualified parts, increased software complexity—and it is the continuation of a trend that started a decade before.

Higher costs were already leading to fewer satellites being ordered, each one built with greater and greater capability. As older satellites began to die, cautions were raised by many, including STRATCOM commander Gen Kevin Chilton, about the fragility of satellite constellations and “gap management.”<sup>30</sup> Launch costs had also been rising for well over a decade, and the flexibility of the launch base had decreased. Driven by the critical role



satellites had come to play in both nuclear and routine defense activities and the increased investment of dollars and schedule that those satellites represented, launch was becoming a “fail-safe” activity. The space business had come a long way from the days of Corona, where the first 13 missions ended in failure, to the present. Figure 2 provides a broad picture of how some of these forces were leading to change in the space establishment.



**Figure 2. Evolution of today's challenges**

These forces tended to build upon one another. Shrinking constellations, rising launch costs, increasing satellite costs, greater reliance, and longer build cycles have all led to the phrase, “The vicious circle of space acquisition.” While there are several illustrations of this cycle, the one developed by Maj Gen Tom Taverney provides perhaps the most comprehensive view (fig. 3).

The cycle drove multiple undesirable outcomes. One of the worst was the impact on technology risk. As constellations become more fragile, and satellite costs increase and schedules are extended, the risk of inserting new technologies into a space-system build increases. As a result, spacecraft planned for construction in the next decade are still using computer processing technology from the late 1990s when they were designed. For example, some billion-dollar satellites launching in 2020 will have missed over 24 years of capability increases driven by Moore’s law, or roughly 16 cycles of processing power increases.\* Another by-product of this cycle is an increase in ordering period

\*Moore’s law states that the processing power of semiconductors doubles about every 18 months. By missing 16 cycles, the processing speeds of our future spacecraft could be more than 50,000 times less capable than they could be if technology risk did not inhibit its adoption.

between satellites. As it does, obsolescence creeps in, factories become less efficient, and any industrial learning to be garnered is lost. The result, of course, is that costs climb and the cycle spins off into a parallel spiral.

## The Vicious Circle of Space Acquisition

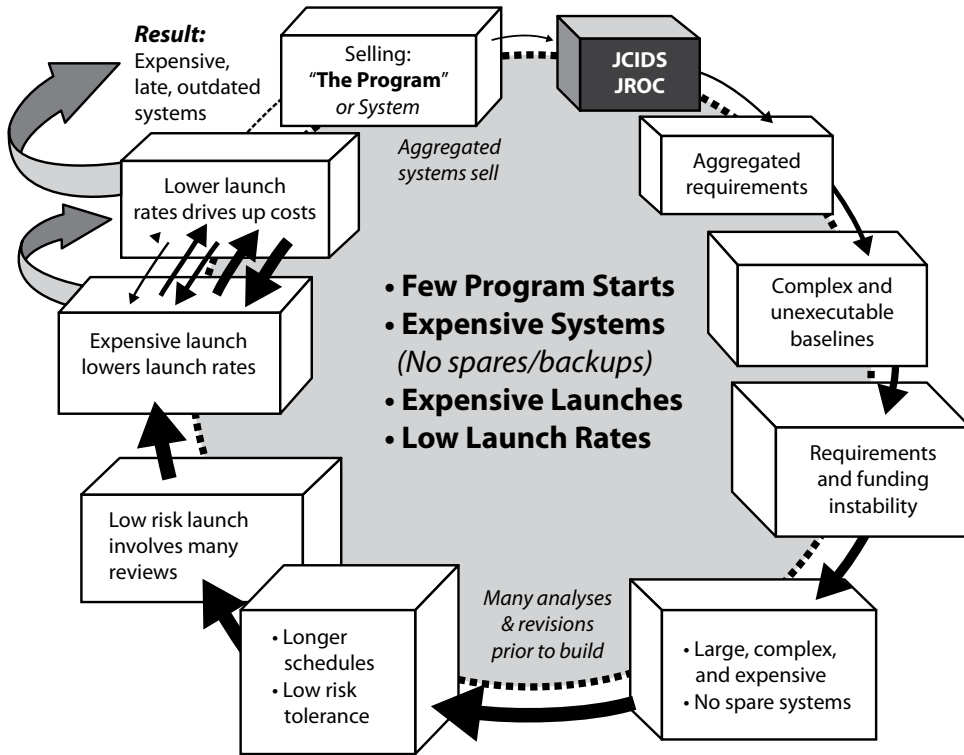


Figure 3. Space system acquisition “vicious circle” (Maj Gen Thomas Taverney, “Resilient, Disaggregated, and Mixed Constellations,” *Space Review*, 29 August 2011.)

## The Final Straw

The forces discussed in the preceding section represent significant changes in the industrial-dependency-threat equation under which space systems developed. The uses, importance, industrial base, cost dynamics, complexity, and competitiveness of space have all fundamentally changed from where we began; but the trajectory of system architectures did not change with them—rather, they continued on their original path. This disparity might be practical if money was no object, but unfortunately it is.

The days of unhindered spending for space superiority and technical advancement are over. At the annual Acquisition Symposium at the Naval Postgraduate School in 2009, Secretary Gates said:

Given America's difficult economic circumstances and perilous fiscal condition, military spending on things large and small can and should expect closer, harsher scrutiny. . . . The gusher has been turned off, and will stay off for a good period of time. . . . The Defense Department must take a hard look at every aspect of how it is organized, staffed, and operated—indeed, every aspect of how it does business.

The combination of all these forces represents disruptive change in the way we approach space systems. As with the music industry discussed earlier, the changes have occurred over decades. Some, such as the Chinese ASAT attack, were acute; others, such as changes in the industrial base, evolved slowly. But the sum total is disruption of the forces that led to the path we have taken. Like the music industry, we ignore these changes and continue on that path at our own peril. A more prudent approach would be to examine the elements of these changes and try to understand if a better path exists.

## **Formulating Responses**

Recognizing disruptive change is difficult enough—determining how to deal with it is even harder. The first step is to try to understand more clearly how the various forces combined with other elements of the system to create the challenges faced. We examined several elements including the impact of acquisition policy and reform, technology readiness, the rise of a commercial satellite market, and the competition for engineering talent. We found the most important elements were not the conditions surrounding what we build, but rather the architectures we choose to build. In figure 4 we trace the impact of building aggregated, highly integrated, long-lived satellites. The impact of that choice contributes directly to many of the challenges we discussed above. Dealing then with those challenges will require we deal with this underlying architectural issue.

Adapting to disruptive changes through an architectural response is not unique to the space industry. In the prologue, we discussed the first submarine attack during the Civil War. As noted there, Admiral Dahlgren was aware of the possibility of attack by this new submersible. In his orders to the fleet a month before, he noted:

I observe the ironclads are not anchored so as to be entirely clear of each other's fire if opened suddenly in the dark. This must be corrected . . . It is also advisable not to anchor in the deepest part of the channel, for by not leaving much space between the bottom of the vessel and the bottom of the channel it will be impossible for the diving torpedo to operate except on the sides, and there will be less difficulty in raising a vessel if sunk.

Order of Rear-Admiral Dahlgren, U.S. Navy, commanding South Atlantic Blockading Squadron, FLAG-STEAMER PHILADELPHIA, Off Morris Island, South Carolina, January 7, 1864.

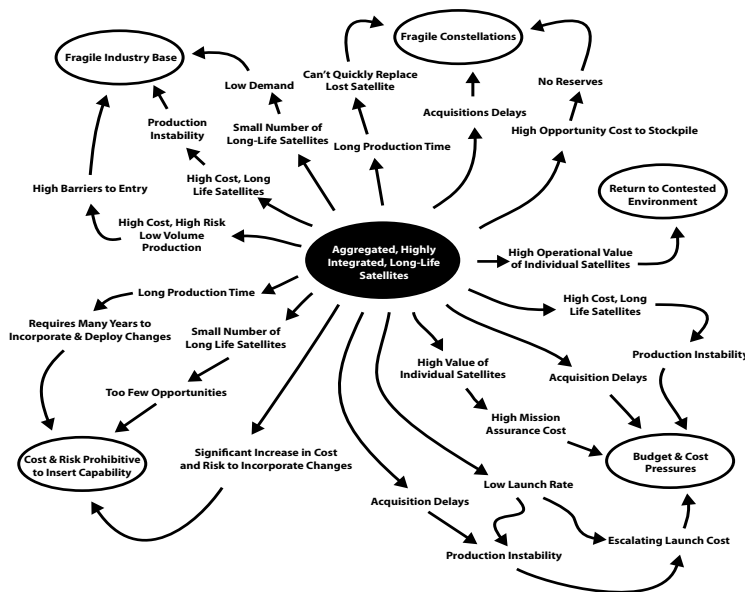


Figure 4. Effect of aggregated, highly integrated, long-life satellites

Both these tactics involved deployment or architectural responses to the new weapon he anticipated within the limits of what he could do with the equipment he had. Of course in the century following the attack, the navies of the world adapted many more responses to this submarine threat (and to an air threat still to come) by creating naval battle groups consisting of disaggregated capabilities as opposed to the unitary battleship architecture which previously had been the rule.

A similar architectural response is demonstrated by the successful music companies of the current decade. Those successful companies (Apple, Amazon, et al.) changed the architecture of the music (and book)

distribution business in response to the digital challenge brought about by the CD, Internet, and storage discussed earlier. Interestingly, this shift was not just a change in the architecture of how music was delivered but also what was delivered. The record industry had abandoned the “single” decades earlier in favor of an integrated album. By delivering songs for 99 cents each, Apple changed both how music was delivered and what was delivered. These architectural responses serve as a guide for how we might address the disruptive challenges we find ourselves facing today.

## Understanding the Details

The preceding discussion is a simplification of both the historical examples as well as the current challenges in space power. In fact, we did a detailed analysis of a variety of areas to understand the root causes of these challenges to determine what responses would be most successful in addressing them.<sup>31</sup> Using an eight-step approach, we decomposed each of the challenges into its driving causes and then looked across all challenges to identify the causes with the greatest effects.

The primary causes found to be propelling all the challenges are shown in table 1. When combined with the lessons we derived from the architectural response to the historical challenges, they provided us with guideposts to judge the adequacy of our responses.

**Table 1. Primary causes of disruptive challenges**

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|---|
| <ul style="list-style-type: none"><li>• Aggregated, concentrated architectures</li><li>• Systems vulnerable, little/no ability to deter/withstand attack</li><li>• Integrated, closed ground architectures</li><li>• High cost of launch</li><li>• Export controls limiting competition/partnering</li><li>• Space acquisition culture and processes biased toward top-down redesign and re-optimization for all new requirements</li></ul> |
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Next, using the same eight-step process, we analyzed potential responses to each of the challenges. We decomposed all the challenges through a series of fishbone charts and examined potential responses to each. We were especially interested in determining if there were common solutions that simultaneously addressed multiple challenges. For example, when we examined the challenge of fragile constellations, we found several possible solutions including investing in protection, buying more and smaller

satellites, storing spare satellites in orbit, and reducing satellite complexity. Similarly, we examined the hesitancy to adopt new technologies due to the impact on the cost and schedule of a system. Possible responses here included taking more risk, buying more and smaller satellites, investing a greater share of resources in technology maturation, and changing US export controls. In both cases, we noted one common response: buying more and smaller satellites. We did this same exercise for each of the challenges enumerated in the discussions above and collected all the common potential responses, as shown in table 2.

**Table 2. Common Responses to Challenges**

Challenges	Common Responses
<ul style="list-style-type: none"> <li>• Fragile constellations</li> <li>• Lack of resilience</li> <li>• Technology stagnation</li> <li>• Fragile industrial base</li> <li>• Inability to quickly supplement or replenish</li> <li>• Rising, uncontrollable cost</li> </ul>	<ul style="list-style-type: none"> <li>• More, smaller, less-complex satellites</li> <li>• Mixed constellations</li> <li>• Increase constellation size</li> <li>• Distribute capability</li> <li>• Encourage low-cost medium launch</li> <li>• Change export controls</li> </ul>

Finally we examined whether the common responses were able to deal with the fundamental causes enumerated in table 1. It was clear that by using more, smaller, and less-complex satellites, we directly addressed the issue of aggregation. Disaggregation lowered the cost of individual vehicles and the operational impact of losing a vehicle. This approach allows more tailored mission assurance and smaller launch vehicles, which reduces the cost of launch. Encouraging the development of low-cost, medium-launch vehicles can lower associated costs even further. By reducing the operational impact of losing an individual vehicle, increasing constellation size, and distributing capability, we also change the effect of an attack and make it harder for an adversary to attain his intended results. Thus, distributing capabilities becomes a foundation for changing the conditions for deterrence. Using smaller satellites, coupled with increased constellation size, requires a more continuous production rate. A production line enables lower-cost options for on-orbit sparing, ground reserves for reconstitution, and a responsive capability if a surge is needed. Finally, smaller,

more distributed capability leads to a more open ground architecture, which is now required to integrate the contributions of these individual and potentially mixed families of capabilities.

While it is clear in theory the responses discussed above could address the challenges that have grown into the space enterprise, it is less than clear if they can be executed in practice. The responses will surely lead to increased resilience and help unwind the vicious circle discussed earlier. And it is clear these responses are *capable* of controlling cost escalation of individual satellites and launches; however, we need to establish disaggregation and production modes which are also affordable at the architectural level. Disaggregated architectures certainly provide greater resilience, more opportunity for technology integration, an enhanced industrial base with more-frequent production buys, and the means for a quick response to changes in the strategic dynamic. But are they more affordable? To understand this question, we looked at the conditions existing in the commercial space market.

## **Commercial Space Market**

The maturity of technology and markets outside of DoD acquisition has changed substantially since the current generation of systems was developed. Historically, the national security segment dominated the global market. In terms of number of vehicles launched, the commercial and military markets reached rough parity around 2000. In 2010, the commercial market launched 50 percent more than the military segment, with growth projected to double the military market by the middle of this decade.<sup>32</sup> This growth and maturity have created new realities in the marketplace that provide significant new opportunities for the DoD.

First, the commercial satellite bus market is the most competitive segment of the space enterprise. This competition has driven companies to find efficiencies in parts and processes to minimize costs and time to market. The result has been to maximize the use of common bus components and modular structures, providing a core capability that enables them to configure, rather than redesign, a satellite to meet its specific mission requirements. This approach minimizes the amount of redesign required for different missions, reducing cost and production time. The result has been a consistent ability to produce satellites in 24 to 36 months, and at much lower price points than the DoD has been able to realize.<sup>33</sup> If our

architectures can be adjusted to take advantage of this highly competitive market, we have the potential to gain substantial savings.

Second, many of the commercial and international satellites being launched today have sufficient margins to allow for a secondary, or “hosted,” payload. With the large number of vehicles going to orbits compatible with DoD missions, hosted payloads provide an opportunity to deploy capabilities at a fraction of the cost of our current systems. There are limitations we must be aware of in using this approach, such as restrictions on the ability to reposition the asset in response to contingencies. But given the global nature of our space missions, hosted payloads could provide a base level of coverage with DoD-owned satellites providing the flexible response needed.

The third opportunity in this commercial environment is the emergence of new entrants, such as SpaceX and Orbital Systems, to the medium-launch market. Both have contracts for 10–12 launches to supply the International Space Station. SpaceX is also under contract with a variety of commercial satellite vendors to support their payloads.<sup>34</sup> This volume is sufficient to establish the reliability and price point these vendors will require to offer medium-launch services and reintroduce competition into this segment of the launch market. While the jury is still out on these specific carriers, the handwriting on the wall is clear—the launch market is going to be more, not less, competitive in the years to come.

If we are to take advantage of these opportunities, the technology enablers must be in place to package our space systems to use commercial buses, hosted payloads, and smaller launch vehicles. With the exception of nuclear hardening, those enablers are already in place today. We demonstrated these enablers recently with the hosting of a wide-field-of-view (WFOV) infrared sensor package aboard a commercial communications satellite launched by SES Americom. The so-called commercially hosted infrared payload (CHIRP) was launched from an international launch base late last year and is now undergoing checkout on orbit.

The CHIRP demonstration showed that standard commercial bus specifications were sufficient to support the power, pointing, and stability necessary for overhead persistent infrared (OPIR) mission area sensors. We likewise have demonstrated off-the-shelf commercial bus capabilities can meet the core requirements needed to support DoD missions and



payloads in the communications mission area. The wideband global SATCOM system (WGS) was developed based on commercial capabilities and is produced on a commercial production line at Boeing. Power, pointing, and stability requirements are met using commercial components.<sup>35</sup>

It is interesting to note that the WGS was originally the wideband *gap-filler* system. It was intended as a placeholder until a more ambitious (advanced wideband) satellite could be developed; later advanced wideband was supplanted by the drive toward an even more ambitious system, the transformation satellite system (TSAT). Both these programs would have represented one more run around the vicious circle with costs constraining us to a four-ball constellation. By staying with the less-complex, more easily produced WGS system, the DoD has been able to save substantial cost, and the size of the WGS constellation has grown from the originally envisioned four satellites to an inventory of 10. Given this experience, it is clear we have the ability to use a commercial bus at a lower cost to significantly reduce the time to produce and deploy capabilities for the war fighter, and to provide those capabilities in a more resilient mode than we have done historically.

The technology to package militarily useful capabilities small enough to be hosted, or to make use of smaller launch vehicles, was demonstrated by CHIRP. Similar small sensors from other vendors have been through ground testing. In the communications mission area, robust commercial encryption standards and components are being leveraged to define releasable, protected communications waveforms, payloads, and terminals that are smaller and less complex than our current systems. Commercial capabilities for unprotected wideband communications supporting RPAs and AISR are already in use and can be packaged as either a hosted payload or on a dedicated platform. These technologies enable options for both hosted payloads and smaller, less-complex satellites. In turn, the smaller satellites enable expanded use of medium-launch vehicles.

Taken together, these opportunities indicate there are approaches available to implement the common responses of smaller, less-complex satellites and distributed capabilities. This opportunity encourages the lower-cost medium-launch market and allows disaggregation of mission capabilities, which supports mixed constellations of small distributed capabilities complemented by the more robust, nuclear-hardened systems.

The successes of the commercial space marketplace suggest these responses can serve to reduce overall system cost.

## **Changing How We Buy—A Payload-Based Approach**

To take advantage of opportunities and effectively and efficiently implement a distributed architectural strategy, some of our acquisition strategies will have to change. Our historic approach to designing and procuring satellites has been to optimize performance from the top down, which almost invariably results in a highly customized bus for each mission, requiring uniquely designed and manufactured components. This approach served us well when the space industry was still in the early stages of discovering what is possible for the war fighter from space. Now the industry and market have matured from building almost exclusively unique and cutting-edge technology systems to a more flexible model of commoditized capabilities and economies of scale; a payload-based approach allows us to follow them.

Continuing our top-down performance optimization approach, which drives unique requirements for things like the satellite bus, will prevent the DoD from taking advantage of the most competitive part of the space industry. It also hamstringing our ability to take advantage of hosted payload opportunities. Today's "top-down" payloads require unique support from the bus; using them as a hosted payload would require support to be added to the commercial bus, or re-engineered in the payload itself. At best, this requirement just adds cost. In most cases it prevents using the payload as a hosted capability at all because the changes in the technical baseline and schedule are unacceptable to the host, even if we are willing to pay the additional cost.

For this new strategy, we need to consider a focus shift of DoD space system development efforts more toward mission payloads. If we design a payload to provide the capability needed by the war fighter and be supported by a commercial bus, the ability to leverage both the commercial bus market and hosted payload opportunities opens up. By acquiring the mission payloads as the core element of a mission-area architecture, we can create a product with the inherent capability to fly on either a dedicated bus or as a hosted payload with minimal or no changes to the production baseline. This shift in focus would allow us to compete for procurement

of a block of buses to support the next several payloads coming off the production line, mirroring current commercial practices.

Hosting payloads need no longer be a “one off” exercise requiring heroic efforts to win approval, modify products, and meet commercial timelines. It becomes an inherent part of our strategy to deploy capabilities on orbit. We can rapidly adjust to take advantage of the host opportunity by matching the timing of a payload coming off the production line to the host schedule. Overall, the time to produce and deploy a new payload can fall from the standard 7–8 years toward the commercial standard of 2–3 years. This change in time line alone will drive a significant reduction in cost.

A second aspect to consider is the amount of capability we choose to package into a single payload. While physics and technology will determine the smallest viable increment, shifting the procurement toward a greater number of smaller payloads creates additional opportunities. If there are a sufficient number of common payloads in the architecture, we can establish production lines to realize the benefits of a learning curve, reducing unit costs and risk and allowing more tailoring for the mission assurance process. This greater number of payloads also creates regular, planned technology/capability insertion points, reducing the time to deploy enhanced capabilities.

A risk to consider is whether or not we will have to compromise mission performance if we use this new strategy. Based on the technological opportunities discussed above, the risk is low for most of the DoD space-mission capabilities.\* Nuclear-hardened capabilities, such as strategic missile warning and nuclear command and control, are the primary areas where we will need to proceed cautiously. These complex, nuclear-hardened systems can especially benefit from disaggregation of unrelated capabilities, such as battlespace awareness and tactical-protected MILSATCOM. Disaggregation will allow us to realize more affordable and resilient capabilities for the theater war fighter while at the same time allowing smaller, nuclear-hardened cores to be retained.

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\*This is not necessarily the case for intelligence community space missions. The peculiar demands of intelligence are less amenable to the disaggregated, smaller approach that appears to bear benefit for the national defense side of space. This article is not intended to discuss those issues.

Finally, when we combine a payload-focused acquisition strategy with the distributed architecture strategy we can see a path to unwinding the vicious circle facing today's space acquisitions. Such an approach:

- reduces complexity, allowing for more predictable and executable program baselines;
- stabilizes requirements by providing a predictable process for capability insertion;
- reduces operational and economic consequences of losing a vehicle, allowing for a more tailored and less-costly risk management, vice risk avoidance, mission assurance approach;
- establishes a consistent replenishment cycle, stabilizing satellite and launch vehicle production lines and creating the opportunity for affordable on-orbit and ground spares;
- creates more numerous launch and deployment (hosting) opportunities, reducing the cost of getting to space; and
- complicates any adversary's calculus of its surety of ability to deny the advantages of space for an extended period of conflict.

It is interesting to note at least one satellite system has followed this architectural and procurement approach from its beginning. GPS is a distributed, disaggregated assemblage of individual payloads, none of which can do its job individually. But taken together, they form a robust, affordable, and resilient architecture, which has an established production line with routine insertions of new technology.<sup>36</sup> The GPS III system has also adopted a payload approach, as indicated above, that uses a nearly off-the-shelf commercial bus paired to a purpose-built navigation payload.<sup>37</sup>

## **Transition—Taking the Next Steps**

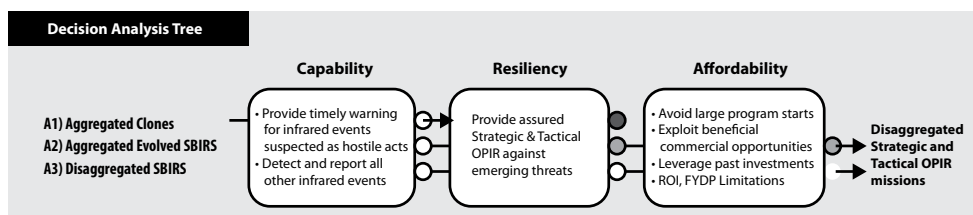
These new strategies cannot be implemented instantaneously, nor do they need to be. Our current space systems, highly capable and the most technologically sophisticated in the world, are serving us well. However, we must begin to move in a new direction if we are to address the disruptive changes discussed above. To begin this shift we need to choose to go against the status quo and undertake the following:

- Define alternative architectures to provide passive resilience and enable protection in depth. Allow mixed architectures that leverage government, commercial, and international opportunities.
- Demonstrate a path through early prototyping and on-orbit demonstration.
- Begin the shift to smaller, distributed, diverse constellations.
- Curtail current productions once a new capability is demonstrated and secure.

This plan establishes a path to enable migration to a mixed architecture over the next 10–15 years. We have taken the first steps along this new path. We have examined the options and opportunities for increasing resilience and affordability in several of our mission-area architectures using the tenets established above. The most mature evaluations are in the OPIR and MILSATCOM mission areas.

## OPIR

Figure 5 shows some of the future architectural options considered for the OPIR mission area and the assessment of how well those architectural options would meet our goals of delivering the required war-fighting capability while increasing the resiliency and affordability of the capability. The criterion used to assess the architectural option against those goals is shown in each respective box. The assessment concluded all the options could meet the capability requirements, but continuing with the status quo architecture (aggregated clones) or evolving the current platform could not meet the resilience or affordability criteria. Therefore, a disaggregated approach to the OPIR mission area splitting strategic and tactical missions into separate payloads which can be flown on a variety of platforms, such as the legacy platform (but now dedicated to strategic warning), a dedicated, small, commercial bus, or a commercial, international, or other US government host is required.<sup>38</sup>



**Figure 5. OPIR architecture decision analysis tree**

Development of a low-cost WFOV staring-sensor payload for tactical missions offers opportunities for significantly lower cost and risk as well as increasing overall resilience by proliferating capabilities across multiple platforms.<sup>39</sup> Strategic warning remains healthy and is less costly due to a smaller strategic-warning payload and significantly reduced complexity and weight.<sup>40</sup> This approach also enables incremental deployment of tactical capabilities to augment current capabilities and gain operational confidence in how to best employ the capability. By conducting an operational demonstration of this capability based on leveraging the technology and experience gained through the CHIRP experiment, we will have the information needed to understand the costs and risks associated with a mixed architecture before needing to make a disaggregation decision on the next production increment of the SBIRS program (vehicles 7 and 8).

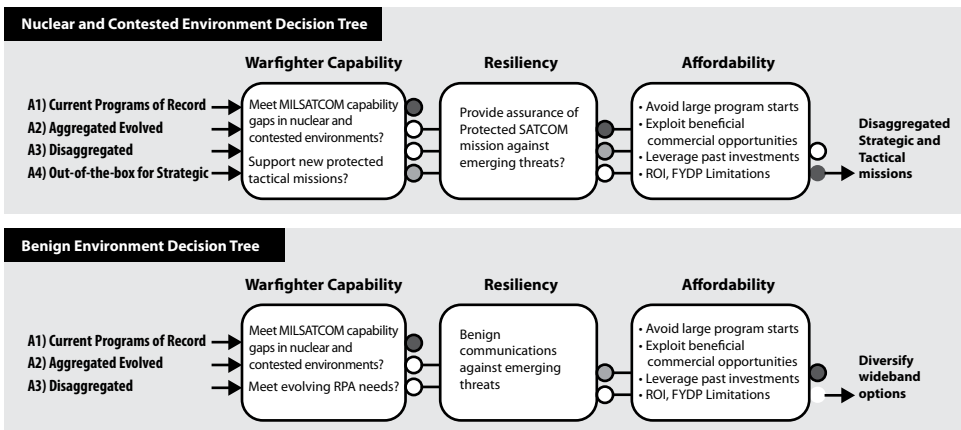
## **MILSATCOM**

Figure 6 shows the future architectural options considered for the MILSATCOM mission area for both the contested/nuclear and benign operational environments. In the case of protected MILSATCOM, there is currently a significant shortfall in capability. The current protected communication capability must grow by a factor of 10 or more to support the full tactical protected requirement. Also, due to the high-grade cryptography employed, the current capability cannot be used to support lower-echelon units or RPAs where there is a likelihood of equipment capture and exploitation. As with OPIR, we assessed how well the alternative architectural options would meet our goals of delivering the required war-fighting capability while increasing the resiliency and affordability of the capability.

The assessment concluded the status quo would not be capable of meeting the required future capability. Evolving the current capability could meet the future capability requirement but with only a limited increase in resiliency and at very high cost. Disaggregating strategic and tactical protected communications enables smaller, lighter, less-expensive payloads for both services. This disaggregation creates the option for a simpler tactical protected capability using releasable cryptography supporting lower-echelon units, RPAs, and allies; it can be provided with much lower cost and risk. It also enables incrementally deploying the tactical protected capability more frequently and in smaller increments, decreasing the impact of delays or unexpected loss of a satellite, and offering a wider variety of deployment

options such as hosting the tactical protected payloads or packaging them on a small commercial bus and more responsive, lower-cost launch vehicle.

Capabilities for the benign communications environment were also assessed. As in the contested environment, there is a growing shortfall in basic capacity and in the specialized support needed for long track airborne ISR platforms. Current programs were not sized to address this requirement, so some modification is necessary. Today's capabilities are largely based on commercial capabilities, the primary difference being the use of communication frequencies reserved for the military; however, they are still concentrated in a small number of platforms. In this area we have already achieved some level of distributed capability between dedicated wideband MILSATCOM platforms and widespread use of leased commercial SATCOM services. To provide the needed capabilities and increase resilience with an affordable solution, we concluded diversifying the wideband SATCOM capability is the best approach. We should continue investments to reduce the cost of our military wideband backbone, augment that capability with hosted payloads and international partnerships, and pursue innovative business strategies with commercial providers, which will enable wider and more-flexible access to commercial SATCOM capabilities.



**Figure 6. MILSATCOM alternative architectures decision analysis tree**

## Conclusions

Having looked at the disruptive changes and challenges facing the United States today in space, we formulated responses to those changes, explored the new opportunities enabling implementation of those responses, and developed a new strategy to allow the DoD to mitigate the challenges (see table 3). From this study we conclude the best means available to affordably provide resilient space capabilities the war fighter can depend upon and adapt as mission needs evolve is to use a distributed architecture strategy coupled with a payload-focused acquisition strategy that will:

- focus government development on mission payloads designed to be supported by commercial bus capabilities,
- create stable payload production rates,
- leverage the highly competitive commercial satellite bus market, and
- leverage hosted payloads on commercial, international, and allied platforms.

**Table 3. Resolution to Challenges**

Challenges	New Strategy
<ul style="list-style-type: none"><li>• Poor Resilience—concentrated capabilities are good targets that are hard to defend</li></ul>	<ul style="list-style-type: none"><li>• Distributed architecture disperses capability across multiple hosts and smaller platforms, complicating adversary targeting and making it harder to sustain effects</li></ul>
<ul style="list-style-type: none"><li>• Fragile Constellations—loss or delay of single platform greatly degrades capabilities</li></ul>	<ul style="list-style-type: none"><li>• Distributed architecture is less dependent on individual platforms; more frequent deployment of smaller increments of capability reduces impacts of delay</li></ul>
<ul style="list-style-type: none"><li>• Escalating costs as budgets decline</li></ul>	<ul style="list-style-type: none"><li>• Costs controlled or reduced through reduced complexity, leveraging highly competitive commercial bus market and hosted payloads, stable production, and more frequent launch to drive down costs through learning curve and other efficiencies</li></ul>
<ul style="list-style-type: none"><li>• Fragile industry base</li></ul>	<ul style="list-style-type: none"><li>• Stabilize lower-tier suppliers through stable production and launch; focuses development resources on maintaining intellectual capital needed for unique military capabilities</li></ul>



Challenges	New Strategy
<ul style="list-style-type: none"> <li>• Technology Stagnation—inserting new capabilities can take decades</li> </ul>	<ul style="list-style-type: none"> <li>• Consistent and frequent technology insertion opportunities due to lower procurement risk; mirror commercial time to market of three years or less</li> </ul>
<ul style="list-style-type: none"> <li>• Requires years to supplement or replenish</li> </ul>	<ul style="list-style-type: none"> <li>• Affordably establish on-orbit reserves through smaller, less-complex satellites and hosted payloads; also enables affordable ground reserves and ability to surge production through a stable production line. More frequent launch and expanded number of launch providers enhances the capability to surge launch if needed</li> </ul>

This approach greatly enhances the resiliency of our space capabilities. By increasing the number of platforms and dispersing our capabilities, we reduce the impact on the war fighter if a satellite is lost to mishap or hostile action. By reducing the cost of each platform, we can affordably create on-orbit reserves for rapid recovery and ground reserves for timely reconstitution. We also have determined this strategy will enhance the affordability of our space capabilities. The distributed architecture strategy looks at the entire architecture cost to determine the best trade between capabilities on individual satellites and overall architecture cost. The cost of higher quantities are offset by savings from hosting, continuous production lines, commercial bus procurements, smaller and less-complex satellites, more-frequent and lower-cost launch, and a more tailored approach to mission assurance. To achieve this goal, it is essential we implement the architectural, business, and budgeting practices to enable the DoD to create sufficient volume so we can access and realize the economies of scale we are seeing in other segments of the space marketplace.

We should also note the new strategy can form the basis of a different framework for deterrence. By using greater numbers of smaller platforms, orbital diversity, rapid recovery, reconstitution options, and international partnering, we increase the complexity of a potential adversary's attack calculus. Such a strategy imposes higher force-structure requirements, more-complex targeting and demanding situational awareness, greater risk of collateral damage, difficulty in sustaining desired effects, and the risk of entangling other parties in the conflict.

With these elements we will have taken the first substantive steps to addressing the disruptive changes that could otherwise lead to a diminution of the critical advantages space forces confer on our war-fighting capabili-

ties today. The early airpower strategist Giulio Douhet said, “Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.”<sup>41</sup> The US Navy enjoyed victory in naval conflict by recognizing submarine warfare had created a disruptive change in the character of war. Major record labels, failing to recognize the disruptive influence of file sharing and digital media and adapt their systems before those changes occurred, began a long, slow decline in stature while digital-ready adversaries such as Apple and Amazon were poised to take their place.

A system’s evolutionary path stays relevant only if the environment that spawned it remains static; but disruptive forces require those paths to be reevaluated. The disruptive forces that drive the need for change to our space architectural strategy are already evident. The means are available, and we have defined a way to adopt them. Space is too important to the national security of our nation for us not to adapt until after change is upon us. **SSO**

## Notes

1. Bern Anderson, *By Sea and By River: The Naval History of the Civil War* (1962; reprint, New York: Da Capo Press, 1989), 34.
2. *Official Records of the Union and Confederate Navies in the War of the Rebellion*, series 1, vol. 15 (Washington: Government Printing Office, 1921), 226–27.
3. Ashley Tellis, “China’s Military Space Strategy,” *Survival* 49, no. 3 (September 2007): 41.
4. *Ibid.*, 45.
5. “Space to Manoeuvre—Satellite Attack Upsets US Space Supremacy,” *Jane’s Intelligence Review*, 7 February 2007.
6. Scott Karp, “Music Recording Industry Will Be First Traditional Media Industry to Be Utterly Destroyed by Digital Technology,” *Publishing 2.0*, 28 December 2007.
7. “And 25 Years Ago Philips Introduced the CD,” *GeekZone*, 1 November 2008.
8. The work reported here is an outgrowth of a think-tank study commissioned in 2010. Contributors to that study include retired general officers Lt Gen Mike Hamel, Maj Gen Tom Taverney, Maj Gen Ken Israel, Brig Gen Jim Armor, Brig Gen Tip Osterthaler, and Brig Gen Len Kwiatkowski; then—Brig Gens Jay Santee and John Hyten, then—RADM Liz Young, Dr. Pete Rustan, Gil Klinger, Joe Rouge, CEO of Orbital Space Systems Dave Thompson, President of Microcosm Dr. Jim Wertz, and author Doug Loverro. Also, a great debt is owed to Tom Cristler and Toni Arnold who led most of the analysis and did all of the writing for the white paper.
9. See Alexei Arbatov, “Russian Perspectives on Spacepower,” in *Toward a Theory of Spacepower* (Washington: NDU press, 2007), chap. 23. As stated there, “In 1957, the Union of Soviet Socialist Republics (USSR) was the first nation in the history of the world to put a satellite in space, and in 1961 it followed with the first manned space flight. During the Cold War, Soviet space power was second to none—in some respects behind and in others ahead of that of the United States.”

10. Gen Thomas S. Moorman Jr. (ret.), speech at American Institute of Aeronautics and Astronomy (AIAA) Space 2007 Conference and Exposition, 21 September 2007, Long Beach, CA.
11. Curtis Peebles, *High Frontier: The United States Air Force and the Military Space Program* (Washington: Air Force History and Museums Program, 1997), 15–26.
12. *Ibid.*, 13.
13. Dana J. Johnson et al., *Space: Emerging Options for National Power* (Santa Monica, CA: RAND, 1998), 38.
14. In the strange calculus of space technology, designing a satellite to survive a non-direct nuclear attack was more straightforward than designing a system that could hold up against nonnuclear mechanisms, since many aspects of a nuclear attack were already accounted for by designing the satellite for extended stay in its natural radiation environment. For example, under natural background radiation conditions in LEO, peak flux for electrons with energy greater than 1 MeV ranges from  $10^4$  for the outer radiation belt to  $10^6$  for the inner. Enhanced solar flux is said to have resulted in  $>1$  MeV electron flux to reach  $10^8$  particles/sq cm sec. Coincidentally, this is the same magnitude computed by the model due to a high-altitude nuclear explosion one day after the burst over Korea. Source: Defense Threat Reduction Agency, *High Altitude Nuclear Detonations against Low Earth Orbit Satellites ("HALEOS")*, DTRA Advanced Systems and Concepts Office, April 2001, 12.
15. *Space-force enhancement* is defined as “force-multiplying capabilities delivered from space systems to improve the effectiveness of military forces as well as support other intelligence, civil, and commercial users.” JP 1-02, *DoD Dictionary of Military and Associated Terms*, 8 November 2010 (as amended through 15 October 2011), 312, <http://www.dtic.mil>.
16. Craig Covault, “Desert Storm Reinforces Military Space Directions,” *Aviation Week and Space Technology*, 8 April 1991, 42.
17. Steven J. Bruger, *Not Ready for the “First Space War” What About the Second?* Naval War College student papers, 17 May 1993.
18. *Ensuring America’s Space Security*, Report of the Federation of American Scientists Panel on Weapons in Space, September 2004, 12.
19. *Gulf War Air Power Survey*, Vol. 2, pt. 1 (Washington: GPO, 1993), 189.
20. Bruger, *Not Ready for the “First Space War,”* 21.
21. *Combat support* is defined as “operational assistance provided to combat elements.” JP 1-02, 60.
22. Gen William Shelton, “The Foundational Role Space and Cyber Play in our Nation’s Defense,” Global Warfare Symposium, 17 November 2011, Los Angeles, CA, 8–9.
23. William J. Lynn, “A Military Strategy for the New Space Environment,” *Washington Quarterly* 34, no. 3 (Summer 2011): 8.
24. The concept of a military “center of gravity” was first proposed by Carl von Clausewitz in *On War*. It is defined in JP 1-02 as, “the source of power that provides moral or physical strength, freedom of action, or will to act.”
25. Sun Tzu, *The Art of War*, trans. by Samuel Griffith (London: Oxford University Press, 1971), 77.
26. “Satellite transit” describes the passage of a satellite, normally in low-Earth orbit, overhead. Knowledge of transit times allows individuals to hide their activities from unwanted surveillance.
27. Mike Orcutt, “Space Over Time,” *Technology Review*, 23 July 2011.
28. *National Security Space Strategy: Unclassified Summary* (Washington: DoD, January 2011), 3.

29. For example, both the space-based infrared satellite and the GPS IIF satellite took over 14 years from contract award to delivery. Other systems (NPOESS, JWST, AEHF) saw similar delays or were even cancelled.

30. Gen Kevin Chilton, "Commander's Perspective," speech to the 2009 Strategic Space Symposium, 3 November 2009.

31. Douglas Loverro, "*Reinventing Space 2011: The Changing Dynamics of Space Power*," May 2011, presentation at the Reinventing Space conference, May 2011, Los Angeles, CA, 23.

32. "Toc-satellites-to-be-built-launched-by-2019.29," *Euroconsult*, <http://www.euroconsult-ec.com>.

33. Futron Corporation, *Satellite Manufacturing: Production Cycles and Time to Market*, May 2004, 2, [http://www.futron.com/upload/wysiwyg/Resources/Whitepapers/Satellite\\_Manufacturing\\_Production\\_Cycles\\_0504.pdf](http://www.futron.com/upload/wysiwyg/Resources/Whitepapers/Satellite_Manufacturing_Production_Cycles_0504.pdf).

34. SpaceX has a launch manifest of over 40 launches, including the station resupply and the Iridium constellation, plus multiple other customers. Orbital Space Systems is still in the process of securing its own launch market.

35. The WGS satellite is based on the Boeing 702HP bus. See [http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/wgs\\_factsheet.html](http://www.boeing.com/defense-space/space/bss/factsheets/702/wgs/wgs_factsheet.html)). This is a common platform configured to support multiple commercial communications satellites including PanAmSat, INMARSAT-5, MEXSAT and others. See <http://www.boeing.com/defense-space/space/bss/factsheets/702/702fleet.html>.

36. GPS modernization was made possible because we found ourselves in the late 1990s with a robust on-orbit constellation and a large number of spare satellites on the ground. We were able to spiral in new technology with the IIR-M satellites (M-code and a second civil signal), provide more in GPS IIF (aviation signal, L5), plus the change to flexible power for both systems. GPS III is being laid out in a similar fashion with routine insertion of technology into an ongoing production line and each satellite simple and inexpensive enough that the risk of insertion remains low.

37. The Lockheed A2100 bus is the basis for the GPS III system, but with hardening appropriate for the medium earth orbit (MEO) in which it flies.

38. Lt Gen Ellen Pawlikowski, "AF Space Portfolio Future Architectures," briefing to secretary of the Air Force, 24 October 2011.

39. John "Pete" Peterson and Jim Bui, "Overhead Persistent Infra-Red (OPIR) Architecture Study," DoD Executive Agent for Space, 17 June 2011.

40. "Space Modernization Initiative Alternatives Analysis," SMC/IS, 1 November 2011. The analysis used the current CAPE ICE SBIRS GEO 3/4 cost estimate as the basis for disaggregation with the following assumptions: (a) costs up to launch, no launch costs considered; (b) GEO 3 NRE and GEO 4 production article; (c) future costs indexed to inflation; and (d) for a disaggregated GEO, assume single scanner sensor and no staring sensor. Based on these assumptions, initial cost estimates show a 20-percent savings for a single scanner satellite needed to support strategic warning mission.

41. Giulio Douhet, *The Command of the Air*, trans. Dino Ferrari (1942; reprint, Washington: Office of the Air Force History, 1983).