

AIR WAR COLLEGE

AIR UNIVERSITY

DETERRENCE 2035 –THE ROLE OF TRANSPARENCY AND
DIVERSITY IN A WORLD OF NANOSATS

by

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Biography

Lt Col Miguel J. Colón was commissioned through the Air Force Reserve Officer Training Corps (ROTC), University of Puerto Rico, in August 1989 as a Distinguished Graduate. He entered active duty and attended the undergraduate space training program at Lowry AFB Colorado earning a follow-on assignment to Falcon AFB, Colorado. He spent the next 4 years as a satellite link ground controller and satellite commander for DoD and NATO communications satellites. While at Falcon AFB, he advanced through the ranks as an instructor, evaluator and flight commander. In 1994, Lt Col Colón was board selected for nuclear duty at the 400th Strategic Missile Squadron, F.E. Warren AFB, the only squadron in the Air Force employing the peacekeeper ICBM. He was selected by the Operations Group commander as the Senior Evaluator Peacekeeper ICBM combat crew at the 90th Missile wing, a position reserved for the top crewmember in the wing. Lt Col Colón is a graduate of the United States Air Force Weapons Instructor Course (WIC). He served as a weapons officer at the 32d Air Operations Squadron at Ramstein AFB, Germany. During the next three years, he directly supported Operation Northern Watch, Deliberate Forge, and Operation Allied Force. He also led the EUCOM theater missile defense operations cell. Lt Col Colón served as a staff officer at the pentagon as the space and missile career field manager responsible for the operations training of all space officers. He was then selected to attend the Western Hemisphere Institute for Security Cooperation at Fort Benning in 2003. He completed the school as a Distinguished Graduate. After school, he was assigned as the Director of Operations to the 45th Operations Support Squadron at Cape Canaveral AFS. In 2006, he deployed to the Air Component Coordination Element, Baghdad as the space and IO lead planner in support of Operation Iraqi Freedom. Upon his return, he assumed command of the 527th Space Aggressor squadron at Schriever AFB. Completing squadron command, Lt Col Colón served as the deputy commander 595th Space Group

responsible for the operational testing of space and missile weapon systems until leaving for his present assignment at the Air War College.

Introduction

The year is 2035; an international company employs a debris removal satellite system. Since 2010, the advances in technology enabled the development of applications such as autonomous satellite repositioning, life extension or “tugboats” that attach and supplement standard propulsion, spacecraft navigation and guidance, satellite refueling, debris removal, repair and salvage and in-orbit assembly. In the case of debris removal or mitigation, a satellite executes an autonomous rendezvous with the target, deploys a robotic grappling arm and places the debris in a canister for deorbiting which lands at a predetermined terrestrial site for recycling. But what happens when the target is not debris but a commercial or military satellite? How does one determine if the action was an accident or intentional? This example highlights the fact that any technology can have a dual, even nefarious, use; in the medium of space, it can become a system that threatens national security. Current developments in the field of nanotechnology are creating pathways for spacecraft to become smaller, lighter, and ultimately affordable. In essence shaping tomorrow’s threat.

This paper describes US’ reliance on space and the effect of the new phenomena called CubeSat. It explores current and emerging threats to spacecraft, the role of nanotechnology in developing new space technology, revisits space policy, and basic deterrence theory. It will further examine how to evolve the traditional understanding of deterrence to limit the potential gain an adversary may try to realize through transparency and diversity or system redundancy. The paper concludes with recommendations to expand the space industrial base to reduce costs and allow technology the ability to drive the miniaturization of spacecrafts along with a modular approach to building satellites and launch systems. Furthermore, improvements to the space

surveillance networks are required to track tomorrow's smaller threat. Only then will the adversary realize that an attack would be futile and ultimately deterred.

Why is Space Important?

Over time the US witnessed a significant growth in dual-use space based capabilities. While space activities are traditionally focused on national security interests, the dual use of space assets for military and civilian purposes also contribute to human safety especially when national technical means are used in disaster response and environmental monitoring. For example, space provides position, navigation, timing, communications, imagery, and weather to both military and commercial sectors on a regular basis. In turn, industry developed commercial applications for what used to be military use.

Several space systems fall in the dual-use category. The global positioning system (GPS) increases the accuracy of modern weapons while also used to track the whereabouts of a felon on probation. Satellite weather data provides a carrier battle group sea state conditions, while the six o'clock news uses the data to track a major storm moving across the Atlantic. Military communication satellites facilitate command and control of forces while at home fans enjoy the NFL sports package on the Dish Network.¹ In short, space services provide several benefits: they enhance security, speed the flow of information, monitor the environment, enable economic activity and growth, and facilitate globalization.

Currently, the US drives the space economy (figure 1). In 2008, the \$66.63B federal government budget made up 26% of the \$257.22B global space budget². Consequently, commercial space activity investment was \$91.0B or 68% of the total for 2008³. In comparison, the international space budget made up of 13 countries represents only \$14.97B (figure 2) or

approximately 17% of the US commitment. Specifically, the US and Russia together accounted for 41 of the 69 orbital launches in 2008. The other 28 missions, representing 38% of the world's total launches, were carried out by other nations or consortia, an increase from a 34% share in 2007. China's emergence as a major space player continued in 2008 as the nation set a new domestic record of 11 orbital launches which included one manned mission and the manufacturing and launching of Venezuela's first satellite, VENESAT-1.⁴

United States Government Space Budget

(Space Foundation, 2009)

<u>Agency</u>	<u>Budget</u>
Department of Defense (DoD)	\$25.95 B
National Reconnaissance Office (NRO)	\$10.00 B
National Geospatial-Intelligence Agency (NGA)	\$3.00 B
Missile Defense Agency (MDA)	\$8.90 B
National Aeronautics and Space Administration (NASA)	\$17.31 B
National Oceanic and Atmospheric Administration (NOAA)	\$0.95 B
Department of Energy (DOE)	\$0.03 B
Federal Aviation Administration (FAA)	\$0.01 B
National Science Foundation (NSF)	\$0.48 B
Total	\$66.63 B

Figure 1: US Government Space Budget⁵

International Space Budget

(Space Foundation, 2009)

<u>Agency</u>	<u>Budget</u>
European Space Agency (ESA)	\$4.27 B
Brazil	\$0.13 B
Canada	\$0.25 B
China	\$1.70 B
France	\$0.97 B
Germany	\$0.44 B
India	\$0.86 B
Israel	\$0.08 B
Italy	\$0.91 B
Japan	\$3.50 B
Russia	\$1.54 B
South Korea	\$0.25 B
United Kingdom	\$0.08 B
<u>Total</u>	<u>\$14.97 B</u>

Figure 2: International Space Budget ⁶

Space applications continue to be increasingly important in everyday life to the point that one cannot conceive broadcasting news or disaster response without the assistance of space satellites and their associated technology. Economic growth is expanded by technological innovation and nations that diligently foster such growth will become and remain economic powers. US' investment in advanced technology has paid handsomely in terms of economic growth and national power; its demonstrated commitment to national interests is clearly understood by potential adversaries who will challenge US' space supremacy asymmetrically chipping away at its source of power--the space industrial base⁷.

What is CubeSat?

In 1999, the CubeSat program was developed in partnership by California Polytechnic State University and Stanford. The program facilitates collaboration with 40+ universities around the globe and participation by several countries, who together are developing new generations of highly capable nano-satellites including what has become the new industry

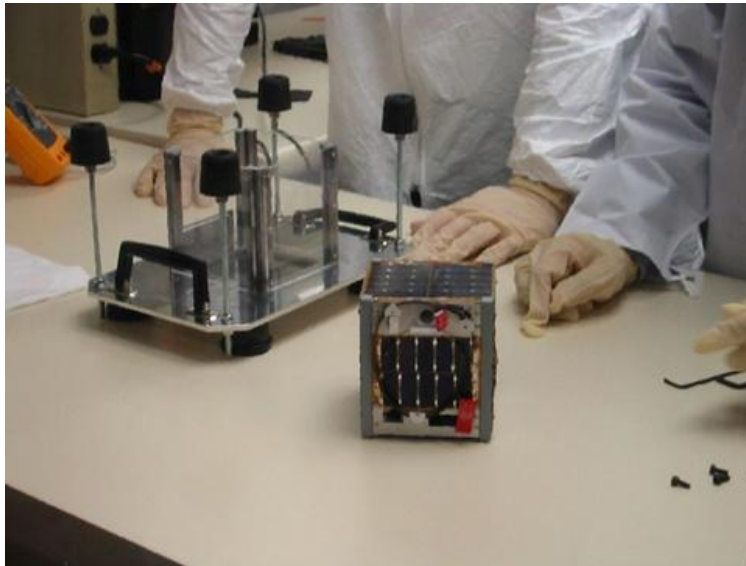


Figure 3: CubeSat built by the University of Tokyo

standard.. CubeSat is a 10cm cube spacecraft with a mass of up to 1kg. This standardized space platform has many benefits: it lowers cost, integrates into virtually any launch vehicle, protects the primary payloads with a standardized orbital deployer⁸ (enabling safe separation) and provides significant

opportunities for academics and students to rapidly develop, test and field academically-important satellite projects.⁹ Government and industry also work with academia to enhance students' academic experience while preparing them for their future role in the space industry¹⁰.

Since CubeSat's inception, students have witnessed success and failure. A total of 38 CubeSats¹¹ launched since 2003 -- 24 were successfully deployed while 14 did not achieve orbit due to a launch vehicle failure on 26 July 2006 -- resulting in a 63 percent success rate. Currently, the cost of launching each CubeSat is approximately \$40,000.¹² Unfortunately for the US' space industry, all CubeSats, with the exception of one (NASA's GeneSat in 2006), were launched on a foreign rocket. This is essentially the outcome of customers searching for the lowest launch cost

and taking their business to that supplier. Thus, CubeSat's success is evidenced by the growing number of members and institutions participating in the consortia, currently in excess of 40 members. CubeSat provides a nation state, group or individual the ability to place a satellite on orbit without upfront costs. Unfortunately, not all players seeking access to space bear good intentions

What is the Threat to Space?

Deception, denial, disruption, degradation, and destruction are threats to space systems. Capabilities to attack the most vulnerable segment, command and control ground stations are increasingly available to a broad range of actors – nations, groups and even individuals. However, direct ascent destructive attacks on satellites require sophisticated capabilities demonstrated only by the Soviet Union (1973), the US (1985, 2008) and China (2007). Reports on space security list many potential threats from most to least probable.¹³

1. Jamming using directed energy
2. Physical attack on ground infrastructure
3. Dazzling or blinding of satellite optics using lasers
4. Pellets cloud aggression (debris-like shotgun pattern)
5. Space-based Anti-satellite weapon
6. Hit-to-kill – direct ascent
7. High Altitude Nuclear Detonation¹⁴
8. Directed energy beams¹⁵

There are many examples of individuals demonstrating their ability to disrupt or deny access to signals from spacecraft. On 27 April 1986, John R. MacDougall, an electronics

engineer working as a satellite TV dealer in Florida, effectively jammed an HBO broadcast to protest a subscription hike of \$12.95. For approximately 4 ½ minutes “Captain Midnight” convincingly demonstrated how a person with some technical knowledge and off-the-shelf equipment can effectively jam a satellite signal.¹⁶ In 2003, NBC reported the Voice of America’s Farsi television programming to Iran, carried on the Telstar-12 satellite, was jammed by individuals in Cuba.¹⁷ In 2005, Libya was accused by the UK¹⁸ of jamming a London-based radio station and disrupting CNN and BBC World broadcasts claiming the content was terrorist propaganda. The common denominator in these incidents was terrestrial jammers. In the future, CubeSat like spacecraft will enable the threat to operate from the medium of space where attribution is difficult.

Recent events provide cause for concern. In January 2007, China demonstrated its ability to destroy a satellite. The employment of a high-speed kinetic anti-satellite system was a surprise for many in the private, civil, and defense sectors. To complicate matters, another potentially hostile space-capable nation emerged in 2009, when Iran launched a satellite into orbit. Recently, a rocket carried a rodent, two turtles and worms into orbit in by an effort by Iran to legitimize its space program.¹⁹ Interestingly, Iran presents a special challenge since it is a nation with motives and aspirations that are not entirely clear. It is especially concerning since the technology required to place a satellite in orbit also establishes the technical basis for a long-range ballistic missile system. By 2035, advanced space technology will enable even dangerous non-state actors to operate in the space domain as affordable dual-use spacecraft are built with the ability to threaten satellites.

The threat against space is not only limited to the space domain. The international community is aggressively challenging US’ leadership. US space technologies are subject to

export controls which are regulated by the International Traffic Arms Regulations (ITAR) limiting the ability to compete internationally. Countries are taking advantage of congressionally mandated export restrictions on US space technology to market their own applications as “ITAR-Free”. Over a 10 year period (1998-2008), China purchased six satellites from European and Israeli suppliers at an estimated cost of \$1.5 to \$3.0 billion²⁰. Although many argue that ITAR has negatively impacted US’ market share, more importantly is the fact that non-US companies are closing the gap and show better understanding of advanced technology. Therefore, maintaining the lead becomes paramount to US security amidst the technological advancements taking place and their projected impact.

What are the Technologies Enabling CubeSat’s Success?

Nanotechnology has the potential to increase the capabilities of electronic components while also reducing spacecraft weight and power requirements, making it an attractive proposition for future satellites.²¹ Currently, scientists are working on producing “memory chips with a density of one terabyte per square inch or greater”²². They are also developing integrated circuits with nano-sized features along with Magnetoresistive Random Access Memory (MRAM) with the potential to provide a memory density of 400GB per square inch.²³ In essence, research in this area is moving closer to putting the computing power of a 2010 desktop in the palm of your hand. The miniaturization of integrated circuits can move industry closer to substantially decreasing the size of satellites which reduces the production, launch, and operating costs. It can also develop an affordable small satellite for a motivated nation state, group or individual.

In addition to advancements in electronic components, nanotechnology also enables the development of carbon nanotubes. A carbon nanotube's molecular structure provides phenomenal strength. The best composite materials, like carbon fiber, are capable of three to four times the strength of steel while nanotubes manufactured today are 50 to 60 times stronger than steel.²⁴ In general, nanomaterials promise to effectively scale down the weight of space systems while increasing material strength and enhancing the survivability of space-based systems. This allows for new capabilities, space transportation, and on-orbit support systems.

Both private and public institutions are actively promoting nanotechnology. The National Aeronautics and Space Administration is researching ways to use nanotechnology to reduce mass, volume, and power consumption of sensors and spacecraft. In academia, the University of Michigan is developing electrostatic thruster technology using micro-electromechanical systems (MEMS) to provide spacecraft propulsion.²⁵ This nano-particle field extraction thruster is a promising technology that may provide higher propulsion efficiency while reducing the size and weight of satellites.

The convergence of nanotechnology, MEMS, and nanomaterials offers numerous ways for spacecraft to become smaller, lighter, and more affordable thus making it much more accessible to non-state actors. These are significant areas since launch costs are proportional to the size and weight of a spacecraft.²⁶ No longer will access to space be limited to wealthy nations as nanotechnology changes the paradigm.

Current Space Policy

US' space "principles" are defined by two overarching documents, the 1967 Outer Space Treaty and the 2006 National Space Policy. The Outer Space Treaty requires signatory "states to

refrain from placing in orbit around the earth any objects carrying *nuclear* weapons or any other kinds of *weapons of mass destruction* or from installing such weapons on celestial bodies” and forms the basis of international space law²⁷. It stipulates that space should be preserved for all and used by all for peaceful purposes. The intent of the treaty is to protect the environment so that it can be used by all rather than being subjected to the limited interests of a nation or commercial entity. However, the treaty does not contain specific provisions to protect space-based assets against attack. To address this shortcoming, the US supplements the treaty with policy championing protections for users.

The National Space Policy clearly states that the US “considers space capabilities vital to its national interests” and will “preserve its rights, capabilities, and freedom of action in space.”²⁸ Additionally, the US will deter others from impeding those rights and take action to protect its space capabilities. One key principle in this policy is that “the United States rejects any claims to sovereignty by any nation over outer space” and “rejects any limitations on the fundamental right to operate in and acquire data from space.”²⁹ These principles also empower non-state actors use of space. Finally, National Space Policy further defines the rite of passage and will interpret “purposeful interference with the space systems as an infringement on its [national] rights.”³⁰ In short, both documents provide the foundation for United States space deterrence.

What is Deterrence?

Consistent with Space policy, the US will preserve its rights, capabilities, and freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; take those actions necessary to protect its space capabilities; respond to interference; and deny adversaries the use of space capabilities hostile to US national

interests.³¹ Joint Publication 1-02, defines *deterrence* as “the prevention from action by fear of the consequences. Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counteraction.” Fundamentally, it is assumed a potential attacker conducts a thorough cost-benefit analysis, and if victory can be denied or the cost inflicted by punishment becomes unacceptable³² then the attacker is effectively deterred.

The cost-benefit calculus examines the potential benefits and the cost of punishment from the perspective of the aggressor. Simply, if the aggressor perceives the presumed benefits outweigh the potential punishment then the aggressor will attack. Conversely, if the potential punishment outweighs the perceived benefit then the aggressor will be deterred. An assumption about deterrence rests on the belief that almost any adversary would act in a rational³³ way and would thus carefully consider the potential costs and the perceived benefits before attacking.

Deterrence is not limited to influencing nation-states; it can be applied to a variety of non-state actors including groups and individuals.³⁴ Terrorists, both groups and even a “lone wolf”, must also be considered since they often seek an audience and even worldwide recognition for their cause. Their hostile actions may be designed to discourage foreign investment, harm economies, seed doubt about a country’s governance, make people feel insecure, and influence government decisions in ways perceived favorable to a terrorists’ cause.

A New Approach to Space Deterrence

The book entitled *Complex Deterrence* states that deterrence works best among major great-powers and is therefore ineffective against rogue groups or terrorists.³⁵ Thus, deterrence must evolve beyond the threat of potential costs imposed by a punishment strategy. Expressed mathematically, deterrence is comprised of gains (G) sought by the adversary and the cost

imposed by punishment (C). Thus, if $G > C$ the actor attacks and if $C > G$ he does not. Usually deterrence concentrates on making the cost or punishment so great that the potential aggressor will not attack. This approach will not work for space because an attack is extraordinarily difficult to attribute to any adversary. For example, in 1998, PANAMSAT's Galaxy IV satellite experienced a battery anomaly leading to a satellite failure that left nearly 40 million customers without paging services.³⁶ What if this incident was not caused by the battery anomaly? Who then attacked the satellite and how? For deterrence to work, one must gather convincing evidence that attributes the attack to someone specific.

Lack of attribution will convince the adversary to attack. First, the probability of a nation-state counterattacking, without demonstrable evidence, is low. Second, the inability to rapidly identify the responsible party reduces the probability of retribution thereby increasing the potential gains to an aggressor. As technology miniaturizes satellites, the potential target becomes smaller, cheaper and can effectively hide in the clutter of space debris. For this reason, the approach to space deterrence must concentrate on significantly reducing the perceived gain (G) or success to be won by an adversary. The conditions must be such that it becomes manifestly clear; attacking another asset in space is pointless and counterproductive. Space deterrence must revolve around two concepts: *transparency* and *diversity*.

Transparency, or the ability to see without obstruction the events that occur in space, creates a peaceful environment which promotes understanding and accountability. Theoretically, when information is released, under the auspices of transparency, it produces an informed and engaged public, one that will hold a culprit accountable.³⁷ The ability to monitor and understand the rapidly changing conditions in space is critical to the preservation of security in space. While the US developed its current satellite capabilities in compliance with international rules and

treaties it also deemed it prudent to develop a space surveillance network to monitor all near space activity and ensure a secure environment for all space faring nations. This network, of ground and space based sensors, provides radar and optical data used to characterize the mission of any satellite, identify the class and type or to simply aid in anomaly resolution.³⁸ Currently, ground systems can track objects with a resolution of 12cm or greater³⁹ making it challenging to track nanosats.

Air Force Space Command's 2030 vision is enabled by technological improvement. It includes upgrades to existing sensors and an increase in the number of space-based optical sensors in an attempt to provide persistent and complete coverage of the near space domain. The resolution of near-term upgrades will improve to 1cm increasing the ability to track nanosatellites.⁴⁰ In order to ensure safe space operations and uphold its commitment to cooperation with other nations and the peaceful use of space, the US consistently provides the orbit positional data⁴¹ via a public website accessible by anyone. The principles and goals stated in the national space policy highlight the nation's vision of leading the way in space surveillance in order to promote and provide a safe operating environment for machines and people.⁴² In the end, for transparency to work, space situational awareness must allow analysts to identify deliberate actions by a spacecraft and its owners and ultimately predict, detect, and attribute an attack⁴³.

The second concept in space deterrence is *diversity*. It provides a tailored approach, focusing on minimizing the impact of an attack, also known as graceful degradation, consequently driving the perceived gains (G) for the adversary as close to zero as possible. Diversity can be achieved through large networked constellations of space-based assets complimenting the existing ground based sensors, with a distributed architecture so that

destruction of one or even several satellites does not take down the entire system. In the past, the US employed the costly approach of maintaining on-orbit spares, hardening on-board components, enhancing uplink and downlink encryption to increase satellite and signal survivability.⁴⁴

In the future, nanotechnology will facilitate redundancy and rapid reconstitution. Presently, several companies, including the Defense Advanced Research Projects Agency, are currently demonstrating the technology. By 2035, on-orbit repair along with the robotic on-orbit refueling of satellites will become standard. Spacecraft will use autonomous navigation and conduct housekeeping tasks independent of a ground station. This is especially useful in the event of a communication failure or loss of the ground segment. Moreover, rapid reaction maneuvering capability will allow spacecraft to evade kinetic kill vehicles. The cornerstone of resilience is agile, capable, and functional technology able to diminish an adversary's gain while increasing the cost of an attack – success in both enables deterrence. Above all, the space industrial base must grow to deliver the technical transformation required to employ this new approach to deterrence.

Recommendations

The US was shocked by a technological surprise on 4 October 1957 when the Soviet Union launched *Sputnik*, a 184 pound satellite, into orbit on top of a rocket weighing nearly 4 tons. In contrast, the *Vanguard* satellite the US developed and had yet to launch weighed only 3.5 pounds.⁴⁵ *Sputnik* completely collapsed the technological comfort zone the US. It heated up the Cold War as peoples' fear grew over what the Soviets might do next; the strategic deterrence

calculus was fundamentally altered. Today the US has the opportunity to shape the future and set conditions for effective space deterrence.

Reconstituting and energizing the space industrial base is critical to future deterrence. Air Force Doctrine Document (AFDD) 2-2 states, “Operators and planners must know as quickly as possible the origin of any anomaly and be able to identify and geolocate the threat in a timely manner.”⁴⁶ In order to meet the intent of AFDD 2-2 the US must embrace the goals identified in the National Space Policy, most importantly to “enable a robust science and technology base supporting national security.”⁴⁷ Without industrial base growth, the international community’s influence will grow and undermine the nation’s future space security. The US cannot allow its own space industry to abrogate its role in national security nor can it continue to set conditions through ITAR and national policies which leave industry with little choice but to divest itself of its space tools. The US government must focus on the following areas: improving space situational awareness, miniaturizing spacecraft and launch vehicles, promoting innovation and risk taking in technology development, and improving export control policies and procedures.

First, the key enabler for transparency is space situational awareness. Today’s space surveillance network is composed of diverse sensors to include tracking radars, optical telescopes and space-based visible sensors. To prepare for tomorrow’s smaller target upgrades are required. The W-band upgrade to the Haystack sensor in Massachusetts increases the ground-based sensor’s collection bandwidth from 1GHz to 8 GHz thereby improving its resolution from 25 cm to 1cm and facilitating the tracking of nanosatellites.⁴⁸ Although the upgrade is significant for the ground-based sensor network, it must be complimented with additional space based capabilities. In this instance, miniaturization becomes a force multiplier as it allows the next generation of space-based space surveillance to be configured with full

motion video. Ground-based sensors can tip-off the space-based sensor to track a specific target. The video's dynamic feedback can in turn provide greater insight into the intent of the adversary as it observes the target. CubeSat has already demonstrated the ability of one nanosat to take a picture of another (figure 3). Consequently, a successful deterrence strategy is dependent on the surveillance network's ability to identify threats, characterize the potential damage, determine an aggressor's intent and ultimately attribute the action to the adversary.

Second, CubeSat redefined the approach to building satellites through the development of standard building modules and taking advantage of the latest breakthroughs in nanotechnology. This approach makes



Figure 4: CubeSat CP4 from California Polytechnic Institute is photographed by AeroCube-2 shortly after the satellite was ejected into space. (Thomsen, 2009)

CubeSat the model for “smaller, cheaper, and faster”. The US government must adopt a similar approach. While tradeoffs are necessary, government interest and investment in the many facets of the space should allow for good decisions about when a technology is “good enough” to satisfy mission and national security requirements. The approach facilitates decreasing the size of satellites, increasing spacecraft redundancy and allowing a higher number of satellites per constellation thereby complicating the targeting equation for the adversary. Its centerpiece focused on driving down the adversary's perceived gain (G) closer to zero. This approach will increase diversity and future space deterrence effectiveness within a dynamic security environment.

Third, advanced miniaturization is creating a growing market for a very small, capable launch vehicle. As CubeSat gains momentum, it creates a strong market dynamic for a very

small and highly responsive launch vehicle. Currently, most CubeSats are launched on decommissioned Russian rockets as secondary payloads⁴⁹. Up to this point, companies like Eurokot and Kosmotras have kept the launch cost to no more than \$40K per CubeSat. As demand rises and slots for secondary payloads become scarce, the cost of each CubeSat will inexorably rise. Sensing a growing need for CubeSats, launch companies are developing a two-stage liquid propellant, launch vehicle capable of delivering 10 kg to a 250 kilometer polar orbit. If successful, such a capability will increase launch market share for the US space industry, enhance growth in other areas and lower launch costs.⁵⁰ Affordable launch enables satellite replenishment. Even if the adversary destroys a satellite, the spacecraft can be quickly replaced minimizing the impact of the attack.

Fourth, changes to US export control laws are required. The primary agencies governing export control are the Department of State (DOS) and the Department of Commerce (DOC). The DOS is responsible for maintaining the US' munitions list which is used to identify which products or services are subject to export controls. Currently, satellites and all related space technologies are under DOS jurisdiction.⁵¹ However, DOS is not the most knowledgeable agency with regard to spacecraft or the associated technology and it uses ITAR to implement requirements established in the arms Export Control Act. According to the Defense Industrial Base Assessment on the US space industry, "US manufacturers have not introduced a new satellite bus since the Boeing 702 was developed in 1999. In contrast, European manufacturers have introduced 3 new busses in the last 5 years and are currently developing a 4th."⁵²

Players within the space industry argue that the US market share dipped from approximately 70% in 1995 to 25% in 2005. Compliance with export control cost US companies an average of \$49M per year from 2003-2006.⁵³ This cost was not applicable to foreign

competitors. Clearly, export controls provide foreign competitors an advantage in marketing to non-US customers because they limit what can be bought and who can buy it. It can also control the actions of the authorized buyers and users in terms of what they can use the technology for and whom they can share the technology with. Such restrictions adversely affect a US company's ability to compete in foreign space markets consequently opening up opportunities for foreign space ventures whose governments are not as particular about how technology is used or who buys it.⁵⁴

In the end, international competition is critical in order to reduce costs, preserve US dominance, forge closer relationships in order to globalize and thereby protect the use of space for all benevolent users. It enables an advanced form of deterrence denying the adversary the option of attacking. In short, space technology must move off the munitions list and into its own category which protects the technology that needs protecting while allowing the US space industrial base to sell non-critical space technology internationally.

Conclusion

Current developments in the field of nanotechnology are highlighting pathways for spacecraft to become smaller and ultimately affordable. As nanotechnology helps solve the problems of spacecraft mass, volume, and power consumption, national leaders must not lose sight of the fact that it is also opening access to space to virtually anyone. Adversaries understand the US' increasing space reliance and will challenge the medium especially if it provides an audience and even worldwide recognition for their cause. As future adversaries benefit from smaller, lighter, and affordable satellites, the US must invest in an approach that

relies on *transparency* and *diversity* as the backbone of a strong deterrence posture to meet the threat in 2035.

This new approach to space deterrence concentrates on significantly reducing the perceived gain (G) or success to be won by an adversary instead of solely focusing on the traditional approach of punishment. In order to lower the adversary's perceived gain, the US' future ability to deter an attack rests on a space surveillance network that allows for the identification and persistent tracking of miniaturized spacecrafts thereby highlighting intent and ultimately attributing an action to a specific actor. Equally important, the US must embrace nanotechnology as the cornerstone to materials magnifying ways for spacecraft to become smaller, lighter, and affordable while further developing the space industry base. Furthermore, nanotechnology will enable diversity or added redundancy in the more autonomous spacecraft and increase survivability in space while lessening dependency on ground stations making the perceived gains (G) of attacking the ground infrastructure close to zero. Lastly, export control reform will allow nanotechnology to power the industrial base engine and minimize the potential for a nation-state, group or individual actor to create a strategic shock to the space sector.

After Sputnik's voyage, public opinion blamed the government for not doing enough and ultimately risking US' national security. The response was a significant increase in funding for military and civil space. In a post-9/11 world, the US cannot allow another technological surprise to occur, especially one perpetrated by non-state actors availing themselves of readily available and inexpensive space capabilities that can be used in ways to fundamentally alter the deterrence calculus. Once again, a significant commitment is required to strengthen the space industry and set the conditions needed for success in 2035. The natural deterrent created by high launch costs is disappearing and the ability to monitor and understand the rapidly changing

conditions in space continues to be critical to the preservation of national security. In short, the nation's best technological approach for future space deterrence lies in becoming the world leader in the application of nanotechnology. It will increase the industrial base, lower launch costs, improve transparency and diversity ultimately setting the conditions for the deterrence calculus to tip in favor of the United States. Only then will the adversary's gain/loss assessment dictate not to attack; effectively deterring him.

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¹K-band, 12GHz to 40 GHz - provides the services discussed here.

² Includes business in addition to government activities

³Space Foundation. *The Space Report 2009*, 81-104

⁴Space Foundation. *The Space Report 2009*, 60

⁵ Ibid

⁶ Ibid

⁷ The industrial base includes academia, government, and the commercial sector.

⁸ Cubesat.org. "CubeSat in the News," <http://www.cubesat.org>

⁹ The emergent space industrial base is a valuable forum for information exchanges between universities.

¹⁰ This is especially important since the space industry is dynamic and demanding; it is always searching for the next great invention and traditionally rewards innovation.

¹¹ David Hinkley and Siegfried Janson. "Building Miniature Spacecraft at The Aerospace Corporation,"

<http://www.aero.org/publications/crosslink/summer2009/06.html>

¹² They are secondary payloads and fit into unused space on an already scheduled rocket. The upfront launch costs are paid by the entity launching the primary payload.

¹³ American Institute of Aeronautics and Astronautics, Inc. conference report. "Satellite Protection: A system's approach," p18

¹⁴ Explosion and electro-magnetic pulse

¹⁵ High power microwaves or hit-to-kill laser

¹⁶ Captain Midnight – TEXTFILES.COM, <http://www.textfiles.com/100/catmign.txt>

¹⁷ Windrem, Robert. "U.S. Satellite Feeds to Iran Jammed," 2003. <http://www.lanuevacuba.como/archivo/notic-03-07-1202.htm>

¹⁸ BBC. "Libya jamming exposed vulnerability," www.news.bbc.co.uk/2/hi/science/nature/4602674.stm

¹⁹ Barry Neild, "Iran claims launch of turtles, rodent into space,"

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²⁰ Zelnio, Ryan. "The effects of export control on the space industry," www.thespacereview.com/article/533/1

²¹ The drive for building satellites that are smaller, cheaper, and faster arguably began in 1994, when the Air Force launched the first MILSTAR satellite capable of providing secure communications to warfighters in the extremely high frequency (EHF) band. Designed to provide strategic communications during and after a nuclear conflict, the cost of each satellite was approximately \$800M; they weighed 10,000lbs and its large solar array was 116ft long. Fifteen years later, Department of Defense and commercial satellites continue to be big, heavy and costly requiring very expensive launches to carry them to orbit. It became evident that this approach was not practical. The need to reduce costs has forced the space industry to use new technology to solve this vexing challenge. Fortunately,

advances in a myriad of science fields are helping resolve this problem but none show more promise than nanotechnology.

²² Dario Borghino. "Newly developed nanomaterials could boost data storage density and cars' fuel efficiency" <http://www.gizmag.com/nanomaterial-boosts-data-storage-fuel-efficiency/13176/>

²³ A. Subramani. "Vortex state in magnetic rings," <http://www.ece.uic.edu/~vbaskara/science.pdf>

²⁴ About.com. "Tensile tests measure strength of carbon nanotubes," <http://www.composite.about.com/library/pr/2000/blwustl1.htm>

²⁵ T. Liu. "Nanoparticle Electric Propulsion for Space Exploration," http://www.aerospace.engin.umich.edu/spacelab/pdf/STAIF_2007.pdf

²⁶ The bigger and heavier the spacecraft, the higher the cost to place the satellite into orbit.

²⁷ "The Outer Space Treaty of 1967," <http://www.history.nasa.gov/1967treaty.html>

²⁸ US National Space Policy. <http://www.nss.org>

²⁹ Ibid

³⁰ Ibid

³¹ Ibid

³² T.V. Paul, Patrick M. Morgan, James J. Wirtz. "Complex Deterrence," (The University of Chicago Press), 5.

³³ Rational. The deterrence framework makes assumptions. One of these is that the target state is rational. It assumes that the state will make a cost-benefit calculation about whether to initiate a conflict. This logical approach highlights the fact that if the costs of an action are higher than the benefits then the state is deterred.

³⁴ Ibid. 133-182

³⁵ Ibid 133-156

³⁶ Jeff Peline. "Outage hits pagers, Net access," <http://news.cnet.com/2100-1001-211407.html>

³⁷ Culprit includes nation-state, group or individual.

³⁸ Its purpose is twofold; first it tracks all objects for flight safety reasons while also providing insight into space faring nations like China, Russia, France, India, Japan, North Korea, and Iran among others.

³⁹ Air Force Space Command A5. "SSN overview slides," slide-11

⁴⁰ Air Force Space Command A5. "SSN overview slides," slide-11

⁴¹ Location of a satellite

⁴² National Space Policy, 2006. <http://www.nss.org>

⁴³ There is much at stake in terms of national treasure and prestige – the United States in particular, has much to lose.

⁴⁴ Tom Wilson, "Threats to United States Space Capabilities," <http://www.fas.org/spp/eprint/article05.html#4>

⁴⁵ David N. Spires. "Beyond Horizons," (Air University Press, 1998)

⁴⁶ AFDD 2-2 Counter Space Operations, 2006

⁴⁷ National Space Policy, 2006. <http://www.nss.org>

⁴⁸ Air Force Space Command A5. "SSN overview slides," slide-11

⁴⁹ The drawback to flying as a secondary payload comes in the form of restrictions; many levied by the owners of the primary payload who also pay all launch related bills. For instance, there are restrictions on propulsion, available orbits and when it will fly since the primary payload drives the schedule.

⁵⁰ This in turn has an added security benefit since it will provide the United States government better visibility into what nations, groups and even individuals are using CubeSats and how these satellites are being used.

⁵¹ Space Politics, "Sherman's March towards ITAR reform," <http://www.spacepolitics.com/2009/04/01/shermans-march-towards-itar-reform/>

⁵² AF Research Laboratory, "Defense Industrial Base Assessment, US Space Industry Final Report," (2007 Dayton)

⁵³ Congress, along with members of the space industry understand the purpose and importance of the export control policy however, the policy needs to be in lock-step with national space policy to achieve its strategic intent and minimize the impact to the space industry. Many companies within the space industry appear to believe that export control can be improved without adversely affecting national security and therefore met with congress on April 2009 to discuss a way ahead.⁵³ In order for the United States' space industry to compete in the international arena, the costs associated with space must decrease and it seems that a good way to meet this goal is through the evolution of export control striking a balance between national security and impact on industry.

⁵⁴ Ibid