SPACE SITUATIONAL AWARENESS: KEY ISSUES IN AN EVOLVING LANDSCAPE

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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C O N T E N T S

February 11, 2020

SPACE SITUATIONAL AWARENESS: KEY ISSUES IN AN EVOLVING LANDSCAPE

TUESDAY, FEBRUARY 11, 2020

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 2:40 p.m., in room 2318 of the Rayburn House Office Building, Hon. Kendra Horn [Chairwoman of the Subcommittee] presiding.

SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Space Situational Awareness: Key Issues in an Evolving Landscape
February 11, 2020
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to examine issues related to Space Situational Awareness (SSA), how the changing space environment is challenging the current SSA system, and the factors anticipated to influence SSA in the future. The hearing will also explore approaches to addressing the challenges, including activities at the international level.

WITNESSES

- **Dr. Brian Weeden,** Director of Program Planning, Secure World Foundation
- **Mr. Daniel Oltrogge,** AIAA Space Traffic Management Space Governance Task Force Chair, Founder and Administrator, Space Safety Coalition, Official International Standards Organization (ISO) representative to the United Nations Committee for the Peaceful Use of Outer Space (UNCOPUOS)
- **Professor Joanne Gabrynowicz,** Professor Emerita of Space Law, University of Mississippi Law Center
- **Professor Danielle Wood,** Director of the Space Enabled Research Group, Assistant Professor of Media Arts & Sciences and Aeronautics & Astronautics, Massachusetts Institute of Technology
- **Dr. Ruth Stilwell,** Adjunct Professor, Norwich University, Senior Non-Resident Scholar, Space Policy Institute, George Washington University

OVERARCHING QUESTIONS

- *Why is SSA important and how is the SSA landscape changing? What factors are anticipated to influence SSA over the next 10 to 15 years?*
- *What is Space Traffic Management (STM) and how is it different from SSA?*
- *Who are the key SSA stakeholder, and how are they engaging to better understand and to more effectively protect the space environment?*
- *What is the current state of international collaboration on SSA issues?*

Background

Over the past decade, the space industry has grown and changed significantly, particularly with the rapid increase of commercial and private activity in low-Earth orbit (LEO). With the advent of megaconstellations, often involving thousands of satellites and new global players launching CubeSats and small satellites into Earth's orbit, operating in the space environment is becoming more complex. The locations and predicted positions of active satellites, defunct satellites, and space debris must be considered in order to avoid collisions and maintain safe operations. These and other emerging changes in the space environment are poised to overwhelm current space flight safety and operational processes.[1] Given this evolving landscape, space situational awareness (SSA) is becoming an essential means to ensuring the safety and sustainability of the space environment.

Defining SSA and STM

SSA encompasses collecting space object location data, processing space object data to characterize the space environment, and developing data products to support satellite owners and operators in decision-making (e.g., when there is potential for collision). SSA data and information inform plans, operations, and protection of space assets and U.S. government operations in space, and also help ensure the safety of the space environment for commercial and non-U.S. operators. A significant aspect of SSA refers to the location and projected location of space objects, including both operational satellites and orbital debris, the avoidance of potential collisions between objects, and the mitigation of collision risks to space assets and human spaceflight activities. The operating environment pertains not only to the location of objects with respect to potential collisions, but also radio frequency interference and the environmental effects of space weather on space objects and how they move through space. [2]

SSA is distinct from but related to what is referred to as space traffic management (STM). While there is no universally accepted definition of STM, many often refer to the International Academy of Astronautics' study on Space Traffic Management which states that STM is a "set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space, and return from outer space to Earth free from physical or radiofrequency interference".[3] In other words, SSA results in data and information as input into safety decisions, while STM provides guidance about how those decisions should be made and implemented.

Changing Landscape

The population of active satellites and tracked debris has changed over the past two decades and is anticipated to change dramatically over the next several years. Of the nearly 9,000 payloads that have launched since 1957, about 5,370 are still in orbit (and are either active or defunct),

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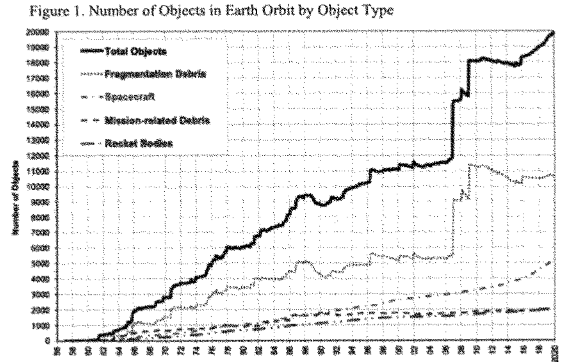
[1] Theodore J. Muelhaupt, Marlon E. Sorge, Jamie Morin, Robert S. Wilson, Space traffic management in the new space era, The Journal of Space Safety Engineering 6 (2019) 80–87

[2] Institute for Defense Analysis, Science and Technology Policy Institute, "Evaluating Options for Civil Space Situational Awareness (SSA)", August 2016

[3] International Academy of Astronautics. Space Traffic Management - Towards a Roadmap for Implementation. 2018

while the rest have disintegrated upon reentry into the Earth's atmosphere. Forty-four percent of these payloads are U.S. payloads.[4] The Department of Defense's Combined Space Operations Center (CSpOC) uses radar and optical telescopes to track space objects and actively maintains a public catalogue of these objects. Figure 1 shows how the number of active payloads is dwarfed by a number of defunct objects, such as rocket bodies, debris from satellite breakups and collisions, and inactive satellites. At present, DoD's public catalogue reports over 20,000 space objects, of which nearly 15,000 objects are classified as debris objects and the remaining are classified as active and defunct payloads.[5,6,7] Statistical models estimate that there are about 34,000 space objects larger than 10 centimeters (cm) and 900,000 objects between 1cm and 10cm in orbit around the Earth, but it is challenging for current radar and optical systems to detect the smallest objects, particularly those below 10cm.[8]

Figure 1. Number of Objects in Earth Orbit by Object Type



Source: Orbital Debris Quarterly Newsletter, Volume 24, Issue 1, Feb 2020 https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv24i1.pdf

Changing debris environment

Active satellites comprise only about 10 percent of all tracked objects in space.[9] The remaining objects comprise spent rocket bodies, defunct satellites, and debris from breakups or collisions. A study conducted in 2017 by NASA's Orbital Debris Program Office found that two major debris causing events, the 2007 Chinese anti-satellite missile test and the 2009 Iridium-Cosmos collision, accounted for about 25 percent of space debris objects.[10] Depending on the altitude and orbit of the object, some debris can enter Earth's atmosphere and burn up upon reentry while other debris will remain in orbit indefinitely.

Travelling at very high velocities, debris of any size can pose significant risk to active space systems and human spaceflight operations. Furthermore, when on-orbit collisions occur, more

[4] Downloaded space-track.org data, accessed Feb 5, 2020.
[5] Orbital Debris Quarterly Newsletter, Volume 23, Issue 4, Nov 2019. https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv23i4.pdf
[6] However, other sources quote the number of objects tracked by DoD's Space Surveillance Network (SSN) as between 23,000 to 26,000
[7] https://www.npr.org/2020/01/29/800433686/space-traffic-is-surging-and-critics-worry-there-could-be-a-crash
[8] https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers
[9] Institute for Defense Analysis, Science and Technology Policy Institute, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", April 2019
[10] Orbital Debris Quarterly Newsletter, Volume 21, Issue 2, May 2017. https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv21i2.pdf

debris is generated and can result in an increased risk of collisions. This phenomenon is known as the Kessler effect.[11] To address this issue, some nations and companies have committed to deorbiting satellites with 25 years of the end of their mission life through the Inter-Agency Space Debris Coordination Committee (IADC), a voluntary multilateral forum for nations to engage on facilitating cooperation on debris research and activities.[12] Active debris removal and other debris mitigation measures are also being explored to address the growing concern of debris and its effect on the space environment.[13]

Outlook for active satellites changing over time

Megaconstellations and small satellites are altering the future of the space environment. The extent of growth in the number of satellites involved and projected to be launched is challenging to predict. In 2018, market reports predicted the number of commercial satellites in orbit would reach between 10,000 - 12,000 by 2030.[14] A revised assessment published in June 2019 predicted more than 20,000 satellites would be launched into orbit by 2030, based on announcements of new planned commercial constellations and license applications filed by satellite companies with the Federal Communications Commission.[15] If all of the projected constellations are launched, the population of satellites in low Earth orbit (LEO) would rise by a factor of 10 over the next decade. Of these planned new entrants into LEO, three megaconstellations of communications satellites are anticipated to make up 82 percent of the total projected number of satellites.[16]

Increasing number of space actors

As of 2019, over 80 countries have had at least one spacecraft in orbit.[17] This number has grown from 2 countries in the 1950s to over 20 by the late 1970s. Commoditization of off-the-shelf satellite components and the introduction of CubeSats and small satellites are lowering the barrier for entry into space for previously non-space faring nations.[18] While the U.S., China, Russia, Japan, France, Germany and other European nation's satellites still make up the overwhelming majority of satellites launched into space, nations such as Rwanda and Ethiopia are now also launching satellites into space.[19] From Earth observation satellites that help nations modernize agriculture and mitigate against drought conditions to communication satellites that offer connectivity to rural areas, more nations are looking to space assets to help address terrestrial challenges and support domestic activities and infrastructure.

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[11] https://www.nasa.gov/centers/wstf/site_tour/remote_hypervelocity_test_laboratory/micrometeoroid_and_orbital_debris.html
[12] https://orbitaldebris.jsc.nasa.gov/library/iadc_mitigation_guidelines_rev_1_sep07.pdf
[13] https://www.esa.int/Safety_Security/Space_Debris/Active_debris_removal
[14] Frost Report. Small-satellite Launch Services Market, Quarterly Update Q1 2018, Forecast to 2030. https://go.frost.com/EU_PR_JHolmes_MDD2_SmallSatellite_May18
[15] Theodore J. Muelhaupt, Marlon E. Sorge, Jamie Morin, Robert S. Wilson, Space traffic management in the new space era, The Journal of Space Safety Engineering 6 (2019) 80–87
[16] Theodore J. Muelhaupt, Marlon E. Sorge, Jamie Morin, Robert S. Wilson, Space traffic management in the new space era, The Journal of Space Safety Engineering 6 (2019) 80–87
[17] Data downloaded from space-track.org, accessed Feb 5, 2020
[18] Institute for Defense Analyses, Science and Technology Policy Institute, "Global Trends in Small Satellites" July 2017
[19] https://listwand.com/ethiopia-joins-the-list-of-african-nations-with-satellites-in-space/

U.S. Government SSA Data Collection and Tracking System

The number of objects being tracked by the DoD is rising for several reasons including the increasing number of objects in space. The DoD's Space Surveillance Network is currently adding the new Space Fence ground-based S-band radar to its network of over 20 ground-based and space-based data collection sites. Space Fence (SF) is expected to collect data on objects smaller than 10 cm, though the exact minimum size of objects that can be tracked is not publicly known. The DoD's Office of the Director of Operational Test and Evaluation recently published an assessment of SF, which is expected to become operational in February 2020. The report states, "SF demonstrated the capability to find many small objects that had not previously been tracked or cataloged. Once SF becomes operational, the number of tracked objects confirmed orbiting the earth is expected to grow significantly". [20] Also, the DoD is regularly declassifying more and more objects that are being added to the public catalogue which is helpful to those governments and commercial entities relying on DoD SSA data.[21] With more objects in the catalogue, SSA and the process for detecting, processing and alerting operators of potential collisions becomes more complex.

Non-U.S. Government SSA Data Collection and Tracking Systems

Commercial and non-U.S. capabilities conducting SSA activities including tracking of objects, cataloguing, processing SSA information and developing collision warnings, are growing. While many countries continue to maintain data sharing agreements for SSA data with the DoD, a number of countries and regions including Japan, Germany, and France are developing their own SSA systems to augment the data they are receiving from the U.S. Furthermore, several commercial SSA companies have emerged to support government and private sector satellite owner/operators in identifying, tracking and supporting potential collision avoidance maneuvers.[22] Commercial and international data, when combined with DoD SSA data, provide more frequent observations than the DoD system alone and can improve the accuracy of SSA information for satellite operators.[23] Other commercial SSA vendors are looking to offer tailored information and SSA services to accommodate individual operator needs.

Technical factors changing the SSA landscape

Traditionally the behaviors of spacecraft on orbit have been fairly predictable and routine. Once at the correct inclination and altitude, most satellites maintain their orbit over the mission lifetime. However, new modes of operating in space including satellite servicing, active debris removal and rendezvous and proximity operations are adding complexity to the task of tracking and predicting the locations of active satellite. In many cases, when an on-orbit maneuver has been conducted, it has been planned, coordinated, and communicated within the SSA community. However, some commercial and government operators are planning to use artificial

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[20] FY2019 Annual Report for the Office of the Director, Operational Test & Evaluation. https://www.dote.osd.mil/Publications/Annual-Reports/2019-Annual-Report/

[21] https://www.popularmechanics.com/space/satellites/a25562991/pentagon-declassifying-space-traffic-data/

[22] Institute for Defense Analysis, Science and Technology Policy Institute, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", April 2019

[23] Institute for Defense Analysis, Science and Technology Policy Institute, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", April 2019

intelligence for determining whether a satellite will autonomously maneuver in a potential collision situation.[24,25] How these unplanned maneuvers would be communicated and coordinated with the SSA community is not yet well understood.

Another challenge in tracking and predicting the location of active satellites is the use of on-board propulsion. Satellites that use chemical propulsion, which thrust at one time with a high impulse, are challenging to track unless the maneuver is planned and coordinated.[26] Satellites that use electric propulsion systems, which thrust over periods as long as months, may require more SSA observations in order to determine the spacecraft's new orbit and track and predict its future locations.[27] In both cases, coordinating and communicating maneuvers with the SSA community can help the fidelity of the ever growing and changing catalog of space objects.

International Cooperation

International cooperation in space dates back to 1959 when the United Nations established the Committee on the Peaceful Use of Outer Space (UNCOPUOS), a Committee mandated to strengthen the international legal regime governing outer space and to support national, regional and global efforts to maximize the benefits of the use of space science and technology and their applications. Since 2011, UNCOPUOS has been developing Long-Term Sustainability Guidelines to promote greater international cooperation in space security and sustainability. The long-term sustainability of outer space activities is defined as, "as the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations."[28] In 2019, UNCOPUOS ratified 21 voluntary guidelines which fall into four major areas: policy and regulatory framework for space activities; safety of space operations; international cooperation, capacity-building and awareness; and scientific and technical research and development.[29]

In addition to the multilateral discussions that take place under UNCOPOUS and the Inter-Agency Space Debris Coordination Committee, the space community has self-assembled to address the challenges of maintaining a safe and sustainable safe environment. In 2019, the World Economic Forum chose a team of researchers, led by the Massachusetts Institute of Technology, to launch the Space Sustainability Rating (SSR) to foster global standards on debris mitigation. The press release for the initiative states, "similar to rating systems such as the LEED certification used by the construction industry, the SSR is designed to ensure long-term sustainability by encouraging more responsible behavior among countries and companies participating in space."[30] Also in 2019, a group of space-industry stakeholders established the

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[24] https://qz.com/1627570/how-autonomous-are-spacexs-starlink-satellites/
[25] https://www.thespacereview.com/article/3800/1
[26] Simon George, Andrew Ash, "Future On-Orbit Spacecraft Technologies and Associated Challenges for Space Situational Awareness" AMOS Conference, 2019. https://amostech.com/TechnicalPapers/2019/Space-Based-Assets/George.pdf
[27] Institute for Defense Analysis, Science and Technology Policy Institute, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", April 2019
[28] https://www.unoosa.org/res/oosadoc/data/documents/2019/a/a7420_0_html/V1906077.pdf
[29] Daniel L. Oltrogge and Ian A. Christensen. Space Governance in the New Space Era. First Orbital Debris Conference. 2019. https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6013.pdf
[30] https://news.mit.edu/2019/space-sustainability-rating-system-mitigate-debris-0506

Space Safety Coalition (SSC) and is building set of best practices for the sustainability of space operations. Other more enduring efforts have included the Consultative Committee for Space Data Systems (CCSDS), which is focuses on stakeholders developing standards and best practices for communications and data systems to enhance interoperability for satellite systems. Furthermore, the International Standards Organization (ISO) is an independent, non-governmental international organization that coordinates to develop voluntary, consensus-based standards to promote safe operations in space. Other issues being discussed in the international community include liability, and approaches to coordinating space traffic among space operators.

Chairwoman HORN. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time. Good afternoon. Thank you for your understanding that we were on the floor in votes. Very glad to have you here, and welcome to everyone who is here, and to our witnesses. We appreciate you being here today. In today's hearing we're going to address and—one of the most important and rapidly evolving issues facing our ability to operate in space: space situational awareness.

At present the Department of Defense's public catalog reports over 20,000 space objects, and with the event of mega constellations, and an increasing amount of players, space is only going to get more crowded. In fact, a June 2019 assessment predicted that more than 20,000 satellites would be launched into orbit by 2030 based on announcements of new planned commercial constellations. Space situational awareness allows us to track and monitor the number and location of space objects, how to characterize a space environment, and identify any potential collisions and—that could be avoided.

A good example of the need for better space situational awareness occurred just a few weeks ago, when officials were closely monitoring two dead satellites with interest and concern. The two satellites, one a NASA satellite, and one an Air Force experimental spacecraft that was launched in 1967, were expected to pass extremely close to each other at speeds of 32,000 miles per hour. If these satellites were closer than estimated, it could've led to a collision creating thousands of pieces of space debris that could have potentially devastating impacts on other operating spacecraft. Satellite and spacecraft operators need reliable space situational awareness to respond to collision threats, because a moving satellite or spacecraft involves time, money, and resources, such as fuel, and the accuracy of situational awareness data, and the reliability of collision warnings are all things that need to be considered.

The bottom line is that space situational awareness, and ensuring the safety and sustainability of the space environment, is an issue that affects our civil space program, our commercial space sector, and our national security space activities, and it's a problem we need to understand and begin to address now. Space is a critical part of our infrastructure. It enables our Nation's commerce, agricultural productivity, banking, and many other aspects of our day to day lives. Imagery and data from orbiting weather satellites and precision navigational and location data from the Global Positioning System, GPS, are essential to countless aspects of national security and commerce. Threats to safety and sustainability of the space environment would have far reaching implications for U.S. Government, commercial, and non-U.S. operations in space, and our Nation's reliance on space activities.

Today's hearing, and the testimony of our witnesses, is a critical start to exploring this topic, because while the problem of space situational awareness is ever more pressing, how we manage it is equally important. This start must include a clear and thorough examination of the rapidly evolving nature of this issue, the broad range of stakeholders involved, and the international and legal aspects of the changing landscape of space situational awareness.

To that end, provisions in the bipartisan H.R. 5666 *NASA Authorization Act of 2020* begin to scratch the surface on improving space situational awareness. Some of the provisions include authorizing NASA (National Aeronautics and Space Administration) to carry out research and development activities on space situational awareness and orbital debris mitigation, directing NASA to conduct an SSA (space situational awareness) research and technology strategy, and directing the administrator, and other relevant Federal agencies, to carry out international discussions and capacity building on orbital debris removement—removing—excuse me, removal. Let's see if I can get that word out. The provisions in H.R. 5666 and today's hearing are what I anticipate will be the first steps in a series of Subcommittee and Committee activities on space situational awareness. Future Subcommittee activities will need to consider the technical capabilities, authorities, and roles and responsibilities for effective, ongoing space situational awareness data and information services.

In closing, space situational awareness is not a U.S. issue. Space knows no national boundaries, and the solutions for ensuring sustainability in space must be international. However, leadership in this effort should come from the United States. We, in collaboration with our international partners, must shape the practices and behaviors of space operators we expect others to follow in ensuring the safety and sustainability of the space environment.

[The prepared statement of Chairwoman Horn follows:]

Good afternoon, and welcome to our witnesses. Thank you for being here today. In today's hearing we will begin to address one of the most pressing and rapidly evolving issues facing our ability to operate in space, Space Situational Awareness.

At present, the Department of Defense's public catalogue reports over 20,000 space objects. With the advent of mega constellations and an increasing amount of players, space is only going to get more crowded. In fact, a June 2019 assessment predicted that more than 20,000 satellites would be launched into orbit by 2030 based on announcements of new planned commercial constellations.

Space situational awareness allows us to track and monitor the number and location of space objects, how to characterize the space environment, and identify any potential collisions so they can be avoided.

A good example of the need for space situational awareness occurred just a few weeks ago, when officials were closely monitoring two dead satellites with interest and concern. The two satellites, one a NASA satellite and one a U.S. Air Force experimental spacecraft launched in 1967, were expected to pass extremely close to each other at speeds of over 32,000 miles per hour. If these satellites were closer than estimated, it could have led to a collision creating thousands of pieces of space debris that could potentially have devastating impacts on other operating spacecraft.

Satellite and spacecraft operators need reliable space situational awareness to respond to collision threats. Because moving a satellite or spacecraft involves time, money, and resources such as spacecraft fuel, the accuracy of the situational awareness data and the reliability of collision warnings need to be considered.

The bottom line is that space situational awareness and ensuring the safety and sustainability of the space environment is an issue that affects our civil space program, our commercial space

sector, and our national security space activities. And it is a problem we need to understand and address now.

Space is part of our infrastructure. It enables our Nation's commerce, agricultural productivity, banking, and many other aspects of our day-to-day lives. Imagery and data from orbiting weather satellites and precision navigational and location data from the Global Positioning System (GPS) are essential to countless aspects of our national systems and commerce. Threats to the safety and sustainability of the space environment would have far-reaching implications for U.S. government, commercial, and non-U.S. operations in space and our Nation's reliance on those space activities.

Today's hearing and the testimony of our witnesses is a critical start to exploring this topic. Because while the problem of space situational awareness is ever more pressing, how we manage it is equally important.

This start must include a clear and thorough examination of the rapidly evolving nature of this issue, the broad range of stakeholders involved, and the international and legal aspects of the changing landscape for space situational awareness. To that end, provisions in the bipartisan H.R. 5666, the NASA Authorization Act of 2020, begin to scratch the surface on improving space situational awareness. Some of these provisions include:

- authorize NASA to carry out research and development activities on space situational awareness and orbital debris mitigation;
- direct NASA to conduct an SSA research and technology strategy; and
- direct the Administrator, along with other relevant Federal agencies, to carry out international discussions and capacity-building on orbital debris removal.

The provisions in H.R. 5666 and today's hearing are what I anticipate will be the first steps in a series of Subcommittee and Committee activities on space situational awareness. Future Subcommittee activities will need to consider the technical capabilities, authorities, and roles and responsibilities for effective, ongoing space situational awareness data and information services.

In closing, space situational awareness is not a U.S. issue; space knows no national boundaries and the solutions for ensuring sustainability in space must be international. However, leadership in this effort should come from the United States. We, in collaboration with our international partners, must shape the practices and behaviors of space operators we expect others to follow in ensuring the safety and sustainability of the space environment.

Thank you.

Chairwoman HORN. Thank you, and I now recognize Ranking Member Babin for his opening statement.

Mr. BABIN. Thank you, Madam Chair. Great to be here today, and thank you to all you witnesses. Today's hearing on space situational awareness, or SSA, is a continuation of the Committee's longstanding interest in this very topic. We've held numerous hearings over the last several years and considered two significant pieces of legislation last Congress, the *American Space Commerce Free Enterprise Act* and the *American Space Safe Act*. I urge my colleagues to once again please consider these important bills.

SSA is an important topic for this Committee to consider, but we should do so in a very deliberative manner. Near-misses in space attract media attention and calls for draconian regulations, but overreacting could be just as detrimental to our Nation's space enterprise. That being said, there are many things we probably all agree on. First, we need better data. The Department of Defense currently operates the lion's share of sensors that inform our understanding of where objects are in orbit, and that will not change. Furthermore, the DOD (Department of Defense) does not release all of its data because of national security concerns, and that is also understandable.

Other elements of the Federal Government play an important role as well. NASA, and more specifically the Johnson Space Center, which I proudly represent, and the Goddard Space Flight Center, are involved in SSA. They sit side by side with the military to monitor satellites and debris in space to ensure the International Space Station and science satellites are safe. But the information the government and private sector are relying on to make sound decisions needs to be improved. Uncertainty about current data is too high, which leads to both unnecessary alerts, and unpredicted conjunctions.

The second issue that we should all agree on is that the DOD should get out of the SSA business. DOD will always maintain sensors for tracking objects in space in order to protect our national security, but they are not the appropriate agency to interact with the private sector, or with our international partners. For this reason, the administration proposed that the Department of Commerce serve as the government's commercial storefront, if you will, for SSA. Commerce can then partner with the private sector, which is something they do well. Commerce already houses the National Institutes of Standards and Technology, the world leader in developing standards, manages export controls for satellite technology through the Bureau of Industry and Security, and coordinates spectrum issues through the National Telecommunications and Information Administration.

Commerce also houses the National Weather Service that conducts forecasts and issues alerts to protect life and property, operates a fleet of weather satellites under NOAA (National Oceanic and Atmospheric Administration), and is the only agency that has statutory authority to license activity in space, space-based commercial remote sensing. They also have a history of providing a light touch with emerging industries. Commerce stood up the Internet Corporation for Assigned Names and Numbers, or ICANN, through a contract with a nonprofit organization. ICANN was the organization responsible for developing policies, coordinating best practices, and managing the processes that led to a stable Internet. We've already seen the space community adopt a similar approach on our own.

Several years ago operators founded the Space Data Association to share information and to improve safety. The Space Data Association demonstrates how the private sector can collaborate and innovate. More recently, the Space Safety Coalition was established to provide similar capabilities for operators in low Earth orbit. Companies are also providing data and services on the open market. They are developing cost-effective, timely, and accurate SSA data, often relying on off-the-shelf and non-military technologies. In some cases, commercial capabilities are superior to DOD's. This is good news for America, and for the global community, and we should help those nascent industries to grow.

The third issue that we should all agree on is that we need to develop better standards and better practices. Rather than imposing a top-down regulatory burden on an emerging sector, we should adopt a crawl, walk, run approach. In this regard, the International Agency for Space Debris Coordination Committee, IADC, is an interesting case study. NASA developed its own orbital debris guidelines that were eventually adopted by the entire Federal Government, and then accepted by most space-faring nations, as part of the IADC process. The guidelines are consensus-based principles that inform spacecraft development and operations, and could form the basis for developing rules of the road going forward. This could be augmented by contributions from the insurance industry, similar to the role they played in the early days of maritime shipping. I believe that we can all work together, and this will be to ensure space remains a safe environment for future generations without stifling industry with burdensome regulations before they ever launch.

I want to thank our witnesses for appearing today, and I yield back, Madam Chair.

[The prepared statement of Mr. Babin follows:]

Today's hearing on space situational awareness, or "SSA," is a continuation of the Committee's longstanding interest in the topic. We've held numerous hearings over the last several years and considered two significant pieces of legislation last Congress: the American Space Commerce Free Enterprise Act and the American Space SAFE Act. I urge my colleagues to once again consider these important bills. SSA is an important topic for this Committee to consider, but we should do so in a deliberative manner. Near-misses in space attract media attention and calls for draconian regulations, but overreacting could be just as detrimental to our Nation's space enterprise.

That being said, there are many things we probably all agree on.

First, we need better data. The Department of Defense (DOD) currently operates the lion's share of sensors that inform our understanding of where objects are in orbit. That won't change. Furthermore, the DoD does not release all of its data because of national security concerns. This is understandable. Other elements of the federal government play an important role as well. NASA, and more specifically the Johnson Space Center, which I proudly represent, and the Goddard Space Flight Center, are involved in SSA. They sit side-by-side with the military to monitor satellites and debris in space to ensure the International Space Station and science satellites are safe.

But the information the government and private sector are relying on to make sound decisions needs to be improved. Uncertainty about current data is too high, which leads to both unnecessary alerts and unpredicted conjunctions.

The second issue that we should all agree on is that the DoD should get out of the SSA business. DoD will always maintain sensors for tracking objects in space in order to protect national security, but they are not the appropriate agency to interact with the private sector or international partners. For this reason, the Administration proposed that the Department of Commerce serve as the government's "commercial storefront" for SSA. Commerce can then partner with the private sector, something they do well.

Commerce already houses the National Institutes of Standard and Technology, the world-leader in developing standards, manages export controls for satellite technology through the Bureau of Industry and Security, and coordinates spectrum issues through the National Telecommunications and Information Administration. Commerce also houses the National Weather Service that conducts forecasts and issues alerts to protect life and property; operates a fleet of weather satellites under NOAA; and is the only agency that has statutory authority to license activity in space—space-based commercial remote sensing. They also have a history of providing a lighttouch with emerging industries.

Commerce stood up the Internet Corporation for Assigned Names and Numbers (ICANN) through a contract with a non-profit organization. ICANN was the organization responsible for developing policies, coordinating best practices, and managing the processes that led to a stable internet.

We've already seen the space community adopt a similar approach on their own. Several years ago, operators founded the Space Data Association to share information and improve safety. The Space Data Association demonstrates how the private sector can collaborate and innovate. More recently, the Space Safety Coalition was established to provide similar capabilities for operators in low Earth orbit.

Companies are also providing data and services on the open market. They are developing cost effective, timely, and accurate SSA data, often relying on off-the-shelf and non-military technologies. In some cases, commercial capabilities are superior to DoD's. This is good news for America and for the global community, and we should help these nascent industries to grow.

The third issue we should all agree on is that we need to develop better standards and practices. Rather than imposing a top-down regulatory burden on an emerging sector, we should adopt a crawl, walk, run approach. In this regard, the International Agency Space Debris Coordination Committee (IADC) is an interesting case study. NASA developed its own orbital debris guidelines that were eventually adopted by the entire federal government and then accepted by most spacefaring nations as part of the IADC process. The guidelines are consensus-based principles that inform spacecraft development and operations, and could form the basis for developing rules of the road going forward. This could be augmented by contributions from the insurance industry similar to the role they played in the early days of maritime shipping.

I believe we can all work together to ensure space remains a safe environment for future generations without stifling industry with burdensome regulations before they ever launch. I want to thank our witnesses for appearing today, and yield back my time.

Chairwoman HORN. Thank you, Mr. Babin. The Chair now recognizes the Ranking Member of the Full Committee, Mr. Lucas, for an opening statement.

Mr. LUCAS. Thank you, Chairwoman Horn, for holding this timely hearing on the situational awareness in space. Only two weeks ago we saw the importance of this issue, as two defunct Federal satellites, each traveling at 17,500 miles per hour, came dangerously close to each other 560 miles above Pittsburgh. While there was no threat to those on the ground, the collision in space could've been significant because the debris would impact other satellites, and potentially even threaten astronauts aboard the International Space Station, depending on the orbit. The satellites ultimately passed each other without incident, but there were widely varies estimates of their chances of colliding, ranging from one in 100 to one in 1,000.

Limitations on tracking data and the satellites' exact characteristics and orientation leads to this kind of uncertainty, which is problematic. For instance, most of the data on objects in space comes from the Department of Defense. While DOD provides data to the international community and the private sector, national security concerns limit the fidelity of the data it can release. The private sector, however, is emerging as an important partner in this equation. Companies are beginning to provide not only visualization products and services, but also sensor data. Furthermore, companies that operate satellites typically have better data on their satellites than anyone else. Nonprofit groups, like the Space Data Association, and the newly formed Space Safety Coalition, are partnering with government agencies, commercial satellite operators, space data providers, and the international community to provide solutions to the challenge of space situational awareness, space debris mitigation, and space traffic management.

The Trump Administration is also paying attention. Vice President Pence, and the National Space Council, released two important policies related to the topic before us today. Space Policy Directive No. 2 calls for streamlining space regulations, and Space Policy Directive 3 calls for a coordinated space traffic management effort to ensure safety, stability, and innovation in space. The principles in these policies track directly with the positions this Committee has advocated in numerous hearings over the last decade. Furthermore, this Committee passed two critical pieces of legislation out of the House in the previous Congress that related to space situational awareness and space traffic management, the *American Space Commerce Free Enterprise Act*, sponsored by Ranking Member Babin, and the *American Space Safe Management Act*, would go a long way to advancing the development of standards, best practices, and rules of the road in a way that would not stifle the private sector.

The Administration also proposed giving the Department of Commerce, rather than the Department of Defense, the responsibility to issue notices of potential collisions. DOD would prefer to focus its efforts on supporting our troops and national security. The Department of Commerce already has experience dealing with the private sector to assist commerce. They also license commercial remote sensing satellite operators, operate a fleet of government weather satellites, protect critical technologies from export, provide safety notifications and forecasting for weather, and understand how to manage technology in a manner that fosters innovation. The Office of Space Commerce and the Department of Commerce is already up and running, and has served a similar function, coordinating the interactions with the U.S. Government, international partners, and the private sector related to global positioning policies as the host of the Position, Navigation, and Timing National Coordination Office.

Unfortunately, our friends in the Minority over on the Senate Appropriations side are preventing the Department of Commerce from reorganizing in a way that can advance space safety. If we want to seriously address the problem of tracking space debris, advance our space object tracking capacities, and develop best practices and rules of the road for operating in space, the first step is allowing the Office of Space Commerce to be the commercial storefront for space situational awareness data. The government can then partner with the private sector and international community to share data and establish consensus-based norms of behavior. This will go a long way to ensuring Earth orbit remains useful for future generations.

I look forward to working with my colleagues here on the Committee, as well as Appropriations, the Administration, and the private sector to advance common sense policy solutions related to space object tracking. Thank you, and I yield back the balance of my time, Madam Chairman.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Horn, for holding this timely hearing on situational awareness in space. Only two weeks ago we saw the importance of this issue, as two defunct government satellites, each traveling at roughly 17,500 miles per hour, came dangerously close to each other 560 miles above Pittsburgh. While there was no threat to those on the ground, a collision in space could be significant because the debris could impact other satellites or even potentially threaten astronauts aboard the International Space Station depending on the orbit.

The satellites ultimately passed each other without incident, but there were widely varied estimates of their chances of colliding—ranging from 1 in 100 to 1 in 1000. Limitations on tracking data and the satellites' exact characteristics and orientation lead to this kind of uncertainty, which is problematic. For instance, most of the data on objects in space comes from the Department of Defense (DOD). While the DoD provides data to the international community and the private sector, national security concerns limit the fidelity of the data it can release.

The private sector, however, is emerging as an important partner in this equation. Companies are beginning to provide not only visualization products and services, but also sensor data. Furthermore, companies that operate satellites typically have better data on their satellites than anyone else. Non-profit groups like the Space Data Association and the newly formed Space Safety Coalition are partnering with government agencies, commercial satellite operators, space data providers, and the international community to provide solutions to the challenge of space situational awareness, space debris mitigation, and space traffic management.

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I look forward to working with my colleagues here on the Committee, as well as Appropriators, the Administration, and the private sector to advance common-sense policy solutions related to space object tracking.

Thank you and I yield back the balance of my time.

Chairwoman HORN. Thank you, Mr. Lucas. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Thank you, Chairwoman Horn, for holding today's hearing on space situational awareness, and thank you to each of our witnesses for your thoughtful prepared testimony.

During the 116th Congress, the Committee on Science, Space, and Technology has been focusing on a number of complex issues, including artificial intelligence, cybersecurity, climate change, and energy innovation to name just a few. The oversight we have been conducting has helped inform our Committee's consideration of potential policy options in each of those areas. Today, the Space Subcommittee will be examining another multifaceted and complex issue-namely the sustainability of the space environment in which we and other nations carry out our space activities.

Outer space is vast. However, some of the orbits around Earth are becoming crowded, and spacecraft are becoming increasingly vulnerable to impacts from space debris. The dangers from space debris are coming at a time when nations are increasingly looking to space to support their national objectives, whether they be scientific, commercial, or national security-related.

Space situational awareness—SSA—involves collecting location data on space objects, processing that data to characterize the space environment, and developing techniques to support satellite operators so that they can avoid potential collisions in space. SSA provides the foundation for any technical or potential future regulatory measures that might be needed to ensure safe operations in space.

Of course, because the problem is global in nature, it will be essential that the United States work collaboratively with our international partners if we are to achieve a sustainable approach to dealing with the challenge posed by space debris.

There are many facets of the SSA problem that will need to be addressed. Namely, what technical capabilities are needed? How will government, commercial, and academic entities contribute to and share space situational awareness data and information? What legal and policy questions will need to be considered?

I hope that today's hearing will provide us with a good introduction to the challenges and opportunities associated with space situational awareness. I also hope to hear from our witnesses about what issues the Committee should prioritize as it begins its work on this important issue.

Our Committee's work in this complex and important area is just beginning today, and I anticipate that we will be carrying out additional hearings and oversight on space situational awareness, orbital debris, and space traffic management over the remainder of this Congress.

I again want to commend Chairwoman Horn and Ranking Member Babin for holding today's hearing, and with that I yield back.

Chairwoman HORN. At this time I'd like to introduce our witnesses. Our first witness today is Dr. Brian Weeden, Director of Program Planning for Secure World Foundation, which promotes cooperative solutions for space sustainability and peaceful uses of outer space. Dr. Weeden served 9 years as an officer in the United States Air Force, working in space and ICBM operations, and he directed the Orbital Analyst Training Program that improved space situational awareness as a part of the U.S. Strategic Command's Joint Space Operation Center. Dr. Weeden received 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 a Doctorate in Public Policy and Public Administration in the field of Science and Technology Policy from George Washington University. Welcome, Dr. Weeden.

Our next witness is Mr. Dan Oltrogge. Did I do it right? OK. I've been practicing, so I'm going to keep practicing. Oltrogge is the founder and administrator of the Space Safety Coalition, which leads the Best Practices for Sustainability of Space Operations Initiative. Mr. Oltrogge is the chair of the American Institute of Aeronautics and Astronautics', AIAA, Space Traffic Management Space Governance Task Force, and he serves as the International Standards Organization representative to the U.N. Committee for the Peaceful Uses of Outer Space. Mr. Oltrogge received a Bachelor of Science Degree in Aerospace, Aeronautical, and Astronautical Engineering from Iowa State University, and a Master of Science Degree in Aerospace Engineering and Astrodynamics from the University of Southern California. Welcome.

Our next witness is Professor Joanne Irene Gabrynowicz, Professor Emerita of Space Law, and Director Emerita of the National Center for Remote Sensing, Air and Space Law at the University of Mississippi Law Center. Professor Gabrynowicz is also Editor-In-Chief Emerita of the Journal for Space Law. In addition, she is the Director of the International Institute of Space Law, IISL, and is an official observer for the IISL to the U.N. Committee on the Peaceful Uses of Outer Space. She received her Bachelor's from City University of New York, and earned her Juris Doctorate from the Cardoza School of Law. Professor Gabrynowicz has also testified before the Subcommittee previously. Welcome back, Professor Gabrynowicz.

Our next witness today is Professor Danielle Wood, Assistant Professor in Media Arts and Sciences in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology. Professor Wood also leads the Space Enabled Research Group within MIT Media Lab, which harnesses space technology to address development challenges around the world. Prior to serving as faculty at MIT (Massachusetts Institute of Technology), Professor Wood held positions at NASA headquarters, NASA Goddard Space Flight Center, Aerospace Corporation, Johns Hopkins University, and the United Nations Office of Outer Space Affairs. She received a Bachelor of Science Degree in Aerospace Engineering, a Master of Science Degree in Technology Policy, and a Doctorate in Engineering Systems from MIT. Welcome, Dr. Wood.

Our next witness is Dr. Ruth Stilwell, Executive Director of Aerospace Policy Solutions, LLC, an adjunct professor at Norwich University, and a senior non-resident scholar at the Space Policy Institute of George Washington University. A 25-year air traffic controller, Dr. Stilwell now manages a consulting firm offering strategic advice and research services for integration of aviation and commercial space operations. Among other areas, Dr. Stilwell also serves on the Technical Committee on Human Space Flight Safety of the International Association for the Advancement of Space Safety, which is developing safety guidelines for human commercial space flight. Dr. Stilwell received a Bachelor's in Labor Studies at the National Labor College, and she earned a Master's in Public Administration, and a Doctorate in Public Administration, from the University of Baltimore. Welcome, Dr. Stilwell.

As our witnesses, you should know you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for this hearing. When you have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel, and we will start with Dr. Weeden. Dr. Weeden?

TESTIMONY OF DR. BRIAN WEEDEN, DIRECTOR OF PROGRAM PLANNING, SECURE WORLD FOUNDATION

Dr. WEEDEN. Madam Chair, Ranking Member, other distinguished Members of the Subcommittee, thank you for the opportunity to testify today on this important issue. Secure World Foundation is dedicated to ensuring the long-term sustainability of space activities so that all of humanity can continue to use space for benefits on Earth. Space situational awareness is the foundation of space sustainability, and working to improve SSA capabilities for all space actors is a major part of our work.

As was referenced earlier, on January 29, 2020, two dead U.S. Government satellites nearly collided about 560 miles above the city of Pittsburgh. The last actual on-orbit collision between two satellites occurred on February 10, 2009, when a dead Russian Cosmos satellite collided with an active U.S. Iridium commercial communication satellite. The Iridium-Cosmos collision generated nearly 2,000 tracked pieces of orbital debris bigger than a softball, most of which will remain on orbit for decades to come. Thankfully, in this latest incident, both objects passed by each other harmlessly, at an estimate distance of about 60 feet.

Comparing the two events highlights what has and has not changed with SSA in the intervening 11 years. The biggest change is the availability of SSA data, and who is providing it. In 2009 the only public source of data on close approaches between space objects was the U.S. military's Joint Space Operations Center. By contrast, the first public notice of the incident this past January came from a tweet sent 3 days before the event by an American commercial SSA company, LeoLabs, which operates its own network of ground-based tracking radars that feed into its own catalog of space objects.

What has not changed is that we cannot yet predict whether two objects in orbit will or will not collide. We can only give an estimated probability of collision, which may change over time. In 2009 the Iridium-Cosmos collision served as a wakeup call for the entire space community to the threat that orbital debris poses to active satellites, as well as the importance of SSA for detecting and avoiding future collisions. Eleven years later, this most recent incident should serve as an alarm bell that there's a lot more still to do.

As a result of the Iridium-Cosmos collision, U.S. policy was changed in 2010 to broaden the SSA mission of the U.S. Air Force to provide close approach warnings to all satellite operators globally. This was an important step that has improved the situation, but only so much. SSA capabilities today are dangerously insufficient to deal with the emerging challenges from the growing number of space actors, large constellations, orbital debris hazards, and a more complex and competitive geopolitical environment.

The key policy issue still to be resolved is the transition of responsibilities for civil SSA from the Department of Defense to another agency as the first step in establishing a national space traffic management regime. The executive branch has worked on this issue for 8 years, across both the Obama and Trump Administrations, resulting in Space Policy Directive 3, issued by the Trump Administration in June 2018. However, Congress has not yet enacted the required changes in authorities or budget to implement SPD-3, or an alternative, and thus the issue hangs in limbo.

Beyond SSA itself, there is the broader issue of implementing a holistic strategy for ensuring the long-term sustainability of space in accordance with existing national policy direction. While the United States has made limited progress on developing orbital debris mitigation standards, it has made zero progress on developing capabilities to remove the existing debris, let alone actually doing so. Neither have made much progress on implementing a space traffic management regime, enforcing debris mitigation standards, or modernizing the oversight and licensing of commercial space activities, all of which relies on improved SSA capabilities.

It is critical that Congress act on this issue now. Improving SSA is fundamental to everything the United States does in space, and all the benefits we derive from space. This includes protecting human exploration in science, ensuring critical weather and climate data, protecting important national security capabilities, and enabling economic growth and innovation in the commercial space sector. Taking the appropriate policy steps on civil SSA will enable a giant step toward ensuring the long-term sustainability of space activities for the United States, and that humanity can continue to use space for benefits on Earth. Thank you for your time, and I welcome your questions.

[The prepared statement of Dr. Weeden follows:]

Hearing of the Subcommittee on Space and Aeronautics

U.S. House of Representatives

"Space Situational Awareness: Examining Key Issues and the Changing Landscape"

Tuesday, February 11, 2020 - 2:00 PM

Testimony of Dr. Brian Weeden

Director of Program Planning, Secure World Foundation

1. Introduction

Madam Chair, distinguished members of this subcommittee, thank you for the opportunity to provide written testimony on this important issue. Secure World Foundation is dedicated to ensuring the long-term sustainability of space activities so that all of humanity can continue to use space for benefits on Earth. Space situational awareness (SSA) is the foundation of space sustainability and working to improve SSA capabilities for all actors is a major part of our work.

On January 29, 2020, two dead satellites nearly collided about 900 kilometers (560 miles) over the city of Pittsburgh.[1] The Gravity Gradient Stabilization Experiment (GGSE-4) was an Air Force technology experiment launched in 1967 and the Infrared Astronomical Satellite (IRAS) was a space-based telescope launched by NASA in 1983. Both had been dead for decades and there was an unusually high chance they would collide. The last such on-orbit collision between two satellites occurred on February 10, 2009, when an inactive Russian military communications satellite (Cosmos 2251) collided with an active commercial communications satellite operated by U.S.-based Iridium Satellite, LLC.[2] The Iridium-Cosmos collision generated nearly 2,000 pieces of orbital debris bigger than a softball, most of which will remain on orbit for decades to come. Thankfully, in this latest incident, both GGSE and IRAS passed each other in orbit without incident at an estimated distance of about 18 meters (60 feet).

Comparing the Iridium-Cosmos collision with the GGSE-IRAS near hit highlights what has and has not changed over the intervening eleven years. In 2009, there were less than 1,000 active satellites in orbit and around 15,000 pieces of cataloged orbital debris. The only public source of

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[1] LeoLabs has published an extensive write-up and analysis of this event here: https://medium.com/@leolabs_space/the-iras-ggse-4-close-approach-a99de19c1ed9

[2] Prior to the Iridium-Cosmos collision, there had 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. Since then, there have been other suspected incidents of active satellites being struck by orbital debris but none resulting in catastrophic destruction.

data on close approaches and collisions between space objects was the U.S. Air Force's First Space Control Squadron, and at that time they were only monitoring for close approaches involving a relatively short list of about 150 important U.S. national security, civil, and human spaceflight objects. As a result of the Iridium-Cosmos collision, U.S. policy changed in 2010 to broaden the SSA mission of the U.S. Air Force, which today provides close approach warnings to all satellite operators globally.[3]

Today there are more than 2,200 active satellites in orbit along with more than 20,000 pieces of cataloged orbital debris. The first public notice of the GGSE and IRAS close approach was a tweet three days before the event from a commercial company, LeoLabs, which operates its own network of ground-based tracking radars that feed into its own catalog of space objects. LeoLabs is one of several commercial companies that have entered the SSA sector in the last decade and who collectively now provide a broad suite of capabilities for tracking space objects in all Earth orbits and an increasingly sophisticated set of analytical products based on that tracking.

In both cases, the best available tracking data and conjunction algorithms were only able to provide a probabilistic answer to whether the two objects would collide. In the case of Iridium-Cosmos, analyses using the lower-quality data made public by the U.S. Air Force at the time suggested they would come within 117 meters to 1.812 kilometers (384 feet to 1.1 miles) over the seven days prior to the collision.[4] The U.S. Air Force has not publicly stated what its internal analysis showed prior to the collision, nor did the public data it made available allow for calculation of a collision probability.[5] For the GGSE-IRAS close approach, LeoLabs provided a visualization four days prior to the event and an updated estimate that ranged from a miss distance of 12 to 100 meters (40 to 330 feet), and a probability of collision that ranged between 1 in 100 to 1 in 1000. After the predicted close approach, both LeoLabs and the U.S. Space Force's 18th Space Control Squadron provided independent public confirmation that the two satellites had indeed missed each other.

The Iridium-Cosmos collision served as a wake-up call for the entire space community to the threat that orbital debris poses to active satellites as well as the importance of SSA for detecting and avoiding future collisions. The Iridium-Cosmos collision also heightened the salience of SSA as a mission area and drove increased focus from policymakers around the world and increased investment in improving SSA capabilities. Some of that focus and investment has resulted in meaningful improvements, yet serious gaps and shortfalls still remain.

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[3] An overview of the SSA Sharing Program that established these changes can be found here: https://swfound.org/media/3584/ssa_sharing_program_issue_brief_nov2011.pdf

[4] An overview and technical analysis of the Iridium-Cosmos collision can be found here: http://celestrak.com/events/collision/

[5] Air Force Space Command conducted an unclassified review of the incident, but the report has never been made public.

The key issue still facing the U.S. government is the transition of responsibilities for civil and safety-related SSA activities from the Department of Defense (DOD) to a civil agency as part of establishing a national space traffic management (STM) regime. Beginning in the summer of 2010, the Obama Administration had an interagency group that worked on STM policy on-and-off for the next six years, which laid the foundation for Space Policy Directive 3 (SPD-3) that was issued by the Trump Administration in June 2018.[6] However, Congress has not yet enacted the changes in authorities and budget that would enable the full implementation of SPD-3 or an alternative solution. The lack of action is due to disagreements between the House and Senate on the importance of assigning new authorities as well as the lack of coordination between the multiple committees with jurisdiction. As a result, creating a civil SSA entity and establishing a STM regime lies in limbo, preventing much-needed progress on managing orbital debris, preventing satellite collisions, and ensuring the long-term sustainability of space.

There are a few other public policy issues that need to be tackled as well. These are competition and overlap between government SSA programs and emerging commercial capabilities, an economic goods analysis of SSA and ensuring the right SSA products and services are available to all user communities, and reducing the restrictions on non-Earth imaging that hinder innovation and development of commercial on-orbit SSA capabilities.

Finally, there is the continued failure of the DOD to improve the computer systems that underpin its own SSA capabilities. In 2004, as a young U.S. Air Force Captain in training prior to an assignment with the 1st Space Control Squadron, I was told the two computer systems we were trained to use would be replaced in 2005. Today, those same two computer systems are still in use and form the backbone of the DOD's SSA capability. There have been multiple failed acquisition programs over the last two decades to try and replace those systems at significant taxpayer expense.[7] While this subcommittee is not responsible for oversight of those programs, the lack of shift to a civil agency providing SSA means the safety of all civil and commercial satellites is beholden to the shortcomings in military systems created by these programmatic failures.

The remainder of my written testimony focuses on the role SSA plays in supporting space sustainability, including enabling orbital debris mitigation, active debris removal, and space traffic management. It concludes with a discussion of current national policy landscape and the public policy and administration issues that need to be addressed by Congress. My testimony refers to and leverages a broader written testimony on a very similar topic that I provided to this

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[6] The text of Space Policy Directive 3 can be found here: https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/

[7] For a summary of these failures up to 2012, see http://swfound.org/media/90775/going_blind_final.pdf For a summary of the failures since 2012, see https://www.gao.gov/assets/710/702424.pdf

subcommittee in a previous hearing[8] held in May 2014, while also emphasizing what has, and has not, changed in the intervening six years.

2. Background on the Current Orbital Debris Environment

More than 70 entities (countries, commercial companies, and international organizations) currently operate more than 2,200 satellites in orbit around Earth.[9] These satellites provide a wide range of social and private benefits, including 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.

Orbital 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. Statistical modeling indicates there are an estimated 900,000 pieces of orbital 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.[10]

As orbital 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 low Earth orbit (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 orbital debris.[11]

Former NASA scientist Donald Kessler was one of the first to predict what has since become known as the Kessler Syndrome.[12] As the amount of space debris in orbit grows, he predicted there would be a critical point where the density of orbital debris would lead to random collisions between orbital debris. These random collisions would in turn generate more debris at a rate

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[8] https://swfound.org/media/169974/weeden%20testimony_may2014.pdf

[9] 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:
https://www.ucsusa.org/resources/satellite-database

[10] For an overview of current estimates of orbital debris, see the European Space Agency website:
https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

[11] 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

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

faster than orbital 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 also not a pristine environment before humans began to fill it with satellites. There has always been a natural debris environment in space due to micrometeoroids. Kessler's 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 orbital 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 Iridium-Cosmos every five to nine years.[13]

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.

Recently, there has been the additional challenge of renewed interest in large satellite constellations.[14] Multiple commercial companies and governments have announced plans to develop and launch constellations ranging from 100 to more than 40,000 satellites each into low Earth orbit between 550 and 1300 kilometers (341 to 808 miles) in altitude. The purpose of these constellations is to either collect imagery and other remote sensing data about the Earth or to provide broadband internet and other communications services to the world, both of which would deliver valuable socioeconomic benefits. However, the sheer size of the planned constellations has driven concerns that they will worsen the orbital debris situation. Modeling done by the European Space Agency of a single 1,000 satellite constellation indicates they will need to comply with strict post-mission disposal and reliability requirements in order to

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[13] 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

[14] For a comparison of the current large constellation proposals with those made during the 1990s, see: https://www.thespacereview.com/article/3747/1

minimize their long-term impact on the space environment.[15] A more in-depth study by NASA that included multiple constellations totaling 8,000 satellites found 99% post-mission disposal and fewer than 1 in 1000 accidental explosions were necessary to avoid a dramatic increase in the orbital debris population.[16]

3. A Holistic Plan for Space Sustainability

Dealing with the orbital debris challenge outlined above requires a holistic approach to space sustainability as shown in Figure 1. Three main lines of effort – debris mitigation, active debris removal (remediation), and space traffic management – are all supported and rely on a foundation of SSA and national policy and regulations. Mitigation, remediation, and traffic management are all complementary initiatives that tackle different aspects of the orbital debris challenge – past, present, and future. Only by undertaking all three can we deal with the problem in a comprehensive manner. Without appropriate and accurate information on the space environment and activities in space, it is impossible to effectively manage the space environment or provide proper oversight in accordance with international obligations.

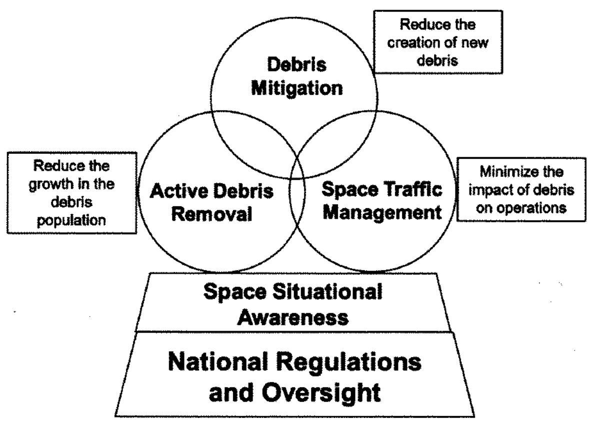

Figure 1. A framework for space sustainability

From a national perspective, it is important to have in place the proper regulations and oversight mechanisms to support all of the activities outlined above across both governmental and non-

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[15] A copy of the ESA study can be found here: https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/507

[16] A copy of the NASA study can be found here: http://www.parabolicarc.com/2018/09/25/nasa-odpos-large-constellation-study/

governmental space activities. These include pragmatic and well-defined licensing requirements for the private sector as well as the ability to continually 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, and soon to be active, in space.

3.1 Orbital Debris Mitigation

Orbital debris mitigation is defined as limiting the creation of new debris through human activities in space. This process 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.

Historically, the United States has been a world leader in both developing orbital 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 space agencies on developing technical debris mitigation guidelines and continues to conduct scientific research on space debris.[17] The key piece of the existing IADC orbital debris mitigation guidelines is the so-called "25-year rule," which says satellites and associated orbital debris should not remain in protected regions of orbit for longer than 25 years beyond their end of mission.

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.[18] At the top level, the 2010 National Space Policy of the United States identified "Preserving the 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 (ODMSP) in their space activities. Space Policy Directive 3 issued by the Trump Administration on June 18, 2018, reinforced the focus on orbital debris mitigation and directed a review of the ODMSP. Led by NASA, that review concluded in late 2019 with the publication of an updated set of ODMSP.[19] However, the update was minimal and fell significantly short of

[17] 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

[18] 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

[19] The updated ODMSP can be found here: https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf

what many outside observers felt was necessary to stay ahead of real-world space sustainability challenges, and continue America's leadership role on debris mitigation.

3.2 Remediation and Active Debris Removal

The existing population of orbital debris will continue to grow over time, even without any new space launches and even with full compliance with the existing mitigation guidelines. In 2011, a study conducted by six space agencies using six different models found an average increase of 30 percent in the LEO orbital debris population over the next 200 years, even with 90 percent adherence to the 25-year rule.[20] Current adherence is around 60% and shows a slight upward trend over time.[21]

Thus, NASA and other space agencies have concluded that actively removing existing orbital debris (ADR), a process also known as remediation, will be necessary. 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 too small to be tracked by current space surveillance systems, and while an impact with them is unlikely to result in a catastrophic collision, it could severely damage or be lethal to an active spacecraft.

Technical experts from around the world have been working intensely on both of these problems over the last decade, and there are some promising technical solutions for removing either large objects or small objects. There are a handful of companies, such as Astroscale, D-Orbit, and ClearSpace, that are working on developing ADR technology for different categories of missions. However, there is unlikely to be a "silver bullet" solution that can deal with both objectives. Moreover, none of these techniques have yet been fully demonstrated in orbit[22] and all of them pose a wide range of legal, policy, and other non-technical challenges.[23] Solving

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[20] 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

[21] The most complete public analysis of this compliance can be found in the annual ESA Space Environment Report: https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

[22] There have been limited experiments of specific technologies or procedures, such as those conducted by the European RemoveDebris mission (https://directory.eoportal.org/web/eoportal/satellite-missions/r/removedebris), but as of yet no demonstrations of removing an existing debris object from orbit.

[23] 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

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.

There are also complementary activities to ADR, primarily just-in-time collision avoidance (JCA). Instead of removing orbital debris, JCA would change the orbit of one of the pieces of orbital debris involved in a very close approach, thus preventing a potential collision.[24] JCA could be done using ground-based lasers to alter the trajectory of a piece of debris, or by creating aerosol clouds in orbit that will slow down objects passing through.[25] However, these technologies are in the early stages of development, and JCA techniques also present a number of legal and policy challenges. That said, JCA could be an important tool to prevent catastrophic collisions and provide more time to develop and carry out direct removal.

The United States has not yet developed or demonstrated the capability for ADR or remediation writ large, or even invested significant funding in R&D, despite clear policy direction to do so for nearly a decade. The 2010 National Space Policy tasked both the DOD and NASA to "pursue research and development of technologies and techniques…to mitigate and remove on-orbit debris." In the intervening ten years since that policy was issued, there have only been a small number of contracts awarded by NASA to do limited risk-reduction studies on debris removal technologies.[26]

The unwillingness of NASA or the DOD to develop ADR technologies is likely due to public policy and administration concerns. Neither has ADR as a core mission area, and neither is funded to develop ADR; and as a result, both are unwilling to take on an unfunded mandate. In June 2014, NASA formally adopted a policy to limit its ADR efforts to basic research and development of the technology up to, but not including, on-orbit technology demonstrations.[27]

Furthermore, the DOD has historically been very sensitive to international perceptions that it is weaponizing space, not necessarily because it does not want to do so, but because of the political impact such perceptions may have on domestic support in Congress and international support from its allies. Thus, the U.S. national security space community has strong concerns that any military-backed initiative for ADR may stimulate comparable programs by others in response or

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[24] 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

[25] 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

[26] The history of U.S. national policy on orbital debris and the lack of progress on ADR technology development can be found here: https://www.thespacereview.com/article/3361/1

[27] Reporting on the policy can be found here: http://spacenews.com/nasas-interest-in-removal-of-orbital-debris-limited-to-tech-demos/

create geopolitical complications. These concerns have shifted recently with the DOD's public declaration that space is a warfighting domain and increased focus on developing new offensive counterspace capabilities, but the same shift has also reduced the DOD's concern about orbital debris.

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. In lieu of any U.S. action on this issue, the European Space Agency has recently commissioned the world's first ADR mission to fund a Swiss company to remove a small upper stage from orbit.[28]

3.3 Space Traffic Management

The third major category of efforts to deal with orbital debris is space traffic management (STM). STM as defined by SPD-3 is the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment.

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).

As a result, most objects on a collision course in space move too fast for the human eye to see, and collisions will likely happen much faster than any human could possibly react to. Trying to develop a regime of active, real-time space traffic control of all space objects by humans is impractical. Such active management is likely only useful for objects that are conducting a planned orbital rendezvous or in proximity to a human-occupied object. Moreover, even an automated reaction to avoid a collision at the last minute is likely not feasible. The extremely

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[28] More information on the EA ClearSpace-1 mission can be found here: https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

short amount of time to react would require a massive amount of thrust to alter the spacecraft's orbit, compared to a maneuver made well before.

Instead, as shown by the earlier examples of both the Iridium-Cosmos collision and the GGSE-IRAS close approach, 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 currently 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 establish their own risk tolerance and use that as a basis for determining whether or not to maneuver their satellite to change its trajectory and avoid the conjunction. 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 orbital 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.[29] 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. For most robotic satellites, the risk tolerance for maneuvers is between 1 in 1,000 and 1 in 10,000.

The other major difference between air and space traffic is that the vast majority of space traffic has no ability to maneuver to avoid a collision. Less than five percent of the tracked space objects bigger than 10 cm are active payloads, and not all active payloads have maneuvering capability. Although the GGSE-IRAS close approach did not result in a collision, that was not a unique occurrence and there are similar events occurring all the time. LeoLabs estimated four other similarly close approaches happened around the same time as the January 29th GGSE-IRAS event. The most worrisome debris-on-debris close approaches are those involving clusters of very large spent upper stages, most of which are Russian and periodically come within 100

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

meters of colliding.[30] Each of those clusters has the same mass as the entire planned OneWeb constellation and a collision between two of them could double the size of the current cataloged orbital debris population.[31]

In addition to on-orbit close approaches, another important element of STM is the interface between orbital traffic and air traffic. In 2016, more than 250 tracked space objects, amounting to more than 50 metric tons, re-entered the Earth's atmosphere according to data provided by the DOD and NASA.[32] 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 a hazard to air traffic. Additionally, the emergence of reusable rocket stages that return to their launch pad and potential growth of sub-orbital tourism is already driving close integration between air and space traffic through efforts such as the FAA's Space Data Integrator.[33]

3.4 Space Situational Awareness (SSA)

All of the efforts to deal with the threat of orbital 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.

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[30] This assessment comes from research done by Dr. Darren McKnight on the collision risk posed by clusters of large rocket bodies. A summary of his recent work can be found here: https://spacenews.com/clusters-not-constellations-pose-biggest-orbital-debris-risk/

[31] Ibid.

[32] This information comes from a presentation by Jer-Chyi Liou from NASA to the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space on February 1, 2017, available here: http://unoosa.org/documents/pdf/copuos/stsc/2017/tech-15E.pdf

[33] More information about the Space Data Integrator can be found here: https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=23476

SSA includes multiple categories of data. The first is metric data, which are observations of space objects that are combined to determine orbital trajectories. The second category is characterization data, which are measures of size, shape, broadcast frequencies, brightness, and other data that provide information about a space object's composition and capabilities. The third category is space weather, which includes data on the interaction between the Sun and Earth's magnetosphere that impacts orbital decay and could cause anomalies in or damage to active satellites. The fourth category is the detection, tracking, and characterization of asteroids and other Near-Earth Objects (NEOs) that could pose a collision risk to the Earth.

The DOD currently has the most comprehensive SSA capability in the world.[34] 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 the U.S. Space Force's 18th Space Control Squadron (18 SPCS) at Vandenberg Air Force Base in California. The 18 SPCS maintains a catalog of space objects and uses that catalog to provide a variety of services and functions. It also makes a lower-accuracy portion of its catalog publicly available on the Internet.

The main drawback to the current DOD SSA capabilities is 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, such as the recent installation of a radar and an optical telescope in Australia[35] and the creation of the first S-Band Space Fence on Kwajalein Atoll,[36] but significant gaps in coverage, capacity, and timeliness still remain.

Over the last decade, many other countries have also increased their own interest in and capabilities for SSA. Russia still maintains the largest and most complete network of government sensors outside the U.S., but China has focused significant efforts on developing its own network. The European Union and European Space Agency have both had Space Surveillance and Tracking (SST) efforts since 2009 aimed at integrating data from multiple European sensors

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[34] 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

[35] For more information on the move of the C-Band radar see https://www.peterson.af.mil/News/Article/1114478/c-band-radar-reaches-full-operational-capability-in-australia/ For more information on the move of the Space Surveillance Telescope, see https://breakingdefense.com/2019/07/air-force-eyes-new-deep-space-sensors-in-australia-spain/

[36] The current status and operational testing report for the S-Band Space Fence can be found here: https://www.c4isrnet.com /battlefield-tech/space/2019/12/11/a-new-radar-to-track-space-objects-is-almost-ready/

and developing new ones. Individual European countries such as France, Germany, Italy, and the United Kingdom have also funded national efforts to develop SSA capabilities. Outside of Europe, Australia, Japan, India, South Korea, and the United Arab Emirates are just a few of many countries to increase their national focus on SSA over the last decade.

Another remaining challenge is the need to combine the tracking of orbital 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 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.

From a policy perspective, current U.S. national space policy emphasizes the important role SSA plays in preserving the space environment. It directs the federal government to develop, maintain, and use space situational awareness (SSA) information from commercial, civil, and national security sources to detect, identify, and attribute actions in space that are contrary to responsible use and the long-term sustainability of the space environment.[37] It states that the Secretary of Defense, in consultation with the Director of National Intelligence, the Administrator of NASA, and other departments and agencies, may collaborate with industry and foreign nations to: maintain and improve space object databases; pursue common international data standards and data integrity measures; and provide services and disseminate orbital tracking information to commercial and international entities, including predictions of space object conjunction. Current policy also identifies SSA as a key area for potential international cooperation and data sharing.

3.5 National Regulation of Private Sector Space Activities

A key part of the current changes in the space domain is the growth in number and diversity of commercial space activities. Billions of dollars in public and private capital are flowing into the commercial space sector, resulting in expanding capabilities to existing commercial space sectors, such as communications and remote sensing, as well as development of completely new capabilities such as satellite servicing, private space stations, and resource extraction and utilization. While the United States already has a national framework for providing oversight to some categories of commercial space activities, it does have significant gaps and shortcomings relative to the pace of change in the commercial sector.

There are currently three U.S. federal agencies with existing regulatory authority over non-governmental space activities. The National Oceanic and Atmospheric Administration (NOAA) under the Department of Commerce (DOC) has the authority to license non-governmental space-based remote sensing of Earth. The Federal Aviation Association (FAA) under the Department of Transportation (DOT) has licensing authority over commercial launch, re-entry or reusable

[37] The 2010 National Space Policy can be found here: https://history.nasa.gov/national_space_policy_6-28-10.pdf

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. All three of these entities include orbital debris mitigation as part of their licensing process, although there are some differences in how they do so.

There are several types of commercial space activities planned for the near future that do not clearly fall under any of these existing licensing authorities. These gaps create uncertainty that gives rise to real-world challenges for start-up companies trying to secure investors and insurers, a phenomenon many new space companies are struggling with. Providing a clear legal pathway for all commercial space companies, including those with new and innovative ideas, to secure a license would send a strong positive signal to markets and encourage more entrepreneurship. Doing so would also help bolster the leadership role the United States has traditionally played on space governance. Historically, other countries have modeled their national policy and regulation on the example provided by the United States. And as more countries acquire the capability to engage in commercial space activities, it will be important for U.S. companies to be working inside a predictable international legal framework that can encourage and protect investments.

Since 2010, both the Executive and Legislative branches have been engaged in a debate about reforming or updating these existing authorities to close these gaps. In response to a report directed by the 2015 Commercial Space Launch Competitiveness Act, the Obama Administration proposed a "mission authorization" framework that leveraged the FAA's existing Payload Review process.[38] Although legislation to enact Mission Authorization in some form has since been introduced in both the House and Senate, to date the two chambers have failed to come to agreement and enact it into law.

Putting in place a more robust national framework for oversight of private sector activities depends heavily on SSA. SSA data provides foundational data on the existing state of the space environment and how it is being impacted by expanding commercial space activities. Thus, good SSA data is a critical input to shape the norms and regulations that will apply to current and future space activities. SSA is also critical to monitoring space activities, enforcing regulatory requirements, and identifying and highlighting irresponsible actions and actors in space.

4. Recommendations for Reform on SSA and STM

Since the Iridium-Cosmos collision in 2009, the United States has reshaped its national policy on SSA. While these efforts have resulted in meaningful improvements, there is still much that needs to be done, particularly on Congressional implementation of these policy efforts in both legal authorities and budget.

[38] The report from the Office of Science and Technology Policy can be found here: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/csla_report_4-4-16_final.pdf

As discussed earlier, before the 2009 Iridium-Cosmos collision, the DOD was one of the few entities detecting close approaches between select space objects. After the collision, a policy decision was made in 2010 that directed the DOD to provide close approach warnings to all satellite operators and expand the range of data and analysis products they offer to commercial and foreign entities. This change was enshrined in the 2010 National Defense Authorization Act.

In addition to providing expanded close approach screenings, the DOD was also authorized to sign SSA data sharing agreements with commercial and foreign entities. To date, the DOD has signed data sharing agreements with Australia, Japan, Italy, Canada, France, South Korea, the United Kingdom, Germany, Israel, Spain, the United Arab Emirates, Belgium, Norway, Denmark, Brazil, the Netherlands, Thailand, New Zealand, Poland and Romania, the European Space Agency, the European Organization for the Exploitation of Meteorological Satellites, and 78 commercial satellite owners or operators.[39] While a few of these agreements involve current one-way or two-way data exchange, most establish the framework for future bilateral data exchanges.

However, reliance on the DOD for all of SSA still has its shortcomings. The DOD has struggled to provide greater transparency into its processes for creating and delivering SSA products and services as well as to upgrade its computer systems to bring in non-traditional SSA data and data from satellite owner-operators. DOD leadership also expressed concerns about the safety mission drawing resources and time away from the national security mission, which has seen renewed focus with the return of Great Power Competition from Russia and China.

Simultaneously, private sector capabilities to provide SSA data products and services have grown significantly. The Space Data Association (SDA), a non-profit organization created by three major commercial satellite operators in 2009, has grown to include most of the major GEO satellite operators and its Space Data Center (SDC) provides SDA members with a range of services. These services include augmenting the close approach warnings provided by the 18 SPCS to take into account a satellite operator's own satellite trajectories and planned maneuvers, and assistance in resolving radio frequency interference (RFI).

On the positive side, the DOD has recently implemented a significant change to its policy for withholding information about national security space objects and activities. In my 2014 testimony, I highlighted how the culture of secrecy was partly responsible for the lack of progress on improving SSA, so this change is a welcome step forward. The U.S. military has removed the "no elements available" tag for approximately 200 objects and has started releasing

[39] Details on U.S. Strategic Command's SSA Sharing Agreements can be found here: https://www.stratcom.mil/Media/News/News-Article-View/Article/1825882/100th-space-sharing-agreement-signed-romania-space-agency-joins/

orbital data for some of them, although the rollout has been slow and some of the newly released are getting very infrequent updates.[40]

Commercial SSA companies have also entered the sector over the last decade. The announcement of the Analytical Graphics, Inc. (AGI) Commercial Space Operations Center (ComSpOC) in 2014 was just the first of several major developments. Today, companies such as AGI, ExoAnalytic and LeoLabs operate independent networks of ground-based telescopes and radars, while other companies such as SpaceNav offer sophisticated mission planning and decision analysis tools. While some of these commercial offerings are better than those provided by the 18 SPCS in specific areas, no single commercial entity can yet replicate the entire 18 SPCS mission. However, it is likely that the ability of these commercial companies to maintain a catalog of space objects and provide useful close approach warnings will exceed that of the U.S. military within the next five years.

There are three unresolved public policy issues with regard to the development of the commercial SSA sector. The first is how the U.S. government engages or competes with these commercial SSA providers. To date, the U.S. government has only engaged in small, limited contracts with commercial SSA providers while spending more than $1 billion a year on government SSA programs. The lack of government purchases and widespread availability of free government-provided data and services is having a deleterious effect on the growth and sustainability of commercial SSA industry. **Existing policy guidance directing federal agencies and departments to refrain from competing with the commercial sector and to leverage commercial products and services to the maximum extent possible should be enforced for SSA.**

Greater cooperation and utilization of commercial SSA data also leads to the second unresolved policy issue – whether SSA data and services are a public good.[41] While leveraging commercial products and services can result in more innovation and lower costs, it introduces challenges on making the data or products derived from commercial data available to all stakeholders and users. Satellite operators and governments may be able to afford to purchase commercial products, but university CubeSat operators, scientists and academic researchers, non-profits and charities, and other non-commercial entities likely cannot. Moreover, keeping data locked away behind paywalls prevents widespread data pooling and analysis that could yield new insights and innovations. **The U.S. government needs to conduct an economic goods analysis of SSA data products and services and determine how to ensure all users and stakeholders have access while maximizing collaboration and innovation.** In doing so, there may be important lessons

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[40] At the time of writing, 170 of the 200 objects still did not have data, according to a list maintained by TS Kelso on the Celestrak website at https://celestrak.com/satcat/pending.php. A few of the objects for which orbital data is being released have not been updated for weeks and one for over a month.

[41] For a more in-depth economic goods analysis of SSA and the potential role of the government, see https://swfound.org/media/206172/frierson_economics_of_ssa_may2018.pdf

to be learned from the weather and remote sensing fields, which are grappling with some of the same issues.[42]

The third major public policy issue with commercial SSA is the current restrictions on on-orbit SSA. While ground-based SSA collection does not require a license, space-based SSA collection falls under remote sensing regulations. Historically, the U.S. government has prohibited any space-to-space remote sensing for national security reasons, but a policy change begun under the Obama Administration and approved by the Trump Administration now allows a limited amount of so-called "non-Earth imaging (NEI)" for U.S. commercial remote sensing licensees. However, there are still significant restrictions that hinder the development of U.S. commercial SSA capabilities for satellite inspection, anomaly resolution, and space safety that do not apply for foreign competitors.[43] **The U.S. government should ensure that only the most minimal restrictions necessary are applied to NEI in order to foster growth and innovation in commercial capabilities.**

An important consideration to keep in mind is that SSA is not something that any one entity can do entirely by itself. This is because SSA 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, governmental or private sector, 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. The key element of the hubs model is the degree of cooperation and data sharing between the hubs.

In May 2014, this subcommittee held a hearing on SSA and STM in which I was also privileged to testify. In that hearing, my main recommendation was that the civil and safety-related parts of the SSA mission be transferred away from the DOD and to a federal civil agency. This recommendation was driven by the need to improve trust and transparency in civil SSA products and services and the inability of the DOD to improve its SSA computer systems or integrate data from non-traditional sources. It would also enable the DOD to refocus its efforts on detecting and countering threats to U.S. national security space systems.

At the time, there was an on-going debate within the Obama Administration on whether to assign responsibility for the civil SSA mission to the Department of Transportation (DOT) or

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[42] See https://spacenews.com/noaa-smallsat/

[43] For a more in-depth discussion of the restrictions and their impacts, see https://swfound.org/media/206172/frierson_economics_of_ssa_may2018.pdf

Department of Commerce (DOC).[44] Each department had their strengths and weaknesses and likely could have taken on the mission. The Obama Administration was leaning towards DOT, and as part of its preparatory activities the Office of Commercial Space Transportation (AST) in the FAA initiated outside studies on how it might implement a civil SSA mission.[45] FAA/AST requested FY18 funding to begin a civil SSA pilot program,[46] which was subsequently appropriated by Congress,[47] they also received FY17 funding for an initial pilot program in partnership with the DOD.[48] However, no formal policy decision giving civil SSA responsibility to DOT was issued by the end of the Obama Administration and in December 2017 AST was directed to cease its preparatory efforts pending a policy review by the Trump Administration.

As previously mentioned, the Trump Administration did indeed conduct their own interagency policy review and published the first U.S. national policy on STM in June 2018 as SPD-3. SPD-3 is very thorough and covers many of the issues addressed in the holistic picture of space sustainability outlined earlier, including updating orbital debris mitigation standards, advancing SSA and STM technology, and developing best practices, norms of behavior, and standards to enhance the safety of space activities. Much of what is in SPD-3 is non-partisan and stems from the preparatory work previously done by the Obama Administration.

The biggest policy change made by SPD-3 is to task DOC, instead of DOT, with responsibility for civil SSA and STM. Under SPD-3, DOC would assume greater authority for licensing and oversight of private sector space activities to address the aforementioned gap in existing authorities between NOAA, the FAA, and FCC. DOC would also assume responsibility for providing the civil and safety-related SSA products and services currently provided by the DOD and develop enhanced future capabilities by fusing data from commercial, scientific, and international sources. As part of this implementation, the Trump Administration has asked Congress to elevate the NOAA Office of Space Commerce (OSC) to become the Bureau of Space Commerce and increase its budget to $10 million annually.

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[44] More details on the Obama Administration's interagency process on STM can be found in Chapter 7 of my Ph.D. Dissertation: https://cpb-us-e1.wpmucdn.com/blogs.gwu.edu/dist/7/314/files/2018/03/Weeden-Dissertation-Final-11Jan2017-1p9swcp.pdf

[45] A study done by the Science and Technology Policy Institute on how DOT might establish civil SSA and STM capabilities, including leveraging commercial capabilities, can be found here: https://www.ida.org/-/media/feature/publications/e/ev/evaluating-options-for-civil-space-situational-awareness-ssa/p-8038.ashx

[46] The funding for the civil SSA pilot program was included on pg. 110 of the DOT's FY18 budget request found here: https://cms8.dot.gov/sites/dot.gov/files/docs/mission/budget/281191/faa-fy-2018-cj-final.pdf

[47] Appropriations for the DOT civil SSA pilot program were included in the 2018 Consolidated Appropriations Act, which can be found here: https://www.congress.gov/bill/115th-congress/house-bill/1625/text

[48] A discussion of the DOD's participation in the DOT civil SSA pilot program can be found on pg. 4 of Lt.Gen Buck's testimony before the House Subcommittee on Strategic Forces in May 2017: https://docs.house.gov/meetings/AS/AS29/20170519/105974/HHRG-115-AS29-Wstate-BuckD-20170519.pdf

While DOC, and OSC specifically, has taken some steps in this direction, most of the changes directed by SPD-3 have not yet been implemented due to lack of changes to their authorities and appropriations by Congress. DOC and OSC have initiated RFIs to determine what commercial SSA capabilities are available, organized reviews of existing space-related standards and norms, and established a landing team to begin coordination with the 18 SPCS. However, the full suite of actions directed by SPD-3 require a change to OSC's authorities and increased budget, steps that only Congress can take.

During the previous 115th Congress, both the House and Senate addressed the SSA issues through legislation, although in contradictory fashion. In June 2018, the House Committee on Science, Space, and Technology introduced the American Space SAFE Management Act that largely would have implemented everything in SPD-3,[49] while in July 2018 the Senate Committee on Commerce, Science, and Transportation introduced the Space Frontier Act that would have reinforced the role of FAA/AST in oversight of new and emerging space activities via a concept called mission authorization.[50] The Senate was silent on SSA authorities, reportedly out of a desire to not go against White House policy, but there are indications they favored that mission going to FAA/AST as well. Neither effort passed both chambers to become law.

During the current Congress, the Senate Committee on Commerce, Science, and Transportation has reintroduced the Space Frontier Act of 2019, which would elevate OSC to a Bureau of Space Commerce and provide it some additional authority, but is silent on SSA.[51] OSC also received a small budget increase to $2.3 million in FY20, instead of the $10 million they requested.[52]

I urge Congress to implement either the Administration's proposal under SPD-3 or an alternative solution as soon as possible. The swiftest solution would be to implement SPD-3 and give the necessary authorities and budget to OSC while elevating it to the Bureau of Space Commerce. This is the quickest path to improving U.S. civil SSA capabilities and laying the foundation for a future STM regime.

However, if a direct implementation of SPD-3 is impossible, the next best solution would be to implement a compromise that splits responsibilities between DOC and DOT, as I outlined in an

[49] Text of the 2018 American Space SAFE Management Act introduced in the House can be found here: https://www.congress.gov/bill/115th-congress/house-bill/6226

[50] Text of the 2018 Space Frontier Act introduced in the Senate can be found here: https://www.congress.gov/bill/115th-congress/senate-bill/3277

[51] Text of the 2019 Space Frontier Act introduced in the Senate can be found here: https://www.congress.gov/bill/116th-congress/senate-bill/919

[52] https://www.appropriations.senate.gov/imo/media/doc/HR%201158%20-%20SOM%20FY20.pdf

op-ed in March 2019.[53] Creating a Bureau of Space Commerce that is the lead agency for promoting commercial space and advocating for industry within the government is an excellent idea. But to bridge the divide, I propose giving responsibility for providing civil SSA data and services, creating safety standards for on-orbit space activities, and managing the air-space traffic interface to the DOT. Doing so would also make it easier to address the concerns over how the rapid increase in commercial space launches may cause disruptions to commercial aviation. These responsibilities should be given to a new Bureau of Space Transportation within DOT, created by elevating AST out of the FAA. Creating a separate bureau allows for a stronger focus on space, better resourcing, and more independence from the FAA and their overwhelming focus on aviation.

I believe there is also a role for NASA to play in leading the research and development of new technologies to improve SSA. While the commercial sector is already innovating to a certain degree, there is still a strong need for research into future technologies to improve SSA and tackle emerging challenges such as large constellations, tracking and identification of CubeSats, and increasing the accuracy of conjunction assessments. NASA's efforts in this area should not be aimed at developing or operating new government capabilities, but rather in enhancing and enabling technological development that can be deployed by the private sector.

A related and important policy issue is assigning authority for space environmental management in order to incent progress on remediation. This is necessary because even with the policy changes directed by SPD-3, there is no federal agency or department that has managing the space environment, including orbital debris removal, as part of its mission. As discussed earlier, this is a critical prerequisite to making progress on implementing the policy directive to create such a capability and begin to remove existing orbital debris. As with STM authority, there are multiple options for where this authority should go and no single agency or department stands out as the overwhelming favorite. DOT, DOC, and NASA are all potential options and the choice will likely depend on how the broader compromise for STM and mission authorization plays out.

The main hurdle to overcome in Congressional action on this issue is the disparate committees and subcommittees with jurisdiction. At the moment, there are at least ten Congressional committees and subcommittees that have at least partial jurisdiction over the various civil, commercial, national security, authorization, and appropriations aspects of these issues. There is no easy solution to this problem, other than to suggest the professional staff of these various committees begin consultations to establish a common understanding of the importance of SSA and STM that could lead to coordinated legislation.

[53] https://www.thespacereview.com/article/3673/1

5. Conclusion

It is critical that Congress act on this issue now. SSA is fundamental to everything the United States does in space, and the benefits derived from such activities. This includes protecting human exploration and science, ensuring critical weather and climate data, protecting important national security capabilities, and enabling economic growth and innovation in the commercial space sector.

The huge amount of change the space domain is currently experiencing across civil, commercial, and national security sectors only adds to the salience and timeliness of this issue. Current SSA capabilities were being stretched six years ago; today they are dangerously insufficient to deal with the emerging challenges from the growing number of space actors, large constellations, orbital debris hazards, and a more complex and competitive geopolitical environment.

Action from Congress should focus on implementing a federal civil SSA agency that has the required regulatory authorities and is appropriately resourced. That agency should be tasked to leverage commercial and international capabilities to build a civil SSA system that can meet the safety challenges of today and lay the foundation for the STM regime of tomorrow. Doing so will take a giant step toward ensuring the long-term sustainability of space activities for the United States and all space actors, and that humanity can continue to utilize space for benefits on Earth.

Biography for Dr. Brian Weeden

Dr. Brian Weeden is the Director of Program Planning for Secure World Foundation and has nearly two decades of professional experience in space operations and policy.

Dr. Weeden directs strategic planning for future-year projects to meet the Foundation's goals and objectives, and conducts research on space debris, global space situational awareness, space traffic management, protection of space assets, and space governance. Dr. Weeden also organizes national and international workshops to increase awareness of and facilitate dialogue on space security, stability, and sustainability topics. He is a member and former Chair of the World Economic Forum's Global Future Council on Space Technologies, a member of the Advisory Committee on Commercial Remote Sensing (ACCRES) to the National Oceanic and Atmospheric Administration (NOAA), and the Executive Director of the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS).

Prior to joining SWF, Dr. 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), Dr. Weeden directed the orbital analyst training program and developed tactics, techniques and procedures for improving space situational awareness.

Respected and recognized as an international expert, Dr. 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. Read Dr. Weeden's publications.

Dr. 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 has a PhD in Public Policy and Public Administration from George Washington University in the field of Science and Technology Policy.

Chairwoman HORN. Thank you, Dr. Weeden. Mr.—I'm going to get it right—Oltrogge. Thank you. I will have it down, because I've got Professor Gabrynowicz, so next time you're here, I'm going to have it down pat. You're recognized.

TESTIMONY OF Mr. DANIEL OLTROGGE, AIAA SPACE TRAFFIC MANAGEMENT SPACE GOVERNANCE TASK FORCE CHAIR, FOUNDER AND ADMINISTRATOR SPACE SAFETY COALITION, OFFICIAL INTERNATIONAL STANDARDS ORGANIZATION (ISO) REPRESENTATIVE TO THE UNITED NATIONS COMMITTEE FOR THE PEACEFUL USE OF OUTER SPACE (UNCOPUOS)

Mr. OLTROGGE. Madam Chair Horn—Chairwoman Horn, Ranking Member Babin, and distinguished Members of the Subcommittee, thank you for the opportunity to testify today on space situational awareness, or SSA, and space traffic management, or STM. Responsible SSA and STM are essential to maintaining the long-term sustainability of space activities, space governance, and national security.

Why are we here today? It's because the many benefits we derive from space, and the welfare of our astronauts, spacecraft, and commercial space industry are all on the line. Today's U.S. flight safety capabilities are insufficient. They produce too many false alarms to be considered decision quality, and the vast majority of lethal objects remain untracked. New capabilities are set to track these small objects, substantially increasing the number of collision warnings. In addition, the U.S. commercial space industry has filed applications for 58,000 new spacecraft into orbit in the next 10 years, 15 times more than any other country, and eight times more than all other countries combined. The U.S. is all in on the bow wave of large constellation initiatives, an investment that will lead to socioeconomic and technological progress in agriculture, banking, navigation, communications, and Earth remote sensing. So we must ensure the sustainability of space as a vital resource.

There are many definitions for SSA and STM, as described in my written testimony. For this session, I will use these definitions shown. SSA and STM can help avert situations like the near collision of two dead spacecraft last month, which could've produced 12,000 new pieces of space debris. We need to make such headlines go away. Such a large-scale collision would reverberate through our burgeoning $1 trillion to $3 trillion space economy, sowing uncertainty and damaging growth.

Left unchecked, the situation may worsen to a cycle of cascading collisions known as the Kessler Syndrome, rendering the use of space unsustainable. If we surpass this ecological threshold, there is no return. We've been lucky so far, but the clock is ticking.

SSA helps lower collision risks. Observing space objects, fusing data, and solving orbits, and detecting and characterizing collision threats enable spacecraft operators to mitigate the threat.

Today's congested environment challenges operators to understand which conjunctions are too close. The number of false alarms and missed alerts is overwhelming spacecraft operators to the point that they sometimes ignore the warning and go home, wondering if they will have a job the next day—true story. The number of objects in space requiring tracking is increasing, a trend spurred by the disastrous Chinese ASAT tests in 2007, and the Iridium-Cosmos collision in 2009.

Today we're only tracking an estimate 4 percent of space debris that can terminate a spacecraft mission. This, along with outdated space tracking algorithms, resulting inaccuracies, insufficient quality control, and a lack of transparency degrade flight safety.

You may be familiar with the space debris situation through the enthralling, but inaccurate, movie "Gravity." Like the film, the depiction at the upper right seems to indicate that spacecraft cannot possibly survive. In actuality, the density of space debris does continue to increase, presenting significant challenges to space sustainability.

I've described our legacy of space debris that New Space large constellations now inherit, and need to operate in. Applications have now been filed to build, launch, and operate over 58,000 more spacecraft within the next 10 years alone. While acknowledging that only a portion of these applications will yield operational spacecraft, we can still expect the active spacecraft population to become four to ten times larger within the next decade. This year alone, the active space population is on track to double. As depicted here, large constellations will experience millions of close approaches, requiring thousands of avoidance maneuvers.

You can think of SSA as a functional chain. The collective performance of this entire chain determines the actionability of the SSA information. The old adage that a chain is no stronger than its weakest link was in play in the 2009 Iridium-Cosmos collision, where a planned maneuver was missed, resulting in a miscalculated collision risk more than a trillion, trillion, trillion off.

These are the basic qualities of viable SSA and STM systems. Paired with advanced astrodynamics algorithms, actionable notifications of impending threats can be provided.

In closing, U.S. SSA and STM services are failing to address global needs at the same time as the commercial space sector is experiencing explosive growth. The lack of a cohesive, properly resourced U.S. Space Traffic Management Program places the U.S. at risk of losing this vital initiative to other countries. To avert this, I recommend that you work together to take the six actions listed here. These actions cannot be accomplished without the full support of Congress. The long-term sustainability of the space environment, the rich set of socioeconomic benefits of operating in space, and the success of the U.S. commercial space industry are all at risk. The time for action is now. Thank you for your attention.

[The prepared statement of Mr. Oltrogge follows:]

Hearing of the Committee on Science, Space, and Technology
U.S. House of Representatives
"Space Situational Awareness: Key Issues in an Evolving Landscape"
Tuesday, 11 February 2020, 2 PM
Testimony of Mr. Daniel Oltrogge
Founder and Administrator, Space Safety Coalition
AIAA STM Space Governance Task Force Chairman
ISO representative to United Nations COPUOS

"*The price of light is less than the cost of darkness*" - Arthur C. Nielsen

1 Introduction to SSA and STM

Madame Chair, distinguished members of this subcommittee, thank you for the opportunity to testify today on Space Situational Awareness (SSA) and Space Traffic Management (STM). My goal is to provide you with an understanding of these foundational enablers to our national security, space governance, and the long-term sustainability of space activities. Today, these goals are being challenged as never before by recent improvements in our knowledge and tracking of debris in space, concurrent with the dramatic increase in the composition, quantity, and complexity of active spacecraft as the "New Space" large constellation era dawns.

In this testimony, I will define SSA and STM and provide a basic building blocks of SSA and STM, including space object tracking, algorithms, close approach assessment, and spacecraft operator decision making. I will then put these in the context of our current and future debris situation and risk profile, particularly focusing on SSA and STM challenges from policy, finance, operations, technical and international engagement perspectives. Finally, I will explore how these challenges impede effective flight safety necessary for the long-term sustainability of space activities (LTS) and provide a list of attributes that an SSA and STM system should have.

2 Defining SSA and STM – What are they?

There are many definitions of SSA and STM. It should not be a surprise that such differences exist, as they stem primarily from the many roles and responsibilities of the people using them. Commercial operators, regulators and national security experts have different SSA requirements and priorities. SSA can be used to avoid collisions, evaluate space and ground capabilities, protect national security, and detect, identify, and attribute actions in space that are contrary to responsible use and the long-term sustainability of the space environment[1].

2.1 Space Situational Awareness

Space Situational Awareness could simply be defined as being aware of one's situation in space. But there is a plethora of SSA definitions in the global space community.

A more inclusive definition is "Comprehensive knowledge and understanding of the space and terrestrial environment, factors, and conditions, to include the status of other space objects, radio emissions from ground and/or space transmitters, and terrestrial and space weather, that enables timely, relevant, decision-quality and accurate assessments, in order to successfully protect space assets and properly execute the function(s) for which a satellite is designed." [2]

While not an exhaustive list, these and other SSA definitions may be characterized as shown in ***Figure 1***.

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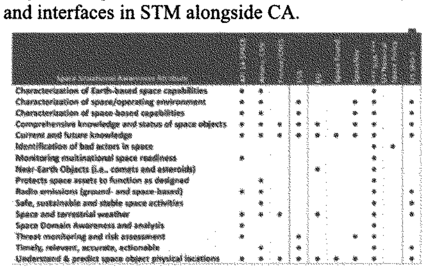
[1] National Space Policy of the United States of America, 28 June 2010.
[2] Alfano, S., Center for Space Standards and Innovation, 2018.

These definitions are very different from each other. While this is an unavoidable outcome of the different perspectives, priorities and missions each organization has, we need to be careful to specify which particular definition we are working with. Although not the most comprehensive definition, for the purposes of this testimony I will adopt the definition set forth in Space Policy Directive 3: "Space Situational Awareness shall mean the knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities."

Note that the Air Force in November 2019 transitioned all of its space organizations over to the term "Space Domain Awareness" (SDA). In defense circles, SDA represents not only the catalog maintenance aspect of some of the narrower SSA definitions, but it also refers to the identification, characterization and understanding of any factor, passive or active, associated with the space domain that could affect space operations and thereby impact the security, safety, economy or environment of our nation. As such, SDA is an inclusive term that aligns well with some of the more comprehensive SSA definitions previously defined.

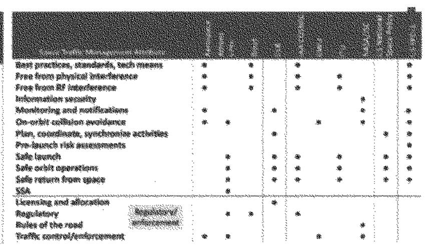
2.2 Space Traffic Management (STM)

Having basic Space Situational Awareness, by itself, is insufficient. To meet their needs, space operators and state actors have realized that they need Space Traffic Management (STM) services. One of the earlier definitions[3,4] of STM was developed in 2006 : "Space Traffic Management (STM) is the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference (RFI)." Note that this definition expressly includes both technical and regulatory aspects, and it encompasses more than just Conjunction Assessment (CA) services. A number of large GEO operators favor this definition, because they have significant concerns about RFI, and they seek forensic and predictive RFI analysis capabilities and interfaces in STM alongside CA.



Characterization of Earth-based space capabilities	*	*						*		
Characterization of space/operating environment	*	*		*			*	*		*
Characterization of space-based capabilities	*	*		*			*	*		*
Comprehensive knowledge and status of space objects	*	*	*	*	*		*	*		*
Current and future knowledge	*	*	*	*	*	*	*	*		*
Identification of bad actors in space								*	*	
Monitoring multinational space readiness	*							*		
Near-Earth Objects (i.e., comets and asteroids)					*			*		
Protects space assets to function as designed		*						*		
Radio emissions (ground- and space-based)	*	*						*		*
Safe, sustainable and stable space activities		*						*		*
Space and terrestrial weather	*	*	*		*			*		*
Space Domain Awareness and analysis	*							*		
Threat monitoring and risk assessment	*			*			*	*		
Timely, relevant, accurate, actionable		*		*				*		*
Understand & predict space object physical locations	*	*	*	*	*	*	*	*		*

Figure 1 Comparison of SSA attribute definitions by source



Best practices, standards, tech means		*		*		*					*
Free from physical interference		*		*		*		*			*
Free from RF interference		*		*		*		*			*
Information security									*		
Monitoring and notifications		*			*				*		*
On-orbit collision avoidance		*	*				*		*		*
Plan, coordinate, synchronize activities					*					*	*
Pre-launch risk assessments											*
Safe launch			*		*	*		*		*	*
Safe orbit operations			*		*	*		*		*	*
Safe return from space			*		*	*		*		*	*
SSA			*								
Licensing and allocation	Regulatory/ enforcement				*						
Regulatory			*	*		*					
Rules of the road									*		
Traffic control/enforcement		*	*				*		*		

Figure 2 Comparison of STM attribute definitions by source.

STM definitions may be characterized as shown in ***Figure 2***, with many of these discussed in detail in literature [5, 6]. For the purposes of this testimony I will adopt the definition set forth in Space Policy Directive 3: "Space Traffic Management shall mean the planning, coordination, and on-orbit

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[3] Schrogl, K.U., Jorgenson, C. ,Robinson, J., and Soucek, A., "The IAA Cosmic Study on Space Traffic Management.

[4] Stelmakh-Drescher, O., "Space Situational Awareness and Space Traffic Management: Towards Their Comprehensive Paradigm," Space Traffic Management Conference, Embry-Riddle Aeronautical University, 17 November.

[5] European Space Policy Institute, "ESPI Report 71: Towards a European Approach to Space Traffic Management," ISSN: 2218-0931 (print) • 2076-6688 (online), January 2020.

[6] Oltrogge, D., Johnson, T. and D'Uva, A.R., "Sample Evaluation Criteria for Space Traffic Management Systems," 1st IAA Conference on Space Situational Awareness (ICSSA), 13-15 November 2017, Orlando, FL, USA.

synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment."

While several STM definitions include important regulatory aspects of orbital debris mitigation, none currently specify "Turn left" or "Turn right," as some authors infer. Rather than directing traffic, the potentially more relevant word is "coordination" – that is, helping coordinate between operators what the risk is and allowing each pair of operators to determine whom best to perform an avoidance maneuver if/when necessary. The terms "oversight" and "control" typically denote observing, cataloguing, attributing and monitoring space objects and monitoring compliance. As a result, the well-used term Space Traffic Management, referring to the current collision avoidance process, might have been more accurately termed Space Traffic Coordination (STC).

In summary, it is important to understand that SSA and STM are <u>not</u> universally defined; at times SSA and STM definitions may be short-sighted and/or narrowly understood to be tracking space objects so that collisions can be averted. The broader, more balanced and visionary definitions include space weather and RF interference and characterization of capabilities.

3 Status of the space debris environment

The movie Gravity was enthralling, if not a bit Hollywoodish. The depiction in ***Figure 3*** would have one believe that in this specific orbit plane, spacecraft simply cannot survive. This is false and misleading. Perhaps you can even find the car tire a colleague inserted?

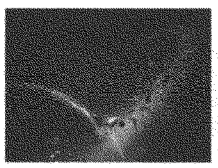

Figure 3 Overstated space debris (source: Adobe)

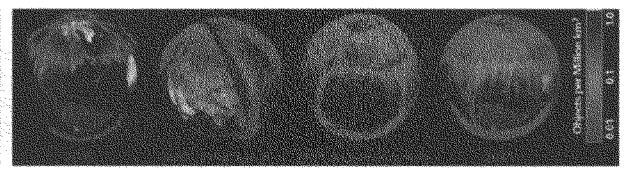

Figure 4 Comparison of STM attribute definitions by source.

Conversely, the consequences of collisions to the space environment can be quite severe. The density of objects in space has been increasing, largely due to collisions and explosions in space. This depiction in ***Figure 4*** is based on publicly-tracked objects, and we know there are many more that we cannot track today. While the sky is not falling yet, the increase by a factor of one hundred in ten short years[7] of the number of fragments in certain orbit regimes is noteworthy and must be addressed.

Overstating a risk can be harmful too, in that people tend to tune out exaggerations. After all, we operate every day in space, and we don't see collisions in space regularly occur.

Or do we? Matter of fact, collisions have occurred in both Low Earth Orbit, or LEO, and geosynchronous, or GEO, orbit regimes. Two of the most serious collisions were the intentional Chinese anti-satellite intercept of the Feng Yun spacecraft in 2007 and the accidental Iridium/Cosmos collision of 2009, as shown by the red banding in the middle two pictures of ***Figure 4***. Operators have announced periodic spacecraft collisions with debris that is too small to be tracked. And Russia reports that in 2019, there

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[7] Oltrogge, D.L. and Alfano, S., "Collision Risk in Low Earth Orbit," IAC-16, A6,2,1,x32763, 67th International Astronautical Congress, Guadalajara, Mexico, 26-30 September 2016.

were 63 violations of the 4 km warning radius used for the International Space Station[8]. While such collisions are troubling as potential mission-terminating events, the real concern is that we are approaching a condition known as the Kessler Syndrome.

We are not there yet. But the Kessler Syndrome is the very real possibility that eventually, enough debris could be in orbit that when two massive objects hit each other, large fragments are generated of sufficient mass and quantity that those fragments in turn collide with other substantial spacecraft or rocket bodies, which in turn produce the next ("cascading") generation of fragments of sufficient mass and quantity that a chain reaction begins. This can also be referred to as an "ecological threshold," which is the point at which a relatively small change or disturbance in external conditions causes a rapid change in an ecosystem. When an ecological threshold has been passed, the ecosystem may no longer be able to return to its state by means of its inherent resilience. Let's emphasize those words: Once the ecological threshold has been passed, we cannot return.

We do have recurring approaches between large objects in space. We've been relatively lucky so far. But we need to take steps to address the 60-year legacy of debris introduction and lack of properly venting energy sources to prevent dead spacecraft from exploding. The clock is ticking.

4 Current space operations challenges affecting SSA and long-term sustainability

The foundational aspect required to do STM is accurate, comprehensive, timely SSA. Yet few appreciate the many moving parts required to obtain such SSA. As shown in ***Figure 5***, major sections of the SSA chain include the SSA system itself, the sensors that observe the space situation, the data pooling and fusion engine, SSA analytical and algorithmic foundation, all of the data associated with space objects, the orbit determination and prediction tools, and Radio Frequency Interference (RFI) tools. These major components provide the underpinning of SSA, STM and regulatory approaches.

The disconcerting thing is that a failure in any one of the many links in this chain can lead to invalid SSA. This was the case in the Iridium/COSMOS collision that occurred in 2009, where a single stationkeeping maneuver failed to be incorporated into the SSA. The result was that the estimated probability of collision skyrocketed from less than one in one trillion-trillion-trillion to 1.0 (when they hit).

Having led the development of our country's first probability-based Launch Collision Avoidance (LCOLA) system in 1996, I know just how difficult it is to assemble all of the links of this SSA chain. Yet having done so, it can be easy to focus on that achievement, rather than a continual focus on ensuring that its inputs, algorithms, and data products are of sufficient accuracy and completeness to support decisionmakers. Many of our current SSA processes do not have any, or any effective, quality control mechanisms, and it is too easy to just assume that the process works fine.

Although some advocate for global SSA and STM services[9] (typically based upon the International Civil Aviation Organization (ICAO) model for air traffic control), there historically have been only a handful of nation states that have had the resources, technical means and global reach to effectively maintain Space Situational Awareness (SSA). Legacy provision of SSA and STM services have typically been provided by the United States government. But increasingly, foreign governments and commercial SSA and STM providers are stepping up to provide enhanced SSA and STM services.

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[8] Russian presentation to the 57th Session of the Scientific and Technical Subcommittee, United Nations Committee for the Peaceful Use of Outer Space, Vienna, 4 February 2020.

[9] LtCol. Smitham, M.C., USAF, "The Need for a Global Space-Traffic-Control Service: An Opportunity for US Leadership," Maxwell Paper No. 57, http://www.au.af.mil/au/awc/awcgate/maxwell/mp57.pdf

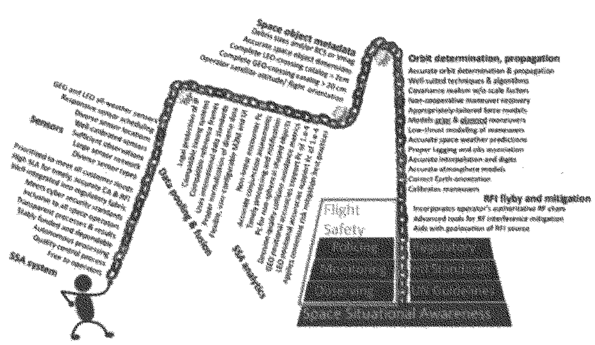


Figure 5 All the components of a comprehensive SSA and STM system

5 Who provides SSA and STM services?

In truth, it is a stretch to assert that anyone provides STM services today, as no one manages, controls or directs operators' spacecraft. But SSA and Space Traffic Coordination (STC) are available today through U.S. domestic and foreign entities as well as the global commercial marketplace.

5.1 U.S. legacy SSA and STC services

While Space Traffic Management is actually not being done anywhere, SSA and STC services have long been provided free of charge to the spacecraft operator community by the U.S. Joint Space Operations Control Squadron (JSpOC) and the 18th Space Control Squadron (18SPCS). Based on the Space Surveillance Network (***Figure 6*** and example radar in ***Figure 7***), the Department of Defense does a laudable job of providing these U.S.-provided SSA Sharing services, to include obtaining the necessary Congressional authority, instituting the requisite operational procedures, and building and maintaining partnerships with various foreign government and commercial entities. The DoD should be commended for its foresight and understanding of the need to support spaceflight for the sustainability of space operations, as well as its diligence in establishing a paradigm for SSA sharing.

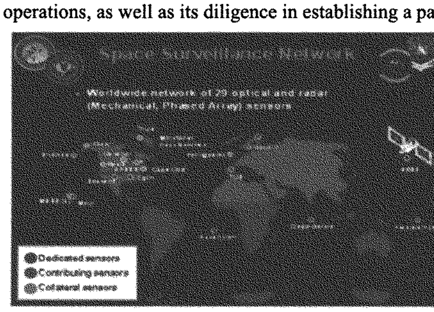


Figure 6 Space Surveillance Network configuration

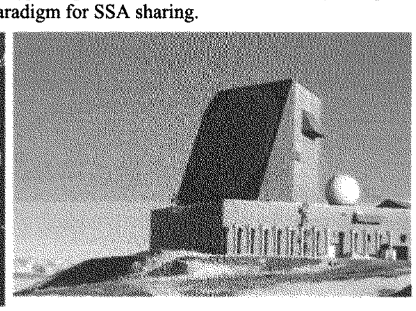


Figure 7 U.S. radar in Thule, Greenland.

However, as acknowledged by the JSpOC, these assessments are intended as a "heads-up" of upcoming potential collision threats rather than a conjunction characterization suitable for collision avoidance decision authorities. Today's U.S.-provided legacy capabilities, as realized in the SSA Data Sharing agreements and instantiated in the results on space-track.org, can be challenged to generate the necessary, operationally-relevant, decision-quality information (accuracy, timeliness/responsiveness, capacity, unambiguity, etc.) demanded by today's space operational environment.

This is no fault of the men and women in uniform performing this duty. Rather, the problem lies with the tools they are provided with, which, simply put, were designed for a different space operational environment 40-50 years ago, back when space was not considered a warfighting domain, and operators had a "space is big" mentality (i.e., with relatively few on-orbit objects, collision risk was acceptably small). These tools fulfilled their requirements for the period of their design, which in the early stage of the space age was simply to be able to "maintain custody" (i.e., reacquire) space objects. But in today's dramatically evolved space operational environment, these legacy tools cannot achieve the SSA performance levels necessary to meet the demands of spaceflight safety and the STM to support it.

Space previously was not considered a warfighting domain. It is now. The U.S. has gone to great lengths – establishing a new branch of the armed services and a new unified command, U.S. Space Force and U.S. Space Command, respectively – to manage space as a warfighting domain. U.S. Space Command (formerly U.S. Strategic Command) has openly voiced a position that SSA sharing and the provision of spaceflight safety services should migrate out of the DoD, to allow warfighter to focus resources on national security issues.

While the Department of Defense (DoD) has provided a commendable public service in standing up and operating the free collision warning service, growing national security space concerns and the increasingly complex space operational environment have rendered the status quo less useful. Today's USG-provided service does not produce the necessary accuracy or realistic covariance to generate decision-quality information; and it cannot respond to rapidly changing/evolving situations, process/fuse all necessary data, or provide sufficient transparency and availability for widespread international adoption. The resulting high false positive alarm rate is not actionable and, combined with the factors above, causes operators to minimize their concern in response to received warnings. The "free" service does have a cost – namely, excessive risk acceptance and a chilling overhang on U.S. Space 2.0 leadership.

Additionally, although total collision risk across the entire space population is significant (and about to substantially increase with the introduction of LEO large constellations), collision risks may be small to an individual satellite operator. Given financial, anti-regulation, cultural and/or optics concerns, satellite operators often underestimate the risks and overstate their measures taken to address them. Similar to other tragedy-of-the-commons situations, it would be understandable if an operator's economic business model simply did not account for "worrying about the effects to the environment". Indeed, decreasing satellite manufacturing costs from mass production and miniaturization may already preclude "natural" market forces from motivating operators to protect the shared satellite operations environment. From a purely financial perspective, an operator may be willing to risk losing a satellite to a collision, especially for large constellations with multiple redundancies and quick re-launch/refurbish capabilities or small/non-economic (e.g., academic) operators.

These considerations, coupled with a lingering false sense by some that "space is big," leads some satellite operators to unilaterally accept their collision risk on behalf of the entire space community. They may rely on the inadequate, free legacy services to justify collisions – after all, how can a USG-provided service be insufficient? Yet collisions, once they occur, are irreversible and can have long-term, costly effects on the rest of the space operator community, potentially degrading the operational environment of the global space economy.

As a practical matter, only the United States afforded operators access to public data. The dearth of alternative SSA systems led operators to accept this freely-available public space data as the best they could do, and the existence of a process based solely upon this limited data convinced many operators that this single solution was "good enough," lulling them into a false sense of security.

5.2 Other global SSA and STC providers

Many other countries operate SSA systems, but their products are not as widely distributed. Russia has a system that is similar to the SSN, but covering different regions of space. The International Scientific Observation Network (ISON) of telescopes provides a detailed catalogue of objects in geostationary orbit. France has limited capability in LEO with the GRAVES system and in GEO with TAROT-Telescopes. Some other devoted or collateral tracking radars (e.g. SATAM, ARMOR 1&2 and NORMANDIE) are used to provide value-added services. Germany employs the TIRA sensor (Tracking and Imaging Radar) for the observation of space objects as well as for the characterization of the small particle debris environment in low Earth orbit.

More recently, there has been a concerted effort in a number of countries to build and assemble a stand-alone Space Surveillance and Tracking (SST) system. Most notable is the European Union's EU SST system.

5.3 Defining the commercial SSA and STM option

More recently, a favorable combination of increased capacities, capabilities and performance at lower cost has enabled a number of competing commercial SSA system alternatives to emerge. Already, several SSA entities are fully operational (Technology Readiness Level 9) and offer comprehensive SSA data and services to the space operator community. It can be difficult on the surface to distinguish which of these entities are capable of meeting a space operator's stringent operational needs. Space operators typically are looking for a well-vetted, transparent, fully-operational SSA system with high availability, advanced algorithms, automated processing, a secure and trusted computational framework and assured availability.

Similar to trends in reusable launch, active debris removal, remote sensing and communications, commercial ventures anticipate SSA needs and accept development risk up front, leveraging modern computing techniques, algorithms and technology to deliver, and currently operate, new, innovative, SSA capabilities that meet the challenges of today's space operational environment. For instance, commercial enterprises, leveraging affordable, but more advanced, technology for ground-based sensors, have installed several 100 sensors globally – far exceeding the numbers of sensors maintained by national governments; by contrast, there are fewer than 20 ground-based sensor sites in the U.S. Space Force's Space Surveillance Network.

Commercial companies establish a cycle of innovation to promote/support continual improvements, thus motivating the commercial marketplace to seek their services. Leveraging cost effectiveness thru commercial approaches makes for affordable investment in efforts/programs that are standing up/modernizing SSA capabilities. It is precisely this cost effectiveness which is allowing countries who have formerly not been involved in SSA (e.g. New Zealand) to make a rapid transition to providing a capable service.

Unfortunately, the burden of significant legacy infrastructure and acquisition processes/culture has made it difficult for the U.S. DoD to employ commercial approaches to modernize its SSA capabilities. The U.S. Air Force has spent over $3B dollars over the last 30 years in failed attempts to modernize its space C2 (including SSA) infrastructure; it is still using decades old technology.

5.4 Emergence of SSA and STM commercial service providers

The commercial community's involvement in SSA began in 1985, when Dr. T.S. Kelso creating the first public space data portal, CelesTrak. The Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES) online conjunction assessment tool was added to CelesTrak in 2004. Originally based on USAF's lower-precision orbit theory (SGP) for all space objects, SOCRATES was upgraded in 2008 to directly ingest highly-accurate operator-predicted spacecraft positional information that incorporated their planned spacecraft maneuvers.

SOCRATES then led to the space operator community's self-formed the Space Data Association in 2009 to provide safety-of-flight services to the global space operator community, and today 29 operators participate in the SDA, collectively flying 780 spacecraft spanning in all orbital regimes. The cloud-hosted SDC provides geographic diversity, military-grade computational security, a robust legal framework, very high availability, ongoing forensics, data quality checks and comparative SSA analyses. The SDC has also evolved to be one of the largest clearinghouses for spacecraft operator data.

More recently, as many as 14 global SSA service providers have been formed, with about half of them being U.S. companies.

5.5 Comparison of U.S., Rest of World (RoW) and Commercial public safety of flight initiatives

It can be interesting to compare some of the interesting SSA and STM activities transparently being accomplished and provided by several countries and companies (***Figure 8***). Far from complete, the intent of this is just to portray that the international community is quite active in SSA and STM.

Aspect	RoW	U.S.	Commercial
Object dimensions and mass database	ESA DISCOS		
24x7 astrodynamics [10] support	EU SST	18SPCS	ComSpOC[11]
Data pooling construct (e.g. OADR)		Space-Trak.org Unified Data Library	Space Data Association
Machine Learning flight safety	CREAM		
Covariance realism	2D Scale factors		ComSpOC
Computational and Legal framework to protect from data misuse			Space Data Association
Data-agnostic fusion			ComSpOC

Figure 8 Comparison of some publicly announced SSA and STM activities internationally

6 How are conjunctions assessed?

Potential collision threats are identified by the SSA system as shown in ***Figure 9***. The SSA systems aggregate network of sensors tracks all objects that it can. The measurements, or "observations," of each space object are sent to an association and orbit determination (OD) processing engine. Advanced OD systems can also directly ingest the operator's planned maneuvers if provided; if not provided, the SSA system can also detect, characterize and account for any maneuvers that were performed.

Automated OD analytics solve the orbits of all tracked objects, providing the predicted positional information accompanied by error metrics and space object metadata to the conjunction assessment

[10] Aerospace engineer with university-level astrodynamics course and/or 5 years space operations support.
[11] As required by customer.

process, which determines when any of the tracked objects come sufficiently close to exceed an operator's warning threshold.

There are many different types of warning thresholds, ranging from straightforward (predicted miss distance) to somewhat complex collision probability assuming spherical objects to quite complex (three-dimensional representations of spacecraft approaching each other in a "bent" or non-linear manner). The type of threshold the operator adopts may be driven by crew resources, available data, and the orbit regime their spacecraft occupies.

In many cases, the SSA data required to evaluate such complex metrics is simply unavailable. Specifically, space object dimensions or overall length, flight attitude rules, and realistic error metrics for supplied SSA positional predictions are largely unavailable. Unfortunately, the operators' avoidance maneuver go/no-go criteria require these inputs and are typically quite sensitive to any errors in them. Many SSA systems today make assumptions on values for these parameters without sharing that vital information with the spacecraft operator.

Once a conjunction is identified, the operator then works with the SSA and/or STM service provider to determine if an avoidance maneuver needs to be conducted, and if it is, what optimal avoidance strategy to use. They then upload the proper commands, the spacecraft maneuvers, and if all is completed successfully, the two spacecraft pass unhindered.

If the second space object is debris, note that the U.S. currently does not provide an assessment of object size, and covariance is largely unavailable.

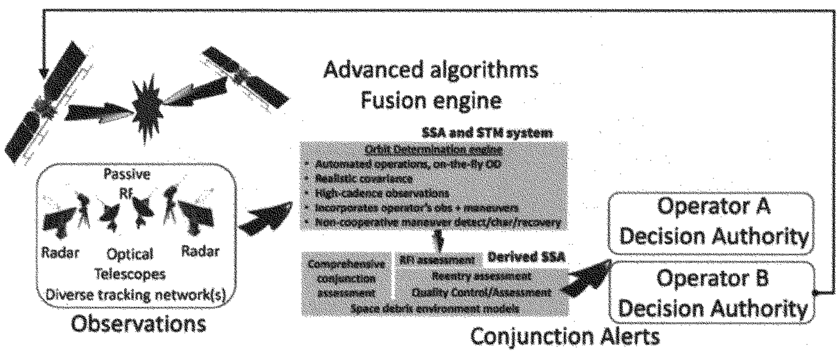


Figure 9 Potential threat, observed by SSA sensors, then orbits are solved, then any potential collision risks are identified. Operators are notified of the collision threat via a Conjunction Data Message. Operator A's mitigation of impending collision threat.

7 SSA and STM as the foundation of long-term sustainability of the space environment

The basic building blocks to space sustainability are clear. We must avoid predictable collisions, minimize creation of new debris and remove massive derelict LEO objects. If we wanted to explain this to a child, we could just say: Don't hit each other, play nice and don't litter, and put your toys away. All three of these basic space sustainability building blocks have it their core SSA and STM as shown in ***Figure 10***.

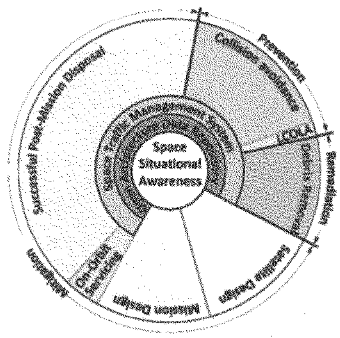


Figure 10 SSA and STM are foundational to all building blocks of long-term sustainability of space activities

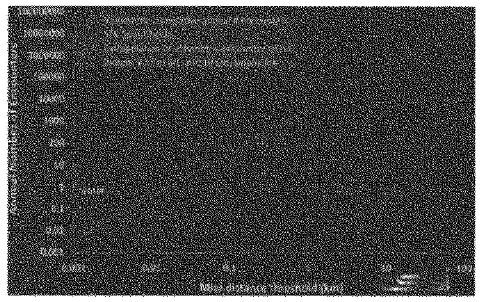


Figure 11 The number of potential threats operators must process depends exclusively upon how accurate SSA predictions are.

The number of potential threats operators must process almost exclusively depends upon how accurate the SSA data is. Increased accuracy obtainable from advanced SSA algorithms can lead to a substantial reduction in spacecraft operator workload by eliminating numerous false alarms[12] as shown in ***Figure 11***.

8 A sense of urgency is required as the SSA and STM landscape rapidly evolves

8.1 The current situation is unsustainable

Even though avoidance of debris-generating collisions is a central pillar of the long-term sustainability of space activities, today's LEO and GEO operators frequently cannot tell when collision avoidance maneuvers are required, often due to limitations in orbital accuracy, precision, completeness, timeliness and transparency in both operator and State-provided data.

In addition, we now recognize the probability of successful Post-Mission Disposal of spacecraft to be one of the most critical parameters to ensure space sustainability. While disposal rates as high as 95% may be required, the European Space Agency estimates today that we are only achieving 60% for spacecraft and 65% for upper stages.

Past collisions of operational spacecraft and the extremely close approach of two dead spacecraft on 29 January 2020 are proof that today's approach to safety of flight is not enough. The status quo is no longer sufficient given current flight safety limitations and in light of new knowledge and anticipated increases in space traffic.

8.2 Potential for a tenfold increase in active satellites

We are entering a phase of unparalleled change. An even more compelling reason that "business as usual" is not an option is that the New Space era is rapidly dawning. Plans have been filed with the International Telecommunications Union and the FCC or announced in the media to build, launch and operate over 58,000 spacecraft within the next ten years alone, a tenfold increase in the number of operational spacecraft (***Figure 12***). We realize that only a portion of these spacecraft applications will be realized as

[12] Oltrogge, D.L. and Alfano, S., "Collision Risk in Low Earth Orbit," IAC-16, A6,2,1,x32763, 67th International Astronautical Congress, Guadalajara, Mexico, 26-30 September 2016.

operational spacecraft, but even if only 10% to 50% of these constellations are become operational, we could easily see an active spacecraft population in the next decade that is between four and ten times larger than is flying today. This year alone, I am confident that the active space population may nearly double. Of these 58,000 possible spacecraft, U.S. companies have proposed 66 times more than any other country, which equates to 25 times more spacecraft than all active spacecraft flying today.

This is an exciting time for space, but it demands that we get prepared on the regulatory, SSA, and STM fronts. As the video shows, these large constellations won't be en force for another few years, so we have a small window to get prepared. But we must act now.

Large constellations will experience millions of close approaches, requiring thousands of avoidance maneuvers, with many being as close or closer than the 29 January close approach of two dead spacecraft, the Ifra-Red Astronomy Satellite and the Gravity Gradient Stabilization Experiment 4 spacecraft. Our updated research results[13] shown in ***Figure 13*** portray the anticipated high rates of collisions, 3 km warnings and 1 km maneuvers required for large constellations against the currently tracked catalog (middle 3 columns) and estimated catalog above 1 cm (right 3 columns). Left unchecked, many collisions are estimated. For example, it has been estimated that the developing Starlink constellation of 4,425 spacecraft will experience two million close approaches over a ten-year mission, resulting in six potentially environment-altering collisions with currently tracked debris if left unmitigated, and an additional 71 potentially mission-terminating collisions against the full population down to 1 cm in size.

While the global population of active spacecraft will grow over the next decade, we do have a few years to prepare for this upcoming rapid growth. But we must take steps now.

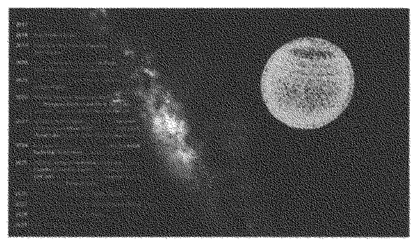
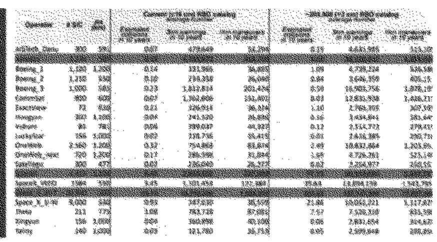


Figure 12 Top 20 large constellations at risk of collision



Operator	# S/C	Alt (km)	Current RSO catalog: Estimated collisions in 10 years	5km warnings in 10 years	1km maneuvers in 10 years	>1 cm RSO catalog: Estimated collisions in 10 years	5km warnings in 10 years	1km maneuvers in 10 years
AstTech_Diamy	300	590	0.07	479,649	54,294	0.19	4,631,905	515,10
[illegible]								
Boeing_1	1,120	1,200	0.14	331,965	36,885	1.09	4,739,224	536,5
Boeing_2	1,210	550	0.10	234,358	26,040	0.84	3,646,359	405,1
Boeing_3	1,000	585	0.23	1,812,814	201,424	0.59	16,903,756	1,878,1
Commsat	800	600	0.07	1,362,606	151,401	0.03	12,835,938	1,426,2
Exactview	72	820	0.21	326,914	36,324	1.16	2,768,355	307,59
Hongyan	300	1,100	0.04	241,520	26,836	0.16	3,434,841	381,64
Hulqun	80	785	0.06	399,037	44,337	0.12	2,514,772	279,43
LuckyStar	156	1,000	0.02	131,736	15,415	0.01	2,616,385	290,71
OneWeb	2,560	1,200	0.32	754,863	83,874	2.49	10,832,464	1,203,5
OneWeb_new	720	1,200	0.17	286,368	31,884	1.69	4,726,261	525,14
Satellogic	300	477	0.02	236,040	26,227	0.02	2,254,977	250,55
[illegible]								
SpaceX_VLEO	7,518	340	5.45	1,101,454	122,380	35.61	13,894,150	1,543,795
[illegible]								
SpaceX_U-W	4,000	550	0.93	347,030	38,559	21.86	10,061,221	1,117,87
Theia	211	775	1.08	783,728	87,081	7.57	7,520,310	835,59
Xingyun	156	1,000	0.04	360,898	40,100	0.06	2,802,654	314,62
Yaliny	140	1,000	0.03	121,780	16,753	0.95	2,599,849	288,89

Figure 13 Collision, warning and maneuver rates for Top 20 proposed large constellations for collisions.

8.3 Potential for a tenfold increase in tracked debris

On the space tracking side, only an estimated 4% of both the LEO and GEO space populations are currently tracked. Out-dated space-tracking algorithms along with insufficient quality control and service level availability further degrade the completeness, accuracy, timeliness, and transparency of the space catalog.

These deficiencies may soon be addressed through the near-term addition of the operational Space Fence, plus the promising advances made by commercial radar-tracking companies. This means that the number of tracked space objects could soon increase tenfold. Note that this reflects objects that are already in space that we simply have not previously been able to track.

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[13] Alfano, S., Oltrogge, D.L., and Shepperd, R., "LEO constellation encounter and collision rate estimation: An update," 2nd IAA Conference on Space Situational Awareness, IAA-ICSSA-20-0021, 14 January 2020.

8.4 Emergence of Rendezvous and Proximity Operations and On-Orbit Servicing

The emergence of Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) spacecraft adds a further layer of complexity. The exciting commercial flight of the on-orbit servicer Mission Extension Vehicle, MEV-1, and other Active Debris Removal platforms preparing for flight further underscores the increasingly complex space environment of the future.

8.5 More commercial and international space operations centers

Some estimate that the Space Situational Awareness (SSA) market worldwide could reach $1.1B by 2025. U.S. commercial SSA and STM service providers are on the leading edge of this global market, applying innovative, cost-saving hardware, algorithms and software to these domains. As a direct result of these innovations, space catalogs are growing with the inclusion of smaller debris with orbits known more accurately than commercial spacecraft operators have ever had. Unfortunately for U.S. commercial SSA providers, the U.S. government has not succeeded in finding ways to incorporate commercial SSA services into government safety of flight analyses and products such as Conjunction Data Messages or CDMs. Providing U.S. government SSA and STM services at no cost to spacecraft operators, while promoting flight safety for the benefit of all, represents direct competition with U.S. SSA companies, who may go out of business soon if this competition is not addressed.

8.6 Greater need to coordinate space traffic than ever before

Collectively, this explosive growth in the number of spacecraft will also change the statistics of the types of collisions, increasing the number of active-on-active spacecraft conjunctions to an all-time high. This will make robust, protected and verifiable information pooling, exchange and standardization essential.

8.7 More advanced SSA processing algorithms and scalable architectures

Despite having been established for centuries, much progress continues to be made in the development of advanced astrodynamics, orbit determination and collision risk assessment algorithms. The application of sequential filters with build-in maneuver detection and characterization allow SSA systems to be much more responsive to the constantly maneuvering active space population. Scalable architectures

8.8 Increasing spacecraft and operating complexities

The anticipated high conjunction rates associated with large constellations will naturally fuel the desire for as yet unproven automated collision avoidance decision making. Automated avoidance would mean that a spacecraft could decide on its own what optimal avoidance maneuver to conduct and when. But if this is not shared with the other spacecraft operator, then the two spacecraft could potentially steer directly into each other.

There are advances in spacecraft propulsion. Large constellations will use low-thrust propulsion as the rule rather than exception. Besides requiring more avoidance time as the name implies, low-thrust maneuvers can cause difficulties for older SSA systems with no maneuver estimation.

Many CubeSats maneuver by "differential drag" and "drag augmentation sail" approaches. In differential drag, the operator changes spacecraft attitude relative to other satellites in their fleet to "catch the wind" and "maneuver". Drag augmentation sails deploy to greatly increase drag to cause the spacecraft to reenter quicker than it otherwise would. Both of these techniques can challenge some SSA systems.

8.9 Increase in the number of space actors

We are also in the midst of an explosion in the number of actors in space. The popularity of CubeSats and mass-produced small satellites is leading to decreasing costs to procure and launch spacecraft, resulting in many new space actors.

9 What's missing in our approach today?

Perhaps the critical piece that is missing from today's flight safety systems is a top-down, requirement-based approach.

9.1 Attributes of a globally-relevant SSA and STM system

A comprehensive international STM system could enhance safe and sustainable conduct of space activities, incorporating international standards, guidelines, multilateral data sharing, registration, notification and coordination of launch, on-orbit, reentry, safety and environmental events.

The Space Surveillance Network (SSN) operated today to meet military needs and provide flight safety to the global spacecraft operator community is a great contribution to long-term sustainability. But it's important to realize that this system was largely built piecemeal, with many of the SSN's dedicated, collateral and contributing sensors, many of which were designed and operated for other purposes such as missile warning, were repurposed or time-shared with the SSA mission. As a result, this SSA and flight safety system has not been developed via a top-down requirement-driven approach.

If one were to instead design an SSA system from the ground up consisting of multiple sensors, sensor types, and advanced algorithms, a potentially more cohesive and comprehensive flight safety system could be achieved. Top level attributes of such a globally-relevant SSA and STM system would to combine government, satellite operator and commercial SSA data at the observational level to achieve actionable SSA, to continue to freely provide a basic level of service to spacecraft operators while not adversely harming established commercial SSA and STC avenues, to appropriately protect intellectual property and proprietary data issues associated with international government military, civil and commercial operator space data, apply advanced algorithms and SSA hardware, have high availability, be transparent, and adopt space standards (published thru ISO and CCSDS) to be accessible and relevant to the global space market. A detailed evaluation of required attributes is provided in a separate study[14].

10 Suggested approach

The space sector is experiencing explosive growth, and our legacy approach to SSA and our lack of cohesive progress in STM raise concern that we are losing the initiative in SSA and STM. To address these many issues, here are my top five recommended actions:

(1) Continue down the path advocated in Space Policy Directive-3 to transition public safety of flight services over to a non-military organization. Such public flight safety services, while very important, do not require the care and protection that national security systems require. We have the opportunity to lead Space Traffic Management standards identification and development.

(2) Fund a rapid U.S. STM prototype this year and encourage operators to utilze the prototype.

(3) Follow the lead of other countries and develop a complementary way for the U.S. government to nurture and incorporate commercial-provided SSA and STM services.

(4) Develop, model and implement rules of the road or other assignments (e.g., spacecraft agility required above certain altitudes).

(5) Follow the lead of other countries to fund and conduct active debris removal tests.

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[14] Oltrogge, D., Johnson, T. and D'Uva, A.R., "Sample Evaluation Criteria for Space Traffic Management Systems," 1st IAA Conference on Space Situational Awareness (ICSSA), 13-15 November 2017, Orlando, FL, USA.

About Dan Oltrogge

Dan Oltrogge is a globally recognized expert in space debris, launch and orbital operations, collision avoidance, RF interference mitigation, space situational awareness, and space traffic coordination and management. Mr. Oltrogge is a frequent author of technical papers and in-depth analysis reports. He also holds three patents for astrodynamics and risk assessment methods associated with collision risk, probability of collision and safety of flight. He has developed numerous international standards and best practices for space operations and debris mitigation under the auspices of ISO, CCSDS, CONFERS, AIAA, ANSI, and IAA. Mr. Oltrogge is frequently quoted in leading news outlets and trade publications and is a sought-after speaker at conferences and forums around the world.

Mr. Oltrogge is the director of AGI's Center for Space Standards and Innovation (CSSI) and is the lead policy and analysis expert for its Commercial Space Operations Center (ComSpOC). Mr. Oltrogge also serves as the program manager of the Space Data Center, now in its tenth year of global flight safety operations for 29 operators flying approximately 275 GEO and 470 LEO spacecraft.

Mr. Oltrogge led the development of the nation's first probability-based launch Collision avoidance (LCOLA) system in 1996, and 23 years later, that system still provides mission assurance launch flight safety product largely unchanged from the original capability. Conjunction screening conducted by him revealed previously unknown recurring collision threats to high-value NASA and national assets from several other spacecraft.

As the founder and administrator of the Space Safety Coalition (SSC), Mr. Oltrogge leads a commercial industry "Best Practices for Sustainability of Space Operations" initiative to collect and endorse a living set of space sustainability best practices. This innovative best practices document draws upon existing international space treaties, guidelines and standards developed by the United Nations, the IADC, the International Organization for Standardization (ISO) and the Consultative Committee for Space Data Standards (CCSDS). This first-of-its-kind coalition is comprised of space operators, space industry associations, and space industry stakeholders from across the globe.

Mr. Oltrogge has a Bachelor of Science degree in Aerospace, Aeronautical, and Astronautical Engineering from Iowa State University and a Master of Science degree in Aerospace Engineering and Astrodynamics from the University of Southern California.

Chairwoman HORN. Thank you, Mr. Oltrogge. Professor Gabrynowicz?

TESTIMONY OF PROFESSOR JOANNE GABRYNOWICZ, PROFESSOR EMERITA OF SPACE LAW, UNIVERSITY OF MISSISSIPPI LAW CENTER

Ms. GABRYNOWICZ. Chairwoman—excuse me. Chairwoman Horn, Ranking Member Babin, Members of the Committee, thank you for inviting me here. I was asked to provide a brief overview of the law applicable to SSA, and today that is an amalgam of treaties, contracts, and national law and regulation. A key element of SSA is orbital debris, so I will address the legal regimes and available juridical fora regarding debris. I will conclude by raising two crucial SSA issues for which new law is needed, the need to formulate international agreements to establish internationally recognized norms, and to prevent small conflicts from escalating, and two, the—addressing the gap in United States regulations regarding U.S. private sector activities on orbit.

Space is governed by an inter-related collection of space specific treaties. The first, and most important, of these is the Outer Space Treaty and it recognizes that space use and exploration shall be in accordance with international law, including the Charter of the U.N. This means that space is also governed by public and private international law, and includes international humanitarian law. The Outer Space Treaty also provides that a State Party has the obligation to avoid harmful contamination and harmful interference with the use of space.

Regarding SSA and debris, the Liability Convention is of particular relevance. It codifies two liability regimes, a fault-based negligence regime which is applicable in space and an absolute liability regime for harm caused on Earth and to aircraft in flight. Excuse me. An additional set of guidance, but non-treaty based, is the guidelines provided by the Inter-Agency Space Debris Coordination Committee. It provides guidance regarding orbital debris, and contains a set of voluntary orbital debris mitigation guidelines which were adopted by the U.N. General Assembly. They are not legally binding, but they do provide persuasive authority for addressing orbital debris mitigation.

At the national level, orbital debris is slowly evolving as a matter of law. It is specifically addressed in the national laws of Austria, China, France, Japan, and in the United States. In the United States, orbital debris is addressed as part of licensing space-based applications. There are a number of different available juridical fora for the adjudication of conflicts regarding debris and SSA. They include diplomatic channels, which is the first and preferred option, a Claims Commission that can be established under the Liability Convention, as well as the courts, and tribunals, and agencies of launching States. And also, of course, if there are any additional agreements between and among States outside of the treaty regime that is applicable to conflict resolution.

Recently, formal arbitration has been added to the roster of conflict resolution options through the Permanent Court of Arbitration. However, as a practical matter, these are unlikely to be used either by nation-states or governmental space actors. A juridical forum of any kind means rendering control of the situation to the forum. Nation-states are sovereigns, and giving up control is anathema to their nation—nature. Additionally, the possibility of exposing acutely sensitive technological and operational information is antithetical to some national interests.

There are two issues for which law is still needed for SSA. At the international level, we need agreements to establish internationally recognized norms, and to prevent small conflicts from escalating into large conflicts. There is little political will currently for making new legally binding treaties, and recent action indicates there may be declining support for non-binding options. Nonetheless, new agreements, both binding and non-binding, are needed. The issues that must be addressed include the balancing of national security, value of data, and the need to share data, applicable conflict mechanisms, legitimacy of non-governmental data providers, mistrust issues between governmental and non-governmental providers, and the commercialization of SSA data.

At the national level there exists a regulatory gap in the United States regulations. Currently there are no Federal—there's no Federal agency that has the jurisdiction to authorize and continually supervise private sector on-orbit activities, and this is occurring at the same time that the United States is planning to increase its reliance on the private sector. In 2015 the Congress required a report from the Office of Science and Technology Policy on how the United States could authorize such private sector activities, and OSTP (Office of Science and Technology Policy) proposed legislation that would establish an inter-agency process. To date, due to political forces, this has not yet been done.

[The prepared statement of Ms. Gabrynowicz follows:]

Space Situational Awareness: Key Issues in an Evolving Landscape

Written Testimony of

Prof. Joanne Irene Gabrynowicz, Emerita

Before the

Subcommittee on Space and Aeronautics of the Committee on Science, Space, and Technology United States House of Representatives

February 11, 2020

Chairwoman Horn, Ranking Member Babin, Members of the Committee: Thank you for inviting me to address the key legal and liability issues related to space situational awareness (SSA). I am delighted to respond. I thank the Subcommittee for giving me this opportunity.

I. The Legal Environment

I was invited today to provide a brief overview of the legal environment for SSA. Currently, the law applicable to SSA is an amalgam of treaties, contracts, and national law and regulation. One key element is orbital debris. Therefore, I will briefly address the existing international and national legal regimes and the available juridical fora for the adjudication of conflicts regarding debris. I will conclude by raising two crucial SSA issues for which new law is needed, 1.) the need to formulate international agreements to establish internationally recognized norms and to prevent small conflicts from escalating and, 2.) the gap in United States regulations regarding U.S. private sector on-orbit activities.

A. *Space Treaty Regime, International Law, and National Law*

Space is governed by an inter-related collection of space specific treaties.[1] The first, and most important of these is the Outer Space Treaty and it recognizes that space use and exploration "shall...[be]...in accordance with international law, including the Charter of the United Nations..."[2]. This means that space is also governed by Public and Private International Law and includes International Humanitarian Law and important legal principles like the "inherent right of individual or collective self-defence".[3]

Under the Outer Space Treaty the United States has "international responsibility" for space activities by "governmental agencies or by non-governmental agencies".[4] What constitutes "responsibility" is part of a growing

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[1] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, opened for signature Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty];

Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, opened for signature Apr. 22, 1968, 19 U.S.T. 7570, 672 U.N.T.S. 119 [hereinafter Rescue and Return Agreement];

Convention on International Liability for Damage Caused by Space Objects, opened for signature Mar. 29 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Liability Convention];

Convention on Registration of Objects Launched into Outer Space, opened for signature Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15 [hereinafter Registration Convention]; and,

Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, opened for signature Dec. 18, 1979, 1363 U.N.T.S. 21 [hereinafter Moon Agreement].

[2] Outer Space Treaty, *supra* Note 1, at Art. III.

[3] U.N. Charter art. 51.

[4] Outer Space Treaty, *supra* Note 1, at Art. III.

body of law that has strengthened and matured in recent years[5] The United States Government will ultimately be responsible for reparation if it is deemed necessary because of events arising from United States governmental or nongovernmental space activities.

The Outer Space Treaty also provides that a State Party has the obligation to "avoid…harmful contamination" and if a Party "has reason to believe that an activity…by it or its nationals in outer space…would cause potentially harmful interference…" with the space activities of other Parties "it shall undertake appropriate international consultations."[6]

Regarding SSA and debris, the Liability Convention is of particular relevance. It codifies two liability regimes: a fault-based (negligence) regime applicable in space;[7] and, an absolute liability regime for harm caused on Earth and to aircraft in flight.[8] The first regime requires proving that the party that caused the harm knew, or should have known, its actions would lead to the harm. The second regime requires proving only that the responsible party's object caused the harm. It is irrelevant that the responsible party was not negligent. The two different liability standards are based on the fact that if objects in space cause harm, the entities that placed the objects in space will be best situated to determine what caused the harm and who is the responsible party. In contrast, if the harm is caused on Earth or to an aircraft in flight, the injured party has no

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[5] James Crawford, Jacqueline Peel, Simon Olleson, *The ILC's Articles on Responsibility of States for Internationally Wrongful Acts: Completion of the Second Reading*, 12 EJIL 963 (2001).
[6] Outer Space Treaty, *supra* Note 1, at Art. IX.
[7] Liability Convention, *supra* Note 1, at Art. III.
[8] Liability Convention, *supra* Note 1, at Art. II.

way of knowing what did or did not happen in space to cause the harm. Therefore it would be unjust to require the harmed party to prove something it would be impossible to know.

An event involving the Outer Space Treaty and the Liability Convention and the creation of debris by a United States space object was the 2008 launching of the USA 193—an "engagement of an inoperable National Reconnaissance Office (NRO) satellite, which [was] in a decaying orbit."[9]

The United States acted in accordance with the Outer Space Treaty and Liability Convention. "In the interests of transparency...consistent with the provisions of the 1967 Outer Space Treaty..." the United States informed the international community of the engagement. The U.S. further acknowledged that a party to the Convention "will be 'absolutely liable' for damages 'caused by its space object on the surface of the Earth or to aircraft in flight.' The U.S. is a party to that convention, so any liability to other treaty parties would be determined in accordance with its terms."[10]

B. *The IADC*

The Inter-Agency Space Debris Coordination Committee (IADC) Mitigation Guidelines[11] is a non-treaty based source of guidance regarding orbital debris.

[9] Statement by Ambassador Christina Rocca, Permanent Representative of the United States to the Conference on Disarmament, Geneva, February 15, 2008.
[10] *Id.*
[11] United Nations, Report of the Scientific and Technical Subcommittee on its thirty-seventh session, held in Vienna from 7 to 18 February

These are a set of voluntary orbital debris mitigation guidelines that were formulated by the IADC—an international governmental forum comprised of the space agencies of satellite operating nations—for "the worldwide coordination of activities related to the issues of [human]-made and natural debris in space". The guidelines were adopted in the UN General Assembly.[12] Although not legally binding, they provide persuasive authority for addressing orbital debris mitigation.

C. *National Law*

At the national level, orbital debris is slowly evolving as a matter of law. It is specifically addressed in the national laws of Austria, China, France, Japan, and the United States.[13] Some of these laws address orbital debris as a distinct subject.[14]

In the United States, orbital debris is addressed as part of licensing space-based applications.[15] These include telecommunications satellites licensed by

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2000, A/AC.105/736, 2000, http://www.unoosa.org/oosa/oosadoc/data/documents/2000/aac.105/aac.105736_0.html.

[12] United Nations, International Cooperation in the Peaceful Uses of Outer Space, A/RES/62/217, Office for Outer Space Affairs, 2007, http://www.unoosa.org/oosa/oosadoc/data/resolutions/2007/general_assembly_62nd_session/ares62217.html.

[13] UN Committee on the Peaceful Uses of Outer Space, *General exchange of information on national legislation relevant to the peaceful exploration and use of outer space*, A/AC.105/C.2/2012/CRP.8 (March 16, 2012).

[14] Austrian Federal Law on the Authorization of Space Activities and the Establishment of a National Space Registry (Austrian Outer Space Act), entered into force on 28 December 2011. (Requires compliance with the "state of the art" and "internationally recognized guidelines for the mitigation of space debris".) *Id*, at 3.

[15] 51 U.S.C.; 14 C.F.R. 400-499; NPR 8715.6A; NASA-STD 8719.14;

the Federal Communications Commission; commercial launches and re-entries licensed by the Department of Transportation; and, commercial remote sensing satellites licensed by the Department of Commerce National Oceanic and Atmospheric Administration.[16]

Telecommunication satellites license applications require including end-of-life disposal plans involving atmospheric reentry and surviving debris. Remote sensing satellites must be disposed of in a manner acceptable to the President.

II. **Available juridical fora for the adjudication of conflicts regarding debris and SSA**

A. *Existing Options*

There are a number of forum options available for bringing an orbital debris case. The Liability Convention recognizes that diplomatic channels are the first and preferred option.[17] The Liability Convention has provisions for establishing a special Claims Commission in the event a settlement has not been reached through diplomatic channels.[18] The courts, tribunals or agencies of the State responsible for launching the space object are also available.[19] And, of course, any agreements between and among States outside of the treaties that provide for conflict resolution are also available.

U.S. Government Orbital Debris Mitigation Standard Practices; 47 U.S.C.; 47 C.F.R. Parts 5, 25, and 97; Order, FCC 04-130; 47 C.F.R. 25.160-162.

[16] 47 C.F.R. Parts 5, 25, and 97; Order, FCC 04-130; 47 C.F.R. 25.160-162.

[17] Liability Convention, *supra* Note 1, at Art. IX.

[18] Liability Convention, *supra* Note 1, at Art. XIV, XV.

[19] Liability Convention, *supra* Note 1, at Art. XI.

Recently, formal arbitration has been added to the roster of conflict resolution options. In 2011, the Permanent Court of Arbitration in The Hague developed *Optional Rules for Arbitration of Disputes Relating to Outer Space Activities*[20] and has added arbitration of space disputes to its dispute resolution services.[21]

III. Practical Considerations

As a practical matter, the existing legal regime and juridical fora, briefly outlined above, are unlikely to be used either by Nation-States or non-governmental space actors. And, if they do, they are likely to encounter a number of legal uncertainties, including the accepted definition of basic terms of art like "fault."[22]

As for Nation-States, seeking conflict in a juridical forum of any kind means rendering control of the situation to the forum. Nation-States are sovereigns and giving up control is anathema to their nature. Additionally, the possibility of exposing acutely sensitive technological and operational information is antithetical to national interests.

Nongovernmental entities have concerns about insurance. Potentially large losses and high levels of uncertainty regarding how losses occur, means

[20] https://pca-cpa.org/wp-content/uploads/sites/6/2016/01/Permanent-Court-of-Arbitration-Optional-Rules-for-Arbitration-of-Disputes-Relating-to-Outer-Space-Activities.pdf
[21] Permanent Court of Arbitration, https://pca-cpa.org/en/home/.
[22] Swiss Reinsurance Company Ltd., Space Debris: On Collision Course for Insurers? (2011) https://www.swissre.com/dam/jcr:b359fb24-857a-412a-ae5c-72cdff0eaa94/Publ11_Space+debris.pdf

rising insurance costs that can be a significant portion of overall launch costs.[23] Exposing information about intellectual property and technological vulnerabilities also present causes for concern. All of these are incentives for governmental and nongovernmental actors to seek settlement outside of available juridical fora.

In fact, the only case in which the Liability Convention was formally invoked by two of its States-Parties was in the 1978 *Cosmos 954* case. Canada claimed 6 million Canadian dollars for damage caused by radioactive debris from the re-entry of the malfunctioning Soviet satellite on Canadian Territory. Ultimately, Canada and the Soviet Union settled the claim for 3 million Canadian dollars.[24] The case demonstrates the Liability Convention worked by providing a formal forum for dispute resolution. The existence of a formal mechanism, and wanting to avoid it, provided, in part, the incentive to settle.

IV. Crucial SSA issues for which new law is needed

Space is not lawless. But the law is unclear. The changing nature of space operations and technology, and the ever-increasing reliance on space assets, has evolved into a legal environment in which there are serious legal gaps that must be addressed.

A. *International Agreements to Establish Internationally Recognized Norms and to Prevent Small Conflicts from Escalating*

[23] *Id.* at 23. "The drafters of the treaty shed little light on the meaning of 'fault' and the term as it appears in the treaty has never been tested in a formal way. Carl Christol, in The Modern International Law of Outer Space, suggests that if the drafters (representing many different countries and legal systems) had tried to define this term, they would still be working on the Convention."
[24] Canada-Union of Soviet Socialist Republics: Protocol on Settlement of Canada's Claim for Damages Caused by "Cosmos 954," 20 I.L.M. 689 (1981).

As the amount of orbital debris continues to grow, it becomes increasingly necessary be able to detect the difference between active space objects and debris. For overall SSA, it is also increasingly necessary to share relevant information with appropriate entities in order to prevent relatively minor events from escalating into major conflicts. Currently, specific agreements with specific rules to do so are lacking.

The global community has little political will for making new legally binding treaties. Since the end of World War II non-binding agreements have proliferated: MOUs, declarations, guidelines, principles, codes of practice, recommendations, programs, charters, and terms of reference. The now stalled draft Code of Conduct for Outer Space Activities indicates that support for non-binding options is also faltering.[25]

Nonetheless, new agreements—both binding and nonbinding—are needed. Some of the issues that must be addressed include the balancing of the national security value of data and the need to share data; applicable conflict resolution mechanisms; legitimacy of nongovernmental data providers; mistrust issues between governmental and nongovernmental providers; commercialization of SSA data; whether or not the Outer Space Treaty's obligation to avoid harm[26] includes providing information about the space

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[25] Michael J. Listner, The International Code of Conduct: Comments on changes in the latest draft and post-mortem thoughts, The Space Review, (Oct. 26, 2015), https://www.thespacereview.com/article/2851/1.
[26] Outer Space Treaty, *supra* Note 1, at Art. IX.

environment; and, which technical and scientific standards will be recognized; among others.

B. *Regulatory Gap in United States Regulations*

At the national level, the United States has a profound regulatory gap regarding authorizing private sector on-orbit activity.[27] No federal regulatory agency has jurisdiction to "authorize and continually supervise"[28] private sector on-orbit activities. This is occurring at the same time the United States is planning to increase its reliance on the public sector in space.[29]

In 2015, Congress required a report from the Office of Science and Technology Policy (OSTP) on how the United States could authorize and

[27] See, for example, Subcommittee on Space of the Committee on Science, Space and Technology, U.S. House of Representatives, Hearings on Space Traffic Management: How to Prevent a Real Life "Gravity," May 9, 2014, https://science.house.gov/legislation/hearings/space-subcommitteehearing-space-traffic-management-how-prevent-real-life; and Hearings on Exploring Our Solar System: The ASTEROIDS Act as a Key Step, September 10, 2014, https://science.house.gov/legislation/hearings/subcommittee-space-exploring-our-solar-system-asteroids-act-key-step.

[28] Outer Space Treaty, *supra* Note 1, at Art.VI.

[29] NASA, Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two – Quantifying Demand, Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two – Quantifying Demand. (2019). https://www.nasa.gov/sites/default/files/atoms/files/forecasting_future_nasa_demand_in_low-earth_orbit_revision_two_-_quantifying_demand.pdf; and, NASA, NASA Plan for Commercial LEO Development to achieve a robust low-Earth orbit economy from which NASA can purchase services as one of many customers. (2019). https://www.nasa.gov/sites/default/files/atoms/files/commleodevt_plan_6-7-19_final-links-new.pdf

continually supervise private sector on-orbit activities to meet its Outer Space Treaty obligations.[30] OSTP proposed legislation that would establish "an interagency process in which designated agencies would review a proposed mission in relation to specified government interests, with only such conditions as necessary for fulfillment of those government interests."[31] To date, this has not been done. Due to political forces that attempted to eliminate most authorizing legislation, no legislation has been promulgated for on-orbit activities. Since 2015, only one payload review has been conducted and it is not a precedent for future reviews.[32] If the private sector will participate in future on-orbit SSA activities, it will be necessary to have a clear regulatory regime that protects them and United States national interests.

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[30] U.S. Commercial Space Launch Competitiveness Act, P.L. 114-90. (2015), Section 108.

[31] Executive Office of the President, Office of Science Technology Policy, Report submitted in fulfillment of a requirement contained in the U.S. Commercial Space Launch Competitiveness Act, April 4, 2016 ("Section 108 Report"). https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/csla_report_4-4-16_final.pdf.

[32] FAA, Fact Sheet—Moon Express Payload Review Determination, August 3, 2016, https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20595. ("This determination does not extend to future missions by Moon Express, Inc. or similar missions from other entities. Any future requests for a payload determination from Moon Express, Inc. or another entity will be evaluated on a case-by-case basis…Future missions may require additional authority to be provided to the FAA to ensure conformity with the Outer Space Treaty.")

Joanne Irene Gabrynowicz
(662) 801-6868; jgabryno@olemiss.edu, www.joannegabrynowicz.com

Prof. Gabrynowicz is Professor Emerita of space law, Director Emerita of the National Center for Remote Sensing, Air, and Space Law, Univ. of the Mississippi Law Center and the Editor-in-Chief Emerita, Journal of Space Law. She managed a faculty and staff off 6 - 8 people, 10 - 15 student workers, and a multi-million dollar budget.

Prof. Gabrynowicz has taught space law since 1987 and currently lectures at various universities around the world including the University of Vienna, the Univ. of Warsaw, the Univ. of Copenhagen, and the Beijing Institute of Technology School of Law, and Beijing University of Aeronautics and Astronautics. In 2014, 2015, and 2019 she was invited by the Subcommittee on Space of the U.S. House Committee on Science, Space, and Technology to testify regarding the legality of asteroid mining; remote sensing law; and, commercializing the *International Space Station*. She is currently a Fulbright Scholar and a member of the Ad-Hoc Remote Sensing Space Systems Advisory Committee for the Government of Canada, Global Affairs Canada. Prof. Gabrynowicz briefed former U.S. Secretary of the Interior Gayle Norton as part of the Secretary's preparation for the Earth Observation Summit. Prof. Gabrynowicz briefed Frank A. Rose, Deputy Assistant Secretary for Space and Defense Policy, U.S. Department of State on legal aspects of orbital debris. She was the organizer and chair of the U.S. Federal Advisory Committee for the National Satellite Land Remote Sensing Data Archive.

Prof. Gabrynowicz was a founding faculty member of the Space Studies Department at the University of North Dakota, where she also served as its Director of Graduate Studies. From 1992-94, Prof. Gabrynowicz was a member of The Congress of the United States Office of Technology Assessment Earth Observations Advisory Panel. From 1994-96, she was a member of the National Research Council Committee that produced Bits of Power: Issues in Global Access to Scientific Data. In 1994-95, Prof. Gabrynowicz was awarded a NASA/American Society of Engineering Education Summer Faculty Fellowship from Goddard Space Flight Center where she also served as the 1997 Dean of the NASA Space Academy. Prof. Gabrynowicz has been invited by the U.S. Dept. of Commerce/NOAA, the U.S. National Research Council, the NASA Public Health Applications Program on Confidentiality and Geospatial Data, the Univ. of Cologne Institute of Air and Space Law to participate in a number of studies. Prof. Gabrynowicz was the managing attorney of a NYC law firm. She is a member of the American Bar Association Forum on Aviation and Space Law.

Prof. Gabrynowicz is a Director of the International Institute of Space Law (IISL) and is an official observer for the IISL to the UNCOPUOS Legal Subcommittee and has made a number of presentations to that group on space law issues. She was a member of the Advisory Board for the Permanent Court of Arbitration for the Draft Arbitration Rules on Disputes Relating to Outer Space Activities and has presented to the UN Institute for Disarmament Research. The UN Office of Outer Space Affairs (UNOOSA) invited Prof. Gabrynowicz to lecture on space law at all of its space law capacity building workshops for government officials and policymakers and she is the lead author for UNOOSA's remote sensing law curriculum. In 1999, the IISL invited Prof. Gabrynowicz to write and present the remote sensing law position paper at UNISPACE III. In 2001 she was awarded the Women in Aerospace *Outstanding International Award*. In 2011 she was awarded the IISL *Distinguished Service Award*. In 2014, Prof. Gabrynowicz received the China Institute of Space Law 1st *International Service Award*. In 2016, she was awarded the IISL *Lifetime Achievement Award*. In 2017, her work was recognized by the International Astronomical Union by naming an asteroid "(9002) Gabrynowicz"

Chairwoman HORN. Thank you, Dr. Gabrynowicz. Dr. Wood, you're recognized.

TESTIMONY OF PROFESSOR DANIELLE WOOD, DIRECTOR OF THE SPACE ENABLED RESEARCH GROUP, ASSISTANT PROFESSOR OF MEDIA ARTS & SCIENCES AND AERONAUTICS & ASTRONAUTICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Ms. WOOD. Thank you, Chairwoman Horn, and I express my thanks to Ranking Member Babin, and to the Members of all the Subcommittee and the full Committee. All of us have the privilege and responsibility to lay a foundation for a sustainable space environment, to make it a safe environment, to perform missions without undue risk of harm. In one sense, we are here because space activity brings tremendous social, economic, and cultural value on Earth. I lead a research group called Space Enabled at the MIT Media Lab. Our mission is to reduce barriers to applying space technology in support of a thriving society on Earth, and to work toward space sustainability.

In a recent keynote speech before the American Institute of Aeronautics and Astronautics, I highlighted the ways that the aerospace industry must contribute to global challenges, such as climate change, global economic inequality, human migration, and public health. Space is the perfect vantage point from which we watch our home planet of Earth. As a former member of NASA's Earth Science Team at Goddard Space Flight Center, I advocate for the societal value of NASA's fleet of Earth observation satellites. It is clear from satellite data that our civilization is facing several inter-related crises of sustainability that span our oceans, our lands, our atmospheres, our glaciers, and Earth's orbit. In each of these zones, our economic activities deposit unmanaged populations of waste. Carbon dioxide in our atmosphere, plastics in our ocean, and objects in Earth's orbit. Our civilization has the opportunity right now to review how we will manage this waste, and create a sustainable future.

The United States has a leadership role to play in response to this integrated crisis, or opportunity, of global sustainability on land, in the ocean, in the atmosphere, and in space. Today I'd like to recommend several policy actions. No. 1, the U.S. Government should adopt a commitment to space sustainability as a principle driving space activity. No. 2, the U.S. Government should continue to engage deeply as a leader in international space fora, and look for ways to build common vision with emerging space nations. No. 3, the U.S. Government should ensure there's adequate funding and mandates allocated to improve space situational awareness, and develop concepts related to space traffic management. As noted in the seminal Outer Space Treaty, space is the providence of all humankind. I spent much of the last 15 years performing academic research about the applications of space, using Africa, Latin America, and Southeast Asia, and studying their national space programs.

Every country on Earth is a space country, but this does not mean that all countries enjoy equal access to the benefits of space. The countries that have been most active in pursuing space activity, including the United States, we are also the countries that have created the most risk for future sustainable space operations. That is why U.S. leadership is so important. We must take an integrated and long-term approach to defining space situational awareness, and ask questions about future trends. Where will objects be located in space in future operations? What are the impacts of currently crowded orbits? What is the demand from industry to use certain orbital regimes? Who are the new players in space? What are the sustainable options for expanding space activities? Our close collaborators in the International Space Station, especially in Europe and Japan, are actively innovating in methods to increase space sustainability through programs dedicated toward orbital debris removal, as well as better understanding SSA, and thinking about STM.

Chair—Ranking Member Babin mentioned the idea of promulgating better practices in space, and one approach to do this is through a positive incentive not through government activity, but through non-government activity. I'm actually collating a team that's creating such an incentive system. It's called the Space Sustainability Rating. An international team is designing this rating that includes the World Economic Forum, the European Space Agency, Bryce Space and Technology, the University of Texas at Austin, as well as my institution at MIT.

The Space Sustainability Rating will be a score that any satellite operator can apply to receive. As part of the process of creating the rating, we are engaging with many of the companies that are proposing unprecedented business models to its large constellation of satellites. We hope that governments will join us by promoting this methodology as a way to recognize responsible behavior in space. Here in the U.S., this work will be particularly relevant to those that are providing review of commercial space operations, especially the FAA (Federal Aviation Administration), NOAA, and FCC (Federal Communications Commission). Our activity is really aligned with the 21 guidelines for long term sustainability of outer space coming out of the U.N. COPUOS (Committee on the Peaceful Uses of Outer Space).

As we've mentioned, there's also a need for further thoughts on space traffic management. My research team has performed a study showing the great interest of countries around the world, including Latin America, Africa, and in Eastern Europe, and their desire to be part of the dialog to design a future STM, so it's beneficial that the U.S. shows leadership by also building strong international relationships with these emerging space players to build a vision for global STM. Thank you.

[The prepared statement of Ms. Wood follows:]

Statement of

Dr. Danielle Wood

Director of the Space Enabled Research Group
Assistant Professor of Media Arts & Sciences and Aeronautics & Astronautics
Massachusetts Institute of Technology

before the

House Committee on Science, Space and Technology
Subcommittee on Space and Aeronautics

Hearing on "Space Situational Awareness: Key Issues In An Evolving Landscape"

February 11, 2020

I want to start by expressing my thanks to Chairwoman Horn, Ranking Member Babin, to the members of the subcommittee and the full committee for the opportunity to testify today. It is a pleasure for me to speak before you today. All of us have the privilege and great responsibility to live in a time during which the global community in general and the United States in particular have the opportunity to make decisions that can lay a foundation for a sustainable space environment for years to come. Making space sustainable would mean that we make sure it is a safe environment to perform commercial, academic, scientific and security missions without undo risk of harm due to human-created risks such as satellite collisions.

Let us reflect on why we are here. Why is it valuable for us to set aside this time to speak about Space Situational Awareness and Space Sustainability?

In one sense, we are here because human activity in space brings tremendous social, economic, environmental and cultural value on earth. I lead a Research Group called Space Enabled at the MIT Media Lab. Our mission statement in the group is that we seek to advance justice in earth's complex systems using designs enabled by space. This simply means that we want to consider all the ways that space technology, science and innovation can support healthy, thriving communities on earth. If you would like to hear more examples about this, you can watch my TED talk which is called "Six Space Technologies We can Use to Improve Life on Earth."[i] In the TED Talk, I share examples of satellite earth observation being used to understand the growth of crops. I talk about using satellite communication systems during times of disaster to ensure relief workers can communicate and using satellite communications to connect doctors to distant patients. In the talk, I show the use of satellite-based positioning systems for tracking wildlife. Many of us also enjoy the benefits of satellite positioning when we order a ride share or navigate a new city. My talk also argues that microgravity research and human space flight benefit society broadly when we transfer knowledge of how the human body, plants and animals adapt to the space environment to rethink products, health care, exercise, manufacturing and food production on earth. I remind us in the talk that there are hundreds of spinoff technologies from NASA alone, and meanwhile NASA's sister agencies around the world also produce their own examples of capabilities designed for space and moved into other sectors via patents, publications or the movement of people. Finally, I argue in the TED talk that fundamental space research, such as astrophysics and the study of the Sun's impact on the earth in the form of space weather, brings both long-term and short-term benefits to society. As we slowly unlock deep research questions around planets that orbit other stars, the behavior of water on planets throughout our solar system, and the evolution of distant galaxies, we are also training engineers, computer scientists, data scientists and technicians. I often celebrate the Square Kilometer Array[ii] project that will create the largest radio telescope in the world located in both the continents of Africa and Australia. Many new engineers, scientists, hotel managers, telecommunication network specialists and communications experts will emerge from this project.

Human activity in space provides us with useful services and inputs to our global economy. Recently, I was honored to be invited by the American Institute of Aeronautics and Astronautics to give a keynote speech on the first day of their annual SciTech Forum[iii]. The theme of the event was "Driving Aerospace Solutions for Global Challenges" and the theme the organizers asked me to address was "Using Space to Support a Sustainable Society."[iv] I greatly admired the organizers of the event because they showed true leadership in our aerospace community by selecting these themes. The aerospace industry does have a key role to contribute to ensuring that we move toward meeting global challenges such as climate change, global economic inequality, the changing nature of work, human migration, natural disasters, economic uncertainty and global public health. Space is also the perfect vantage point from which we can watch our special home planet of Earth, to understand how it is changing and what our global cycle of production and consumption is doing to it. I used to work for NASA's Earth Science[v] team at the Goddard Space Flight Center in Greenbelt Maryland. I will always be an advocate for the excellent work of NASA's fleet of earth observation satellites[vi] that capture both images and measurements of the state of the oceans, land, atmosphere and glaciers. From this satellite-based perspective, it is clear that our civilization is facing several, interrelated crises of sustainability. I invite us to see this as one crisis or one opportunity for sustainability that spans our oceans, our land, our atmosphere and Earth's orbit. In each of these zones, our human economic activities of consumption and product have deposited unmanaged populations of waste. We dump waste carbon dioxide into our atmosphere, waste plastics into our oceans and waste objects from launch vehicles and retired satellites in Earth's orbit. The behavior follows similar patterns in each zone. Our civilization has the opportunity right now to review how we will manage this waste and create a sustainable future for our children and their children.

Another reason we are here is that space is one of the domains that carries a paradox. It is at once both highly open and welcoming to everyone and at the same time it is exclusive and strongly influenced by a few countries. During the first week of February 2020, I presented at the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space. This is the United Nations committee that curated the five seminal space treaties that govern international space law, including the Outer Space Treaty which states in Article I, "The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all [hu]mankind." In many ways this principle is true. I spent the much of the past 15 years performing academic research about the applications of space used in Africa, Latin America and Southeast Asia and studying the many countries in these regions that are starting and expanding national space programs.[vii] Dozens of countries in every region of the world have completed national satellite projects and trained local engineers in satellite design and operations. Every country hosts teams and offices responsible for ensuring that they can participate in space communication infrastructure and apply satellite earth observation data for creating strategic maps that inform environmental management. Today, as countries participate in small satellite projects, microgravity research projects in the International Space Station and space entrepreneurship, the global space community is constantly growing. Thus, every country on earth is a space country. However, this does not mean that all countries enjoy equal access to the benefits of space.

The countries that have been the most active in pursuing human activity in space, including the United States, are also the countries that have created the most risk for future space operations being unsustainable. This is why we must come together to talk about Space Situational Awareness. In the short term, SSA may mean asking whether today's satellite are safely avoiding colliding with one another or with existing debris. In the long term, an integrated approach to Space Situational Awareness also means asking what are the trends for where objects are located in space? What are the impacts of currently crowded orbits for the risk of future satellite missions in those orbits? What is the demand from industry to use specific orbital regimes and what is driving that demand? Who are the new government, commercial and academic players who seek to participate in space activity and what are their needs? What are the sustainable options for expanding space activity given the existing set of waste that is already orbiting the earth?

When I was an undergraduate studying aerospace engineering at MIT, trying to learn how to build a satellite, I never considered that a potential design constraint on a new space mission is whether there is enough room in space for my mission to operate safely. Now, as we all sit here and imagine a satellite orbiting around earth, we might say, of course there is enough room. Space is Big! But this does not take into account the key technical challenges of Space Situational Awareness. Space may be big, but it is technically very difficult to detect, track and identify all the objects that orbit the earth, especially the small objects that are the results of collisions or break ups for which we know little about their shape and make up. Space may be big, but there are a few key locations that many satellite operators prefer to operate. Space may be big, but satellite collisions are low probability, high consequence events that have an impact far beyond the owners of the specific satellites. Due to these concerns, it is necessary to start teaching engineering students that they should consider methods to reduce the risk of collisions as part of their regular space mission design activities.

The global space community is working on many fronts to both identify methods to improve Space Situational Awareness and identify actions that satellite operators can take to reduce the likelihood that they will cause a collision or long-term debris. The United Nations Committee on the Peaceful

Uses of Outer Space Adopted the 21 Guidelines for the Long-term Sustainability of Outer Space Activities[viii]. These provide a starting point to recommend decisions that regulators and satellite operators can take to reduce their own contributions to debris.

As we look around the world, there is not a uniform regulatory regime or code of behavior that all types of satellite operators are following regarding contributing to Space Situational Awareness knowledge or reducing the risk of space debris. This is understandable given the historical development of space activity within countries. Because of this global diversity, there is an opportunity for a non-government approach to complement formal international instruments, national regulation and industry initiatives. The complementary approach can be a positive incentive that rewards any satellite operator, government, commercial or academic, who takes proactive measures to contribute to space sustainability. I part of a team that is creating such a positive incentive; it is called the Space Sustainability Rating.[ix]

The Space Sustainability Rating was conceived by the World Economic Forum's Global Future Council on Space[x] in response to the planned operation of many new commercial satellite constellations in Low Earth Orbit. The World Economic Forum saw an opportunity to encourage each satellite operator to consider how they could behave in a responsible manner with their satellites as the number of missions in LEO is expected to drastically increase. The World Economic Forum held a competitive solicitation process to request teams to volunteer to create the Space Sustainability Rating. I was selected to co-lead the team creating the rating. The organizations involved include the World Economic Forum, the European Space Agency, Bryce Space and Technology, the University of Texas at Austin and my institution, the Massachusetts Institute of Technology. The SSR will be a score that any satellite operator can apply to receive. The score considers two key factors. First, the score asks where a satellite mission plans to operate and what the current state of that orbital regime is based on past satellite operations. In other words, the SSR asks whether Earth orbit has the capacity for a new mission to join the satellites and debris that are already in a specific altitude and inclination. Second, the SSR asks what the satellite operator will do to increase their Space Situational Awareness of their own mission, to decrease the time their satellite spends on orbit after the mission is complete and to coordinate effectively with other space operators in order to avoid collisions. Our team is still in the process of designing the Space Sustainability Rating and deciding how it will function operationally. Our hope it that it will become a routine process for space operators of all types, from universities, firms and governments, to apply for an Space Sustainability Rating during the design phase of their mission and to use the information to help them select responsible behaviors. They can continue to apply for the SSR throughout the life of their mission as their mission plans evolve and impact their level of sustainability. In order to make the SSR relevant around the world our team is pursuing regular outreach to government, academic and civil society audiences. We are receiving input via workshops and meetings from satellite operators, launch providers, government regulators and universities. We hope that governments will join us in promoting this methodology as a way to recognize responsible behavior in space.

Our planet does not yet have a Space Traffic Management system that directs how satellites are operated and give requirements on physical maneuvers for space operators. There is ongoing dialog at the international space community that now is likely the right time to start global negotiation about a Space Traffic Management system. In anticipation of this, my research team performed a study to consider the interests of countries that are new to space in the way a future Space Traffic Management System might work. The findings of our research showed that countries from all regions, including Latin America, Africa, Southeast Asia and Eastern Europe, expressed great interest in contributing to the design of a global Space Traffic Management System and they hope the process is done in a forum that allows them to share their concerns openly.[xi] The United States clearly plays a leadership role in space for all over countries in the world. This is both a privilege and a responsibility. It means that the US has the responsibility to consider how to achieve national goals while also helping to lay a foundation for global Space Traffic Management regimes that will be beneficial to countries from many backgrounds. It will be beneficial to the United States if we build strong international relationships among emerging space countries by finding common vision with them for how to design and implement a global Space Traffic Management system.

An excellent example of the opportunities of engaging with countries of all backgrounds in space is the case of Bermuda. The small island of Bermuda is well known for hosting a dynamic re-insurance industry and for maintaining beautiful natural settings that attract tourists. The current government of Bermuda seeks to further diversify their portfolio of economic focus areas. They are asking how space will continue to grow in the future as one of their national priorities. Bermuda already participates in the global space community; they host tracking stations that support launch and satellite tracking facilities for NASA and other space organizations. I serve as an advisor on the Space and Satellite Advisory Panel to the Government of Bermuda. Bermuda is developing a national space strategy and keeping Space Sustainability as a key theme in their plans. Countries like Bermuda want to continue benefiting from the services and spinoffs of space. They also want to directly participate in the dialog about how the global community will ensure sustainable space operations for years to come. Bermuda is not alone. I am honored to visit countries regularly in Africa and Latin America who see participation in the global space marketplace as core to their national vision. I have had discussions like this recently in countries such as Colombia, Chile and Angola.

Thanks to historical leadership, the United States has a special role to play in response to the integrated crisis and opportunity of global sustainability on land, in the ocean, in the atmosphere and in space. We do not have adequate Space Situational Awareness to ensure safe operations of space missions for years to come; thus, we must continue to innovate and collaborate to improve the outcomes in this field. The US can also choose to serve as a productive global leader in the dialog on Space Traffic Management. I recommend several policy actions that can help address these challenges.

1) **Commitment to Space Sustainability:** The US government should adopt a commitment to space sustainability as a principle driving space activities. Space Sustainability means ensuring that space is a safe environment for future operations of human space flight, scientific missions, commercial missions and missions by emerging space actors.

2) **Continued engagement in International Dialog via Space Policy Forums.** The US government should continue to engage deeply in international space policy forums such as the Committee on the Peaceful Use of Outer Space and the Interagency Space Debris Coordination Committee.[xii] The US should look for ways to build common vision with emerging space nations who are interested in space sustainability.
3) **Provide government support for SSA and STM work.** The US government should ensure that adequate funding and mandates are allocated to allow robust academic research and operational activity to improve Space Situational Awareness and develop concepts related to Space Traffic Management.

Thank you for your time and I look forward to our dialog today.

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[ii] https://www.skatelescope.org/
[iii] https://www.aiaa.org/SciTech
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[ix] https://www.media.mit.edu/posts/creating-a-space-sustainability-rating/
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Biography
Professor Danielle Wood
Assistant Professor of Media Arts & Sciences and Aeronautics & Astronautics
Director of the Space Enabled Research Group
Media Lab, Massachusetts Institute of Technology

Professor Danielle Wood serves as an Assistant Professor in Media Arts & Sciences and holds a joint appointment in the Department of Aeronautics & Astronautics at the Massachusetts Institute of Technology. Within the MIT Media Lab, Prof. Wood leads the Space Enabled Research Group which seeks to advance justice in Earth's complex systems using designs enabled by space. Prof. Wood is a scholar of societal development with a background that includes satellite design, earth science applications, systems engineering, and technology policy. In her research, Prof. Wood applies these skills to design innovative systems that harness space technology to address development challenges around the world. Prior to serving as faculty at MIT, Professor Wood held positions at NASA Headquarters, NASA Goddard Space Flight Center, Aerospace Corporation, Johns Hopkins University, and the United Nations Office of Outer Space Affairs. Prof. Wood studied at the Massachusetts Institute of Technology, where she earned a PhD in engineering systems, SM in aeronautics and astronautics, SM in technology policy, and SB in aerospace engineering.

Chairwoman HORN. Thank you, Dr. Wood. Dr. Stilwell?

TESTIMONY OF DR. RUTH STILWELL, ADJUNCT PROFESSOR, NORWICH UNIVERSITY, SENIOR NON-RESIDENT SCHOLAR, SPACE POLICY INSTITUTE, GEORGE WASHINGTON UNIVERSITY

Dr. STILWELL. Chairwoman Horn, Ranking Member Babin, distinguished Members of the Subcommittee, thank you for the opportunity to appear before you today. Working as an educator in public administration, and a researcher in the policy and regulatory aspects of space situational awareness and space traffic management, it is an honor to present come of my findings to you today. Space traffic management as a field of study represents a developing need to prevent collisions between objects in space both operating in, and transiting through, shared orbital domains. The reliance on the vastness of space as a mitigation for collision risk is no longer viable, given the current demand.

The commercialization of space is not new, but its current rate of growth is unprecedented, and without structural change to the manner in which space is managed, the sustainability of the orbital domain is in question, both threatening national space assets, and constricting a vibrant and growing sector of our economy. Approaching the policy question of space traffic management as a decentralized safety service, rather than a regulatory function, can help provide clarity on the appropriate role of the international community, the government, and the private sector.

The first question that arises in a discussion of space traffic management is who has the authority over the orbital domain? Quite simply, how do you regulate it if you don't own it? This is where we find clear parallels to the maritime domain. Safety on the high seas is assured by the application of international standards and agreements enforced by the State under whose flag the vessel operates. This aligns with the continuing supervision provisions of the Outer Space Treaty. It does not rely on one authority, but rather on the agreement of the seafaring nations of the world to enforce agreed-upon standards.

While we consider the prevention of collisions in space when we discuss space traffic management, the sustainment and protection of the orbital domain includes issues that go beyond tactical collision avoidance, and have additional parallels to international maritime operations. Debris, contamination, and salvage affect both domains, and we can look to maritime law as a model. Debris mitigation and remediation guidelines to prevent major debris-generating events require international agreement to be sustainable and effective. By dividing the concept of space traffic management into its component parts, the policy framework and appropriate structures become more clear.

The foundational element, space situational awareness, provides the information infrastructure upon which the safety regime can be built. This includes the detection, collection, and dissemination of information on the location and trajectory of natural and manmade objects in space. There are many sources of data, including space surveillance, observation, and operator data. Built on top of that is the Conjunction Assessment and Alerting Service. Currently both services are provided by a single entity through the U.S. Government, but we are already seeing commercial providers. This clearly illustrates that there is a path to a decentralized model for space traffic management, however, this will not occur organically.

The transition from a service provided by the United States military on a no-cost basis to every satellite operator in the world to one where there are multiple providers who can provide conjunction assessment and alerting services tailored to the needs of individual operators requires a structured transition with deliberate oversight. The steps needed to build a decentralized STM include, one, the international agreement on standards of behavior for the purpose of collision avoidance. This is a government function that cannot be delegated. The creation of standards and best practices can, and should, be driven by industry, but transforming those standards and best practices into an international agreement is the role that only governments can fill. Two, processes and agreements for the collection, validation, and sharing of space situational awareness information, including space surveillance and operator information. This is a joint effort between government, industry, and academia to create a robust system that allows for inputs of space situational awareness data from multiple sources, including the intent data from operators. And, finally, the expansion of a market for conjunction assessment and alerting services.

Under the current model, hundreds of thousands of conjunction messages are generated every year, resulting in only a few hundred avoidance maneuvers. The industry bears an enormous cost in evaluating these assessments. A competitive commercial market incentivizes investment in analytics tailored to customer needs. This is not a unique concept. It bears a lot of similarity to the National Weather Service and the GPS models. In both cases, services built primarily for government purposes are provided to the private sector, and support a robust and innovative commercial industry. Using these models can provide a path that allows for the transition from the current state to a decentralized global model that ensures a sustainable space environment.

I thank you for your time and attention to this important issue, and I welcome your questions.

[The prepared statement of Dr. Stilwell follows:]

Statement of Dr. Ruth E. Stilwell
Adjunct Professor, Norwich University
Senior Non-Resident Scholar, George Washington University Space Policy Institute

Space Situational Awareness: Key Issues in an Evolving Landscape

Before the
Subcommittee on Space an Aeronautics
Committee on Science, Space and Technology
United States House of Representatives
February 11, 2020

Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee, thank you for the opportunity to appear before you today. Working as an educator in public administration and a researcher in the policy and regulatory aspects of space situational awareness and space traffic management, it is an honor to present some of my findings to you today.

Space Traffic Management as a field of study represents a developing need to prevent collisions between objects in space, both operating in, and transiting through, shared orbital domains. The reliance on the vastness of space as a mitigation for collision risk is no longer viable given the current demand.

The commercialization of space is not new, but its current rate of growth is unprecedented and without structural change to the manner in which space is managed, the sustainability of the orbital domain is in question, both threatening national space assets and constricting a vibrant and growing sector of our economy. Approaching the policy question of space traffic management as a decentralized safety service rather than a regulatory function, can help provide clarity on the appropriate role of the international community, the government, and the private sector.

The first question that arises in a discussion of space traffic management is, who has the authority over the orbital domain? Quite simply, how do you regulate it, if you don't own it? This is where we find clear parallels to the maritime domain. Safety on the high seas is assured by the application of international standards and agreements, enforced by the state under whose flag the vessel operates. This aligns with the continuing supervision provisions of the Outer Space Treaty. It does not rely on one authority but rather on the agreement of the sea faring nations of the world to enforce the agreed upon standards.

While we consider the prevention of collisions in space when we discuss space traffic management, the sustainment and protection of the orbital domain includes issues that go beyond tactical collision avoidance and have additional parallels to international maritime operations. Debris, contamination, and salvage affect both domains and we can look to maritime law as a model. Debris mitigation and remediation guidelines to prevent major debris generating events require international agreement to be sustainable and effective.

By dividing the concept of space traffic management into its component parts, the policy framework and appropriate structures become more clear.

The foundational element, space situational awareness, provides the information infrastructure upon which the safety regime can be built. This includes the detection, collection, and dissemination of information on the location and trajectory of natural and manmade objects in space. There are many sources of data, including space surveillance, observation, and operator data.

Built on top of that data is the Conjunction Assessment and Alerting Service. Currently, both services are provided by a single entity through the US government. But we are already seeing commercial providers. This clearly illustrates there is a path to a decentralized model for space traffic management. However, this will not occur organically.

To transition from a service provided by the United States military on a no cost basis to every satellite operator in the world, to one where there are multiple providers who can provide conjunction assessment and alerting services tailored to the needs of individual operators requires a structured transition with deliberate oversight.

The steps needed to build a decentralized STM:

1. International agreement on standards of behavior for the purpose of collision avoidance.

This is a government function that cannot be delegated. The creation of the standards and best practices can, and should, be driven by industry. But transforming those standards and best practices into international agreement is a role that only governments can fill.

2. Processes and agreements for the collection, validation, and sharing of space situational awareness information, including space surveillance and operator information.

This is a joint effort between government, industry, and academia to create a robust system that allows for inputs of space situational awareness data from multiple sources, including intent data from operators.

3. Expansion of market for conjunction assessment and alerting services.

Under the current model, hundreds of thousands of conjunction messages are generated every year resulting in only a few hundred avoidance maneuvers. The industry bears an enormous cost in evaluating these assessments. A competitive commercial market incentivizes investment in analytics tailored to customer needs.

This is not a unique concept. It bears a lot of similarity to the National Weather Service and GPS models. In both cases, services built primarily for government purposes are provided to the private sector and support a robust and innovative commercial industry. Using these models can provide a path that allows for the transition from the current state to a decentralized global model that ensures a sustainable space environment.

Thank you for your time and attention to this important issue, and I welcome your questions.

Maritime Law as a Model for Space Traffic Management

Introduction

Global governance models for space, and for Space Traffic Management (STM) in particular, are constrained by the principles of the Outer Space Treaty. The provisions of Article II, stating, "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means" is often cited as a limiting factor in the regulation of a safe and sustainable orbital environment.

However, the recognition of space as an international domain invites comparison to the regulation of other international domains.

Space, as an international domain, is distinct from international waters (maritime) and international airspace (aviation) from a treaty perspective. Both aviation and maritime domains had well established commercial operations at the point of international agreement. The concepts for the regulation of international airspace were built upon the existing standards for international waters and the high seas. Aviation treaties refer to "high seas airspace" as a defining term. In contrast, the Outer Space treaty was developed not to facilitate safe commercial use, but as a "non-armament" treaty built on the principles of the Antarctica treaty. The purpose of the space treaty was to promote peaceful use and scientific discovery, while the underlying principles of the maritime and aviation agreements were to facilitate safe use for commercial transportation. This creates a structural challenge in trying to model space traffic management on other modes of transport as the underlying treaties are based on different and in certain ways, conflicting, assumptions.

If we are to develop a space traffic management regime for the purposes of preserving a safe and sustainable orbital environment, an evolution from a non-armament construct to one that facilitates safe and accessible commercial use is needed. While the technology of space operations may be more similar to aviation, from a policy perspective, international maritime agreements may provide the more instructive model. The international space community may look to the existing standards and practices in maritime operations for registry, oversight, right-of-way, and salvage as models for the development of space traffic management practices. This approach uses a globally accepted construct for maintaining safety and establishing regulatory oversight for operations in a domain where no claims of sovereignty can be made and the concept of free access is well established.

Regulation vs. Control

For aviation, the safe, orderly, and expeditious flow of aircraft through international airspace is achieved through the concept of air traffic management. Under this concept, an appropriate Air Traffic Services Authority is responsible for preventing collisions between aircraft in a designated volume of airspace. For airspace over the high seas, where no state can exert a claim of sovereignty, a contracting state to the United Nation's International Civil Aviation Organization assumes the authority through a regional air navigation agreement approved by the ICAO Council. Air traffic services are provided in accordance with ICAO standards and recommended practices by a state with exclusive authority, but not sovereign control. The distinction is that the enforcement authority of the rules of the air remains with the state of registry for aircraft operating in high seas airspace.

Table 1: Comparison of Maritime and Aviation Authorities

MARITIME	AVIATION
Multiple authorities operating in shared domain	Single authority over designated volume of airspace
Control – Prevention of collisions between vessels through action and judgement of operator of the vessel.	**Control** – Prevention of collisions between aircraft through appropriate ATS authority with jurisdiction over a designated volume of airspace.
Regulation – Enforcement of Law of the Sea and related standards subject to the authority of the Flag State where the vessel is registered.	**Regulation** – Enforcement of Rules of the Air subject to the authority of the State of Registry.
Standards – Collaborative process under UN Specialized Agency, International Maritime Organization (IMO).	**Standards** – Collaborative process under UN Specialized Agency, International Civil Aviation Organization (ICAO).

Components of STM

The tactical elements of collision avoidance in both aviation and maritime domains are similar and can be extrapolated to the space domain:

Space Situational Awareness (SSA) - the detection, collection and dissemination of information on the location and trajectory of natural and manmade objects in orbit around the Earth;

Conjunction Assessment and Alerting (CAA) – the evaluation of natural and manmade objects in Earth's orbit to identify potential collisions and notification of operators to determine if avoidance maneuvers are necessary, and;

Regulation – enforcement by the State of Registry/Launch under Outer Space Treaty obligation of "Continuing Supervision."

However, the sustainment and protection of the orbital domain includes issues that go beyond tactical collision avoidance and have additional parallels to international maritime operations. Debris, contamination, and salvage affect both space and maritime law in a way that is not mirrored in aviation.

From a governance perspective, maritime law evolved over centuries, but global standards development became institutionalized with the advent of the United Nations. For aviation, the umbrella Chicago Convention is updated through amendment to a series of annexes, while the IMO uses a series of topic specific independent conventions that can be amended as needed. The

IMO approach may prove to be more agile to accommodate technical innovation and market changes in space operations.

Debris

Space Debris is a particular risk that is not present in the aviation domain. The debris risk can be divided onto two categories from a policy perspective. One, mitigating the risk of collision with debris (hazards) and two, to minimize debris generating behaviors (pollution). Similar issues are addressed in several IMO conventions, including:

Nairobi International Convention on the Removal of Wrecks
Convention on the International Regulations for Preventing Collisions at Sea
International Convention for the Prevention of Pollution from Ships
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
International Convention on Salvage

Conclusion

While Air Traffic Management can provide certain concepts to facilitate the development of an international Space Traffic Management regime, maritime law may serve as a more appropriate model. Rather than seeking to control the operations within a designated volume of space, the maritime model allows multiple regulators to exercise oversight over individual operators in a shared domain. In addition, issue specific international agreements may provide an evolutionary approach to global standards of behavior in orbit.

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Decentralized Space Traffic Management

Dr. Ruth Stilwell

Senior Non-Resident Scholar, Space Policy Institute, George Washington University, 1957 E

Street NW Suite 403, Washington, DC 20052 USA
Adjunct Faculty, Norwich University, 158 Harmon Dr., Northfield, VT 05663 USA
Email: rstilwel@norwich.edu

ABSTRACT

This paper examines the political, policy, and regulatory barriers to the provision of STM as a global safety service. It considers the concepts under development for airspace from 20km to 100km to accommodate new entrants in aviation and space and discuss how those concepts may provide a path forward for decentralized space traffic management.

1. Introduction

Space Traffic Management as a field of study represents a developing need to prevent collisions between objects in space, both operating in and transiting through shared orbital domains. The reliance on the vastness of space as a mitigation for collision risk is no longer viable given the current demand.

Researchers look to models in other domains, including air traffic management to provide a path forward. Certainly, there are clear similarities in the emergence of air traffic management in aviation and the concerns of space traffic today. The early years of air transport did not require traffic management as the demand for airspace was low and the barriers to entry were high. However, the declining cost of air travel, coupled with increasing competition between airlines, created a safety concern and the need for external controls; air traffic management. One can draw clear parallels between air traffic and space traffic in this regard. However, air traffic management is predicated on the legal authority of a state to exercise control over a sovereign volume of airspace. The space environment includes no such authority.

This question of sovereignty can be seen as an insurmountable barrier to the development of a functional space traffic management regime. However, by approaching the policy question of space traffic management as a decentralized safety service rather than a regulatory function, the question of sovereignty becomes less of a barrier.

2. Definitions

Discussions of Space Traffic Management are complicated when it is considered without a common agreement on what is meant by the term. For the purpose of this paper, terminology presented to the International Association for the Advancement of Space Safety is used [1]. The functional elements of space traffic management are defined as follows:

Space Situational Awareness (SSA) - the detection, collection and dissemination of information on the location and trajectory of natural and manmade objects in orbit around the Earth.

Conjunction Assessment and Alerting (CAA) – the evaluation of natural and manmade objects in Earth's orbit to identify potential collisions and notification of operators to determine if avoidance maneuvers are necessary.

Space Traffic Management (STM) – the control of the orbital environment by an appropriate authority responsible for the prevention of collisions between operational satellites and natural or manmade objects.

To facilitate a comparison of STM to ATM, it is useful to compare these terms to similar concepts in aviation.

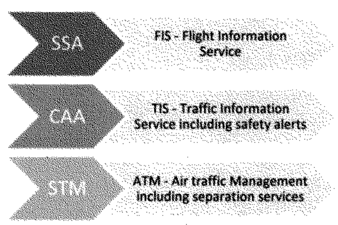

Figure 1: Comparison of terms between STM and ATM

Air traffic control systems provide different levels of service based on the airspace designation. At its most basic level, air traffic service is the provision of information to aircraft through a flight information service that includes information on meteorological conditions, aerodromes, and possible hazards to flight. It does not necessarily include separation services. A traffic information service provides information about active air traffic and can include safety alerts regarding a collision risk, but the decision on the avoidance maneuver lies with the operator of the aircraft. Air Traffic Management is the comprehensive application of air traffic control to prevent conflicts between aircraft to eliminate a collision risk through the positive control of aircraft by the air traffic service provider.

The primary distinction between air traffic services that are advisory (FIS and TIS) and where separation services are provided (ATM) is the authority and responsibility for the avoidance decision. At the level before separation services are provided, the decision to execute an avoidance maneuver lies with the operator (pilot). Where separation services are provided, the decision lies with the air traffic control service provider (ATC). Additionally, there is a distinction between separation and collision avoidance. Separation is the application of a specific separation standard to eliminate a collision risk. This depends on a regulatory requirement for the operator to comply with the instructions from the service provider. Air traffic separation and collision avoidance are not interchangeable terms. When air traffic separation services are applied the collision risk, and consequently the need for a collision avoidance maneuver is eliminated. This is a fundamental distinction; the application of a separation standard and the responsibility to maintain that separation is an air traffic control function. While a pilot maintains responsibility for safety of flight, including collision avoidance, a pilot is not responsible for maintaining a distance prescribed by a separation standard. The pilot responsibility is to comply with the air traffic clearance, it is the controller's responsibility to issue an air traffic clearance that provides distance between aircraft consistent with a prescribed separation standard. The importance of this distinction in responsibility is key to the sovereignty question.

While both advisory and separation functions are safety services, the transition from an advisory service, where the decision to maneuver rests with the operator, to a separation service, where the decision rests with the service provider, triggers the need for a common regulatory authority. A common regulatory authority raises the questions sovereignty and control.

3. Barriers

If STM is defined as a service at the level of ATM where separation services are provided, there are considerable barriers to the implementation of a single space traffic management regime. One of the primary barriers is the question of sovereignty. In other models for managing traffic, particularly air traffic management, the model is predicated on a regulatory authority exercising positive control over a specified volume of airspace. The underlying premise is that an entity has the sovereign right to exercise or delegate that authority. This does not exist in the space regime and the outer space treaty clearly states that no claim of sovereignty can be made.

The assertion that there is no regulatory authority in space is inaccurate, as each state of launch is responsible to exercise oversight and continuing supervision over the activities of nongovernmental entities in space. The authorization to launch carries with it the obligation for the authorizing state to continually supervise the activities. This implies regulatory authority.

The transition from space situational awareness to space traffic management conjures images of a command and control structure similar to that of air traffic control, where an external entity exercises control over all operators within a given volume of space. It is important to recognize that the majority of collision risks in space involve a non-maneuverable object or debris. This makes STM modeled after ATM impossible. However, we can look to ATM as it developed systems to mitigate risks from non-maneuverable objects including obstacles, terrain, and weather.

3.1. *Political*

The political barriers to the implementation of a global space safety system to provide STM are not unique to space. The underlying intergovernmental questions of who benefits and who pays drive the political discussion. A free service provided by a single state, or even a coordinated effort of several states is not sustainable as changes in priorities within the providing state could compromise the availability of critical safety information for internal and external users. Political disturbances in the providing state could have global consequences for STM if the industry relies on an oligopolistic model.

This is where the distinction between space situational awareness (SSA) and conjunction assessment and alerting (CAA) becomes important. The core information may be provided by a limited number of state sources, but assured access to the information is only sustainable to the extent that the primary purpose of the data serves a core mission of the state provider.

There are well established precedents for the provision of no cost civil services from infrastructures developed and funded for state purposes. These services or data can lead to commercial and private development of expanded applications. The GPS signal provides a relevant model. The GPS constellation was developed, deployed, and funded for military purposes, but there is no additional cost to making the signal available for other applications. Similarly, the space catalog and tracking infrastructure is funded for the purpose of protecting national space assets. Making the information available for civil purposes has little additional cost and serves as a benefit to the state mission. However, the cost of developing and improving the conjunction alerting system to provide services to commercial operators changes the paradigm.

Currently, the CAA system provides hundreds of thousands of alerts each year that result in no avoidance action by the operator. The cost of assessing these alerts and determining what, if any, action is necessary is born by the recipient of the alert. If there is a desire to improve the accuracy of the alerts to reduce the costs of evaluation, the costs would shift from operator to provider. By separating the SSA from CAA, we create an opportunity for the industry to reallocate resources to improve the accuracy of the CAA function. If the decision to maneuver remains with the operator, the CAA function of STM can be provided by multiple sources through a competitive industry.

Funding is ultimately a political question. A state funded service is only viable to the extent that it remains a sufficient priority over other state functions. Investment in new technologies and maintaining a state-of-the-art system is a competition for resources against unrelated industries and priorities. This is outside the control of the space industry and the industry should consider a state funded "free" CAA service as undesirable.

Conversely, a state service funded by industry fees or excise taxes should not be used as a revenue stream to support other state priorities. For state-provided/industry-funded services it is important to develop structures that ensure revenue is dedicated to providing the services. This is also an area where STM can look to ATM for governance models. Funding for air traffic control systems is managed through a small number of models globally and is a frequently debated issue in the US [2].

3.2. *Policy*

With regard to policy, the absence of a common definition for Space Traffic Management is a fundamental barrier to developing a global policy. It is important to identify what is meant by STM. Is it the collection and distribution of space situational awareness data or does the process of STM begin with the conjunction analysis and alerting? Does STM require that an appropriate authority direct the actions of the space actors in an encounter, and if so, does it assume the liability for those actions? A common understanding of what constitutes STM is needed to shape a policy that can be implemented across space faring states.

3.3. *Regulatory Authority*

The absence of sovereignty in space precludes the establishment of a regulatory authority based on models established for ATM [3]. However, like aviation operations in uncontrolled airspace, while the operations may be uncontrolled, they are not unregulated. While aviation operations in uncontrolled airspace are subject to a "see and avoid" standard for collision avoidance, operations are subject to rules of the air and regulatory standards for determining responsibility, liability and right of way. The rules of the air apply to operations whether or not they are subject to intervention by air traffic control. Similarly, each state exercises regulatory authority over their space operators. While there is a specific obligation placed on the state of launch, some authorities have opted to exercise control over space operations conducting by citizens even when launched from another state. The US uses this model in both space and aviation. For aviation operators, US regulations apply outside US airspace to persons with a US aviation certificate and to aircraft under US registry, regardless of the location of the operation. The question of airspace sovereignty does not restrict the ability of the US authority to exercise oversight of the operations.

It is important to recognize the distinction between the regulation of on orbit activities and the obligation for states to provide authorization and continuing supervision of ongoing activities in space under article VI of the Outer Space Treaty. Prevention of collisions in space is a continuing obligation of states under articles VII and VIII of the treaty. As this obligation applies to each state as a party to the agreement, it is necessary to create a model for STM that reflects that distributed obligation. A decentralized approach to space traffic management requires a view of regulatory authority that moves away from an air traffic management model, where ATC controls operations within a volume of airspace, to one that considers the enforcement of a common set of rules of operation, including right of way, similar to the concept applied in uncontrolled airspace.

3.3.1. *Rules of the Air*

If we consider the evolution of collision avoidance in aviation and the manner in which obstacles, terrain, weather, and other hazards to flight are mitigated, a rule-based approach to STM augmented by SSA becomes possible.

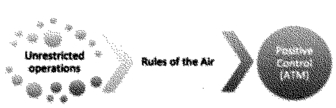

Figure 2: Evolution of ATM Collision Avoidance

In comparing STM to ATM, the presumption is that there is a need to jump to an end state that models current air traffic management. This approach overlooks the value of the transformative stage in ATM where rules of the air were developed to govern actions of individual operators in order to prevent collisions, augmented by the use of advisory services to support the operator's decision making. Requirements like operating right of the centerline of an airway, hemispheric altitudes for direction of flight, and requirements to maintain specified distances from clouds were all developed for the purpose of collision avoidance. The operators were obligated to comply with the rules, and states are required to enforce this compliance, however the individual responsibility for collision avoidance remained with the operator.

Formally, Rules of the Air were established on an international basis through the Convention on International Civil Aviation [4]. This rule-based approach relies on contracting states to ensure compliance but does not interfere with their sovereignty. This led to the development of air traffic separation services as traffic congestion warrants and eventually the systems of air traffic management currently in place. While services are provided at different levels and utilize different funding mechanisms based on the determination of the providing state, the rules, standards, and recommended practices are consistently applied around the globe. Agreeing to a common set of rules for the purpose of collision avoidance in space, where the state of launch has the obligation to ensure compliance, could provide a path to decentralized space traffic management by creating a common regulatory framework without impinging on the sovereignty of the state.

4. Concepts for "Near Space" traffic management

The evolution of ATM in the high-altitude/near space domain is considering many of the same issues as STM. In many ways, this domain has more similarity to space operations than other aviation domains:

- Most operators in the region above 20KM (60,000 feet) are unmanned and may be long duration flights.
- The totality of the airspace is low density, but growth in the market is increasing demand.
- The airspace has a mix of high performance and low-maneuverability aircraft.
- In most of the world, the airspace above 20KM is either uncontrolled or undesignated.
- Developments in this area include concepts of cooperatively managed airspace.

Ideas for this airspace, while still in the development stage, may create opportunities for the space community to consider different models under development and leverage any safety cases that are developed. Concepts for near space traffic management include a shared situational awareness picture, where all operators have knowledge of the traffic and hazards in the airspace and are subject to rules of the air, including right of way. While the operator is responsible for determining the avoidance maneuver, the decision is supported by common information with known fidelity. This approach requires participation from all operators in the airspace. The participation requirement is tied to the ability to access the airspace.

5. Policy Model for Decentralized STM

In building a decentralized model for STM, consideration should be given to developing advisory services that leave the decision-making process for collision avoidance maneuvers with the operator. This allows for multiple providers of CAA services and moves beyond the sovereignty question, as no state has exclusive authority over the domain. However, in order to go beyond the current system where a conjunction message is issued, the operator evaluates the level of risk, takes into account maneuvers, and decides whether to perform an avoidance action and their operational constraints [5], an agreed upon set of rules that prescribes the circumstances under which action is to be taken, including right of way, and a requirement for operators to share information on the maneuver, is needed.

This creates a structure that allows for the collection and distribution of situational awareness data and a requirement that operators react to conjunction risks in a predicable manner. Governments, industry, academia and other entities with the capacity to collect space surveillance information are expected to continue to provide that data. Between the space situational awareness and the avoidance maneuver is the conjunction assessment and alerting. This is the opportunity for a decentralized service. The analytics used to determine whether a conjunction between a maneuverable and non-maneuverable object, or between two maneuverable objects will occur, need to be sufficiently reliable to form the basis for a required action under an agreed upon set of rules. In addition, maneuvers must be reported back into the shared situational awareness picture to ensure accuracy.

By decoupling SSA from CAA, there is a greater opportunity for competition in the field of STM. There is intrinsic value in encouraging conjunction assessment and alerting as a commercial service. It fundamentally transforms the satellite industry from user to customer of STM services. This has policy benefits in the ability to direct resources and incentivizes CAA providers to continually improve accuracy and quality of the alerts. There is often resistance to this concept due to the perception of additional costs because conjunction alerting is currently provided as a "free" service from government entities. However, the cost to the industry of processing hundreds of thousands of alerts that do not require an avoidance maneuver is substantial. As a user, rather than customer of the service, the industry lacks the ability to demand investment in improving alerts. The costs are born by the industry whether it is through processing false alerts or investing in more accurate predictive capability.

Steps needed to build a decentralized STM

1. International agreement on standards of behavior for the purpose of collision avoidance.
2. Processes and agreements for the collection and sharing of space situational awareness information, including space surveillance and operator information.
3. Expansion of market for conjunction assessment and alerting services.

Finally, the collection and distribution of space situational awareness information will always be subject to limitations from states that choose not to share information on national security assets. While the SSA does not require information on the purpose of a given space object, some states will seek to also conceal the position information. While space surveillance systems may render this effort moot, aviation provides a policy model to address this concern. The issue of state aircraft and national security was a similar concern in the development of the international treaty on civil aviation. The concept of "due regard" was established in the convention to allow state aircraft to operate outside the rules of the air provided they operated with "due regard" for the safety of other aircraft. This placed the full burden for the avoidance of collision on the state aircraft in exchange for the ability for those aircraft to operate outside the common rules, including the ability to be undetectable by other operators and service providers.

6. Summary and Conclusion

Decentralized STM requires the development of a set of enforceable standards of behavior and the decoupling of space situational awareness (SSA) and conjunction assessment and alerting (CAA) and continues the model where the operator determines avoidance maneuvers. This model exists in aviation as aircraft in most airspace classes are not required to utilize separation services. This approach designs STM as a safety advisory service eliminating the sovereignty barrier that occurs with the development of a regulatory model that mirrors air traffic control or ATM. The regulatory authority to enforce a common set of rules of behavior for the purpose of avoiding a collision in space remains with the state of launch rather than with an established authority controlling a volume of space.

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RUTH E. STILWELL

office@aerospacepolicysolutions.com

Dr. Ruth Stilwell is the Executive Director of Aerospace Policy Solutions LLC, an adjunct professor at Norwich University, and Senior Nonresident Scholar at the Space Policy Institute of George Washington University. She is one of the world's leading authorities on integrated space and aviation policy and governance.

A 25-year air traffic controller, experienced labor leader and policy expert, Dr. Stilwell is also an accomplished researcher and lecturer. Her numerous publications and presentations, which cover a wide range of space and aviation, public safety, human factors, administration, financing, and industry reform topics. In addition to her publications, she is a contributing author to McGill University's Global Space Governance: An International Study. Dr. Stilwell's specific areas of expertise include: integrating commercial space operations in civil airspace; projecting air traffic controller retirement and staffing requirements; FAA funding and financing structures; workers' rights and more.

Dr. Stilwell served from 2010-2015 as the industry expert representing air traffic controllers on the International Civil Aviation Organization (ICAO) Air Navigation Commission in Montreal. Her air traffic control experience includes 25 years of operational duty at the Miami Air Route Traffic Control Center, two years as liaison to the FAA Requirements Service, and six years as Executive Vice President of the National Air Traffic Controllers Association.

The founding chairperson of the Air Traffic Services Committee of the International Transport Workers Federation, a position she held for four years, Dr. Stilwell currently serves on the Technical Committee on Human Spaceflight Safety of the International Association for the Advancement of Space Safety, which is working to develop safety guidelines for human commercial spaceflight.

Dr. Stilwell earned her BA in Labor Studies at the National Labor College and her MPA and DPA at the University of Baltimore. A resident of Florida, she enjoys skiing, long-distance running, and spending quality time with her stepson.

Chairwoman HORN. Thank you, Dr. Stilwell, and thank you to all of the panelists for your incredible detailed, and comprehensive, and important testimony that really touches on the wide variety of issues. At this point we'll begin our first round of questions, and the Chair recognizes herself for 5 minutes.

Given the breadth, and the depth, and the scope of the issues that we're facing, I want to start out by asking all of the panelists this question, that, you know, while many people are eager—while there are many of us that are eager to settle the questions about U.S. agency roles, public, private, what is—how—what is that right balance? And we'll consider some more of those as we carry out our work. I think further identifying the scope and prioritizing the order of addressing the solutions is something that we need to start with, and I'd like to ask each of you, and we'll just go down the line, to briefly identify the most pressing issue, and how you would propose to address it. So we'll just start with you, Dr. Weeden.

Dr. WEEDEN. Yeah. So—thank you for that. My most pressing issue is the policy question. I mean, that's partly because I'm a policy wonk, so I think that's, you know, I—lot of time on, but I currently think all the other issues, on improving the technology, improving the coordination, all hinge on that policy question. So, for me, the most important thing is that transition of the civil SSA responsibility to wherever it's going to go, and making sure that happens in a smooth manner, as mentioned by other ones, is the most important thing. And I believe all the other issues on improving the accuracy, and collecting more data, and better data fusion, and sharing, and collaboration all flows out of that decision.

Chairwoman HORN. Thank you.

Mr. OLTROGGE. Yeah, thanks for that question. It's going to seem like I'm giving two most important things, but it's really one. It's transitioning to an entity that nurtures and facilities commercial innovation and better algorithms. This is something that we have not made good headway on, and I think that's crucial that we get that going. And, as I showed in my presentation, we need to get going now. Thank you.

Chairwoman HORN. Thank you.

Ms. GABRYNOWICZ. I believe it's going to be crucial to have an interdisciplinary response to SSA. I think we absolutely need international agreements to address a lot of the things that the panel said, but that has to rest on a bedrock of agreed upon technical standards, and the acceptance of providers to provide the data. And so there needs to be an interdisciplinary approach in which the technology is the foundation for implementing the policy and the law.

Chairwoman HORN. Thank you. Dr. Wood?

Ms. WOOD. Thank you. I would like to actually sort of echo and repeat many of the things the other panelists said, so what I'd like to add is the idea of having integrated cross-agency commitment to the various needs, whether it's looking at improving research in an academic setting, and making sure it's funded, so we can bring in new technology and a new workforce, at the same time as having new operational activities. So I think what's needed is coordination across agencies.

Chairwoman HORN. Thank you.

Dr. STILWELL. I think it's clear that the first step needs to be establishing who is the lead authority for the government in advancing this work forward.

Chairwoman HORN. Um-hum.

Dr. STILWELL. When it comes to international agreement, that clarity is essential, and there is a lot of work going on in a lot of different places. Without a clear understanding of which agency is the lead agency, I think we will not make progress.

Chairwoman HORN. Thank you very much. And, following on from that, I think the critical question is addressing the patchwork that we have identified as part of the problem of international coordination, Federal regulations, debris mitigation, all of the things that have been addressed. And I'm going to ask this for all the panelists, we'll just go back in the other direction, so you get to go twice in a row, Dr. Stilwell. And I was—I think it's interesting to look at other similar answers to this question—I'll be very quick about this—maritime as a model. And how do we move very quickly from this—like, this patchwork to create a holistic framework? Is it along the lines of the OSTP inter-agency process to identify, or—just very quickly, because I don't have much time left.

Dr. STILWELL. I'll try and answer quickly. If that model is adopted, there are agencies that are experienced with it. The movement to commerce lets them follow models that already exist, so there's technical expertise within the department in how to bring in the industry information, developing it into international technical standards, and moving forward to international agreement. So the way you move quickly is assign the duty to those who have expertise in that area.

Chairwoman HORN. Dr. Wood?

Ms. WOOD. I just want to repeat the same idea, that one of the key opportunities to see where expertise has been developed in small communities within the agencies, and to make sure that it is not lost in transition periods.

Ms. GABRYNOWICZ. And whoever is chosen to be the lead agency, they have to have in-house capability commensurate with the task, and right now there is no one agency that has it all. They are going to have to—they can be the lead, but they're going to have good working relationships with other agencies and space expertise. NASA comes to mind. They're not a regulatory agency, they can't do it, but they've got to be in this loop.

Chairwoman HORN. Thank you.

Mr. OLTROGGE. Yeah, also to sort of re-frame what Dr. Stilwell said, there are existing frameworks out there. It behooves us to take advantage of those, and get moving. But one of the studies that I led for AIAA (American Institute of Aeronautics and Astronautics) was a space traffic management governance study, what's out there, and what I found is really fascinating. There is a fabric, a continuum, of space governance out there. People like to say what's the right answer for a certain thing, but what I've found is that there are many instruments out there, and we need to get comfortable with employing all of those instruments, I think, to get to were we need to go.

Dr. WEEDEN. Um-hum.

Mr. OLTROGGE. Thank you.

Chairwoman HORN. Thank you.

Dr. WEEDEN. So I just want to echo and reinforce that point made earlier. There are multiple potential answers. There is no agency that stands out as the clear favorite. Several possible, all have pros and cons, all could probably work. That makes it a little bit harder, because there's—again, there's no clear answer. And the same thing with these models. We have all written papers comparing space to maritime, or space to air traffic, or space to, you know, weather, or GPS sharing, and there is a little bit of analogy there, but it's also a little bit different. So, again, there is no one clear answer that fits we can just copy. We're going to have to pull the best parts from each one of those.

Chairwoman HORN. Thank you very much. I'm well over my time. Recognize Ranking Member Lucas for 5 minutes.

Mr. LUCAS. Thank you, Madam Chair, and listening to those last responses, I'll turn to you, Dr. Stilwell. As a former air traffic controller, let's talk about whether we adopt for the space sector the air traffic control model to emulate, or the maritime domain. Expand on that, if you would, as being valuable to study, I guess is the way I should word that.

Dr. STILWELL. I'm happy to. So there are significant differences between air traffic control and the concepts of space traffic management, the most significant of which is that air traffic control is predicted on a single entity having authority over a physical volume of air space, and that does not exist in the space domain. That brings rise to the maritime comparisons, where there are multiple authorities responsible for operators within the domain.

So there are issues in air traffic control that are very useful, and very instructive, and that is particularly in the way that international standards are reached through the ICAO (International Civil Aviation Organization) process, that, without reaching new treaties or new agreements, new technical standards can be adopted by the world. And what we see in the ICAO process, which I would like to note is—seeks consensus, but is not a consensus-based process. It is an industry expert driven process to reach standards that can be implemented by all nations in the world.

And what we see is that, when ICAO is able to develop guidance material, it is adopted because that material is valuable. It saves each individual country from trying to develop their own standards. So the value occurs long before we reach an enforceable standard, and at the guidance material level. So if we use that model, bringing in the industry expertise to develop what starts as guidance material, and evolves into a standard, we get a jump start on the process for reaching those international agreements.

For us to develop behaviors in space that are applicable only in the U.S., or only in the U.S. or Western Hemisphere countries, doesn't get us where we need to go, in terms of space situational awareness and space safety. So there are instructive models, but it is not a plug and play. We cannot say let's do what we do with air traffic control, because the environment and the governance is dramatically different.

Mr. LUCAS. Several witnesses, Dr. Stilwell, discussed the challenges that DOD faced upgrading their SSA systems and software. And, despite considerable taxpayer funding and many years, they're still using the same system. Your testimony highlights how the private sector is much more innovative, and can adopt new challenges more quickly. How could a distributed governance model for space situational awareness allow operators of space assets to become customers of data, rather than simply users for data? And please elaborate on the importance of this difference as it pertains to innovation, and the burden on the taxpayers, I would note.

Dr. STILWELL. It's quite important, because the—StratCom is very competent at fulfilling their mission, which is to protect U.S. assets in space, and they develop their systems to do that. The ancillary benefit to the space community of providing conjunction alerts is an additional service that's provided, and it's not intended to be tailored to meet a specific satellite operator's needs, nor should it be. As you mentioned, the taxpayers have no obligation to fund specifically tailored services.

By dividing the two elements, the space situational awareness, where the infrastructure of data about the location and trajectory of objects in space, and the conjunction alerting services into two separate functions, we have the ability to use the infrastructure as a joint use infrastructure as—the same as we do with radars and navigational aids on the terrestrial domain, and allow the industry to use that data to develop more bespoke tools. You become a customer when you are paying for a service. If you are—there's a high cost to a free service, and the industry's experiencing that high cost in their cost of evaluating hundreds of thousands of conjunction alerts.

If we allow a healthy competitive industry to develop in this layer between the operator and the infrastructure, then there is an opportunity to innovate quickly, and, in a competitive environment, there is an incentive to invest in the analytics to provide more precise information to those customers. There's not an incentive for government to invest in that because it is not the priority under the current model. The priority under the current model is to protect U.S. space assets in space, and StratCom does that very well.

Mr. LUCAS. Continuing with you, Doctor, in your opinion, are the problems of orbital debris, space situational awareness, and space traffic management, would you describe them as data issues or behavioral issues? And as you think about that, I guess I would ask are most operators good actors?

Dr. STILWELL. It's a combination of the two. We—better data gives you better information so that you can make better decisions. So the question of whether it is a data issue or a behavior issue——

Mr. LUCAS. Um-hum.

Dr. STILWELL [continuing]. Is not—they're not divorced partners. Your behavior is based on the data that you have available. However, in the question of good actors, you can only be a good actor if you have rules to follow. We can't expect someone to comply with a rule that doesn't exist. So when it comes to particularly a conjunction between two maneuverable satellites, who executes the maneuver is important, because there's an economic cost to executing that maneuver. It reduces your mission life of the satellite, and companies should not be expected to be altruistic in being good actors. They should expect—be expected to follow the rules. However, without any rules, it comes down to a negotiation, and we should not expect two commercial enterprises to ask each other to sacrifice their viability in the absence of any structure.

In both the maritime and aviation domains we have right of way, and that answers that question for you. So the fact that you are a good actor does not negate the need for good rules, which we do not have.

Mr. LUCAS. Thank you, Doctor, and my time has expired, Madam Chair.

Chairwoman HORN. Thank you, Mr. Lucas. The Chair recognizes Mr. Beyer for 5 minutes.

Mr. BEYER. Thank you, and thank you all of you for being here today. The—this is my 6th year on the Committee, and we have often had glancing blows about space debris. This is really the first time we've really gone to the experts to really understand what's moving on it, so thank you very much, and Madam Chair, thank you.

Mr. Oltrogge, you talked about the Kessler Syndrome, and the chain reaction effect, and specifically about the ecological threshold that, once passed, we cannot return. Even in a nuclear fissile thing, when there's a chain reaction, it gets to the end of the chain reaction. Why is—what would happen if you don't get back to the way things were? What's the—space look like, or the world look like?

Mr. OLTROGGE. Yeah. The Kessler Syndrome is a collisional chain reaction that just keeps going. Fact is, it will eventually reach some sort of stability point. The real issue with that stability point is by the time it does, you have a huge number of small particles out there, and fragments. And the overall space debris population is already quite large.

Mr. BEYER. So many of the existing satellites will be taken out?

Mr. OLTROGGE. Yes. It puts satellites at risk. We are—globally, and in commercial innovation market, working to track smaller and smaller things. There is a construct that operators today have when they fly their satellite. They look for information on what's coming close to them. The population, as was mentioned earlier, is about 22,000 publicly released objects. That could grow by a factor of 10, as I mentioned.

Mr. BEYER. So let me pivot to Dr. Weeden. As you talked about active debris removal, we see—we're talking about carbon capture here all the time, in terms of carbon in the environment. They got rid of the trash—they're trying to get rid of the trash at Base Camp at Everest. People are trying to collect the plastic from the ocean. Why do you think NASA and DOD have been so reticent to develop ADR (active debris removal) technology?

Dr. WEEDEN. Fully put, it's not their job. You know, so 2010, the Obama Administration issued a national space policy that directed both NASA and the DOD to jointly develop the technology, but it is not a core mission area for either organization to manage the space environment or to remove space debris. And so, when they put it up against all the other priorities they have from all the things that are in their mission statements, they've been directed by Congress to do, it emerges an unfunded mandate, and there is not that organizational interest in taking care of——

Mr. BEYER. So which organization should do it? Perfect world.

Dr. WEEDEN. So that is—like the question we were discussing before about SSA, there are a couple of options. NASA could do it. My sense, though, is that they would be—it would be overwhelmed by all of the other things NASA's focused on, moon, Mars, science, all those things. I think in a perfect world I would probably marry this what I'll call space environmental management mission with the space traffic management mission, and the SSA mission, because they all share and overlap a little bit.

Now, that does not mean that a government agency should be the one removing debris. I think there's a lot of room for the commercial sector to do there, but you should have the government agencies providing oversight of that, and helping incentivize that.

Mr. BEYER. Great. Professor Gabrynowicz, it's—you're the first person I've ever met that has a satellite named after them, or an asteroid, rather. In politics we get bridges and schools and stuff after we're dead, but——

Ms. GABRYNOWICZ. Mine is an asteroid.

Mr. BEYER. Asteroid, it's very cool. But you talked about the now-installed draft code of conduct for outer space activities being stalled, and we look and say we can't ratify the International Criminal Court, or the law of the sea, or—how are we going to—why is there so little interest not just in the United States, but globally, for these binding, seemingly necessary treaties?

Ms. GABRYNOWICZ. I think there's two answers. One answer is that we are dealing with topics that do, by nature, involve the entire globe, so that makes it difficult for individual nations to understand truly what their responsibility is, and what they can afford to do. When you talk about the climate, when you talk about the oceans, no—that's bigger than any one nation can handle, and we're trying to figure out how to allocate responsibility.

The second answer is, I think, and this is more of the law professor answer, is I think we're at a time where the nature of legal agreements is changing. It's like the early 15-, 1600s, where the treaty appeared for the first time. Before that there were no such things as treaties. Treaties came into being because we needed them to come into being. It was the kind of agreement we had to do because nations were beginning to interact with one another. And, in fact, the nation-state as we understand it today didn't exist until then.

There's something going on now globally where—with the constant shift of political power and economic needs, and shifting borders that is going to require different kinds of agreements, and we've been doing that since the end of World War II. We have declarations of principles, codes of conduct. There's all kinds of agreements that are trying to satisfy the needs that the formal treaty process has been able to satisfy for a number of years, and we're still working on it.

Mr. BEYER. Well, thank you for painting the picture where we need to go. And I'd yield back, Madam Chair.

Chairwoman HORN. Thank you, Mr. Beyer. Chair recognizes Mr. Posey.

Mr. POSEY. Thank you, Madam Chair, for holding this hearing on the challenges affecting the current Space Situational Awareness Program. The present Space Policy Directive 3 is the policy to improve the SSA and space traffic management through broad interagency coordination. Now, one of the goals is to transfer the space debris repository from the Department of Defense to the Department of Commerce so hopefully DOD can focus on its mission of protecting the United States and our allies, and the Commerce Department can focus on space debris with the expected launch increases.

Part of this process involves setting standards. The National Institute of Standards and Technology is currently working on the best practices to encourage space safety and innovation. That's a really good thing. And according to Mr. Kevin O'Connell, Director of the Office of Space Commerce of the Department of Commerce, these new standards are in part key to making sure that the United States remains the flag of choice for space entrepreneurs. I think we all want to do that.

Dr. Stilwell, with the number of launches expected to increase this year, space traffic management is important to our space program, and vital to our national security. How do you think SPD-3 will allow for more launches to occur in a safe manner?

Dr. STILWELL. In my experience, SPD-3 has been very well received by the space community, and that there is a lot of enthusiasm for those concepts to move forward in order to facilitate growth and action. It's important that, as we talk about debris mitigating behaviors and active debris removal, that we not set new entrants up for a situation where they're designing a launch that doesn't meet standards that will be developed shortly after, or even years after. If we can develop those standards early, we support that industry, we support that growth, and we create an environment where people know what their target is.

Specific questions about end of life access, so that we don't have two dead satellites that are heading toward each other, that—honestly, having better data about their collision doesn't make the system safer. It just makes us know better that two non-maneuverable objects might collide. What we need to do is reduce the number of non-maneuverable objects that remain in space. And as a design function for the industry, they need to know what that expectation is. So there are a number of elements within SPD-3 that set us down the path to giving predictability to a growing industry, and that's a very important part to support industrial growth.

Mr. POSEY. If you just had to guess, what do you think some of the suggestions would be?

Dr. STILWELL. The 25-year rule is a very long rule. That's a long time to leave your objects in space. It doesn't take advantage of the technological innovation that has occurred since that rule was put into place. How you de-orbit your satellite at end of life, there are a lot more options now than when those concepts were developed. Those are important, and also the removal of large objects. There may be a very clear path that says you have an obligation, if you leave a large object in orbit, for the future active debris removal when that becomes available.

Mr. POSEY. I would hope that we would see that. Do you think it's realistic to require internationally that every single satellite that's launched have a solid plan for how to deactivate that satellite, and remove it from space?

Dr. STILWELL. I do think it's realistic, and the interest of the international community is the same as ours. Often in the space discussions people say, well, would China do this? China, as an emerging space-faring nation, has the same, if not a growing, interest in ensuring the sustainability of space. There is an interest from every country that wants to be able to exploit the opportunities that space provides to ensure that that is available, that it is not a high-risk environment.

So the beauty of working in the space industry is it tends to be non-partisan and non-controversial. We want a lot of the same things. The international community wants that as well. We don't have these conflicts where they—where people are saying no, let's do nothing. Everybody wants somebody to do something, and the U.S. is in the perfect position to take that leadership role.

Mr. POSEY. That's great. I hope we do. Thank you.

Chairwoman HORN. Thank you very much. Chair recognizes the gentleman from Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. Thank you. It's a busy afternoon, so I missed a couple of the questions, but just sort of piggybacking on what you and Mr. Posey were just talking about, Professor Stilwell and Professor Gabrynowicz, these questions are to the two of you, because I'm really trying to understand the legal framework here, and whether the law of the sea is actually expressed in any of our treaties, and how, if it isn't, how we get there to put some kind of structure in place. You say everybody wants to do something, but we also know that there's national security issues. You know, we've got some satellites up there we don't want anybody to know about, or, you know, technology within it.

So how would you both suggest we get to a framework—and I think you both talked about debris, contamination, and salvage that might otherwise be expressed in the law of the sea? How do we get from here to there?

Ms. GABRYNOWICZ. First of all, let's reach an agreement on salvage. Right now there is no legal right to salvage in space, and there's a very good reason for that, and that's because when the treaties were being negotiated, neither the Soviet Union nor the United States wanted to give the other party an excuse to grab their space object and reverse engineer it. So salvage——

Mr. PERLMUTTER. But don't we still have a little bit of that problem today?

Ms. GABRYNOWICZ. You asked for a legal answer.

Mr. PERLMUTTER. OK, all right.

Ms. GABRYNOWICZ. OK. Remember, even during the height of the cold war, we reached agreements with the Soviet Union because we had to, because it was in both our interests. We would not have space law today if the Soviet Union and the United States didn't agree on the treaties. The confidence building measures like the hotline agreement, we can do those things. If we could do that during the height of the cold war, there's no reason why we can't do those things now. All we have to do is find things where there is common interest, and then get serious about putting the political will behind it. It's not all about, you know, hugging, and airy-fairy, and all that kind of stuff. It's pragmatic. We need to——

Mr. PERLMUTTER. All right. So——

Ms. GABRYNOWICZ [continuing]. Save out satellites.

Mr. PERLMUTTER [continuing]. We—does somebody have to call to convene a treaty conference? Is that where we are? Is that what needs to be done? Or can we do it one on one with China, one on one with——

Ms. GABRYNOWICZ. You can do it any way you think the avenue is going to work for you. If I were queen of the world, I would say which avenue is going to be the most productive? I think the most—the beginning of the most productive is you talk to nations who have as much to lose in space as you do, and then you sit down and say, look, let's stop blaming each other for the moment, but the debris caused by the X incident and the Y incident are things we can't do again in the future if we both want to continue our space program, so let's create some rules of the road.

Mr. PERLMUTTER. So, Professor Stilwell, does NASA convene this, does the International Association of Insurance Agencies convene this? Who—how do we get this going? Because everybody on this panel seems to be of one mind about we'd better get busy here.

Dr. STILWELL. This is a State Department function. It's international diplomacy, and Professor Gabrynowicz gave a good description of mutually assured destruction, and that's a powerful motivator. And we have that in space right now because if the space environment becomes unsustainable, there are tremendous costs for not only the space-faring nations of the world, but, as Dr. Wood pointed out, every country is a space country. So the U.N. Office of Outer Space Affairs has the committee on the peaceful uses of outer space. They have mechanisms available. What we need is the political will to start moving this forward.

Mr. PERLMUTTER. And you would suggest that the law of the sea is a common denominator, something that we're all comfortable—we, the world, is comfortable with the general parameters of maritime law?

Dr. STILWELL. And it has evolved over hundreds of years in a very constructive way, and illustrates that, even if you don't have a ratified treaty, countries comply with the provisions. And that's an important element as well.

Ms. GABRYNOWICZ. And may I add, if you read "The Shadow War," James Clapper also says we need the law of the sea for space, and a number of his colleagues as well. So it's there.

Mr. PERLMUTTER. OK. I thank you all for your testimony today. I think you have made an impression on—certainly me, and I thank you. And I yield back.

Chairwoman HORN. Thank you. The Chair recognizes Mr. Olson.

Mr. OLSON. I thank the Chair, and welcome to our five witnesses. Well, low Earth orbit is getting real crowded. This SSA and STM started on October 4 of 1957 with the launch of the Sputnik 1 satellite. Now, challenge is there because she was powered for maybe a week or two, came down after 21 days, no collision chances up there in orbit, but that started then. Right now, though, that world has changed, as you all know. We have over 9,000 satellites up there orbiting right now. Almost 2/3 are dead, out of fuel, mission's complete. 1/3 are actually viable right now.

We do have an idea what happens if we have a collision. Intentional collisions with China anti-satellite missile firing I guess it looks right around 2007. Our debris, in that graph you put up there, Dr. Weeden, doubled almost overnight with that missile shot, and that was intentional. You all scared me pretty earlier talking about the crisis over Pittsburgh, Pennsylvania. Those two satellites, coming at each other about 32,000 miles rate of closure, came about the width of this room from a collision. 500 miles over Pittsburgh, Pennsylvania, almost have a collision the size of this room. That'd have been catastrophic.

Having grown up about two miles from the Johnson Space Center, my main goal is to make sure that those human beings who have been there now for 20 straight years on orbit every single day do not have an impact from some satellite debris, that we control their safety. And it's not just for America. We are now the world's space travelers. China's doing a little bit, but us, Russia, ESA (European Space Agency), we are dominating space flight to the entire world, and so I want to make sure we're proactive instead of reactive with this debris field that's growing. That means SSA is proactive. That's what it should be. STM is kind of reactive, and so I think nothing helps us more with being proactive than artificial intelligence. I'm the co-Chairman of the House AI Caucus, and so my question for all of you is what role does AI play in the world of SSA? Dr. Stilwell?

Dr. STILWELL. I'm not an expert in artificial intelligence, and I think it's only responsible to defer to those who are.

Mr. OLSON. Dr. Wood?

Ms. WOOD. Thanks so much for the introduction and for the questions. I want to highlight one of the things we've been discussing is the practices, and what it means to have healthy practices that reduce the uncertainty. So this began actually during the design phase of the satellite before it even goes to space. There are actions operators can take, including how they use tools like artificial intelligence, to understand how they're going to be the best operator they can, how they're going to know where their satellite is, share that, hopefully, with their own government, and with other operators through groups like the Space Data Association.

Then some teams are interested in using SS—artificial intelligence to help figure out how to operate their satellite. It's actually an emerging technology, and it's interesting, but it also creates confusion, meaning if you operate your satellite, and you use an algorithm partly informed by artificial intelligence to plan when you want to maneuver from one orbit to another, that could be interesting technically, but it also creates more uncertainty for other operators around you to know where you're going to be at a given time.

So, actually, I think it's an open academic research question and operational question, but certainly we do, as the space community, want to take advantage of the benefits of these tools. So I think overall we want to say operators should be incentivized both by government requirements as well as by peer pressure among the commercial community to do what they can in the design phase and in the operation phase to be as transparent as possible. That means better communicating where you are, then having the right physical objects on your satellite so you can track yourself. We need to be able to identify and track objects. But we can also use artificial intelligence as we try to understand the complex behavior of satellites in space, so multiple answers.

Mr. OLSON. Thank you. Ms. Gabrynowicz?

Ms. GABRYNOWICZ. Remembering I'm a lawyer and not a scientist, I agree with Dr. Stilwell that you need to ask AI experts. But, from a legal perspective, two of the most important things you're going to have to deal with if you're going to be using AI is intellectual property rights and liability.

Mr. OLSON. Mr. Oltrogge? If I pronounced——

Mr. OLTROGGE. Thank you. Yes, you did. Let's see. I'm a person who feels that a holistic approach is very important here. We have to try and address the threat of space debris through all avenues. AI is a very important one, and I think it needs to be a heavy area where we do research. The issue, though, is that a lot of the data that would feed that AI, I feel, today is not out there, and it's just not to the level where it can be operationalized yet. So all across we need to pursue.

Mr. OLSON. Thank you. Dr. Weeden?

Dr. WEEDEN. Yeah, I just want to echo what Dan said, and say the same thing. A lot of what we call AI is actually machine learning algorithms, and a lot—and they're essentially only as good as the data you feed them. And, to echo what Dan just said, we don't have the underlying data in a point where we have enough of it, we understand its precision, its accuracy, its confidence. We don't really understand to the point where I would feel confident to feed that into an algorithm at this point in time. So I think we start with fixing the data, get a better handle on that, and then, yes, I think we're going to have to move to an area where we adopt things like machine learning, other things, to help improve—situation.

Mr. OLSON. I'm out of time. On behalf of our Chairwoman, can you all say hook them? Anybody?

Dr. WEEDEN. I'm from New York, I'm sorry.

Mr. OLSON. I yield back.

Chairwoman HORN. I thought you would've learned your lesson, given that you still owe me a bunch of tamales. So, you know, eventually.

Mr. OLSON. They're coming.

Chairwoman HORN. OK. I'm holding you to that.

Mr. OLSON. La Cucina.

Chairwoman HORN. I'm ready. Well, thank you all so much, to the witnesses. This has been an incredibly informative and helpful hearing, I think, to lay out the expanse of the challenges we're facing, and we're about the wrap up. There's one small question I want to close out with, because there's much more that we'll follow up with. But the 25-year rule that was just discussed, I want to circle back on that because—and, Dr. Wood, I'll direct this to you, and if anyone else has anything, we can add to it, but the—there was recently—in December of 2019 there was a NASA-led interagency task force that talked about updated standard practices that still included the 25-year rule, which seems to be very counter to all of the things that we've been talking about here. So I'd like to hear from you what the impact of these standards are going to be, likely, on the space community, and how widely they're being adopted or perceived.

Ms. WOOD. Thanks so much for the opportunity. You know, I think one thing we haven't done enough today is talk about how there are different ways to operate, depending on which altitude you're in in space, and so we should think about how we might require or expect different behavior from operators somewhere in the 400 to 600 kilometer location, which is very popular for certain low Earth orbit missions, versus the medium Earth regime, versus geostationary. So I think we really want to target our advice, or our behavior expectations, depending on where you are, and ask what's been the historic usage of an area. And not just are we going to have the Kessler Syndrome, but is that particular altitude of particular interest and popularity, and therefore it requires special concern, and special rules?

So, of course, with our space sustainability rating, what we're trying to do is actually encourage operators to do better than what's required by current law, so we would hope, even if a government requires 25 years, that they would see it as actually a commercial benefit to perform better, to actually get their satellite out of orbit, especially if they're in an orbit where they are known that they're sharing it with a lot of other commercial operators. So that's part of what we do, we calculate both—how popular is that orbit, how much is there—already been a use of that orbit? And that's drawing from the techniques developed by the European Space Agency partners, and then we ask what will be the likely benefits of removing your satellite from that particular orbit, not in general, because that orbit's popular, or because there's already a lot of satellites there. So when we ask what's the importance of removing your satellite, we should also ask what's already been happening historically in that orbit, and why is it so important that your particular mission will make room for future missions in that orbit.

But I do think there's an opportunity, and there's a lot of consensus among the technical experts that it is feasible to remove satellites faster than 25 years in many cases, especially in orbits that area already popular, that already have historic—laden with debris, and so therefore it behooves us, both by voluntary choice, as well as by government action, to really move toward shorter times in orbit beyond the mission lifetime. Thank you.

Chairwoman HORN. Yes, Dr. Gabrynowicz?

Ms. GABRYNOWICZ. Again, speaking as a lawyer, I have no opinion as to whether 25 or some other number of years makes a better rule, but I will say we call it a rule, but it's not legally binding. The only entity who is legally bound by the 25-year rule is NASA. Unless the 25-year rule goes through the APA (*Administrative Procedure Act*) rulemaking process, it is not binding on any other Federal agency. Other Federal agencies have said, we will try to abide by this, but there is no legal requirement that they do so, and there certainly is no requirement outside of the United States for anybody else to be bound by the 25-year rule. And if you change it to 5 years or 10 years, that's still going to be the situation.

Mr. OLTROGGE. Yeah.

Chairwoman HORN. Go ahead.

Mr. OLTROGGE. So I'm founder of the Space Safety Coalition. We have 37 space organizations who have joined to develop best practices, and also align with international best practice, but develop our own aspirational ones over and above what the international consensus and documents are. So orbit lifetime there, aspirationally, we seek, in that document, to be done in 5 years. Get your satellite out of orbit 5 years—within 5 years of the end of your mission. So aspirational best practices in the commercial arena, where operators do want to do the right thing, are a very powerful thing, in that, in advance of international consensus, the commercial operators and companies can strive to do better. So that's, I think, a very positive thing.

In terms of the 25-year rule itself, developed in 1995, based on the then population, and the then analyses that were done, that was something that at the time seemed to be a reasonable compromise between the cost of immediately bringing your satellite out of orbit versus leaving it up there forever. So it's a compromise. The ODMSP (Orbital Debris Mitigation Standard Practices) that was just released last year, 2019, does something interesting, in that it still requires a 25-year rule, but it aspirationally adds that we should take these satellites out of orbit as soon as we can. Thank you.

Dr. WEEDEN. Quickly just to add on to that, I want to touch on the point that was made about not having a blanket rule for everything. I think that is the regime we should be thinking about. Instead of 1, 25, 15, whatever, everything, we need to think about a tailored approach to different orbital regimes, because they are different.

The second is to talk about enforcement. At the moment the European Space Agency is the only entity I know of that's monitoring who's complying with this. It's roughly around 50 to 60 percent compliance with this existing 25-year rule, or suggestion. That's good, should be a lot better. So enforcing—better enforcement through—it's going to come through national legislation. National policy is where it needs to be, as well as thinking about less of a blanket rule, more of a tailored approach.

Chairwoman HORN. Thank you very much. Would you like to contribute to that? OK. I'm happy to—if you'd like. It's fine. I want to say thank you again. This is incredibly important, and informative, and further identifies the need for us to move quickly, to take action, and highlighting the multiple layers of challenges, and the need to be intentional and tailored in the way that we address this using incentives, some regulations, other voluntary—commercial—I think there's—there are many different layers to this that can help us to address these issues. You have all touched on many of those areas, and we're very grateful, and we'll continue.

Before the hearing closes, I want to make sure that we note that the record will remain open for 2 weeks, and for any additional statements from the Members, or any additional questions that the Committee might ask, I can almost assure you that we will have additional questions for the record, so we—be prepared for those. But, again, this testimony was invaluable. I thank my colleagues on both sides of the aisle for the importance of this issue, and the witnesses are excused. The hearing is now adjourned.

[Whereupon, at 4:12 p.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Brian Weeden

Responses to Questions for the Record

Submitted by Mr. Brian Weeden

April 14, 2020

Answers to questions from Chairwoman Horn

1. It is difficult to assess precisely which federal agencies are funding R&D for SSA because it is not a well-defined term and not all agencies break out that funding as line items in their budget documents. To the best of my knowledge, the Department of Defense is the primary source of R&D funding on SSA. In the past, NASA has also done some limited efforts at Ames and Johnson field centers.
   a. I think the federal government should play a strong role in supporting SSA R&D activities, as it does in many other areas of scientific inquiry. The main role should be funding basic R&D into the scientific study of orbital debris, developing improved astrodynamics algorithms to enhance the accuracy of orbit propagation and space environment modeling, and new analytical products for turning SSA data into actionable information.
   b. The areas for R&D mentioned above could translate into a better understanding of the orbital debris population, more accurate propagation of orbital trajectories, and the creation of more useful products to help satellite operators make decisions. All of that would help reduce the risks of on-orbit collisions while also reducing the increase in effort needed to do conjunction assessment as the number of space objects and active satellites continues to grow.

2. Much of the existing gaps stem from the shortcomings of the DOD's existing Space Surveillance Network. Most of the sensors in that network were originally intended for missile warning and thus were not designed for optimal SSA performance or placed in optimal geographic locations for SSA. They are concentrated in the Northern Hemisphere, leaving large gaps in coverage below the Equator. The computers, processing equipment, and communications networks used to operate and connect these sensors tends to be decades old, which limits their capacity. The system was also designed to be a closed, trusted network, which limits the ability to bring in outside data to augment or supplement what the SSN can provide. Finally, the bulk of the sensors in the SSN cannot regularly track space objects smaller than 10 cm in size.

   Over the last decade, the DOD has taken several steps to try and remedy these shortcomings. These include building a new S-Band Space Fence on Kwajalein Atoll, moving a widefield telescope and old C-Band mechanical radar to northern Australia, and conducting a series of service life extension programs at existing sensor sites.
   However, many of these upgrades and new sensors were designed for national security SSA requirements and are not necessarily optimal for civil safety requirements. Moreover, their

primary role in supporting national security limits the ability of the DOD to share information from these sensors and collaborate outside of the national security community.

3. The space insurance community has to date taken a limited role in assessing the impact of space collisions. They are looking at the problem and studying it, but typically rely on historical trends and statistics to inform their pricing. So to date, the risk of on-orbit collision represents a small fraction (typically a few percent at most) of an insurance premium. Moreover, many satellite operators do not purchase insurance beyond the initial launch and first year of operations. Out of the 2,500 or so satellites currently on orbit, less than 300 are currently insured and the vast majority of those are commercial communications satellites in the geostationary belt. Most governments and large constellation operators self-insure against collisions, either through redundancy on orbit or having spare satellites to launch.

   In the future, I do expect insurance to take a somewhat bigger role, but it will likely be a lagging one that reacts to increased risks and collisions rather than a leading role that gets in front of them. In January 2018, Secure World Foundation partnered with the Stimson Center to hold a workshop on space insurance that discussed these issues.[1]

   Additionally, I should note that the recent report and order by the Federal Communications Commission (FCC) on orbital debris mitigation enacts a new requirement for licensees to indemnify the United States government against claims as a result of liability for damages caused on-orbit.[2] I expect many companies to resolve this by purchasing additional insurance.

4. a) I believe the federal government should be trying to incorporate as much flexibility as possible into a civil SSA system. We do not know the exact scope or timing of how the space environment will change, but we do know that our current SSA capabilities are inadequate for the challenges of today let alone tomorrow.
   b) I believe the best way to incorporate flexibility in SSA is to make the system as open and transparent as possible so that it can incorporate data from many different and diverse sources. In that sense it would likely be similar to the data sharing model currently used by NOAA for weather data.[3] It might also borrow some features from the open source software movement, where developers are able to take the publicly-available source code and iterate to improve it. SPD-3 and a 2019 RFI from the Office of Space Commerce[4] refer to a civil SSA system that provides "basic" data that would ensure public safety on its own, but also leave room for companies to provide higher quality information for satellite operators.

5. This is a difficult question to answer because I do not know what the requirements are for US leadership on SSA. To my knowledge, no one has yet done a public analysis of what SSA

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[1] A summary of the workshop can be found here; https://swfound.org/media/206112/2018_stimson_swf_insurance_event_report.pdf
[2] "FCC FACT SHEET", Mitigation of Orbital Debris in the New Space Age, Report and Order and Further Notice of Proposed Rulemaking, IB Docket No. 18-313, April 2, 2020.
[3] NOAA's online portal for accessing weather and climate data sets is here: https://www.ncdc.noaa.gov/data-access
[4] https://www.federalregister.gov/documents/2019/04/11/2019-07169/request-for-information-on-commercial-capabilities-in-space-situational-awareness-data-and-space

capabilities will be required to support the breadth of SSA needs across civil, national security, and commercial users. The only work I'm aware of is that done by the DOD to understand just the national security component. Therefore, I would submit that doing such a study on the civil and commercial SSA needs is a prerequisite for determining the necessary capabilities, workforce, and research.

Answers to questions from Congressman Bera

1. a) Given the uncertainties in the current conjunction assessment process, I do not think it is possible to make a broad determination of what actions should be taken in all circumstances. Until we have better data that drives down the uncertainty and eliminates more false positives, I think the decision of what mitigation steps, if any, should be taken needs to be left up to the satellite operators involved in the situation. At most, I would recommend that the operators talk to each other to determine an agreed upon course of action.
   b) Under the current international legal framework, I do not think it is practical to enforce collision avoidance policies globally. There is no international agreement on what those policies should be and each State is responsible for supervising their own national space activities and the activities of their private sector entities. I think we need to first come to international agreement on what the collision avoidance standards should be and then we need the relevant countries to create national regulatory regimes to implement and enforce those standards. That will take quite a while to create.

   In the interim, the only way to "enforce" collision avoidance policies is to "encourage" them through incentives (both positive and negative). These could be anything ranging from public praise to insurance prices to reduced (or increased) license processing timelines.

2. a) General Raymond is referring to the case of a Russian satellite, Cosmos 2543, which has been maintaining an orbital trajectory that closely matches that of a classified U.S. satellite, USA 245. My personal judgement is that this is an example of intelligence gathering and surveillance of the activities of that U.S. satellite[5].

   I do think the intent should be of concern because at this moment there are no agreed-upon norms of behavior for this type of shadowing or close approaches between satellites of different countries like we have done in the air and maritime domains. In the maritime domain, for example, there was the Incidents at Sea Agreement[6] between the United States and Soviet Union that laid out standards for how military ships and aircraft could approach and interact on the high seas. Without those agreed-upon norms, it is difficult to judge whether or not this shadowing activity presents a legitimate threat.

[5] More detailed analysis of this event can be found on pages 2-7and 28 of the 2020 Global Counterspace Capabilities Report located at https://swfound.org/media/206955/swf_global_counterspace_april2020.pdf
[6] https://2009-2017.state.gov/t/isn/4791.htm

There are some national security concerns with sharing data on this type of event, but I think they are outweighed by the benefits. The main concern is that the mission and function of the U.S. satellite involved is not publicly acknowledged, so sharing information about it could reveal those classified details. However, without sharing information about this event it is almost impossible to communicate to the public and international community about the gravity of the situation.

There is a degree of SSA data sharing going on between different countries. Russia has a similar system to that operated by the U.S. military and has historically shared a portion of their data with the U.S. as part of a periodic exchange. The U.S. and Russia have also engaged in data sharing as part of protecting the International Space Station. China likely has less capable SSA systems but is rapidly improving them. To the best of my knowledge there has not been extensive SSA data sharing between the United States and China.

b) There are currently mechanisms in place for the DOD to share SSA information with commercial and foreign entities. The SSA Sharing Program was created in 2010 to enable the DOD to share SSA information more broadly to prevent future satellite collisions.[7] As of April 2019, United States Strategic Command has signed more than 100 such data sharing agreements with governments, universities, and companies.[8] These agreements put in place the ability to share data, although in some cases not every partner has the ability to provide data or can the DOD accept data from other sources due to format or communications problems.

A drawback to this system is that it is military-centric and closed. None of the agreements are public and the data is only made available to the DOD. I would prefer to see an alternative system created for civil SSA that is more open and publicly accessible, which would likely exist in parallel to the more closed relationships and system that the DOD maintains for national security purposes.

At this point in time I do not believe establishing an international governmental body to coordinate SSA information sharing is warranted. However, there are existing international standards on SSA data and message formats developed through the Consultative Committee for Space Data Systems (CCSDS) that all entities should be encouraged to adopt and use.

c) When it comes to civil and safety matters, such as avoiding collisions between commercial or civil satellites, I believe SSA data should be shared as widely and publicly as possible through a civil federal agency. This responsibility currently rests with the Department of Defense. The Trump Administration has proposed that the Department of Commerce's Office of Space Commerce take on that role. The major benefit to a civil agency performing this role is that they are better able to work with nongovernmental and international sources of data.

[7] A summary of the creation of the SSA Data Sharing Program can be found here: https://swfound.org/media/3584/ssa_sharing_program_issue_brief_nov2011.pdf

[8] https://www.stratcom.mil/Media/News/News-Article-View/Article/1825882/100th-space-sharing-agreement-signed-romania-space-agency-joins/

On national security issues, I believe it makes the most sense to establish secure, bilateral communication channels between the DOD and foreign militaries to share SSA data that can help reduce misperceptions and tensions. However, in certain circumstances, it may be more effective to go public, such as the Kennedy Administration did in sharing classified reconnaissance photos on Soviet missile deployments in Cuba with the United Nations during the Cuban Missile Crisis.

Responses by Mr. Daniel Oltrogge

EDDIE BERNICE JOHNSON, Texas
CHAIRWOMAN

FRANK D. LUCAS, Oklahoma
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6375
www.science.house.gov

April 2, 2020

Mr. Daniel Oltrogge
Founder and Administrator, Space Safety Coalition
AIAA STM Space Governance Task Force Chairman
Official ISO representative to the United Nations Committee for the Peaceful Use of Outer Space (UN COPUOS)
7150 Campus Drive, Suite 260 Colorado
Springs, CO 80920

Dear Mr. Oltrogge:

On behalf of the Committee on Science, Space, and Technology, Subcommittee on Space and Aeronautics, I want to express my sincere appreciation for your participation in the February I I, 2020 hearing entitled "Space Situational Awareness: Key Issues in an Evolving Landscape."

I have attached a transcript of the hearing for your review. The Committee's rule pertaining to the printing of transcripts is as follows:

> The transcripts of those hearings conducted by the Committee, when it is decided they will be printed, shall be published in substantially verbatim form, with the material requested for the record inserted at that place requested, or at the end of the record, as appropriate. Individuals, including Members, whose comments are to be published as part of a Committee document shall be given [he opportunity to verify the accuracy of the transcription in advance of publication. Any requests by those Members, staff,' or witnesses 10 correct any errors other than errors in the transcript, or disputed errors in transcription, shall be appended to the record, and the appropriate place where the change is requested will be footnoted. Prior 10 approval by the Chair of hearings conducted jointly with another Congressional
>
> Committee, a memorandum of understanding shall be prepared which incorporates an agreement for the publication of the transcript.

Transcript edits, if any, should be submitted by April 16, 2020. If no edits are received by the above date, I will presume that you have no suggested edits to the transcript.

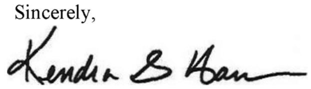
Oltrogge, D.L.

I am also attaching questions submitted for the record by Members of the Committee. Please submit answers to all of the enclosed questions no later than April 16, 2020.

All transcript edits and responses to questions should be submitted to me and directed to the attention of Griffin Reinecke. If you have any further questions or concerns, please contact Griffin Reinecke at Griffin.reineeke@gnail.house.gov or at (202) 225-6375.

Please also take the time to complete a voluntary survey to help Congress better understand the backgrounds of the witnesses who appear at Congressional hearings. Your participation in this survey helps Congress ensure that our policies and legislation are inclusive and work for Americans of all backgrounds. All data remains anonymous and protected according to the United States House of Representatives' policy and data security practices. The survey can be found at the following link: Witness Diversity Survey

Sincerely,



Kendra S. Horn
Chairwoman
Subcommittee on Space and Aeronautics

Enclosure: Transcript
Attachment: Questions for the Record

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

"Space Situational Awareness: Key Issues in an Evolving Landscape"

Questions for the Record:

Mr. Dan Oltrogge

Submitted by Chairwoman Horn

1. Advanced computing techniques like artificial intelligence (AI) are beginning to be incorporated into space situational awareness (SSA) algorithms and satellite operations. What does the inclusion of AI in SSA mean for SSA going forward?

    a. What are the opportunities and challenges of using AI in satellite operations and SSA algorithms?

As I shared in House testimony in February, the number of expected close approaches for large constellations will number in the millions for large constellations, as shown in the table below. The consequence is that a single operator could be faced with over 40,000 close approaches every day! Imagine trying to assemble a human crew of flight dynamics analysts large enough to handle the workload of painstakingly assessing which of those 40,000 close approaches need to be avoided on that day, and then needing to do that the next, and the next…

So clearly, we need to be taking steps to enable such automation, and AI and Machine Learning (ML) will be needed to address collision avoidance decisions … eventually. One cannot overlook the huge AI and ML opportunities to automate this arduous task of analyzing all close approaches to decide which are risky enough to warrant spending precious maneuvering fuel to actively avoid, and which can safety be ignored.

Operator	# S/C	Alt (km)	Current (c10 cm) RSO catalog average number			~200,000 (≈2 cm) RSO catalog average number		
			Estimated collisions in 10 years	*3km warnings in 10 years*	*1km maneuvers in 10 years*	*Estimated collisions in 10 years*	*3km warnings in 10 years*	*1km maneuvers in 10 years*
AISTech_Danu	300	591	0.07	479,649	53,294	0.19	4,635,985	515,109
Amazon	3,236	590	**0.18**	**3,768,872**	**418,764**	**0.09**	**36,120,810**	**4,013,423**
Boeing_1	1,120	1,200	0.14	331,965	36,885	1.09	4,739,224	526,580
Boeing_2	1,210	550	0.10	234,358	26,040	0.84	3,646,359	405,151
Boeing_3	1,000	585	0.23	1,812,814	201,424	0.59	16,903,756	1,878,195
CommSat	800	600	0.07	1,362,606	151,401	0.03	12,835,938	1,426,215
ExactView	72	820	0.21	326,914	36,324	1.10	2,768,355	307,595
Hongyan	300	1,100	0.04	241,520	26,836	0.16	3,434,841	381,649
Iridium	85	781	0.06	399,037	44,337	0.12	2,514,772	279,419
LuckyStar	156	1,000	0.02	318,736	35,415	0.01	2,616,385	290,710
OneWeb	2,560	1,200	0.32	754,868	83,874	2.49	10,832,864	1,203,652
OneWeb_next	720	1,200	0.17	286,598	31,844	1.69	4,726,261	525,140
Satellogic	300	477	0.02	236,040	26,227	0.02	2,254,977	250,553
SpaceX	4,425	1,200	**6.43**	**2,050,452**	**227,828**	**77.73**	**30,310,084**	**3,367,787**
SpaceX_VLEO	1584	550	3.45	1,101,453	122,384	35.63	13,894,159	1,543,795
Space_X_M-T	20,940	500	**43.13**	**13,753,896**	**1,528,211**	**404.53**	**157,747,388**	**17,527,488**
Space_X_U-W	9,000	330	0.93	347,030	38,559	21.86	10,053,221	1,117,025
Theia	211	775	1.08	783,728	87,081	7.57	7,520,310	835,590
Xingyun	156	1,000	0.04	360,898	40,100	0.06	2,831,654	314,628
Yaliny	140	1,000	0.03	321,780	35,753	0.05	2,599,648	288,850

But there are significant challenges with applying artificial intelligence to safety of flight, and collectively they lead me to conclude that the global space community is not yet ready to operationally employ AI to avoid collisions between an active spacecraft and another (or a debris fragment):

i. The Space Situational Awareness (SSA) data is not up to the task in its present state, because it only reflects 4% of what we believe to represent a mission-ending debris population, and because SSA data is not precise enough at this time. This is the underlying reason that the U.S. needs to act swiftly to get going on STM now: The U.S. don't yet have an STM system, and the underlying SSA data is ill-suited to the task of avoiding collisions, whether assessed via automated (AI) or manual means.

ii. Despite these deficiencies in positional accuracy, AI could potentially be applied were it not for the fact that current estimates of positional error and error growth rate can grossly misrepresent the real errors. This could "throw AI tools off the scent", leading to bad choices.

iii. So-called “rules of the road” have not yet been established. If two active spacecraft are at risk of collision and there was an established maneuvering rule like we have when two cars simultaneously arrive at stop signs and the car on the right proceeds first, spacecraft could be programmed to know that one spacecraft has the responsibility to maneuver and the other must not maneuver. But we do not have that at this time.

iv. Consensus has not yet been reached on what collision metric and threshold should be used, or even what algorithm should be used to estimate that metric. In fact, one can make a good case that consensus never will be reached, because operators adopt collision risk metrics that best meet their individual needs. And even if two operators happen to choose the same metric, the corresponding threshold they choose may likely be different, because what sufficiently protects one operator’s spacecraft may not be sufficient to protect another’s.

v. Several large constellation operators are new to the process for assessing collision risk and are unfamiliar with the potential for collisions in their orbital regime and current deficiencies in SSA data, products and services.

vi. Current AI constructs allow the spacecraft to decide **if, when, and how** to maneuver to avoid a collision threat. But this cannot be done in a vacuum. Other operators may have spacecraft with similar AI-based maneuvering systems that automatically choose avoidance maneuvers that nullify the benefit of your spacecraft’s AI-based avoidance maneuver, resulting in a catastrophic collision.

b. To what extent do autonomously operating systems pose challenges for transparency and real-time SSA?

Autonomous spacecraft have been operational for many years, where the spacecraft’s on-board processor decides if, when and how to maneuver to meet mission objectives, maintain one’s assigned orbital slot or relative position (stationkeeping), and adhere to power, thermal and mission-related constraints. Operators of such autonomous spacecraft are faced with a quandary: How do I know what my spacecraft plans to do, so that I can plan ahead and coordinate with other operators? AI applied to the collision avoidance problem is yet another source of uncertainty, where the machine decides how to avoid a collision threat and it may be difficult for the operator to know (a) what the spacecraft is going to do; and (b) how to be able to share that information with other operators and SSA service providers (to ensure tracking) in a timely manner.

In summary, the development of robust and transparent AI-based maneuver avoidance strategies, especially when implemented onboard the spacecraft, must be an active area of research by the community. We won’t be able to safely operate such large constellations without it. Yet there remain significant concerns about AI’s operational use for collision avoidance today, because current legacy SSA algorithms and processing systems are insufficient, rules of the road don’t exist, the space catalog is incomplete, error depictions are known to be misleading, and consensus approaches to evaluate and avoid collision risks are not established.

Oltrogge, D.L.

2. You mentioned in your written testimony that "the critical piece that is missing from today's flight safety systems is a top-down, requirement-based approach"? Can you please expand on this comment? What is a requirements-based approach and how would it be used?

Requirements-based approaches are commonly used for U.S. government procurements of military systems. The goal of a requirements-based approach is to determine what the proposed system is required to do, couched in performance terms such as coverage, availability, timeliness, accuracy, networking, security and geographic diversity. Such requirements are developed well before any facilities or hardware is built. The requirements-based approach is best suited for procurement or implementation of a new system. Once achieved, suitable metrics can be monitored to ensure that the procured system actually meets the requirements that the customer paid for.

In the case of the Space Surveillance Network (SSN) that serves as the backbone of U.S. SSA services, the sensors and facilities which constitute the SSN were, with rare exceptions, not expressly designed to meet SSA requirements. These systems were built to perhaps track missiles or new launches, and monitor a designated corridor. While the aggregation of these disparate sensors has yielded a truly capable system, the composite SSN system does not meet the requirements one might choose to impose on a dedicated STM system, in terms of timeliness, accuracy, transparency, interoperability and flexibility to incorporate advanced capabilities and services.

In a top-down dedicated STM approach, specific detailed performance requirements for both historical and forward-predicting accuracy can be set, as well as for realism in predicted positional error estimates. Systems designers can use these requirements to compare and contrast various algorithms, sensor types and mixes, sensor sites, networking, adherence to international standards and geographic diversity required to make sure that the as-built STM system actually meets the baseline STM requirements.

3. What new or innovative SSA tools and services are being provided and developed in the private sector and non-U -S. government sectors?

The private (commercial) sector has developed operationally mature SSA techniques to ingest disparate 'sensor observation data' into modern software that can simultaneously fuse and process various types of sensor data (optical, radar, Passive RF, ranging, planned maneuvers, etc.) to produce best-of-breed, decision quality SSA information services. These tools can also independently detect, characterize, regain and maintain track custody of non-cooperative spacecraft. While open sources of SSA data can at times be useful for public awareness, what spacecraft operators need are operationally-relevant SSA data analytics, data visualization, decision-quality conjunction warnings, probability of collision estimates, avoidance maneuver recommendations and decision aid tools.

a. What are the opportunities and challenges of using such tools and services at the U.S. government level?

We are facing a potential tenfold increase in the number of active spacecraft within ten years, and a potential tenfold increase in the amount of existing debris that we are able to track within three years. We have the opportunity today to apply mature commercial SSA algorithms, tools, processes and SSA services to ensure that we are up to this challenge. But in order to do so, we must rapidly transition to these commercial algorithms and services or risk losing the initiative and imperil our burgeoning space economy.

b. What would be involved in "fusing" such tools and services with existing federal government services provided to civil operators?

The fusion algorithms and tools already exist. All that is required is for commercial and government SSA data to be brought together to be fused at the observational level. Operational demonstrations of this capability have been running for years, but these fusion capabilities are not yet embraced by our legacy SSA infrastructure.

4. Beyond the location of space objects, what are the critical pieces of information about space objects that SSA researchers and operators need to know in order to improve algorithms that predict the locations of these objects in the future?

Most people think that if operators were to just share their predicted positions over time (called an "ephemeris") each day spanning the upcoming week, all would be well. And while this is certainly an important start, there are many other data elements that are required not only to predict future locations, but also to properly assess the risk of a collision to the health and safety of (a) the spacecraft; (b) the mission that this spacecraft is performing; and (c) the environment in which the spacecraft operates.

To address the needs of a comprehensive STM system, operators and SSA service providers should strive to share as much data as they are willing to share, to include not only the space object's ephemeris, predicted error profiles (called a "covariances"), space object size (largest dimension), cross-sectional area, dimensions, mass, drag coefficient, attitude flight rules, planned maneuvers, health and status of the spacecraft, sensor observations, and potentially even its Radio Frequency (RF) characteristics such as power, gain, frequency, transponders, antenna patterns, etc. when such information can be used to improve flight safety and reduce Radio Frequency Interference (RFI).

5. What practices and technologies do civil and commercial space operators use to minimize the risks of collisions in space?
    a. Similarly, what techniques and procedures can space operators use to minimize the future growth of orbital debris?

Space operators today employ a truly diverse set of SSA systems, algorithms and sensors to strive to avoid collisions. Operators generally realize that currently provided free SSA services are good but insufficient, especially for certain classes of spacecraft (low-thrust), certain orbit classes (lower LEO or GEO) and orbits (LEO equatorial).

This realization has led to the operator self-formed operator associations (such as the Space Data Association and the Satellite Industry Association) and coalitions of like-minded space operators and industry stakeholders (such as the Space Safety Coalition) to try to take aspirational, non-binding action in the here-and-now to ensure flight safety in advance of international treaties, guidelines and national regulations.

The more advanced and knowledgeable spacecraft operators utilize commercial SSA services (such as AGI's Commercial Space Operations Center or ComSpOC) and/or sensor time to better assess where their vehicle will be and where other space objects will be so that they can have more confidence in identifying the highest collision threats and in maneuvering to avoid those threats.

You are wise to ask this question in two parts, because the practices and thresholds operators choose to protect their spacecraft and the mission it performs can be different from the practices operators choose to protect the space environment to ensure the long-term sustainability of space activities.

6. You testified that the commercial space sector provides very capable commercial SSA and STM services that can match or, in some cases, even exceed government legacy capabilities. How do you define "commercial" in this context?

Consistent with FAR Part 2, I think of commercial capabilities as being developed exclusively under private investment (independent of government contracts) and made available to the general public (i.e., outside of the government community) for non-government purposes, independent of government contracts.

There are several U.S. regulations (the FAR, and § 855 of the 2016 National Defense Authorization Act and U.S. Code § 2377) which mandate that the U.S. government has a legal preference for commercial items. Several studies (DSB and Standish Chaos Report of 2015) and a commission report (2014 Ashton Carter-led Innovation Commissions) also recommend leveraging commercial goods and services.

7. Can you define what is meant by "space data" as referenced in your testimony? What, in your view, are the priorities for the use and application of space data to address SSA?

Space data can include all of the data elements listed in my answer to question #4 above (the space object's ephemeris, covariance, size, cross-sectional area, dimensions, mass, drag coefficient, attitude, maneuvers, health and status, sensor observations, and RF characteristics, space data includes points-of-contact for debris and spacecraft required to facilitate rapid and robust communications between operators).

a. To what extent can the space debris problem be solved simply by openly sharing such data or should the focus be on data fusion and improved analytics?

Data sharing by itself is not sufficient to address the real problem. The focus must be placed on data fusion and better algorithms and analytics. As attractive as open sharing of data might at first appear, several factors make it less practical and useful in real-world operations:

- While operators are increasingly willing to share ephemerides, operators are typically reluctant to share many of the parameters (listed above) that are critical for decision-quality SSA and STM services. Assertions that operators will willingly share this more comprehensive set of space data to the public are unrealistic.
- Operators often do not have access to predicted covariance data for their spacecraft, because the orbit determination tools supplied by the spacecraft manufacturer are not configured or capable of providing that data. This means that collision probability cannot be assessed using their supplied data without making assumptions.
- Operators can have systematic biases in their data that they are unaware of because they do not have the benefit of incorporating observations from other diverse sensor sites and sensor types.

b. Walk us through the process of what really needs to be done with that data for the sake of flight safety and long-term sustainability.

What's needed is "Data fusion at the observational level" combined with all of the algorithms and processes referenced in my answer to question #3 above. Once operators have solved their spacecraft orbits and shared them with others, there is no convenient way to "blend" those independent orbit solution with any other (e.g., from an SSA tracking solution independently generated by an SSA center for that same space object). That'd be like trying to bake a strawberry-rhubarb pie by baking a strawberry pie and (separately) a rhubarb pie and mashing them together.

c. What data does a commercial satellite operator rely on to determine if it should make a maneuver to avoid a potential collision, and what factors or decision support analysis are used to make such a decision?

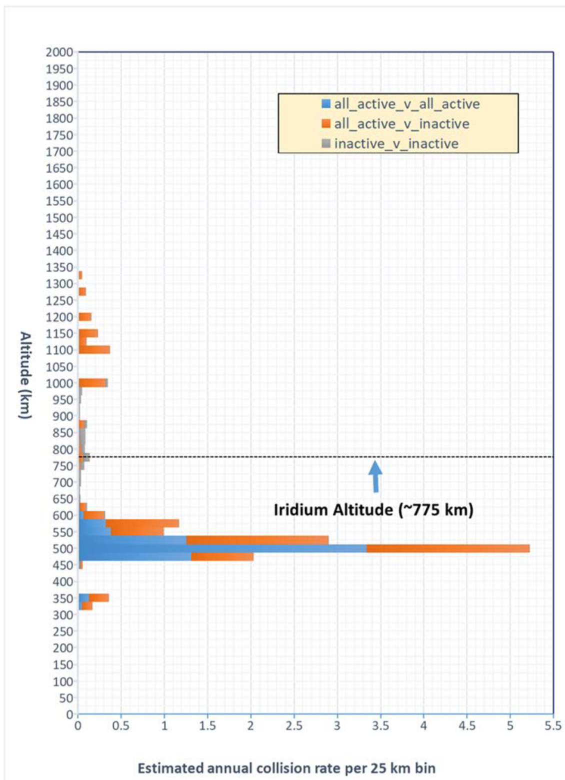
The data required depends upon the collision risk metric and threshold the operator (or national regulator) chooses to adopt and/or enforce. This choice is not as clear-cut as one might think; I can quickly list more than a dozen such metrics. Operators use this diverse set of metrics to detect and quantify risk: some use predicted close approach miss distance, while others try to estimate the probability that their spacecraft will collide with another space object. Operators/regulators typically base their selection of a collision risk metric upon (a) how crowded the orbit regime is that their spacecraft occupy; (b) how much extra fuel their spacecraft has; (c) how many flight engineers they can allocate to run the analytics; (d) how complex the metric is to estimate; (e) what data is available to compute the metric; (f) can they trust the SSA data they have for computing the selected metric; and (g) whether there are environmental effects that influence the utility of some metrics more than others.

For example, collision probability (Pc) is one of the most commonly used metrics for mid-LEO orbit operators, because Pc mathematically incorporates all elements required to assess how likely it is for two objects to collide in space. Pc requires ephemeris for both objects, object sizes or dimensions, and covariance. Using Pc allows operators to minimize fuel usage in this crowded portion of LEO. But unfortunately, Pc is less conservative and a good deal more complex to estimate that other metrics, and in many cases, input data (specifically object sizes and covariance) are largely unavailable.

Conversely, GEO operators often recognize that object sizes and covariance are largely unavailable, and because they also don't have as many conjunctions as operators in LEO, they can afford to be more cautious with their school-bus-sized spacecraft. For these reasons, GEO operators often choose miss-distance-based or radial-separation-based metrics that are simple to compute.

8. How common is it for operating satellites launched as of 2010 to have active propulsion capabilities so that they might be able to maneuver in response to a collision threat? In other words, how likely is it, in general, that one or both parties in a potential collision event could even avoid it?

The typical definition of an "active spacecraft" is that it can still communicate. While I don't have a good statistics on what percent of active spacecraft can maneuver, most are able to maneuver unless they are of the CubeSat form factor or have run out of propellant. While currently identified conjunctions are dominated by space debris hitting other space debris, we anticipate that within ten years as large constellation spacecraft take a dominant role in the space population, the portion of conjunctions between two actively maneuvering spacecraft will become the major concern in certain orbit regimes. This will drive the need for operators to cooperate with each other to a much greater degree than is required today to ensure the long-term sustainability of our operations in space.



Oltrogge, D.L.

a. Should satellites that do not have propulsive capabilities be treated differently, such as in the context of STM? If so, how?

This is an active debate, one which has recently been brought to the forefront by the FCC's recent Orbital Debris Mitigation NPRM. The idea of partitioning orbital altitudes by maneuvering capability was proposed some years ago (Sundberg, circa 2013).

Much science and mission success has been achieved by non-maneuvering spacecraft at all orbital regimes, and no constraints are currently placed on altitude other than the prescribed maximum post-mission orbit lifetime of 25 years.

However, there is also merit in the thought that any spacecraft that could pose a collision risk to human-habitable spacecraft such as ISS (orbiting roughly at or above 400 km) or future Chinese space stations should be able to avoid a collision with it.

In the Space Safety Coalition (spacesafety.org) Best Practices document, an aspirational voluntary goal is to ensure that spacecraft operating above 400 km must be able to maneuver to avoid collisions with tracked objects.

People tend to view CubeSats as inexpensive ways to operate in space. I caution that while they can be inexpensive to purchase and sometimes inexpensive to launch, that does not mean that operating such inexpensive spacecraft may also be inexpensive. Independent of spacecraft size or form factor, our evolving expected operational norms of behavior may soon impose the need for maneuverability, decision-quality SSA data and analytics and drag augmentation/reentry and design-to-demise capabilities.

This should not necessarily be seen as imposing a constraint on CubeSats, since low-thrust systems for CubeSats and small satellites have been in active development for several years not and some may be nearing operational readiness. As well, CubeSats are also using "differential drag" to effect a change to their orbit by changing their effective drag-facing cross-sectional area.

9. Your prepared testimony suggests that the U.S. should fund a rapid "Space Traffic Management Prototype." What would such a prototype consist of and by what metrics could we assess its value or contribution?

Many people don't realize that we don't need to build a comprehensive STM system from scratch. Operationally-proven commercial SSA systems and algorithms can readily address current gaps in SSA and STM capability.

We just need to bring these elements together in a collaborative environment, where new STM algorithms, processes, tools, sensors and capabilities can be developed by the commercial space industry and academia at a low Technical Readiness Level (TRL), the commercial industry can operate mature (High TRL) STM capabilities, and the government can oversee and contribute data to the STM initiative.

Consistent with that, the rapid STM Prototype would demonstrate a commercial capability which leverage existing U.S. industry technology to provide a basic STM Safety of Flight service. This prototype would, under the management auspices of the Department of Commerce, consist of a limited-time trial of the comprehensive integration and processing of commercial and government-contributed SSA data. The prototype would provide a no-cost service (conjunction analysis, risk assessment and safety of flight modeling) to self-nominated operators spanning the global civil and commercial satellite operator community who can rely on the information provided as "decisional quality" for operations.

SSA data sources would include satellite operator sensor and spacecraft data, concurrent legacy SSA data and products from the 18 SPCS conjunction assessment service, and the augmented catalog of resident space objects incorporating passive optical, radar and RF observations from commercial and government sensors).

Metrics to quantitatively measure the value of the of the STM service would include timeliness, utility, completeness, positional differences, consistency, error depiction realism, conjunctions time and miss distance discrepancies. The specific approach used to assess these metrics, and the LEO, MEO and GEO spacecraft involved in the prototype, would be jointly selected by the participating satellite operators and the U.S. Commercial Prototype operator.

Question for the Record

Mr. Dan Oltrogge

Submitted by Congressman Bera

I. In Professor Gabrynowicz's written statement, she says that "it is also increasingly necessary to share relevant information with appropriate entities in order to prevent relatively minor events from escalating into major conflicts. The day before the hearing; Gen. Raymond, commander of the US Space Force, talked about the unusual and disturbing actions of a pair of Russian satellites which are tailing a multi-billion-dollar US spy satellite.

a. Should the intent behind these actions concern us when it comes to talking about international data sharing and shared responsibilities? Are there are any national security concerns with sharing such information? Are other countries, like China and Russia, sharing the same caliber of information with us today?

These questions would best be answered by members of our national security organizations.

b. What mechanisms could be used to share information with appropriate entities? And through what international body should such a process be coordinated?

Per UN treaty and recently-adopted Long-Term Sustainability (LTS) guidelines, space objects are to be registered with the United Nations Office of Outer Space Affairs (UNOOSA). Running a data exchange portal for all space actors would require extensive resources and maintenance and be orders of magnitude complex.

That said, there are multiple, viable avenues for sharing space data, including a government-provided platform (such as Space-Track), the commercial space operator self-funded non-profit Space Data Association, and numerous commercial and government SSA service providers.

Given the security concerns that companies and countries have, I believe that our focus must be to provide a suitable secure government repository that can accommodate the diverse set of SSA and STM data I mentioned in answer to Question 4.

c. Who should be responsible for sharing this information and notifying the appropriate actors at play?

Ultimately, State Actors (space operators) should be responsible. But implementation is complicated by the fact that governments have national security concerns to deal with, and commercial companies at all levels of the space enterprise (spacecraft manufacturers, SSA and STM service providers, launch operators, spacecraft operators, On-Orbit Servicers, Active Debris Removers) are concerned about the need to protect their intellectual property and proprietary data from their competition. State Actors need to balance their regulatory approach commensurate with treaty obligations and their national interest (including national security and economic factors).

Responses by Dr. Ruth Stilwell

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Space Situational Awareness: Key Issues in an Evolving Landscape

Dr. Ruth Stilwell response to Question for the Record submitted by Congressman Bera:

The actions of the two Russian satellites that were observed to be behaving in a manner similar to inspection satellites has understandably raised concerns, but also points to the national value of a robust system of international information sharing for space situational awareness data.

Regarding the specific questions:

a: Should the intent behind these actions concern us when it comes to talking about international data sharing and shared responsibilities? Are there any national security concerns with sharing such information? Are other countries, like China and Russia, sharing the same caliber if information with us today?

It is important to distinguish between the sharing of position and intent (intent in this case referring to the intended trajectory and movement of the satellite) data of operating satellites and mission intent (the purpose or mission of the satellite). The possibility that a satellite could be used as a provocation in the international relationship between two parties is discrete issue appropriately addressed by the national security community. However, a transparent global system of shared space situational awareness decreases the opportunity for state actors to operate in an adversarial manner undetected. Simply put, if a common system has access to sensor data from government, commercial, academic, and other sources around the globe, the ability for one satellite operator to conceal their behavior is diminished. Space Situational Awareness does not simply rely on the operator or controlling state to provide data, but also includes the sharing of sensor data collected by various states and entities about the orbital environment as a whole.

So, while the behavior of the Russian satellites should be of concern to the defense community, the sharing of information does not increase that concern and indeed an international data sharing regime disincentivizes this type of behavior from individual actors. The information shared by the US in a SSA context is limited to the declassified elements of state operated satellites, however, there are concerns that the US may consider some position information as classified even though the data is available through other sources including sensors and visual observation. It is a policy matter for the US to determine whether it is appropriate to restrict information on the position of space assets when that information is readily available from other sources.

b. What mechanisms could be used to share information with appropriate entities? And through what international body should such a process be coordinated?

The transfer of civil space situational awareness to a civil agency will expand transparency and access to the SSA data. When it comes to information sharing, the mechanisms need to consider both access to and collection of data. Expanding the data sources available to input into the SSA data pool as well as expanding access to information output from the SSA system are of equal importance. The government, as steward of the data, will develop the secure mechanisms for appropriate parties to both input and extract data. The National Offload Program of the Federal Aviation Administration can prove instructive in this regard. FAA is able to freely share government data regarding the operational environment with appropriate airspace users through a system of validation and agreements that provides for an automated interface between user and government service provider. While this system has evolved over time and is specific to the needs of the aviation community, it may provide an instructive administrative model for information sharing.

The international body with jurisdiction over space affairs is the UN Office of Outer Space Affairs which provides support to the Committee on the Peaceful Uses of Outer Space. In addition, matters of spectrum allocation are under the jurisdiction of the International Telecommunications Union, the UN Specialized Agency for telecommunications. While UN OOSA and COPUOS are not specialized agencies, together they provide a framework for the development of policies and agreements in the international space community. Space faring nations of the world participate in the process and the US maintains a permanent presence through the US Mission to International Organizations in Vienna. This structure provides the framework for technical participation in the same manner as other State Department missions to UN Agencies, where the State Department maintains the diplomatic relationship but relies on the appropriate US government agencies for technical expertise and input.

c. Who should be responsible for sharing this information and notifying the appropriate actors at play?

There is a clear need for the US to designate a civil department as the lead agency for Space Situational Awareness and information sharing. The current model, relying on the Department of Defense to provide information services to the global civil space community is outside the military mission. A civil agency can provide additional sensor data from outside sources to support the military mission, but it is not reasonable to ask the military to collect civil data for the purpose of civil distribution. While there has been some historic discussion on which civil agency is most appropriate, continuing a prolonged debate stifles progress and threatens US leadership in this matter. The Administration's Space Policy Directive – 3 supports transferring these functions to the Department of Commerce and the department has stood up and began to staff the Office of Space Commerce to provide this function. The space community is generally supportive of this approach. Absent a significant barrier to this course of action, the Office of Space Commerce should assume responsibility for this function.