NPS-SP-08-005

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

AN OPERATIONALLY RESPONSIVE SPACE ARCHITECTURE FOR 2025

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22 June 2008

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Prepared for: The National Reconnaissance Office

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This report was prepared for SS4051 Military Space Systems and Architectures
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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 15 June 2008	3. REPORT TYPE AND DATES COVERED Technical Report

4. TITLE AND SUBTITLE: An Operationally Responsive Space Architecture For The Year 2025	5. FUNDING NUMBERS
6. AUTHORS Rob Aikins, et al.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER NPS-SP-08-005
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) The National Reconnaissance Office	10. SPONSORING/MONITORING

11. SUPPLEMENTARY NOTES The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Unlimited Distribution	12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

The distance learning team was tasked to produce an architecture that would best support future Operationally Responsive Space requirements in the 2025 timeframe. The 'bottom line up front' to this analysis showed that the current space architecture already provides some level of responsiveness. However, ORS will demand modifications of the current space architecture vice certain 'pre-conceived' notions of quick launch or a separate ORS architecture altogether.
The team developed a 'baseline' vision for deeper analysis focused on the Combatant Commander supported by analytical categories named 'Pillars' as follows: Improved Organizational Relationships, Asset Loss Mitigation, Availability, Flexibility, and Streamlined Acquisition Processes. These pillars allowed the solutions, material and non-material, to be organized for further analysis, relevancy, and value to the architecture. Constraints and alternative solutions were considered. Analysis was further supported by a performance versus cost process which provided a final test of solution feasibility. Relative cost was determined by comparison of existing program or like capabilities with future inflation. Differing combinations of solutions could provide ORS value by modification of the metrics. The final analysis showed an Operationally Responsive Space architecture that meets all metrics and that could support all COCOM requirements.

14. SUBJECT TERMS ORS, NSS, Space Architecture, JP 3-14, Space Support, Space Control, Force Application, Force Enhancement, Method of Evaluation	15. NUMBER OF PAGES 91
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UU

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PREFACE

SS4051 is the second course of a two course sequence which comprises the capstone project for the Space Systems Operations program at NPS. SS3041, the initial course, teaches the students the architectural design process – from generating basic requirements through conceiving of and evaluating alternative solutions and ultimately selecting the preferred approach. During SS3041, the students are presented a project – derived from current challenging and relevant efforts in the National Security Space area – and their primary "deliverable" at the completion of the class is a set of requirements for the assigned architecture to satisfy.

For the FY2008 effort, Operationally Responsive Space (ORS) was selected as the topic of study. In SS3041, the students defined what ORS "should be," and described the characteristics and capabilities of an ORS architecture. In SS4051, the students took these definitions and capabilities and generated alternative approaches to satisfying them. This report describes the result of that effort.

For FY2008, there were two in-residence teams of 10 students, and a single distance-learning team of 7 students. While most of the in-residence students had no space-related experience other than their time in the Space Systems Program at NPS, the majority of the distance-learning students had worked in or were currently working in space-related jobs.

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I. INTRODUCTION

Operationally Responsive Space (ORS) and the architecture that supports it are a key part of the future of the United States Military. With the emergence of new asymmetric threats and the advancement of technology, the timeline to react and complete military tactical operations has shortened. In the year 2025, other nations will have grown to rival the United States as peer powers, terrorists and other asymmetric threats will evolve, and reaction times for the military will decrease further. The need exists for the United States Space Forces to be responsive to the end user. The specific time required to be considered responsive is as varied as the objectives of the particular end user. This is the primary difficulty in defining ORS.

A. Current Reality

In defining ORS, it becomes clear that the U.S. military has many facets that are already responsive. Capabilities such as secure communications and imagery can be delivered to the operational user quickly, and in sufficient time to meet individual operational needs. Unfortunately, issues with bureaucracy, lack of interoperability and limited resources make the current systems and architecture unable to maintain responsiveness to most users.

For example, a Marine force using MILSTAR satellites for secure communications is receiving responsive space support. He may lose this capability, however, to a surfacing Navy submarine because the submarine has priority on the network. The architecture allows for responsiveness to the submariner. He will always have the capability to receive secure communications when he comes to the surface as a result of his high priority. Due to the limited amount of resources, however, the Marine is left without communications. Space communication for this end user is not responsive.

Another example is an Army platoon requiring imagery prior to advancement on the ground. The user is unable to receive imagery from satellites overhead because there is no procedure to task them or even request products. Currently the U.S. military uses

both military and commercial space assets to provide troops with imagery and situational awareness of the battlefield. Each service has its own pathway and procedure to request imagery, but the architecture is not well integrated or built for timeliness. Satellites are overhead and have the capability to take pictures quickly, but are owned by other organizations, military, government and civilian, and the infrastructure does not exist to allow them to be tasked or deliver imagery to the Army user. In this case, only some of the tools necessary to achieve responsiveness are in place. The hardware is capable, but the organization and interoperability does not exist.

B. ORS Vision

The group defined ORS as follows: Space services focused upon the particular combat and support needs of the military, in particular the combatant commander, upon demand in support of combat operations, without negative impact by non-military government space requirements.

The combatant commander was determined to be the most appropriate end user due to current force structure. There will never be enough assets for every platoon leader to have responsive space capability at his or her fingertips, but the combatant commander who is responsible for military operations in a specific AOR should.

C. Five Pillars

A key prerequisite to developing an implementation plan for ORS involved identifying the key aspects of ORS in general terms. For this exercise, the experiences of the group's members were essential, but had to be combined with varied assessments of the evolving nature of ORS. To no small extent, the term Operationally Responsive Space presented a modest stumbling block to the group's ability to develop what was eventually dubbed the “Pillars of ORS.” These pillars encapsulated the group's most basic understanding of the absolute requirements for fielding an operationally-responsive space architecture.

The group's initial understanding of ORS was based heavily on the term itself. Given the group's varied military background, all of the members had a general notion of what the desired end-state for a responsive space system should be. However, the initial investigation simply described the desired experience for end-users: "when I need space support, I get it without delay." It did not include the implementation details. The group knew what should be delivered to the warfighter, but the process of identifying the key components involved in creating an architecture capable of delivering the desired user experience required a far deeper examination, including a careful dissection of the issues involved in responsiveness.

For our purposes, the group settled on the basic idea that the warfighter must have immediate access to space support, upon demand, without the need to share limited resources. This led us to take a critical look at existing space systems and assess their ability to provide this level of responsiveness. As the group delved into this issue, we were quickly struck by the differences between the ability to quickly send commands to space systems, and the ability to actually obtain support in an operational environment. While the satellite operators and technicians could generally send commands to satellites in relatively short time frames, the warfighter had no direct connection to them. When a combatant requested space-based support, especially for ISR, the request had to navigate through multiple organizational levels, weather varied approval authorities, and eventually be queued for collection based upon a priority system designed to make the most effective use of limited resources. Not all requests survived this extensive vetting and prioritization. These observations led to our identification of the concept of adequacy as it relates to responsiveness.

In our analysis, we realized that the inherent responsiveness of some satellite systems was negatively impacted by the inadequacy of the resource to service all requests. This forced the satellite operators and authorities to develop organizational processes to manage the employment of those resources in an attempt to ensure they were best allocated. The issue of adequacy and responsiveness became one of the guiding principles of our investigation into the underpinnings of ORS, eventually helping us to develop the five pillars. It is notable that adequacy was not directly adopted as a pillar,

primarily due to our belief that the measurement of adequacy was dependent on too many factors to make it a usable guide for fielding an architecture. Other, more specific and easily measurable traits such as availability were deemed more useful as criterion for ORS.

Beyond our initial notions of what a space system must deliver to be considered responsive, we found ourselves delving more deeply to identify the "behind the scenes" aspects of responsiveness. Of note is the need to mitigate loss of portions of the architecture. While the warfighter lives in the realm of "give me what I need when I need it," as space professionals and architecture designers, we must address the capabilities essential to ensuring that the warfighter receives prompt support. Without the ability to quickly recover from losses of portions of the architecture, whether from hostile action or due to other causes, an architecture will have the potential to suffer greatly reduced responsiveness. This led directly to the adoption of Asset Loss Mitigation as one of the five pillars of ORS.

As the group discussed and debated various aspects of space systems and their relation to ORS, the issue of acquisitions arose repeatedly. Several of the group members were directly involved in acquisitions, and others had familiarity with the issues surrounding acquisition of space systems. The group unanimously agreed that acquiring space systems on a 10 to 15 year cycle was not conducive to an operationally responsive space architecture. Indeed, the concept of prompt asset loss mitigation alone was sufficient to drive the adoption of a Streamlined Acquisition Process as one of the five pillars. The reasoning here is simple. With very long acquisition cycles, space systems can only be anticipatory. This works to the extent that predictions about the nature of required space system support are accurate, but in the more likely situation where unforeseen circumstances arise, there must be existing capabilities to promptly react in an operationally relevant time frame.

After much analysis, the group arrived at consensus about the “5 Pillars of ORS.” They were identified as:

- Improved Organizational Processes
- Asset Loss Mitigation

- Availability
- Flexibility
- Streamlined Acquisition Process

These pillars of ORS encompass the primary ingredients required for successfully implementing an ORS architecture without specifying how that architecture should be constructed. This is an important distinction that the group intentionally maintained. The technical solutions that support the creation of an operationally responsive space architecture may be varied, and the possibilities may change over time. The pillars, however, are designed to transcend specific capabilities, with a focus on ensuring that properly focused architectures are designed with responsiveness in mind.

1. Improved Organizational Processes

The first of these pillars, Improved Organizational Processes, arose directly from observations of existing architectures and their associated management infrastructures. These management infrastructures, designed to ensure distributed insight and control, typically placed much of the operational decision-making authority for whole space architectures into committees comprised of members with often competing interests. While this may help to ensure that all interested parties have an opportunity to influence the operations of key space systems, it is often counter to maintaining a high level of responsiveness. Based on the belief that excessive bureaucracy in the management of current space systems effectively diminishes responsiveness, the first pillar was initially dubbed “Minimized Bureaucracy.” After some reflection, it was altered to become Improved Organizational Processes in a concession to the inevitability of bureaucracy and the realization that not all bureaucracy will negatively impact the operational responsiveness of space systems. By altering the focus from minimizing bureaucracy to improving organizational processes that could impact responsiveness, the focus of this pillar is narrowed and becomes more realistically attainable.

An example of improved organizational processes for ORS involves the management of National ISR systems. At a basic hardware level, these systems are highly responsive to satellite operator input. The real issue with responsiveness from the warfighter perspective involves getting the satellite operators to send commands supporting their needs. The connection between warfighter and satellite operator is defined by the organizational processes, making them key to effectively exploiting the responsiveness available at the hardware level.

Unfortunately, these highly complex and capable national satellite systems typically provide information to multiple government organizations, both military and civil. Due to this broad customer base, the need to account for all customers' needs can easily become a major task. The typically adopted solution involves complex management structures and myriad committees that all must weigh in on changes to satellite usage. This has the common effect of producing operational delays when opportunities or requirements for change arise. Under our concept for improving organizational processes, the focus would rest upon changing these decision processes to improve responsiveness, even at the expense of assuring broadly-based insight and control for the widest possible range of organizations. Indeed, one of the favored improvements would involve pushing operational authority to very low levels and removing committees from the operational decision-making chain.

2. Asset Loss Mitigation

The second of the ORS pillars is Asset Loss Mitigation. Based on an evaluation of current space architectures, it is clear that the loss of an existing asset's capability or capacity cannot typically be mitigated. Instead, the overall architecture only receives additional capacity or capabilities when the long lead times for previously planned additions are satisfied. The ability to quickly field replacements for unexpected losses does not exist. This is clearly a problem for the responsiveness of any architecture: satellites will inevitably die, and they are becoming progressively more susceptible to direct attack as anti-satellite technologies develop. Without the capability to respond to

the loss of existing assets, under any condition, responsiveness will be seriously degraded.

Examples of Asset Loss Mitigation are essentially the same for satellite malfunction and for direct attack. In either case, the issue is to quickly and effectively replace the lost capacity or capability. This could be accomplished by maintaining an inventory of similar satellites that can be quickly launched, or by maintaining the capability to quickly build a replacement satellite. In either case, the key is to have the replacement operational within the shortest amount of time possible. Alternatively, emplaced systems might be designed with intentionally excessive capacities that would enable immediate mitigation without the need for a launch and the associated engineering checkout.

3. Availability

The third pillar, Availability, arose from a realization that current systems are not always available to the warfighter. This typically arises from lack of capacity or competition from other entities for the available capabilities. Additionally, a lack of availability can arise from system problems and satellite malfunctions. Ideally, to be fully responsive, an architecture would ensure that the warfighter has full access to the system upon demand and without the possibility of losing that access to a competing organization. To have a truly available system, these issues must be addressed.

An example of availability might be an Army brigade that requires immediate information to support an imminent operation in Iraq. Before the operation, they must have assured access to all requested relevant information that the satellite can provide in support of the operation. Additionally, once the operation is underway, they must have guaranteed access to information from the satellite about the current situation in the operations area. Without such availability, the responsiveness of the architecture is compromised, as is the brigade.

4. Flexibility

The fourth pillar of ORS is Flexibility. An examination of the current on-orbit architectures clearly shows that many are highly specialized as far as geographic coverage. Additionally, the capability to change geographic coverage or focus is often highly limited. When talking about operational responsiveness, the capability to quickly and effectively focus space systems on specific regions offers great benefits to the warfighter.

An example of flexibility might be the rapid realignment of ISR satellite orbits to increase collection capabilities against an emergent theater of military operations. This could be accomplished by movement of existing satellites, or by the fielding of newly-launched satellites specifically positioned to maximize coverage of the area of interest. In either scenario, capability and capacity is quickly focused on the area within a responsive time frame, preferably no more than weeks.

5. Streamlined Acquisition Process

The fifth and final pillar is a Streamlined Acquisition Process. The current paradigm for acquiring satellites often stretches across 10 to 15 years. During that time, technologies and requirements are subject to change which often leads to changes in the program. Given the rapid evolution of technology, including adversary technologies aimed at negating our space infrastructure, this timeline is unacceptable from a responsiveness viewpoint. Instead, the acquisition system must maintain the capability to quickly turn warfighter requirements into operational assets ready for use. Ideally, this timeline would be less than one year long.

An example of streamlined acquisition might involve the development of new and highly effective anti-satellite technologies by an adversary. The only way to counter this threat is to have specialized satellites on-orbit. This urgent need would not be satisfied by a 10 to 15 year acquisition cycle. Instead, the only responsive way to deal with such a situation involves the capability to quickly acquire and field new satellites.

II. PERFORMANCE / COST ANALYSIS PROCESS

While brainstorming and analyzing a number of solutions for the mission areas, the group required a consistent process by which to determine all final solutions. This was extremely challenging, as many solutions appeared to be viable and responsive options which met all of our metrics. These metrics were developed based upon our 3041 ORS pillars and will be further discussed in the mission and sub-mission area sections. As such, in order to properly evaluate and screen our preliminary solutions, and meet the spring quarter timeline, we used a simplified process based upon Space Mission Analysis and Design (SMAD).[1]

The group had to determine if the considered solution(s) met all performance metrics. To do so, we used a simplified version of the Work Breakdown Structure (WBS) as referenced in SMAD.[2] Figures 1 and 2 show our tailored WBS process. Solutions that did not meet all metrics were eliminated and placed on our alternative list of solutions. If multiple solutions met all metrics, then the next step would be to evaluate based off Rough Order of Magnitude (ROM) cost figures. We did not have a pre-determined cost ceiling or limit, however, based off the team member's programmatic and operational experience, we decided to use a modification of the SMAD analogy-based cost estimating method.[3] We measured costs based off what might be reasonable as compared to existing programs or capabilities.

Many of these solutions, however, were considered to be non-material and thus provided a greater challenge in estimating a budget. Some of these solutions included an increase in manpower structure and changes in organizational relationships. A similar approach was taken for these solutions which considered second order effects of such complex changes as much as was possible.

Material solutions were further analyzed and costed using a component or system approach. Common components and capabilities were priced with a holistic system

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1 Larson, W. et al. (2006). Space Mission Analysis and Design. El Segundo, CA. Microcosm Press.

2 Ibid.

3 Ibid.

approach using current programs of record as a baseline. A 30% inflation increase was added to forecast year 2025 costs and budgeting using the inflation factor chart listed in SMAD.[4]

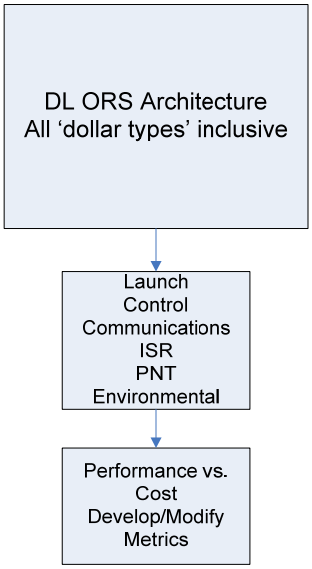


Figure 1 - Work Breakdown Structure

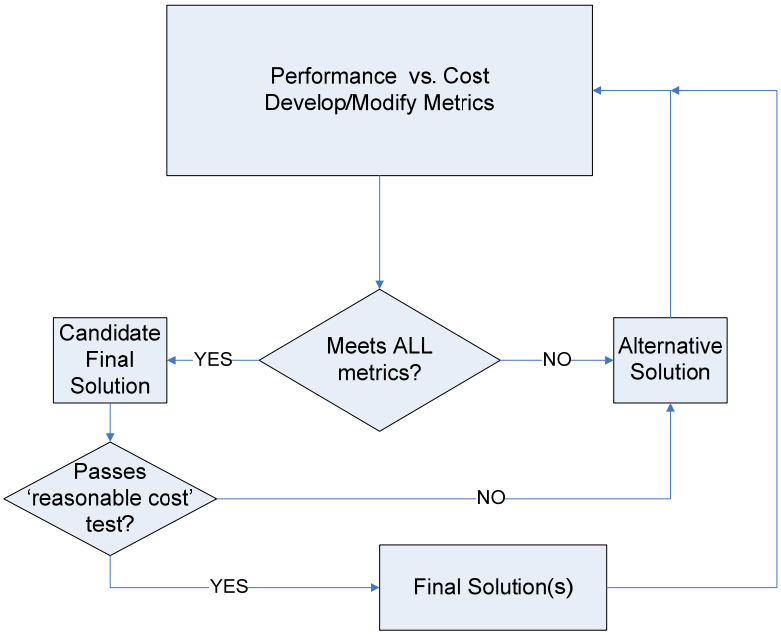


Figure 2 - Solution and Cost Estimating Process

4 Ibid.

III. SCENARIO DEVELOPMENT CONTEXT

To aid in developing measures of performance and prospective solutions for ORS, the group developed two separate scenarios. The scenarios were to be used as a basis to build metrics for operations. The future of military operations is always unclear, but trends from today can be used to predict future threats. An attempt was made to create one scenario for each of the most realistic military threats that could be predicted in the 2025 timeframe.

The first scenario was a conflict with a peer power. For decades now, the United States has been the world's only super power. That will not be the situation forever. Like the U.S.S.R. in the twentieth century, another nation will grow to rival the U.S. in the oncoming decades. Space Power that is responsive must meet the needs of the COCOM in a large conflict. A single, well-defined adversary defines this scenario. Operations will be long in duration covering large geographical areas. Responsive space power will be required over entire countries, or even continents. Military organizations will be primarily involved, reducing the need for interoperability with civilians. This does not rule out the need to supplement military space assets with commercial resources as needed. Lead times for operations will be measured in weeks, even months, as they have been for major conflict operations in the past. A large amount of bandwidth will be required during tactical operations; however, due to the potentially large number of participants and the need to counter the enemy's surge of capability associated with their military operations.

The second scenario developed was a Special Operations Force (SOF) Operation against an asymmetric enemy. An asymmetric enemy is one who attempts to offset a deficiency of military quality or quantity by using unconventional methods. Terrorist sects, insurgent fighters, and violent political factions are examples of groups that use asymmetric warfare. They cannot compete against the power or technological advantage of a military the size and strength of the United States, so they use other methods such as bombing, kidnapping and targeting the civilian populace. In the second scenario, the enemy consists of multiple, loosely organized, or completely compartmentalized

adversaries. As a result, tactical operations will be much shorter than against a peer power. Areas of operations will be small, but may be numerous in number and widely dispersed. Coverage could be required over several city-sized areas simultaneously. Coordination will be required with other government agencies such as FBI, CIA, local police, etc., increasing the need for interoperability. Lead times for tactical operations will be short, measured in minutes or hours. Extremely flexible assets will be required to conform to a quickly changing mission.

Keeping these two scenarios in mind, the group developed metrics for each mission area and evaluated them correspondingly.

IV. MISSION AREAS

A. Prioritization

Due the group's limited assets of personnel as well as time, and with consideration of the difficulty in collaboration between team members located both across the country and abroad, certain mission areas were focused on in greater detail than others. An initial investigation into Space Control, Space Force Enhancement, Space Support and Space Application was conducted, in order to identify which areas were most in need of advancements in responsiveness, and where the most benefit could be achieved. After a review of these initial findings, the following mission areas were focused on: Intelligence, Surveillance and Reconnaissance (ISR), Communications, Space Control, Position, Navigation and Timing (PNT) and Launch.

B. ISR

As defined by Joint Pubs 3-14: Joint Doctrine for Space Operations, Space Force Enhancement consists of force enhancement operations that multiply joint force effectiveness by enhancing battlespace awareness and providing needed warfighter support. One function of Space Force Enhancement is that of Intelligence, Surveillance, and Reconnaissance (ISR). Responsive ISR is vital to the warfighter and a critical capability of Operationally Responsive Space. Achieving responsive ISR through our defined pillars of ORS is a process that began with the investigation of desired capabilities and objectives for ISR in the future. To identify what capabilities and levels of responsiveness would be desired in the future it was necessary to understand that our current reality includes a selective responsiveness attitude driven by inadequate resources and bureaucratic constraints. The primary objective and focus of our ISR responsive posture was to focus on supporting the COCOM.

1. Objectives / Desired Capabilities

After identifying our current situation and the primary objective, the process to a final ISR solution began with brainstorming. The PDR identified many of the initial objectives/requirements of responsive ISR within each of the five pillars previously discussed. These initial objectives/requirements may or may not have influenced the final solution. As briefed they are as follows:

Improved Organizational Processes

- Make ISR data available to all COCOMS, Services, and Government Agencies/Organizations
- Seamless transition from request to receipt
- Share data between organizations through one data system (unified collection efforts)
- Responsive common collection tasking program to maximize efficiency and effectiveness of all assets
- One data bank to meet warfighter and intelligence community needs with meaningful data
- Embedded Space Cadre act as liaison between COCOMS and tasking organizations

Asset Loss Mitigation

- Rapidly reconfigurable, interoperable architectures/satellites/collectors
- Rapid reconstitution with rapid launch and plug and play satellites
- Surrogate satellites offering ISR capabilities from aircraft, drones, High-Altitude Airships
- Fusion of data into one information grid contributing to consolidated ISR products
- Protection schemes factored into spacecraft design

- Reboot, dazzling mitigation

Availability

- ISR on-demand
- Wide area coverage 24/7
- Streamlined process using flatter command structures, more autonomy to forward-operating forces, and commensurate revisions in training, doctrine, and command
- COCOMs should not notice the sharing of collection assets
- Increase OODA loop cycle
- Fusion-analysis-dissemination loop, intelligence on new threats, near-continuous coverage of high interest targets, and adequate strategic warning

Flexibility

- Rapidly reconfigurable, interoperable architectures/satellites/collectors
- Robust, integrated, common architectures to include small satellites
- Precision engagement and rapid maneuver
- Access to precise, dynamic, highly responsive data

Streamlined Acquisition Process

- Take lessons learned from SBIRS acquisition process
- Acquisition of ISR platforms on-time, on-budget

2. Metrics / Performance

To improve the operational responsiveness of ISR, selected architecture solutions were decided on through use of a metrics based approach when applying responsiveness

to the two previously discussed scenarios. In order to ensure versatility and responsiveness in different situations, a Peer Power scenario and an Asymmetric Warfare scenario were employed in order to drive the creation of metrics. The final metrics chosen for each of the pillars of responsiveness as pertains to operationally responsive ISR were as follows:

Improve Organizational Processes – A maximum of 2 layers between the end-user and the asset.

This metric was chosen to ensure that ISR responsiveness was not hindered because of multiple, unnecessary levels standing in between the end-user and the satellite. The greater the number of layers, the greater the delay in receiving a product. Ideally the two layers would consist of the embedded Space Cadre at the COCOM and the personnel actually tasking the satellite.

Asset Loss Mitigation – Reconstitution within one month of notice and reconfigurable architectures/satellites/collectors within 24 hours for Peer Power (2 hours with a 4 hour threshold for Asymmetric).

Reconstitution within one month correlates with the responsive launch architecture. The times for reconfiguration were chosen with consideration that in a Peer Power situation the constraint on responsiveness is less due to a longer duration conflict. In an Asymmetric scenario the assets are required much quicker.

Availability – Request-to-receipt of ISR services on-demand within 15 minutes, 24/7 access to a large, country size AOR anywhere on earth for Peer Power (4 smaller, city size AORs for Asymmetric), and coverage of any specified area with a maximum revisit time of 15 minutes.

The AOR size is dependent on the adversary, larger in a Peer Power scenario than in an Asymmetric scenario. Also, it is likely that Asymmetric conflicts may require multiple AORs simultaneously around the earth. Fifteen minutes is chosen in both scenarios because this is the chosen threshold to maintain responsiveness in a tactical environment.

Flexibility – Reconfigurable architectures/satellites/collectors within 24 hours for Peer Power (2 hours with a 4 hour threshold for Asymmetric).

The times for reconfiguration were chosen with consideration that in a Peer Power situation the constraint on responsiveness is less due to a longer duration conflict. In an Asymmetric scenario the assets are required much quicker.

Streamlined Acquisition Process – Spiral mature technologies through an incremental approach across multiple systems and program initiation to IOC within 12 months on budget.

Spiraling mature technologies into development and program initiation to IOC in 12 months are metrics that decrease the likelihood of delays in placing assets in orbit, thus improving responsiveness.

3. Final Solution and Cost

After metrics were chosen to measure responsiveness performance in both scenarios, it was necessary to choose solutions that would contribute to achieving the metrics. This was done through a performance versus cost approach as previously described. Every considered solution was evaluated to be reasonable or not through common sense and a realistic 2025 technology forecast, before evaluating whether or not it met some or all of the metrics. This was to be the performance aspect of the solution.

In addition, cost had no predetermined limit and was simply focused on large system breakdown. Each of the final solutions for ISR responsiveness with a brief explanation (broken down by material and non-material solutions) and the performance versus cost/constraint considerations taken into account when choosing them follow:

Non-Material

Expand the influence and powers of the ORS office: allow the ORS office the capability to quickly task, deny, deceive, degrade, or destroy assets at the request of the COCOM
Performance: Contributes to Improve Organizational Processes and Streamlined Acquisition
Cost/Constraint: Cooperation between organizations, Policy

Provide trained space cadre personnel to designated billets at COCOM level: Space Cadre have a direct line to ORS office for asset tasking
Performance: Contributes to Improve Organizational Processes and Availability
Cost/Constraint: Distributing trained personnel, Policy

Integrate common ISR collection tasking program to facilitate fusion and maximize efficiency and effectiveness: it should allow for the common tasking of all spaced-based ISR assets through a relatively simple interface combining the collection capabilities of SIGINT, IMINT, ELINT, etc., its use should be mandated
Performance: Contributes to Improve Organizational Processes and Availability
Cost/Constraint: Cooperation between organizations, $100 Million

Procurement of commercial ISR services in lieu of increased government satellites: greatly expands ISR coverage and access possibilities
Performance: Contributes to Availability and Asset Loss Mitigation
Cost/Constraint: $5 Billion

Spiral mature technologies through incremental approach across multiple systems:
Performance: Contributes to Streamlined Acquisition
Cost/Constraint: N/A

Material

ORS office develop and acquire catalogue of plug and play satellite systems: will lead to large constellation possibilities by 2025
Performance: Contributes to Asset Loss Mitigation, Availability, and Streamlined Acquisition
Cost: $10 Billion

Hosted ISR payloads on designated U.S. commercial satellites: will expand ISR access and coverage capabilities
Performance: Contributes to Asset Loss Mitigation and Availability
Cost: Policy, $2.5 Billion

Deploy reconfigurable satellite payloads: examples are reconfigurable in frequency ranges or reconfigurable from optical to infrared imagery
Performance: Contributes to Availability and Flexibility
Cost: $2.5 Billion

Real-time fusion of ISR data from space and terrestrial assets (SIGINT, IMINT, ELINT, etc.) into common database contributing to consolidated ISR products for DOD and IC (w/ 2 mirror locations): common database should have a relatively simple user interface with filtering options (ex. filter data by latitude/longitude, time, or type of intelligence to build the user a filtered operating picture on request)
Performance: Contributes to Availability, Asset Loss Mitigation, and Improve Organizational Processes

Cost: $3 Billion

Though there was no predetermined limit in cost for our ORS solution there were cost factors that were consciously considered in the selection of our responsive ISR solution. The first was recognition of new architectures being expensive; therefore, common architectures, when possible, would mitigate some of the cost. Also, large constellations as well as large satellites would be minimized if possible, as small satellites are generally capable of reducing cost in development and launch. To further mitigate cost it was understood that the wide area coverage would not include full capabilities in Polar Regions. Lastly, hardware development and deployment is expensive; therefore, when possible, software upgrades are ideal. The associated costs in the preceding final solutions were derived from the following cost table and based on rough order of magnitude calculations including an additional 30%:

Cost for ORS Initiative	Cost/Each (M)	Quantity	Total/Line Item (M)
Procurement of commercial ISR svcs	$500	10	$5,000
Common collection tasking program	$100	1	$100
Catalogue of plug and play satellites	$100	100	$10,000
ISR payloads on commercial satellites	$50	50	$2,500
Reconfigurable satellite payloads	$50	50	$2,500
ISR fusion database/architecture	$1,000	3	$3,000
Annual 2025 Costs plus 30%			**$30,030**

Table 1 - ISR Cost

4. Technology Forecast

The following is the results of the technology and capability forecasting of the ISR section of Operationally Responsive Space by the year 2025. All items listed are

assumed to be reasonable possibilities in this timeframe and were taken under consideration during solution selection:

- Wide area coverage overlapping all AORs and accessible 24/7 (not just CENTCOM)
- Robust, integrated, common architectures of ISR capable small-satellites
- Strategic warning capability – finish SBIRS
- Rapidly reconfigurable, interoperable architectures/satellites/collectors on demand capable of meeting warfighter requirements, intelligence needs, and providing meaningful data
- Organizations controlling assets must be on the same page – unified collection efforts (NRO, NSA, NGA, etc.)
- Responsive common collection tasking program to maximize efficiency and effectiveness of all assets
- Precision engagement and rapid maneuver capable from ISR products – "access to precise, dynamic, highly responsive data: oncall, real-time, target-quality[5]" (hit the right target, kick in right door, 100% of the time)
- Imagery satellites with military grade resolution accessible 24/7
- Rapid reconstitution (rapid launch, plug and play satellites)
– "ISR from sensors other than satellites, such as nationally-owned air-breathing platforms, would have to be fused with satellite data and the overall picture made user-friendly to commanders.[6]" (real-time fusion contributing to COP)

"Fused, integrated, joint, and responsive intelligence picture that directly supports the joint warfighter.[7]"

5 Thomas G. Behling and Kenneth McGruther. (1998). Satellite Reconnaissance of the Future.
6 Ibid.
7 Ibid.

- "Protection schemes factored into spacecraft designs and reconnaissance architectures.[8]"
- "Streamlining the flow of intelligence from sensor systems to operators will require flatter command structures, more autonomy to forward-operating forces, and commensurate revisions in training, doctrine, and command.[9]"
- "Military success depends on the fusion-analysis-dissemination loop, intelligence on new threats, near-continuous coverage of high interest targets, and adequate strategic warning.[10]"

5. Constraints

Perhaps the largest constraint faced in the Space Force Enhancement ISR solutions is that of cooperation between organizations/agencies and the policy/mandates that coincide. There is no doubt that bureaucratic constraints and the willingness to share assets and information will hinder the achievement of the selected solutions in our ORS posture. For example, the fusion of INTs applied to a common product or operating picture is difficult to coordinate in real-time/near real-time; therefore, procedures that make real-time fusion possible and repeatable must be established and mandated with multiple organization cooperation.

6. Alternative and Considered Solutions

Other considered solutions and alternatives include the following in addition to a brief explanation for not choosing them as a final solution:

8 Ibid.
9 Ibid.
10 Ibid.

Reconfigurable, interoperable architectures/satellites/collectors

The decision was made to choose reconfigurable satellite payloads only due to the large sums of money and extreme amount of time required to reconfigure entire architectures responsively.

Cluster/fractionated satellites on orbit capable of replacing failed/destroyed sections quickly

It was decided that launching one satellite's worth into space on multiple launches would be expensive.

Require data standardization and sharing from all hardware (NRO, AFSPACE, etc.)

This was not chosen due to the extreme/unrealistic amount of cooperation between organizations that would be necessary.

Reduce restraints/requirements on fielding satellite systems to allow for rapid assembly and launch

Restraints/requirements are there for a reason, often to increase the likelihood of success on a particular mission. Successful missions are required for responsive ISR.

Eliminate data ownership

Unrealistic cooperation constraints make this impossible in today's world and no major changes are foreseen by the year 2025.

Improve terrestrial fiber

This is beyond the realm of our ORS solution.

Develop and deploy common network

Separate networks are desired for reasons (classification, releasability, etc.).

Networking space assets (like the internet)

This would be expensive and individual constellations are already networked.

Build and stockpile force enhancement assets for ready-launch

Stockpiling satellites is expensive. If we are going to do it then they should be stockpiled in space for rapid operation. Technology will advance as the years pass and stockpiled satellites are left unused.

Field ISR constellations that are not agency specific

The bureaucracy constraints would be extreme.

A dedicated space force

Enhancing the powers of the ORS office was chosen instead.

7. Summary / Conclusions

The ISR infrastructure of the future will continue to be a vital asset to the warfighter in both the strategic and tactical environments. The situation in which responsive ISR becomes necessary can mean knowing what is on the other side of a mountain in a Peer Power scenario or knowing what is on the other side of the door before kicking it down in an Asymmetric Warfare scenario. Operationally Responsive Space is dependent on the critical component of responsive space-based ISR, and steps can be taken to achieve it by 2025 through both material and non-material solutions.

C. Communications

As one of the critical capabilities of operationally responsive space, communications persists as the core networking infrastructure for all other mission areas. All space mission areas require an adequate and robust communications infrastructure.

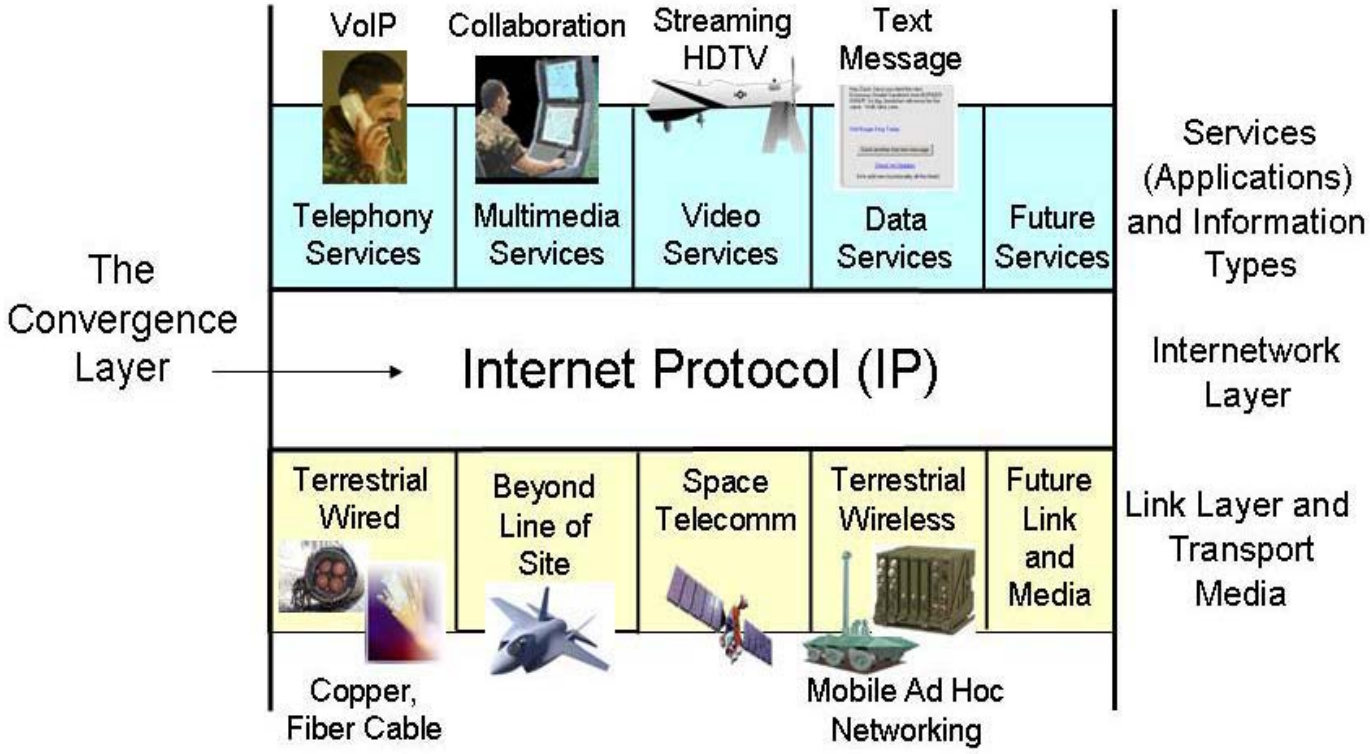


Figure 3 - Communications Infrastructure[11]

As depicted in Figure 3, the communications sub-mission area should be viewed in context of a holistic approach with satellite and space-based communications providing a piece of the overall network capability and infrastructure. Similar to the current Internet, Internet Protocol (IP) standards provide a common baseline by which disparate networks may exchange information. Many types of data that require real time network availability will meet the needs of a number of users. Additionally, information may traverse the network by pathways other than satellite communications.

11 Office of the Secretary of Defense (June, 2007). Department of Defense Global Information Grid Architectural Vision. Prepared by DOD CIO.

1. Objectives / Desired Capabilities

As was mentioned previously, the beginning of this process began with brainstorming many ideas for communications capabilities. The PDR articulated many such potential requirements that may or may not have influenced the final solution. These requirements indicate the holistic communications and networking approach and cover every aspect of capabilities required for an operationally responsive network. However, as will be discussed later, the core communications metrics may only summarize a portion of these earlier requirements and show the end state priorities of communications responsiveness. The initial requirements as organized in the original 5 pillars are as follows:

Improved Organizational Processes

- Improved integration of architectures across DOD, IC, and NASA.
  - 'sharing' of communications and networking infrastructure
- Significant shifts in key Defense processes (e.g., JCIDS, PPBE, DAS, and T&E), policies, tactics, operational concepts, and culture.
- Information producers recognize that their information is a strategic, enterprise asset to be shared to the fullest extent possible.
- The traditional need-to-know model (based on an information producer's determination of who needs to know) is changed to a right-to-know and need-to-share model.
- Cross-domain and cross-organizational COIs are established, resourced, and empowered – to ensure that shared information is understandable – by agreeing on common syntax and semantics (vocabularies) where most needed.
- Realizing government and industry support of architecture-level integration that must endure and be capable of incorporating unanticipated new technologies

Asset Loss Mitigation

- Secure & available information transport
    - Encryption initially for core transport backbone; goal is edge to edge; hardened against denial of service.
- Information/Data Protection & Surety (built-in trust)
    - Producer/Publisher marks the info/data for classification and handling; and provides provisions for assuring authenticity, integrity, and non-repudiation
- Defense Against an Adversary From Within – persistently monitor, detect, search for, track, and respond to insider activity and misuse within the enterprise.
- Transactional Information Protection – granular end-to-end security controls that enable protected information exchanges
- 'Open Standards' to provide 'self healing' capabilities
    - For example, re-route around jammed RF carrier.
- Automated, distributed real-time spectrum management capabilities optimize spectrum use. (Available/Flexible)

Availability

- Internet & World Wide Web Like
    - Adapting Internet & World Wide Web constructs & standards with enhancements for mobility, surety, and military unique features (e.g., precedence, preemption).
- Trusted & Tailored Access
    - Access to the information transport, info/data, applications & services linked to user's role, identity & technical capability.
- Shared Applications & Services

    - Users can pull multiple applications to access same data or choose same apps when they need to collaborate. Applications on “desktop” or as a service.
- Post in parallel
    - Producer/Publisher make info/data visible and accessible without delay so that users get info/data when and how needed (e.g., raw, analyzed, archived).
- Incredible increase in bandwidth/throughput to support intensive applications such as IMINT and SIGINT (see tech forecast)
- Instantaneous support for voice/video/data
- Interoperable with commercial systems
- Reconfigurable and mobile gateways / teleports. (support for space control/protection)
- Robust ground infrastructure
- Better support for ‘disadvantaged’ and/or low power ground terminals/users.
- Each asset/node, whether it be space/air/ground, operates with same timing source

Flexibility

- Support for all terrain mobile operations
- Quality of service
    - Tailored for information form: voice, still imagery, video/moving imagery, data, and collaboration.
- Flexible and efficient application of globally distributed computing and communications resources including frequency spectrum, communications satellite control, and network management
- Configuration is managed by software that detects new devices, determines the authorization of any devices, ensures proper configuration and enables and disables all devices with minimal time and effort.

- Assets automatically provide status, enabling enterprise-wide situational awareness and performance management to GIG-wide service level agreements (SLAs).
- Digital policy-enabled (pre-programmed and dynamic) network management permits more effective and efficient use of available bandwidth and network self healing, with automatic routing of packets over diverse networks in the event of congestion or outages, enforcement of access, and a range of tailored responses to attacks and vulnerabilities.
- Support multiple network classifications
- Resource / priority mgt – Dynamic and common network management capability across all assets
- Interoperable across waveforms, frequencies, modulation schemes, and across different military satellite programs.
- Reconfigurable across all nodes to include space, air, and ground
- Ground terminal leverage experience of young operator – 'cell phone like / Windows like'. (Flexibility?)
    - Small/hand held form factor
    - Integrated with PNT and mapping capabilities
- Terminal capable of logging on to any satellite at any altitude, i.e. LEO, MEO, or GEO.

Streamlined Acquisition Process

- Standardizing network capabilities for commonality across buses / subsystems – 'Plug and Play'
- Evolutionary, not revolutionary – Incremental / spiral approach
- Maximum use of COTS
- Each satellite has 'unique' mission
    - i.e. Extremely high gain antenna

2. Metrics / Performance

Unlike other mission areas, we determined that communications could be measured by the availability pillar alone. The justification is that we believe that communications resources must be available to the user, such as with terrestrial networks like the Internet or cellular networks. If the network is not available, the other attributes, capabilities, or pillars are unimportant. And, if the network is not available, then critical information is not exchanged and, therefore, organizations will not be able to overcome political barriers or acquisition issues. As such, we feel that communications and networking metrics can be broken down or simplified into the following metrics:

- Network Availability – percentage time available for all terminals (ground, air , space):
  - Threshold: 95%
  - Objective: 99.999%
- Coverage:
  - Peer Power: 65 – 65 degrees latitude / longitude.
  - SOF: (4) small AORs simultaneously
- Interoperability across terminal population
  - Threshold: 90%
  - Objective: 100%

Network availability describes the ability, frequency, or consistency by which users may exchange information. Like the Internet, many factors comprise this metric or capability. This includes ease of access or logon to the network, and other parameters such as Quality of Service (QoS) and resource/network management schemes. Just as many civilian terrestrial network infrastructures are measured by percentage of availability, and many have expectations of “five 9’s of reliability”, the group feels that an operationally responsive network should be that responsive to the user. This would

also support the Net centricity concepts articulated by OSD as discussed in the Global Information Grid (GIG) Net centric Vision document.[12]

Traditionally, coverage has always been a measuring stick for satellite communications. As such, the satellite network needs to provide a level of almost global availability leading to the traditional GEO 65 – 65 degrees coverage for the peer power scenario. For the smaller scenario, this requirement would still remain as the location of the smaller AOR's could be unknown prior to the conflict, and, therefore, the network would need to be available at all points within the GEO earth coverage beam.

Terminal interoperability and synchronization with the space segment has been a persistent issue across the user population, and affects the ability of the satellite network to be available and responsive. As such, the space network layer needs to provide a certain level of interoperability across all ground and air terminals. This would require a cross-banding capability and employment of a common networking standard such as Internet Protocol (IP). As it stands today, many satellite communications networks remain stove piped and are binned into the following categories: Narrowband, Protected, and Wideband. The details of the proposed solution enabling such a broader capability are discussed in the following section.

12 Office of the Secretary of Defense (June, 2007). Department of Defense Global Information Grid Architectural Vision. Prepared by DOD CIO.

3. Final Solution and Cost

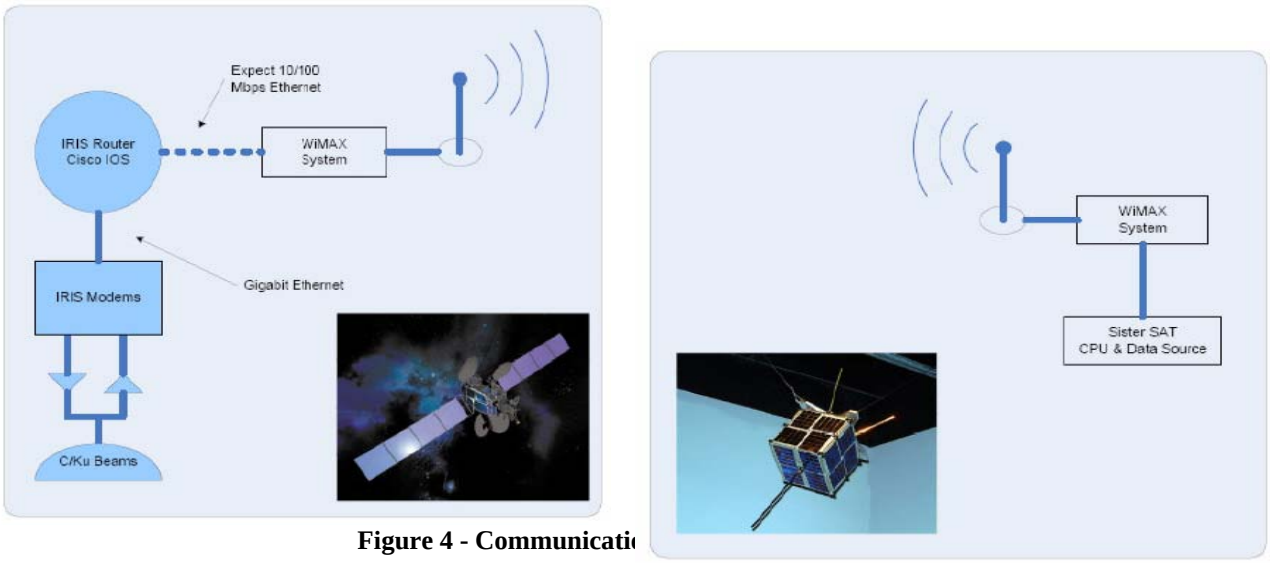


Figure 4 - Communicati

Figure 4 provides a visualization of the final communications solution. As most communications solutions employ GEO layer capabilities for many reasons, such as high bandwidth and throughput, it was logical to begin development of the future responsive communications architecture at this point. However, the final justification for this solution was that it best met the performance and cost metrics previously discussed as compared to other potential solutions. These other solutions will be presented and discussed later.

The intent with this solution was to move beyond a bent pipe communications architecture which supports only ground and airborne terminals. This is a very good solution and has supported users for many years. However, the group feels there is much room for improvement and a new architecture could provide a greater level of responsiveness as measured against the metrics. Additionally, this architecture could support information that is generated in space such as from ISR and weather satellites.

Geostationary satellites, both government and commercial, could provide a Wide Area Network (WAN) type presence supporting a common air interface across the GEO

13 Caulfield, J. (2008). Hosted Payloads, IRIS and Co-location Blue-Sky Discussion with NSSO. Paper/discussion during meeting with NSSO. Fairfax, VA.

space layer. As mentioned, this will support data generated by ISR satellites by providing an alternative gateway vice the ground infrastructure. This could also conceivably reduce Size, Weight, and Power (SWAP) requirements for ISR satellites given that transmission distances could be reduced from 26,000km to almost 15km. However, the greatest benefit for availability of ISR information would be the ability to leverage multiple GEO communications satellites as gateways given the commonality of the air interface across the network. This could increase the availability of ISR information towards the 99.999% availability objective.

A WAN presence across the network will also support the metric of terminal interoperability. By providing a common interface, communications satellites of different waveforms and frequencies (such as UHF and SHF) will communicate across an IP "backplane" while core routers and modems provide the "translation" between the waveforms. Hypothetically, this will allow a tactical UHF terminal to exchange information across the space layer with a commercial Ku terminal, or broadcast using multicast IP addressing to many terminals.

As was previously discussed, two operational scenarios were developed by which we provided a further evaluation of the operational utility of our solutions. In this case, the availability of information, such as intelligence and logistics, will be critical to both scenarios. Information sources will require a redundant and robust network to send data to users. Such as with the Internet, our solution will employ a common infrastructure across the space layer that will allow IP packets to be sent via a number of routes to their destination. As any operational scenario will be extremely fast paced, this solution will allow network access from many access points and provide the level of availability for all users to include strategic, operational, and tactical.

Specific component solutions would most likely employ the IEEE 802.16 standard for WAN air interface and common industry routers and modems for the remaining networking components. Example router solutions would include Cisco and Juniper employing common routing protocols such as Border Gate Protocol (BGP) and Open Shortest Path First (OSPF). Modem solutions would include many currently

employed modems, or to be employed, by ground terminals such as Viasat Linkway, iDirect, and Joint IP Modem (JIPM).[14]

The cost breakdown would be as follows:

	COST / EACH (M)	QUANTITY	TOTAL / LINE ITEM (M)
Average cost of commercial communications satellite	250	8	2000
Average cost of govt wideband communications satellite – WGS	350	6	2100
Average cost of govt protected communications satellite – AEHF	800	4	3200
Average cost of MUOS	400	4	1600
Modems	0.5	22	11
Space router	5	22	110
WIMAX components	1	22	22
Year 2025 adj / 30%			1.3
SOLUTION TOTAL			11755.9

Table 2 - Communications Cost[15]

The methodology behind this approach is to begin by taking rough order of magnitude (ROM) costs of current satellite communications programs (WGS, AEHF,

14 Institute of Electrical and Electronics Engineers. (2007). Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems. New York, NY. Retrieved 25 May, 2008, from http://www.ieee.org/.

15 National Security Space Office (2008). Discussions with subject matter experts to obtain rough order of magnitude costs.

MUOS, and commercial) and adding the capabilities that do not exist, but which would provide a completely available networking solution. Additional costs were retrieved from discussions with vendors and organizations who are researching the future employment of similar capabilities in the future. Finally, a 30% increase for year 2025 cost inflation or general increases was included to make the estimate more probable.

4. Technology Forecast

As many components of this solution have yet to be employed in current architectures, the consistent advancement of technology in the near future will be critical for a 2025 solution. However, many of these components have been employed and proven in the terrestrial networking world, showing promise to future development. As such, our communications technology forecasting included the leveraging of these common terrestrial capabilities and standards of which we will assume to become space qualified and standardized in the future. Future capabilities will be required to show the following developments in space networking technology:

- Each node or spacecraft supports routing
- Minimum of terabyte level of processing and BW.
- Space based energy concentration / transmission devices to support mW ground terminals.
- Space based applications, i.e. PBX, DHCP, etc.
- All payload waveforms and modulators are software definable and reconfigurable
- Assumption of global standardization such as IETF for terrestrial
- Mature Optical / Laser technology to support all levels of links / air interfaces
- Mature nanotechnology to support a Pico satellite constellation at LEO
- Integration of COTS such as WiMax
- Terminals:
    - Phased array / small aperture / gain over 50 dB

    - Hand Held form factor
- Combined wideband with AJ/LPI/LPD at GEO
- Mature Optical / Laser technology to support mobile links
- IPv6 technologies (and beyond) that support an assured, reliable, end-to-end, scalable, and survivable mesh transport infrastructure.
- Service Oriented Architecture (SOA) Infrastructure technologies that provide the tools, capabilities, processes, and methodologies to deploy an SOA-enabled DOD enterprise.
- Mobile Ad-hoc Networks (MANETs) and sensor technologies that support the building of ubiquitous, assured, and agile tactical networks that are federated with the non-tactical domains of the target GIG. Mobile and sensor technologies enable (1) users, appliances, intelligent agents, and other edge devices, wired or wireless; (2) universal access; and (3) exchange of video, voice, and data information of any kind, from anywhere. These networks are self-healing and allow for reconfiguration around failed nodes.
- Semantic Web technologies that enable user agents to process and share metadata-tagged, actionable information. This includes the automated metadata tagging and discovery technologies that support information sharing.
- Mature nanotechnology to support a Pico satellite constellation at LEO
- Terminals:
    - Phased array / small aperture / gain over 50 dB
    - Hand Held form factor
- Overall network includes all ‘legacy’ categories of satellite communications to include Wideband, Protected, and Narrowband.
- Ubiquitous RFID tagging for tracking of products, components, and humans throughout the network.
- Very large scale data storage, delivery, and transmission technologies that support the need to index and retain streaming video and other information coming from the expanding array of theatre airborne and other sensor networks. The network

will support capacities exceeding **exabytes (1018 bytes) and possibly yottabytes (1024 bytes) of data.**

- IA technologies that enable transaction-based access control, information sharing across security domains, protection of information and resources, and maintenance of Situational Awareness in the network.
- Black core enabling technologies that support end-to-end protection of information exchanged among users and services located anywhere in the network.

5. Constraints

As with any network like the Internet, limitations will constrain the user community, at times, from the full and robust features of the infrastructure. And, as a space-based solution, our network will show a deeper level of constraints which the future community will be forced to attack throughout many operations. The complete list of communications constraints, from our analysis, is as follows:

- Frequency / spectrum availability
- Flexible budget cycles
- Agreement on standards
- Segment synchronization
    - i.e. terminals, space segment, control
- Efficient acquisition balanced with thorough testing procedures
- Information Assurance / Multiple security levels to support Joint and Coalition
- International agreements
- Planning long-lead-time space system developments while communications technologies are rapidly advancing
- Maintaining current services while transitioning to Internet-based technologies

- Reconciling DOD and intelligence community needs to achieve transparent interoperability. These two communities have different missions and requirements, and the issue is who controls use of the assets.
- Requirements 'creep'
- Efficient acquisition balanced with thorough testing procedures

It is not the intent to discuss every constraint, however, a few will be highlighted which will provide significant issues in the future. First, as the space network will rely upon wireless connectivity, frequency allocations and spectrum throughput will continue to be a limiting factor. As robust user applications will further increase bandwidth requirements, spectrum may not keep pace with this demand surge across the network. And, in reality, this is an issue for today's networks which will be exacerbated by spectrum auctions by FCC and ITU as well as international competition across all the space community. Efficient resource and network management schemes may help alleviate this issue in the future, but it will remain an important constraint.

Another key concern will be standardization across both government and commercial assets representing many international programs. One course of action to address this constraint could be to emulate the Internet Engineering Task Force (IETF) by establishing a body to address space networking and satellite communications standards. Current efforts include bodies such as the Consultative Committee for Space Data Systems (CCSDS) which have been somewhat effective with developing standardization. However, consistent adoption across the network and communities, such has been with IETF, will be required.[16]

Lastly, as networks become more interconnected and employ standard IP technologies, network security concerns will dramatically increase, as has been seen across the Internet. This has been an area of specialty in of itself and will be addressed not only by improved technology, but by organizational relationships as well. This will be briefly discussed in the alternative solutions section.

16 The Consultative Committee for Space Data Systems. (2008). Source information retrieved 1 June, 2008, from http://public.ccsds.org/default.aspx.

6. Alternative and Considered Solutions

In reality, there is no single solution that will meet 100% of the requirements. We chose our primary solution to meet the given metrics, however, changing the metrics would in turn alter the final solution. That being said, the following is a list of other considered solutions, a few of which are very close to meeting all stated metrics, and some of which could very well provide a robust and responsive communications architecture. A discussion regarding a few of these solutions will follow:

Considered Solutions

1. GEO: Near Field / WAN communications capability on government and commercial communications satellites (final solution):
    - Performance: Meets all metrics
    - Cost: $9.6B
2. LEO: Host IP routers and LEO-GEO ISL capabilities on commercial LEO communications satellites
    - Performance: Could meet all metrics (?) – if combined with solution 1
    - Cost: ~$500M - $3B
3. LEO: Host IP routers and LEO-GEO ISL capabilities on Govt owned LEO communications constellation
    - Performance: Could meet all metrics (?) – if combined with solution 1.
    - Cost: ~$1B - $3B
4. Create Office of Federal CIO
    - Performance: Not known what metrics this will meet.
    - Cost: N/A
5. Procure more WGS and AEHF satellites
    - Performance: Meets 1 of 3 metrics
    - Cost: $5B, based off quantity
6. Maintain status quo for Transformational Communications Architecture
    - Performance: Meets 1 of 3 metrics

- Cost: In excess of $30B for govt assets only

7. Unmanned Aerial Systems as communications nodes
    - Performance: Partially meets one metric
    - Cost:
8. Meet all communications requirements with commercial assets
    - Performance: Meets 1 metric
    - Cost: $600M per year on O&M funds, /10 year lifecycle = $8 - $10B.
9. Host all govt communications payloads on commercial assets
    - Performance: Meets 1 metric
    - Cost:
10. Mobile Teleports
    - Performance: Meets 2 of 3 metrics?
    - Cost:
11. Deploy additional Teleports
    - Performance: Meets 2 of 3 metrics?
    - Cost:
12. Improve ground / fiber infrastructure
    - Performance: No metrics
    - Cost:
13. Deploy mobile cell phone towers throughout the AOR
    - Performance:???? – feasibility of actual implementation
    - Cost:???/

Several of these alternative solutions may still be required to employ a more robust space network. As networks and systems become more interconnected, re-alignment of organizational relationships may be required due to increased security threats and the consistent application development cycle. As such, we recommend a higher authority within the federal government to provide the level of supervision that will be required across all government networks, not just DOD networks. One course of action would be to establish the Office of Federal CIO which would report to the

President. This could provide a level of authority to adequately connect and protect networks as information traverses every network. From a security aspect, this could also fulfill the Designated Approval Authority (DAA) at the federal level and remove the barrier of "risk" from lower level network managers and leadership.

Another solution that merits consideration is a government owned LEO communications constellation. Many current and emerging applications will not require the extensive bandwidth that GEO satellites offer, and many of these current applications are met today by commercial LEO capabilities such as Iridium. Applications such as Blue Force Tracking (BFT), Radio Frequency Identification (RFID), and Autonomic Logistics will require transmission paths measured in kilobytes, and, as such, could be fulfilled by LEO architectures. Furthermore, the developing field of pico and nano-satellites, such as Cubesat[17], could provide a very affordable solution when compared to commercial systems. While not listed as final solutions for this project, both of these solutions have great merit and require further analysis.

7. Summary / Conclusions

The communications infrastructure will become a critical piece for all mission areas. Similar to the modern Internet, future space networks will be required to perform in a "matrixed" format: all nodes will need consistent network access with high availability. This will be a delicate balance between technology standardization and re-alignment of organizations. Only then can the user community experience a "net-centric" environment, and an Operationally Responsive Space capability.

17 The Cubesat Project. (2008). Source information retrieved 5 October, 2007, from http://cubesat.atl.calpoly.edu/.

D. Space Control

Space control is defined by Joint Publication 3-14 as operations to provide freedom of action in space for friendly forces while, when directed, denying it to an adversary, and includes the broad aspect of protection of US and US allied space systems and negation of adversary space systems. Space Control can be broken down into the four sub-mission areas of surveillance, negation, prevention and protection. Surveillance provides individual forces with situational awareness of the battlespace environment through the use of space assets. Negation limits the enemy's use of space systems by destroying, degrading, denying, disrupting or deceiving the ground, communication or space element. Prevention precludes the enemy's hostile use of systems and can be achieved through either military or political action. Protection means ensuring the use of space for friendly forces.

1. Objectives / Desired Capabilities

Using this definition of Space Control, the group developed requirements for space control for the year 2025. Requirements were focused on supporting the combatant commander. They were broken down within the pillars of ORS to help categorize them for future analyses of alternatives.

Improve Organizational Processes

-
  - Systems capable of integration to form single SSN under one governing body
  - Single entity capable of controlling space
  - Ability to use directed or kinetic energy weapons in space
  - Delegation of space weapon "release" authority to COCOM or lower

Asset Loss Mitigation

- Must sustain minimum operational capability (provide COCOM with space situational awareness)
- Capable of quick launch replacement
- Plug and play systems for inclusion on ready-to-launch satellites
- On orbit diagnostic, reporting, and restoration capability

Availability

- Satellites with maneuver capability to avoid attack
- Space Surveillance Network (SSN) able to track and catalog all adversary space assets
- SSN info readily available to users on the GIG
- Timely characterization of threats vs. non-threats
- Relay using node terminals
- Timely space based information available 24/7
- Deny/degrade/destroy capability available 24/7
- Deny enemy ability to detect/deceive friendly assets
- Space segments capable of withstanding environment and atacks
- Ground segments must be secure (EMP, Conventional attack, Jamming, spoofing, information or personnel attacks)
- On-board detection and defense against space environment hazards
- Spoofing Satellites
- Identification and mapping of enemy optical tracking stations**Flexibility**

- Must be capable of executing operations against all orbital regimes
- Capability to track enemy surge
- Capability to adjust orbit or launch into specific orbit to counter threat

- On call strike assessment/ BDA
- Ability to jam/spoof adversary control
- Space Situational Awareness accomplished by both ground, air and space assets
- Multiple methods for hazard avoidance
- Ability for space segment to shift operations or missions

Streamlined Acquisition Process

- Rapid fielding of capability against adversary's technological advancement (our acquisition must be faster than our adversary)
- Spiral acquisition of emerging defensive satellite/ground segment technology
- Plug and play systems to encourage quick integration and space-to-space or space-to-ground communications

2. Metrics / Performance

Following the brainstorming of requirements, the group set about creating Measures Of Performance (MOPs). Measures of performance determine the degree to which a task must be completed to be considered satisfactory. The MOPs attach a measurable number to a requirement that serves as a threshold or objective gate which must be met. For the Space Control mission area, the MOPs were defined with respect to the two 2025 scenarios developed by the group. Figures 5 and 6 depict the MOPs for Space Control.

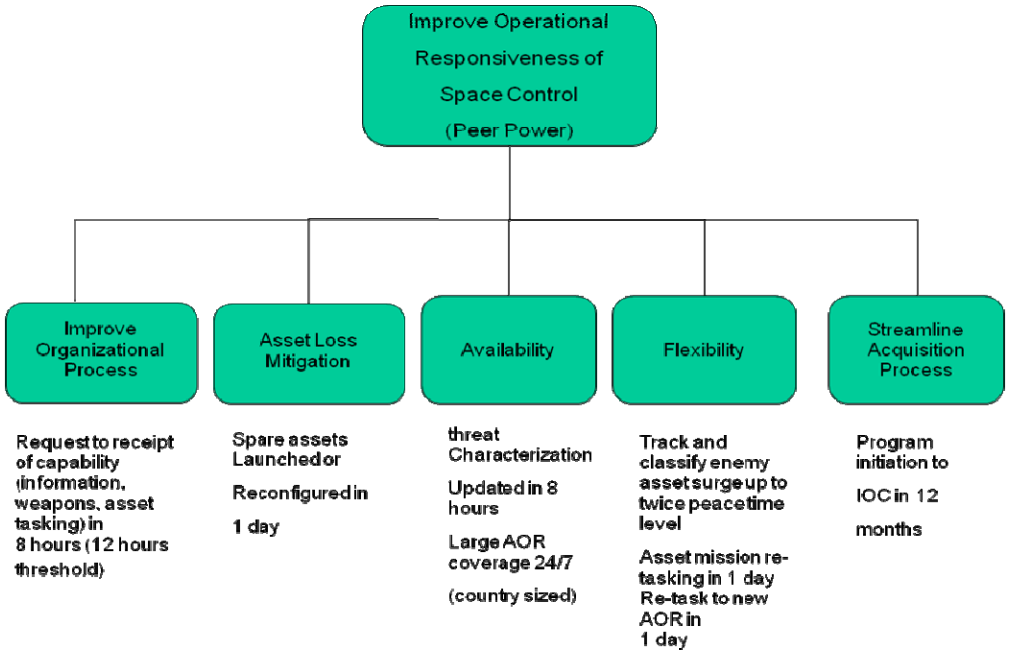


Figure 5 - Space Control Peer Power Metrics

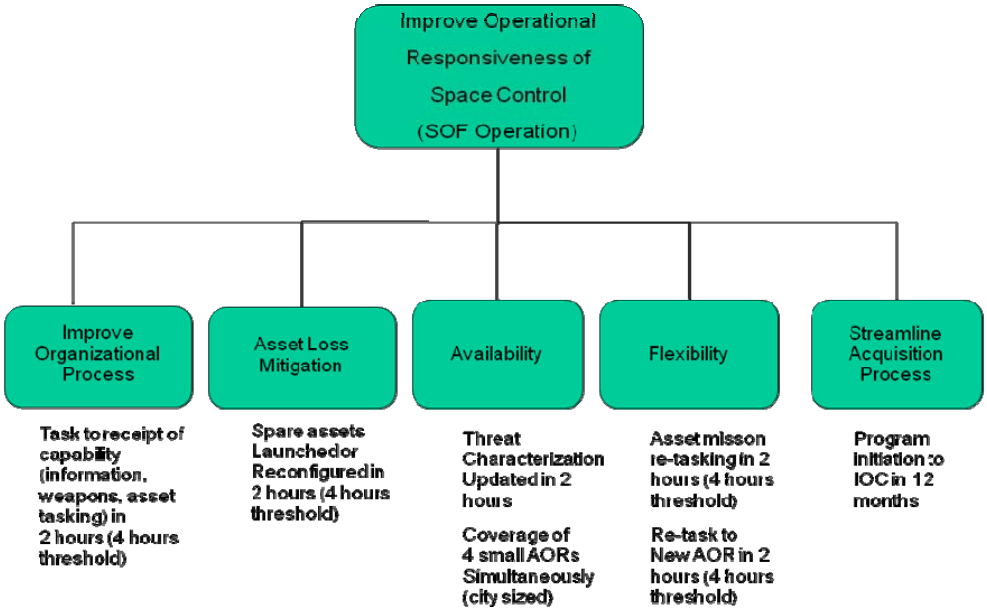


Figure 6 - Space Control SOF Metrics

The major difference in performance metrics between the two scenarios is that the SOF Operation timelines are generally shorter. Operations against a peer power will include more large scale planning, requiring less rapid adjustment of the space assets, but a greater need for surge capability to keep up with enemy production. Also, the coverage area of the peer power scenario would be very large, with potentially sizeable personnel and equipment movement and a need for situational awareness and control of a wide geographic region. The SOF Operation scenario would potentially require as large an area, but most likely would entail coverage of several small, dispersed areas of responsibility. The specific numbers set as measures of performance are a best guess estimate based on the group's minimal experience with SOF operational timelines.

3. Final Solution and Cost

Armed with the MOPs, the group performed an analysis of possible solutions to determine the best actions to be taken to achieve operational responsiveness by 2025. The following solutions were recommended by the group:

1. Expand the influence and powers of the ORS office.

Allow the ORS office capability to quick-task deny, deceive, degrade, and destroy assets at COCOM request. Reduce redundant personnel in acquisition cycle. Establish a small, fully trained space cadre team within the ORS office performing program management SE, and T&E. This would reduce the oversight on space programs, but the benefit of quicker schedule is an appropriate trade-off.

2. Provide trained space cadre personnel to designated billets at COCOM level to serve as liaison between operational and space forces.

Space Cadre would have a direct line to ORS office for asset tasking greatly increasing both the interoperability of forces and flexibility of assets.

3. Require standardized data among SSN systems.

This would be a first step toward fully integrated GIG information repository that is a goal of Network-Centric-Warfare. The policy change now will cause material change over the lifetime of many programs allowing costs to be spread out over 15 years of acquisition. Once established, the data standard will reduce the problem of "data ownership", allow for quicker relay of data/information, and enhance ability to reconfigure assets.

4. ORS office develop and acquire catalogue of plug and play satellite systems.

This will lead to a wide variation of available satellites and constellation possibilities in 2025. It would also make the process of building operational checkout of spacecraft much quicker.

5. Deploy cheap near-space assets to provide large percentage of space control information.

This would increase availability and allow for additional flexibility. Combined with standardized data requirements, users could receive Space Control information and awareness for multiple sources. High altitude airships and aircraft will supplement space assets in the same way that commercial assets do today.

These solutions were arrived at by an analysis of alternative solutions using the MOPs developed from the two scenarios. Each of the initial solutions considered was evaluated for its ability to meet one or more of the metrics. Cost, schedule and performance were then weighed for each solution as either pros or cons, benefits to other areas of ORS were accounted for, and finally, a determination was made.

4. Technology Forecast

As part of the analysis, the group researched available and emerging technology and attempted to forecast to the year 2025. The major systems of Space Control that are currently in use or under development for the next decade are: USAF Counter-Satellite Communications System (CSCS), Counter-Surveillance Reconnaissance System (CSRS), Rapid Attack

Identification Detection Reporting System (RAIDRS), Space Based Space Surveillance (SBSS), and the Orbital Deep Space Imager (ODSI). Each of these systems has a different coordinating and operating authority, and different development and acquisition timelines. To meet the requirement for integration, common database development was examined to see if a feasible single-point database may be available by 2025. These individual systems could be required to begin standardization of systems now, such that almost twenty years of progression could work towards eventual interoperability in the future. This aligns with the Department of Defence push toward a Global Information Grid in Network Centric Warfare. There is also significant progress in near-space vehicles. A combination of these assets, in conjunction with a plug and play catalogue of modular system building blocks, will allow for an effective supplement to space-borne control assets.

5. Constraints

An analysis of constraints was performed which were considered while evaluating possible solutions. For Space Control there exists the political difficulty of consolidating funding from multiple systems and programs controlled by separate organizations. Along the same lines of politics is the need to justify reserve assets. It is difficult for the military to justify spending billions of dollars on reserve spacecraft that would sit on the shelf. Most, if not all, of the time, congress will provide funding for the minimum capability required and no more. There is a great deal of uncertainty in forecasting the technological and political future of space weapons. The fast pace of adversary Anti-Satellite systems is also a major constraint. With the Chinese demonstration on ASAT technology in 2008, it is clear that the United States is already behind. The inability for defensive technology to keep up with ASAT technology will potentially cause very high cost risk for any future defensive material solutions. There are challenges to be overcome when attempting to create spacecraft capable of hazard avoidance in space. Orbital mechanics severely limits the possibilities available as do size, weight and power requirements with current and foreseeable technology. There is also a lack of available plug-and-play systems for use in space. Much like plug-and-play components for personal computers in the last two

decades, modular hardware for spacecraft needs to be developed. Currently, spacecraft are all handmade, making build and checkout times extremely long.

6. Alternative and Considered Solutions

The recommendations for implementation to achieve responsive Space Control were picked from a list of potential solutions formed through brainstorming and employing both the requirements and definitions of the pillars of ORS. Initially, nothing was considered beyond the scope of the exercise in order to include as many options as possible. Solutions were categorized as either non-material, which include policy, training, force restructure and CONOPS, and material, which include new systems and system capabilities. Several solutions, developing CONOPS to target enemy ground segments with conventional attack (deny, degrade, destroy), using optical surveillance data to locate ground targets and developing CONOPS to defend friendly ground terminals against all types of attack (nuclear, chemical, biological), would have had very low cost and schedule risk, but they did not offer sufficient performance and did not meet as many of the metrics as chosen solutions.

The concept of integrating ITW/AA systems with SSN systems under control of a single entity was very similar to the final recommendation of standardizing data, but bringing ITW/AA systems into the picture would induce too much risk with integrating current systems. The large number of satellite surveillance networks discovered in the technology forecast led the group to believe that the risk of adding to ITW/AA systems was not worth the extra capability.

With the wide dispersal of space systems among the services, creating a Space Force as a sub-service of the Air Force or as its own force was considered. It would be a single point for services to coordinate usage of space assets. It would also ensure a non-conflicting focus on space by separating funding so it didn't directly compete with funding for aircraft, ships, tanks, etc. The reason this solution was not chosen was the amount of money required, and the immense political difficulty of creating a new service. Logistically, the solution was not feasible. Better coordination between the current services and proper regulation of funding and assets would accomplish the same results without the large amount of risk.

Providing or increasing funding for counter-satellite and satellite defensive technologies would have moderate cost if spread over 15 years, but as stated earlier in the constraints section, the technological risk associated with trying to keep up with enemy speeds of development of ASAT weapons is far too high.

Political efforts to loosen restrictions on what technologies are allowed in space were considered in an effort to open the possibility of both nuclear systems in space and kinetic/directed energy weapons. This was not chosen due to the lack of available systems for space application. Years of development at high cost would be needed and would carry a very high risk of schedule slippage. This was the same problem with many of the material solutions which were considered. New mobile ground terminals, ground deployed kinetic ASAT weaponry, spacecraft with orbital maneuverability capability, enhanced survivability countermeasures, and "bodyguard" micro-satellites as companions to high value assets were the material solutions that were ruled out for not being cost and schedule effective. The chosen solutions could still provide responsive Space Control capabilities with lower costs and reduced schedule risk.

7. Summary / Conclusions

Space Control is a key mission area for responsive space, and many aspects of it are integrated and dependent upon other mission areas. The recommendations of the group will not only make Space Control more responsive, they will also allow other mission areas to benefit. This, along with future technology and constraints previously discussed will allow U.S military forces to have surveillance, negation, prevention and protection and maintain Space Control.

E. PNT

1. Objectives / Desired Capabilities

Current and future PNT information and solutions are and will be integrated into a wide variety of systems. These systems need to insure the following: accuracy, availability, integrity, timeliness, coverage, continuity, precision and security. These systems must also adapt to current and future threats. This means replenishing our current constellation with the next generation of upgraded satellites. The capabilities that will be chosen were developed with regard to the five pillars.

With respect to improved organizational processes, improved requirement definition and integration across the many stakeholders of PNT in necessary. Also, a reduction in roadblocks which prevent international cooperation would facilitate all associated processes.

For asset loss mitigation, robust anti-jam capabilities by user equipment are needed to ensure the capability is not lost. This capability is not just for aircraft, but also for the disadvantaged handheld user. Spectral spillover and blue force jamming could cause an asset to be lost. The health of a satellite also is of great concern in order to not lose an asset.

Availability was the metric which after much investigation on PNT distinguished itself as the most important pillar. If a user such as a disadvantaged or low power ground user is unable to get a signal, the capability is lost. Augmentation systems such as pseudolites could give the user the ability to navigate without the signal from a satellite. The interface between the user and the device has to be understandable for the user. This has been an area where the commercial sector has made great strides from which the military can take lessons learned.

Flexibility is also a key pillar for PNT. Denial, the ability to stop the enemy from using our systems both for themselves and turning it against us, is an aspect of flexibility. PNT systems need to be interoperable across waveforms, frequencies, modulation schemes, and across different satellite programs to increase the flexibility of the system. Also, if PNT systems were integrated with other systems for mission specific needs, such as with a communications device for squad level missions, the systems could help each other.

A streamlined acquisition process could facilitate the delivery of PNT products. Some objectives to cover would be standardizing form factors and commonality across subsystems. Well defined requirements would be another objective of this process.

2. Metrics / Performance

As stated previously, some factors that are very important for PNT are accuracy, availability, integrity, timeliness, coverage, continuity, precision, and security. Measures of performance were created from these factors. MOP's for accuracy depend on the situation. Small diameter bombs require sub meter accuracy where as a soldier on the ground is content with 10 meter accuracy. There are too many applications and systems that use PNT to consider each individually, but an availability of 100% for world wide coverage is the standard at which PNT systems should be held. Integrity is a hard factor to quantify, but tests can be conducted in order to determine if a system is being spoofed. Timeliness is a factor much like accuracy in which the measure of performance relies on the situation. Time to First Fix (TTFF) is the time it takes for the piece of user equipment to produce a valid solution. This time can vary for each application. A soldier in the field may need to know his location in a matter of seconds. On the other hand, an F-16 has a 15 minute lead time from start up to take-off, when it needs its solution. Again, there are too many situations to list them all. Coverage of 100% by the satellite can be achieved by keeping a full constellation. This must be achieved with consideration of the unknown location of future conflicts. Continuity is as yet an unknown factor, which will require future investigation, including backward compatibility and common form factor. Precision is a factor that affects the user equipment. The equipment has to receive the signal from space and employ that solution to turn it into 95% targets accuracy. The motto for PNT should be one target, one bomb. Security is a hard factor to put a measure of performance. It is unclear how many security breaches can be considered acceptable. With PNT integrated into countless systems, the security of these systems needs to be held to the highest standard.

To determine which measures of effectiveness to use, we must find which factors are most important to each user group. Then we can take these factors and put them in a matrix or two axis charts to compare the solutions. Examples of this are list below.

- Accuracy vs. Availability,
- Availability vs. Integrity,
- Timeliness vs. Integrity,
- Accuracy vs. Coverage

The final metrics were developed according to the pillars. These metrics aligned with the desired capabilities and objectives discussed previously in this section. As stated, the metrics for PNT are most restrictive with regard to availability. Flexibility also induced more metrics than the other pillars. The metrics were developed against each operational scenario. The peer power scenarios are much more focused on large platforms and PNT integrated into other systems. The special operations force scenario lends itself to the individual soldier on the ground who needs light compact low power solutions.

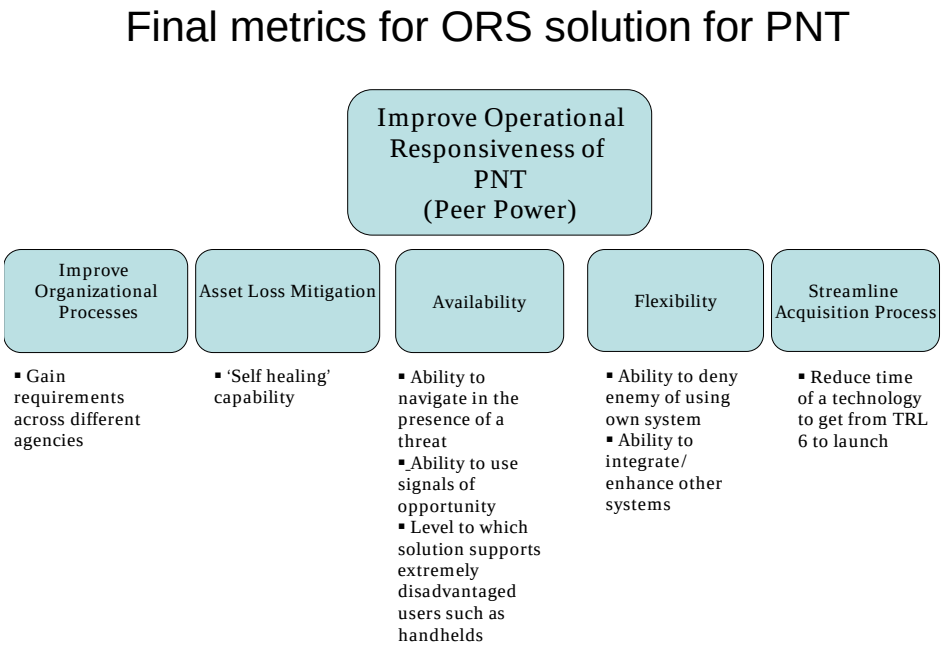


Figure 7 - PNT Peer Power Metrics

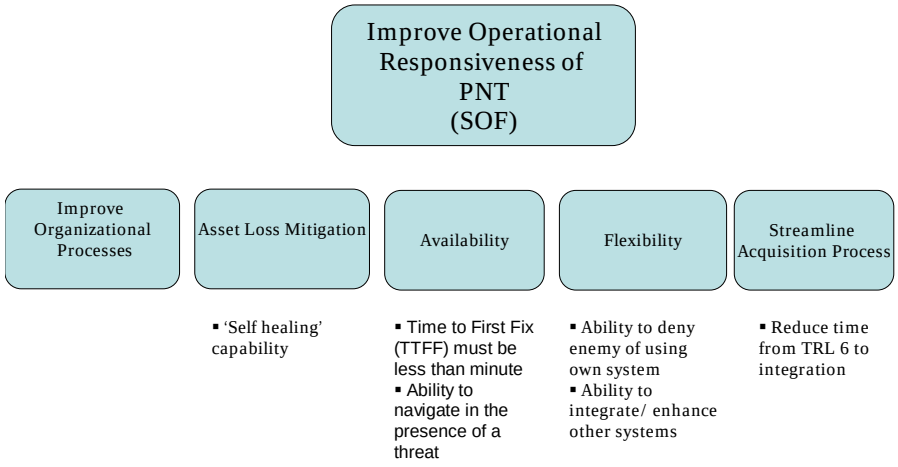


Figure 8 - PNT SOF Metrics

3. Final Solution and Cost

After much consideration, the spot beam, ability to direct beam of M-code of GPS satellite for increased power over AOR, was chosen as the final solution for PNT. As for all of the solutions, the performance and cost were evaluated.

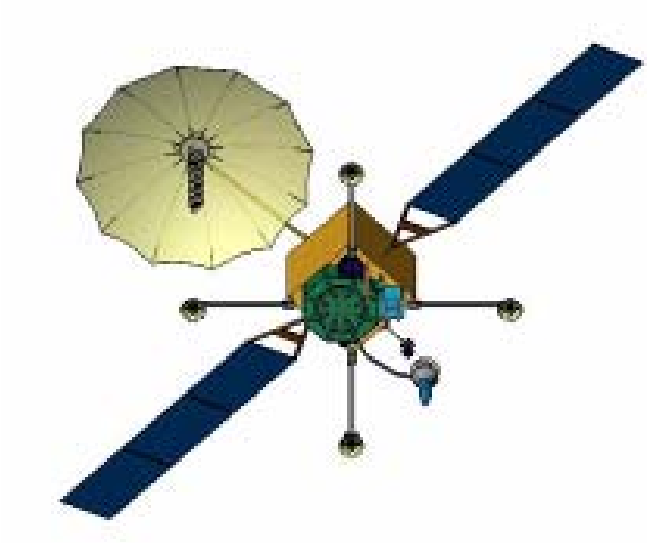


Figure 9 - GPS Satellite with a Spot Beam Antenna

In terms of performance, the spot beam increases the anti-jam capability for users which could produce an increase of up to 20dB. One of the most useful features of the spot beam is that no extra power is needed by users. All users within the spot beam can benefit if they have the correct crypto keys to access the signal. With Over The Air Rekeying (OTAR) this keying process will be much simpler, so more users will be able to use the military signal. The 20dB gain is a huge advantage to low power users that are unable to add more size, weight, and power to their already overloaded packs. Also, the Army is putting Defense Advanced GPS Receivers (DAGRs) into HUMVEES to run other systems that rely on PNT.

Cost for the spot beam is roughly 35 million per satellite. The new GPS III contract was signed by Lockheed Martin and the Global Positioning Systems Wing for $1.46 billion dollars for 8 space vehicles. This 35 million would be about a 20 percent increase in the satellites overall cost. This added cost is the direct result of more power needed on the satellite to produce this spot beam. Larger batteries, an extra antenna and larger solar arrays would be needed, but there would not be a need for any alterations of the signal itself. To employ this solution, the military would need to replace 24 satellites for global coverage, which would amount to a total of 840 million. This cost may seem high, but it supports hundreds of thousands of military users. With over half a million receivers currently fielded, the cost per user would be greatly reduced. This also avoids the hassle of upgrading each of the different types of user equipment.

	COST / EACH (M)	QUANTITY	TOTAL / LINE ITEM (M)
Cost of current GPS III SVs	180		
Upgraded capability for Spot Beam and integration costs is 20% of current SV costs	35	24	840
SOLUTION TOTAL			840

Table 3 - PNT Cost

4. Technology Forecast

Present

- Ultra tight Coupling (UTC)
- MEMS, INS
- Antenna Technology –Digital, Adaptive processing

10 Years from now

- Chip Scale Atomic Clock (CSAC)
- Spot Beam
- Flex Power

20 Years from Now

- Crosslinks

Enablers

- Quantum applications (processing; comm)
- Optics and laser capabilities
- Distributed & Networked PNT Services
- New spectra / radiometrics available for PNT services
- Improved astrometry
- Precision gravimetrics and bathymetrics
- Improved topographic mapping

Applications

- Blue Force Situational Awareness
- Urban / Interior Navigation
- Intelligent Transportation
- Missing Person Locator
- Machine Level Location
- Orientation
- Data security and verification (including location)
- GEO and Deep Space Missions

5. Constraints

The constraints seen by PNT are very similar to the constraints seen by other mission areas. Most of these constraints can be felt by all programs within acquisitions.

- No frequency / spectrum availability
- Flexible budget cycles
- Agreement on standards
- Segment synchronization i.e. user, space, control
- Efficient acquisition balanced with thorough testing procedures
- Information Assurance / Multiple security levels
- International agreements

6. Alternative and Considered Solutions

The DoD needs to change its policy to have "throw away" receivers. This would lower the cost and put more receivers in the hands of the warfighter. The cost of a current handheld receiver is about $1200, and the cost of the less stringent receiver would be about $700. The lower cost would allow for more receivers to be purchased. With regards to performance, there is a higher risk on damaging item, and it not working.

Another solution would be to reduce redundant personnel in the acquisition cycle. This group would be a small, fully trained space cadre team performing program management, systems engineering and test and evaluation. This is common among the different mission areas. This would lower the cost, but it could leave too small of a workforce in times of heavy workload.

There is a need to encourage military effort toward smaller, simpler, and faster built receivers. This would lower the cost and plug and play reduces integration costs. This also reduces risk of integration issues down the line.

Allowing Technical Assistance Agreements (TAAs) to cover a broader range of projects rather than being so specialized would help to reduce paper work and bottlenecks in the acquisition process. This is a no cost fix, but it can introduce risk by allowing too many eyes to see work. Reduction in paper work and bottlenecks in acquisition process could offset this risk.

Allowing the use of "signals of opportunity" would improve and enhance the PNT solution during periods of limited or unavailable GPS signal. The cost of an antenna system could be in the $25,000 to $100,000 range. This is a low cost solution since other nations and agencies are paying for the satellites. A large advantage of this solution is that it is highly accurate, while still being able to navigate without GPS. A big risk of this is the fact that the military is relying on foreign devices for US military interest.

In terms of material solutions, the military could use technologies such as inertial systems like MEMS and gyros. The cost is low at around $1000's and it can improve anti-jam capabilities. This PNT solution can lose accuracy, however, without an update from GPS satellites.

CSAC technologies could improve timing in handheld receivers. The cost is currently in the range of $10,000, but need to be close to $1000 to be an option. As far as performance, it uses a great deal of power, but improves accuracy.

Augmentation Systems like cell phone navigation can help give a PNT solution in the absence of a GPS signal. The cost is low to medium depending on the augmentation system used. These augmentation systems improves accuracy without additional power, but must be set up prior to use which is a large detraction from using systems like this.

An obvious solution would be to increase current satellite coverage of GPS satellites. This means simply launching more satellites, but satellites have a high cost at about $200M per satellite. Having more satellites in the sky increases the accuracy and availability, but there is limited launch availability which is a significant deterrent.

Better antenna technologies like digital antennas, antenna electronics, adaptive processing would be beneficial to PNT processes as well. These are technologies are present today. This is low cost solution, and it improves accuracy and anti-jam capabilities, but takes time to develop and acquire antennas.

Crosslinks on satellites give the ability for each satellite to talk to each other. This capability also allows an operator to send messages uploaded from the control station. The cost for this solution is high and requires other satellites with the same capability for it to be useful.

Flex power is a capability to increase power of a satellite during a limited time during operations. The power increase would not be as great as the spot beam. A big advantage of this technology is that users don't need any extra power to see benefits, but it's only available for a short period.

A GEO PNT satellite to give better urban navigation performance would be useful, but it would come at a high cost. This is caused by the high power needed to broadcast from GEO. In addition, it's only operable over a particular area, so the satellite would have to be placed in specific present locations.

7. Summary / Conclusions

Many different possible solutions were looked at for PNT. More material solutions than non-material concepts emerged, but every solution was looked at for possible implementation. While only one solution was selected, many have value and should be considered for possible employment. A single solution was selected due to its high ability to enhance all PNT users without any extra effort on their part. With the integration of PNT into countless other systems, requests for such data are going to be ever increasing in demand.

F. Launch

Joint publication 3-14 defines Space Support as "operations that launch, deploy, augment, maintain, sustain, replenish, deorbit, and recover space forces, including the command and control network configuration for space operations." (JP 3-14, 2002) This definition is a little too in depth in the details for our purposes, but the first two aspects must be regarded as extremely important when dealing with Operationally Responsive Space (ORS). The reason launch and deployment are so important is because they are the bottleneck or limiting factor when attempting rapid constellation employment or reconstitution. Space Support is typically broken into three areas: spacelift, satellite operations and reconstitution of space forces. The spacelift portion provides the launch, rapid reconstitution, deployment, and responsiveness required to place all satellite systems on orbit. The task of spacelift comprehension and rapid launch vehicle execution required to achieve a responsive space initiative is extremely complex due to the "only one chance" reality that is launch. The five pillars will enable a thorough review of all available solutions.

1. Objectives / Desired Capabilities

Using the five ORS pillars as the foundation in designing an operationally responsive spacelift structure, we can ensure a methodical process of developing objectives and eventually metrics. These metrics will be the key focus in considering all available and proposed solutions.

Launch vehicle development has been one of the most difficult systems to mature in the space arena. The complexities involved in harnessing a million pounds of thrust require a mature system based on an evolutionary process of rocket design. To revolutionize spacelift incurs too much risk on the payload and mission success. This realization is well understood in the Aerospace industry due to the difficulties of brining new components, boxes and systems into one working launch vehicle. The evolutionary process reduces test and developmental costs since block system upgrades require less technical design reviews and system engineering. By evolving the current launch vehicles through systematic testing and increments to meet current demands the majority of the operational launch systems will be capable of making the ORS spacelift fleet. The following objectives are organized within the five pillars and will later be broken out into more specific metrics.

Improve Organizational Processes – Reducing the non value added levels of coordination and verification will create launch systems capable of bringing the warfighter critical assets in drastically reduced time.

Asset Loss Mitigation – Ensuring the loss of existing assets can be quickly mitigated to create an uninterrupted net centric support to the warfighter can be facilitated through rapid launch vehicles.

Availability – Uninterrupted launch services offered to the warfighter upon request without delay is the key component of an available launch system.

Flexibility – Making launch assets adaptable to varying mission requirements and constraints through the creation of multiple launch systems is the most important component of flexibility.

Streamlined Acquisition Process - Ensuring that acquisition processes follow a timely fashion with little delay is the cornerstone of the launch acquisition mindset.

2. Metrics / Performance

To develop a truly responsive spacelift system each of the five pillars must be established and applied to the launch system lifecycle from early product acquisition to space vehicle separation. Using the five pillars as the core areas on which to develop the objectives, and subsequently the metrics, allows for a thorough cradle to grave process. A 2025 ORS Spacelift structure can be built around these chosen metrics to bring light to appropriate risk reduction and process improvement procedures. Each metric is then reviewed for solutions spanning the whole spectrum of technology readiness levels. Beginning with the end in mind starts with the five pillars to develop metrics with which to evaluate the proposed solutions.

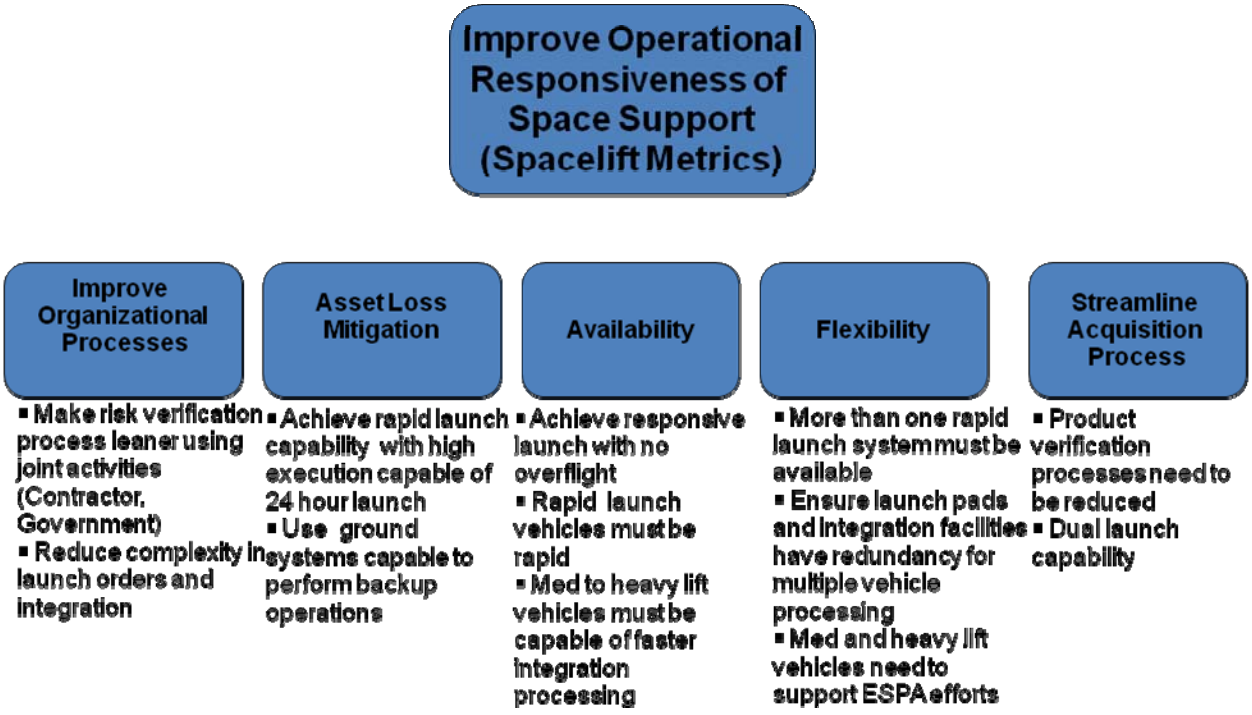


Figure 10 - Launch Metrics

Improve Organizational Processes – The best way to ensure each verification level is required and brings value to the system is by joining the launch service provider and customer together during risk verification processes. By joining Government and contractor pedigrees and verification matrixes, launch schedules and costs can be reduced yielding rapid preparation and production. This alignment results in a team reminiscent of the pre-commercial days when the government performed all verifications and launch development. Another area which would

improve the organizational processes is by reducing the complexity in launch orders and integration. Current processes are not structured to be rapid or focus on timely integration. This impedance to ordering and integration evolved by the unappreciated need to rapidly support the warfighter with all possible capabilities. This is explained as ORS being a capability that decision makers felt had no mission. A changing focus is bringing new thought to old practices by generating ideas and making change throughout all leadership levels.

Asset Loss Mitigation – This may occur through replacement of existing systems or developing redundant surrogate systems capable of backup operations. Of the two metrics developed to reconstitute or substitute space assets the most important for spacelift is the ability to achieve rapid launch capability with high execution capable of a 24 hour launch notice. The secondary metric is to use ground systems capable of performing backup operations to facilitate launch processing time and ensure the warfighter acquires continual information from space assets.

Availability – The metrics for availability are based around current initiatives to create responsive spacelift systems. These metrics are to achieve responsive launch with no over-flight and use rapid launch vehicles which are truly rapid. For the medium to heavy lift vehicles initiatives must be in place to decrease processing time and integration activities, thus creating a more rapid integration cycle. These three metrics will produce launch vehicles focusing on responsiveness.

Flexibility – This pillar includes metrics demanding a variety of systems which are similar to support each other during times of rapid launch or grounded vehicle issues. Another metric is to ensure launch pads and integration facilities have redundancy for multiple vehicles processing. These metrics fall under the heavily supported Assured Access to Space (AATS) initiative. By 2020-2025 the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) will have completed testing and been sufficiently integrated into launch processing as a standard interface bringing up to six systems online in a single launch. This is one of the first great acquisition processes started in our time.

Streamlined Acquisition Process - Ideally, concept to launch will be no longer than 12 months. Product verification processes need to be reduced and dual launch capability needs to be truly dual launch capable amongst each class of vehicles.

3. Final Solution and Cost

The metrics allowed for open minds to generate ideas and remove roadblocks. This process brought about solutions ranging from current capabilities to near sci-fi like systems. By performing this we kept the solutions abundant giving more thought into the requirements and capabilities. Many solutions were evaluated which were trimmed down to become the chosen ORS solution sets while others were evaluated and have been shelved until more research and testing is performed and their technology readiness level is raised. The chosen systems to perform launch and early orbit assist are:

- **EELV Launch Systems:** Evolved Expendable Launch Vehicles have been heavily funded by both Government and Contractors. The evolution of the Atlas V and Delta IV dates back to the 1950's when the focus was on creating Intercontinental Ballistic Missiles (ICBMs.) The evolutionary approach has made the vehicles highly reliable. The vehicles offer the ability to be dual launch capable providing a variety of launch date options for the satellite vehicle based on the current launch manifest. Another critical capability is the AATS support which ensures separate vehicles are available to reduce the potential of grounding the entire fleet of medium to heavy lift vehicles should an anomaly arise. These vehicles have the capability of lifting 40,000 lbs into Low Earth Orbit and up to 26,000 lbs into a Geosynchronous Transfer Orbit at a reasonable expense.

Figure 11 - Atlas V 551 Vehicle

Performance: Meets all metrics

Cost: $2B per Year (Sustainment and Hardware)

- **Air Launch Rapid Vehicles:** Based out of Kirkland, WA, Airlaunch is developing their Quickreach vehicles capable of being air launched from a C-17 eliminating over flight restrictions and weather delays. "AirLaunch's QuickReach vehicle is specifically designed to meet the needs of the DARPA / US Air Force Falcon Small Launch Vehicle program, capable of delivering 1,000 pounds to low earth orbit for $5 million per launch, with a 24-hour response time" (Facktor-Lepore, 2006.) This rapid capability is being heavily supported due to its proven capability and simplistic approach. The key performance parameter is that the system allows no overflight restrictions which eliminates the complexity of day of launch (DOL) preparation.

Figure 12 - Airlaunch Quickreach

Performance: Meets Rapid Launch Requirements

Cost: $500M annually

- **EELV Secondary Payload Adapter (ESPA):** Reducing launch costs and increasing payload capability by offering one primary and five secondary payloads the ESPA Ring is a marvel of current science. The system was tested on 9 March 2007 with the successful launch of the first ESPA ring aboard the Atlas V STP-1 mission. The capability to offer reduced launch costs and rapid deployment of six satellites is here and ready to support the ORS initiative.

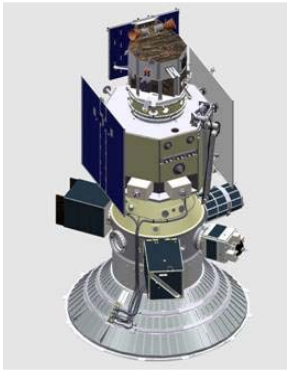


Figure 13 - ESPA

Performance: Meets vehicles capable of being auxiliary payloads

Cost: $50M – $150M annually

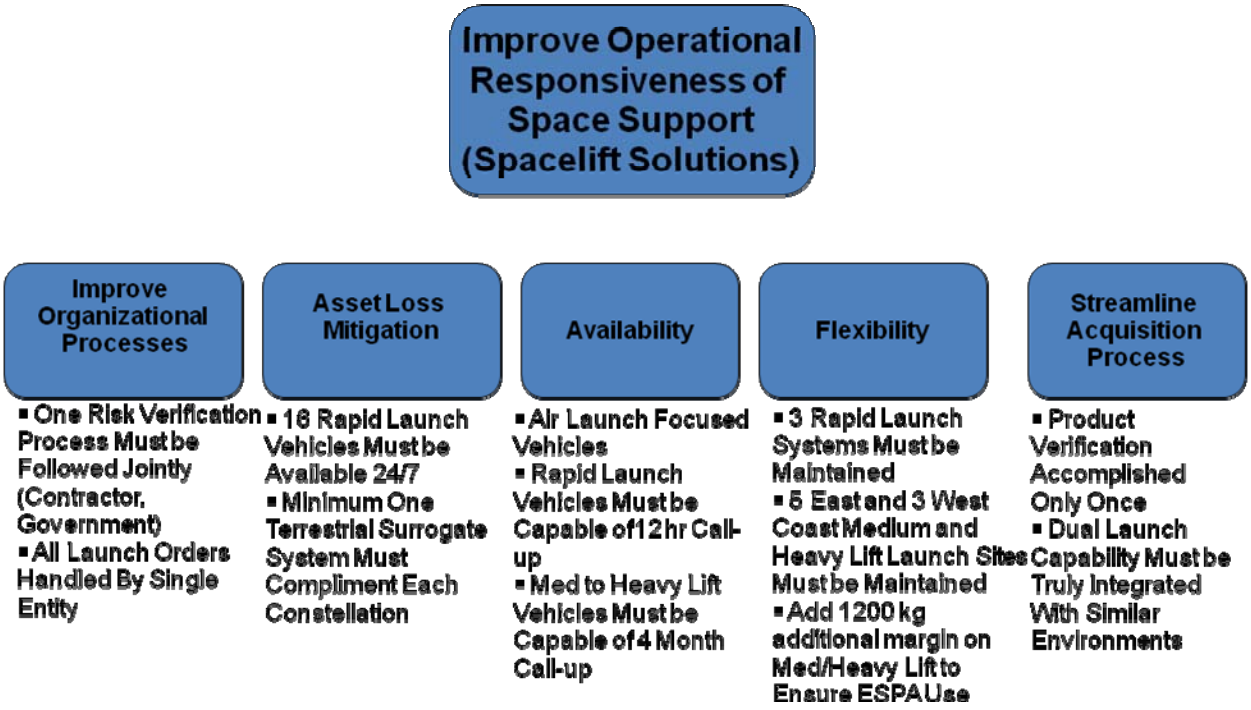
- **Small Rapid Launch Vehicles:** The Pegasus launch vehicle and the Minotaur follow-on vehicle are viable options due to the great success they have achieved over the last two decades. These systems are reasonably priced and evolving to meet the demands of an ORS mindset along with the great progress towards offering small secondary payloads a ride at a reduced cost.

  Performance: Meets low cost quick launch rates

  Cost: $70M – $240M annually

These chosen systems will be the hardware backbone of the ORS launch initiatives bringing about a reliable, evolved, launch force focused on rapid and continual launch options. These systems will bring technology to the warfighter with a higher fidelity and supportive design far greater than what is currently offered. The technology has been initiated and will take a few years to realize. The performance of the selected solutions can be seen in Figure 14 and the associated cost of such capabilities is estimated in Table 4 (including added 30%).

Figure 14 - Launch Solution



Launch Cost for ORS Initiative	Cost/Each (M)	Quantity	Total / Line Item (M)
Heavy - Medium lift vehicles			
Atlas V	$140	6	$840
Delta IV	$160	6	$960
Falcon 9	$100	1	$100
Small Sustained Launch Vehicles			
Minotaur	$23	3	$69
Rapid Response			
Pegasus	$30	8	$240
Air Launch Quickreach Vehicle	$5	16	$80
Microcosm Sprite	$7	8	$56
Annual 2025 Costs plus 30%			**$3,049**

Table 4 - Launch Cost

4. Technology Forecast

In foretelling a country's launch industry system 10-15 years in the future, one would imagine great leaps in rocket development. The fact is, rocketry is such a complex and unforgiving industry that the future will look very similar to today's industry. Rockets attempting to break the boundaries of technological readiness levels end up as museum exhibits or fizzled out research projects shelved for the bits of data they might hold for future endeavors. Reviewing the systems with panoramic lenses it is easy to see the evolutionary process from the 1950's, to current time, and following technology out to 2025. The focus to make a responsive spacelift lies in the push by COCOMs to request such rapid capabilities. The systems capable of being operational in 2015 will fulfill the needed areas of rapid reconstitution and responsive launch.

Though changes seem evolutionary, there will be revolutionary inputs offering quicker launch through plug and play systems and reduced mission preparation time. These capabilities bring about call-up times in the hours, not months. To shorten this time further, systems will need to be stored in a near launch state. This state indicates a fully assembled system ready to be

loaded with fuel. The payloads will need to take a similar approach and need to be available on short notice as well.

5. Constraints

By using current systems, the R&D funding will not nearly be as high as developing a completely new vehicle. This approach brings a great savings to an already limited-funded area of space systems. The EELV launch vehicles will need to focus on sustainment, and development projects will only be in the areas of rapid launch vehicles. These developmental projects are the final milestones in bringing actual tested systems into operational status. The political decisions will be the most restrictive constraints to responsive Spacelift due to the hesitation of answering the question of whether ORS is a capability we need.

6. Alternative and Considered Solutions

- **Affordable Responsive Spacelift (ARES):** Early focused efforts on bringing back the first stage pre-orbit and only orbiting the second stage has been proposed since 2003. This concept is a reverse of the current space shuttle configuration. By having the first stage return to earth prior to going exoatmospheric it will not require heat resistive capabilities and is planned to be as simple to prepare and deploy as a current airplane. Sweetman (2006) noted that "Compared with a fully reusable system, ARES requires the development of about one third as much reusable hardware, with a less challenging speed and temperature envelope. Compared with a fully expendable system, ARES expends about one third as much mass".

Figure 15 - ARES

  - Performance: Could meet all metrics if complexity for re-flight is resolved
  - Cost: ~$1B - $3B RDT&E with a goal of $2200/kg to orbit

- **Space Elevator:** Seen in Sci-fi movies due to the viability and physical capability to actually be tethered to Earth from a geostationary orbit, the space elevator elicits intrigue and amazement when discussed. If not for the extreme cost and high targeting potential from terrorism the space elevator might be further explored. Many scientists have researched and proposed down to detail the fibers used and repair options to maintain such an elevator. The technology readiness level, nor level of corporate support is not sufficient enough to entertain any further research into choosing the space elevator as a feasible option in the 2020-2025 time frame.

  Performance: Could meet all metrics, technological fiber cost is feasible for 38,000km

  Cost: $40B development and expected at $220/kg to orbit

- **Gun Propulsion Satellite Launching System:** Early research shows capability in small systems. The true challenge is the extreme environment created on the payload from a sudden acceleration. The shock and force is too powerful for satellites to sustain without mission risk. The technology gap is also too difficult to jump to larger systems.

  Performance: Only designed for small amateur, communication, and research satellites. Limited to satellites below 2,000lbs.

  Cost: ~$10M following RDT&E

- **Nuclear Pulse Propulsion:** Will most likely be the way for long space voyages. Not going to be thoroughly pursued in the satellite deployment market in the foreseeable century due to the complexity, extreme cost, and Earth environmental threats.

  Performance: Not technologically ready and fear of nuclear over flight/re-entry

  Cost: $20B Start-up, Possible $500M per launch

This list of considered but not chosen solutions shows the future of space technology. Even though they are not technologically ready the mere pursuit of such technology shows the science community is continuing to keep an open mind and sharp practice on pushing the physics envelope. Some of these considered solutions offered benefits that some chosen solutions did not offer. The decision factor was based on realistic achievement in development over the next 10-15 years. The technology readiness factor was a primary focus to ensure the technology was mature enough to be feasible in 2025.

7. Summary / Conclusions

Referencing Figure 10 it can be seen that the process to accurately and effectively choose ORS launch systems begins with metrics defining what is needed to be truly responsive. The metrics defined the key performance parameters and Figure 14 showed the chosen solutions to meet these parameters. Each metric and solution used the five pillars of ORS as a basis beginning with improving the organizational processes and ending with required changes to make the acquisition process more streamlined.

The first obstacle to overcome in the organizational processes was making the risk verification process leaner using joint activities (Contractor, Government). This greatly reduces the cost and time associated with launch vehicle preparation. The solution to overcome the current sluggish process is to create one risk verification process joining the contractor and government in a simultaneous approval process. This example shows how the metric to solution process works. By following the metrics and implementing the solutions an ORS Spacelift launch structure will be ready to meet the demands of Combatant Commanders in all future conflicts. "One of the key focuses of the DoD's recent efforts in space system development has been creating a capability for launching satellites into space within a few days of the 'go' command in order to provide timely communications, ISR, and other tactical support to the warfighter." (Hoyt, 2006) With our proposed solutions, we believe we meet this objective.

V. CONCLUSION

The architecture developed by this team may not be a complete solution, but it is a strong beginning to build upon. Constraints were identified within individual mission areas, and overall limits of scope were thoroughly discussed. The proposed solutions were chosen based on a collaborative process of creating pillars, brainstorming ideas, forming metrics and scenarios to evaluate these ideas and selecting the best performance to cost concept. With different group members supplying input, or using a slightly modified baseline of pillars, changes would certainly ripple through the overall architecture, causing numerous alterations in considered and final solutions. For this purpose, all considered solutions were included, such that others may develop these concepts further, should they warrant them to contain sufficient merit. In addition, the process employed by this group, including the formation of our pillars and guiding principles as well as the assessment of future possibilities and constraints, is documented such that one can follow and understand the group's reasoning, while allowing for the possibility of disagreeing with the final results. These limitations in mind, the concepts and ideas proposed within this document represent our group's best vision of a 2025 space architecture.

Developments with regard to improved organizational processes, asset loss mitigation, availability, flexibility and streamlined acquisition processes, as identified and explained in our five pillars, will help to create a space architecture that fulfills our stated purpose: to provide space services focused upon the particular combat and support needs of the military, in particular the combatant commander, upon demand, in support of combat operations, without negative impact by non-military government space requirements. This was the group's initial vision of ORS, and it has guided us throughout the developmental process. Selected solutions found within each chosen mission area are in direct support of this objective, and through consideration of this initial definition, our team has built a comprehensive space architecture which we believe will successfully fulfill future space needs.

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