Hearing of the Committee on Science, Space, and Technology

U.S. House of Representatives

"Space Traffic Management: Preventing a Real Life 'Gravity'"

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Testimony of Mr. Brian Weeden

Technical Advisor, Secure World Foundation

1. Introduction

Mr. Chairman, distinguished members of this subcommittee, thank you for the opportunity to testify today on this important issue. Secure World Foundation is dedicated to the long-term sustainability of the space environment so that all of humanity can continue to use space for benefits on Earth. The growth in space debris and increasing congestion of critical regions of Earth orbit present significant challenges to space sustainability, and addressing those challenges is a key part of our work.

On February 10, 2009, an inactive Russian military communications satellite, designated Cosmos 2251, collided with an active commercial communications satellite operated by U.S.-based Iridium Satellite LLC.[1] The incident occurred approximately 800 kilometers (500 miles) above Siberia. The collision produced almost 2,000 pieces of debris that have been cataloged so far and many thousands of pieces more that are too small to track with our current technology. Much of this debris will remain in orbit for decades or longer, posing a collision risk to other objects in Low Earth Orbit (LEO).

This was the first-ever collision between two satellites in orbit[2] and it served as a wake-up call for the entire space community to the threat that space debris poses to active satellites as well as of the long-term negative impact catastrophic collisions can have on the space environment. The collision increased the amount of space debris in what was already one of the most densely populated and heavily used regions of Earth orbit by both governments and the private sector.

The collision profoundly impacted how satellite operators viewed the space environment. Before the collision, it was common for satellite operators to invoke the "Big Sky" theory when asked

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[1] A summary of the Iridium-Cosmos collision can be found in the SWF Fact Sheet on the event: http://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf

[2] There have been previous collisions in orbit between two pieces of space debris or between a satellite and a piece of space debris, but not between two satellites.

about the possibility of collisions between space objects. There had been some efforts by a few operators to detect and avoid satellite collisions, but collisions were generally regarded as not being a significant threat. More importantly, the vast majority of satellite operators were flying blind – they had little to no access to information about what other objects were near their own satellite. The Iridium-Cosmos collision forced the space community to come to grips with the reality of today's space environment.

My written testimony covers several important issues that are relevant to dealing with the challenge of space debris and supporting the safe operations of existing and emerging civil and commercial space operations. First, it begins with an overview of the current space environment and the challenge posed by space debris. It then discusses the three main ways of dealing with space debris – mitigation, removal, and space traffic management (STM). It then turns to the importance of space situational awareness (SSA), which provides the foundation that enables all the other activities, and looks at the evolution in both SSA and STM. Finally, I discuss the current federal agency roles and responsibilities to support these four areas and provide a series of options for moving forward.

The key question facing the U.S. government moving forward is whether or not the Department of Defense (DoD) should continue to be the single federal agency responsible for all SSA activities and providing operational STM for the world. I believe the answer is no. Instead, I believe it is time for the U.S. government to shift responsibility for the part of the SSA mission that directly impacts on-orbit safety and sustainability to a non-DoD entity. There are three main options for doing so, each of which has its strengths and weaknesses. The best option depends on what the long-term priorities and goals are for the U.S. government and the role it wants to play in global space activities.

It is important to note that there is no consensus on what terms like SSA and STM mean across the space community. The different definitions that exist are the result of varying perceptions on what the true challenges are and different motivations as to what the solution should be. Thus, one of the first steps to resolving these issues is to recognize the nuances in the definitions and perceptions of these terms and establish the context in which this subcommittee is approaching the issue. In the case of this hearing, the context is supporting existing and emerging civil and commercial space operations, and it will frame the remainder of my testimony.

I would also like to make clear my personal context for approaching this subject matter. My first exposure to these issues was as a captain in the United States Air Force, where I spent three years in the Air Force unit responsible for tracking human-generated objects in space. My experiences on both the operational side and as an instructor helping to develop tactics, techniques, and procedures gave me insight into the national security aspects of the mission. Since leaving the Air Force in 2007, I have spent the last several years continuing to study and analyze these issues. During that time, Secure World Foundation's ongoing interactions with a number of U.S. government agencies, the private sector, and the international community have provided me with a broader perspective from multiple stakeholders.

2. Background on the Current Space Debris Environment

More than 70 entities (countries, commercial companies, and international organizations) currently operate more than 1,100 satellites in orbit around Earth,[3] providing a wide range of social and private benefits. These include enhanced national and international security, more efficient use and management of natural resources, improved disaster warning and response, and near-instantaneous global communications and navigation.

Space debris - dead satellites, spent rocket stages, and other fragments associated with humanity's six decades of activity in space - represents a growing threat to active satellites. The DoD tracks close to 23,000 pieces of human-generated debris in Earth orbit larger than 10 centimeters (4 inches) in size, each of which could destroy an active satellite in a collision. Research done by scientists from various space agencies indicates there are an estimated 500,000 pieces of space debris between 1 and 10 centimeters (0.4 to 4 inches) in size that are largely untracked, each of which could severely damage an active satellite in a collision.

As space debris is generated by humanity's activities in space, it is concentrated in the most heavily used regions of Earth orbit where many active satellites also reside. These regions include the LEO region below 2,000 kilometers (1,200 miles) in altitude and the geostationary Earth orbit (GEO) region, approximately 36,000 kilometers (22,000 miles) above the equator. Of the two regions, LEO currently presents the most pressing challenge for long-term sustainability and increasing collision threats to satellites from space debris.[4]

Former NASA scientist Donald Kessler was one of the first to predict what has since become known as the Kessler Syndrome.[5] As the amount of space debris in orbit grows, he predicted there would be a critical point where the density of space debris would lead to random collisions between space debris. These random collisions would in turn generate more debris at a rate faster than space debris is removed from orbit by the Earth's atmosphere. Unlike the dramatic scenario presented in the movie *Gravity*, this process would take place much more slowly over decades or centuries. Space was not a pristine environment before humans began to fill it with satellites. There has always been a natural debris environment in space due to meteoroids. Kessler's

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[3] The most accurate public estimate of the active satellites current in Earth orbit is the database maintained by the Union of Concerned Scientists available here: http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html

[4] The debris threat in the GEO region is not yet as significant as in LEO, but that may change in the near future. For an excellent overview of the debris threat in GEO, see Mcknight, DS and Di Pentino, FR, "New insights on the orbital debris collision hazard at GEO", *Acta Astronautica*, http://dx.doi.org/10.1016/j.actaastro.2012.12.006

[5] Don's own summary of the history of the Kessler Syndrome can be found here: http://webpages.charter.net/dkessler/files/KesSym.html

prediction was that these cascading debris-on-debris collisions would result in a human-generated debris population that would pose more of a threat to satellites than the natural debris.

There is now a general consensus among scientists that this critical point has come to pass and there is enough human-generated space debris concentrated in the critical region in LEO between 700 and 900 kilometers (430 to 560 miles) to create more debris even if no new satellites were launched. Computer simulations conducted by six different space agencies predict that this critical region will see additional catastrophic collisions similar to Cosmos-Iridium every 5 to 9 years.[6]

These debris-on-debris collisions will not lead to an infinite growth in the debris population. Rather, they will lead to a future equilibrium point that has a larger population of debris than today. This increased amount of debris will increase the risks and thus the associated costs of operating satellites in critical regions such as LEO. These increased costs could come about through the need for more spare satellites to replace those lost in collisions, heavier and more overly engineered satellites that cost more to build and launch, and increased operating costs to try to detect and avoid potential collisions. These rising costs will likely hinder commercial development of space and will place additional pressure on government budgets, potentially resulting in the loss of some of the benefits we currently derive from space or preventing discovery of new benefits.

3. Dealing With Space Debris

Efforts to tackle this problem fall into three major categories. Each category addresses a different aspect of the problem – limiting the creation of new space debris, addressing the legacy population of space debris already in orbit, and minimizing the negative impact of the existing debris on space activities.

3.1 Space Debris Mitigation

Space debris mitigation is limiting the creation of new debris through human activities in space. Debris mitigation includes designing satellites and space systems so as to minimize the amount of debris they release during normal operations, developing methods to reduce the risk of fragmentation or explosion at the end of life by venting leftover fuel or discharging batteries, and properly disposing of spacecraft and spent rocket stages after they are no longer useful.

The United States has been a world leader in both developing space debris mitigation guidelines and in implementing them through national regulation. NASA was a founding member of the Inter-Agency Space Debris Coordination Committee (IADC) where it worked with other major

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[6] These simulations can be found in the study "Stability of the Future LEO Environment", IADC-12-08 Rev 1, January 2013: http://www.iadc-online.org/Documents/IADC-2012-08,%20Rev%201,%20Stability%20of%20Future%20LEO%20Environment.pdf

space agencies on developing technical debris mitigation guidelines and continues to conduct scientific research on space debris.[7]

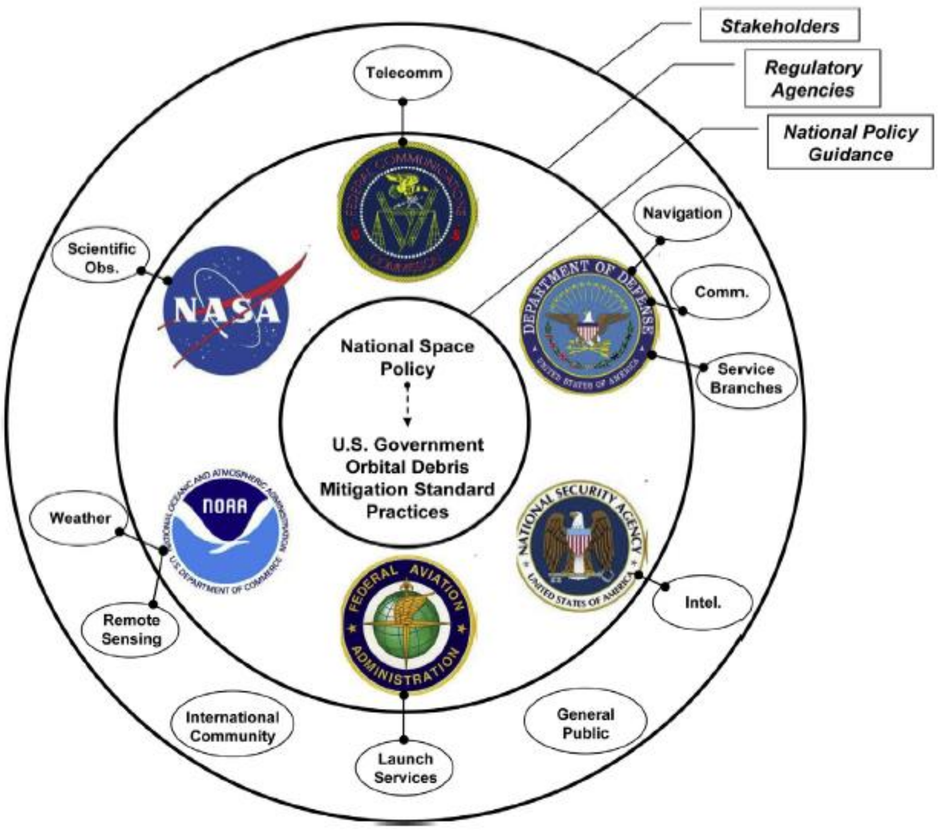

Figure 1. General structure of U.S. debris policy implementation[8]

The U.S. government has also put in place some of the most comprehensive policy and regulatory instruments to implement these technical guidelines in national space activities.[9] At the top level, the 2010 National Space Policy of the United States identified "Preserving the

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[7] The IADC Space Debris Mitigation Guidelines can be found here: http://www.iadc-online.org/Documents/IADC-2002-01,%20IADC%20Space%20Debris%20Guidelines,%20Revision%201.pdf

[8] This image is from Percy, TK., Landrum, DB, "Investigation of national policy shifts to impact orbital debris environments", *Space Policy*, http://dx.doi.org/10.1016/j.spacepol.2014.02.003 Used with permission.

[9] An overview of these authorities and the relevant regulations can be found in a conference room paper presented by the U.S. delegation to the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space on March 24, 2014: http://www.oosa.unvienna.org/pdf/limited/c2/AC105_C2_2014_CRP15Add01E.pdf

Space Environment and the Responsible Use of Space" as one of its seven intersector guidelines. It directs federal agencies to implement the U.S. Government Orbital Debris Mitigation Standard Practices in their space activities. The various federal agencies that conduct governmental space activities each have their own policy guidance and framework for implementing these directives. There are some parts of the implementation that is coordinated through the interagency process, but also some parts that are left to agency discretion.

There are also three federal agencies with existing regulatory authority over non-governmental space activities that implement and enforce space debris mitigation guidelines on the private sector. The National Oceanic and Atmospheric Administration (NOAA) under the Department of Commerce has the authority to license non-governmental space-based remote sensing of Earth. The Federal Aviation Association (FAA) under the Department of Transportation has licensing authority over commercial launch, re-entry or reusable vehicles, commercial launch or re-entry facilities, and also commercial human spaceflight. The Federal Communications Commission (FCC) also has the authority to provide licenses to radio frequency spectrum for non-governmental satellite activities.

In general, the space debris mitigation guidelines are currently implemented for non-governmental space activities as part of the licensing processes in each of these three agencies. However, there are differences in the requirements set by these agencies. For example, the FCC requires that licensees present a plan for debris mitigation during both normal operations and post-mission disposal, whereas NOAA requires that licensees present a plan for just post-mission disposal of their remote sensing satellite. The FCC also requires licensees to follow the 25-year rule in de-orbiting all pieces from a space launch whereas the FAA does not.[10] These differences in licensing requirements and rules are largely due to the differences the two agencies have in their approach to risk mitigation as a result of different legislative and policy mandates. Furthermore, only NOAA currently has regulatory authority over operational space activities.

There needs to be an in-depth study of the debris mitigation portions of the licensing requirements of these three agencies. Harmonizing the requirements across the licensing process would help ensure that the relevant risks are being addressed without undue burden on the private sector. This study should also look for gaps between the existing regulatory authorities and emerging categories of private sector space activities. For example, the technology is currently being developed for satellite communications using optical wavelengths instead of radio frequencies. Satellites using this new technology would likely fall outside of the commonly accepted definition of the FCC's current mandate, and thus may fall outside of the current licensing regime.

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[10] A brief discussion of this and other differences can be found on page 144 of the recent National Research Council study of NASA's Orbital Debris Mitigation Programs: http://www.nap.edu/catalog.php?record_id=13244

3.2 Active Debris Removal (ADR)

The existing population of space debris will continue to grow over time, even without any new space launches and even with full compliance with the existing mitigation guidelines. Last year, a study conducted by six space agencies using six different models found an average increase of 30 percent in the LEO space debris population over the next 200 years, even with 90 percent adherence to the debris mitigation guidelines.[11]

Thus, NASA and other space agencies have concluded that actively removing existing space debris, a process also known as remediation, will be necessary at some point. These removal or remediation efforts can take one of two different directions depending on the goal. If the goal is to reduce the growth in the debris population and reduce the threat over the long term, then the objective should be to remove five to ten of the largest debris objects per year. This would eliminate these large objects as potential sources of new debris should they collide with another object. But if the goal is to reduce the threat to operational satellites in the short term and medium term, then the objective should be to remove the small debris objects in the size range between 1 and 10 centimeters (0.4 and 4 inches). These objects are currently untracked by space surveillance systems and while an impact with them is unlikely to result in a catastrophic collision, it could severely damage an active spacecraft.

Technical experts from around the world have been working intensely on both of these problems over the last several years, and there are some promising technical solutions for removing either large objects or small objects. However, it is largely a choice between the two goals. There is unlikely to be a "silver bullet" solution that can deal with both objectives. Moreover, none of these techniques has been operationally demonstrated in orbit and all of them pose a wide range of legal, policy, and other non-technical challenges.[12] Solving those challenges will require close coordination and cooperation among the engineers and scientists working on the technology, as well as the lawyers and policymakers developing policy and regulatory oversight.

At the moment, the full scope of the U.S. government's efforts on ADR is unclear to the outside observer. The 2010 National Space Policy tasks both the DoD and NASA to "pursue research and development of technologies and techniques… to mitigate and remove on-orbit debris." I am aware of only one small contract awarded by NASA to do a risk-reduction study on one particular technology for debris removal. ***It would be useful for the Executive Branch to clarify what its strategy is for developing and assessing these technologies, and how NASA and the DoD are working together on this issue.***

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[11] These simulations can be found in the study "Stability of the Future LEO Environment," IADC-12-08 Rev 1, January 2013: http://www.iadc-online.org/Documents/IADC-2012-08,%20Rev%201,%20Stability%20of%20Future%20LEO%20Environment.pdf

[12] An overview of these challenges can be found in Weeden, B, "Overview of the legal and policy challenges of orbital debris removal," *Space Policy*, http://dx.doi.org/10.1016/j.spacepol.2010.12.019

At some point it will be necessary to conduct one or more on-orbit technology demonstration missions for ADR to both prove the concepts and do further risk reduction. Such missions would also be very useful for working out some of the specific legal, policy, and other non-technical challenges of conducting debris removal, particularly if they involved commercial entities and international partners.

There are also potential alternatives to ADR. Some have proposed a concept known as just-in-time collision avoidance (JCA) to minimize or even eliminate debris-on-debris collisions. Instead of removing space debris, JCA would change the orbit of one of the pieces of space debris involved in a very close approach, thus preventing a potential collision.[13] One way to do this would be to use ground-based lasers to alter the trajectory of a piece of debris.[14] However, this technology it also in the early stages and JCA techniques also present a number of legal and policy challenges. ***More study and analysis is needed to determine whether or not JCA is a more cost-effective solution than ADR, or whether the two are best used in tandem.***

3.3 Space Traffic Management

The third major category of efforts to deal with space debris is space traffic management (STM). It should be noted that there is no consensus on what this term means, nor even what it should be called. For the sake of clarity, I will define STM in this testimony as measures taken to minimize the impact of space debris on space activities.

Under that definition, the largest element of STM is detecting and mitigating collisions between active satellites and other space objects. While there is some similarity between how this is done in space and air traffic management, the two concepts are not completely analogous. The most important difference between the two is the speed at which objects in space move. The speed of an object in orbit is dictated by its orbital altitude. The lower in altitude an object's orbit is, the faster it must move to avoid being pulled into the atmosphere by the Earth's gravity. At 800 kilometers (500 miles) altitude, an object in orbit travels at approximately 7.5 kilometers per second (17,000 miles per hour). The most likely scenario for a collision is when two objects in similar orbits at the same altitude cross paths near one of the Earth's poles, and in those cases the combined relative speed can be upwards of 10 to 14 kilometers per second (22,300 to 31,300 miles per hour).

Unlike the portrayal in the movie *Gravity*, this means that most objects on a collision course in space move too fast for the human eye to see and that the collision will happen much faster than

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[13] An overview of the JCA concept and a comparison to ADR can be found in McKnight, DS, Di Pentino, F, Kaczmarek, A, and Dingman, P, "System engineering analysis of derelict collision prevention options", *Acta Astronautica*, http://dx.doi.org/10.1016/j.actaastro.2013.04.016

[14] An overview of one concept for using ground-based lasers to do JCA can be found in Mason, J, Stupl, J, Marshall, W, and Levit, C, "Orbital Debris-Debris Collision Avoidance", arXiv, http://arxiv.org/abs/1103.1690

any human could possibly react to. Active, real-time space traffic control of space objects by humans is not realistic, with the possible exception of two objects that are conducting a planned orbital rendezvous. Moreover, even an automated reaction to avoid a collision at the last minute is likely not feasible. The extremely short amount of time to react would require a massive amount of thrust to alter the spacecraft's orbit.

Instead, STM is almost entirely a predictive process done by computers and sophisticated software. This process, known as conjunction assessment, uses estimates of the orbital trajectories of tracked space objects, the error in those estimates, and models of the Earth's atmosphere and other perturbations to predict where space objects will likely be a few days into the future. This process does not result in a definitive "yes" or "no" answer as to whether or not two objects in orbit will collide. The numerous uncertainties present in each input to the calculation mandate that the best it can do is provide a probability of collision between two objects.

Based on these conjunction assessments, a warning is provided to the satellite operator or operators involved along with the probability of collision. It is currently up to each operator to determine their own tolerance for risk and use that as a basis for determining whether or not to maneuver the satellite to change its trajectory and avoid the close approach. This is not always a straightforward decision to make, as maneuvering consumes fuel that could reduce the operational lifespan of the satellite and may interrupt the services it provides or the mission it is conducting. Moreover, maneuvering comes with its own risks as it may in some circumstances make the situation worse or create an even more dangerous close approach in the future.

Risk tolerance will vary between satellite operators and with the mission the satellite is performing. For example, NASA has determined that if the probability of collision between a piece of space debris and the International Space Station is greater than 1 in 100,000, a maneuver will be conducted if it will not result in significant impact to mission objectives.[15] If the probability is greater than 1 in 10,000, a maneuver will be conducted unless it will result in additional risk to the crew. As another example, the French government recently announced that it had conducted an avoidance maneuver for one of its military satellites because the probability of collision was greater than 1 in 2,000.[16]

The other major difference between air and space traffic is that the vast majority of space traffic has no ability to maneuver to avoid any collisions. Less than five percent of the tracked space objects bigger than 10 cm are active payloads and not all active payloads have maneuvering

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[15] An overview of NASA's collision avoidance procedures can be found here: http://www.nasa.gov/mission_pages/station/news/orbital_debris.html

[16] de Selding, P, "France Maneuvers Intel Satellite to Avoid Dead Weather Spacecraft," *SpaceNews*, 23 April 2014: http://www.spacenews.com/article/military-space/40317france-maneuvers-intel-satellite-to-avoid-dead-weather-spacecraft

capability. In fact, the number of non-maneuverable payloads is growing, due to the recent boom in small satellites. Commonly referred to as cubesats or microsatellites, they are becoming increasingly popular with universities as part of engineering programs, but also with new space actors such as start-up companies and developing countries. Between November 2013 and February 2014, there were three space launches that together placed more than 100 cubesats into LEO.[17]

Although cubesat technology is advancing very quickly and these systems can have surprisingly advanced capabilities, many lack any sort of propulsion system. This means that even though they may be performing an active mission, when involved in a close approach with another space object they are for all intents and purposes just another piece of space debris. Their small size also makes them difficult to track with conventional radars and telescopes. Furthermore, many cubesats are being developed and operated by new space actors who may not have the experience to do so safely or responsibly.

The combination of these factors means that ensuring proper national oversight of cubesat activities is an important issue for policymakers and regulators. ***Existing national regulations and licensing procedures need to adequately cover cubesats and ensure that overall safety and responsible behavior is maintained while still enabling innovation and new entrants into the space sector.***

In addition to on-orbit close approaches, another important element of STM is the interface between orbital traffic and air traffic. In 2013, 300 tracked space objects re-entered the Earth's atmosphere according to data provided by the DoD and NASA.[18] Nineteen of these were controlled re-entries by spacecraft or rocket stages. The rest were uncontrolled re-entries of more than 100 metric tons of dead payloads, spent rocket stages, and smaller bits of debris. Tracking data on these objects are combined with models of the Earth's atmosphere to predict where they might re-enter. However, this process has significant uncertainties and currently it is not possible to predict with any certainty exactly when and where a space object will re-enter the atmosphere more than a couple of hours in advance, except under very specific circumstances.

The odds of a re-entering space object hitting an aircraft in flight is extremely remote, largely because air traffic is concentrated over a relatively small fraction of Earth's landmasses. However, there are certain circumstances, such as the tragic breakup of Space Shuttle Columbia on its re-entry approach over the United States, where a large amount of orbital debris may pose

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[17] An overview of the growth in cubesats can be found in Jones, N, "Mini satellites prove their scientific power", *Nature,* 16 April 2014: http://www.nature.com/news/mini-satellites-prove-their-scientific-power-1.15051

[18] This information comes from a presentation by Mark Matney from NASA to the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space on February 13, 2014, available here: http://unoosa.org/pdf/pres/stsc2014/tech-27E.pdf

a hazard to air traffic. In the future, if sub-orbital tourism becomes a thriving industry or commercial space launch services expand further, it may be necessary to more closely manage their interactions with air traffic.

3.4 Space Situational Awareness (SSA)

All of the efforts to deal with the threat of space debris – debris mitigation, debris removal, and STM - rely on SSA. SSA, broadly defined as characterizing the space environment and its impact on activities in space, is a fundamental requirement for successfully tackling the many challenges related to the long-term sustainability of space activities. SSA began as the military space surveillance mission and in recent years has expanded to include more types of information as well as additional services.

The DoD currently has the most comprehensive SSA capability in the world.[19] This includes operating the largest tracking network of ground and space-based sensors and maintaining one of the most complete catalogs of objects in Earth orbit. Its Space Surveillance Network (SSN) consists of more than 30 radars and optical telescopes located around the world and in orbit. Tracking data from the SSN are collated and analyzed by U.S. Strategic Command's (USSTRATCOM) Joint Space Operations Center (JSpOC) at Vandenberg Air Force Base in California. The JSpOC maintains a catalog of space objects and uses that catalog to provide a variety of services and functions. It also makes a low accuracy version of part of its catalog publicly available on the Internet.

There are other countries that have their own SSA capabilities, with Russia being the most advanced. None have the global coverage of the DoD, but even the DoD's SSA capabilities have shortcomings. The main drawback is in the location and distribution of the tracking sites. Many of their tracking radar locations are optimized for their original missile warning functions and are thus located on the northern borders of the United States. This means that the system's coverage is focused mainly in the Northern Hemisphere. Thus there are large gaps in the tracking coverage for LEO space objects and sometimes significant time between tracks. There are efforts underway to alleviate some of these gaps, as in the recent decisions to move a radar and an optical telescope to Australia, but most of the gaps will remain. ***More cooperation and data sharing with other countries and private sector entities with their own SSA capabilities is the most prudent way to address this gap.***

A bigger challenge is the need to combine the tracking of space debris and other non-cooperative space objects with owner-operator data on active satellites. A satellite operator typically has much more precise data on the location and trajectory of their own satellite than can be

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[19] An overview of global SSA capabilities can be found in Weeden, B, Cefola, P, and Sankaran, J, "Global Space Situational Sensors," paper presented at the 2010 Advanced Maui Optical and Space Surveillance Conference. Available from: http://swfound.org/media/15274/global%20ssa%20sensors-amos-2010.pdf

determined by remote analysis. Moreover, satellite operators also are aware of upcoming maneuvers they plan to conduct. Without knowledge of these maneuvers, future predictions of their satellite's trajectory and any potential close approaches it has can be disastrously wrong.

3.5 A Holistic Picture of Space Sustainability

The relationship between the four concepts discussed in this section - debris mitigation, debris removal, STM, and SSA - is shown in Figure 2. Mitigation, removal and STM are all complementary initiatives that tackle different aspects of the space debris challenge – past, present, and future. Only by undertaking all three can we deal with the problem in a comprehensive manner. All three are supported by and rely on SSA. Without appropriate and accurate information on the space environment and activities in space, none of the others are possible.

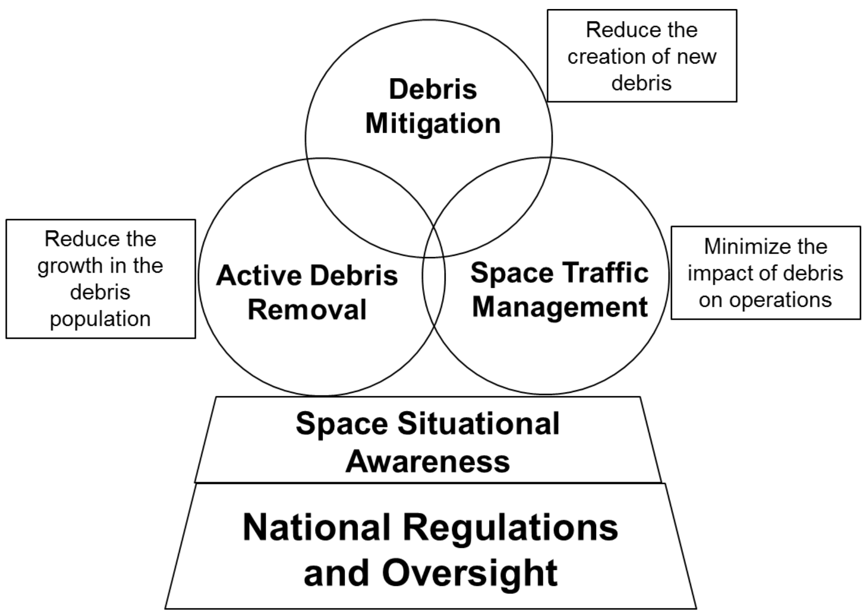

Figure 2. A framework for space sustainability

From a national perspective, it is important to have in place the proper regulations and oversight mechanisms to support all four of the activities outlined above across both governmental and non-governmental space activities. These include pragmatic and well-defined licensing requirements for the private sector as well as the ability to monitor and enforce those requirements, and clearly defined roles, responsibilities, and interagency protocols in place between the various government entities. At the same time, it is also important to keep in mind the international context, and the interactions and relationships between the activities and capabilities of the United States and the many other countries currently active in space. ***As is the case with air traffic management, working with other countries to develop standards, protocols, and mechanisms for safe STM is essential.***

4. Towards the STM System of the Future

There has been a significant shift in SSA and STM activities over the last few years. Before the 2009 Iridium-Cosmos collision, the DoD was one of the few entities to look seriously at conjunctions between space objects.[20] This is partly because of its national security focus but also because the DoD was one of the few entities with access to the data necessary to do the analysis. At the time of the Iridium-Cosmos collision, the DoD was conducting a daily screening for potential close approaches between a select list of important U.S. government satellites and other space objects. This list did not include Iridium satellites, and so there was no advance warning of the collision. The Russian military was also performing a similar function for some of its own national security satellites using its own tracking data, and it too failed to notice the potential collision because the dead Cosmos satellite was no longer included in its screening process.

4.1 Current SSA and STM Authorities and Practices

After the collision, the DoD was faced with a difficult choice. As the organization with the best SSA capability in the world, it could help prevent such future collisions. Doing so would be in its own best interests, as it is also the organization with the most active satellites in orbit and the most reliant on space capabilities. More collisions would produce more debris that could threaten critical U.S. national security space capabilities. One way the DoD could address this problem would be to give satellite operators access to the more precise tracking and trajectory data it uses for its own internal assessments. Doing so would allow satellite operators or other entities to perform their own conjunction assessments. However, national security considerations led the DoD to instead change their own conjunction assessment process to include a screening of all operational satellites for all satellite operators. This eventually became part of USSTRATCOM's SSA Sharing Program[21] and ever since, the JSpOC has been providing hundreds of warnings of close approaches to satellite operators around the world each year.

These warnings have both greatly increased awareness of the magnitude of the challenge and encouraged satellite operators to take collision threats and responsible behavior in orbit more seriously. USSTRATCOM has also worked hard to overcome the significant technology and personnel challenges it faces in delivering this service and has also worked with many satellite operators to improve the warnings. It is likely, although not provable, that the warnings provided by the JSpOC have prevented other collisions in orbit from occurring.

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[20] A summary of the U.S. military's conjunction assessment protocols prior to the collision can be found here: http://www.thespacereview.com/article/1314/1%29

[21] An overview of the history of the SSA Sharing Program, including references to the Congressional legislation authorizing the program, can be found in this SWF Issue Brief: http://swfound.org/media/3584/ssa_sharing_program_issue_brief_nov2011.pdf

4.2 Shortcomings in the Current System

However, the current process still has serious shortcomings. The mathematical process by which the JSpOC generates these warnings is still largely a "black box," with little information provided on their accuracy or reliability. Studies done by both commercial and U.S. government satellite operators indicate that the close approach warnings provided by the JSpOC may have as much as a 50 percent false positive rate and 50 percent false negative rate.[22] Other studies conducted by international satellite operators indicate that at least three percent, and in some cases as many as 20 percent, of the DoD's locations of operational satellites are wrong. This is largely because the JSpOC does not have access to satellite operators' data on the location of their own satellites or information about any upcoming maneuvers. The JSpOC is unable to correct this at the moment because their computer systems are currently unable to automatically process satellite operator or other outside data.[23]

The current DoD policies for protecting the orbital locations of national security satellites have also created problems. The JSpOC does not publish orbital trajectory information for many U.S. and some allied national security satellites, nor trajectory information for other objects from the same launch, such as spent rocket stages. As more and more launches involve secondary payloads, this policy has led to withholding the trajectory information on these objects as well, resulting in situations where universities, scientists, and even some NASA researchers cannot get trajectory information to try to locate and communicate with their payloads.[24]

All of this has led to dissatisfaction on all sides over the current situation. From the satellite operators' perspective, the JSpOC is not responsive or flexible enough to provide the services they need, nor does it give any insight in the reliability of the services and warnings it provides. At the same time, the DoD is being asked to take on this new requirement to provide these services for all satellite operators without significant additional resources such as personnel and funding. The DoD is also being asked to provide these services with obsolete computer systems that are more than 150 percent over capacity and were not designed to share data with or accept data from sources outside the traditional DoD tracking network.

There are also cultural and bureaucratic challenges that DoD is struggling to overcome. Its primary focus is on national security and protecting DoD assets and capabilities. Neither providing a public safety service for the entire world nor supporting the development of

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[22] Morring, F, "USAF satellite-conjunction advisories called inaccurate", *Aviation Week & Space Technology*, 2012, February 24: http://www.aviationweek.com/Article.aspx?id=/article-xml/awx_02_24_2012_p0-429306.xml

[23] For a detailed overview of the history of these systems and the failed attempts to replace them, see: http://swfound.org/media/90775/going_blind_final.pdf

[24] Some of these challenges are referenced in a recent National Research Council study on NASA's Orbital Debris Mitigation Programs: http://www.nap.edu/catalog.php?record_id=13244

commercial activities are missions that the military is usually expected to tackle, especially when those missions require it to work day-to-day with many different commercial companies and foreign countries around the world. The DoD also lacks the flexibility in its acquisitions programs to be able to take into account the needs of its commercial and foreign customers in designing future capabilities and services.

4.3 The Emergence of Non-governmental Actors in SSA and STM

As a result of these shortcomings, a growing number of civil and commercial satellite operators are looking to other entities for assistance. One major source is the Space Data Association (SDA), a non-profit organization created by three major commercial satellite operators in 2009. Its membership currently includes more than 20 commercial satellite operators and three government agencies who are together responsible for more than 360 active satellites in orbit and more than half of all satellites in GEO.[25] Its Space Data Center (SDC) provides SDA members with a range of services, including much more detailed conjunction assessments that take into account a satellite operator's own satellite trajectories and planned maneuvers, and assistance in resolving radio frequency interference (RFI).

There are also very recent developments towards potential private SSA services in the near future that may provide significant alternatives to the JSpOC or other governmental programs. Earlier this year, Analytical Graphics, Inc. (AGI) announced its new Commercial Space Operations Center (ComSpOC). The ComSpOC plans to offer paid subscription access to a number of advanced SSA services, including much more accurate orbital trajectory information than what the DoD provides publicly, more accurate and timely conjunction assessments, assistance in planning avoidance maneuvers and assistance in resolving spacecraft anomalies. AGI is currently negotiating with dozens of optical telescopes, radars, radiofrequency systems, and other sensors already in existence around the globe to provide data for the ComSpOC. There are also a number of other private sector initiatives that are still in the early stages and could provide significant SSA capabilities in the near future.

Overall, these private sector activities show considerable efficiency and sophistication. The total cost of creating and operating the SDC since its inception is on the order of several million dollars. Most of the functions of the SDC are automated and the servers themselves are virtualized and distributed across three different geographic regions. This means that they require a very small number of analysts to operate, are fault tolerant, and can respond very quickly to increased computational needs. Although the ComSpOC is much newer and not yet fully operational, early indications are that it has some very sophisticated SSA capabilities. In both cases, there is strong evidence of private sector innovation being more agile than, and potentially

[25] An overview of the SDA and its current membership and services can be found in this presentation from its March 2014 Public Users Meeting: http://www.space-data.org/sda/wp-content/uploads/downloads/2014/03/20140310_SDA_Users_Mtg_p.m._Session.pdf

even surpassing, governmental capabilities. This innovation should be embraced and encouraged, not stymied.

An important consideration to keep in mind is that SSA is not something that any one entity can do entirely by itself. It requires combining data from a large number of geographically distributed sensors on Earth and in space with operator data on precise locations and upcoming maneuvers. SSA also has many different commercial, civil, and national security applications that are unlikely to be fulfilled by a single entity. Moreover, it is unlikely that any one entity will be trusted enough by all space actors to serve as a single, global SSA provider. Instead, I see SSA evolving to a model where there are multiple data providers that act as hubs, each serving a set of trusted users. In this model, a key element is the degree of cooperation and data sharing between the hubs.

4.4 The Future SSA and STM System

Taking all these considerations into account, ***the key question facing the U.S. government moving forward is whether or not the DoD should continue to be the single federal agency responsible for all SSA activities and providing operational STM for the world.*** I believe that the answer is no. While space surveillance began as a national security function, SSA has evolved into much more. It plays a fundamental role in the breadth of space activities being conducted by not only the military but also civil government agencies and the private sector. It encompasses not only building and operating a geographically distributed network of radars and telescopes to track space debris, but also combining those tracking data with data from satellite operators on the location of their own satellites and upcoming maneuvers. Finally, it requires a willingness and ability to work with a wide range of international entities.

At the core of this problem is the issue of trust. There is currently a lack of trust among the various stakeholders in SSA that is hindering efforts to improve SSA to address the pressing challenges outlined earlier. This lack of trust stems from deficiencies in the current system and organizational culture, and inertia. The DoD does not trust others in its mission to protect U.S. national security and is wary of providing information that could reveal its capabilities or limitations. This attitude leads it to operate its services as “black boxes” with little to no information provided as to how the analysis was done or its accuracy.

Commercial and government satellite operators are unwilling to base the safety of their valuable assets on services and analyses that cannot be validated or verified. They also have no input on capabilities and requirements for the new SSA architectures and services the DoD is pursuing. Some governments are also unwilling to fully trust the SSA data and analyses being provided by the DoD, hindering the ability of the global community to use SSA as the foundation for political agreements to enhance space sustainability and security. This includes efforts currently underway to create best practice guidelines for enhancing space sustainability, develop international standards for safe space operations, and establish and enforce norms of behavior and develop transparency and confidence building measures to improve security.

4.5 Diversifying SSA and STM Away from the DoD

I believe it is time to consider creating an operational role in SSA and STM for a federal entity other than the DoD. Assigning this role to a non-DoD government entity provides several benefits. First, it increases the likelihood that the U.S. government will be able to provide timely, accessible, and agile services to civil and commercial customers. Second, it would be more likely for a non-DoD entity to be able to integrate many different types of SSA data from many different sources. This would increase SSA for both the U.S. government and all other users. Third, by being able to provide better services and integrate more data, this shift puts the U.S. government in a better position to ensure that it will continue to play a leadership role in SSA. Failing to do so increases the likelihood of a shift away from the U.S. government towards private sector and foreign actors, a shift that could have consequences for U.S. national security.

This non-DoD entity would be mainly an integrator of data collected by other entities, rather than a primary collector itself. The DoD would still operate its existing networks of radars and other sensors, many of which perform missions other than SSA. However, the DoD would be responsible for passing sanitized data from its tracking networks to this non-military organization. The non-DoD entity would be responsible for maintaining a catalog of space objects and information about space weather. This would enable them to provide conjunction analyses and other safety-related services to all space actors to support safety of spaceflight and space sustainability. The DoD would retain responsibility for national security aspects of SSA, including characterizing space objects and determining intent and threats, by combining the civil SSA data with other sources of data. Figure 3 provides a graphical summary of this division of labor.

Figure 3. Division of labor between national security and civil SSA authorities

The non-DoD agency would be able to also ingest data from other sources to perform its mission, including satellite operators, other governments, private organizations, and even amateur satellite observers. These data would be provided on a voluntary basis, enabling other data providers to exclude information on their own national security space objects if desired. Such exclusions would come with the implicit assumption that they are then liable for responsible operation of and any damage caused by those protected objects in accordance with international law and established norms of behavior. This is essentially the same exclusion that applies to state aircraft under current air navigation treaties.

Shifting responsibility for basic SSA services to a non-DoD agency allows it to focus on building relationships and establishing trusted services with all users while simultaneously allowing the DoD to focus on the elements of SSA that are critical to national security. The non-DoD agency can work more closely with satellite operators and potentially even some of the private sector SSA services to focus on safety of spaceflight. The DoD can take the basic catalog provided by the other agency and add additional classified sources of data to provide the more robust capabilities necessary for detecting and countering threats to U.S. national security space systems.

4.6 Organizational Options for a New SSA/STM Authority

Making this change is not without considerable challenges. First and foremost is determining which federal department or agency should be assigned this new role. One option is to assign it to an agency that already has some authority for regulating and licensing private sector space activities. Giving an agency both regulatory authority and direct access to the information to enforce that authority could result in both better regulations and a more efficient process. However, current regulatory authority is divided across the FCC, FAA, and NOAA and each has its own specific competencies. Moreover, the FCC and FAA do not have any significant organizational expertise in actually performing space operations.

Another option could be to assign it to a federal agency that already has significant expertise in space operations and space debris such as NASA or NOAA. NASA is the lead federal agency for space debris research and development of space debris mitigation guidelines. It also operates a number of its own satellites. NOAA also operates some of its own satellites in both the LEO and GEO regions and does have some regulatory

However, NASA does not have any authority to regulate private sector space activities, and it does not make sense to give it such authority. Assigning this role to NASA would also require deciding which NASA field center or centers would perform the new mission. This is likely to be a contentious debate, as Johnson Space Center, Goddard Space Flight Center, and Ames Research Center are all involved in various aspects of space debris, SSA, and STM.

A third option would be to assign this role to a new federal agency, something akin to a "Coast Guard" for space. Just as the U.S. Coast Guard is responsible for safety on the nation's waterways and maritime regions, and works hand-in-hand with the U.S. Navy on national security issues, a similar agency could be created to deal with space. The Coast Guard has responsibility for issues ranging from developing and maintaining infrastructure to regulating private boating activities and enforcing those regulations.

This is an option that has been much discussed in the past and has its own positives and negatives.[26] On the positive side, it is a proven model for providing a public safety service that interacts closely with national security. Assigning this new agency with both an operational role in SSA and STM and a regulatory role for licensing of private sector activities could provide significant efficiencies and complementarities. On the negative side, implementing this option has significant political and administrative challenges. It would require an almost complete overhaul of the existing governance structure for space and reassigning functions spread across several federal agencies to this new entity.

In choosing any one of these options, an important consideration will be the extent to which this non-military entity has the power to require satellite operators to comply with its instructions. There are those who wonder why the existing conjunction warning system does not mandate that satellite operators move their satellites. The answer is mainly due to the fact that no government has authority over all space objects. In the air traffic model, aircraft under active control are in an air space where there is clear national sovereignty and control by a single State. In space, launching states exert sovereign control over their space objects but there is no control over the orbital regions they are passing through.

The one set of circumstances where such power may be necessary in STM is where there is a potential threat to a spacecraft carrying humans. If an active satellite is deemed to have a probability of colliding with spacecraft carrying humans, right-of-way should be given to the spacecraft with humans. However, this is likely to be an infrequent scenario. Most active, robotic spacecraft orbit at much higher altitudes than spacecraft carrying humans. This is due to the Van Allen radiation belts, which for the most part limit long-duration human spaceflight in Earth orbit to an altitude of around 500 kilometers (310 miles) or lower.

4.7 National Security Considerations

This proposal to shift some responsibility for SSA away from the DoD will prompt concerns from some that it will jeopardize U.S. national security. The primary reason for all of SSA to

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[26] Two good discussions of this topic are "The Guardians of Space" by LtCol Cynthia McKinley in the Spring 2000 edition of *Aerospace Journal* (http://www.airpower.maxwell.af.mil/airchronicles/apj/apj00/spr00/mckinley.htm) and "Proposing a Space Guard" by James Bennett in the Winter 2011 edition of *The New Atlantis* (http://www.thenewatlantis.com/publications/proposing-a-coast-guard-for-space)

remain with the DoD is that it allows the military to control the data and protect the locations of sensitive U.S. national security space assets. While it is true that shifting part of the SSA mission to another entity will make it harder to hide those objects, I believe that battle has already been lost. The accelerating diffusion and innovation of SSA capabilities by commercial entities, foreign actors, and even private citizens has already eroded the DoD's control of information on the existence and location of space objects. I believe it is better for the U.S. government to harness that innovation to improve its own capabilities than to try and stymie it.

A good analogy can once again be made with the air traffic regime that faced a similar dilemma. The Convention on International Civil Aviation, signed in Chicago in 1947, made the air traffic rules only applicable to civil aircraft. State aircraft (defined as those of military, customs, and police services) were exempt and only required to operate with "due regard for the safety of navigation of civil aircraft.[27]" Under this model, the air traffic management system focuses solely on civil and commercial traffic. Military aircraft are formally exempt and the only stipulation is that they do not jeopardize the safety of civil traffic. In reality, military aircraft often follow the same air traffic protocols as civil and commercial aircraft except in very specific situations where national security considerations take priority. ***I believe the same principle of due regard is appropriate for the future of STM as well.***

The DoD's current approach to both satellite communications and space-based remote sensing may also offer useful analogies for the future of SSA. At one time, the U.S. military tried to acquire and operate all of the satellite communications and remote sensing capability it needed. That desire quickly met with reality as military systems were unable to meet the operational demand. Today, more than 80 percent of all satellite communications capability used by the U.S. military flows over commercial satellites, including nearly all of the bandwidth for unmanned aerial vehicles supporting counterterrorism operations around the globe. Meanwhile, privately operated remote sensing satellites are providing an increasing share of imagery products to national security customers. Commercial industry was able to provide more flexible, timely, and cost effective capabilities, and those capabilities have only gotten better as government demand for them has increased.

There are still niche national security mission needs that are not provided by the private sector where the U.S. military still develops and provides its own capabilities. These include strategic, hardened, protected satellite communications and exquisite intelligence collection capabilities. The end result of this approach where the government focuses its efforts on what the private sector cannot provide has been increased capability for the military, lower costs to the taxpayer, and a booming commercial industry that is innovating faster than ever before.

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[27] The various editions of the Chicago Convention can be found on the website of the International Civil Aviation Organization (ICAO): http://www.icao.int/publications/pages/doc7300.aspx

5. Conclusions

It has become almost trite to point out that the space world has changed, but in the context of space debris, SSA, and STM, it is worth making the point again. The current systems for providing those services were designed and developed in a different age, when space activities were dominated by the two super powers. Today's world is much different. The continuing expansion in the number of space actors and the types of space activities has created a much more complex space environment. At the same time, technological diffusion has commoditized space capabilities to fuel a surge of innovation and has created the possibility for many new uses of space for benefits here on Earth.

It is vitally important for the U.S. government to evolve its approach to stay abreast of this ongoing change. The U.S. government's strong efforts on space debris mitigation over the last decade and a half are a good start, but need to be part of a more comprehensive approach. Space debris mitigation needs to be accompanied by renewed emphasis on STM, development of the technical capability for targeted removal of space debris, and significant improvements in SSA.

Part of this comprehensive approach includes re-examining the current federal agency roles and responsibilities for regulating and overseeing private sector space activities and providing services to support those activities. These roles and responsibilities are currently spread out across four government agencies across three departments, with regulatory and licensing powers separated from the capability to monitor space activities and potentially enforce those regulations. There are differences in how the three agencies responsible for regulating private sector activities implement the space debris mitigation guidelines. The sole agency responsible for monitoring space activities – the DoD – is not the agency best equipped to handle civil safety and commercial support responsibilities. Moreover, there does not appear to be a strategy for developing the capability to actively remove space debris.

There are steps that can be taken to address these issues. First, this subcommittee can look at ways to harmonize the implementation of the debris mitigation guidelines by the three agencies with regulatory power. Doing so could result in a more efficient and effective process, with benefits to commercial industry and innovation. Second, this subcommittee can work with the various departments and agencies and other committees with jurisdiction to re-examine the roles and responsibilities for SSA. I have made the case that part of that mission should go to a federal agency other than the DoD. There are three general paths for doing so, each with their own advantages and disadvantages. Third, this subcommittee can call on the relevant executive branch agencies to articulate a comprehensive strategy for developing the capability to remove debris from orbit. This includes deciding whether to pursue large or small debris objects, the most promising technologies for doing so, and putting in place programs to mature those technologies towards one or more on-orbit technology demonstration missions.

There are also specific areas of research and analysis that could be useful in supporting the subcommittee's work on these issues. These include:

- A study on the current implementation of orbital debris mitigation guidelines by NOAA, FAA, and FCC that focuses on specific areas where they might be harmonized, whether or not they adequately cover existing and planned future private sector space activities, and whether or not they adequately deal with cubesats;
- A study comparing the relative costs and benefits of ADR to remove large pieces of debris, ADR to remove small pieces of debris, JCA to prevent debris-on-debris collisions, or some combination of the three;
- A study to determine which elements of SSA are necessary to support safety of spaceflight and commercial space activities, along with the requirements for timeliness, accuracy, and precision of SSA data to provide those elements;
- A study that weighs the various options for assigning part of the SSA mission in support of civil safety to a federal non-DoD agency; and
- An assessment of the U.S. government's current strategy for developing and maturing technologies for actively removing orbital debris.

Thank you for your time and attention. I would be happy to answer any questions you might have.

Biography for Mr. Brian Weeden

Mr. Brian Weeden is the Technical Advisor for Secure World Foundation (SWF) and has 15 years of professional experience in the national and international space security arena. His wealth of technical knowledge and expertise has established him as a thought leader for providing critical analysis that supports development of space policy.

Prior to joining SWF, Mr. Weeden served nine years on active duty as an officer in the United States Air Force working in space and intercontinental ballistic missile (ICBM) operations. As part of U.S. Strategic Command's Joint Space Operations Center (JSpOC), Mr. Weeden directed the orbital analyst training program and developed tactics, techniques and procedures for improving space situational awareness.

In his current role as Technical Advisor, Mr. Weeden conducts research on space debris, global space situational awareness, space traffic management, protection of space assets, and space governance. He also organizes national and international workshops to increase awareness of and facilitate dialogue on space security and sustainability topics. He is also Vice-Chair of the World Economic Forum's Global Agenda Council on Space Security.

Respected and recognized as an international expert, Mr. Weeden's research and analysis have been featured in The New York Times, The Washington Post, National Public Radio, USA Today, The BBC, Fox News, China Radio International, The Economist, The World Economic Forum's Annual Meeting in Davos, academic journals, presentations to the United Nations, and testimony before the U.S. Congress.

Mr. Weeden holds a Bachelor of Science Degree in Electrical Engineering from Clarkson University, a Master of Science Degree in Space Studies from the University of North Dakota, and is also a graduate of the International Space University Space Studies Program (2007, Beijing). He is currently a Doctoral Candidate in Science and Technology Public Policy at George Washington University.