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THE NEED FOR A GLOBAL SPACE-TRAFFIC-CONTROL SERVICE:

AN OPPORTUNITY FOR US LEADERSHIP

by

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Biography

Lt Col Matthew C. Smitham (BS, Physics, University of Washington; MS, Engineering Physics, Air Force Institute of Technology; MA, Military Operational Art, Air Command and Staff College) is a student at the Air War College, Maxwell AFB, Alabama. Prior to Air War College, Lt Col Smitham was the payload deputy program manager for a next-generation imaging satellite constellation at the National Reconnaissance Office, Chantilly, Virginia. In this capacity, Lt Col Smitham led a system program office team, which directed a contractor team in the development, integration, test, launch and initialization of the mission payload.

Lt Col Smitham has served in a variety of technical management, leadership and staff positions in the Air Force. Previous assignments include Air Staff positions as a program element monitor and deputy division chief in the Directorate of Information Dominance, Assistant Secretary of the Air Force (Acquisitions), Washington D.C.; research, development and program management positions at the National Reconnaissance Office, Chantilly, VA in the Advanced Science and Technology, and Signal Intelligence Directorates; and scientific research efforts to mitigate space weather impacts on US space systems at the Space Vehicles Directorate, Air Force Research Laboratory, Hanscom AFB, Massachusetts.

Introduction

Losing a satellite to an accidental on-orbit collision is no longer hypothetical, but real and increasingly likely. As a result, the need for a global space-traffic-control service must be addressed by the space-faring nations of the world, especially the United States. The fiscal and national security ramifications are too significant to ignore. The replacement cost of a satellite, perhaps hundreds of millions of dollars, is the most obvious impact. But, this may be the most trivial consideration. The greatest concern is the potential catastrophic loss of vital communications, navigation, weather, and other services we depend on for daily global commerce and defense. This paper explains the problem, examines some possible paths to address the problem, and recommends actions.

In February 2009, a spectacular collision grabbed headlines around the world. In low-earth orbit (LEO) 400 miles above Siberia, an American commercial communications satellite, *Iridium 33*, collided with the defunct Russian satellite, *Cosmos 2251*.[1] The probability of this first known satellite-to-satellite collision was estimated to be one in 100,000.[2] With a closing velocity of 22,000 miles per hour, the satellites were instantly pulverized into debris clouds creating more than 870 objects observed by the US Air Force's (USAF) Space Surveillance Network (SSN).[3]

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[1] Secure World Foundation, *Iridium 33-Cosmos 2251* Collision Factsheet, 13 February 2009, www.SecureWorldFoundation.com; Liz DeCastro, "Update on Iridium Satellite Constellation," Bethesda, MD, 11 February 2009, www.iridium.com

[2] William Ailor, "Space Traffic Control and Space Debris," briefing, 8 May 2009, Director for Center for Orbital & Reentry Debris Studies, The Aerospace Corporation

[3] Lt Gen Larry James, "Keeping the Space Environment Safe for Civil and Commercial Users," Statement of Lieutenant General Larry James, Commander Joint Functional Component Command for Space before the Subcommittee on Space and Aeronautics, House Committee on Science and Technology, 28 April 2009,

The specter of collisions is not new, despite the theory of "big sky."[4] Although *Iridium-Cosmos* is the first known collision between two satellites, this was the fourth documented accidental collision in space (intentional destruction will be described later). In 1991, coincidently, another defunct Russian satellite, *Cosmos 1934*, collided with a fragment from another *Cosmos* launch.[5] Five years later, the French reconnaissance satellite *CERISE* was damaged by a colliding with a fragment from an *Arianne* rocket body, another French object. In this collision, the fragment struck *CERISE* with a closing velocity of 32,400 miles per hour cleaving its 20-foot boom in half. Experts estimate the probability of this collision was one in a million[6]--so much for the big sky theory. Luckily, the satellite remained operating.[7] In 2005, the third confirmed collision occurred. The final stage of a US *Thor Burner 2A* rocket, in orbit more than 31 years, struck a fragment from the upper stage of a Chinese *Long March 4* rocket.[8]

Beyond collisions, other events also present dangers to satellite traffic. Lieutenant General Larry D. James, commander of the Joint Functional Component for Space, reported the Chinese anti-satellite test which destroyed *Fengyun-1C* in January 2007 was the worst fragmentation event in the history of spaceflight. This event added "2,400 pieces of potentially destructive debris," increasing the number of objects tracked by USAF Space Command by over

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http://gop.science.house.gov/Media/hearings/Space09/april28/james.pdf (Accessed 16 September 2009).

[4] "Big sky" theory, borrowed from the aviation community, proposes space is so large the probability of a collision is infinitesimally small. Some also use the term "big space."

[5] Tony Reichhardt, "Satellite Smashers, Space-faring nations: Clean-up low Earth orbit or you're grounded," *Air and Space Magazine*, 1 March 2008; William Ailor, "Space Traffic Control and Space Debris"

[6] William Ailor, "Space Traffic Control and Space Debris"

[7] Tony Reichhardt. "Satellite Smashers, Space-faring nations: Clean-up low Earth orbit or you're grounded."

[8] Tony Reichhardt, "Satellite Smashers, Space-faring nations: Clean-up low Earth orbit or you're grounded"; William Ailor "Space Traffic Control and Space Debris"

10%.[9] A month later, a Russian upper stage from a *Proton* rocket, loaded with fuel leftover from a failed boost, exploded and created another 1,100 pieces of debris.[10] As of April 2009, the Air Force was tracking approximately 19,000 objects larger than 10 centimeters. If the Air Force could track objects down to one centimeter, it estimates the amount of debris would be 300,000.[11]

As space becomes more crowded with debris, it may be reaching a precarious tipping point. In 2006, NASA scientists warned unless space debris is removed, the likelihood of collisions will increase. They predict beyond 2055 "the creation of new collision fragments exceeds the number of decaying debris" and the "current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the dominant debris-generation mechanism in the future." In other words, as collisions create more debris, the collisions themselves become the primary source for debris.[12] As a result, NASA is concerned about the risk debris poses to its manned systems.

During 2008, with the aid of the Department of Defense's Joint Space Operations Center (JSpOC), NASA made five collision avoidance maneuvers to protect its human-space-flight

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[9] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 3.
[10] US House, Committee on Science and Technology, Subcommittee on Space and Aeronautics Hearing Charter, *Keeping the Space Environment Safe for Civil and Commercial Users*, 28 April 2009, http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Space/28apr/Hearing_Charter.pdf. (Accessed 16 Sept 09).
[11] NASA briefing, "The Threat of Orbital Debris and Protecting NASA Space Assets from Satellite Collisions," 28 April 2009. Note: Although space debris mitigation, by physical means, policy or international agreement, is an important topic unto itself, it has been extensively discussed by others and is not addressed in this paper.
[12] Nicholas Johnson and Jer-Chyi Liou, "Risks in Space from Orbiting Debris," *Science Magazine*: Washington: 20 January 2006. Vol. 311, Iss. 5759, pg 340; Tony Reichhardt, "Satellite Smashers, Space-faring nations: Clean-up low Earth orbit or you're grounded,"

missions and maneuverable robotic assets.[13] In March 2009 alone, the International Space Station had three near misses, which required the crew to prepare for emergency evacuation in one case and change orbit in another.[14] GeoEye, a commercial imaging company, reported it has maneuvered its Ikonos satellite seven times and GeoEye-1 satellite four times to avoid space junk in the LEO region.[15] In addition, Massachusetts Institute of Technology's Lincoln Laboratory has recommended 65 avoidance strategies in the GEO belt since 1997.[16] Although these efforts are encouraging, they are insufficient.

Today, most of the world's satellites fly in the blind, operating under the safety assumptions inherent in the big sky theory. However, General Kevin P. Chilton, commander of US Strategic Command, stated big sky has now "[come] to a close."[17] As of April 2009, USAF Space Command and JSpOC were tracking 19,000 objects including 1,300 active payloads.[18] In the next decade, an additional 200 payloads are expected.[19] This growth in satellite numbers and the world's dependence on these systems points to the need for global space-traffic control. As the

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[13] NASA briefing, "The Threat of Orbital Debris and Protecting NASA Space Assets from Satellite Collisions," 28 April 2009.
[14] Doug Messier, "Secure World Foundation Proposes Global Space Debris Tracking System," *Parabolic Arc*, 29 April 2009, http://www.parabolicarc.com/2009/04/29/secure-world-foundation-proposes-global-space-debris-tracking-system/. (Accessed 17 September 2009).
[15] Ferster, Warren, "GeoEye Dodging Space Junk with Increasing Frequency," *Space News*, 4 November 2009, http://www.spacenews.com/earth_observations/091104-geoeye-dodging-space-junk.html. (Accessed 22 November 2009).
[16] Richard Abbot and Timothy Wallace, "Decision Support in Space Situational Awareness," *Lincoln Laboratory Journal*, Volume 16, Number 2, 2007, 313.
[17] General Kevin P. Chilton, (address, Strategic Space and Defense Conference, Offutt AFB, NE, 4 November 2009). In this speech, General Chilton refers to "big sky" as "big space."
[18] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 3. Note: the number of active payloads cited in literature varies from 900 to 1,300. For consistency, this paper will use 1,300 payloads cited by General James during his 2009 Congressional testimony. In addition, the math for the number of objects reported in public forums by the USAF does not add in a straight forward manner either. For example, 6,000 objects are tracked but not cataloged because the launching country cannot be determined.
[19] Ibid.

Iridium-Cosmos collision illustrates, the ad hoc efforts of NASA and others are not enough. Without a robust service to mitigate potential collisions, operators of military, civil and commercial satellites are without the means to avoid catastrophe.

This paper advocates the United States establish a global service with the cooperation of the international community and private sectors. To support this recommendation, this paper will examine existing global services which could serve as a model for a space-traffic-control service. But first, this paper will describe the functional components of a service, the current space environment, the state of fielded space situational awareness (SSA) systems, gaps in these systems, and liability implications.

The Current Landscape

Before discussing the current space environment and the systems which monitor space, let's first describe what would make up a world-wide 24/7 space-traffic-control service. From a functional view, this service must be able to accurately search, detect, track, identify, and catalog space objects in earth's orbit. The service would then need to predict the future positions of these objects, analyze the traffic for possible collisions (referred to as conjunctions), issue timely warnings to affected parties, and direct avoidance maneuvers, if required. If damage is sustained, per international treaties, the service would then need to assist to the greatest extent feasible in identifying the space objects and nations involved to help determine liability.[20] Logically, these functions can be organized into three categories: acquire, analyze and act (see Figure 1), which parallels how data can be transformed into information and knowledge.

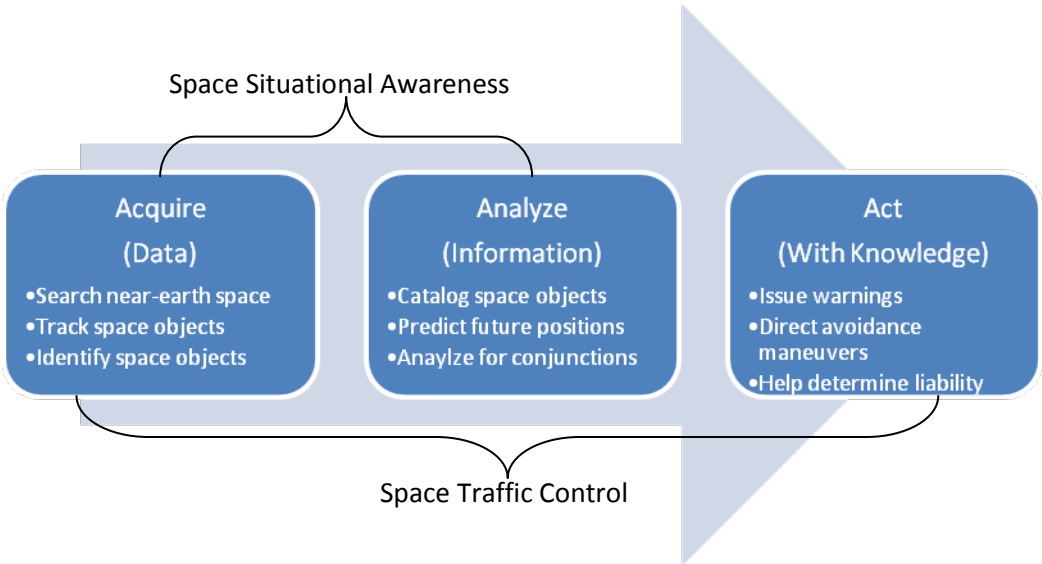

Figure 1. Functional view of a global space-traffic-control service

[20] US Congress, Office of Technology Assessment, *Orbiting Debris: A Space Environmental Problem—Background Paper*, OTA-BP-ISC-72 (Washington, DC: US Government Printing Office, September 1990).

Monitoring and understanding the space environment[21] comprise the essential first steps towards building a space-traffic-control service. This is traditionally referred to as SSA. SSA by itself is necessary, but insufficient. A space-traffic-control service goes beyond this by also actively mitigating potential collisions (acting with knowledge, see Figure 1). Currently, a service which actively controls the global-space traffic does not exist.[22] To begin this discussion, let's first examine the near-earth-space environment.

The number of man-made objects in earth's orbit tracked by the Air Force has quadrupled to 19,000 over the past 29 years.[23] By 2015 the Air Force plans to upgrade its space surveillance network. With its increased sensitivity, the Air Force expects the catalog to grow five-fold to 100,000 objects.[24] The vast majority of these space objects and debris are in the LEO region.[25] This is the orbital region of most manned-space flights and also where all the collisions described earlier occurred. However, objects in the LEO orbit are not the only ones susceptible to collision. The GEO belt is another region of concern.[26] Almost one-third (380) of the total 1,300 active payloads is in the GEO belt. Most of these are the high-value, high-bandwidth

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[21] For this paper, *space environment* is narrowly defined to be just the man-made space objects and associated debris orbiting the earth. It does not include space weather commonly included in the definition of space environment.

[22] The United States, in a non-routine limited fashion, maneuvers some of its high-priority satellites to avoid collisions. But the United States only does this only for its own satellites. A global service that could direct space traffic for all satellites irrespective of their origin (governmental or non-governmental) does not exist. The CFE program (discussed later in this paper) does provide some collision avoidance warnings for non-US-government entities, but these warnings lack sufficient accuracy for collision avoidance maneuvers. The Air Force only passively warns and makes suggestions; it does not recommend maneuvers or enforce maneuvers for collision avoidance. In fact, the Air Force cautions the users to use the information at their own risk. See Space-track.org, *User Agreement*, www.space-track.org/perl/new_account.pl.

[23] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 3.

[24] Jim Hodges, "Space Fence Reinvented," *C4ISR Journal*, October 2008, 37.

[25] LEO is defined as an orbit less than 2,000 kilometers in altitude.

[26] GEO is defined as an orbit 36,000 kilometers above the earth. Note: the medium earth orbit (MEO) region, although containing some important constellations such as Global Positioning System (GPS), currently is at low risk for collisions and is not discussed at length in this paper.

communication satellites used for television and communications. To complicate matters, another 750 dead satellites dangerously drift uncontrolled in the GEO belt.[27] In all, the Air Force tracks between 2,000 and 2,500 objects in GEO.[28]

Beyond satellite-to-satellite collisions, as discussed earlier, satellite collisions with debris are another concern. Historically, 94% of all tracked objects are debris. Debris includes nonfunctional spacecraft, spent rocket bodies, breakup fragments, deterioration products, exhaust products, objects released during spacecraft deployments and operations, and refuse from human missions.[29] In the last 20 years, fragmentation debris comprises roughly 40-45% of all objects tracked. Large debris, such as dead satellites and old rocket bodies, comprises another 35-40%.[30]

Recent events in the LEO region have made the debris environment even messier. The 2007 Chinese anti-satellite test added another 2,400 pieces of potentially destructive orbital debris, a 2.7-fold increase in debris centered at 850 kilometers in altitude. The *Iridium-Cosmos* collision added another 870 objects, a 33% increase at 780 kilometers.[31] As discussed earlier,

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[27] Richard Abbot and Timothy Wallace, "Decision Support in Space Situational Awareness," 306.
[28] USSTRATCOM, Space Control and Space Surveillance Fact Sheet, 19 February 2008, http://www.stratcom.mil/files/STRATCOM_Space_and%20Control_Fact_Sheet-25_Feb_08.doc. (Accessed 18 September 09).
[29] Committee on Space Debris, *Orbital Debris: A Technical Assessment*. (Washington, DC: National Academy Press, 1995), 12.
[30] US Congress, Office of Technology Assessment, *Orbiting Debris: A Space Environmental Problem—Background Paper*, 2; Committee of Space Debris, *Orbital Debris: A Technical Assessment*, 22.
[31] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 3; NASA briefing, "The Threat of Orbital Debris and Protecting NASA Space Assets from Satellite Collisions," 28 April 2009, 5.

unless debris can be removed, the problem will only get worse. Scientists predict by 2055 new debris generated by collisions will outpace debris naturally removed through orbital decay.[32]

Currently, only two nations have the necessary network of ground-based sensors and computational capabilities to attain a minimum degree of SSA, which could be used to bootstrap a global space-traffic-control service. These are the American SSN and Russian Space Surveillance System (SSS).[33] Other government agencies with limited or nascent capabilities include the Chinese, French, and German militaries and the European Space Agency (ESA). In addition, non-governmental agencies such as the International Scientific Optical Network operated by the Russian Academy of Sciences and amateur astronomers also produce orbital data.[34] However, to achieve a truly global system, none of these are adequate; they all require upgrades and/or cooperation.[35]

The US SSN is by far the most comprehensive system in the world. The SSN is a global network of 29 ground-based sensors. In general, it uses radars to track LEO objects and optical telescopes to track GEO objects. Combined, these sensors provide the JSpOC with roughly 300,000 to 400,000 measurements (observations) per day. The JSpOC then has the enormous computational task of merging these observations into tracks, correlating the tracks with *a priori* information on known objects, and updating the 19,000 objects in the unclassified space

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[32]Nicholas Johnson and Jer-Chyi Liou, "Risks in Space from Orbiting Debris," 340; Tony Reichhardt, "Satellite Smashers, Space-faring nations: Clean-up low Earth orbit or you're grounded."

[33] Committee of Space Debris, *Orbital Debris: A Technical Assessment*, 32.

[34] Brian Weeden, "The numbers game: What's in Earth orbit and how do we know?," *The Space Review*, 13 July 2009, http://www.thespacereview.com/article/1417/1. (Accessed 16 September 2009).

[35] Committee of Space Debris, *Orbital Debris: A Technical Assessment*, (Washington, DC: National Academy Press, 1995), 32.

catalog.[36] For high-priority US military and NASA analyses, the JSpOC also generates high accuracy analyst sets only available to military personnel at JSpOC.[37]

In comparison, the Russian SSS has 22 sensors, which include military and civilian radars and telescopes. These systems collect approximately 50,000 observations per day. To make up for fewer observations (as compared to the Americans), the Russians depend on superior mathematical and predictive abilities to maintain their catalog. However, the SSS is not a global-wide network; it is geographically confined to the longitudes of Russia and former Soviet republics. As a result, this geometry hinders their ability to track low-inclination LEO satellites and GEO satellites in the western hemisphere. Further, unlike the Americans, the Russians do not publish a publically available catalog.[38]

For self-stated reasons of sovereignty and independence, the Europeans are proposing a space-surveillance network of their own. The European Union realizes its economy depends on space technologies and protection of space systems is vital to its security. Some of its member states, such as Germany and France, already have some space-surveillance assets, but these are limited and not integrated into a holistic system. ESA's Director General said "Europe is blind

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[36] USSTRATCOM, *Space Control and Space Surveillance Fact Sheet*, 19 February 2008, http://www.stratcom.mil/files/STRATCOM_Space_and%20Control_Fact_Sheet-25_Feb_08.doc. (Accessed 18 September 2009).

[37] The US military uses two different mathematical models to describe orbits and conduct its analyses. The first is general perturbations; it describes orbits with two-line element (TLE) sets compatible with the Simplified General Perturbation computer model; these are made public. The second method, far more accurate and complex, is special perturbation which uses state vectors with double-precision positions and velocity vectors. It is only used for high-priority mission support on a case-by-case basis. State vectors are available only to the US government and are not shared with the public like TLE sets. See United States Space Command Instruction 10-5, "DoD, Commercial, Civil and Foreign Space Support," 1 April 2002, pages 2 and 9.

[38] Committee of Space Debris, *Orbital Debris: A Technical Assessment*, 32.

to what happens in space and wholly dependent on US supplied data."[39] To remedy this situation, the ESA plans to invest $66 million over the next three years to develop its own capability.[40]

A new US government initiative is also emerging. In 2003, Congress directed the Secretary of Defense to conduct SSA for all US government space systems and as appropriate for commercial and foreign entities (CFE). In response, USAF Space Command made available conjunction analyses via the Space-track.org website to non-governmental entities as a pilot program. As of September 2009, 18 commercial companies, which operate 66 satellites, have signed quid-pro-quo agreements with the US government for conjunction analyses and launch support. In October 2009, USAF Space Command transitioned CFE to US Strategic Command as an operational program. However, high-precision conjunction analyses needed for effective collision avoidance are not universally available. This is limited to high-value satellites (as prioritized by the US military) because it is labor intensive and not automated.[41]

Along with Space-track.org (as part of CFE), several other public-domain services such as HeavensAbove.com and Celestrack.com also publish the space catalog on the internet. Although they provide a valuable service, they are not necessarily providing new data. Essentially, they re-publish the unclassified space catalog provided by the Air Force, the so called "two line element" (TLE) sets. Although available to the world, these TLE sets do not have the requisite accuracy needed for precision conjunction analysis. In fact, the Air Force warns Space-track

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[39] Quoted in Peter B. De Selding, "Despite SSA Collaboration, Europe Leery of U.S. Intentions," *Space News*, 19 January 2009, 6.
[40] Ibid.
[41] Lt Col Charles Spillar, interview by author, 24 September 2009, Peterson AFB, CO; Lt Col Charles Spillar, "Commercial and Foreign Entities (CFE) & U.S. Government (USG) SSA Sharing," USAF Space Command/A3CN briefing, 24 September 2009.

users to use the data at their own risk.[42] In addition, at least 6,000 objects do not appear in the Space-track catalog because the launching nation could not be identified.[43] With these restrictions and limitations, the underlying message is users need more accurate data.

In an apparent response to this, three of the world's largest commercial satellite operators—Intelsat, SES and Inmarsat—in a cooperative private venture, created the Space Data Association in November 2009. They expect eight companies to participate in collision avoidance and another 14 companies to be involved in reducing satellite radio-frequency interference. Although they acknowledge the US CFE program has some benefit, they feel compelled to invest their own capital because the "information is not always as precise or up to date—nor is it disseminated as quickly—as it needs to be to protect against close encounters between satellites."[44]

Two other organizations also provide conjunction analyses and warnings of possible satellite collisions. Lincoln Laboratory, as part of a cooperative-research-and-development agreement, fielded the Geosynchronous Monitoring and Warning System (GMWS) for its four member partners. The automated GMWS, via high-precision orbits derived from three Lincoln Laboratory-operated radars merged with SSN data, produces sixty-day watch lists and two-week warning lists of close encounters for 60 commercial satellites. Lincoln Laboratory typically reports 250 conjunctions per year and has recommended 65 avoidance strategies to its partners

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[42] Space-track.org, *User Agreement*, www.space-track.org/perl/new_account.pl, (Accessed 17 November 2009).
[43] Brian Weeden, "The numbers game: What's in Earth orbit and how do we know?"
[44] Peter B. De Selding, "Satellite Firms Moving Ahead on Orbital Database," *Space News*, 18 November 2009, http://spacenews.com/satellite_telecom/091118-satellite-firms-moving-ahead-orbital-database.htm. (Accessed 22 November 2009).

since 1997.[45] A second service, the Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES), is hosted on Celestrack.com and available to anyone interested. It provides twice-a-day analyses for all orbital regions based on the Air Force's unclassified two-line element sets. Although it's not very accurate—the positional uncertainties are hundreds or thousands of meters due to the limitations of the TLE sets—the SOCRATES reports can be used as tip-offs by satellite operators for further investigation.[46]

Despite these efforts, there is a significant gap between what the current space surveillance capabilities can do and what is needed for comprehensive global space-traffic control. For example, as good as the US system is, General James says it still lacks the ability to acquire all on-orbit objects. He stated the SSN has significant coverage gap in the southern hemisphere and often loses some GEO satellites.[47] To plug this hardware gap, the Air Force is investing $45 million to field a new ground-surveillance system, an expansion of the "Space Fence," with initial deployment by 2015.[48] In addition, the Space-based Space Surveillance system, slated to launch in 2010, will provide the ability to scan the entire GEO belt from space and maintain

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[45] Richard Abbot and Timothy Wallace, "Decision Support in Space Situational Awareness," 307-313.

[46] Lt Gen (ret) John Campbell, et al., "Examining Codes and Rules for Space," (panel, Forum on National Security Space, George C. Marshall Institute, Washington, DC, 27 June 2007), http://www.marshall.org/pdf/materials/554.pdf, 17. (Accessed 16 September 2009).; T.S. Kelso and S. Alfano, "Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES)," (address, 2005 AAS/AIAA Space Flight Mechanics Conference, 23-27 January 2005), http://celestrack.com/publications/AAS/05-124/. (Accessed 17 November 2009).

[47] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 8.

[48] Jeremy Singer, "Air Force Seeks to Triple Funding for Space Surveillance," *Space News*, 7 April 2008, 50.

"track custody" of GEO objects every 24 hours.[49] However, these efforts address mainly data acquisition (see Figure 1), not holistic solutions for space-traffic control.

Beyond hardware, the US software system is also imperfect and antiquated. In some cases, the Americans are behind Russian mathematical practices to process and predict high-quality space tracks.[50] For example, the US military is still using decades-old astrodynamic techniques to create element sets, mainly because the costs to redesign and recertify its operational systems would be enormous.[51] To make up some of this deficit, the Air Force uses the brute force method of over sampling (lots of observations) versus elegant mathematics. In addition, JSpOC until recently was performing conjunction analyses only for priority US satellites, such as manned flights and US defense satellites. After the *Iridium-Cosmos* collision and renewed interest by Department of Defense senior leaders,[52] JSpOC recently upgraded its computational systems to give it the ability to run conjunction analyses for all active satellites within the catalog. However, precision analysis needed for positive collision avoidance is still only on a case-by-case basis because it is labor intensive and not automated.[53]

Another challenge is data sharing. Currently only the United States shares its unclassified space TLE catalog with the world (with some restrictions). But its information sharing is

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[49] Lt Gen James, "Keeping the Space Environment Safe for Civil and Commercial Users," 8.
[50] Author's personal experience and knowledge
[51] Brian Weeden, "The numbers game: What's in Earth orbit and how do we know?"
[52] Lt Col Charles Spillar, interview, 24 September 2009
[53] In addition to its antiquated data processing and orbit prediction software, the associated Air Force databases are also archaic. Currently, the database is hardcoded to handle only a limited number of objects. So, it will also need to be upgraded. "Out of the 69,999 entries allocated for cataloged objects, about half are already used and growth is accelerating every year. Compounding this situation are the plans to add new sensors to the SSN in the near future that will greatly expand the number of objects tracked." Refer to article by Brian Weeden, "The numbers game: What's in Earth orbit and how do we know?"

criticized for being untimely and insufficient for conjunction assessment and warning.[54] Russia and China currently do not share.[55] And the ESA does not plan to publicly share data either. An ESA official stated, "We will send our data only to those who really need it."[56] Further complications arise from security. For example, the Americans do not share orbital information on their national-security satellites. The French were frustrated the United States publishes data on French classified satellites and were asking the Americans to withhold this information.[57] Dr. Ailor, Aerospace's Director for Center for Orbital & Reentry Debris Studies, states an effective space-traffic-control system would need to incorporate data from all sources, government and private, and would need to protect proprietary and sensitive data.[58]

Beyond the inadequacies of data policies, there are also no international treaties or guidelines, which "mandate a legal set of approaches towards space traffic management."[59] Currently, only liability resulting from collisions is addressed by international law. The *Outer Space Treaty of 1967*, the *Liability Convention of 1972*, and the *Registration Convention of 1976* make it clear both intergovernmental organizations and state parties are liable for damages caused by their space objects (including their components) whether on the ground, air or outer space. Unfortunately, the treaties are silent on the issues of debris management or removal. If

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[54] Iridium Satellite LLC "Iridium Provides Update on Satellite Constellation," 9 March 2009, http://www.iridium.com/; Peter De Selding, "Satellite Firms Moving Ahead on Orbital Database."
[55] Edward O'Hara, *Space Situational Awareness*, Technological and Aerospace Committee, European Security and Defense Assembly, Assembly of Western European Union, Document C/2035, 6 May 2009, 6.
[56] Quoted in "ESA Approves Space Situational Awareness Program," *C4ISR Journal*, 7-8 July 2008, 8.
[57] Lt Gen (ret) Campbell, et al., "Examining Codes and Rules for Space," 17.
[58] William Ailor, "Space Traffic Control and Space Debris."
[59] House, Committee on Science and Technology Subcommittee on Space and Aeronautics Hearing Charter, *Keeping the Space Environment Safe for Civil and Commercial Users*, 20.

debris happens to be involved in a collision, the *Registration Convention* obligates nations with space-surveillance systems to assist to the greatest extent feasible in identifying the origin of the space object.[60] To address this problem, the State Department's Deputy Director of Space Policy is looking "at ways to protect critical government and commercial space infrastructure against orbital debris" and improve SSA at the 2010 United Nations Conference on Disarmament.[61]

If a global service is required to avoid satellite collisions, is there precedence for such a service? The next chapter surveys three global services operating today, some of which have been in use for more than a century.

[60] US Congress, Office of Technology Assessment, "Orbiting Debris: A Space Environmental Problem," 28-31.
[61] Amy Klamper, "Obama Space Policy to Focus on International Cooperation," *Defense News*, 7 December 2009, 44.

Precedents for Global Services

This chapter outlines three existing services which could be models for a global service.[62] These include a US-operated service free to the world and international services helping manage the global commons on behalf of their members.

The Global Positioning System (GPS) demonstrates the first type of a global service, one provided free by the United States. Today, GPS is used by virtually the entire world for positioning, navigation and timing. According to senior US State Department officials, although its genesis was military uses, GPS evolved into a global utility and a centerpiece of US diplomacy. In 1983, President Reagan offered free civilian access to GPS to help enhance aviation safety around the world. President Clinton in 1996 expanded the policy to ensure the service be made available on a world-wide basis for peaceful civil, commercial, and scientific purposes, free of user fees. And in 2004, President Bush furthered the policy to ensure GPS meets the increasing and varied domestic and global requirements. These successive policies "helped unleash the power of free markets and private enterprise for the good of all users worldwide."[63] Clearly, this type of service is a likely candidate. And with the largest, most comprehensive space-surveillance system in the world, the United States is uniquely poised to offer another free service to the world.

A second precedent for a global utility is the International Telecommunication Union (ITU), a specialized United Nations agency based in Geneva, Switzerland. The ITU manages the

[62] This paper does not attempt to analyze these services in detail in terms of structure, cost, or degree to which they provide totally comprehensive solutions—only as appropriate examples to consider.
[63] Alice A. Wong and Raye E. Clore, "Promoting International Civil GNSS Cooperation Through Diplomacy," *High Frontier*, Vol 4, 25-27.

world-wide radio spectrum usage and GEO orbital-satellite-slot allocation on behalf of its members. The ITU currently consists of 191 member states (nations), 574 sector members (commercial companies) and 150 associates (commercial companies). The members underwrite operations and participate in its decision-making.[64] The ITU ensures the rational, equitable, efficient and economical use of radio frequencies and orbital slots, both which are finite resources, and creates the conditions that harmonize development of systems, taking into account all parties involved. According to the Director of its Radiocommunication Bureau, the ITU "plays a vital role in the global management of radio-frequency spectrum and satellite orbits." [65]

The third example of a global service is another international agency, the International Civil Aviation Organization (ICAO). Founded in 1947, it governs the international civil aviation system. At the time of World War II and with the rise in aircraft use, the United States and others saw the need for a global aviation system. "A vast network of passenger and freight carriage was set up, but in order for air transport to support and benefit the world at peace there were many political and technical obstacles to overcome. In those early days of 1944, the Government of the United States conducted exploratory discussions with other allied nations to develop an effective strategy."[66] ICAO is now a specialized United Nations agency with 190 member states that have voluntarily entered into its conventions. These conventions established the rules, procedures, requirements and techniques to govern the movement of international civil aviation. Although each nation governs air traffic within its own sovereign territory, the ICAO

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[64] ITU membership overview, http://www.itu.int/members/index.html (accessed 21 November 2009)

[65] Valerie Timofeev, "Welcome to ITU-R," http://www.itu.int/ITU-R/index.asp?category=information&rlink=itur-welcome&lang=en. (Accessed 17 September 2009).

[66] International Civil Aviation Organization, "Memorandum on ICAO," http://www.icao.int/icao/en/pub/memo.pdf . (Accessed 21 November 2009).

successfully established protocols and procedures for the operations of international traffic, the transition of aircraft from one nation to the next, and the operation of aircraft over global commons, such as the high seas.

Figure 2. In November 1944, under the leadership of the United States, 54 nations met in Chicago resulting in a *Convention on International Civil Aviation*. Later in 1947, shown above, ICAO became permanent. Photograph courtesy of ICAO.

Possible Solutions

Which model is most appropriate for the management of a global space-traffic-control service? One USAF general advocates a unilateral solution for protecting global utilities. "Having the Air Force assume responsibility for global satellite protection as an extension of its existing space-control responsibilities seems the most feasible option. Since the Air Force is tasked with controlling space, placing global utilities under the protective umbrella of space control would be a matter of policy—not an expansion of technology or costs."[67] On the other hand, the State Department's International Security Advisory Board proposes a multilateral solution and recommends the United States "should seek to enlist allies and friendly nations in cooperative efforts to improve situational awareness."[68] This chapter examines four possible constructs and their pros and cons.

The first conceptual model is a US-owned and -operated service akin to GPS. There are many compelling reasons why the United States government could do this. First, it is probably the most expedient avenue to establish a global service because it could quickly leverage the existing SSN infrastructure and nascent CFE program. Second, the United States, as the leading space-faring nation and the only nation with the necessary resources, has treaty obligations to ensure safety of space operations in the global commons. Lastly, as matter of national interest, the United States has the most at stake and most to gain. As the world's superpower benefiting

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[67]General Bruce Carlson, "Protecting Global Utilities: Safeguarding the Next Millennium's Space-Based Public Service," *Air & Space Power Journal*, Vol. XIV, No. 2, Summer 2000, 37-41.

[68] United States Department of State, International Security Advisory Board, "Report on U.S. Space Policy," Washington, D.C., 25 April 2007, http://www.state.gov/documents/organization/85263.pdf. (Accessed 16 September 2009).

from globalization, maintaining international institutions and their associated systems that contribute to the current world order is paramount to its economic security. In addition, a global space-traffic-control service would enhance military space security as a defensive system.

However, many believe there is a significant drawback to this type of service; that is, a utility provided by a single nation with the power to turn it off. For example, despite US public law, presidential policy, and diplomatic engagement, many nations are still wary of US intentions with GPS and are pursuing their own navigational systems. The Europeans, Russians, and Chinese all have satellite programs aimed to instantiate organic capabilities. With respect to space situational awareness, it's much the same. ESA's Director-General articulated Europe's worry of being "blind" and wholly dependent on US-supplied data.[69] Despite these reservations, the US could leverage this opportunity and promote US leadership and diplomacy just as it has done with space-based navigation applications.[70]

A second model could involve a multi-national cooperative service as "it takes a village to build a (good) catalog."[71] This could be a bi-lateral or multi-lateral arrangement among the United States, Russia, China and/or the European Union. Although this would require significant diplomatic negotiations to establish, the benefits could be significant. "The key benefit to international participation in SSA is greater capability for relatively low cost, by combining existing sensor and data sources."[72] It would also align with President Obama's

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[69] Peter B. De Selding, "Despite SSA Collaboration, Europe Leery of U.S. Intentions," 6.
[70] Alice Wong and Raye Clore, "Promoting International Civil GNSS Cooperation Through Diplomacy," 25-27.
[71] Weeden, Brian, "The numbers game: What's in Earth orbit and how do we know?"
[72] Doug Messier, "Secure World Foundation Proposes Global Space Debris Tracking System," *Parabolic Arc*, 29 April 2009, http://www.parabolicarc.com/2009/04/29/secure-world-foundation-proposes-global-space-debris-tracking-system/ (accessed 17 September 2009).

anticipated space policy focusing on international cooperation.[73] Another benefit, as each nation would have access to the same space operating picture, it would work to lower mutual suspicion and increase international security.

But there are also several drawbacks to this construct. Data sharing could be sticky, especially information about defense satellites each nation would want to protect.[74] As stated earlier, Russia and China currently do not share their catalogs and the Europeans already expressed reluctance to share theirs. In addition, equitable cost sharing associated with the operations, maintenance and upgrades of this service would need to be negotiated, probably not an easy matter. The service could disintegrate if one or more of the cooperating nations decided to withdraw from the arrangement.

The third model could be a commercial utility with clients—nations or private sector—who would pay for the service. As mentioned earlier, a fledgling operation similar to this, the Space Data Association, is already in planning stages. The Association plans to compile satellite positional data from its members' satellite telemetry feeds. A benefit to this kind of service, as a result, is the built-in perception it is independent from any one state or member. The Association also aspires to be more nimble, timely and responsive compared to the current US CFE paradigm.[75] However, without a robust organic space-surveillance system, its situational awareness will be limited to the collective knowledge of its members. Therefore, it would not be able to globally track non-member satellites or debris unless a government augments the data.

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[73] Amy Klamper, "Obama Space Policy to Focus on International Cooperation," 44.
[74] Edward O'Hara, *Space Situational Awareness*, Technological and Aerospace Committee, European Security and Defense Assembly, Assembly of Western European Union, Document C/2035, 6 May 2009, 10.
[75] Peter De Selding, "Satellite Firms Moving Ahead on Orbital Database"

The last model examined is an international global utility similar to ICAO. Several, including Dr. Ailor (cited earlier) and Secure World Foundation, a space-policy think tank, propose such a solution. They advocate a non-profit space-operations clearinghouse with a board of governors and members drawn from governments of space-faring nations and major non-governmental satellite owners "to establish common standards and practices."[76] This service would have the benefit of being recognized as legitimate and unbiased by nations and private-sector interests alike. The purpose and aims of such an organization could be orchestrated to parallel existing international laws and customs, such as the Outer Space Treaty and US space policy. This organization would also provide a forum for substantive discussions on debris control and unimpeded, safe access to the global commons. One drawback from such an arrangement would be its members would be subject to rulings from an international body. However, this is no different what already happens today with ITU and ICAO.

In summary, an ICAO-like service has the most advantages and is more likely to enjoy international support, thereby most likely to succeed. Pursuing this model would constructively leverage both existing SSA infrastructures and capabilities, and international cooperation while suppressing mutual suspicions. The United States, as the leading space-faring nation in the world, would additionally benefit indirectly in terms of diplomatic leadership and international prestige. It would also benefit directly, as would the world, from improved military and economic security via improved space control and a safer environment for commerce.

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[76]William Ailor, "Space Traffic Control and Space Debris"; Peter N. Spotts, "Does space need air traffic control? As more countries race to launch satellites and manned craft, some warn of a space jam," *Christian Science Monitor*, 14 March 2008, http://www.csmonitor.com/2008/0314/p01s02-usgn.html. (Accessed 17 September 2009).; Doug Messier, "Space Traffic Control Conference to be Held Next Week in DC," *Parabolic Arc*, 20 March 2009, http://www.parabolicarc.com/2009/03/20/space-traffic-control-conferences-held-week-dc/. (Accessed 17 Sept 2009).

Findings and Recommendations

Based on this research, this paper identifies five critical findings. First, the "big sky" theory for safe operations is no longer valid. Space is becoming congested and prone to collisions. It will only get worse with time. Second, the global economy and international security are in part dependent upon space systems. Consequently, safe operation of satellites is essential. Third, no governmental, international or non-governmental organization is ultimately responsible for global space-traffic control. Some governments, namely the United States, and several non-governmental organizations have taken nascent steps to address this problem. However, these efforts are not synchronized or comprehensive. Fourth, an international consensus is building for improved SSA and space-traffic control.[77] Finally, the United States is the world's premier source for SSA. However, even with its future planned hardware upgrades, the United States is not configured to meet the needs of global space-traffic control, especially in terms of timely high-precision data analysis, data sharing, and policy.[78]

These findings coalesce into a need for a global space-traffic-control service. This paper recommends first, as in 1944, the US Department of State in concert with applicable US agencies and departments should convene an international conference with the purpose to establish a

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[77] William Ailor, "Space Traffic Control and Space Debris"; Peter N. Spotts, "Does space need air traffic control? As more countries race to launch satellites and manned craft, some warn of a space jam"; Doug Messier, "Space Traffic Control Conference to be Held Next Week in DC"; Peter De Selding, "Satellite Firms Moving Ahead on Orbital Database"; Doug Messier, "Secure World Foundation Proposes Global Space Debris Tracking System"; Space.com Staff, "Out There: Space Traffic Control System Needed," *Space.com*, 9 November 2008, http://www.space.com/new/081109-space-traffic.html. (Accessed 17 September 2009).

[78] Albert Glassman, "The Growing Threat of Space Debris," *IEEE-USA Today's Engineer online*, July 2009, http://www.todaysengineer.org/2009/jul/space_debris.asp. (Accessed 27 October 2009).

global space-traffic-control service. Within the next two years, the United States should engage space-faring nations and interested private-sector companies in exploratory discussions to develop an effective strategy for such a service. Second, USAF Space Command in concert with US Strategic Command should upgrade its antiquated software and databases utilized to track and catalog space objects. Although the planned Space Fence and Space Based Surveillance System will greatly expand data available, by themselves these hardware upgrades do not fundamentally bridge the processing gap required for timely, accurate collision mitigation.

As revealed by the fourth documented collision in space and the increasing orbital congestion, the need for global space-traffic-control service is clear. Ignoring the issue will not ease the problem. Within the US Government, the Air Force, NASA, Strategic Command, State Department, and Congress all have stated the need to improve SSA and mitigate orbital collisions. Outside the US Government, ESA, the Secure World Foundation, and private industry have also advocated the need. What is missing is a comprehensive, synchronized plan to addresses the problem in its entirety. As a matter of national prestige, leadership and security, the US Government should endeavor to establish an international institution to govern global space traffic.

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