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AVOIDING COLLISIONS IN SPACE: IS IT TIME FOR AN INTERNATIONAL SPACE INTEGRATION CENTER?

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ABSTRACT

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For decades and even today, the "Big space--little satellite" theory, that there is adequate room to operate an ever-increasing number of satellites, maintaining spacecraft and space debris separation, and ensuring there are no collisions, is how many governments and commercial organizations operate. Currently, there are hundreds of satellites operated by dozens of international organizations without a standard process or organization established to integrate, communicate or analyze threats to these valuable assets. As the global economy continues to rapidly expand, connecting billions of people, organizations and machines with the ability to transfer and process information at an ever faster rate, world governments, militaries, nongovernmental and international organizations, and even individuals are endangered by a threat no one sees and few are aware exists. The potential results of the loss of space capabilities including communications, navigation, timing, imagery, surveillance, warning, reconnaissance, weather and/or scientific satellite payloads are catastrophic. This paper will identify current space surveillance, tracking and collision avoidance and deconfliction programs and processes in use. Additionally, it will review space law and its application to freedom of navigation and spacecraft operations. Finally, a proposal with international implications that will significantly reduce the uncertainty for satellite operations will be developed.

AVOIDING COLLISIONS IN SPACE: IS IT TIME FOR AN INTERNATIONAL SPACE INTEGRATION CENTER?

> 40-45 million pager subscribers lost service; some ATM and credit card machines could not process transactions; news bureaus could not transmit information; and many lost television service—all because of the loss of one satellite.[1]
>
> —Lieutenant General Bruce Carlson

According to Thomas Friedman, the world is becoming flat as technology convergence and the information revolution connect people and machines globally, anytime, to accomplish anything. Flying above the Earth bonding networks together is an increasing reliance on satellites to provide invaluable services. The above illustration is not a science fiction story, but is ripped from May 1998 news stories, the result of losing a satellite nine years ago.[2] One can only imagine, and should worry, about the impact if it happened today, when we rely on space for communications, navigation, precision timing, weather, radio and television, national defense, scientific advances and more. With increased worldwide demand, orbits are becoming crowded and collision prevention in space critical.

A wide range of U.S. government (USG) and commercial organizations as well as their international counterparts use space and attempt to protect their spacecraft. This paper proposes a solution that would significantly reduce the likelihood of collisions in space, the establishment of an International Space Integration Center (I-SPIC). The discussion opens with an overview of the space operating environment followed by a review of applicable space law and policy. The final section focuses on creating an I-SPIC, including challenges and benefits to its establishment.

Space Environment

Space is a unique environment, much different than air, land and sea. Its properties must be understood before solutions to collision avoidance (COLA) and operations challenges can be developed. The following section provides a foundational understanding of orbits, COLA and space situational awareness (SSA).

Satellite Orbits: Highways in Space

If you were to step outside at night, you might see a spot of light moving across the sky, one of over 100,000 items[3] orbiting the earth that is either an operational satellite or debris.[4] Although operational satellites work in a wide range of orbits and locations, exactly how many items are in orbit is unknown due to inadequate space identification resources, capabilities, and an inability to integrate existing systems.[5]

Nearest to the Earth at an altitude up to 2,000 km is Low Earth Orbit (LEO).[6] In addition to the Space Shuttle, satellites perform, intelligence, scientific, and communications missions, circling the earth every 90 minutes,[7] traveling approximately 36,000 kmh. Debris as small as 1 mm can produce mission impacting damage;[8] 1 cm objects will cause catastrophic damage preventing proper disposal of a satellite;[9] and 10 cm objects will virtually destroy a satellite.[10] Collisions may create debris, increasing the threat to all LEO spacecraft from weeks to 20,000 years.[11]

Primarily communications and weather satellites operate in Geosynchronous Earth Orbit (GEO), the next most utilized region of space, at around 36,000 km. From the ground, they appear to remain over a point on the earth and complete one revolution each day.[12] It is precisely because of the satellite's ability to continually focus on a specific area that the most efficient operating slots supporting high demand areas have multiple spacecraft. Recent studies identified potential collisions of two satellites exceeding 2,200 kmh producing 2,800 potentially catastrophic damage-sized fragments[13] and increasing overall GEO collision risk by 37 percent.[14]

Considering satellites cost up to one billion dollars, finite number of systems, and limited orbital space, organizations take great measures to extend service life. Even with state-of-the-art technology and capabilities, only a handful of LEO spacecraft can be physically repaired.[15] For all others, operators on the ground, using on-board computer systems, troubleshoot problems and switch to backup components. The inability to repair a system can result in a satellite becoming debris. Over time, components fail due to age; batteries lose the ability to maintain power; fuel is depleted; or the operator's nightmare can happen--a collision with debris or another satellite. To prevent the worst case from happening, many satellite operators spend tremendous resources developing COLA methods.

Collision Avoidance: A Spacecraft "Insurance" Policy

Most nations understand satellite safety is in the world's best interest to ensure their continued availability. Many spacecraft operators focus on the three pillars of COLA: damage mitigation, debris prevention and COLA maneuver.[16] To address these issues, international organizations and governments established space policies.[17]

Since orbits are littered with debris, it behooves all involved to build spacecraft that can mitigate the impact of collisions. Undoubtedly, a satellite owner wants to optimize system capabilities and maximize spacecraft life, and operators of other spacecraft want that owner to minimize the creation of debris. Unfortunately, the more physical protection added, (e.g. shields, backup components) the more the satellite weighs, driving increased launch costs and spacecraft fuel consumption, forcing a choice between collision mitigation and mission duration. To that end, the 1995 USG Orbital Debris Mitigation Standards established a baseline for satellites to limit the probability of catastrophic results with the collision of debris smaller than 1 cm.[18] The task of building an acceptable spacecraft falls to the designer, who must also avoid creating debris during nominal operations.

Approximately 55 percent of known space debris was created during nominal operations by either the failure to maintain control over components (e.g. explosive bolts used to deploy systems), explosions (e.g. leaking fuel containers)[19] and carelessness (e.g. astronaut's glove left unsecured in the space shuttle's cargo bay).[20] In essence, the initial design can mitigate much of the debris before a satellite is in orbit. For example, satellite safeguards could include tethers to prevent components from drifting away or better power systems to prevent overloads and explosions.

Once on station, the operator is responsible to maneuver the vehicle out of harm's way, a common procedure conducted to maintain a proper orbit. However, moving to avoid a potential collision assumes availability of additional key decision-making variables. First, the operator must be aware of the impending situation. Second, one must have accurate spacecraft and debris positions and their future trajectories data. Third, mission planners must understand the collision probability and include an error "bubble" around each object, which could be several kilometers in diameter, due to their inability to know exact measurements for all of the variables.[21] Driving down those inaccuracies and unknowns is the focus of much of this paper.

Space Situational Awareness: What's Out There and Where's It Going

SSA helps gain a better picture of not only what is currently in orbit, but also what an object is doing and will do in the near future. Analysts need to find, track, and project the orbits of space debris and in the case of the 3,153 on-orbit payloads, predict actions.[22] Essentially, there are five processes to create a space picture with different levels of fidelity, including worldwide integrated Space Surveillance Networks (SSN), space observers, and satellite operators calling other operators. A serious limitation is the inability to integrate all these organizations and systems and provide actionable information for optimal decisions.

Currently, governments or consortiums operate the most capable ground based space surveillance systems. Unfortunately due to competing requirements, the majority of these systems are not dedicated SSN assets. Many are considered collateral and contributing sensors with additional mission requirements.[23] Comprised of tracking, detection and imaging radars, optical telescopes, and passive receivers, space surveillance systems have varying levels of sensitivity and availability. Furthermore, due to the great distances involved, extremely small field of view for some sensors, weather, and daylight and moonlight restrictions, their ability to identify objects is severely limited. For instance, the Goldstone Bistatic Radar Complex can detect LEO items as small as 2 mm at very low altitudes and 1 cm at 4000 km. However, the system's availability is 100 – 200 hours annually with a narrow 0.02 degree field of view. Although there are some sensors that can detect GEO objects as small as 20 cm, 1 m is a more reasonable size.[24] In contrast to the integrated U.S. and Russian SSNs, the European Space Agency (ESA) reports their systems are effective but not linked, relying on U.S. data to acquire 94 percent of their objects.[25]

Placing space surveillance sensors in orbit is another option, but it carries a high price tag. Currently, there is only one dedicated on-orbit satellite, Mid-course Space Experiment (MSX), integrated into the U.S. SSN, accounting for over 200 daily observations.[26] The U.S. is replacing MSX with a more robust GEO identification system aboard a constellation of spacecraft.[27]

The International Laser Ranging Service (ILRS), a consortium of academic and scientific organizations with about 50 global facilities,[28] employs lasers to determine nearly instantaneous satellite location within 2 cm accuracy. However to use laser ranging, the satellite must be equipped with reflectors to bounce the laser beam off. This results in the ILRS' ability to only track 38 satellites and inability to track debris.[29] Another limitation hinges on the laser's power. Although several are strong enough to reach the moon, most can only track LEO satellites.

A less accurate, but viable system is based on a worldwide network of Independent Space Observers (ISO). Using stop watches, binoculars, telescopes, radio monitoring equipment, computers, and cameras, ISOs in 23 countries[30] scan the night sky for anything out of the ordinary. Coordinating observation efforts, these volunteers find and identify objects in orbit with an accuracy of .05 degrees and .1 seconds. As part of the 1960's Western Range Research Network, 26 ISO teams provided 22,000 "very high quality" observations of 365 satellites[31] and more recently aided ESA in restoring control to the Abrixis spacecraft.[32] The final process that contributes to SSA is another human-dependent system.

Satellite operators know exactly where their spacecraft is by conducting location determination procedures during standard operations.[33] From this information, maneuvers are developed. Operators also contact the satellite to determine its state of health and look for component failures. Even with an in-depth knowledge of their satellite, operators often do not have good SSA.

Identifying a potential collision and then taking actions to avoid it are two separate challenges. There is neither a central SSA integration capability nor processes for an early warning system identifying potential collisions available to most operators. As a result, the National Aeronautics and Space Administration's Orbital Information Group provided public data up until 2004.[34] This service is continued by the U.S. Air Force's (USAF) Commercial and Foreign Entity (CFE) Program website[35] as the primary source for space object location information. Including over 10,000 items, the catalogue has significant limitations for day-to-day satellite operations since it does not predict close approaches or potential collisions of most items.[36] Limited SSN resources and the large number of objects in space results in data observations of low priority items[37] that may be days or weeks old. The quality of the data can result in widely varying predictions of close approach times and distances, increasing the predictive error "bubble" around objects and driving suboptimal decisions.

Some satellite operators have developed relationships and informal agreements with other operators to exchange accurate orbit and maneuver information in an attempt to reduce inaccuracies and improve safety. Unfortunately, this situation is the exception, since several governments do not coordinate operations, highlighting the need for a process or SSA clearing house. A second hurdle discouraging information exchanges hinges on liability issues. It has been 50 years since Sputnik was launched, yet the realm of space law and policy is still evolving with tremendous ambiguity.

Space Law and Policy

The UN recognizes 192 states, of which 38 own or operate objects in space.[38] Although the U.S., Russia and China account for 95 percent of the payloads,[39] the entire world is dependent on space. Therefore since many systems can be viewed as a global utility and the barriers to the use of space are rapidly falling, the question arises, who is ultimately responsible for COLA? A small number of international space treaties begin to answer the question.

Legal Regimes: Space Do's and Don'ts

The basis for law involving satellite operations is found in four space treaties[40] promulgated by the UN and known as the Outer Space Treaty,[41] the Registration Convention,[42] the Liability Convention,[43] and the Astronaut Rescue Agreement.[44] Despite the lack of consistent terminology or definitions, these treaties are the primary sources that set precedent and regulating principles.[45]

The first principle vital to space operations is the freedom of navigation and freedom from interference. Establishing the international right to use space, the Outer Space Treaty declares free access to space for all states,[46] and enables unfettered travel by indicating space is an international domain, "not subject to national sovereignty."[47] It further requires that if a planned action "would cause interference" with another satellite, the owning state, "shall undertake appropriate international consultations."[48] However, the Outer Space Treaty is vague as to who is the owning state.

Taken as a whole, the treaties clearly place ownership of all space objects and activities on the launching state, including those operated by "non-governmental entities."[49] Although there are four categories of launching states, a state that: launches a space object, procures the launching of an object, whose territory it is launched from, and from whose facility the spacecraft was launched,[50] the Registration Convention directs each object be registered by only one of the launching states.[51]

Regardless of agreements among the launching states, the registering state "will have jurisdiction and control over space objects it launched," and is responsible for "every tangible thing on the rocket, including payload, but also paint, bolts, and every other component part, all the way to the microscopic level."[52] It would stand to reason the registering state should track their space objects and notify satellite operators of potential threats. This is not the case for several reasons. First, few states maintain a SSA capability and there is no existing mechanism integrating available systems to provide an accurate space picture. Second, although a state may be responsible for space objects, it is not liable for damages unless the debris created was "from an act of gross negligence … or omission done with the intent to cause damage."[53] If determining negligence or omission was not tough enough, case law adds to the difficulty. In the only decided case involving space liability, Canada successfully sued the Soviet Union for damages resulting from "the Cosmos 954 satellite, and the deposit on Canadian territory of hazardous radioactive debris."[54] Although Russia was held accountable, its deorbiting operations were not out of the ordinary and arguably not the result of gross negligence, omission or intent to do damage. In another case, no action was taken when a French communications satellite was struck by an Ariane rocket stage, severing the primary stabilization boom and reducing its operational life.[55] However, damage caused by debris from China's deliberate destruction of a weather satellite by an anti-satellite weapon on 11 January 2007 may result in legal action if a future collision occurs and is proven.[56] Despite treaties establishing broad parameters for satellite operations, there are no legal teeth minimizing debris creation or collision avoidance notification.

The International Telecommunications Union (ITU) maintains the final internationally accepted, legal regime by assigning satellite frequency allocations along with authorized global coverage areas. Although the ITU prevents frequency interference, ensuring multiple GEO satellites operating in proximity use different transponders,[57] it exacerbates the COLA problem. Since there are a limited number of optimal orbital locations for transmitting to high demand regions, satellites congregate around these slots, each with ITU approval. As many as seven satellites vie for the optimal position within an operating box, requiring precise maneuvers to ensure adequate separation.[58] Therefore, the ITU does little in the realm of improving operations safety.

Policy: Self-imposed Limits

A review of national space laws and policies reveals a focus on three topics, sovereignty, liability and desire to minimize debris creation.[59] Numerous nations, commercial entities and international organizations, including the UN Office for Outer Space Affairs (UNOOSA),[60] have or are in the process of adopting guidelines like the USG Orbital Debris Mitigation Standard Practices. The short fall of these policies is an emphasis on creating a safer future environment, not coordination for COLA activities today.

To overcome inadequate SSA data, some commercial satellite operators develop informal working relationships for planning purposes.[61] In contrast, most government operators are often restricted from discussing or coordinating COLA efforts with commercial operators or foreign governments. By 2004 U.S. Strategic Command authorized Department of Defense (DoD) satellite operators to contact non-USG operators, but only if the satellite was U.S. owned and operated. Within days, USAF and commercial operators coordinated on upcoming COLA activities and maneuvers, resulting in the first-ever USAF satellite maneuver based on non-DoD data, significantly reducing risk, improving efficiencies, and minimizing SSA variables.[62] However, if a non-U.S. entity owns or operates the spacecraft, then the State Department must coordinate with the nation having jurisdiction, which in turn works with the entity operating the vehicle.[63] This process is extremely inefficient, overly burdensome, and unable to respond to operator and COLA needs.[64]

A further problem is the lack of standardized processes and systems. Each operator determines their own acceptable level of risk. Questions include debris mitigation when designing spacecraft, disposing of obsolete or failing satellites, and COLA planning details. Given the critical role satellites play, our inability to physically fix most of them once launched, and the number of variables and unknowns, it is no surprise industry and operators are seeking assistance. In 2001, the U.S. Congress' Space Commission[65] declared the need of, "engaging U.S. allies and friends, and the international community, in a sustained effort to fashion appropriate "rules of the road" for space."[66] Three years later, in the 2004 Defense Authorization bill, Congress authorized and in 2006 directed a DoD "pilot program to determine the feasibility and desirability of providing non-USG entities space surveillance data,"[67] which evolved into the CFE. However, the program's authorization expires in 2009. The CFE is an excellent first step, but it does not create the relationships or integrate the systems required to fill the information void preventing operators from achieving optimal mission performance. Nations have a mutual interest to develop an international capability that reduces communication barriers between satellite operators, integrates SSA processes, and enables the free exchange of space object information.

International Space Integration Center

A cost-effective solution for that capability is within reach, the I-SPIC. The section opens with a discussion on the necessary development foundation and organizational structure for an effective center. Next, the challenges to the I-SPIC's establishment are addressed followed by the benefits.

Development: Giant Leap for Space Operations

The cornerstone of a strong SSA capability requires consolidating data from various systems into one accessible source.[68] Once the data is gathered, it must be processed into usable information and then disseminated. The task at hand is to determine what the I-SPIC would require to collect the data, services it should provide, and its organizational structure.

The I-SPIC must allow users to get a good picture and understanding of the space environment. However, exploiting international systems, by integrating the five sources of SSA data: ground and space-based SSN, ILRS, ISO, and satellite operators, is not a simple task. First, the I-SPIC must have access to relevant data, thereby necessitating formal relationships and agreements with system providers and owners. This effort requires tremendous bandwidth to transfer data. Next due to the need to convert enormous amounts of available data in non-standardized formats, the I-SPIC would require large computing and processing power. Finally, the organization must have a distribution capability for the processed information.

Focusing on services that reduce the potential of collisions in space and satellite operators' needs, the I-SPIC should increase their situational awareness of the surrounding environment and reduce dangers to spacecraft. A more precise and complete space object catalogue than currently available would create a foundation. Monitoring close approaches or coordinating maneuvers are not universally conducted satellite operations practices due to cost, capability, willingness, or expertise. Therefore, a COLA notification service is essential. Considering many operators are prevented by policies from coordinating their actions, the center should facilitate maneuvers, serving as a go-between providing a pre-coordinated means to exchange information and assist in resolving ambiguous situations. Since solar radiation and pressure can have significant degrading affects on spacecraft, the I-SPIC should distribute space weather information. Finally, the center should work with organizations preparing to launch new satellites and identify orbits that minimize collision risks. Essentially, the I-SPIC should be a one-stop shop for SSA. Meeting the above requirements and providing the identified services may not necessitate a large facility or staff if a system of systems approach is used. Utilizing a distributed architecture, employing a virtual operations center, or sharing responsibilities are options that may depend on the organizational structure.[69]

Organization: Putting It All Together

The I-SPIC must be able to provide the same services and work with all organizations equally, and must demonstrate that no one is receiving different information that provides a competitive or security advantage. For international SSA, transparency is stabilizing and encourages data sharing. As a result, the organization must be under international jurisdiction, such as the UNOOSA, not a single state.

However, having responsibility does not translate to directive authority over space operations. On the contrary, countries fiercely protect their spacecraft sovereignty and may not support an international initiative increasing restrictions already in place.[70] Jurisdiction would only cover associated I-SPIC operations (e.g. acceptable data, configuration control, internal/external relationships) and guide an organizational structure.

The U.S.-Russian Joint Data Exchange Center (JDEC) for missile warning could serve as a model of cooperation. Established to reduce the likelihood of launching a retaliatory missile attack due to false warnings, the center rapidly evaluates indications and provides an analysis. A direct parallel can be made to the I-SPIC's SSA mission. Both nations manage, and operate the JDEC with trained experts, provide near real time processed data from their warning networks and integrate the information into a "unified database for a multilateral regime for the exchange of notifications."[71] For the I-SPIC, an international organization of spacefaring nations should manage the capability and draw on SSA representatives to operate the center. Similar to missile warning data, the center would provide SSA information integrated from all five systems into a standardized and actionable database. However, there are two major differences between both centers. First, unlike JDEC data, I-SPIC information would be available to anyone or nation at no cost. Second, due to the global utility of space services and the benefit to all of mankind, funding should not be limited to spacefaring states, which already bear the burden of operating in space.

Data collection and processing are not limited to a specific time, and in many cases do not require a man in the loop if machine-to-machine operations are maximized. Taking into account data can rapidly move across the globe in seconds and computers can be linked as a network, the need to have a large standing organization of experts centrally located is unnecessary. An operations center established with a virtual network integrating SSA data, processing systems, and analysts is adequate to conduct normal operations. Considering much of the SSA data is already available (albeit in non-standardized format), processing hardware and space experts exist, and every sector involved in space agrees it is essential do develop an integrated space picture, it should "not take a large portion of the treasury"[72] to establish an I-SPIC.

Challenges: Hurdles to International Cooperation

If it was easy to create an I-SPIC, it would already exist. Why does a capability overwhelmingly supported by industry, operators, academia, and most government agencies remain fragmented while many of the systems required for integration already exist? A review of the literature indicates five challenges: perceptions, secrecy, stovepipes, use our system, and enforcement. Taken individually each could easily be overcome, but the cumulative impact places a high hurdle in the road.

The mere mention of establishing an international organization comes with perception questions. For some, an I-SPIC equates to an expensive and bloated bureaucracy. Others might be skeptical due to the fear of corruption while another group is concerned with the loss of sovereignty and increased restrictions.[73] These are valid concerns, but an international entity is not predestined to fulfill these perceptions. Spacefaring nations would determine the actual size and makeup. The I-SPIC proposes a small, flat organization incorporating the distributed capability of all SSA systems. The center is essentially a data integration, processing, analysis, and distribution capability, not a committee or governing body. Of course, products for distribution depend on the data received, and some entities prefer to keep the status of satellites proprietary.

Whether for a commercial advantage or national security, locations of some spacecraft are sensitive and not easily shared. However, the global nature of objects in space results in the discovery of most large objects such as satellites. Even with the added secrecy of not disseminating orbit data, organizations such as the Union of Concerned Scientists[74] or the ISO publish information that is not part of the satellite catalogue. The data is already available for many satellites, regardless if the owner approves or not. States need not submit data on their secret programs, but recognize the information already exists, albeit at a lower fidelity. The I-SPIC does not require exact locations of every space object, provided the owner understands the responsibilities to avoid collisions is theirs.

Of the five SSA processes, only the U.S. SSN[75] integrates two systems (ground and space SSN) on a regular basis and a third system (satellite operators) when a potential collision is identified. Even the ESA's 32 systems primarily operate independently and rely on Washington for a majority of space object acquisition data.[76] The ILRS and ISO may use the satellite catalogue for a cross reference to assist in acquisition, but their data does not crossflow. Satellite operators in their quest to find a way to avoid collisions will integrate data from the catalogue and when authorized other satellite operators. Unfortunately, due to the stovepiping of information, the data is not as good as it could be if all SSA systems were integrated in one center. If the goal is to minimize collisions in space, then one must have the best data possible from all sources to reduce variables and prediction errors.

In addition to the CFE, there are numerous organizations advocating their own systems to provide space object data and COLA information. The Center of Space Standards and Innovation produces a daily "Top 10" satellites with the highest probability of a close approach,[77] while companies, such as Space Exploration Engineering will develop the most efficient orbit for a satellite and COLA maneuver recommendations.[78] Other than their expertise in analyzing and processing data, their products and services are not unique.

However, most base their processes on the CFE catalogue and data provided by satellite operators, emphasizing DoD's dominant role in providing global SSA data. Despite the good information and services provided, the international community may have concerns on its continued reliance as the primary source of space object data, especially during times of conflict. These same concerns would arise if another state, consortium or commercial entity was providing the data.

The ongoing debate involving the Global Positioning System (GPS) is an excellent example applicable to the discussion.[79] GPS provides free, highly accurate, global navigation services. Considering the enormous amount of resources required to develop similar systems, why is ESA building Galileo and Russia reconstituting GLONASS? The answer revolves around two primary issues: trust and dependability. Since the U.S. owns and operates GPS, it controls availability and access. States, who may disagree with the U.S. in the future, want to ensure services. In other words, they do not completely trust the U.S. and are concerned GPS may be degraded in the future.

Going hand-in-hand with guaranteed distribution is dependable data, i.e. most accurate available. GPS users expect the better than three-meter accuracy levels that improve system requirements by 50 percent. However, DoD is only required to provide the lower performance.[80] This mismatch combined with an ability to further degrade the unencrypted signal results in some users questioning dependability. Similar to GPS accuracy concerns, the CFE's data lacks the precision required for highly accurate COLA predictions. Additionally, the SSN prioritizes data collection efforts in accordance with U.S. requirements. Finally, the process for non-U.S. agencies to request current COLA support is characterized as slow and unresponsive.[81] Considering the above, it is understandable why the owner of a system benefits from its universal acceptance while others desire an impartial capability.

Enforcement of rules and regulations is the I-SPIC's final challenge. As envisioned, the center would have no enforcement role. Its focus would be a capability to integrate, process, and distribute space object information. As an international entity, the creation and enforcement of laws, regulations and standards would be the responsibility of the governing organization, most likely the UN. Regardless of the challenges to creating an I-SPIC, they are far outweighed by the benefits.

Benefits: Securing the Final Frontier

Development of an I-SPIC will have far reaching impacts greater than just preventing collisions. Integrating SSA processes leverages high demand, low density systems and improves space operating environment understanding. Additionally, increased space object fidelity enables more efficient anomaly resolution while the accompanying transparency is stabilizing. Furthermore, the I-SPIC builds on common international objectives, encouraging cooperation.

The limited number of radars, telescopes, lasers, ISOs, and satellite operators that can collect SSA data need only to be optimized. Every day, SSA systems track, identify and/or discover space objects, often times observing the same items with minimal coordination, interaction, or data exchanges. By reducing or eliminating tracking redundancy, the low density systems can refine data on known objects and identify new ones. For example, integrating operator data from the 134 satellites the Air Force supports[82] and the additional 38 spacecraft the ILRS tracks, the U.S. SSN could reduce collection requirements on these objects.[83] Furthermore, the data gained from the ILRS and operators could make up for the lack of extensive Southern Hemisphere observation capabilities.[84] As a result, potential SSA efficiencies gained by leveraging systems and process would be tremendous.

The I-SPIC improves SSA with an increased understanding of and ability to predict future space object activities. As an internationally sanctioned organization, it enables an unprecedented level of coordination and cooperation between operators for maneuvers, disposals, and launches. The current slow and unresponsive process of state-to-state communications, ad hoc operations, and informal agreements drives inefficiencies resulting in shorter spacecraft missions. Increased space object knowledge will reduce orbit prediction errors and variables. The result of combining better data and increased operator coordination is a reduction in COLA maneuvers and associated analysis effort, thereby lowering operations costs and extending spacecraft service life.[85]

Increased SSA also assists the ability to identify potentially hostile actions in space. China's demonstrated anti-satellite weapons, lasing an U.S. spacecraft[86] and destroying a satellite, brings into focus the need to identify hostile intent in space. As offensive space capabilities multiply, many states will approach satellite anomalies as hostile actions first and then as a spacecraft problem.[87] The improved understanding of what is in space provides better tracking, and analysis of objects, enabling a more rapid identification of actions that are out of the ordinary and potentially hostile. Furthermore, integrating information from and encouraging coordination of operators into the I-SPIC results in a forum of open discussion of spacecraft activities and if necessary the direct query as to intent. The ability to help determine hostile intent is a direct product created by the I-SPIC's inherent space environment transparency.

Considering the proliferation of launch-capabilities and the ability of virtually any organization to operate a satellite, provided adequate funding, the need for transparency of space becomes increasingly critical. Unless a state is willing to take preemptive actions and prevent the launch of a spacecraft or disable it in orbit, there will be more objects in space, some of which may have offensive capabilities. Similar to arms control efforts on Earth, transparency is the foundation for verifying compliance and ensuring security.[88] Just as the Strategic Arms Reduction Treaties provided on-site inspections and national technical means overflight to create transparency and a better understanding of U.S.-Soviet/Russian nuclear platforms, the I-SPIC can serve a similar purpose for space, without new legal regimes, by integrating SSA systems providing a more complete space picture.[89]

By verifying expected COLA, stationkeeping or even rendezvous maneuvers,[90] and virtually eliminating the number of unknown satellites, the I-SPIC reduces international tensions.

On the other hand, I-SPIC transparency results in an understanding that hostile actions will be detected, associated with an aggressor, and countered by an early warning,[91] reducing the likelihood of such actions, once again contributing to international stability. This increased space transparency reemphasizes the need for spacefaring states to work with each other.

There is virtually unanimous agreement that preventing collisions is a priority and every effort should be taken to avoid these problems. Finding common ground in space is difficult as witnessed by the European Union's inability to coordinate a collective military space policy.[92] However, the I-SPIC sets aside discussions of weapons in space, liability, profits, and legal regimes, and focuses on one aspect that is common to all spacefaring nations, the need to prevent collisions in space. By identifying a unified objective and integrating available data, the stage is set for all parties to take a leap forward in international space cooperation.

Conclusion

The space community overwhelmingly agrees preventing collisions is critical for uninterrupted service. As the world becomes increasingly dependent on global space services, the number of on-orbit satellites will increase and so will the probability of collisions with other satellites and the estimated 100,000 debris objects in orbit. Although current space treaties and legal regimes are adequate to assign ownership and liability for manmade objects in space, the reality of demonstrating spacecraft operations negligence in creating debris, except for deliberate acts, is virtually impossible. This pragmatic position coupled with opposition to additional restrictions lead to a recognition that future treaties are unlikely. Reducing collisions is a priority for all spacefaring nations and is built on a foundation of three pillars. States and non-state entities are already taking steps in the satellite design and operation to prevent debris creation and mitigate collision damage, two pillars of COLA. However even with the best procedures and design, there will always be a need to improve the third pillar, spacecraft COLA maneuver.

Although conducting a maneuver is a common occurrence, COLA planning includes variables with considerable unknowns resulting in suboptimized decisions, increased risk, and shortened spacecraft mission life. Reducing the orbital unknowns is critical and can be done today by establishing the I-SPIC and integrating SSA systems. Internationally governed and operated by system experts, the I-SPIC would focus on increasing satellite operator SSA by providing COLA services including a more comprehensive space object catalogue, close approach warnings, launch-space object deconfliction support, and facilitating communication between operators.

The I-SPIC can overcome challenges to its establishment. By focusing on services, not enforcement, and establishing a flat organizational structure, the perceptions of a potentially bloated bureaucracy can be allayed. Likewise, the general consensus among space users holds that integration of current SSA stovepiped systems is more a policy and not a technology or cost issue. Furthermore, the desire by organizations to advocate their own systems and capabilities does not resolve the concerns of potential trust and dependability raised by states. Finally, maintaining spacecraft location secrecy is not an issue due to SSA capabilities proliferation and recognition that entities operating secret satellites share the desire to avoid collisions and will take actions to maneuver.

Encouraged by and inherent in the I-SPIC is increased international cooperation enabling new resource allocations. The ability to leverage low density, high demand systems will immediately improve SSA and reduce the risk of collisions. Additionally, the increased space environment transparency created by the I-SPIC will provide a stabilizing influence by identifying hostile intent and actions. Likewise, anomaly resolution will become more efficient, while the need to maneuver to avoid collisions will decrease, thereby increasing spacecraft mission life. Space services from navigation to weather to communications are integral to the global economy. Yet, these systems face a danger that threatens their capabilities, but could easily be reduced by the establishment of the I-SPIC.

Endnotes

[1] Lt Gen Bruce Carlson, USAF, "Protecting Global Utilities," *Aerospace Power Journal* (Summer 2000); available from http://www.airpower.maxwell.af.mil/airchronicles/apj/apj00/sum00/carlson.htm; Internet; accessed 3 February 2007.

[2] PanAmSat's Galaxy 4 satellite lost attitude control 19 May 1998 and disrupted 80 – 90 percent of all pagers in the United States. CNN Interactive, "Pager messages lost in space;" available from http://www.cnn.com/TECH/space/9805/20/satellite.outage/; Internet, accessed 8 February 2007.

[3] NASA Orbital Debris Program Office, "Orbital Debris Frequently Asked Questions," available from http://orbitaldebris.jsc.nasa.gov/faqs.html#1; Internet; accessed 26 February 2007.

[4] Although there are numerous definitions for objects in space, for the purposes of this paper an operational satellite is any manmade object, including the Space Shuttle and International Space Station, orbiting the earth that has an ongoing mission and is at least partial mission capable. Space debris includes natural occurring items such as portions of a comet or other objects caught in the earth's gravity and NASA's NPD 8710.3B, 27 January 2003, definition of operational debris: (1) Spacecraft or payloads that can no longer perform their mission. (2) Rocket bodies, payload adapters, and other hardware (e.g., bolt fragments, lens

covers, spin weights) left in orbit as a result of normal launch and operational activities. (3) Fragmentation products from failures or collisions.

[5] Spacecraft operate in numerous orbits, but the discussion of LEO and GEO serve to highlight the issues that are applicable to all regions in space. Other orbits include: Medium Earth Orbit (MEO), favored by the precise position, navigation, and timing constellations of the U.S. Global Position System (GPS) operating at 17,700 km, Russian Global Navigation Satellite System (GLONASS) operating at 19,100 km, and European Union Galileo operating at 23,250 km. Each system uses more than 24 spacecraft. However, the first Galileo vehicle was launched in 2005 and the system will not be fully operational until 2010 or later. Highly elliptical orbits, such as Molniya, orbiting from 500 km to 40,000 km from Earth, enable long dwell time over certain regions.

[6] NASA Orbital Debris Program Office, "Orbital Debris Graphics," available from http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html#leo; Internet; accessed 14 November 2006.

[7] National Aeronautics and Space Administration, Exploration Systems "Steering Satellite Technology in the Right Direction," available from http://www.exploration.nasa.gov/articles/ satellitetech.html; Internet; accessed 14 November 2006.

[8] National Aeronautics and Space Administration, *NASA Safety Standards Guidelines and Assessment Procedures for Limiting Orbital Debris*, NSS 1740.14, (Washington, D.C., Office of Safety and Mission Assurance, August 1995), B-2.

[9] U.S. Government. Orbital Debris Mitigation Standard Practices, "Objective 3, Selection of Safe Flight Profile and Operational Configuration;" available from http://orbitaldebris.jsc.nasa. gov/library/ USG_OD_Standard_Practices.pdf; Internet; accessed 13 January 2007.

[10] National Aeronautics and Space Administration, *NASA Safety Standards Guidelines and Assessment Procedures for Limiting Orbital Debris*, B-3.

[11] The amount of time debris remains in orbit is dependent upon gravitational forces. In LEO, objects less than 500 km will remain in orbit for a few weeks while objects over 2,000 km will remain in orbit for up to 20,000 years.

[12] National Aeronautics and Space Administration, Exploration Systems.

[13] At these speeds in GEO, debris as small as 10 cm can cause catastrophic damage, staying in orbit for millions of years.

[14] The Aerospace Corporation and 4th Space Operations Squadron conducted a study on the potential result of a collision between Milstar Flight-2 and Yamal 201. Allen B. Jenkin and John P. McVey, "Debris from a Collision of Geosynchronous Satellites, Phase 2, Part 1 Status," briefing slides, Schriever Air Force Base, 6 July 2005.

[15] The Space Shuttle can operate at altitudes up to 400 km. Therefore, crewmembers can service satellites in very Low Earth Orbit.

[16] The concept of three pillars of COLA is a new framework proposed by the author. Although initiatives to mitigate damage, prevent debris creation, and maneuver to avoid collisions are not new, specifically identifying and combining them into a COLA construct is. Currently, a large amount of effort, programs, and literature emphasize the proactive need to reduce debris, while maneuvers are reactive. The author's view is improving COLA maneuvers, not debris creation, should be a focus. Even if debris reduction programs are successful, debris and the threat of collision will always be present in the space environment. Therefore, developing optimized COLA identification and maneuver capabilities, and affiliated systems and processes are imperative.

[17] However, directives are self-imposed with rather easily obtained waivers for mission requirements that do not have the force of law, but are in reality guidelines only applicable to the establishing organization.

[18] U.S. Government. Orbital Debris Mitigation Standard Practices, "Objective 3, Selection of Safe Flight Profile and Operational Configuration;" available from http://orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf; Internet; accessed 13 January 2007.

[19] Failure to follow debris mitigation procedures can rapidly increase the number of objects in space as witnessed by two events within five days producing over 1,000 debris particles. On 19 February 2007, a Russian Breeze-M rocket stage motor exploded and on 14 February 2007 a Russian SL-12 rocket auxiliary motor exploded. Although an exact cause has not been determined, remaining on-board fuel that should have been depleted is likely responsible. "Two More Incidents Add To Growing Space Debris," *Space News,* 26 February 2007, 4.

[20] The data identifies approximately 5,000 known operational and fragmentation debris objects. United Nations, *Technical Report of Space Debris: Text of the Report Adopted by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Use of Outer Space*, (New York: United Nations 1999), 14.

[21] For an increased understanding of the impact of uncertainty see: William Ailor, Director, Center for Orbital and Reentry Debris Studies, Aerospace Corporation, "Collision Avoidance and Improving Space Surveillance," *Astropolitics* 2, no. 2 (April - June 2004): 107-120.

[22] Center for Space Standards & Innovation, "SATCAT Boxscore," 28 February 2007 linked from *CelesTrak Home Page* at "Online Satellite Catalogue," available from http://celestrak.com/satcat/boxscore.asp; Internet; accessed 3 March 2007.

[23] Lt Col Glen Shepherd, AFSPC/A3CD, "Space Situational Awareness," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[24] Nicholas L. Johnson, Chief Scientist for Orbital Debris, NASA Johnson Space Center, "Monitoring the Heavens, Today and Tomorrow," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[25] Gerhard Brauer, Head of Security Policy, European Space Agency, "European SSA: A Status Report," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[26] Lt Col Craig Bomber, Commander, 1st Space Operations Squadron, e-mail message to author, 20 February 2007.

[27] The constellation will be called the Space Based Space Surveillance system.

[28] International Laser Ranging Service, "Stations," 11 January 2007, linked from *International Laser Ranging Service Home Page* available from http://cddis.gsfc.nasa.gov/sp3c_satlist.html; Internet; accessed 20 January 2007.

[29] International Laser Ranging Service, "Satellite Missions," 1 February 2007 linked from *International Laser Ranging Service Home Page* available from http://ilrs.gsfc.nasa.gov/stations/index.html; Internet; accessed 14 February 2007.

[30] Paul D. Malley, Johnson Space Center Astronomical Society, "Capabilities and Roles of Independent Observers," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[31] Gary A. McCue, James G. Williams, and Joan M. Morford, *Optical Characteristics of Artificial Satellites,* SD 70-55 (Space Division, North American Rockwell, n.p., 1 July 1970), iii, 1, 2, 38.

[32] Malley, telephone interview by author, 27 February 2007.

[33] Operator information is up to 10-times more accurate than lower precision data. W. Ailor, Director, Center for Orbital and Reentry Debris Studies, The Aerospace Corporation, "Predicting and Detecting Collisions," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[34] The U.S. Congress authorized in 2004 and in 2006 directed DoD provide satellite tracking support to non-USG entities. At that time, NASA discontinued the Orbital Information Group.

[35] Currently the program is authorized until 2009.

[36] Richard DalBello, Vice President Government Affairs, Intelsat, and Joseph Chan, Manager Flight Dynamics, Intelsat, "Space Situational Awareness: Observations on a Global Satellite Element Warehouse," briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[37] Since the U.S. SSN is primarily a defense program, priority is placed on objects that pose the greatest threat to U.S. and Allied nations. Depending on the type of object and orbit predictability, the SSN will observe certain items much more frequently than others.

[38] Space-track identifies 60 entities with operational payloads in space. However, several are consortiums, commercial or multi-state owned.

[39] Information is current as of 3 March 2007.

[40] It can be debated there is a fifth treaty, the Agreement Governing the Activities of States on the Moon and other Celestial Bodies, 18 December 1979, commonly known as the Moon

Agreement. Michael Taylor argues in *Orbital Debris: Technical and Legal Issues,* Thesis (Montreal: Institute of Air And Space Law, Faculty of Law, McGill University, August 2006), and the author agrees, that the Moon Agreement does not apply to satellite operations. Major spacefaring nations are not signators and enforcement would be impossible.

[41] The treaty's formal title is the Treaty Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

[42] The treaty's formal title is the Convention on the Registration of Objects Launched into Outer Space.

[43] The treaty's formal title is the Convention on the International Liability for Damage Caused by Space Objects.

[44] The treaty's formal title is Agreement on the Rescue of Astronauts, the Return of Astronauts.

[45] Maj Michael W. Taylor, Chief, Space and International Law, Air Force Space Command, e-mail message to author, 19 January 2007.

[46] Outer Space Treaty, Article I.

[47] The treaty continues its discussion on national sovereignty with " … by means of use or occupation, or by any other means." Outer Space Treaty, Article II.

[48] Outer Space Treaty, Article IX.

[49] Outer Space Treaty, Article VI.

[50] Major Michael Taylor, *Orbital Debris: Technical and Legal Issues,* 42, 43.

[51] Registration Convention, Article II.

[52] Taylor, *Orbital Debris: Technical and Legal Issues*, 44, 45.

[53] Liability Convention, Article VI.

[54] Japan Aerospace Exploration Agency, "3-2-2-1, Settlement of Claim between Canada and the Union of Soviet Socialist Republics for Damage Caused by "Cosmos 954," linked from *Space Law Home Page* at "Online Satellite Catalogue," available from http://www.jaxa.jp/library/space_law/chapter_3/3-2-2-1_e.html; Internet; accessed 21 December 2006.

[55] Surrey Satellite Technology Ltd., "Space Debris Collides with CERISE Microsatellite in Low Earth Orbit at 31,000 Miles Per Hour," 15 August 1996, linked from *University of Surrey, Surrey Space Centre Home Page* at http://www.ee.surrey.ac.uk/SSC/CSER/UOSAT/press/cerisepr1.html; Internet; accessed 15 February 2007.

[56] The satellite destruction produced over 525 debris objects. On 2 February 2007, the International Space Station maneuvered to avoid debris from the destroyed satellite. Within three weeks of China's test, debris passed within three miles of satellites 500 to 600 times. United Press International, "Space station moves to avoid debris," *NewsTrack-Science*, 2

February 2007; available from http://.upi.com/NewsTrack/view.php?StoryID=20070202-03112-8664r; Internet; accessed 2 February 2007. Approximately sixty percent (1,860) of on-orbit payloads (3,150) are endangered by the debris. Paula Sutter, Assistant Secretary of State, quoted in Colin Clark and Jeremy Singer, “China A-Sat Test Scuttles Any Chances of Space Work with NASA,” *Space News,* 5 February 2007, 5.

[57] Valery Timofeev, “About the ITU Radio Communication Sector Brochure,” linked from the *International Telecommunication Union Radio Communication Sector Home Page* at “Mission Statement,” http://www.itu.int/ITU-R/information/docs/brochure-BR-en.pdf; Internet; accessed 8 December 2007.

[58] DelBallo and Chan.

[59] The UNOOSA, *Space Law Home Page,* available http://www.unoosa.org/oosa/en/ SpaceLaw/index.html, provides extensive links to international space law documents, conferences, and directories.

[60] It is expected guidelines will be adopted at the 44th meeting of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Use of Outer Space.

[61] Richard Denny, Vice President, Satellite and Network Operations, Inmarsat Global Ltd., “Commercial Perspective on Rules of the Road,” briefing slides, Improving Our Vision: Approaches for Shared Space Situational Awareness Conference, Colorado Springs, 15 September 2007.

[62] Lt Col (R) Keith Hinson, former 3d Space Operations Squadron Commander, telephone interview, 24 February 2007. The squadron continues to receive weekly maneuver data from SES-Americom. Michael Kiefer, 3d Sapce Operations Squadron Orbital Operations Officer, e-mail message to author, 23 March 2007.

[63] United States Strategic Command authorized the 50th Space Wing to coordinate directly with satellites that were both U.S. owned and operated. The Cheyenne Mountain Operations Center is also authorized to coordinate efforts between DoD satellite operators and non-DoD, U.S. spacecraft operators.

[64] In the author’s ten years of working with satellites, he is unaware of any successful effort following this system.

[65] The organization’s formal title was, Commission to Assess United States National Security Space Management and Organization.

[66] Honorable Donald H. Rumsfeld, *Report of the Commission to Assess United States National Security Space Management and Organization: Executive Summary,* 11 January 2001, available from http://www.defenselink.mil/pubs/space20010111.html; Internet; accessed 27 July 2006.

[67] Space Programs, US Code, Title 10, Subtitle A, Part IV, Chap. 135, 22 Dec 06.

[68] Maj. Gen. William Shelton, joint component commander for DoD space operations quoted in Gopal Ratnam, "U.S. STRATCOM Launches Space Control Plan," *DefenseNews*, 16 October 2006, 17.

[69] The intergovernmental Group on Earth Observation is in the midst of a 10-year plan establishing a similar center, Global Earth Observation Systems of Systems (GEOSS), to integrate Earth observation information to better understand environmental, climate, ecosystems, and water issues. "GEOSS will be a "system of systems" consisting of existing and future Earth observation systems, supplementing but not supplanting their own mandates and governance arrangements. It will provide the institutional mechanisms for ensuring the necessary level of coordination, strengthening and supplementation of existing global Earth observation systems, and for reinforcing and supporting them in carrying out their mandates." Additional GEOSS information is available at: GEO, "GEOSS 10-Year Implementation Plan," 16 February 2005, linked from *Group on Earth Observations Home Page*, available from http://www.earthobservations.org/index.html; Internet; accessed 22 February 2007.

[70] The 2006 U.S. National Space Policy, para 2, Principles, specifically calls for opposing "the development of new legal regimes or other restrictions that seek to prohibit or limit U.S. access to or use of space. Proposed arms control agreements or restrictions must not impair the rights of the United States to conduct research, development, testing, operations or other activities in space for U.S. national interests." President George W. Bush, "U.S. National Space Policy," 31 August 2006, linked from *Office of Science and Technology, Executive Office of the President Home Page* at "White House News: 10-10, U.S. National Space Policy," available from http://ostp.gov/html/US%20National%20Policy.pdf; Internet; accessed 15 September 2006.

[71] President William J. Clinton, "Memorandum of Agreement Between the United States of America and the Russian Federation on the Establishment of a Joint Center for the Exchange of Data from Early Warning Systems and Notification of Missile Launches," 4 June 2000, linked from *Federation of American Scientists WMD Resources* at "Arms Control," available from http://fas.org/nuke/control/jdec/text/000604-warn-wh3.htm; Internet; accessed 4 January 2007.

[72] Shelton quoted in Ratnam.

[73] For examples of recent international corruption and efforts to prevent continued corruption see: Transparency International, "Transparency International, global coalition against corruption: Annual Report 2005," 1 June 2006, linked from *Transparency International, global coalition against corruption Publications Home Page*, at "Download Transparency International's Annual Report 2005," available from http://www.transparency.org/publications/annual_report; Internet; accessed 22 February 2007.

[74] The Union of Concerned Scientists is an activist organization that integrates science into their public policy positions. Issues of importance to them include global warming, energy, security, and food. Additional information is available at http://www.ucsusa.org.

[75] The author was unable to confirm whether Russia integrates other SSA systems into their SSN.

[76] 32 includes all potential ESA SSN contributing radars and telescopes. For an overview of each facility and system see: Dr. Heiner Klinkrad, Head of ESA Space Debris Office,

"Monitoring Space – Efforts Made by European Countries," available from http://www.fas.org/spp/military/program/track/klinkrad.pdf; Internet; accessed 2 March 2007.

[77] Additional information on Center for Space Standards & Innovation is available at http://www.centerforspace.com. For the latest "Top Ten" lists see CSSI, "Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space," available from http://www.celestrak.com/SOCRATES; Internet; accessed 15 December 2006.

[78] Space Exploration Engineering, "Spacecraft Operations, Mission Planning and Space Systems Engineering," available from http://www.see.com; Internet; accessed 3 November 2006.

[79] The author has been involved in GPS operations for almost 10 years. Much of the following discussion comes from personal experience.

[80] Interview 2 Mar 07, Lt Col Kurt Kuntzleman, Commander, 2d Space Operations Squadron, responsible for all GPS operations.

[81] DelBallo and Chan.

[82] General T. Michael Moseley, "HAC-D Readiness Hearing Written Testimony," 18 January 2007; Air Force Aim Points available from http://www.afspaeagle.com/NewsPublic/CSAF_Readiness_Hearing.htm; Internet; accessed 26 February 2007.

[83] U.S. National Space Policy, para 3, United States Policies Goals calls for encouraging international cooperation to advance national security.

[84] The Henry L. Stimson Center, "Key Element: Improving Situational Awareness in Space," available from http://stimson.org/wos/?SN=WS20040412654; Internet; accessed 13 January 2007.

[85] One of the primary service life limiting factors for spacecraft operations is the amount of available fuel. Once minimum fuel levels are reached, operators dispose of the satellite. Other factors include solar array power collection ability, component malfunction due to age or quality, and on-board batteries' ability to maintain a charge and recharge.

[86] Warren Ferster and Colin Clark, "NRO Confirms Chinese Laser Test Illuminated U.S. Spacecraft," 2 October 2006; available from http://www.defensenews.com/story.php?F=2141128&C=airwar; Internet; accessed 14 November 2006.

[87] Shelton quoted in Ratnam

[88] There is considerable Arms Control literature discussing the critical role transparency plays in ensuring verification, stability and security. An excellent declassified U.S. Strategic Command document provides insight into Arms Control "Safeguards, Transparency & Irreversibility" principles is, Major J. L. Hogler, "White Paper: Post-START II Arms Control," 18 September 1996; linked from *The Nautilus Institute Nuclear Strategy Project* at "STRATCOM White Paper," available from http://www.nautilus.org/archives/nukestrat/USA/Force/stratcom96.pdf; Internet; accessed 22 February 2007.

[89] Lt Col Peter L. Hays, *United States Military Space: Into the Twenty-First Century*, U.S. Air Force Institute for National Security Studies Occasional Paper 42 (Maxwell Air Force Base: Air University Press, September 2002), 64-70.

[90] Several states have initiated experimental satellite programs testing unmanned rendezvous capabilities. One such program is the Air Force's Experimental Satellite System-11 (XSS-11). Additional XSS-11 information can be found at, Air Force Research Laboratory Space Vehicle Directorate, "XSS-11 micro satellite," available from http://www.vs.afrl.af.mil/FactSheets/XSS11-MicroSatellite.pdf; Internet; accessed 14 November 2006.

[91] Stimson Center.

[92] Brooks Tigner, "EU Struggles for Accord on Military Space," *DefenseNews*, 23 October 2006, 24.