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Insights From Pre-Space Age Approaches to Military Capabilities

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What is ViTTa®?

NSI's **Virtual Think Tank (ViTTa®)** provides rapid response to critical information needs by pulsing our global network of subject matter experts (SMEs) to generate a wide range of expert insight. For this SMA Contested Space Operations project, ViTTa was used to address 23 unclassified questions submitted by the Joint Staff and US Air Force project sponsors. The ViTTa team received written and verbal input from over 111 experts from National Security Space, as well as civil, commercial, legal, think tank, and academic communities working space and space policy. Each Space ViTTa report contains two sections: 1) a summary response to the question asked; and 2) the full written and/or transcribed interview input received from each expert contributor organized alphabetically. Biographies for all expert contributors have been collated in a companion document.

[1] For access to the complete corpus of interview transcripts and written subject matter expert responses hosted on our NSI SharePoint site, please contact **gpopp@nsiteam.com**

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Question of Focus

[Q15] What insight on current space operations can we gain from understanding the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings before the advent of the space age?

Expert Contributors

Major General (USAF ret.) James Armor[2] (Orbital ATK); **Marc Berkowitz** (Lockheed Martin); **Dr. Damon Coletta and Lieutenant General (USAF ret.) Deron Jackson** (United States Air Force Academy); **Colonel Dr. Timothy Cullen**[3] (Air University); **Dr. Malcolm Davis** (Australian Strategic Policy Institute, Australia); **Faulconer Consulting Group**; **Jonathan D. Fox** (Defense Threat Reduction Agency Global Futures Office); **Harris Corporation**; **Theresa Hitchens** (Center for International and Security Studies at Maryland); **Dr. John Karpiscak III** (United States Army Geospatial Center); **Dr. Krishna Sampigethaya**[4] (United Technologies Research Center); **Victoria Samson** (Secure World Foundation); **ViaSat, Inc.**

Summary Response

This report summarizes the input of 13 insightful responses contributed by space experts from National Security Space, industry, academia, government, think tanks, and space law and policy communities. While this summary response presents an overview of key subject matter expert contributor insights, the summary alone cannot fully convey the fine detail of the contributor inputs provided, each of which is worth reading in its entirety.

Approaches to Military Capabilities Before the Advent of the Space Age

Since long before the space age, capabilities such as surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings have been critical core-competencies of powerful nations. With the emergence of the space age, these capabilities expanded exponentially, both in power and precision, as well as importance to national security and defense objectives. While pre-space age approaches serve as the foundation for current approaches to these capabilities, space-based manifestations have brought clear advancements and new vulnerabilities with them. In response to these new challenges, both scholars and practitioners have started to look back to pre-space age approaches to uncover insights and lessons learned from older methods that might be used to mitigate some of the vulnerabilities in present-day systems.[5]

Navigation, Positioning, and Timing

Before the advent of the space age, approaches to navigation, positioning, and timing capabilities consisted largely of "looking to the stars" (Sampigethaya; Samson). This, Dr. Krishna Sampigethaya of

[2] Armor's personal views, and not those of his organization, are represented in his contribution to this report.
[3] The views expressed in Cullen's answer to this question do not reflect the official policy or position of the United States Air Force, Department of Defense, or United States Government.
[4] Sampigethaya's personal views, and not those of his organization, are represented in his contribution to this report.
[5] See the contribution from Sampigethaya for further discussion of this reflection.

United Technologies Research Center explains, entailed "performing geometry-based calculations based on celestial bodies and their alignment with respect to the visible horizon on Earth to compute a current position, in terms of latitude and longitude, on Earth." Today, navigation, positioning, and timing capabilities are founded in a GPS-based approach. This modern GPS-based approach has distinct advantages over pre-space age celestial navigation, according to Sampigethaya: "it provides altitude and timing data; is more scalable, accurate, and granular; and no human intervention is needed for position computing." On the other hand, GPS-based navigation, positioning, and timing is prone to security vulnerabilities that pre-space age celestial navigation-based approaches were not. Such security challenges include the ability for potential attackers to directly target GPS satellites; to observe, disrupt, and jam GPS signals and data; and to exploit ground-based GPS systems. Despite these present-day challenges, the assertion from Victoria Samson of the Secure World Foundation, that "obviously the use of stars for navigation is not as predictable as our current navigation capabilities stemming from space," illustrates how far the approaches to navigation, positioning, and timing capabilities have advanced.

Surveillance, Reconnaissance, and Indications and Warnings

Like the approaches to navigation, positioning, and timing capabilities, approaches to surveillance, reconnaissance, and indications and warnings capabilities have advanced with the emergence of the space age. Modern satellite-based approaches to surveillance, reconnaissance, and indications and warnings have emerged as superior to the pre-space age approaches, which largely relied on air- and ground-based sensors.[6] Satellites, Sampigethaya explains, make surface-to-air systems more robust, allowing for unmanned operation, greater accuracy and stealth, and instantaneous communication between air and ground systems. Moreover, Samson suggests, satellite-based systems have marginalized some of the capability limitations stemming from overflight and airspace sovereignty constraints that hamper air- and ground-based approaches. The emergence of unmanned aerial vehicles (UAVs) offers an example of what Sampigethaya describes as a "hybrid" approach, combining elements of the pre-space age air-based approach with modern satellites to produce enhanced surveillance, reconnaissance, and indications and warnings: UAVs are "controlled by human pilots, more cost-effective, adaptive, and accurate, but rel[y] on satellites for navigation, timing, and communications." The contributors did not specifically mention any vulnerabilities that emerge from the modern satellite-based approach to surveillance, reconnaissance, and indications and warnings capabilities, but there is no reason to believe that satellites are immune to the same security challenges (e.g., adversarial targeting, observation, disruption, jamming, and exploitation) that can limit the space-based approaches to navigation, positioning, and timing capabilities.

Insight on Current Space Operations

The emergence of the space age has propelled advancements in surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings capabilities, both in implementation and output. Pre-space age approaches to these capabilities have not been entirely forgotten, however, and in some cases these foundational approaches are still applied, albeit typically to a lesser extent than in the past.

[6] Sampigethaya and Samson further detail the pre-space age, air- and ground-based sensor approaches to surveillance, reconnaissance, and indications and warnings capabilities. The primary implementation of the air-based approach, according to Sampigethaya, entailed using "stealthy high-altitude manned aircraft, such as the U-2, carrying a high-resolution camera onboard" to surveil, sense, and capture imagery from above. The ground-based approach, Samson explains, largely required having "boots on the ground…or some sort of capability nearby" to surveil, sense, and monitor surrounding environments and threats.

Together, the contributors' reflections on the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings capabilities before and after the advent of the space age suggest four general insights.

- Controlling the "high ground" is still important.
- Space domain advancements can and should be capitalized on to maximize military effectiveness.
- There are risks and vulnerabilities associated with being too dependent on space-based approaches and capabilities.
- More efficient and effective space systems and processes are needed.

Controlling the High Ground

The military significance of controlling the high ground has persisted across the spectrum of time, both before and after the advent of the space age. With the emergence of the space age, however, its location has changed: Outer space has become the new high ground.

Surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings capabilities are all influenced by the high ground. While simply possessing or using these capabilities does not require control of the high ground, if the goal is to achieve capability dominance and superiority, controlling the high ground can be fundamental. Contributors from Harris Corporation reflect that before the emergence of the space age, superiority in capabilities such as surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings was largely dependent on "controlling the high ground, initially terrestrially and later in the air," and ensuring "line of sight." They emphasize the wide-ranging importance of controlling space as the new high ground:

> As the new 'high ground,' and medium through which an increasing percentage of our communications flows, controlling space will be critical...Controlling the high ground is critical to surveillance, reconnaissance, and indications and warnings, making space situational awareness and space superiority absolutely critical to these functions. Space also offers another path in support of redundant, robust, and protected lines of communications in support of command and control, navigation, and timing.

Thus, the Harris Corporation contributors conclude that, "whoever can achieve the highest [ground] will always have the best space situational awareness. Whoever has the best space situational awareness has a military advantage in very simplistic terms over the adversary."

Maximizing Military Effectiveness

The importance of capitalizing on space domain operations, and the enhanced military capabilities space systems offer, in order to maximize overall military effectiveness is an insight that several contributors echo.[7] In considering the lessons that can be gleaned from pre-space age approaches to military capabilities, Dr. Malcolm Davis of the Australian Strategic Policy Institute reflects on the approaches to military conflict of the past. He describes a time in which warfare was "a blunt and imprecise affair" that focused on "brute force application" and "the use of attrition in battle." This is a stark contrast to the "modern information-age" approach to warfare that has emerged since the advent of the space age.

[7] Armor; Davis; and Harris Corporation.

Davis' reflection on the pre-space age approach to military conflict reveals a key insight on current space operations.

> The clearest and most important aspects we [can] take from pre-space age operations is an understanding that space opens up a much greater ability to understand the battlespace, control forces, and apply precision effect against an opponent in both time and space in a manner that maximizes military effectiveness.

Major General (USAF ret.) James Armor of Orbital ATK also highlights the importance of capitalizing on space-based capabilities for overall military effectiveness, stressing the importance of increasing resilience and enhancing alternate capabilities. The best approach for achieving success in this sense, he suggests, is to "normalize the use of space in military operations." Contributors from Harris Corporation express similar thinking, and point to approaches to military capabilities in the air domain as a particularly relevant model. They argue that, "the space domain is no different than the air domain when it comes to the key mission areas. We talk about space superiority, offensive space control, defensive space control. We need to talk about offensive and defensive counter-space, suppression of enemy space defenses, and space intelligence, surveillance, and reconnaissance."

Avoiding Over-Dependence on Space

While the emergence of space-enabled capabilities has driven significant advancement in military capabilities, several contributors[8] caution against relying entirely on space-based approaches for military capabilities. Colonel Dr. Timothy Cullen of Air University most adamantly raises this caution, arguing that military operations and capabilities "should not be wholly dependent upon information or activity from a global commons" such as space.[9] His caution stems from concerns relating to ensuring the security and credibility of military capabilities and operations. Military capabilities, he believes, are "most credible and secure when founded in sovereign territory, airspace, or waters, or when the capabilities are encompassed completely within the design of the weapons system itself."

To illustrate this point, as well as the feasibility of non-space approaches, Cullen points to US inter-continental ballistic missile (ICBM) capabilities, which he describes as the "most credible deterrent to date against threats of sovereignty by near-peer adversaries because their navigation systems are completely self-contained" (i.e., US ICBM capabilities are not dependent upon information originating from outside of the US or allied territory). ICBMs, he explains, were initially designed to hit far-ranging targets without the support of space-based timing or navigation capabilities. Moreover, the non-space-based technologies and capabilities that support ICBMs have only improved and become more affordable in the time since the initial development of the ICBM.

Ultimately, Cullen is clear in his assertion that more secure and credible non-space approach alternatives exist and should be considered. Further solidifying his argument that approaches to military operations and capabilities should not, and do not have to, be entirely dependent on space, he posits that "terrestrial and airborne approaches may remain more financially efficient and as adaptable and responsive as less capable legacy weapon systems for generations to come."

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[8] Cullen; ViaSat, Inc.

[9] There are several military capabilities, in particular, that should not depend entirely on space-based approaches, according to Cullen. These include enemy surveillance and reconnaissance; human and machine navigation; tactical, operational, and strategic communications; coordination and timing; and threat indications and warning.

Developing Efficient and Effective Systems and Processes

Several contributors[10] suggest that surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings capabilities would benefit from more efficient and effective systems and processes. Contributors identify three areas that need improvement: integrating space operations and programs, overcoming innovation-stifling bureaucratic processes, and enhancing of space capability systems.

Integrating Space Operations and Programs

Dr. John Karpiscak III of the United States Army Geospatial Center and contributors from Harris Corporation highlight the need for improved integration of space operations and programs. Harris Corporation contributors describe US space programs as being too stove-piped and devoid of synergy. Notably, this is not the case in other domains, they explain, as the US has "been able to unlock the synergies across all the services and mission areas with a joint force" on the land, on the sea, and in the air. In the space domain, however, US space programs and operations are overly compartmentalized. This lack of synergy has clear consequences, they stress, because "to be truly effective in any domain requires all of our capabilities within that domain to understand each other's mission areas and leverage them in support of their own mission areas. Until we can do that, we take on more risk and we will not be as effective as we could be going forward." Karpiscak III similarly highlights the need for improved integration of US space programs and operations, arguing that "what we really need is a change in mindset on being able to integrate all of these things. It's not just one thing—we need to be able to integrate all of them."

Overcoming Bureaucracy

Marc Berkowitz of Lockheed Martin and Karpiscak III highlight the need for more efficient and effective approaches to bureaucracy. Karpiscak III identifies government bureaucracy, and the glacial pace of progress that deep-rooted bureaucracy causes, as a clear problem. Bureaucracy, he explains, "creates an incremental, slow to change culture due either to an inability, or perhaps even unwillingness, of the decision makers to understand how to properly exploit the technology, and the cost and imposed acquisition limitations by federal acquisition regulations, US policy, etc."

Berkowitz comments on the bureaucratic sources of the shortcomings of US space indications and warnings systems. He points to a lack of direction and coordination between USG and DoD agencies as the crux of the problem: "There is no clear delineation of authorities and responsibilities among US intelligence agencies to provide operations intelligence support for space indications and warnings. Nor are there adequate human and technical resources allocated for such support." To begin overcoming these institutional deficiencies, he suggests that "the US national security establishment could gain some understanding by going back to pre-space age basics for the creation of an effective space indications and warnings system."

Improving Space Capability Systems

Contributors from ViaSat, Inc. reflect on potential improvements to capability systems and approaches, focusing on satellite communication systems in particular. They posit a more robust approach, one in which "a multi-layered satellite architecture is available to deliver capability to users, agnostic of satellite, when needed." Highlighting the upside of this approach, they explain that "purpose-built

[10] Berkowitz; Harris Corporation; Karpiscak III; and ViaSat, Inc.

satellites are valuable for specific missions but the failure to take advantage of other systems can create gaps and seams. The [US] government can [instead] adopt an approach with satellite communication...in which the best available system is employed to meet mission requirements."

Conclusion

With the emergence of the space age, capabilities such as surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings have expanded exponentially, both in power and precision, as well as importance to national security and defense objectives. Pre-space age approaches provide the foundation for current approaches to these capabilities. Space-based manifestations have brought both clear advancements and new vulnerabilities with them.

The expert contributors to this report reflect on the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings capabilities before and after the advent of the space age. This reflection ultimately uncovers four general insights on current space operations.

- Controlling the "high ground" is still important.
- Space domain advancements can and should be capitalized on to maximize military effectiveness.
- There are risks and vulnerabilities associated with being too dependent on space-based approaches and capabilities.
- More efficient and effective space systems and processes are needed.

Subject Matter Expert Contributions

Major General (USAF ret.) James Armor[11]

Staff Vice President, Washington Operations
(Orbital ATK)

7 August 2017

WRITTEN RESPONSE

Need to normalize the use of space in military operations. Need resilience and alternate capabilities—that simple.

Marc Berkowitz

Vice President, Space Security
(Lockheed Martin)

12 June 2017

WRITTEN RESPONSE

None, with the exception of indications and warning (I&W). In the case of I&W, neither the President, the Commander of US Strategic Command, nor the Commander of the Joint Space Component Command have the ability (perhaps except for nuclear or certain kinetic attacks) to determine if the US is about to be or is under attack in space. While the National Space Defense Center was established to address this issue, the problem has not yet been solved. Indeed, there is no clear delineation of authorities and responsibilities among US intelligence agencies to provide operations intelligence support for space I&W. Nor are there adequate human and technical resources allocated for such support. Consider, for example, the numbers of intelligence personnel assigned to the Combined Air Operations Centers supporting US Central Command, US Pacific Command, or US European Command compared to those assigned to support the NSDC or Joint Space Operations Center. Consequently, the US national security establishment could gain some understanding by going back to pre-space age basics for the creation of an effective space I&W system.

[11] The response here represents the sole views of Armor, and is not intended to represent the position of Orbital ATK.

Dr. Damon Coletta & Lieutenant Colonel (USAF ret.) Deron Jackson

United States Air Force Academy

Dr. Damon Coletta
Professor of Political Science

Lieutenant Colonel (USAF ret.) Deron Jackson
Director, Eisenhower Center

8 August 2017

INTERVIEW TRANSCRIPT EXCERPT

Lt Gen Elder:[12] So, you're getting into the crux of the issue here. Realistically, you do have some thoughts that the preemptive approach might be required to be effective, and, by the way, I think that's partially what's driving this line of thinking that we need to start thinking about space as a warfighting domain, and in the way that we would of a conventional type domain. For example, if we thought that someone was posturing to take out our ability to defend ourselves, then we would feel compelled to take some kind of action. I think there's some reasonability to that, but that is still actually a little bit different than the way we would treat a warfighting domain. The fact that we would take action to defend ourselves is one thing, but once we start talking about preemptively operating that space, that's where it gets a little murky, I think.

So, I'm just pointing out what I think could be the issue. The reason we're having these conversations is to try and help us better understand the issues, and one of the things that we're looking at is the implications on the United States of treating space a warfighting domain. So, we're trying to understand all aspects of this, and my earlier question comes from the standpoint of enabling us to start thinking about the preemptive-type activities for defense that work well. If we inadvertently do something that leads an actor to think that we're about to take away something of theirs, how does the escalation control work? We haven't really talked that through, so I don't know if you guys have thought about that.

D. Jackson: This was actually part of the first roughly 15 years of debate within the nuclear strategy community, when they were trying to grapple with all these ideas that we now come back to look on as being deterrence theory. There is an article by Glen Snyder from the 1960s that contrasts deterrence and defense, and points out a dilemma that as you are building up your force structures, there are some things to help you defend and then there are some things to help you deter, but they're not the same systems, they're not interchangeable.

The dilemma is: at what point do you need to have capabilities that don't have any defensive value (i.e., capabilities that are purely offensive), and then how do you manage that mix, and then also how does your adversary see that as they are building up, and then can this relationship in anyway be construed as being stable? I think for the first at least 15 years, the scholars of that time were trying to wrestle with these problems, just as we now are trying to apply them in space, because there's not a uniform continuum of have options for people. It comes down to, at some point we may need to be preemptive. This was on the table in the early ages of the nuclear confrontation. So, ultimately, this problem is new in this domain, but it's not a new problem—the classic dilemma emerges, and the relationship between states goes through a certain phase.

D. Coletta: On the nuclear side, the way it gets resolved is that you end up moving towards launch on warning and the so called hair trigger strategy, so it makes the whole thing, I guess, less stable—

[12] Lieutenant General (ret.) Dr. Bob Elder (George Mason University)

you have lower crisis stability. I guess one of the things that you're liable to run in to if you are responsible for treating it as a warfighting domain is, at what point is it worth it? How unstable are you willing to go, and how unstable is the other side willing to go, because they have voice in this too?

Just the recognition that if you can't harden satellites, if you can't build the technology to allow them to run away, and if you start moving toward preemption, then you are starting to change the level of stability, and you are probably going to enter a competition in risk taking there. In the nuclear domain, you have agreements to kind of stop that competition—you have moves to reduce crisis stability on both sides, and then recognition that it is probably not a good idea, at least in the nuclear realm (it would probably also not end up being a good idea in the space realm, either). Then, eventually, you come to some kind of verifiable agreement to keep that instability in check. So, that's where that eventually goes.

D. Jackson: So, to come back to Lt Gen (ret) Dr. Elder's example of the home game for space, cities were the early targets and they couldn't be hardened or moved, so they had to come to grips with that dilemma. Space was essential in providing stability in that area, because it gave you some idea of what the other side's capability was when the early reconnaissance programs came on board. In the domain of attacks on aerial reconnaissance, the space domain was a necessary evolution for awareness of the other actor's capability, deployment patterns, and ultimately warning of launch so you weren't blind and, therefore, stuck not being able to identify an attack before it was really too late to do much about it. So, maintaining that role for space in space itself, and circling back on the idea of situational awareness and surveillance and maintaining a good picture of what's going on will, like it was during the nuclear era, probably be absolutely essential to maintaining some sort of stable relationship amongst powers in the space context.

D. Coletta: Just to dovetail on that, space was part of moving toward that so called verifiable agreement—"verifiable" being one of those ambiguous terms. Space was the key element of that. So, if you're going to defend assets in space, treating space as a warfighting environment by reducing crisis stability, then the next step, as long as the adversary also feels the heat, is moving towards some kind of verifiable agreement, not to eliminate instability but to somehow hold it in check. There is only so far that can go before it is against the interests of both sides. I guess, looking back at the nuclear era, that is where we would see that dynamic going over time.

Colonel Dr. Timothy Cullen[13]

Commandant and Dean
(School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base)

15 August 2017

WRITTEN RESPONSE

Military operations including enemy surveillance and reconnaissance; human and machine navigation; tactical, operational, and strategic communications; coordination and timing; and threat indications and warning should not be wholly dependent upon information or activity from a global commons, to include space. These capabilities can be most credible and secure when founded in sovereign territory, airspace, or waters or when the capabilities are encompassed completely within the design of the weapons system itself. For example, US inter-continental ballistic missiles remain the most credible deterrent to date against threats of sovereignty by near-peer adversaries because their navigation systems are completely self-contained—they are not dependent upon

[13] The views expressed in Cullen's answer to this question do not reflect the official policy or position of the United States Air Force, Department of Defense, or United States Government.

information originating from outside US or allied territory. US engineers designed ICBMs to hit their targets accurately from thousands of miles away without space timing or navigation support. The technology necessary for inertial navigation, data processing, active and passive detection systems, and timing have only improved in the decades since the development of the ICBM. The relative costs of these technologies has also declined rapidly, and despite reductions in the cost of space access, terrestrial and airborne approaches may remain more financially efficient and as adaptable and responsive as less capable legacy weapon systems for generations to come.

Dr. Malcolm Davis

Senior Analyst—Defence Strategy and Capability
(Australian Strategic Policy Institute)

21 August 2017

WRITTEN RESPONSE

Key Findings

- Space is becoming both contested and congested. The development of adversary 'counter-space capabilities' (kinetic and 'soft-kill' ASATs) threatens US Space Assurance.
- Although adversaries would have to consider the implications of US retaliation in the event of ASAT use, they are under less constraint in terms of introducing operational space weapons capabilities than the US and its allies in western liberal democratic states.
- Commercial space, and 'Space 2.0' open up both risks and opportunities. Space 2.0 technologies in particular make it easier to exploit space for military purposes in innovative new ways, but also see broader access to Space for a wider range of state and non-state actors including those who are unfriendly to the US.
- A key transformation to watch is the development of reusable launch capabilities – reusable rockets, airborne launch, and on the horizon, aerospace planes – which could dramatically lower cost, improve responsiveness and boost cost efficiencies in accessing and exploiting space. These potentially represent disruptive innovation that could fundamentally transform military space operations.
- The US needs to formulate an effective deterrence policy for space to dissuade adversary use of counter-space capabilities. This should be based around a combination of strengthened resilience, and rapid reconstitution of capabilities, the use where appropriate of terrestrial and 'near space' capabilities to fill gaps, and perhaps most controversially, the ability to undertake deterrence by punishment against an opponent's satellites using non-kinetic 'soft kill' ASAT capabilities.
- The loss of space capabilities – a 'day without space' – would force the US and its allies back to an older, less precise and more costly form of warfare. We would not be able to fight a 'Western way of war' which emphasizes, speed, precision effect and gaining and sustaining a knowledge edge over an opponent. Instead, the playing field would be levelled to an extent where an adversary could better exploit asymmetric capabilities more effectively.

Introduction

Humanity is approaching the 60th anniversary of the launch of Sputnik 1 (4th October, 1957) and with it, the beginning of the 'Space Age'. The last sixty years of Space activities has seen some key milestones. The most prominent of course was the first manned landing on the Moon on July 20th, 1969 with the crew of Apollo 11. Amazing achievements have been made exploring the Solar System with unmanned space probes to all the major planets. Our progress in undertaking space science has been matched by the widespread growth of networks of satellites that have played a fundamental role in transforming human society and enabling globalization in the latter decades of the 20th Century and into the 21st Century. The development of satellite technology is underpinned by global norms of behavior in space, with key legal documents such as the 1967 Outer Space Treaty

seeking to reduce the risk of an 'arms race in space' in what has traditionally been seen as a 'global commons' akin to Earth's oceans, or the advent of cyberspace.

However as is the case with the oceans and cyberspace, Space is not free of military activities and its perceived status as a global commons is being challenged. Since the 1960s Space has been 'militarized' with satellites used for a broad range of military purposes, including intelligence, surveillance and reconnaissance (ISR), communications, missile early warning and nuclear detection, meteorology and geodesy, and precision-navigation and timing (PNT) through systems like the US Global Positioning System (GPS) network. The growth of other states' military space capabilities continues to gather pace, providing similar capabilities for US allies and foes alike. Space has become a vital 'center of gravity' because access to space is essential in ensuring an ability to wage modern network-centric information-based warfare. In 2014, Brian Weeden of the Secure World Foundation published a seminal report,[14] 'Through a Glass, Darkly – Chinese, American and Russian Anti-Satellite Testing in Space', which highlighted Chinese and Russian development of anti-satellite (ASAT) weapons. There is broad consensus that traditional view of Space as a global commons is increasingly challenged. Space is becoming 'contested and congested', as space transitions from militarization to 'weaponisation'. The Obama Administration's policy[15] of Strategic Restraint through dissuading threats in Space has not prevented the development of increasingly sophisticated space weapons capabilities. The growing risk of space debris[16] further adds to a complex and challenging operational environment.

The US and its allies must respond to dramatic change in the Space domain, and deal decisively with the threat posed by adversaries which seek to challenge US and allied access to space. The notion[17] of a 'Pearl Harbor in Space' at the outset of a military conflict could deal a decisive blow to US military power, and allow an adversary to level the playing field, then bring their asymmetric terrestrial military capabilities to bear in a much more effective manner. In the absence of space support, the US (and its key allies which also depend on US Space systems) would be forced back to an older and cruder approach to the use of force that is more costly in lives and platforms, is based on attrition, and is likely to be prolonged and with little certainty of military success.

This paper will explore some key issues related to Space as a contested domain. These include: what are the motivations and impacts of an opponent contesting space access; the implications of commercial space for US and allied space security; the role of Space in US deterrence strategy; and lessons emerging from other domains in terms of 'C4ISR-PNT' capabilities. It seeks to inform discussion and debate on the implications of Contested Space Operations as part of a Strategic Multi-Layer Assessment on this issue for US Air Force Space Command (AFSPC) in cooperation with US Strategic Command (USSTRATCOM) and Headquarters Air Force.

What insight on current space operations can we gain from understanding the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warnings before the advent of the space age?

The clearest and most important aspects we take from pre-Space age operations is an understanding that Space opens up a much greater ability to understand the battlespace, control forces, and apply precision effect against an opponent in both 'time and space' in a manner that maximizes military effectiveness. Prior to the space age (and even in the early period of the Space age, for example, during the Vietnam War), the use of military force was unable to exploit a clear knowledge edge over an opponent at most times during war, at least at the operational level of warfare. There was much greater emphasis on brute force application – either with the greater reliance on nuclear weapons to offset quantitatively superior Warsaw Pact forces in Europe – or the use of attrition in battle, such as in Vietnam. War was a blunt and imprecise affair that was more akin to the battles of the Second World War than modern information-age warfare.

[14] https://swfound.org/media/167224/through_a_glass_darkly_march2014.pdf
[15] https://www.aspistrategist.org.au/space-security-obama/
[16] https://www.orbitaldebris.jsc.nasa.gov/
[17] http://www.newsweek.com/2016/05/13/china-us-space-wars-455284.html

In the 21st Century, war is still a bloody contest, and the arrival of information-age warfare does not herald a fundamental change in the nature of war. Certainly the character and conduct of war *has* changed. Gaining and maintaining a knowledge edge over an opponent allows us to use military power with greater speed and precision than ever before, and understand a battlespace more rapidly. The 'fog of war' is still present, and 'friction' still affects military actions. Clausewitz remains relevant, and geography still matters. But certainly the use of space capabilities allows more effective command and control of forces across a geographically dispersed region with much greater effectiveness. For example, the use of 'Blue Force Tracker' in the 2003 Iraq War demonstrates the value of satellite communications and precision-navigation and timing. The ability to deliver precision munitions guided by GPS satellites orbiting at Medium Earth Orbit (MEO) represents a new type of capability never before achieved, and the 2003 Iraq War has often been described as the first 'space war' as a result.

However, it is important to caveat these observations. The use of space capabilities in previous operations such as the 1991 Persian Gulf War, the 1999 Kosovo conflict, and the 2003 Iraq War, has not occurred against a peer adversary, equipped with their own space capabilities, and an ability to interfere or threaten our own. In these conflicts, and in Afghanistan from 2001, the US had a high degree of space dominance. In a future conflict, against a peer adversary such as Russia or China, there is no guarantee that the US and its allies will be able to gain or maintain this dominance. It is more likely that we will have to struggle to gain and sustain space dominance, we may only have it in local areas, or may have to regain it if lost due to an adversary's counter-space operations. That would limit our ability to sustain a knowledge edge over an opponent. Adversary threats to our space capabilities if successfully applied could see us forced back into an older and more costly form of conflict.

This suggests a vital requirement will be to gain and maintain control of space from the outset. Our adversaries will seek to achieve the same outcome. The success or failure of terrestrial military operations is likely to be decided most fundamentally by which side can successfully control and deny space capabilities to the other over the course of a conflict. The conclusion of the war – victory or defeat – will be decided in space. Space in this sense, is a true center of gravity that must be defended.

Conclusion

It is an undeniable reality that space as an operational environment is becoming both contested and congested. Contestability is a serious challenge for US and allied military capabilities, and our adversaries are not likely to be restrained by perceived international norms, or even arms control or legal documents. We should expect that immediately prior to, or at the outset of a future military conflict, our critical space systems will come under threat from adversary counter-space capabilities in a desire to level the playing field and take away our ability to gain and sustain a knowledge edge that is so critical to fighting a Western way of war. The transformation of the space sector, with the rise of 'Space 2.0' is an important development that could fundamentally change how payload is launched into orbit, and how space operations are undertaken. As these technologies mature, the importance of new paradigms that emphasize the 'small, many and low cost' over 'large, expensive and few' introduce new ways of undertaking militarily relevant space operations, but also proliferate potential counter-space threats. Revolutionary advances in space launch, such as reusable rockets, airborne launch and ultimately aerospace planes, could see a fundamental shift in space access over the next twenty years. However, it is fanciful to suggest that these technologies can remain the sole purview of the US and its allies. Our adversaries will develop these capabilities too, making their access to space, quicker, cheaper and more effective. In doing so, there will be greater ease for counter-space threats to become a reality.

Faulconer Consulting Group

Walt Faulconer
President

Mike Bowker
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Associate

15 August 2017

WRITTEN RESPONSE

Research the fundamental principles prior to the space age and understand how those are being addressed in the current schema. This would be a good academic effort to study.

Jonathan D. Fox

Strategic Foresight Practitioner and Forecaster
(Defense Threat Reduction Agency Global Futures Office)

21 July 2017

WRITTEN RESPONSE

Pre Space-Faring Era Precedents

To admit that free and unhindered innocent navigation and utilization of space is as elemental to global order as rule-based transit of the High Seas strains neither credulity nor the rules of legal interpretation. To equate the two principles demonstrates the analogous nature of these two distinct and disparate physical realms. One is essential as a highway for the maintenance of global commerce and trade; the other is home to critical infrastructure for the effective operation of increasingly dependent civilian financial and governmental information exchange, management and communication functions (including the navigation, safety and security of both ocean-borne and land transport). Undisturbed innocent passage of vessels properly registered and openly identifiable, subject to detailed and recognized limitations, is a freedom exercised by all sovereign nations, the violation of this precept being one of the oldest justifications for war; this freedom applies to both sea and space, particularly as to those space-faring vessels that perform a governmental or military function. Likewise, the traditional obligation of mariners to render aid to those in peril on the sea, irrespective of nationality, has been extended to space through the wording of Article V of the Outer Space Treaty and has never been questioned in state practice. All of these are existing analogous functions found in both of these physical realms, addressing similar legal obligations and dangers.

This does not imply an unerring and ironclad commitment to traditional terrestrial precedent as unalterably governing all matters of celestial navigation and exploration, particularly where conflicting or outdated precedents exist. Law and state practice serve a changing reality and themselves can change to reflect that reality. Private property ownership and public sovereignty both once implied inviolable possession to the core of the Earth and to the deepest reaches of space; modern law now articulates restrictions to that legal power. An analogous example

would be that of allowing the undisturbed freedom of flight over the High Seas as found in Article 2 of the 1958 Geneva Convention on the High Seas.

The issue of competing precedent assumes expanded importance when we consider that the very nature of the future exploration of space may have more in common with Elizabethan England than the 20th Century of NASA. In more than a few ways, that time provides significant lessons in the potential path the future (20+ year) space environment might develop. When young Elizabeth the First ascended her throne, England was bankrupt and divided, surrounded by enemies. She replenished the country's treasury and kept its enemies at bay by enlisting and rewarding private sector gamblers and entrepreneurs like the "Sea Beggars" led by Drake, Hawkins, Raleigh and the like. Unable to bear the cost of a standing navy or official merchant fleet, but dependent upon maritime trade and new markets for very survival, Elizabeth's reign saw the government licensing, sponsorship and approval of these functions to privatized risk takers who would bear risk of loss in exchange for a guaranteed percentage of such profit as might ultimately accrue. Along with the legal protection afforded the "Companies of Gentlemen Adventurers" by official recognition (not the least of which was the relief from treatment as pirates by the other competing sea-faring powers), this relationship guaranteed a percentage of the profit to the Crown. By the time Elizabeth passed, England's coffers had been replenished by this mutually rewarding relationship, a permanent Navy was on the verge of establishment and the Companies had founded the beginnings of the New World colonies. With global governments facing not dissimilar financial constraints likely to worsen over the next 20-30 years, the privatization of space becomes an increasingly likely possibility, and the Elizabethan economic/commercial governance model becomes newly relevant to more than Masterpiece Theater audiences.

For this model to mature, there are three prerequisites. The first is almost in place- a burgeoning private sector space program increasingly adept and backed by sufficient venture capital to absorb the risks attendant with such speculation. The second is evolving- global governments achieving the uncomfortable recognition that economic expansion, risk-taking and innovation necessary for systemic survival is beyond restriction to their public resources and ability. The third element is yet insufficiently matured and requires a definitive answer before this path becomes feasible-is there sufficient potential economic reward attendant in the privatized exploitation of space that justifies the undertaken risk and required commitment? At this point, any answer would be purely speculative. Until such an answer can be effectively formulated, risk/benefit analysis associated with the potential efficacy of the privatization of space can't really be undertaken. And without this risk benefit analysis, there can't be a determination as to whether future rules governing the navigation and exploitation of space follows one of two potential paths, the communal/humanitarian model outlined in the Outer Space Treaty of 1967 (space as *mare liberum,"*free to all and belonging to none") or a commercial rights administered by state parties (i.e., "Exclusive Economic Zone") and associated international mining rights authority model analogous to the 1982 Law of the Sea Treaty (UNCLOSIII).

Until a definitive risk/benefit analysis can be undertaken, the lessons learned from traditional state practice and evolved norms of behavior (particularly in maritime law and the Law of the Sea) default by analogy to traditional maritime law as the governing rules of behavior in space matters. And of these, two remain foundational. The first is that innocent right of passage by appropriately registered and lawfully operated space faring vessels (either privately or governmentally owned), whether civilian or military in nature, is an inherent right available to and exercisable by all. The second is that the denial of this right, unless allowable by state practice and international understanding, is a grave breach of international law and justification for a redressing use of appropriate force to coerce compliance with the law. These understandings are clearly derived from the traditional law of nations and are logically transferable from sea to space.

Harris Corporation

Brigadier General (USAF ret.) Thomas F. Gould
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Vice President, Senior Executive Account Manager for National Security Future Architectures

15 September 2017

WRITTEN RESPONSE

Simply stated...the overall importance of controlling the high ground and keeping lines of communications open. As the new "high ground," and medium through which an increasing percentage of our communications flows, controlling space will be critical. Before space was utilized, superior surveillance, reconnaissance, and indications and warnings were typically tied to controlling the high ground, initially terrestrially, and later in the air. Space will be no different.

Navigation and timing were typically tied to one's ability to have line of sight with a "known" reference...whether physical or via data. Like surveillance, reconnaissance, and indications and warnings, controlling or performing these functions from the high ground offers the simplest and most wide-spread solution.

Assured communications relied on controlling the infrastructure carrying communications; ensuring there were multiple paths and techniques available to communicate; and that the information was protected en route. Space offers a highly efficient and flexible path to flow information through, but in many ways, is just another medium.

Bottom-line: Controlling the high ground is critical to surveillance, reconnaissance and I&W, making space situational awareness and space superiority absolutely critical to these functions. Space also offers another path in support of redundant, robust, and protected lines of communications in support of command and control (C2), navigation, and timing.

INTERVIEW TRANSCRIPT EXCERPT

Interviewer: Okay. Very interesting. The last sentence on the first page and then the first sentence on the second page, if I can indulge by asking, what is likely a billion-dollar question, but is there a feasible solution to the existential problem you're describing there with converting what is supportive capabilities into what would be the proper first steps that are deterrent and offensive capabilities in space.

T. Gould: Okay, so there's two issues. One is our current capabilities were designed to operate in a domain that was a support domain versus a real warfighting domain. The second part of the sentence is more about non-state actors or second-tier state actors who are never going to be able to go toe-to-toe with us in space. The idea of being, their biggest bang for the buck will be to disrupt operations in space versus try to compete with us in space. I would equate this, and I think we might have talked about this during the first discussion, The Germans were never going to achieve maritime domain superiority, but the U-Boats could certainly disrupted the domain and forced us to completely rethink and reallocate resources early in WWII to counter their effort.

Everyone knows space gives us an asymmetric advantage and that they will have to address that. Depending on their capabilities, I suspect some nations will look to disrupt our operations versus trying to compete with us directly to achieve space superiority. And as a nation, are we prepared to overcome that disruption to space? Certainly Jen has a lot of experience in that particular area

with some of the missions she worked. I see there's two different things. I don't know if I've answered your question. But I think you were talking about how do we go from an equipment that is meant to support the war fighter to equipment that frankly fights in space?

Interviewer: Correct.

T. Gould: Okay. Well, again, if the capability is not dual-use, the first thing that has to happen is for the USG and USAF…at the appropriate classifications…to tell industry these are the things we need. I will tell you that the space domain is no different than the air domain when it comes to the key mission areas. We talk about space superiority, offensive space control, defensive space control. We need to talk about offensive and defensive counter space, suppression of enemy space defenses, and space intelligence, surveillance, and reconnaissance.

I mean when you take that mindset from the air domain, you can pull it to the space domain and then you can quickly derive the types of capabilities you will need to achieve those effects…obviously lots of milestones between now and then, but it starts with, "Okay, what are our mission areas? What are the capabilities we need to support those mission areas?" and then move out. In the meantime, you've got to find a way to make the systems you have in that domain sort of support those lines and effort and make them a little more survivable than they currently are.

[…]

Interviewer: Okay. I think we can move on. Next question here. I think this also on the point you made about "lessons learned." We've heard a couple of times is landlines compared to cell phones and how other countries have skipped with that and setting up all the landline structure and simply using cell phones for communication. I'm wondering if maybe you have other examples of these lessons learned that you could speak to.

T. Gould: I'll equate it to the air domain, the Air Force is all about gaining and maintaining your superiority. If that's the case, then you would think the Air Force would apply that across the domain and take care of that all. When in fact, we only achieve or seek to achieve and maintain air superiority in select places at select times. The rest of the time, the FAA monitors the air space. Domain situation awareness is outsourced to a government agency, or in some cases, it could be a private agency in the future. The same thing would be true in space. Is there really a reason for the space domain, writ large, to be entirely managed by the Department of Defense and others. Or are there certain missions and parts of the domain that will be managed by the government…and when required, the DoD to achieve space superiority, at a time and place of our choosing.

When you think about situational awareness of the space domain. does a nation have to do it with its own space situational awareness assets or does it rely on somebody else or another part of its government to do that so they can concentrate on mission critical areas of the domain? I think that's where we're going on this particular answer.

[…]

Interviewer: Okay. Thank you. Okay. At the end of page four, you mentioned the new high ground. I'm just wondering if that taxonomy refer to different orbits? What exactly do you mean by high ground? It's the last question on page four. What insight on current space operations can we gain from understanding the process used for surveillance, etcetera? The first sentence, the first couple of sentences of your answer simply stated the overall importance of controlling the high ground and keeping the lines of communication open.

T. Gould: Sure. You want to understand where in the space domain is considered the high ground?

Interviewer: Correct.

T. Gould: I don't mean to be flippant, but since space is infinite in depth, who's ever the furthest from the Earth in some ways, would own the high ground. The high ground means you've isolated the threat below you, from a military perspective. When you're on the ground, the threats come from all around you. Right? It's very difficult to defend yourself. As you move up, then you can really isolate the threat from one direction, it's much easier to mitigate that threat and it also allows you to see more broadly with regards to ISR. For example, during World War I, our original airplanes, and frankly before the airplanes, the air domain was used as an ISR domain because we put balloons over the battle field to understand where everybody was. Right?

The team that had the best situation awareness of the situation on the ground would win the battle. It's no different in space. As you get up high in space, whether with a geosynchronous satellite or a lower earth orbit satellite that is collecting intelligence surveillance & reconnaissance…it gives us better insight and an advantage in the tactical or operational situation below. Eventually, someone will is going to try to come and take that away from us. That's one reason space is going to be a war-fighting domain.

The LEO orbit is the most vulnerable. It'll move out to the GEO or highly elliptical domain going forward. I don't know if I've answered your question on that particular item. But for intelligence, surveillance, and reconnaissance in the space domain, the high ground keeps moving up and will continue to be contested. Whoever can achieve the highest will always have the best space situational awareness. Whoever has the best space situational awareness has a military advantage in very simplistic terms over the adversary. For navigation as I mentioned, you need line of sight of something else. In general, all we've done is made the line of sight a little higher through our GPS satellites. Being in a satellite allows you to have a line of sight to that satellite from frankly almost 180 degrees of the air surface so you can navigate anywhere in that area which is much better.

From a navigation standpoint, It doesn't need to go any higher than it currently is. I think navigation and timing synchronization, and communications are the same going forward. Surveillance and reconnaissance will always go higher. For navigation, communication, timing and synchronization, we just need to have line of sight. Literally, you could put something on the moon. As long as you could see the moon, you'd have a timing reference. It would be a timing reference that might be difficult to knock out….if you have to knock it out physically…but the signal could be interfered with.

Interviewer: This is very interesting point that I have to encounter, and it is interesting how it's getting higher. Those were all the questions I had, but before I open up the floor for other questions, I just want to see if there was anything you and Jennifer would like to reemphasize here or any point you'd like to extend on or a tertiary point you'd want to make?

T. Gould: So two points. One, from a deterrence policy perspective, if we're going to make it a war-fighting domain, we have to have a well thought out deterrent policy. That policy needs to be communicated through the appropriate channels and integrated at the strategic level with our other deterrent policies going forward. The second thing is now that we've called it a war-fighting domain. We need to take the gloves off and treat it like a war-fighting domain.

Jen might be able to talk to this better. But we are so, stove piped with our programs within space. There's very little synergy. The reason we're effective on the ground, sea and in the air as is because we've been able to unlock the synergies across all the services and mission areas with a joint force. In space, for whatever reason, everything is highly compartmentalized or stove piped. To be truly effective in any domain requires all of our capabilities within that domain to understand each other's mission areas and leverage them in support of their own mission areas. Until we can do that, we take on more risk and we will not be as effective as we could be going forward.

Then with regards to space as a war-fighting domain…if we're war-fighting domain, then let's embrace the concept, articulate the requirements and ask the industry's help to move out towards meeting those requirements.

J. Moore: The one thing I would add is that you take a big leap by saying space is now war-fighting domain without necessarily, I think, considering the cost of preparing the people to fight in that domain. We seem to think we can create very high-tech capable space systems and that the value from those systems is intrinsic in the good technology, where it truly comes from the people who operate a few things. I think right alongside pushing for a new technology and new capabilities in space, we have to build up the infrastructure and the capabilities for the operators who will actually be responsible for bringing the capabilities to bare. We haven't done that traditionally. Those are the first things that generally they cut from programs, a lot of times in the last minute add or consideration. I would say that that's a very different approach in the air community. There's a great focus on preparation of the pilot. It's another point that I think we have to take into account.

T. Gould: Yeah that is a good observation and to Jen's point, there's a whole organize train and equip aspect of operating in a domain that's a war fighting domain versus operating a domain that's a support domain to the other domains. Jen is actually leading an effort to operationalize the training for operators in space. In many ways, it mirrors what we did in the air domain or have been doing in the air domain.

Theresa Hitchens

Senior Research Associate
(Center for International and Security Studies at Maryland)

19 July 2017

WRITTEN RESPONSE

I don't understand this question. Although, I would say that one always needs to have a Plan B, and even a Plan C. If space systems are compromised, are there earlier approaches, other tech that can do the same job? And do we have the skill sets still to use those methodologies? Are people trained in back-up methods (like a slide rule)?

Dr. John Karpiscak III

Physical Scientist
(United States Army Geospatial Center)

19 July 2017

INTERVIEW TRANSCRIPT EXCERPT

Interviewer: Given all of this rapidly developing technology, plus the increasing number of actors that are getting involved in the space domain, how should space feature in US deterrence strategy? And what kind of changes to US deterrence strategy might be needed to account for a rapidly evolving space domain?

J. Karpiscak III: That is probably the most important question on your list. I think you can look at this a couple different ways. Overall, I think there are 3 key factors: preemption, integration of thought, and monopolization.

By preemption I mean getting people to work with us and to expose the fact that we can see things in country X and elicit a worldwide response. We can do that via continual monitoring of certain areas and sharing the data. This is not just from a military weapon standpoint (i.e., monitoring for new missiles new launch complexes) but also to reveal things like the extent of resource depletion in a country that might be going to war with another country. From space, we can monitor all sorts of resources to identify indicators and warnings of resource depletion—for example, we can monitor many important factors regarding water, minerals, and forests. Resource depletion has always been a historical reason of going to war, for one reason or another, so the more we can share or understand the extent of those resources and how they're being depleted, the better the likelihood that would be able to intervene and step in and address the issue before it escalates into a war between the two countries. I think this, in terms of deterrence—is probably the biggest thing that we can do—something in the form of preemption.

Another important factor is the integration of thoughts, especially for the active military or as a reserve officer, to avoid two-dimensional thinking and have an integrated approach to deterrence in whatever you do rather than making space some kind of an afterthought.

With respect to the third factor, monopolization, the way to maintain multi-domain deterrence is simply to be the best at it and have everybody come to you. To do so, you have to make space access more affordable to people and provide more incentive to partner with the US and other countries and organizations. But we also have to understand that the big caveat here is: regardless of what you do, you'll never ever be able to prevent a bad actor from getting access to space—you only may be able to limit their access for time or limit their access through another party. Like I said earlier, the gun control example is probably the best one. I think with the rate of technological change coupled with other things like additive manufacturing, the game has changed permanently with regards to launch and other things.

But along those lines too, I would think that still the most important need that we have at this point is probably detection and warning. Not limited to ICBMs or spikes in EM transmissions prior to the start of aggressive actions, but also with regard to space debris and the occasional asteroid impact. I like looking at the things like the Chelyabinsk meteorite. How did that get through? Well, it was too small for survey telescopes and it "came out of the sun." Nobody found it. But this kind of thing is going to happen again. So, detection and warning really needs to be rolled in to our overall space strategy.

Interviewer: So, you mentioned preemption, and a big part of preemption would seemingly be monitoring and assessing. You also mentioned detection and warning. I think these two issues segue nicely into the next question, which is: what insight on current space operations can we gain from understanding the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warning before the advent of the space age?

J. Karpiscak III: Historically, bureaucracy remains at a glacial pace, regardless, though, I think of what technologies are brought to bear. Personally, I think we need to change the mindset because I've noticed that we have far too many people in the bureaucracy that are too preoccupied with accountability and authority to act, rather than being more concerned with doing the right thing. One thing I've also noticed in my nearly 60 years of life is that as you get older, you tend to go with what you know rather than exploit new capabilities, which is why most people over 60 years old still have the clamshell cellphones and everybody under 60 has smartphones. This creates an incremental, slow to change culture due either to an inability, or perhaps even unwillingness, of

the decision makers to understand how to properly exploit the technology, and the cost and imposed acquisition limitations by federal acquisition regulations, US policy, etc.

A good example is if you remember in the movie True Lies with Arnold Schwarzenegger, they put a GPS tracker in the purse of the leading actress? Well, back in the early 1990s, I helped develop GPS-based tracking beacons, and somebody from the movie came in to check on what new kinds of stuff was going on in the laboratory I was working at, at the time. They saw that we were working on GPS-based tracking beacons and decided to incorporate it (with a few Hollywood tweaks), into the movie. But we took things like this, like GPS-based tracking beacons, to the FAA in 1994 and said "hey, wouldn't this really be a great thing to put on aircraft so if you ever have an aircraft that is losing altitude below the radar, you can track it." At that time, the FAA passed because the device wasn't created at the FAA. Unfortunately, that kind of attitude still permeates the government.

What we really need is a change in mindset on being able to integrate all of these things. It's not just one thing—we need to be able to integrate all of them. This is why I've always been a fan of MASINT because it involves a lot of other INTs, which enables you to more properly and in depth assess a certain situation or capability.

[…]

Interviewer: Thank you so much for working through all of those questions with me. One thing we do at the end of these interviews is ask a more general question, which I will ask you as well. Is there anything that I haven't asked you that I should have, or is there any last point that you would like to highlight or conclude with?

J. Karpiscak III: Well, something that I think should probably be addressed, is bringing space technology down to the tactical war fighter level so things that are seen up at the very high levels can be brought down to the level of the individual soldier, individual fighting men and women. I think this is important because, on the ground, they may not be able to see over a hill, but if some device can see that over the other side of that hill is a bunch of tanks or some artillery, then it would be of immense help to them and would assist them in conducting their operations to either attack something or avoid something.

From a warfighter perspective, the further down that you can provide information that is of use to the tactical warfighter and within the timeframe for him or her to use it, the better. We always talk about getting inside and enemy's decision cycle. Well, that's just as true at the tactical level as it is at the operational and strategic levels. So, whatever we can do to provide something that will let warfighters know what's on the other side of that hill or what might be coming their way in terms of an intermediate range ballistic missile, would be helpful.

Dr. Krishna Sampigethaya[18]

Associate Director for Cyber Security
(United Technologies Research Center)

8 September 2017

WRITTEN RESPONSE

From Before the Advent of Space Age to Current State-of-the-Art: Some Insights

What insight on current space operations can we gain from understanding the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warning before the advent of the space age? We discuss some insights on current space operations by reviewing navigation, surveillance, and reconnaissance before space age.

Navigation

Let's consider the area of navigation and timing, both of which have always made us look up to the skies for guidance. Celestial navigation was the primary means of air, land, and sea navigation, until the advent of space age demoted it to a secondary means. This approach includes performing geometry-based calculations based on celestial bodies and their alignment with respect to the visible horizon on Earth to compute a current position, in terms of latitude and longitude, on Earth; typically we can get a position fix with at least three to five stars at night time.

Current GPS is built on this classic means of navigation. Artificial satellite design derives from celestial mechanics theory and motion of celestial satellites such as the Moon. We learnt how to launch an artificial satellite and place it as an Earth-orbiting reference point. Because artificial satellites are much smaller than celestial objects, they are not always visible to the human-eye on Earth. Hence, they actively transmit radio signals towards Earth-based receivers that capture these transmitted signals. An orbiting satellite is not always in range of a given receiver on Earth, so a network of over 24 satellites, in at least 6 different orbits at an altitude of about 13,000 miles, ensures at least 8 satellites are within receiving range of any GPS receiver in the US to compute a 3- dimensional (latitude, longitude, and geometric altitude) position and the current global time. We need command-and-control of these artificial satellites, so an uplink channel is included.

Compared to celestial navigation, GPS has distinct advantages: it provides altitude and timing data; it is more scalable, accurate, and granular; and, no human intervention is needed for position computing. On the other hand, GPS has security weaknesses not present in celestial navigation. An attacker is able to: directly target the GPS satellites; observe, disrupt, or jam any signals and data used for navigation; and, exploit ground systems. Celestial navigation, on the other hand, is a passive means, i.e., not relying on signals, based on celestial objects and geometrical measurements and estimations by a human on Earth; hence, immune to cyberattacks.

Efforts are ongoing to make GPS-based navigation more robust and resilient to cyber and cyber- physical attacks using celestial navigation as a basis; for example, combining it with a celestial navigation sensor, inertial measurement unit, and barometric altimeter. These additional sensing data sources, which are not dependent on external signals and data, would require attacker to change physics of a GPS receiver and its host, not just the related signals and the data.

Reconnaissance and Surveillance

Before space age, ground- and air-based sensors were used for reconnaissance and surveillance. Stealthy high-altitude manned aircraft, such as the U-2, carrying a high-resolution camera onboard was the primary means. Satellite-based reconnaissance and surveillance capabilities emerged from the search for a better option than U-2.

[18] Sampigethaya's personal views, and not those of his organization, are represented in his contribution to this report.

Robustness to surface-to-air weapons, unmanned operation, and higher accuracy and stealth made satellites the better option. In addition, satellites added the capability of real-time communication using radio signals to send collected data to the ground systems in real-time. UAV in the air domain offers a hybrid between U-2 and satellite-based surveillance and reconnaissance capabilities; it is controlled by human pilots, more cost-effective, adaptive, and accurate, but relies on satellites for its navigation, timing, and communications.

Victoria Samson

Washington Office Director
(Secure World Foundation)

22 August 2017

INTERVIEW TRANSCRIPT EXCERPT

Interviewer: Okay. Great. So, let's transition to the last question that I sent over to you. What insight on current space operations can we gain from understanding the approaches used for surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warning before the advent of the space age?

V. Samson: To be honest, I'm not entirely sure I understand this question. Are you asking if there are things that we used to do in the past that we could use today should space fail? Or, what are you looking for here?

Interviewer: So, are there any insights, lessons learned, successes, failures, etc. that we could derive from past efforts and approaches, maybe before our heavy involvement in the space domain, that could provide insight on our current space operations? Similar to the question that I asked you earlier about lessons learned from deterrence efforts in the maritime domain that might be relevant to deterrence in the space domain, but in this case with respect to surveillance, reconnaissance, navigation, communication, timing synchronization, and indications and warning.

V. Samson: That's a tough question because before you had space for things like surveillance and reconnaissance, you were limited to air, and you were limited to whether you could have overflight capabilities. One of the nice things about space, is that it established from the very, very beginning with Sputnik that overflight was not going to be a concern, and that overflight would be okay. So, that would be something you would have to work out if you went back to a time before space. I'm not necessarily a maritime expert in navigation, but with respect to things like navigation, prior to the level of involvement in space that we are now accustomed to, if you just think back to what they used to use for navigation, they actually did use space—they used stars. Obviously the use of stars for navigation is not as predictable as our current navigation capabilities stemming from space, but it did work so long as you had access to the stars. Again, I'm biased, but it's the same idea as using line of sight for landing planes. The use of line of sight for landing planes could be done, and it was done well before radar started being used to get a better situational picture.

So, I think these sort of things—surveillance, reconnaissance, navigation—are all capabilities we had prior—they were just not as dependable without space. With respect to timing synchronization, I can't really say for sure because I have no idea how they used to do it. With respect to indications and warnings, this ties back to surveillance, as well, but there was that capability before space and it required you have boots on the ground, people in the air, or some sort of capability nearby, and I think that leads to a whole other level of complication and discussion. It doesn't mean it can't be done, but it's difficult to do.

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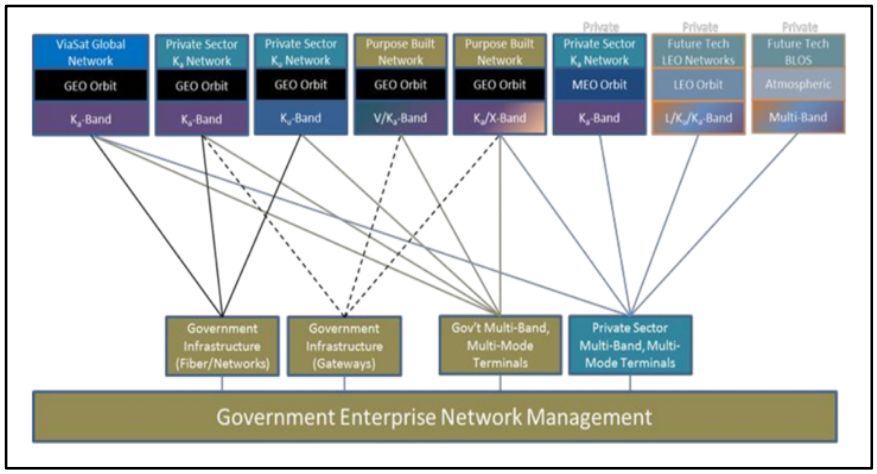
WRITTEN RESPONSE EXCERPT

Terrestrial operations have taken advantage of information superiority and pervasive battlespace awareness. This fact is central to how the US executes combat operations in Iraq and Afghanistan. For instance, persistent monitoring of high threat areas in combat zones provides commanders insight into movements and activities of adversaries. In planning missions, combat air patrols are on station in a theater of operations to support ground force movements and missions. If troops are in danger or a high-value target is identified, the correct aircraft with the right weapons are sent to address the threat while other aircraft backfill their previous assigned area of patrol. This carefully orchestrated activity provides combat effects when and where needed using the best available aircraft, whether that is a USAF F-16 or a Navy F-18, to execute the mission. Space operations could benefit from adopting a similar approach in which a multi-layered satellite architecture is available to deliver capability to users, agnostic of satellite, when needed. Purpose-built satellites are valuable for specific missions but the failure to take advantage of other systems can create gaps and seams. The government can adopt an approach with Satcom similar to that illustrated above with combat strike aircraft in which the best available system is employed to meet mission requirements.



The military/government could improve mission effectiveness, increase flexibility and enhance resilience of space services by leveraging commercial and allied space services. The traditional view of Government and Military Satcom assumes historically high cost, limited supply, and the lack of survivability and protection. ViaSat believes the highest network resiliency is achieved through a layered heterogeneous network with a mixture of multiple private sector and purpose-built Satcom systems, which provides the greatest performance and mission assurance. A distributed system provides much greater resistance across all threat vectors than any single network can, and ViaSat has implemented this concept through our Best Available Network (BAN).

To maximize mission assurance, an architecture study would consider the entire set of systems comprising a communications network. ViaSat views resilience and mission assurance as layered concepts that can be measured

in many ways, and at many levels. Individual Satcom networks can have different levels of resilience, based on layered attributes within the network, and individual networks can be layered together to form a multi-network ecosystem. From the users perspective, the goal is easy access to a network of networks where multiple transport options are available at any given time and at any given location, including: multiple transponders/beams from one satellite; multiple satellites from one private sector provider; multiple Satcom networks from multiple different private sector providers; and even a mix of government (AEHF, WGS, leased Ku, etc.) and multiple private sector Satcom networks.

We seek to maximize overall mission assurance by layering heterogeneous networks with different attributes (orbital regimes, frequencies, beam sizes, waveforms, gateways, networking protocols, network management and terrestrial networks) into a cohesive user experience. In building VGNet® we developed expertise evaluating all elements of individual networks, and combinations of networks operating together.

Our experience has shown us that while single networks can provide good mission assurance, combinations of networks—with terminals capable of roaming and enterprise network management capable of operating across multiple transport paths are needed to maximize network robustness, capability and resilience. The figure shows an example network architecture including sovereign and private sector elements.

The combined communications systems may employ many different orbital regimes (geostationary or, geosynchronous, medium- and low-earth orbits), many different frequencies (L-, X-, Ku-, Ka-, and V- bands), many different waveforms, networking protocols, gateway architectures, terminals and network management and cyber defense mechanisms. As the network is made up of many disparate elements, it introduces cost and complexity on an adversary that would attempt to disrupt/exploit it: no single attack vector is likely to be successful against all the component networks in any one dimension (jamming, cyber, intercept, etc.), therefore the adversary must develop and field multiple capabilities to have any chance of disrupting this type of heterogeneous network. These networks include both private sector and government purpose built assets, and are joined together by multiple different types of terminals (some commercial, some government) that can roam across many different networks. It's unlikely that a single terminal will support all possible networks, but maximizing mission assurance requires a terminal (or set of terminals) that can roam across as many networks and frequencies as feasible and affordable. These networks also require a Government Enterprise Management System that can interact with the individual network management systems. Individual systems that are inherently resilient result in a capability that easiest to use, if it can support all needs and counter all threats. The reality is that no single system is sufficient to counter all threats. Individual systems can be rated on their resilience against any given threat, and then a combined together to form a more complex network that is more resilient that any of the component network.