Air Force Space Command

Resiliency and Disaggregated Space Architectures

White Paper

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"Our satellites provide a strategic advantage for the U.S., and as such, we must consider the vulnerabilities and resilience of our constellations. My staff at Headquarters Air Force Space Command, alongside the team at the Space and Missile Systems Center, is leading efforts at balancing resilience with affordability. They are examining disaggregated concepts and evaluating options associated with separating tactical and strategic capability in the missile warning and protected communications mission areas. We are also evaluating constructs to utilize hosted payload and commercial services, as well as methods to on-ramp essential technology improvements to our existing architectures. Beyond the necessity of finding efficiencies and cost savings, we may very well find that disaggregated or dispersed constellations of satellites will yield greater survivability, robustness and resilience in light of environmental and adversarial threats."

- General William L. Shelton, Statement to the Senate Armed Services Committee, 24 April 2013

INTRODUCTION

National security space assets provide Joint Warfighters and our nation with strategic warning, assured communication, and precision positioning, navigation and timing—an unrivaled advantage in today's security environment. Use of these capabilities has evolved considerably in recent years; however, the space systems themselves have not. Many of these systems have designs that date back to the Cold War. Requirements in that era were driven by the compelling need for nuclear attack warning and the desire to maintain a bilateral balance of power. Threats to space systems were deemed a tolerable risk, since an attack in space would be provocative and escalatory and might be interpreted as a prelude to nuclear war.

However, the security environment of today is much different than in the past. Previous considerations led to satellite designs that maximized the size, weight, and capability of every payload within the constraints of a given launch vehicle.[1] Performance was prioritized over protection as the threat of "mutually assured destruction" reduced any risk of an attack. System designs naturally evolved to become increasingly complex, integrated and expensive. Our current satellites are marvels of modern engineering, but their suitability is critically dependent on the strategic balance of a foregone era.

This paper examines the need to provide resilient and affordable capabilities to preserve our operational advantage in space. The focus is on "disaggregating" space capabilities onto multiple platforms or systems. Disaggregation improves mission survivability by increasing the number and diversity of potential targets, thereby complicating an adversary's decision calculus

[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): 27-54.

and increasing the uncertainty of successful attack. Disaggregation is of value whether the threat is a hostile adversary, or an environmental threat, such as orbital debris.

A NEW SECURITY ENVIRONMENT

Warfighting requirements on the surface of the earth have rapidly evolved. The rate of change continues to accelerate, virtually guaranteeing the future security environment will be different than today.[2] In *Joint Force 2020*, the Chairman of the Joint Chiefs of Staff echoes the defense strategic guidance for that environment, including two elements of crucial interest: projecting power despite anti-access/area denial challenges, and deterring and defeating aggression. Considering the lengthy time required to develop and field our current space assets, almost by default, the space systems that met yesterday's challenges must address today's problems, and today's architectures must address the future security environment.

The overwhelming success of *Desert Storm* delivered a global wake-up call to our adversaries. State and non-state actors saw firsthand the advantages of networked command and control, overhead surveillance and precision targeting. Conventional forces gained prominence as the centerpiece of U.S. national power projection and began to slowly change our adversary's perception of nuclear power as the central focus of national deterrence. Meanwhile, space systems were increasingly viewed as critical to U.S. conventional power. Combined with the fact that space capabilities are provided by a few, relatively vulnerable satellite architectures, led to the assessment that U.S. reliance on space was a potential Achilles Heel.

These factors have contributed to rapid growth in threats to our space systems. Adversaries have had over twenty years to react to *Desert Storm* and they have concentrated efforts on countering our space advantages. In 2007, China successfully demonstrated the capability to destroy a satellite in low earth orbit, and open source reporting described their capability to interfere non-kinetically with optical space systems using laser dazzling.[3] While kinetic threats could obviously be devastating, non-kinetic threats, such as radio-frequency jammers and cyber attacks, can be equally destructive and are far more prevalent. Cyberspace threats, in particular, have exceptionally low barriers to entry and are growing rapidly. Space systems that rely on complex software and radio-frequency links could be susceptible to these attacks, despite robust cryptographic protection.

Not only man-made threats from state and non-state actors have increased; dangers inherent in the space environment itself have evolved, including increased amounts of debris,

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[2] "Capstone Concept for Joint Operations: Joint Force 2020", Martin E. Dempsey, General, U.S. Army, Chairman, Joint Chiefs of Staff, 10 September 2012

[3] "Chinese ASAT Capabilities and ABM Capability, GlobalSecurity.org, viewed 7 Mar 2013, http://www.globalsecurity.org/space/world/china/asat.htm.

competition for electromagnetic spectrum and the sheer number of satellites in space. While not the result of a hostile and intelligent adversary, the environmental hazard is no less real. In 2009, the first collision involving an active satellite occurred when COSMOS 2251 and Iridium impacted on orbit, creating thousands of pieces of debris.[4] In short, the threat environment has changed extraordinarily, and we must adapt critical U.S. capabilities if our operational advantage is to endure.

No discussion of the changing security environment is complete without addressing current fiscal challenges and budgetary trends. Continued funding of expensive space systems is no longer assured, and is in fact assumed to be impracticable. Large, complex systems that require many years of sustained investment to design, develop, field and operate may no longer be affordable. Moreover, given the growing threat environment, they may place a significant amount of national treasure at increased risk. While astute mission assurance measures have decreased launch failures to record lows, there is always the risk that a single launch failure, early-orbit anomaly, environmental event or hostile act could result in the loss of hundreds of millions, or even billions, of dollars.

RESILIENCE AND DISAGGREGATION

Given the challenges of a rapidly changing security and fiscal environment, new and innovative approaches to provide capability in an affordable way merit close examination. One response to these changes that secures capability for the Joint warfighter and the nation is to seek resilience in space systems. With respect to satellite constellations and space architectures, AFSPC/CC defined resilience as follows:

> *"Resiliency is the ability of a system architecture to continue providing required capabilities in the face of system failures, environmental challenges, or adversary actions."*

Disaggregating space architectures is one strategy to improve resiliency, offering a means to trade cost, schedule, performance, and risk to increase flexibility and capability survivability. To establish a common lexicon, we are proposing the following definition of *space disaggregation*:

> *"The dispersion of space-based missions, functions or sensors across multiple systems spanning one or more orbital plane, platform, host or domain."*

A disaggregated system design offers a means to avoid threats, ensure survivable capabilities despite hostile action, and develop the capacity to reconstitute, recover or operate through

[4] "Effects of Worst Satellite Breakups in History Still Felt Today," Space Insider, 28 Jan 2013. http://www.space.com/19450-space-junk-worst-events-anniversaries.html.

adverse events should robustness fail. Carefully pursued, disaggregation can lead to less costly and more resilient space architectures in the face of a rapidly evolving security environment.

ATTRIBUTES OF DISAGGREGATION

Disaggregation is a strategy to affect multiple elements of our overall space architecture. Its purpose is to provide options within architecture to drive down cost, increase resiliency and distribute capability. Disaggregation has other benefits. It allows systems to be less complex, easier to maintain and affords the Air Force the ability to lower per-unit production costs and improve industrial base stability. Given program of record acquisition decisions we are facing in pending budget deliberations, the timing is right for reassessment of the historical paradigm of fielding monolithic space systems that result in costly, and vulnerable, space architectures.

Although the primary focus of this paper is on disaggregation of the space segment, it is important to note that disaggregation should be considered at an enterprise level, to include connecting nodes, ground systems, command and control, and launch vehicle architecture. System planners should consider all aspects of an architecture, including additional ground entry points, added complexity for mission planning and command and control, and commercial or foreign elements intertwined with the DoD ground segment.

Disaggregation offers significant leverage in keeping pace with advancing technologies and associated benefits in terms of requirements discipline, sustainment of the space industrial base, achieving affordability, and deterring adversary action against U.S. space systems. Each of these opportunities is described below, with considerations for operational impact and costs.

Increased Technology Refresh Opportunities

Current satellite systems have developmental timelines of up to 14 years.[5] Once on orbit these systems routinely exceed 10 years of life. During development, incorporating advances in technology is often difficult as it slows design development and adds significantly to system costs. Once on orbit, hardware upgrades are not practicable. This combination results in technology being "locked in" for what may be a lengthy period of time. This is a substantial drawback considering the pace of technology change, rapidly evolving user needs, and constantly changing tactics, techniques and procedures of adversaries. To remain responsive to these demands requires mission flexibility and an adaptable acquisition process. Through less complex satellites employing more flexible designs, disaggregation facilitates the incorporation of new technology before the end of a space constellation's lifetime. In this regard, it represents an evolution of system acquisition that enables adaptable platforms, software, and capabilities to more effectively match emerging needs.

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[5] Pawlikowski et al, "Space: Disruptive Challenges, New Opportunities and New Strategies" 34.

Improved Requirements Discipline

As discussed, one consequence of our historical approach to space system design is an extended development timeline. Coupled with rapidly advancing technology, these timelines and associated acquisition paradigms may place pressure on program managers and system developers to adapt and incorporate new requirements during the design phase—to make systems exquisite, in other words—adding significantly to their costs.[6] Disaggregation and the potential to refresh technology, as discussed above, provides an opportunity to enforce stricter requirements discipline with all the associated value in cost and schedule. That is, program managers have increased opportunity to lock in a firm requirements baseline that will not be deviated from, as they know there may be increased opportunity to incorporate system changes later, even after satellites have begun launching. This model of "constant adaptability" is a significant deviation from current acquisition practices, and could improve affordability and resiliency.

Increased Launch and Space Industrial Base Stability

As noted in the most recent National Space Policy, the U.S. space industrial base plays a vital role in providing and sustaining space capabilities and national security. Continuous incorporation of new technology into space systems and higher rates of production will also enable industry to remain on the cutting edge of technology and provide additional business stability and incentives. Higher throughput and more stable production rates should produce a larger market for space-qualified parts, thus providing incentives for more companies to enter the marketplace. Improving stability is an important factor in maintaining critical system expertise and sustaining "one-of-a-kind" manufacturing capabilities.

Disaggregation could also foster healthy competition and assist with distributing workload over multiple contractors. Payloads flown on separate spacecraft groups could be provided by different contractor teams, potentially dividing large contracts, creating industrial competition and allowing technology insertion on independent timelines. While beneficial, this approach would require increased focus on integration efforts, starting with stated requirements, and spanning multiple contract team products.

Depending on the approach to disaggregation employed, it could lead to more frequent and predictable launch profiles. An increased launch rate may smooth episodic launch schedules, providing a more stable workload for the launch industry. Further, increased frequency of launch would allow industry to amortize the significant specialized manpower costs associated

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[6] "Prevent project cost overruns with these four essential processes", TechRepublic, http://www.techrepublic.com/article/prevent-project-cost-overruns-with-these-four-essential-processes/1038752, Viewed 7 Mar 2013

with the operation and maintenance of launch capabilities, while helping to sustain individual suppliers whose only customer arises with each individual launch.

Higher production throughput and increased stability may further enable incorporation of commercial best practices[7] and competition into national security space architectures when commercial best practices align with system requirements. Commercial best practices in satellite system designs have been shown to minimize the amount of redesign required for different missions, reducing cost and production time. For example, the commercial satellite bus market has demonstrated the ability to produce satellites in 24 to 36 months and at much lower price points than DoD has been able to achieve.[8] Less complex systems may also increase the willingness for sponsors to forgo the costly mission assurance associated with current launch vehicles and accept increased risk.

Increased Affordability

The DoD is facing a fiscal environment that requires innovative approaches to deliver required mission capability. Declining budgets will mean fewer resources available for system sustainment, procurement, manpower and operation. These factors, combined with cost escalation in the space domain that far exceeds the Consumer Price Index ,[9] drives a requirement for systems that are less costly to manufacture, operate and maintain. Smaller, less complex and lighter systems may shorten procurement timelines, save upfront RDT&E investment and reduce risk in technology development. Combined, these characteristics of disaggregated space architectures may lead to cost savings. Increased production lots would also allow manufacturing production lines to be utilized for longer periods of time at optimized production rates, thus reducing per unit cost and leveling procurement spikes. A good example of this effect is the Global Positioning Satellite system, where larger production numbers provide a more stable manufacturing environment and long-term facility and equipment utilization.

Previous satellite system acquisition programs have experienced large cost overruns and schedule delays. While root causes vary by program, a common reason for cost increases is the difficulty of integrating multiple payloads onto a single bus. This often proves to be technologically challenging and can significantly delay fielding a system. In the National Polar-

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[7] True higher production throughput is achieved through proliferation of disaggregated payloads that have been further simplified.

[8] 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.

[9] According to the Future Years Defense Plan (FYDP) for 2006 through 2011, funding for development and procurement of major unclassified space systems grew by more than 40 percent in 2006 (to $6.9 billion from $4.9 billion in 2005). Center for Strategic and International Studies http://www.csis.org/burke.

Orbiting Operational Environmental Satellite System (NPOESS) program, complexity associated with integrating multiple, diverse sensors on a single platform grew to be so expensive and difficult to manage that the program was cancelled, opening the possibility of a future gap in capability.[10] Disaggregation reduces this type of integration risk by focusing on less complex designs that may provide singular functions (or components), but operating together provide a capability comparable to the original monolithic design.

Smaller programs of record across the Future Years Defense Program (FYDP) may also provide advantages in program execution, as large, single investment programs are sometimes needed to act as "bill payers" in times of budget decline. Less costly programs can smooth erratic spikes in program funding profiles, most often associated with a launch event or satellite production. These spikes have a negative impact on other programs in the portfolio, as budgets are typically capped at a pre-determined ceiling and other program schedules may need to be modified to accommodate the short-term increase in spending.

As noted by a recent report from the Government Accountability Office, more action is needed to identify opportunities to leverage the governments' buying power through increased efficiencies in launch acquisitions.[11] In addition to any savings realized in terms of satellites, lighter, smaller systems may benefit from reduced launch costs by combining multiple payloads on a single launch vehicle or by reducing the size and complexity of the required booster. Today, launch services are projected to consume approximately 30% of AFSPC's budget over a 20 year plan; advancing launch capability to create an overall balance between affordability, performance and resilience for space must remain a top priority.

Improved Deterrence

Given U.S. dependence on space systems that are often difficult to defend or protect, it is in our best interest to deter attacks on these systems in the first place. Two characteristics that are often associated with deterrence theory are "imposing costs" and "denying benefit." This follows the "carrot and a stick" idiom for offering rewards and punishment. Repercussions for adverse behavior in space should be apparent while any benefit for attacking space systems should be uncertain. Disaggregation improves this deterrent posture by complicating an

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[10] For an empirical description of the exponential relationship between space system cost and complexity, and the potential gains to be realized from emphasizing less complex space systems, see David A. Bearden, "A complexity-based risk assessment of low-cost planetary missions: when is a mission too fast and too cheap*?" Acta Astronomica* 52 (2003): 371-379. Further discussion of the strategic possibilities inherent in the relationship between complexity and cost are covered in Howard E. McCurdy, *Better, Faster, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore, MD: Johns Hopkins University Press, 2001) and Liam Sarsfield, *The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Science* (Santa Monica, CA: RAND, 1998).

[11] "DoD is Overcoming Long-Standing Problems, but Faces Challenges to Ensuring Its Investments are Optimized," Government Accountability Office (GAO), 24 April 2013.

adversary's targeting calculus and increasing the uncertainty of successful attack. Smaller payloads that are more easily produced, coupled with rapid/responsive launch capability, also increase the ability to reconstitute quickly, denying benefit to be gained from a successful attack. In short, the goal is to make attack against our systems as difficult as possible, while increasing the possibility of capability survival in the face of hostile action.[12]

If, as many experts assert, an attack in space is inevitable, disaggregation will enable new tactics, techniques and procedures (TTPs) to take advantage of the unique attributes of a dispersed architecture.[13] Mission flexibility may be increased, offering alternatives to how we could "fight through" an attack in space rather than relying on our current valuable, and vulnerable, monolithic satellites. In addition, some missions such as nuclear attack warning would be understood to be clearly "off limits," or the aggressor would risk nuclear escalation.

ADDITIONAL STUDY

As a strategy, disaggregation requires careful analysis and mission-specific assessment. Given the vulnerability inherent in current space architectures, combined with the danger of an escalating threat, our future architectures demand a thorough examination of the potential benefits of disaggregation.

There are specific challenges that need to be addressed. Using disaggregation to off-load complexity from the space segment could transfer this complexity to other parts of the system. Consideration needs to be made for increased ground entry point assets, terrestrial communications, and processing requirements for the ground segment, along with additional demands on frequency allocations and satellite Telemetry, Tracking and Control (TT&C) operations. Thus innovative satellite operations concepts need to be examined along with disaggregation to avoid transferring the satellite savings to ground segment costs.

Higher technology refresh rates put pressure on our ability to mature and transition technology in our space acquisition; it will require greater emphasis on acquisition flexibility and adaptability. If not carefully planned and assessed, each new insertion could lead to changes in the communications and ground segments to adapt to new signal formats, higher data rates, commercial standards, increased data storage needs or multi-level security solutions to meet the latest cyber standards.

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[12] While this approach does not deter attacks to components of the system on the ground, terrestrial systems can be "hardened" and are in general more accessible to initiate repairs or replacement than a system in space.

[13] In 2001, the "Space Commission," led by the Honorable Donald Rumsfeld, warned of a potential "Pearl Harbor in Space." More recently, it has been noted that "the principles of war and the logic of competition remain as they have always been" and this will inevitably lead to competition, contestation, and/or war in space, especially between the U.S. and the People's Republic of China, is inevitable. See Everett Carl Dolman, "New Frontiers, Old Realities," Strategic Studies Quarterly 6, no. 1 (Spring 2012): 78-96.

With regard to using hosted payloads on commercial and allied systems, attention needs to be paid to military requirements for radiation hardening, redundancy, and other protective measures. Being secondary to the primary satellite operator also increases the chances for conflict of interest; for example, the primary operator may want to relocate the satellite when the secondary payload operator, in this case the DoD, does not. These issues are currently being addressed in DoD policy and at the Hosted Payload Office in SMC.

While improvements to industrial base stability offer significant advantages, more detailed study is required in launch costs, range operations and ground system complexity to ensure less costly yet increased numbers of satellites don't offset expected savings. Less complex satellites could cost significantly less than legacy systems, but an increase in the number of platforms on orbit may eventually offset this savings through increased life-cycle costs from additional launches and ground system costs. On the other hand, lighter, less complex satellites may lead to smaller launch vehicle requirements or enable multiple payloads per launch, leading to even greater affordability. These system trade-offs are being carefully assessed within each applicable architecture.

CONCLUSION

Today, our current space architectures are vulnerable to attack. Our adversary's counterspace capabilities and actions continue to grow in sophistication, number and employment with the intent to hold our space systems at risk. If the premise is accepted that national security space assets will someday be attacked, then we have a military and moral obligation to examine protective measures that minimize this risk and protect our nation's warfighters, citizens, and economy. Standing still in an environment populated with intelligent adversaries seeking to contest our leadership in space and the operational advantages it affords is a strategy for falling behind. Disaggregation is an innovative opportunity to stay ahead of our adversaries, to change their targeting calculus, and to mitigate the effects of a widespread attack on our space assets. In addition, resilience serves as a deterrent, which may be the best way to preserve our capability by avoiding an attack.

While disaggregation is only part of the equation for space system resiliency, it offers the possibility to increase technology refresh opportunities, improve requirements discipline, increase launch and space industrial base stability, increase affordability and improve deterrence. The existing Cold War paradigm of protecting space systems through the threat of mutually assured destruction may no longer apply to today's security environment; it must be augmented by a natural evolution of the current status quo, toward innovative and creative solutions such as disaggregated space architectures.

APPENDIX: CONCEPTS FOR DISAGGREGATION OF SPACE ARCHITECTURES

This paper identifies five approaches to achieving disaggregation: *Fractionation, Functional Disaggregation, Hosted Payloads, Multi-Orbit,* and *Multi-Domain*. Each of these approaches has differing advantages and disadvantages and may be more applicable for a certain type of satellite mission. In short, there is not a "one-size-fits-all" approach to disaggregation.

Fractionation refers to the "decomposition of a system into modules which interact wirelessly to deliver the capability of the original monolithic system."[14] In this concept, multiple subcomponents interact on orbit to holistically create the capability of a single monolithic satellite. This approach has several potential advantages, such as being able to upgrade or replace a single subcomponent without having to replace the entire satellite, reduced payload mass expanding launch options, lower integration and checkout cost, and an innate ability to accept more risk.

Functional disaggregation refers to the dispersion of sensors or distinct sub-missions onto separate platforms that were previously hosted on a single system. A good example of functional disaggregation would be decomposing the AEHF satellite into separate strategic nuclear and tactical communication satellite payloads. This concept may reduce platform complexity, increase requirements stability and shorten acquisition timelines, leading to rapid matching of solution to need and more frequent technology refresh opportunities.[15] These reductions in platform complexity through functional disaggregation may lead to cost savings at the system or satellite level. The synergies between launch costs and reduced size and complexity of payloads, described above, may also reduce the overall cost of architectures. While not yet proven, the potential benefits are significant and should drive exploration into these options.

Hosted payloads are similar to functional disaggregation, but take advantage of a primary payload that would typically be fielded even without the secondary, hosted payload. AFSPC experience with the advantages of hosted payloads is extensive. For example, core elements of the Space-Based Infrared System are the infrared Highly Elliptical Orbit payloads hosted on a U.S. government spacecraft. The hosted payload uses available spacecraft power, processing, thermal and attitude control capabilities without the necessity of fielding a separate satellite bus of its own. The host could be a national security space asset or even a completely different mission or agency, such as was the case with the Commercially Hosted Infrared Program

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[14] "The Value Proposition for Fractionated Space Architectures," DARPA, Owen Brown and Paul Eremenko, AIAA, 2006.

[15] Note that the amalgamation of multiple missions on a single platform often greatly increases system complexity and creates a daunting integration challenge. A good example of this is the NPOESS satellite program, where nine advanced sensors were intended to operate on a single satellite. Technology maturation and integration issues proved to be too difficult, and the program was discontinued.

(CHIRP). CHIRP is a DoD experimental payload hosted on a commercial satellite.[16] Hosting a government payload on a commercial satellite may lower program costs while complicating an adversary's decision calculus regarding attacking a commercial system.[17] While offering great potential, there are some challenges to address. Secondary payloads aligned with a primary host satisfying a different mission (e.g., ISR sensor on a SATCOM host) face inherent challenges in integration, signal and structural interference and thermal constraints which must be worked early in the systems engineering phases to avoid launch delays. Hosted payloads are beginning to show some promising results, but the added legal and availability concerns need to be carefully weighed.

Multi-orbit disaggregation takes advantage of multiple orbital planes to increase resiliency and complicate an adversary's targeting calculus. We currently employ this type of disaggregation in architectures such as weather and Overhead Persistent Infrared; however, it is done to provide necessary geographic coverage. For example, weather satellites are placed both in a geosynchronous orbit to provide continuous coverage and in a sun-synchronous orbit to provide periodic revisit using sensors that are most effective at lower altitudes. This same concept could be applied to improve architecture resiliency to the extent that the chosen orbit meets both mission needs and resilience objectives. Multi-orbit disaggregation is a well understood option to enhance resiliency, but it often comes at a cost to sensor performance or communication link delays. Multi-orbit options must be examined with an eye towards technology maturation in order to maintain acceptable system performance.

Multi-domain disaggregation would take advantage of systems in more than just the space domain. An example of multi-domain disaggregation is the cooperative contributions of AFSPC Ground-Based Radars and Overhead Persistent Infrared sensors to deliver Launch Detection and Missile Tracking capabilities. This may be the most resilient approach, but would have to be carefully designed to provide a cost effective solution. Multiple systems could be designed to cooperatively provide a complete solution, with space sensors providing wide-area coverage and air- or ground-based sensors providing more tactical solutions. Disaggregated space capability across multiple domains provides inherent contingency planning as compared to parallel development of redundant/replacement systems.

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[16] Pawlikowski, et al.

[17] This is a tactic that may be somewhat analogous to Iraq's attempt to sway public opinion during the first Gulf War by placing signs reading "Baby Milk Factory" at valid military targets that had been attacked. Attacking a commercial communications satellite for example, may instill a much different perception in the public eye than interference with a purely military space asset.

Remarks of James P. Finch
Office of the Under Secretary of Defense for Policy
United States Institute of Peace Workshop
November 19-20, 2013

Bringing Space Crisis Stability Down to Earth

I'm pleased to be here with you today to talk about the emerging environment over the next thirty years. I will take an expansive view of the term environment, because I believe that one cannot talk about the space environment as if it were somehow abstracted from the terrestrial political situation, or in the case of great powers, abstracted from nuclear or strategic stability. In much the same way, I will argue that we should not talk about a terrestrial crisis or strategic stability as if they were somehow separate from what's happening or could happen in space.

Let me begin by stepping back. Over the past five to ten years, it has become common to focus on "strategic stability" as the new *modus vevendi* between great powers. In many ways, for those not schooled in nuclear strategy, this term has come to replace "Mutually Assured Destruction" in defining the relationship between potentially-adversarial nuclear powers.

The precise definition of strategic stability varies, and in fact several of the panelists you'll hear from over the next two days have contributed to an excellent volume of essays. It's called "Strategic Stability: Contending Interpretations" and was published by the Army War College. It is an excellent work that I commend to all of you. It provides a solid foundation to understand the concept, yet in my view, largely overlooks the critical role of space that we are gathered here to discuss.

In one of the most insightful chapters of that volume, Bridge Colby states that "strategic stability should be understood to mean a situation in which no party has an incentive to use nuclear weapons *save for vindication of its vital interests in extreme situations.*" He goes on to say that "In a stable situation, then, major war would only come about because one party truly sought it, not because of miscalculation."

As I mentioned, most of the chapters in this volume are focused on nuclear weapons and nuclear stability, and that is understandable. For at least the four-some decades of the Cold War, nuclear weapons have been the coin of the strategic realm. During this period, the safety of space systems was maintained by their close linkage to nuclear force structures.

In peacetime, space systems provided reassurance that the other party was complying with nuclear arms-control treaties. During crisis and wartime, space systems could provide early warning of an attack, enable nuclear command and control authorities to dole out the appropriate level of retaliatory devastation, and conduct battle-damage assessment to confirm weapons detonated as planned.

Given these roles, decision makers in Washington presumed that an attack on space assets would prefigure a nuclear confrontation. Thus, the problem of space deterrence or crises stability in space <u>independent</u> of nuclear stability was uninteresting at best. This is no longer the case.

And that is why these next two days are so important. Collectively, we need to better understand how space systems fit into broader notions of strategic stability, crisis stability, and arms race stability. Bruce MacDonald and USIP have lined up an impressive array panelist to approach this problem from different perspectives.

I particularly applaud the inclusion of Professor Li Bin, who I know will provide an insightful and invaluable perspective.

For my part, I will try to set the table, describing the imperative based upon the emerging environment. In the coming years, I believe that instability in the space domain may grow due to a lack of common understanding about the implications of counterspace systems. With this lack of common understanding will come a growing risk of miscalculation in a terrestrial political crisis. If not explicitly addressed, this instability in space could even create a chasm that undermines the well-crafted tenets of strategic or nuclear stability.

I'll do this in two parts – first, I'll describe the importance of space systems to strategic stability more generally. Then, I'll discuss how the emerging environment in space can and will impact the dynamics of crisis stability. I'll close by explaining why I believe the next two days are so important, as frank discussions such as this are currently our best hope at reducing the risk of miscalculation and inadvertent escalation during a crisis.

Let me first turn to the importance of space systems to strategic stability. I think I can contend with little opposition from this audience that space is vital to the national security of the United States. As noted in the U.S. National Space Policy, space-based capabilities enable our Armed Forces to see with clarity, communicate with certainty, navigate with accuracy, and operate with assurance. Maintaining the benefits afforded by space is also essential to economic growth and prosperity, not only in the United States, but also around the world.

U.S. and allied forces rely upon satellites to operate far from established terrestrial communications networks. Satellite communications provides the backbone for long-haul ISR data streams, such as those provided by remotely-piloted vehicles, which themselves are operated via satellite. The Global Positioning System provides our forces critical position, navigation, and timing information, allowing joint forces to better understand the contour of the battlespace, target with precision, and to synchronize effects. Space-based assets provide for global and theater missile warning, and assets operated by the DoD and NOAA provide accurate, timely weather information. All of these capabilities are critical to a joint force projecting power far from the homeland.

For an adversary seeking to disrupt or deny the ability of the United States to project power, space capabilities may provide an appealing target, especially early in a crisis or conflict. As such, space as a domain is inextricably linked to crisis stability. First, space capabilities are critical enablers for joint forces, and may be viewed as an Achilles Heel for that force. Second, many space capabilities can be degraded through electronic means, enabling the use of weapons systems like jammers that may be perceived by an adversary as less escalatory. And finally, it is often said that "satellites have no mothers." An adversary may therefore believe that they can attack such targets without fear of retaliation.

But focusing exclusively on the U.S. use of space systems misses a significant change in the larger environment – a change that will only become more pronounced in the coming decades. The fact is, we are not alone in our growing reliance on space for political, economic, and military purposes. The unique attributes of the space domain – global coverage, persistence, access to denied areas – are attributes that are valuable to all societies and militaries irrespective of their political ideologies.

USIP has specifically identified China as a topic of interest today, and while China has contributed to new challenges in space, it should be recognized that China also shares our interest in the safety, stability, and security of the domain. President Obama and President Hu agreed in their last summit together that "the two countries have common interests in promoting the peaceful use of outer space and agreed to take steps to enhance security in outer space."

China, like the rest of the world, continues to derive significant economic benefit from space capabilities. And, like the United States, China has also discovered the military benefits enabled by space.

A critical feature of China's so-called anti-access/area denial (or A2/AD) strategy is the ability to engage an adversary's force at a distance. This is best accomplished relying on the "ultimate high ground." Space provides an ideal location to identify and target forces, to communicate and guide weapons systems, and to assess damage after the strike.

For the past decade, the strategic community has thought of dependence on space systems and the accompanying vulnerability as a "U.S.-problem." While this was accurate a decade ago, I believe that this is increasingly a problem for any modern state seeking to project power regardless of their political motivation.

The implication is profound.

If both sides depend on their space systems to ensure that their military forces can achieve their political objectives (or deny the political objectives of their adversary), then the overall stability of the space domain will become a central component of the overall stability of a crisis.

Let me put that another way.

A great power contemplating a terrestrial conflict will assess the overarching stability of the situation, including the relative balance of forces at different levels of conflict. Such a power may assess that the balance is against them, and therefore decide not to undertake an act of aggression. However, if that same power foresees a chance to alter that balance by preemptively undercutting a critical source of the adversary's power, for example, by denying vital space capabilities, their calculus may be different.

As such, strategists must seek to ensure that deterrence is balanced across domains and balanced across elements of national power. The alternative is to risk that vulnerability in one narrow area, such as space, can collapse the threshold for deterrence failure more broadly.

Simply put, strategic stability must be sought in space, and space stability must help maintain the overarching stability and deterrence posture here on Earth. They are inextricably linked. Allow me to be provocative by suggesting that this is as true for the United States as it is for China. And it is for this reason that we must give serious attention in the next two days to how to achieve and maintain crisis stability in space.

Let me now turn to **how space affects crisis stability dynamics**, and how space dynamics could easily conspire to undermine arms race and crisis stability. This, in some ways, is more complex than nuclear stability. First, there exists today a clear taboo against the use of nuclear weapons. Crossing that firebreak at any level has immediately recognizable and significant implications. Second, in the context of nuclear weapons, theorists can (at least arguably) discriminate escalatory motives based on the *type of weapon* – strategic or tactical – and based on the *type of target* –counterforce or countervalue targeting. This was most famously sketched out in the form of an escalation ladder by Herman Kahn's 1965 book, On Escalation.

This convenient heuristic for understanding escalation based on the target and the weapon type is arguably more complex for space. This is because there exists a lack of mutual understanding on the implications of the weapon and the value of the target. Let me briefly address both of these factors, because they describe the playing field, if you will, on which a terrestrial crisis could spiral into space conflict. Efforts to manage crises, therefore, must account for these complexities.

To begin with, there is no taboo against many types of counterspace systems. Starting our framework with weapon type, the threshold for use of temporary and reversible counterspace weapons appears to be much lower. We see instances of electronic jamming happening all over the world today. And the number of actors who possess counterspace weapons like communications jammers is much higher. Given the low cost and relative simplicity of some counterspace weapons, even non-state actors have found utility in employing them. As former Deputy Secretary of Defense William Lynn noted, "Irregular warfare has come to space." So this type of weapon – temporary and reversible – appears at first glance to be less escalatory and prone to miscalculation than kinetic weapons.

At the other end of the weapon axis are weapons that have permanent and irreversible effects. The extreme version of such a weapon would be a debris-generating kinetic kill device such as the kind that was tested by the United States and Soviet Union during the Cold War, and by China more recently. These weapons are particularly insidious because they generate large amounts of debris which will indiscriminately threaten satellites for decades into the future.

One additional dimension to the weapon axis that that merits consideration in the context of crisis stability relates to the survivability of the weapon.

It is well regarded that space is an offense dominant domain, which is to say that holding space targets at risk is far easier and cheaper than defending them. This can create first-strike instability by creating pressure for early action at the conventional level here on Earth, before counterspace attacks can undermine the capability for power projection. But the offense-dominant nature of the domain has implications for both peaceful satellites as well as space-

based weapons. This can also create first-strike instability with respect to space-based weapons, since advantage would go to the belligerent who uses their space weapon first. In this way, space-based weapons may be uniquely destabilizing in ways that their more survivable, ground-based relatives are not.

Adding complexity to Kahn's heuristic, however, is the situational context surrounding the employment of a counterspace systems. Today, in the space context, strategists will have to consider not just weapon type, and the nature of the target, but also the context.

Today's electronic jamming has primarily been witnessed in the Middle East, where regimes have sought to deny the freedom of information to their populations by jamming commercial communications satellites. The same weapon type – a satellite communications jammer – applied against a satellite carrying strategic nuclear command and control communications during a crisis, could be perceived much differently.

The inverse is also true – the application of permanent, irreversible force against a commercial or third party satellite would have a much different effect on crisis dynamics than jamming. Such attacks could raise a party's stake in the conflict, by either threatening their power projection capabilities or by threatening their assured ability to retaliate against a nuclear strike.

Simply put, the weapon, target, and context all contribute to the perceived intent and effects of a counterspace attack. All of those variables are open to interpretation in crises. And it should be remembered that an inherent characteristic of crises are short timeframes for decision making. And when time is short and the potential cost of inaction is significant, or even catastrophic, decision-makers tend to lean towards worst-case interpretations of an adversaries actions.

This is a clear recipe for potential miscalculation.

So, I think it is safe to say the emerging space environment insofar as it relates to crisis stability can be called "complex." And these complexities represent, in my opinion, the seeds for crisis instability and a **great potential for miscalculation**. This is why your contribution over the next two days is important.

The Cold War adversaries had many years to develop mutual understandings about the nature and role of nuclear weapons, and this understanding contributed to strategic stability. These understandings were borne out of real-world crisis, such as the Berlin crises, the Korean War, and the Cuban missile crisis. They also emerged from dialogues, such as formal summits and long-running arms control negotiations. The former is certainly much more dangerous than the later, and I don't think anyone wants to see a space equivalent of a "Cuban Missile Crisis".

There are signs of progress, with the United Nations' recent recommendations of bilateral and multilateral transparency and confidence building measures and the on-going discussions to develop an international "Code of Conduct for Outer Space Activities." While these will help promote the responsible use of space, they don't squarely address the current lack of mutual understanding about how space attacks will be perceived in the midst of a crisis.

At the Track 1 level, we do not currently have a productive venue for the United States and China to develop a mutual understanding of how space plays into crisis stability. We are taking steps in the right direction, but these have been slow, tentative steps, and there is much work to be done.

I was in China a few weeks ago as part of a Track 1.5 and it is clear that there is a lot of mistrust and misperception by both sides. The United States continues to raise questions about China's military modernization, and the potential coercion of regional neighbors over contested territory. China continues to question the implications of expanding U.S. missile defenses, and, to a lesser extent the U.S. rebalance to the Asia-Pacific region.

Suspicions about space activities fit within this broader geopolitical mistrust. The United States continues to express concern about Chinese space activities and China's lack of transparency when it comes to unique space launch profiles or robotics experiments. China, for their part, expresses concerns about U.S. activities, such as the X-37B. These misperceptions are hard to resolve, both because of the inherent dual-use nature of space systems and the difficulty in creating transparency for a regime so-far removed from *terra firma*.

I'd like to close by returning to the quote from Mr. Colby. "In a stable situation, then, major war would only come about because one party truly sought it, not because of miscalculation." Miscalculation is best avoided when each side understands the implications of their actions, and understands how the other side will interpret and react to those actions.

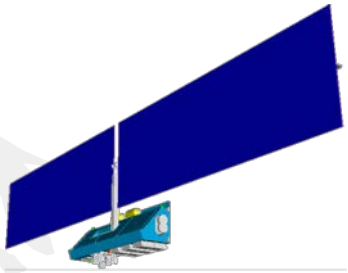
This situation does not exist in today's environment with respect to space systems and space weapons. We lack a common understanding of how space will contribute, or come to define, potential crises between the United States and China. And given both sides' growing reliance on space systems to achieve their military and political aims over the next few decades, this lack of understanding comes with great peril.

That is why I'm pleased that USIP has gathered you all here for the next two days. It is our challenge to make a useful contribution towards crises stability by developing and sharing various perspectives that could reduce the risk of miscalculation and improve crisis stability. I know you are up to the task.

Thank you.

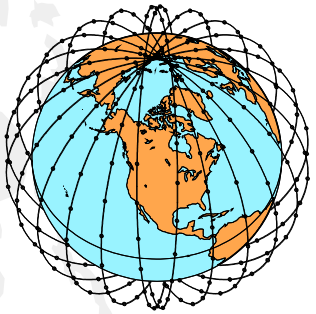
Achieving Space System Resiliency

Service Availability



- **Substantial effort has been expended developing NGSO system architectures to achieve cost-optimized performance.**

- **"*Service Availability*" is a key metric used in defining overall system performance.**



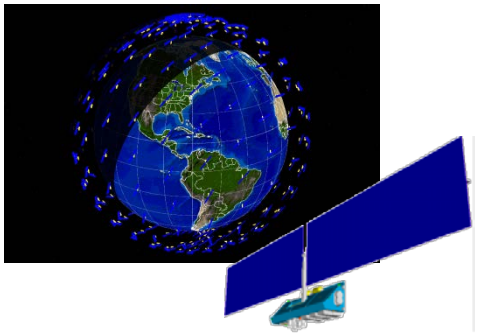
$$\textit{Service Availability} = \frac{\textit{Access Time}\ (T_{life} - T_{down})}{T_{life}}$$

- **T_{down} for a typical NGSO commercial system is the time the system cannot satisfy intended service capability e.g. due to:**
  - System degradation (reliability)
  - Natural events (debris, weather)
  - Operator error
  - Element replacement delays

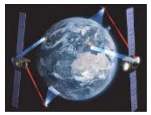
- **Advisory Threat – terrestrial fiber build-out**

Service Availability

- **Service Availability modeling drives physical aspects of system design from top level architecture definition through development and the operations & maintenance approach.**



System Architecture



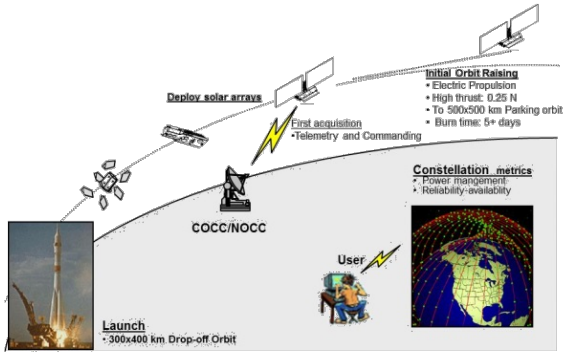
OISL

CICs

Batteries

Propulsion

Component Technology Selection



O&M Approach

- **Affordable operational persistence is achieved through:**
  - Optimized system design - "Service Availability modeling"
  - Robust Supply Chain – Ensured Supply
  - Technology Readiness - Maturation of key enabling technologies
  - etc.

- **Persistent Operational Capability ~ System Resilience**

Teledesic "Resiliency" Components

TELEDESIC VISION:

GLOBAL BROADBAND INTERNET SERVICE TO > 20M USERS AT COST AND PERFORMANCE EQUIVALENT TO TERRESTRIAL NETWORK

BUSINESS / MISSION VIABILITY COMPONENT

- VIABLE MARKET, PRODUCT AND SCHEDULE
- REGULATORY APPROVALS ACHIEVABLE (E.G. SPECTRUM)
- FINANCEABLE
- BUSINESS CASE "CLOSES"

SYSTEM DESIGN COMPONENT

- REDUNDANT FOOTPRINT AND BEAM COVERAGE TO REDUCE S/V COMPLEXITY AND COST
- ROBUST MESH NETWORK (ISLs)
- ON-ORBIT SPARES

SYSTEM DEPLOYMENT COMPONENT

- DESIGN FOR MULTIPLE S/V PER LAUNCH
- REDUCE LAUNCH PROCESSING

SERVICE ADAPTABILITY COMPONENT

- IP – BASED NETWORK
- RECOGNIZE USER NEEDS WILL EVOLVE
- INFRASTRUCTURE INDEPENDENT FROM OFFERED SERVICES
- FLEXIBLE CAPACITY ALLOCATION

SERVICE AVAILABILITY COMPONENT:

- SERVICE AVAILABILITY TO USER > 99.9%

SERVICE COST COMPONENT

- "OPTIMIZE" SERVICE COST TO USER - NOT TOTAL SYSTEM COST
- COST TO USER < $0.01 / MB

SYSTEM MANUFACTURING COMPONENT

- DESIGN FOR PRODUCTION, UNIT COST
- DESIGN QUALITY INTO PROCESS, NOT FINAL TEST
- ECONOMIES OF SCALE AND LEARNING CURVE

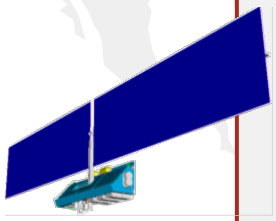
SYSTEMS ENGINEERING COMPONENT

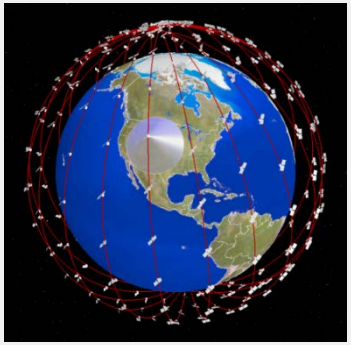
- STRONG INDEPENDENT SE TEAM
- WORK WITH, NOT AGAINST PRIME
- REQUIREMENTS *VS.* "DESIREMENTS"

Requirements Interpretation

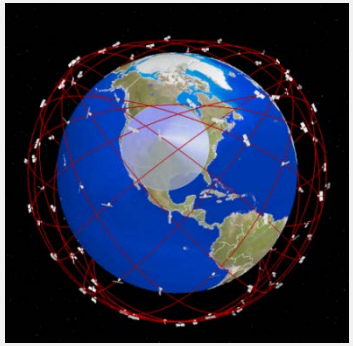
Two Proposed Space Segment Solutions.

- Both contractors bid to the same requirements set
- Both were approximately the same cost
- T126 had 1/10 the throughput capacity of T288

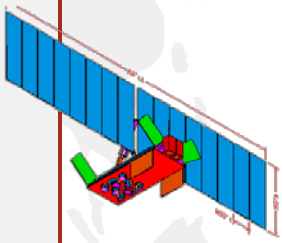




Teledesic T288 Constellation

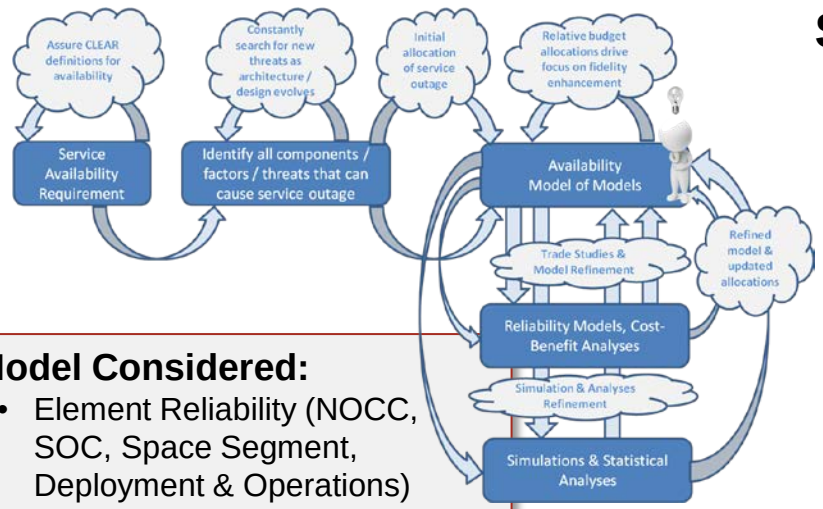


Teledesic T126 Constellation



The service availability modeling process enabled Teledesic to effectively assess the various proposed system solutions and clarify system level requirements.

Teledesic Service Availability Modeling

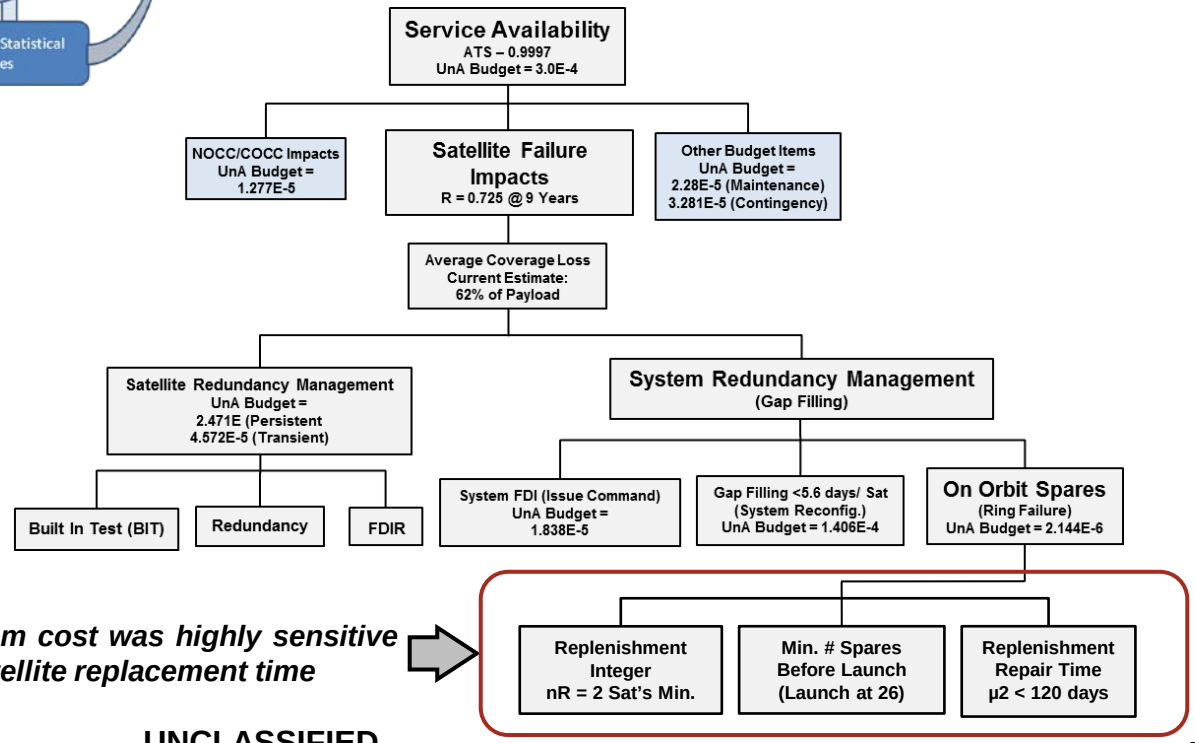


Service Availability Modeling:

- Capability and cost were fix from the start
- Customer subject matter experts vs. tools
- Technology readiness and capability knowledge
- Requirements definition
  - At the service level
  - Supplier participation essential
  - Good enough vs. exquisite

Model Considered:

- Element Reliability (NOCC, SOC, Space Segment, Deployment & Operations)
- FDIR Persistent Failure
- FDIR Transient Failure
- Satellite Design Life Constraints
- Recovery timing (short & long term)
- Human Interface
- Orbital Debris
- Space Weather
- Service Interference
- Weather

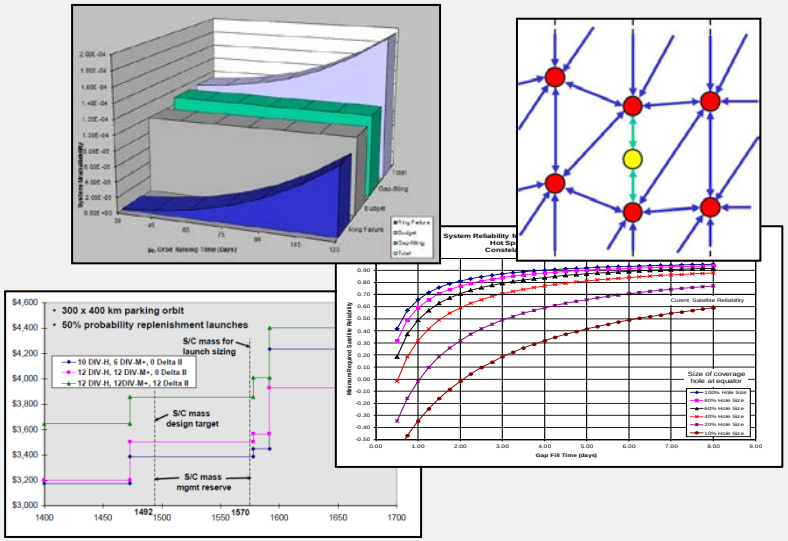


System cost was highly sensitive to satellite replacement time

Service Availability Modeling Results Example
- *Satellite Replacement* -

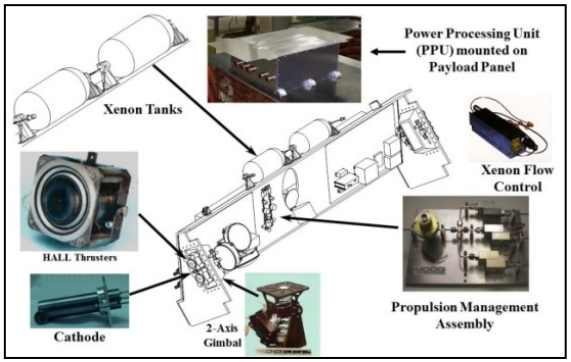
- **Overall system cost was very sensitive to the time allocated for replacement of a failed satellite.**

- **Increased replacement time required**
  - Higher reliability satellites
  - Increased number of satellites
  - Increased SOC activities
  - Increased number of launch vehicles and launch vehicle mix



Availability Modeling enabled identification of critical technologies.

- Hall thruster propulsion proved to be the optimal solution for both orbit raising, repositioning, deorbit.
- No domestic supplier base existed at that time.

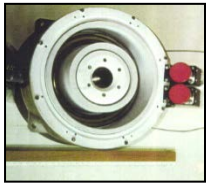


Teledesic - Example Technology Maturation

1) Ensure a robust supplier base for critical technologies

- Developed a domestic source for Hall propulsion
- Established new U.S./Russian partnership team to gain access to TsNiimash propulsion technology.
- Obtained a U.S. manufacturing rights agreement with the Russian Space Agency and MoD.

Rocketdyne TsNiimash

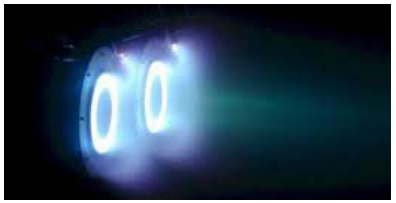


ARC / Fakel

Primex (Aerojet)

2) Technology maturation

- Three thrusters, all built in the U.S, were successfully tested as part of the supplier procurement evaluation process.



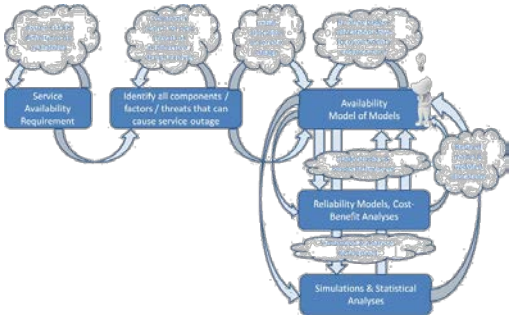
AEHF

3) Xenon propellant production

Teledesic "Resiliency" Conclusion

- **Teledesic defined "Persistent Operational Capability" as the system's ability to provide the designed level of performance, adapt to support future customer service needs over the design life of the system.**

- **The Service Availability modeling process was the primary tool used by the Teledesic team to identify the physical and operational aspects of the system design.**



- **Effective Service Availability modeling requires:**
  1. Defined system requirements
  2. Threat environment knowledge

- **The availability modeling tools plus subject matter experts with technical domain knowledge enabled Teledesic to guide and assess the prime contractor system designs.**

- **The customer must possess a strong systems engineering capability to maximize the benefit of the Service Availability model.**

SES Government Solutions

COMSATCOM
Contributions to a Resilient Architecture

Tip Osterthaler, President and CEO
OSD/AFSPC Resiliency Forum

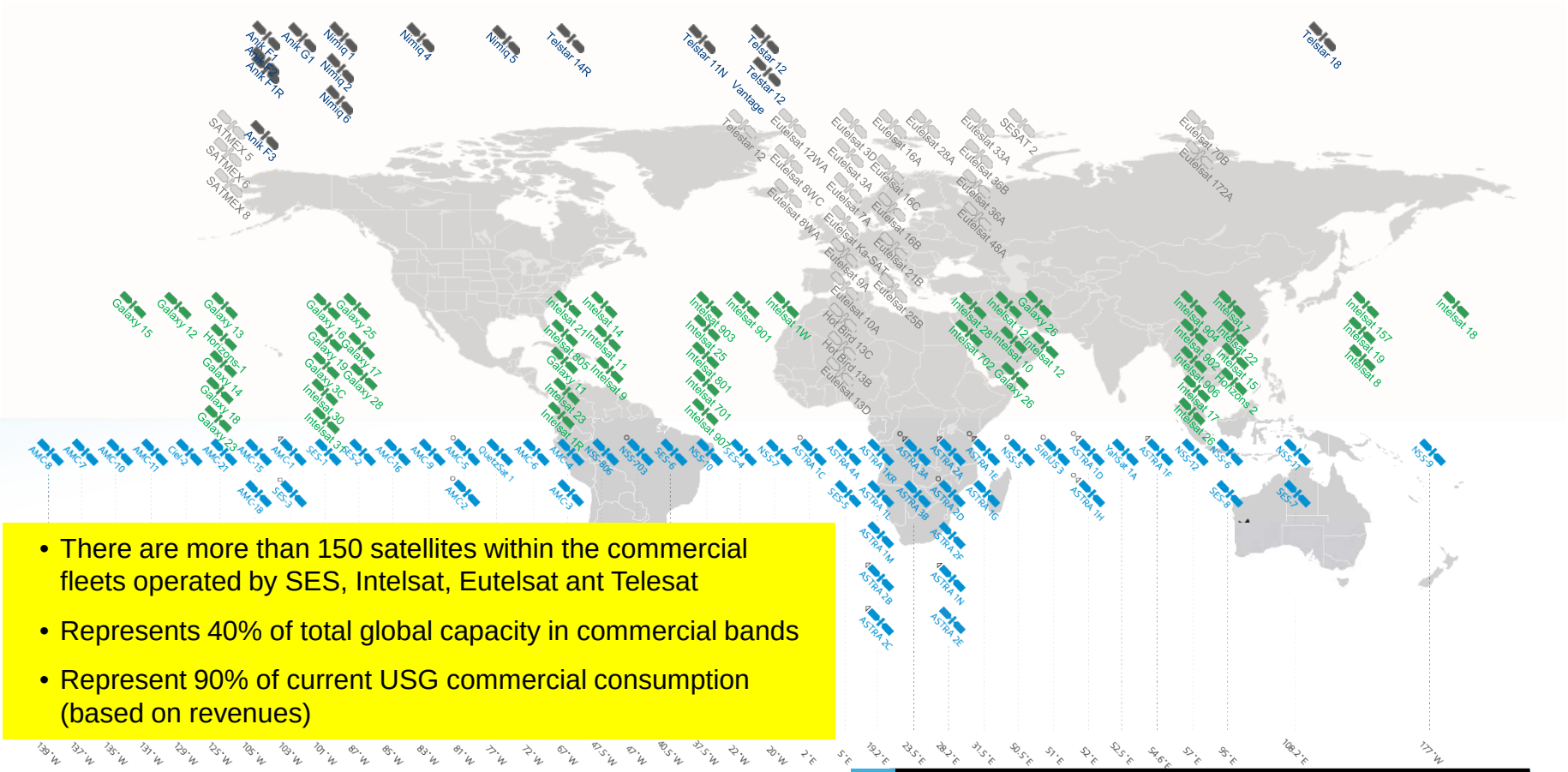
February 12-13, 2014

The USG SATCOM Market in Numbers

80%	More than 80% of the SATCOM utilized by the U.S. Government is provided by commercial operators
85%	The U.S. Government accounts for 85% of the global government demand for COMSATCOM
5%	Experts forecast a CAGR of 4.8% for U.S. Government SATCOM demand through 2022
$1.2B	The U.S. Government spends approximately $1.2 billion annually on commercial SATCOM capacity
26%	Only 26% of the COMSATCOM leased today by the USG is over the U.S. The balance is leased to support global operations

Commercial SATCOM Today

The Big 4



- There are more than 150 satellites within the commercial fleets operated by SES, Intelsat, Eutelsat ant Telesat
- Represents 40% of total global capacity in commercial bands
- Represent 90% of current USG commercial consumption (based on revenues)

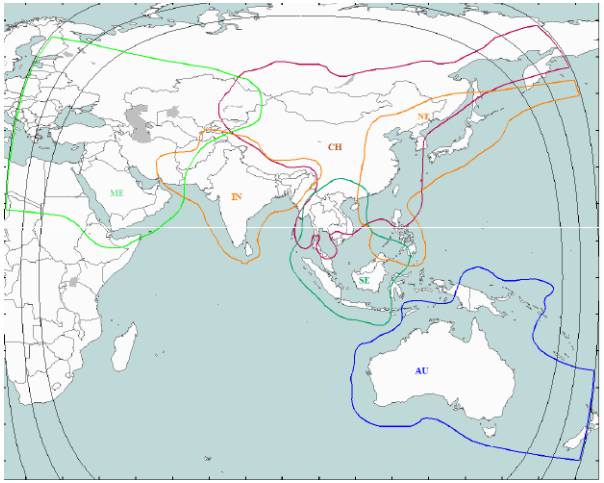
LAUNCHES

Company	2013	2012	2011	2010	Avg Launches Per Year
Intelsat	0	5	2	2	2.25
Eutelsat	2	2	2	1	1.75
Telesat	1	1	1	0	0.75
SES	3	3	4	2	3
Total	6	11	9	5	7.75

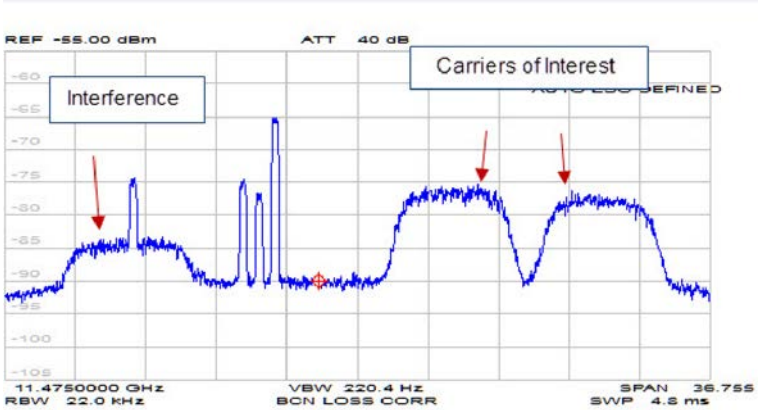
Commercial Satellite Features Today

(99.999% Availability is the Typical Commercial Standard)

- Multiple beams complicate or prevent jamming
- Steerable beams can isolate RFI
- Substantial mission assurance investments
- Anti jamming technologies to combat purposeful jamming as well as inadvertent ASI (Eutelsat hosting experimental AJ capabilities on a future Middle East satellite as financed by the French and European Space Agencies) each
- Geolocation and monitoring services are maturing rapidly
    - Every commercial satellite is monitored 24/7
    - Spectrum is digitized and analyzed for rogue carriers, interference, etc.
    - Carrier ID is a commercial initiative underway to combat interference
    - Carrier under carrier identification now possible



Typical Commercial satellite with multiple beams (satellite above is SES satellite NSS-6)



Mission Assurance Category (MAC) Levels

- MAC I systems: Satellites that employ NSA-approved Telemetry Tracking & Control encryption. Disaster and Recovery planning call for little to no effect on operational continuity

- MAC II systems. Satellites that employ NSA-approved Telemetry Tracking & Control encryption. Disaster and Recovery planning call for resumption of essential business functions within 24 hours of event

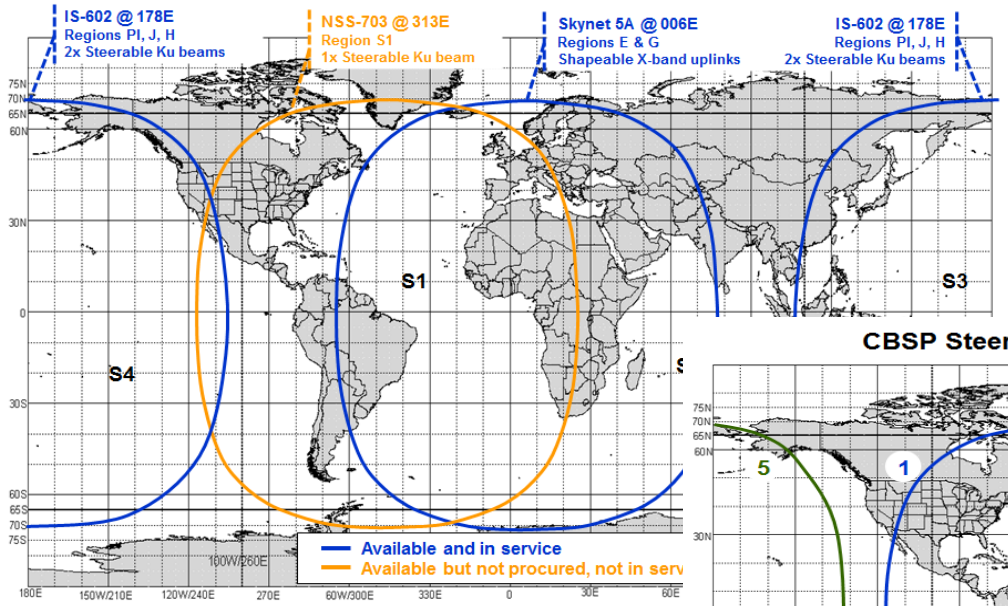
- MAC III systems: Satellites that employ FIPS140-2 type Telemetry Tracking & Control encryption. Disaster and Recovery planning calls for partial resumption of mission within 5 days of event

Steerable Beams

COMSATCOM Capability Available for Increased Resiliency

SES Government Solutions

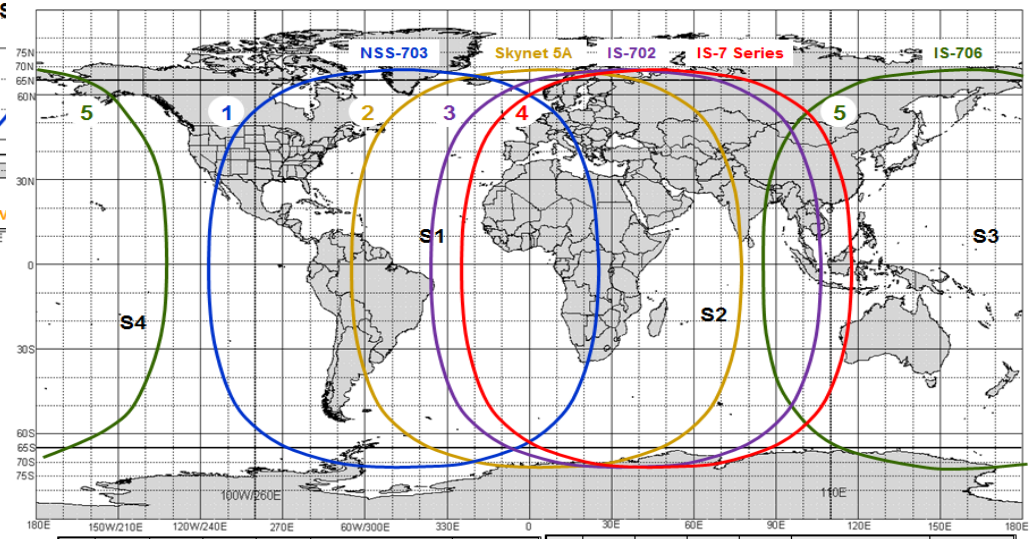
CBSP Steerable and Shapeable – Available Today



Case Study:

Navy Commercial Satellite Broadband Program (CBSP)

CBSP Steerable and Shapeable – Available In Future



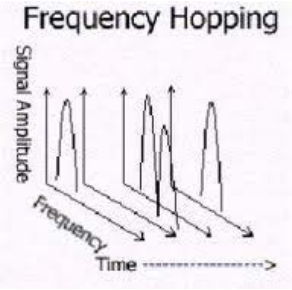
	Satellite	Orbital Position	Band	Region	Capabilities	Timeframe
1	NSS-703	313E	Ku	S1	3x Steerable Ku beams	Now
2	Skynet 5A	006E	X	S1	Shapeable Uplink	Now

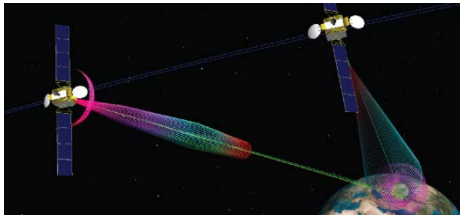
	Satellite	Orbital Position	Band	Region	Capabilities	Timeframe
3	IS-702	033 E	Ku	G, S2	3 x Steerable Ku beams	4th Qtr, CY2012
4	IS-7 Series	047.5E	Ku	G, S2	3 x Steerable Ku beams	3rd Qtr, CY2012
5	IS-701	157 E	Ku	PI, J, H	3 x Steerable Ku beams	Jun-2012

Additional Available Technologies

Interference is a daily occurrence in satellite communications. As available spectrum becomes more scarce, new technologies are being developed to eliminate, mitigate or identify the sources of interference.

- Nulling technologies
  - Phased Array antennas
  - Multi-feed antenna arrays
  - Ground-based beam forming networks
- Onboard processing
- Advanced wave forms and frequency hopping modems
- Embedded Carrier ID





Hosted Payloads

1. Proven economics based on shared bus and launch costs (CHIRP achieved 85% of wide field-of-view infrared objectives at 15% of the cost of a military owned/operated spacecraft)
2. Short cycle times, low schedule risk
3. Proven technical viability
4. Provide alternative/supplement to small numbers of exquisite assets (aka high-value targets)
5. Complicate targeting problem (political and application diversity)
6. Allow for regular and timely technology insertion

Existing Commercial Infrastructure Delivers Resiliency on the Ground

SES Government Solutions

- Commercial business demands robust networks
- USG benefits from investments made to increase terrestrial reliability to support 99.99% availability

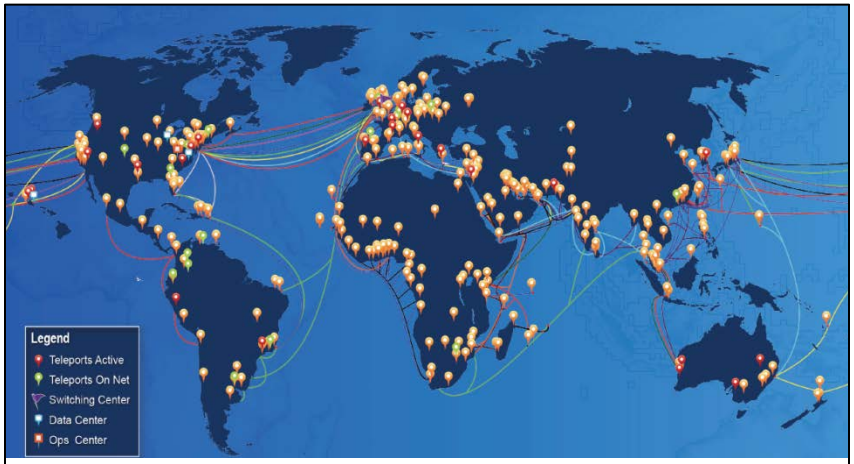
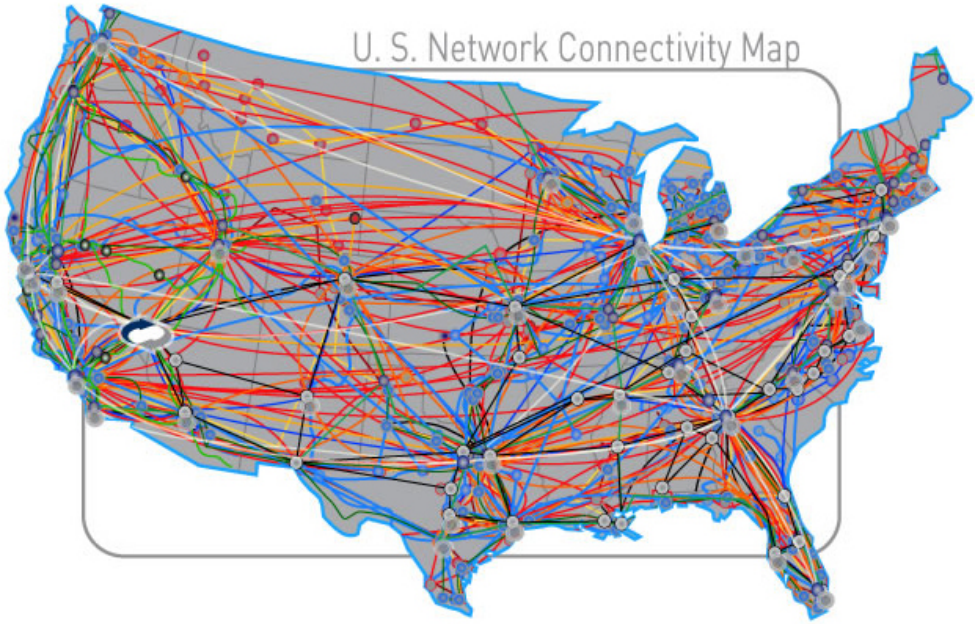


Photo courtesy of SCS Networks, one of many global MPLS providers

- Enhanced security, including Internet traffic separated using different MPLS routes (access to routers) to ensure redundancy
- Secure, diversified, and redundant capabilities deliver a resilient network

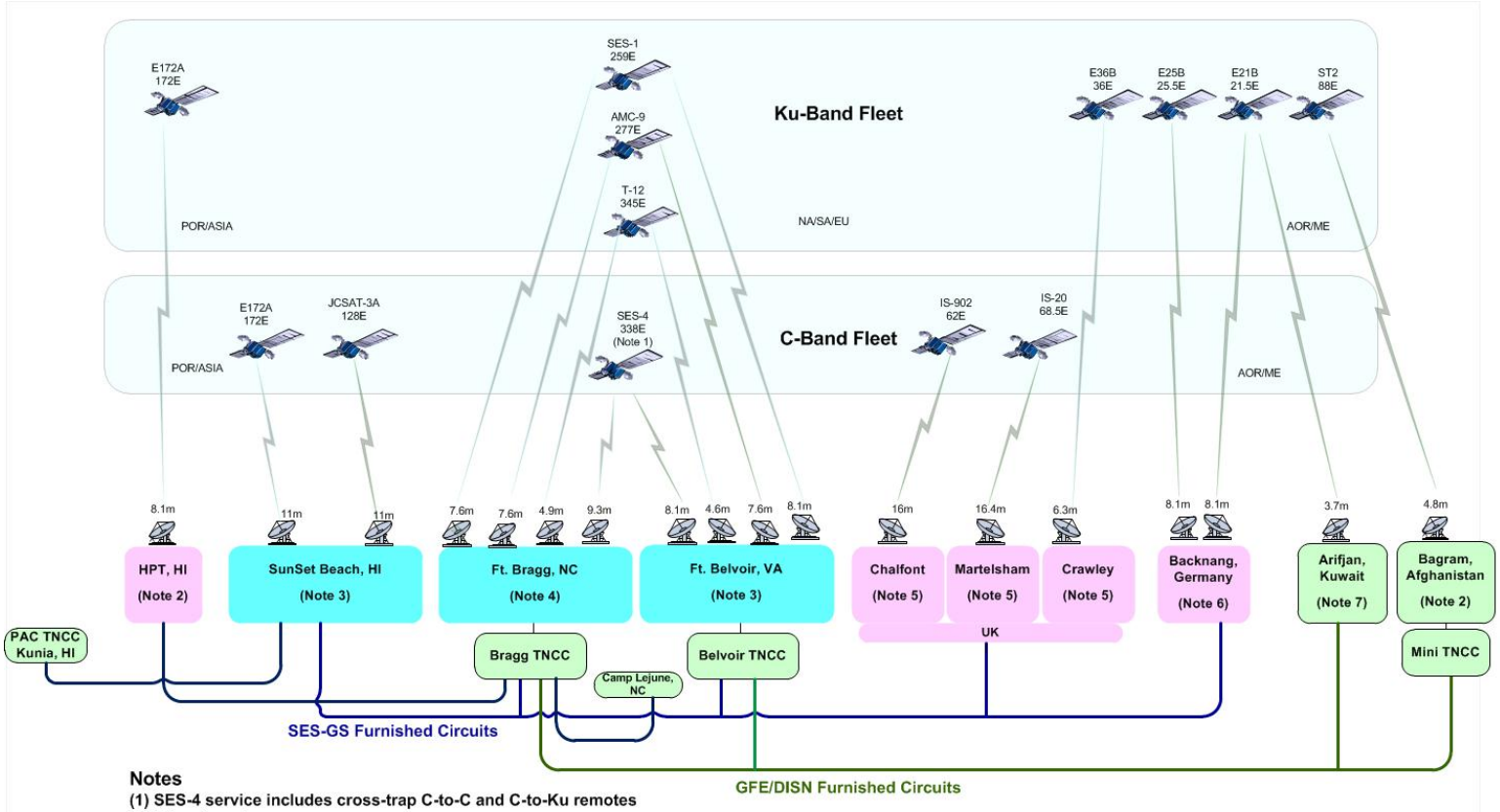
Commercial Fiber

There are multiple commercial fiber providers we can rely on. Multiple providers ensures robust coverage areas and redundant pathways.



Individually On-Net National Backbones

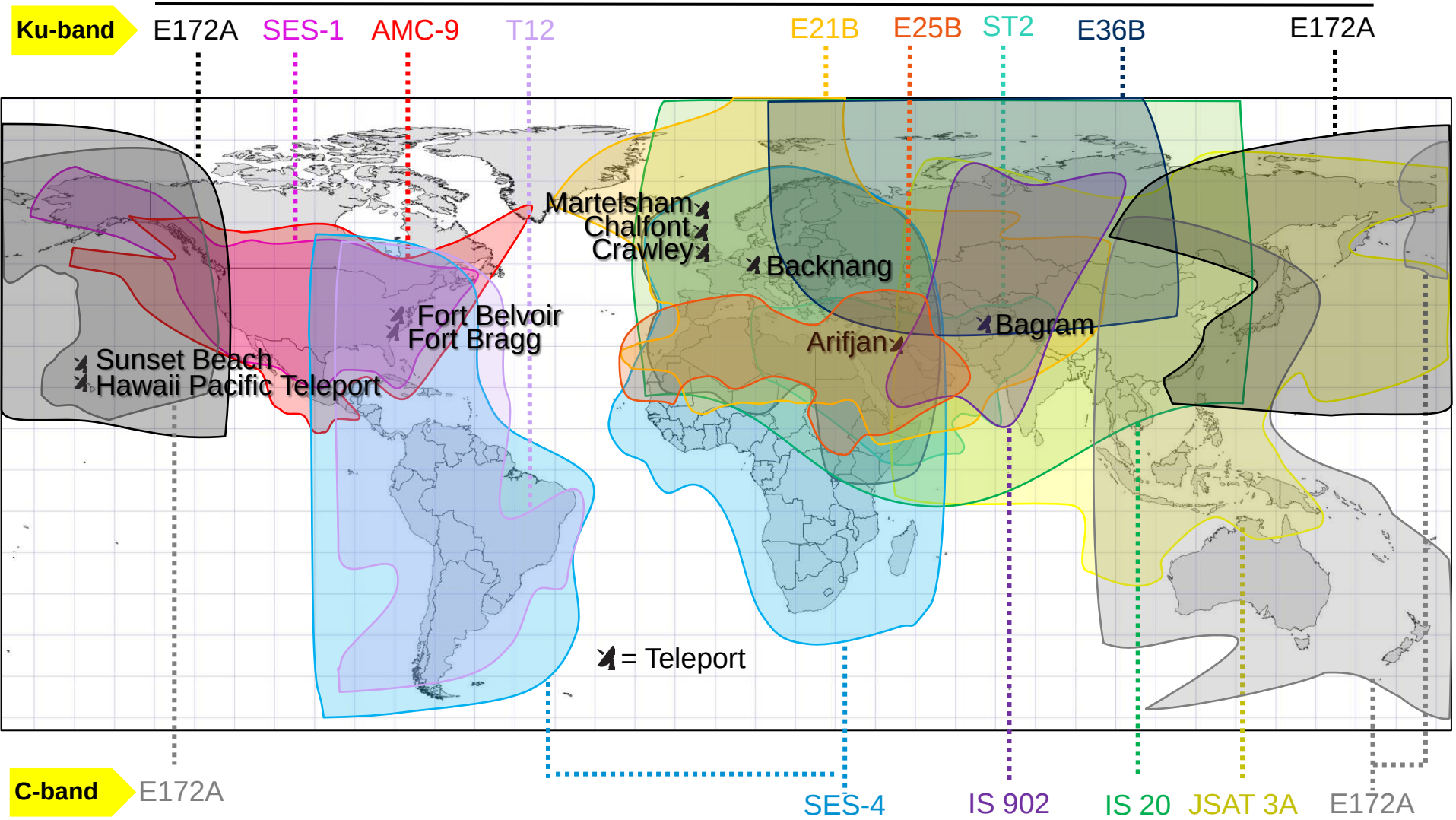
US Army INSCOM Trojan Network



Sensitive and Proprietary Information

Trojan Global Coverage Map

SES Government Solutions



Sensitive and Proprietary Information

Conclusion

- Existing commercial satellite architecture offers path diversity inherent in a global fleet of more than 150 satellites (combining trusted operators SES, Intelsat, Eutelsat and Telesat)
- COMSAT owner/operators 8 launches per year, each with hosted payload and special feature opportunities
- The commercial satellite architecture is politically, technologically and geographically diverse today, and could be made more so
- If the US Government accepts that commercial satellite bandwidth will remain an essential capability, IA standards should be established and long-term access arrangements must be created

THE VALUE OF PERFORMANCE.

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Space Resiliency

Jeff Grant

VP & General Manager Space Systems

Northrop Grumman Aerospace Systems

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Protection/Resilience Context

Breaking Down the Problem to Effectively Define and Measure Protection/Resilience

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1. Capability:
Quadrennial Defense Review

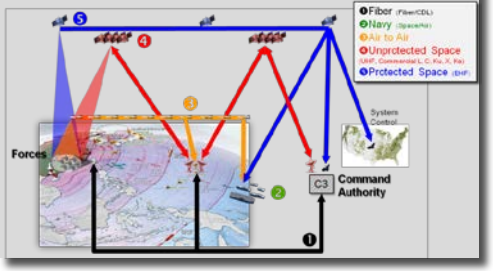
2. Enterprise:
Defense Budget

- Force Projection
- Situational Awareness
- Logistics
- Environment / Budgets
- War Fighting Doctrine
- Decision Authorities

System Engineering – Piecing the systems together

3. DoD Systems:
System Acquisitions

DoD System KPPs



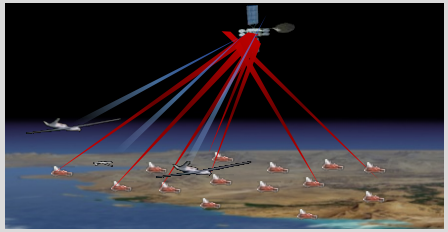
DoD System:

Type	MILSATCOM
Cost	$30B
Reliability	0.9

Every system has breaking points

4. Threat Systems:
Adversary Capabilities

Successful threat system



Threat System (break point):

Type	Jamming
Cost	$5M
Reliability	0.999

Identifying the weak links

Protection/Resilience can be Characterized by System Breaking Points

Understanding Asymmetry (Example: jamming)

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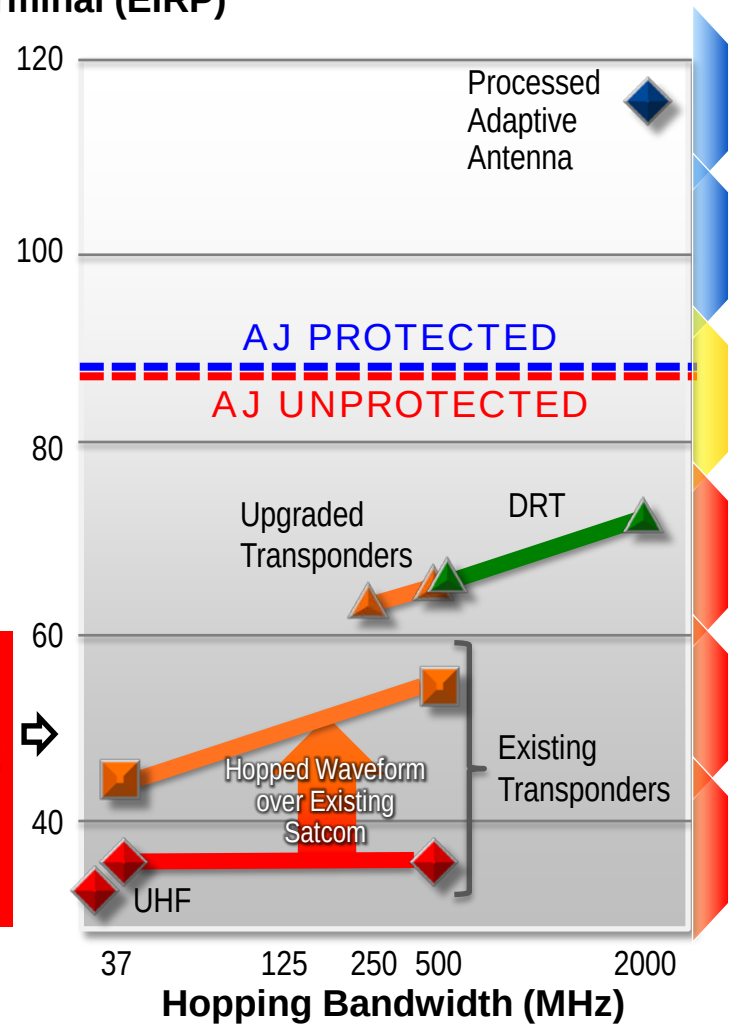
Power to Disrupt OTM Terminal (EIRP)



100x Jamming Improvement with Little Asymmetric Benefit

Configuration / Cost	Standoff (miles)	Dynamics /Quantity	Asymmetry Costs (Threat / Mitigation)
Exotic	~10	1s	
Fixed		10s	
Trans-portable		20s	
Mobile	>1000	50s	
Vsat	>1000	100s	
Suit case	>1000	100s	

Assessing Space Protection/Resilience

Guiding principles to be used for Architecture and Acquisition

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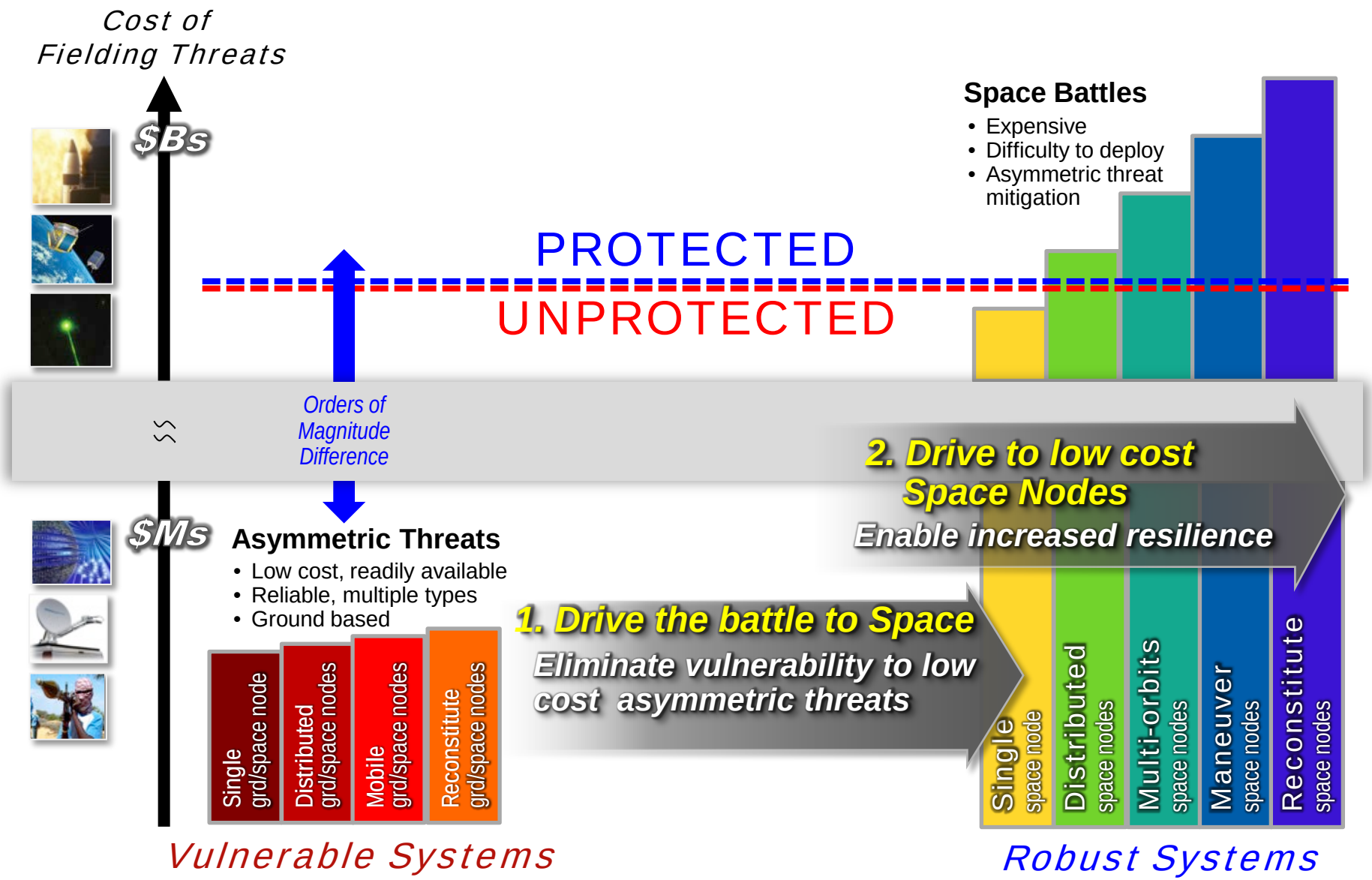

Summary

- The space industry has been very successful in building “resilient” systems, ie surviving:
    - Launch
    - Human contact in ground test environments
    - Errant commands
    - Single point failures
    - Infant mortality

- We have been used to “playing” golf…it is us against vs. a varying, but deterministic challenge

- We are now “playing” hockey… it is us against a human adversary who will seek to exploit our weaknesses and not stand quietly by while we make our shot

- We can deal with an adversary in this environment as the ground, air and naval communities have for decades/centuries