SPACE SITUATIONAL AWARENESS: GUIDING THE TRANSITION TO A CIVIL CAPABILITY

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

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C O N T E N T S

May 12, 2022

Appendix II: Additional Material for the Record

SPACE SITUATIONAL AWARENESS: GUIDING THE TRANSITION TO A CIVIL CAPABILITY

THURSDAY, MAY 12, 2022

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

The Subcommittee met, pursuant to notice, at 10 a.m., in room 2318 of the Rayburn House Office Building, Hon. Don Beyer [Chairman 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: Guiding the Transition to a Civil Capability

May 12th, 2022
10:00 a.m. Eastern Time
Hybrid: 2318 Rayburn House Office Building and Online via Zoom

PURPOSE

The purpose of the hearing is to consider testimony regarding planning for the transition of certain space situational awareness services and information to a civil capability, among other issues.

WITNESSES

- **Dr. Matthew Hejduk**, Senior Project Leader, The Aerospace Corporation
- **Dr. Moriba Jah**, Associate Professor, Aerospace Engineering and Engineering Mechanics Department, Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering, Oden Institute for Computational Engineering and Sciences, The University of Texas at Austin
- **Mr. Andrew D'Uva**, Senior Policy Advisor, Space Data Association
- **Mr. Kevin M. O'Connell**, Founder, Space Economy Rising, LLC
- **Dr. Mariel Borowitz**, Associate Professor, Sam Nunn School of International Affairs, Ivan Allen College of Liberal Arts, Georgia Institute of Technology

OVERARCHING QUESTIONS

- *What should be the goals and objectives for an evolvable civil space situational awareness capability?*
- *What is needed to ensure an effective transition of certain space situational awareness services and information from the Department of Defense to a civil government entity or entities?*
- *What are the potential challenges in transitioning space situational awareness services and information to a civil capability, and how should those challenges be addressed?*
- *To what extent is research and development important to the future of a civil space situational capability and an eventual space traffic coordination framework?*

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. Given this evolving landscape, space situational awareness (SSA) is becoming an essential means to ensuring the safety and sustainability of the space environment.

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 the environmental effects of space weather on space objects and how they move through space. SSA is distinct from but related to what is referred to as space traffic coordination (STC), which uses SSA data and information as input into safety decisions for on-orbit operations.

Currently, the Department of Defense (DOD) has the role of collecting space object location data, maintaining a catalog of space objects, processing space object data to characterize the space environment, determining the potential for collisions, and disseminating notices of potential collision risks to space operators.[1]

U.S. Government SSA Data Collection and Tracking System

The DOD Combined Space Operations Center (CSpOC) uses radar and optical telescopes to track space objects and actively maintains a public catalog 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 catalog reports over 44,000 space objects, of which only about 5,600 have been publicly verified as active payloads.[2] Statistical models

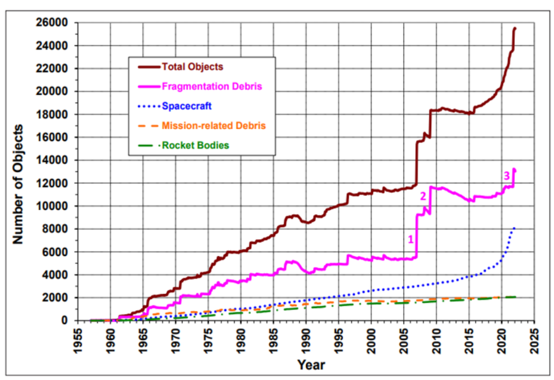

Figure 1. Number of Objects in Earth Orbit by Object Type. Source: Orbital Debris Quarterly Newsletter, Volume 26, Issue 1, March 2022.
https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv26i1.pdf

[1] Title 10 United States Code, Section 2274
[2] https://www.space-track.org/auth/login

estimate that there are over 36,000 space objects larger than 10 centimeters (cm) and 1,000,000 objects between 1cm and 10cm in orbit around the Earth, however DOD's Space Surveillance Network is not capable of tracking the smallest objects, particularly those below 10cm.[3,4]

The number of objects being tracked by the DOD has been rising, due to the increasing number of objects in space and the ability of commercial and non-U.S. capabilities to track them.[5] Commercial and international data, when combined with DOD SSA data, can provide more frequent observations of space objects than the DOD system alone and can improve the accuracy of SSA information for satellite operators.[6] Furthermore, several commercial SSA companies have emerged to support government and private sector satellite owner/operators in identifying and tracking potential collisions and supporting potential collision avoidance maneuvers.[7] With an increasing number objects in the catalog and the availability of non-government SSA data and services, among other factors, SSA and the process for detecting, processing, and alerting operators of potential collisions becomes more complex.

Space Policy Directive-3, National Space Traffic Management Policy

In June 2018, The Trump Administration issued Space Policy Directive-3, or SPD-3, the National Space Traffic Management Policy. SPD-3 was issued to promote space safety as means of maintaining U.S. leadership in space. The policy identifies principles, goals, and guidelines on managing the integrity of the space operations environment; roles and responsibilities for space situational awareness and space traffic management; and provides other relevant guidance. SPD-3 also recognizes the need to transition certain space situational awareness data and information services to a civil entity. Specifically, SPD-3 states: "To facilitate…enhanced data sharing, and in recognition of the need for DoD to focus on maintaining access to and freedom of action in space, a civil agency should, consistent with applicable law, be responsible for the publicly releasable portion of the DoD catalog and for administering an open architecture data repository."[8]

SPD-3 also provided guidance on agency roles and responsibilities, including that,

- "The Secretaries of Defense and Commerce, in coordination with the Secretaries of State and Transportation, the NASA Administrator, and the Director of National Intelligence, should cooperatively develop a plan for providing basic SSA data and basic STM [Space Traffic Management] services either directly or through a partnership with industry or academia";
- The Secretary of Defense would maintain the authoritative catalog of space objects; and
- "The Secretary of Commerce, in coordination with the Secretaries of State, Defense, and Transportation and the NASA Administrator, and the Director of National Intelligence,

[3] NASA, Orbital Debris Quarterly Newsletter, Volume 26, Issue 1, March 2022. Available at: https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv26i1.pdf
[4] https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers
[5] https://www.popularmechanics.com/space/satellites/a25562991/pentagon-declassifying-space-traffic-data/
[6] Institute for Defense Analysis, Science and Technology Policy Institute, "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", April 2019
[7] *Ibid.*
[8] Space Policy Directive-3, National Space Traffic Management Policy. Issued on June 18, 2018.

> shall develop standards and protocols for creation of an open architecture data repository to improve SSA interoperability and enable greater SSA data sharing."

In addition, SPD-3 stated the importance of science and technology for SSA and STM: "Members of the National Space Council, or their delegees, shall coordinate, prioritize, and advocate for S&T [Science and Technology], SSA, and STM, as appropriate, as it relates to their respective missions. They should seek opportunities to engage with the commercial sector and academia in pursuit of this goal."

Congressional Activities

Over recent Congresses, legislative proposals have been introduced toward a civil capability for SSA services and information; however, Congress has not yet granted a civil agency with the authority for certain civil SSA responsibilities.

Congress has appropriated funding to initiate work on civil SSA activities. The explanatory statement for the Consolidated Appropriations Act, 2021, included language directing the Office of Space Commerce, within the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, to begin work on prototype for a civil SSA data system, and provided appropriated funding for the effort:

> *Within the funding provided, the agreement directs NESDIS* [National Environmental Satellite, Data, and Information Service] *and OSC* [Office of Space Commerce] *to initiate a space traffic management (STM) pilot program, in collaboration with industry, the Department of Defense, the Federal Aviation Administration, NASA, and other Federal partners, as appropriate, to develop STM technical prototypes, initiate an open architecture data repository* [OADR]*, and perform STM demonstrations and experiments….*[9]

The Consolidated Appropriations Act, 2022 appropriated the Office of Space Commerce with $16 million, an increase of $6 million over the 2021 enacted appropriation, and included direction for the Office of Space Commerce to continue work on advancing space traffic management and SSA capabilities in collaboration with industry and Federal partners.[10]

Office of Space Commerce Open Architecture Data Repository

On February 11, 2022, NOAA publicly announced and demonstrated a cloud-based prototype Open Architecture Data Repository (OADR), which was developed in collaboration with Federally-funded Research and Development Centers (FFRDCs) and academia. The prototype has been tested against 20,000 space objects in collaboration with DOD, NASA, and the commercial sector.[11] A completed system, once operational, is anticipated to process SSA data

[9] Explanatory Statement Submitted by Mrs. Lowey, Chairwoman of the House Committee on Appropriations, Regarding the House Amendment to the Senate Amendment to H.R. 133, Consolidated Appropriations Act, 2021; Congressional Record Vol. 166, No. 218 Issue and Section: December 21, 2020 - House (Vol. 166, No. 218)

[10] Explanatory Statement Submitted by Ms. DeLauro, Chair of the House Committee on Appropriations, Regarding the House Amendment to the Senate Amendment to H.R. 2471, Consolidated Appropriations Act, 2022; Congressional Record Vol. 168, No. 42

[11] National Oceanic and Atmospheric Administration. "Media Briefing: Open-Architecture Data Repository (OADR)" February 11, 2022. Available at: Media Briefing: Open-Architecture Data Repository (OADR) - YouTube

and provide notifications to space operators on potential collisions. According to NOAA, an initial operational capability is anticipated by 2024 and a full operational capability is planned for 2025.

In addition, NOAA's Office of Space Commerce has taken initial steps to understand the availability of commercial data sources of space situational awareness data that can fill gaps in existing government facilities for tracking space objects, including debris, especially in the southern hemisphere, and the ability to task such tracking sensors. The Office issued a NOAA Space Object Commercial Data Request for Information in February 2022 and subsequently, in April 2022, noticed its intent to purchase low Earth orbit object tracking data and SSA support.[12]

NASA Role in SSA

NASA has a long history of carrying out SSA in the interest of mitigating the risk to its own assets of potential collisions with debris and active satellites. The NASA Conjunction Assessment and Risk Analysis (CARA) program is an Agency-level program required for all operational robotic operational assets. To support NASA teams, the CARA program maintains an interface with DOD to receive close approach information, monitors and assesses potential collision threats, and advises NASA robotic mission teams on potential avoidance maneuvers.[13] In addition, Mission Control at NASA's Johnson Space Center works with DOD to assist NASA's human spaceflight managers in monitoring potential conjunctions, developing conjunction avoidance maneuvers, and conducting risk assessments of the International Space Station (ISS) and ISS visiting vehicles and human exploration vehicles, whether with or without crew.[14]

In December 2020, NASA released the *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*. The handbook reflects the goal of SPD-3 in developing safety standards and best practices, outlines NASA's own best practices in risk assessment and mitigation for space safety, and provides best practices regarding spacecraft and satellite constellation design, launch preparation and activities, and on-orbit collision avoidance.[15] For owners and operators of spacecraft, the handbook is intended to offer approaches for lowering collision risks and operating safely and sustainably in space. For providers of SSA information or conjunction assessment services, the handbook offers information to augment or improve upon existing capabilities for the benefit of the entire space industry.

[12] Department of Commerce. *Notice of Intent: Low Earth Orbit (LEO) Space Object Commercial Data*. General Services Administration. Available at: https://sam.gov/opp/5f4eea2cd55145ce990e2777be2fcfd5/view
[13] NASA. "CARA: Conjunction Assessment Risk Analysis", Available at: https://satellitesafety.gsfc.nasa.gov/CARA.html
[14] NASA Procedural Requirements NPR 8715.6B
[15] NASA. *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*. 2020 (Report No. NASA/SP-20205011318). Available at: https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf

Chairman BEYER. This hearing will come to order. And without objection, the Chair is authorized to declare recess at any time.

Before I deliver my opening remarks, I wanted to note that the Committee is meeting both in person and virtually. A couple of reminders for the Members about the conduct of this meeting. First, Members and staff who are attending may choose to be masked, but it is not a requirement. However, any individuals with symptoms, a positive test, or exposure to someone with COVID–19 should please wear a mask while present.

And Members who are attending virtually should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones, and please keep your microphones muted unless you are speaking. Finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the meeting.

So good morning, and welcome to today's hearing, "Space Situational Awareness: Guiding the Transition to a Civil Capability." First, thank you to our distinguished panel of witnesses for being here virtually today. I'm pleased that we are finally able to handle this important hearing. Previously scheduled hearing dates had to be postponed due to changes in the House voting schedule and to a memorial service for a former House Member.

But today, we're here and we're ready to discuss this urgent issue: Space Situational Awareness, or SSA. SSA is the ability to identify, understand, and predict the locations of objects in space so that potential collision risks can be calculated and this information shared with operators.

The growth in space activity has made SSA crucial. Space-enabled services like communications, national security activities, banking, weather forecasting, and Earth imaging all depend on the ability of systems to operate safely in space. However, safety is far from guaranteed. Mega constellations of thousands of satellites are creating orbital congestion, and the orbital debris left behind is compounding the risks of operating in space. The sustainability of the space environment is in peril if we don't act. Understanding and mitigating the risks starts with SSA.

While the Department of Defense (DOD) has been providing SSA services and information to space operators for decades, the increasing complexity of the SSA function, the resources required to manage it, and the need for ongoing improvements are becoming an increasing burden. In 2018, Space Policy Directive–3 (SPD–3) recognized the need for a civil agency to carry out basic SSA capabilities so that DOD can focus on its national security mission. I totally agree. But then how will a transition from a DOD-based system to a fully operational, civil SSA capability actually occur?

Some entities suggest that commercial companies can perform the civil SSA function and already do so, if only on a smaller scale, and others argue the problem has been studied to death and we need to just get on with it. But first, we need to know exactly what we're getting on with because the transition to civil SSA remains unclear.

What functions and responsibilities should be transitioned? What SSA data are needed, and who will provide it? What services and

information, and at what level, will the civil capability provide? And what roles will the government have and where should the commercial sector contribute?

The current approach to civil SSA is the Department of Commerce's (DOC's) Office of Space Commerce (OSC) Open Architecture Data Repository—OADR. In 2021, the Office demonstrated its OADR prototype to enable SSA data sharing among government and commercial space operators. For Fiscal Year 2023, the Office is requesting a whopping 550 percent increase in funding toward bringing the pilot to an operational capability.

What the OADR is, what it would be required to do and how it would evolve, however, are open questions. And the path forward for civil SSA has not been defined, and it needs to be to avoid the mistakes of past programs gone awry. DOD's own attempts to upgrade its legacy SSA systems ended up in nearly a billion dollars spent and a decade lost before the agency canceled the JMS (Joint Space Operations Center Mission System) program.

Today's hearing will examine the questions, actions, and issues that must be addressed to enable an effective transition. We need a plan to move quickly. And while SSA is an essential first step, it is just one element of space safety. We need aggressive actions to mitigate the further creation of orbital debris. We need a framework to define who moves where and when in space, so-called space traffic management or space traffic coordination.

And while the United States has led the world in actionable SSA services and information, other nations are quickly getting into the game and developing advanced approaches to SSA and space traffic coordination. We can't afford to lose our edge. Because while space safety is a global issue that requires spacefaring nations to work together, we must continue to lead the way.

I'm pleased that the Biden-Harris Administration is doing just that by taking initial steps on norms of responsible behavior, which includes their new recent announcement of a new commitment by the U.S. Government not to conduct anti-satellite missile testing, and this is in stark contrast to behavior of some of our global adversaries.

This Subcommittee and the Full Committee are taking very seriously the establishment of a robust, evolvable civil SSA. We're currently working on the draft *Space Safety and Situational Awareness Transition Act of 2022.* Today's hearing will inform that process, and I look forward to working with my friend, the Ranking Member Dr. Brian Babin, all our Members, and the broader stakeholder community as we advance legislation to address this pressing issue.

[The prepared statement of Chairman Beyer follows:]

Good morning, and welcome to today's hearing, "Space Situational Awareness: Guiding the Transition to a Civil Capability." I want to thank our distinguished panel of witnesses for being here today.

I'm pleased that we are finally able to hold this important hearing. Previously scheduled hearing dates had to be postponed due changes to the House voting schedule and a memorial service for a former House Member.

Today, we are here and ready to discuss this urgent issue-Space Situational Awareness or SSA. SSA is the ability to identify, understand, and predict the locations of objects in space so that potential collision risks can be calculated and shared with operators.

The growth in space activity has made SSA crucial. Space-enabled services like communications, national security activities, banking, weather forecasting, and Earth imaging depend on the ability of systems to operate safely in space.

However, safety is far from guaranteed.

Mega constellations of thousands of satellites are creating orbital congestion, and orbital debris from past missions-and reckless anti-satellite tests-are compounding the risks of operating in space. The sustainability of the space environment is in peril if we don't act.

Understanding and mitigating the risks starts with SSA.

While the DOD has been providing SSA services and information to space operators for decades, the increasing complexity of the SSA function, the resources required to manage it, and the need for ongoing improvements are becoming an increasing burden.

In 2018, Space Policy Directive-3 recognized the need for a civil agency to carry out basic SSA capabilities so that the DOD can focus on its national security mission.

I couldn't agree more. How will a transition from a DOD-based system to a fully operational, civil SSA capability occur?

Some entities suggest that commercial companies can perform the civil SSA function and already do so, albeit on a smaller scale.

Others argue the problem has been studied to death and we need to get on with it.

First, we need to know exactly what we're getting on with, because the transition to civil SSA remains unclear.

- What functions and responsibilities should be transitioned?
- What SSA data are needed and who will provide it?
- What services and information, and at what level, will the civil capability provide?
- And what roles will the government have and where should the commercial sector contribute?

The current approach to civil SSA is the Department of Commerce's Office of Space Commerce open architecture data repository-OADR. In 2021, the Office demonstrated its OADR protype to enable SSA data sharing among government and commercial space operators. For Fiscal Year 2023, the Office is requesting a whopping 550 percent increase toward bringing the pilot to an operational capability.

How the OADR would evolve, however, is an open question. The path forward for civil SSA has not been defined, and it needs to be to avoid the mistakes of past programs gone awry.

DOD's own attempts to upgrade its legacy SSA systems ended up in nearly a billion dollars spent and a decade lost before the agency cancelled the JMS program.

Today's hearing will examine the questions, actions, and issues that must be addressed to enable an effective transition.

For starters, it's clear we need a plan to move quickly. And while SSA is an essential first step, it is just one element of space safety.

We also need aggressive actions to mitigate the further creation of orbital debris.

And we need a framework to define who moves where and when in space-so-called space traffic management or space traffic coordination.

While the U.S. has led the world in actionable SSA services and information, other nations are quickly getting into the game and developing advanced approaches to SSA and space traffic coordination.

We can't afford to lose our edge. Because while space safety is a global issue that requires spacefaring nations work together, we must continue to lead the way. I'm pleased that the Biden-Harris Administration is doing just that by taking initial steps on norms of responsible behavior, which includes their recent announcement of a new commitment by the U.S. government not to conduct direct-ascent anti-satellite missile testing, a stark contrast with the behavior of some of our global adversaries.

I want to thank our witnesses again for being here and I look forward to your testimony. Establishing a robust, evolvable civil SSA capability is an essential part of space safety and one the Subcommittee and Committee are taking very seriously.

The Subcommittee is currently working on the *"Space Safety and Situational Awareness Transition Act of 2022"* and today's hearing will inform that process. I look forward to working with Ranking Member Babin and Members of the Subcommittee and Committee and the broader stakeholder community as we advance legislation to address this pressing issue.

Chairman BEYER. And with that, let me now recognize our Ranking Member, the good gentleman from Texas, Dr. Babin.

Mr. BABIN. Thank you, Chairman Beyer. I really appreciate your leadership.

This Committee has focused on Space Situational Awareness, or SSA, for several years. We've held numerous hearings and considered two significant pieces of legislation: the *American Space Commerce Free Enterprise Act,* which passed the House by voice vote, and the *American Space Situational Awareness and Framework for Entity Management Act.* These efforts by the Committee informed the development of Space Policy Directive No. 3, which called for the Department of Defense to transfer its current responsibility to share SSA data to the Department of Commerce.

The debris created by a recent Russian anti-satellite test highlights why SSA remains an important issue. As I said at our Subcommittee's hearing in 2020, 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. There are, however, some important issues that I think we can still all agree on.

First, we need better data. The information the government and the private sector rely on to make sound decision absolutely needs to be improved. Uncertainty is too high, which could lead to unnecessary alerts and unpredicted conjunctions. As a result, the private sector is stepping up to the plate. They are developing cost-effective, timely, and accurate SSA data and services, 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 foster the growth of these nascent industries.

Secondly, the Department of Commerce is the right agency for the job. I am closely following Commerce's plans to stand up this capability. They don't need to create a bloated bureaucracy. Nor should they duplicate DOD's existing architecture or reinvent the wheel by building new systems and sensors. They should just be a commercial storefront that takes the government's data, integrates it with any necessary commercial and operator data, and makes that information available to the public through commercial architectures. We aren't ready for "space traffic management" or being a "traffic cop in space."

Instead, we should elevate the Office of Space Commerce out of NOAA (National Oceanic and Atmospheric Administration) so that they can better coordinate across the Department and throughout the government and internationally as well. Commerce already houses several agencies that are relevant to space. I will list a few: NIST (National Institute of Standards and Technology), BIS (Bureau of Industry and Security), ITA (International Trade Administration), NTIA (National Telecommunications and Information Administration), and the National Weather Service, and NOAA. Elevating the Office is key to their long-term success.

Commerce also has a history of partnering with the private sector to nurture emerging industries. Commerce stood up the Internet Corporation for Assigned Names and Numbers, or 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 that we enjoy today.

We've already seen the space community adopt a similar approach on their own. Several years ago, operators founded the Space Data Association (SDA) to share information and improve safety. The SDA 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 (LEO).

The third issue we should all agree on is that we need to develop better standards and practices. And rather than imposing a top-down regulatory burden on an emerging sector, we should adopt a crawl, walk, run approach. NASA (National Aeronautics and Space Administration), while not a regulator, has a long history of demonstrating responsible behavior and researching orbital mechanics. NASA, along with academia and the private sector, can play an important role in advancing our understanding of the orbital domain, as well as facilitating the development of non-binding consensus-based standards, best practices, and customs.

This could be done similarly to how NASA developed internal orbital debris mitigation standard practices that eventually informed the international Inter-Agency Space Debris Coordination Committee's space debris mitigation guidelines. These standards and best practices could also be augmented by contributions from the insurance industry, similar to the role that they played in the very early days of maritime shipping.

We have a lot to learn about how to operate in space, but I am very optimistic. I believe that we can all work together to ensure space remains a safe and prosperous domain without smothering the private sector with burdensome regulations or crowding out of commercial solutions.

So I want to thank you, Mr. Chairman, and I look forward to an interesting panel of witnesses. And I yield back.

[The prepared statement of Mr. Babin follows:]

This Committee has focused on Space Situational Awareness, or "SSA," for several years. We've held numerous hearings and considered two significant pieces of legislation: the *American Space Commerce Free Enterprise Act,* which passed the House by voice vote, and the *American Space Situational Awareness and Framework for Entity Management Act.* These efforts by the Committee informed the development of Space Policy Directive 3, which called for the Department of Defense to transfer its current responsibility to share SSA data to the Department of Commerce.

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Instead, we should elevate the Office of Space Commerce out of NOAA so that they can better coordinate across the Department, throughout the government, and internationally. Commerce already houses several agencies that are relevant to space - NIST, BIS, ITA, NTIA, the National Weather Service, and NOAA. Elevating the Office is key to their long-term success.

Commerce also has a history of partnering with the private sector to nurture 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 SDA 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.

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. NASA, while not a regulator, has a long history of demonstrating responsible behavior and researching orbital mechanics.

NASA, along with academia and the private sector, can play an important role in advancing our understanding of the orbital domain as well as facilitating the development of non-binding consensus-based standards, best practices, and customs.

This could be done similar to how NASA developed internal Orbital Debris Mitigation Standard Practices that eventually informed the international Inter-Agency Space Debris Coordination Committee's Space Debris Mitigation Guidelines. These standards and best practices could also be augmented by contributions from the insurance industry, similar to the role they played in the early days of maritime shipping.

We have a lot to learn about how to operate in space, but I am optimistic. I believe we can all work together to ensure space remains a safe and prosperous domain without smothering the private sector with burdensome regulations or crowding-out commercial solutions.

Thank you and I look forward to an interesting panel.

Chairman BEYER. Dr. Babin, thank you very much.

I'd now like to ask for unanimous consent to enter into the record a written statement from the Commercial Spaceflight Federation. If there's no objection from Dr. Babin——

Mr. BABIN. No objection.

Chairman BEYER. And if there are Members who wish to submit additional opening statements, your statements will be added to the record at this point or at any point during the hearing.

[The prepared statement of Chairwoman Johnson follows:]

Good morning. Thank you, Chairman Beyer, for holding today's hearing on space situational awareness, and thank you to each of our witnesses for testifying today on this important topic.

Some of you may recall that this Subcommittee has previously held a hearing on the role of space situational awareness - or SSA - in the sustainability of the overall space environment. SSA involves collecting location data on space objects, processing that data to understand how those space objects move in space, and developing information to support spacecraft operators so they can avoid collisions in space.

As the amount of space debris and number of satellites orbiting the Earth have exponentially increased in recent years, SSA is critically important to maintaining space safety and ensuring that we continue to reap benefits on Earth from monitoring, operating, and living in space.

Currently the Department of Defense has the authority to publicly provide basic SSA information and notify space operators of potential collisions. Transitioning some of these services to a civilian authority is not a trivial task and there are important questions that must be answered.

We need to ensure that a clear path is in place.

The role of a strong SSA civil capability to our future in space is too important to risk limping along through a transition. We need a plan to do this responsibly.

The civil SSA system is the foundation on which we will build toward space traffic coordination. Our capability must consider international engagement to ensure space safety and sustainability in the years to come. The global community will not watch and wait for the United States to take action. The time is now.

I want to commend Chairman Beyer and Ranking Member Babin for holding today's hearing. This Subcommittee has been working hard on this topic and I look forward to the testimony and discussion on the considerations for transitioning to a civil space situational awareness capability.

Thank you, and I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairman Beyer. Today's hearing on space situational awareness is an important one. Russia's anti-satellite launch this fall brought the issue of space debris once again into mainstream discussion.

Fortunately, there were no collisions with the International Space Station as some worried would happen, but it did highlight the need for effective monitoring and coordination of space objects and debris.

In the two years since we last held a hearing on this topic, the commercial space situational awareness industry has continued to expand. The market is predicted to grow to a $1.8 billion industry by 2026.

That growth is due to the innovation and effectiveness of our commercial satellite operators and space data providers.

If we are to achieve our goal of effectively coordinating space objects, accurately tracking space debris, and advancing space safety, then we need to be sure we don't constrain the commercial industry with poorly considered regulations.

The Department of Defense has been providing the lion's share of space situational awareness information, but the private sector has emerged as a valuable partner with innovative solutions and services.

With the responsibility for sharing this data being transferred to the Department of Commerce following Space Policy Directive 3, it's more important that ever to encourage private sector growth. This industry can fill critical gaps in existing data, providing services, sensor data, and situational awareness.

There is an ever-growing need for these services as more and more industries discover its value.

So it's important that we don't take a heavy-handed regulatory approach that will stifle this growing industry. If the Department of Commerce adopts a clearinghouse approach, then the government can partner with the private sector and international community to share data and establish consensus-based best practices and standards.

This will improve data availability and utility and allow for better information and better services. I'm hopeful that the Department of Commerce will take a pragmatic approach that prioritizes growth and innovation rather than stifling commercial development.

The best way to ensure this is by taking the Office of Space Commerce out of NOAA and returning it to where it is authorized - at the Department of Commerce. That will allow them to provide better coordination and make full use of the Department's resources.

I'm encouraged by the continued growth of the commercial space industry and I'm hopeful that we can continue to encourage that while improving our space situational awareness. I look forward to hearing more from our witnesses today, and I yield back the balance of my time.

Chairman BEYER. At this time, I'd like to introduce our witnesses, who are with us virtually. Dr. Matthew Hejduk is a Senior Project Leader at the Aerospace Corporation and currently serves as the Chief Engineer of the NASA Satellite Conjunction Analysis Risk Assessment, or CARA, program. His research interests include satellite conjunction assessment techniques, satellite radar and optical signature modeling and analysis, estimation theory, and Space Surveillance Network modeling and simulation.

Dr. Moriba Jah is the Director of the Computational Astronautical Sciences and Technologies Group at the University of Texas (UT) at Austin where he is also an Associate Professor of Aerospace

Engineering and Engineering Mechanics. His research focuses on the convergence of policy, technology, and security related to space traffic management and space situational awareness. Prior to being at UT Austin, Dr. Jah worked at the University of Arizona, the Air Force Research Laboratory, and NASA's Jet Propulsion Laboratory (JPL).

Dr. Andrew D'Uva serves as the Strategy and Policy Advisor of the Space Data Association, or SDA, a nonprofit space traffic management organization. Mr. D'Uva led efforts to create the legal and data-sharing frameworks of the SDA and has supported international commercial satellite and telecommunications businesses for more than two decades with the present emphasis on government services, space sustainability, and cybersecurity.

Mr. Kevin O'Connell is the Founder and CEO (Chief Executive Officer) of Space Economy Rising, LLC, and has over 35 years of experience in the U.S. Government and research organizations and is an entrepreneur and business leader. His prior U.S. Government assignments include positions at DOD, the Department of State, and the National Security Council, the Office of the Vice President, the Office of the Director of Central Intelligence, and, most recently, as the Director of the Office of Space Commerce within the Department of Commerce.

Dr. Mariel Borowitz is an Associate Professor in the Sam Nunn School of International Affairs at Georgia Tech. Her research deals with international space policy issues, including international cooperation, Earth-observing satellites, and satellite data-sharing policies. She also focuses on strategies and developments in space security and space situational awareness.

As our witnesses should know, you will each have five minutes for your spoken testimony. Your written testimony, which could be significantly longer, is—will be included in the record for the hearing. And when you've all completed your spoken testimony, we will begin with Member questions. Each Member will have five minutes to question the panel.

So we will start with Dr. Matthew Hejduk. Dr. Hejduk, the floor or the Zoom is yours.

TESTIMONY OF DR. MATTHEW HEJDUK, SENIOR PROJECT LEADER, THE AEROSPACE CORPORATION

Dr. HEJDUK. Chairman Beyer, Ranking Member Babin, distinguished Members of the Subcommittee, thank you for inviting me to join this discussion. I'm on the staff of the Aerospace Corporation, a nonprofit, federally funded research and development center (FFRDC) whose purpose is to provide advice to the government on all aspects of the Nation's space enterprise. The full 33 years of my career in the aerospace discipline have been dedicated to space situational awareness, the last decade of which as a subject matter expert for the orbital safety mission for NASA. It is a great pleasure to give testimony today on the subject that has constituted my life's work.

The very title of this hearing testifies to the consensus, both on the part of the government and within industry, of the need to transition the U.S. Government's support of the civil and commercial orbital safety mission, which is the principal nonmilitary use

of space situational awareness to a civil agency. The remaining question is the best way to do this that provides needed capability while promoting a healthy synergy of government and private industrial roles.

The orbital safety mission, which is the process of keeping active spacecraft from colliding with space debris and with each other, is divided into three parts: satellite conjunction screenings, which look several days into the future to determine which satellites will come within close proximity of each other; conjunction risk assessment, which determines which of these close approaches actually presents a high risk of collision; and conjunction mitigation planning, which plans a satellite maneuver to avoid the high-risk close approach.

In support of civil and commercial space, the DOD actually performs only the first part. These satellite owner-operators presently look to their own resources to perform the latter two parts. The first transition steps should thus be simply to transfer what the DOD is doing presently for civil and commercial operators to the new civil agency using the DOD precision space catalog and the existing DOD algorithm for conjunction screening modified slightly to accommodate a modern computer architecture with a modern and automated user interface.

This part of the process is the most basic and would benefit least from innovation, will serve as a good confidence-building measure among owner-operators, and relies entirely on technology proven over decades. The regular export of the declassified version of the DOD precision catalog for use elsewhere in the U.S. Government is already an established and proven procedure.

Once this first step is established and working, the latter two parts of the orbital safety process can be considered. These tasks are, for many owner-operators, performed either internally or by private industry. This is an excellent opportunity to continue to encourage the SSA industrial sector by allowing such companies to use the civil agency's automated user interface and receive data directly for their owner-operator customers.

An additional industrial opportunity hosted as part of the user interface could be to provide the basic conjunction screening service but with more flexibility and extremely low time latency. The basic free service modeled after the DOD would thus continue, but owner-operators who would benefit from advanced services can obtain them from private industry facilitated by the civil agency.

One worrisome gap in the current process is its inability to accommodate satellites that perform autonomous flight control, including autonomous orbital safety actions without any necessary contact with their ground systems. The SpaceX Starlink constellation operates this way, and it will undoubtedly become a favored mechanism for large constellations. Special orbital safety solutions are needed for autonomous systems, and the civil agency can take the lead perhaps through a government-industry partnership to develop and implement a durable solution.

The availability of commercial SSA data offers exciting opportunities to improve the orbital safety mission through increased data availability, and these opportunities should definitely be embraced. The acquisition of commercial SSA data should, however, be tar-

geted. Not all orbit regimes or objects will benefit appreciably from additional SSA data, and only certain narrow orbital safety objectives will be advanced by an expanded space catalog that contains additional small objects.

Finally, while the transition of the execution of the orbital safety mission is important, overshadowing this is the great need to establish standards, guidelines, and norms of behavior for safe satellite operation. The lack of a reasonable, analytically grounded set of such norms, integrated with the FAA (Federal Aviation Administration) and FCC (Federal Communications Commission) licensing process, is the circumstance perhaps doing the most injury to orbital safety at present. Progress in this area cannot wait for the transition of the orbital safety mission execution to complete. It must be pursued immediately.

This concludes my prepared remarks, and I'm happy to entertain any questions the Subcommittee may have.

[The prepared statement of Dr. Hejduk follows:]

Statement of

Dr. Matthew Hejduk

Senior Project Leader – Civil Systems Group

The Aerospace Corporation

Before the

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

U.S. House of Representatives

"Space Situational Awareness: Guiding the Transition to a Civil Capability"

Chairman Beyer, Ranking Member Babin, and distinguished members of the Subcommittee, thank you for inviting me to join this discussion. I am on the staff of The Aerospace Corporation, a non-profit Federally-funded Research and Development Center whose purpose is to provide advice to the Government on all aspects of the nation's space enterprise. The full thirty-three years of my career have been spent in the Space Situational Awareness (SSA) domain, which has included the design and development of space sensors and command and control systems; basic research on SSA data exploitation algorithms; large-scale simulation of SSA systems; and in the last decade of my career, as a subject matter expert for NASA on the orbital safety problem. I also serve on the graduate faculty of Baylor University and advise dissertations in the Department of Statistical Sciences. It is a great pleasure to give testimony today on the subject that has constituted my life's work.

Introduction

The space population has grown tremendously in the last decade, and recent FCC and ITU filings for large satellite constellations make clear that the rate of growth is likely to remain high. At the same time, the relevant space debris population from existing debris fields decaying into more populated orbital regions and from fresh debris production, such as from the recent Russian ASAT test, is also growing. In combination, this makes the operational orbital safety mission—a set of activities to prevent active satellites from colliding with space debris and with each other—increasingly difficult. The USG's support to the civil and commercial orbital safety enterprise is presently performed by the DOD, which has always been an awkward mission for a military organization. The growing demands in this area are likely to consume more and more resources, could distract the DOD from their principal mission to protect and defend against military threats (rather than natural and unintentional hazards), and increase the disconnect yet further between the needed and actual R&D and architecture investments needed to meet the

operational demands of the present and evolving space activities and ensure long term sustainability of the space environment. This collection of difficulties explains the present impetus to transfer the USG's support to the civil and commercial orbital safety enterprise to a civilian governmental agency, in which there can be both undistracted mission focus and advocacy for the needed short- and long-term investments.

Transitioning this capability and responsibility poses considerable challenges. Accessing the DoD precision space catalogue data from a civil location for execution of the civil and commercial orbital safety mission software is more complex than is generally supposed – especially if one wishes at the same time to update the computer architecture, create a twenty-first-century data exchange mechanism with space operators, and adopt a modest set of proposed algorithmic and methodological improvements from recent academic research that could notably enhance mission performance. Additionally, in an area that previously had been the purview of government, there is now a robust and rapidly growing space situation awareness (SSA) commercial enterprise, offering everything from raw space tracking data to full space catalogues to advanced orbital safety calculations and services; one would certainly wish to attempt to take advantage of the innovative offerings of this burgeoning industrial sector in a reconstituted orbital safety capability. These two considerations conspire to make a seemingly simple transfer of capability and responsibility instead a challenging proposal.

To address the question of how this transition should be executed, it is necessary to examine the different parts of the orbital safety enterprise in order to understand the particular issues and opportunities presented by each. It is best to begin with a discussion of the concept of the space catalogue, as this is the foundational element of nearly all space applications. Next, the operational orbital safety mission will be decomposed into its three component parts, and the challenges and favored transition approaches for each of these will be discussed. After this, known gaps in the present approach and algorithm set will be identified, with paths to resolution suggested. While throughout this whole treatment the question of commercial data and services will be considered as it applies to each part, an extended discussion of the role of commercial data, especially commercial measurement and satellite position data, in the overall enterprise will be given a collective evaluation. Finally, the question of how to evaluate and examine flight safety R&D products, whether offered by academia or industry, that have the propensity to improve the civil agency's flight safety mission execution, will be considered

<u>The Precision Space Catalogue</u>

If the goal of operational orbital safety is to protect active satellites from collisions with space debris and with each other, the enabling first step is to know what objects are in Earth orbit, where they are, and where they are expected to be some number of days into the future. The name given to this collection of information used for accurate astrodynamics calculations is

the precision space catalogue.[1] It consists of both the position and velocity of every known space object (the position and velocity of a satellite are called the satellite "state"), a statement of the uncertainty with which each satellite state is known (called a "covariance"), and the collection of the orbital models that will allow the satellite state to be predicted forward into the future so that the satellite's location at some future time can be determined. There are two ways objects can be added to and maintained as part of a space catalogue: they can be discovered and tracked by satellite tracking sensors and have orbits built for them (the only method available for derelict spacecraft, rocket bodies, and space debris); or the owners/operators (O/Os) of active satellites, who know the present and predicted state information for their spacecraft, can submit this information to be added to a space catalogue. The particulars and issues associated with each of these methods are discussed separately below.

The "non-cooperative" space catalogue maintenance method, which involves space sensors discovering/tracking objects and a central processing facility to receive tracking information and build orbits, is both difficult and expensive. Space sensors, especially for tracking objects in low-Earth orbit (called "LEO" satellites, which have orbital altitudes less than ~2000 km and constitute the bulk of both operational satellites and space debris), usually require radar technology, which is complicated and expensive both to build and operate; and a large number of sensors is needed to obtain satellite tracking over all different parts of a satellite orbit. The generation of satellite orbits from tracking data is difficult and requires both specialized software and subject matter experts to massage the orbit parameters manually for sparsely-tracked orbits, difficult-to-maintain orbits, or situations with corrupted or misfiled satellite tracking data. This complicated, cumbersome, and expensive set of activities is already being performed by the DoD for military purposes, so it is unsurprising that the civil agency charged with taking on this mission for civil and commercial satellites is seeking to obtain the DOD space catalogue, which is complete down to objects approximately 10 cm in size in LEO, for use as the foundational datastore for the orbital safety mission.

There are also several industrial actors who operate their own space tracking sensor networks and maintain their own space catalogues, often with claims of including objects smaller than the publicly available DOD catalogue and thus being more complete. For at least some orbital regimes, these claims are plausible; so the question naturally arises whether a civil orbital safety capability should purchase access to such expanded catalogues and by doing so thus be able to provide more comprehensive orbital safety calculations and recommendations. It is certainly true that working from a more comprehensive space catalogue will produce a more comprehensive result, but there are additional considerations that make the decision more complicated.

It is often presumed that the use of a more comprehensive space catalogue will help to reduce the production of space debris, for it will allow the identification and prevention of satellite collisions that would have produced large amounts of such debris. While more data are

[1] It is important to distinguish between the "high-precision" space catalogue, which uses precision numeric orbit modeling, is required for meaningful orbital safety calculations, and is in bulk shared with only a few agencies within the USG; and the "low-precision" space catalogue, which uses analytic modeling, produces a fast but imprecise solution, and is posted publicly on the Space Force's www.space-track.org website for unrestricted public download.

always beneficial, the improvement is not linear and, for the current LEO situation, expected to be muted. While the dynamics of satellite collision debris production are complicated, analysis shows that the creation of notably large amounts of debris usually requires the collision of two objects larger than about 10 cm in dimension. Because the current DoD catalogue is considered reasonably complete to this object size, an enhanced satellite catalogue with more complete holdings at smaller sizes, while perhaps beneficial for other reasons, is unlikely to make a notable difference in reducing the production of space debris.

Debris production aside, orbital safety calculations based on a more complete catalogue would help to identify and avoid collisions that could end satellite missions. This is a high priority for human space flight; but beyond human-space-flight applications, it may make sense to distinguish between orbital safety improvements that protect the collective good of preserving a space environment free of debris pollution and those that provide primarily individual goods for individual O/Os. The latter may be more appropriately addressed by an advanced service that can be purchased by O/Os should they desire it. This is a policy issue to be considered by the orbital safety civil agency in setting up the parameters of their service.

To complete the discussion of the population of the space catalogue, it remains to describe the alternative mechanism for establishing state and uncertainty information on an active spacecraft, namely receiving this information directly from the satellite O/O. Such a submission generally takes the form of an ephemeris, which is a file containing a series of satellite states at regular time intervals (one-minute intervals are typically used for LEO) usually spanning several days into the future. This method of state representation is substantially superior, one might even say essential, for the orbital safety mission because an O/O ephemeris can both be much less uncertain than one derived from external measurements and, perhaps more importantly, can contain and represent a satellite's planned future maneuvers, which allows the satellite's planned trajectory changes to be considered when identifying close approaches between this satellite and other space objects. The DOD presently accepts O/O ephemerides to use in its orbital safety calculations (although it does not take the next step of using these data to update its official catalogue), but it does not perform any quality checking or validation on these submissions. Some O/O ephemerides, in both their state predictions and uncertainty assessments, are quite good; others are poor. There are presently no established standards for accuracy and precision of such submissions—and there hardly could be, as presently such submissions are voluntary—nor is there any funded entity to evaluate O/O ephemerides to certify their validity. Because O/O ephemerides truly are necessary for credible orbital safety calculations for on-orbit spacecraft that can intentionally change their trajectories, the orbital safety civil agency will quite likely need to work with the FAA and FCC to establish the regular furnishing of this information as a requirement for obtaining a launch or spectrum allocation license; and they will need to establish a capability to evaluate O/O ephemerides to ensure that they meet needed accuracy and precision requirements to enable credible orbital safety calculations. Because both government and private actors will be relying on these O/O data and calculations for critical safety decisions, this type of certification activity includes elements of an inherently governmental function and should expect to be performed either internal to the government or by an independent entity that is free of any financial interest in the outcome.

The Orbital Safety Process

The process of determining whether protected satellite assets are likely to collide with any other space objects, and guiding mitigating actions to avoid any such collisions, comprises three distinct parts:

I. Conjunction Screenings predict the orbits of a protected satellite and all other satellites in the space catalogue several days forward into the future and look for close approaches between them. For any satellites that are expected to come within a particular proximity threshold (which varies by orbit type) to the protected satellite, the states and uncertainties for both objects at the time of closest approach, as well as some other amplifying information, are used to generate a conjunction data message (CDM), which is then dispatched to the protected satellite's O/O.

Receiving a CDM might be considered analogous to the "check engine" light coming on in one's vehicle. It does not mean that an enduring problem exists—indeed, the light (if the author's experience is any guide) often goes off after a few minutes and then stays off; but if it stays on, then it would be wise to take the car to a mechanic to examine the situation more closely. Similarly, receipt of a CDM, especially several days before the time of closest approach, does not indicate an immanent collision; but if CDMs continue to arrive and the predicted proximity between the two satellites remains disturbingly small, then it is prudent to proceed to the next step of the process to see if a durable problem actually exists.

II. Risk Assessment is the careful examination of the CDM history to determine if the conjunction actually represents a high-risk situation. A specialized set of calculations are performed, based on the data in the CDM, to determine both the likelihood of an actual collision, generally expressed as a probability of collision; and the consequence of collision, generally expressed as the number of trackable pieces of debris that would be generated were the conjunction to result in a collision. Examining these results in the overall context of the event establishes whether the conjunction manifests enough of a safety risk that a mitigation action should be pursued.

The risk assessment step is analogous to taking one's vehicle to the mechanic after the "check engine" light has persisted for some time. The mechanic examines the situation and determines if there is a problem that merits actual repair or whether the warning light is just calling attention to something that is not particularly serious. The courses of action here are not always cut-and-dried: a driver who is risk-adverse and truly wants to avoid being stranded by a breakdown may choose to proceed with repairs that are only marginally necessary; a driver who is risk-tolerant may decline such repairs as not required at the present time. The same sorts of discussions occur between orbital safety risk assessment specialists and satellite O/Os regarding the appropriateness of mitigation actions.

III. Mitigation Planning is the identification of a trajectory change to the protected satellite, in response to a worrisome risk assessment from Part II, that will both avoid the

risky conjunction and not introduce any new risky conjunctions. Typically this involves generating trade-spaces that allow O/Os to see what different satellite maneuvers executed at different times might achieve in terms of reducing overall collision likelihood, allowing them to choose a maneuver that resolves the current orbital safety problem and aligns with other satellite mission objectives.

This step is analogous to a mechanic's actually making repairs on a vehicle. Through discussions, the owner and mechanic decide precisely which of several different repair actions are to be pursued, and the repairs are then accomplished. Similarly, the risk assessment specialist and the O/O decide on the actual mitigation action, which the O/O then realizes as a formal maneuver plan.

Orbital Safety Process Transition

There are a number of different ways that the transition of the USG's support of the civil and commercial orbital safety mission from the DoD to a civilian agency can be accomplished. The particular approach described below, which treats the transition of the three different parts of the process separately, appears to the author to present the lowest transition risk, to enable operational responsibility by the civil agency most rapidly, and to further the competing goals of the overall transition in a balanced way.

In discussing Part I (numeration from previous section), which is the conjunction screening process that results in production of CDMs, it is important to note that this represents the entirety of what the DoD provides to civil and commercial entities for orbital safety—the DoD does not provide risk assessment or mitigation planning assistance (Parts II and III). So in discussing the "transition" of the orbital safety mission from DoD to a civil agency, it is really only Part I that is a candidate for transition; if it is desired that the civil agency provide the Parts II and III services, then such a capability will need to be implemented *ab initio*. But in the presence of the DoD space catalogue, the execution of conjunction screenings and the production of CDMs is a straightforward process, driven by a single DoD algorithm set that has sustained full numerical validation and well over a decade of operational exercise.

The first step in an orbital safety transition from DoD to a civil agency is thus to transfer the Part I capabilities from DoD and implement them as presently formulated (with appropriate minor modifications for changes in computer architecture) and an improved portal for data exchanges with satellite O/Os and other organizations. An unclassified version of the DoD Space Catalogue, along with certain additional supporting files, can be exported from the DoD operational database, run through a further declassification procedure, and transferred to the civil agency at regular intervals each day. The DoD algorithm set for orbital safety screenings can then be run on the civil agency system and used to generate CDMs, which can be distributed through a modern distribution portal.

This approach confers a number of advantages. It is known that the DoD data export procedure described above can be accomplished because it is presently used in exactly this same form to declassify and transfer the DoD space catalogue to another civil agency multiple times

per day. The DoD algorithm is highly parallelized, so improved computational performance can be achieved easily by adding additional computational capability. A first step of simply preserving existing capability but with faster turn-around times and an improved user interface is a prudent confidence-building measure with O/Os. Finally, an initial goal that is not overly technically challenging is a good setting for working through the attendant bureaucratic encumbrances and difficulties that transitions such as this invariably engender.

Both the research community and private industry presently offer orbital safety screening algorithms that would appear to be equally accurate to the DoD algorithm yet more computationally efficient. The civil agency would be encouraged to investigate such algorithms and potentially pursue a future upgrade, but a change of the basic algorithm for orbital safety screenings is not recommended until after the transition is complete. Once an R&D evaluation environment is stood up (to be discussed later) and the DoD screening algorithm transitioned and thus available to use as a benchmark for both screening accuracy and performance, then the civil agency will be in a good position to evaluate potential screening algorithmic improvements. But taking on a major numerical validation effort to certify a new algorithm to serve as the core of the orbital safety mission in the midst of a transition activity is seen as unwise.

As remarked earlier, the activities that represent Parts II and III of the orbital safety process (risk assessment and mitigation planning) are not presently performed by the DoD for civil and commercial O/Os. A variety of different sources of solutions are pursued instead: some O/Os limp along with almost no regularized risk assessment and mitigation planning services at all; some have small in-house services for these functions; some contract with third-party commercial providers; and some organizations have enterprise-level solutions for this for all of their missions, examples of which include NASA and the EUSST (European Union Space Surveillance and Tracking Support).

Because of the highly federated set of possibilities for Parts II and III, and because there is already a significant set of commercial vendors presently performing these functions, the situation seems a natural fit for the "advanced services" concept," for which O/Os contract for such services with a vendor of their choice. A role for private industry would fit especially well here because a substantial component of risk assessment and mitigation planning assistance could be described as "bedside manner"—helping to walk the O/O through the risk assessment / mitigation process; interpreting data and calculations that can often be both daunting to understand and initially alarming in their implications; and providing a structured decision framework, especially for events that may develop quickly and thus require rapid decision-making. Additionally, an advanced service could duplicate a basic service but render it with more flexibility and lower latency. For example, if the basic conjunction screening service offered by the civil agency preserved the DoD approach of performing collision screenings (Part I) only once every eight hours, an O/O who wished on-demand screening results might be able to obtain this with a purchased advanced service, presuming that the service provider was in some way able to arrange for access to the civil agency's space catalogue.

Since the DoD does not perform the Part II and III activities, the orbital safety civil agency will need to decide what posture they wish to take towards these activities. They could take a completely *laissez-faire* attitude much as the DoD has done, they could facilitate such

industry-provided services by allowing vendors to offer these services through the civil agency's user interface portal and (with O/O permission) enabling such vendors to obtain appropriate CDM and other data directly, or they could also provide some of the basic risk assessment calculations as part of the CDM as an enhancement to the DoD basic ("free of user fees") service. Both budget constraints and a desire to avoid competing with private industry would counsel against the government's providing too many of the Part II and III activities as part of the basic service; but there are a few small calculations that could be performed to improve the orbital safety decision-making of budget satellite operators without undermining demand for higher-end services, especially since the complexity of the orbital safety topic will ensure an abiding demand for the "bedside attendant" aspect of services for those with expensive assets at stake.

Needed Improvement: Orbital Safety for Autonomously-Controlled Satellites

A major advance in satellite flight dynamics technology has recently been realized in the area of autonomous satellite control—the ability for satellites to maintain and operate in a specified orbit entirely through on-board algorithms, without any human or computer intervention from satellite ground control. Such autonomous capabilities can even include orbital safety. The world's largest satellite constellation, SpaceX's two-thousand-spacecraft Starlink fleet, operates with this paradigm: at each ground contact, each satellite downlinks its intended future trajectory, this trajectory is submitted to the DoD for conjunction screening, the CDMs generated from the screening are returned to SpaceX and uploaded to the satellite, and the satellite makes its own risk assessment and mitigation decisions, without any involvement from ground control. This orbital safety approach is workable, albeit with some restrictions, as part of the current broader orbital safety ecosystem, but with one substantial exception: the advent of two autonomously-controlled constellations operating in proximity to each other. In such a case, which has not yet arisen commercially but surely is not far away, when two satellites from different autonomously-controlled constellations come into a high-risk conjunction with each other, how is the conjunction resolved? Neither satellite knows what the other satellite's intentions are, and there is no expedited communications path by which to exchange such information; so there is a very real possibility that the two satellites could both elect to maneuver and both choose maneuvers that in the end cause them to collide. Such an outcome may seem far-fetched, but it is not: the well-known Iridium-COSMOS satellite collision event of 2009, which produced over 2000 pieces of catalogued debris, took place because, due to the primitive nature of orbital safety operations at that time, the Iridium satellite unwittingly maneuvered into the COSMOS oncoming trajectory. A number of possible solutions have been proposed within the discipline; and the intersection of policy, supporting technical analysis, and interagency cooperation needed develop a durable solution that will be both transparent and recognizably fair, and integrate this solution into the FAA/FCC licensing process, will of course present a number of challenges. The civil agency acquiring the orbital safety mission must recognize that the technical solution for calculating and distributing orbital safety data is really the ten-minute overture to the five-hour Wagnerian opera of policy questions and satellite norms-of-behavior development required in order to ensure safe operation of an enterprise that is changing and developing at a dizzying rate.

Commercial SSA Data

As remarked previously, there is now a robust commercial industry, with multiple independent providers, of commercial SSA data, offering data products that include sensor tracking data on satellites, solved-for orbits, and predicted ephemerides. There are also non-commercial sources of such data upon which the civil agency could potentially make arrangements to draw, such as data collected by the SSA capabilities of the European Union or those of other emerging SSA actors such as Australia. Because it is in general correct to state that increasing the amount of quality data available to the orbital safety enterprise will improve the orbital safety calculations, there is a natural expectation that the civil agency should make broad use of these additional data sources in order to realize such improvements. In the main, this expectation is informed and reasonable; but there are a number of important caveats and limitations that should be considered.

First, for objects that already receive substantial tracking, such as large objects in LEO, and which do not maneuver frequently, additional tracking from non-DoD sources is unlikely to make a meaningful improvement in the quality of orbital safety products. These products are influenced most strongly by decreases in the uncertainty associated with satellite state estimates, and for well-tracked objects the state uncertainty decreases roughly with the square root of the number of measurements used in orbit determination; this means that for objects that already receive a large number of such measurements, the marginal improvement of adding additional data is very small. Efforts to obtain additional SSA data should therefore focus on orbits and objects that presently experience a paucity of tracking data, as this is where meaningful improvements from such additional data will be observed.

Second, there is a mismatch between the kinds of SSA data that would be most easily integrated with the DoD data to produce composite orbital safety calculations and what the commercial SSA sector is likely to offer for sale. There is broad agreement among astrodynamicists that the best technical solution to merging DoD and commercial SSA data is to obtain the sensor tracking data from both DoD and commercial sources and combine them in a single orbit determination process, performed at a single operations center. Unfortunately, this superior technical solution is also the most challenging from an economic perspective. Selling individual measurements to the USG, especially if the measurements can then be redistributed throughout the USG for multiple uses by different agencies and also inform orbital safety products that are then distributed free of charge by the orbital safety civil agency, cuts against the business models for the commercial SSA industry. There also has historically been a reluctance by the DoD to share or redistribute their sensor measurement data, which could potentially reveal vulnerabilities to adversaries.

If it is not possible to obtain and combine sensor measurement data, a plausible alternative is to purchase predicted satellite ephemerides from commercial providers and "fuse" these with an ephemeris generated from the DoD satellite catalogue in order to produce a single, presumably superior, ephemeris that can be used to represent a satellite's predicted future positions. There is developed astrodynamics theory outlining how such a fusion can be legitimately accomplished, although such constructs do not (yet) appear to have been tested on

any large scale. But what is known is that for this fusion approach to work, the uncertainty estimates contained in the purchased ephemerides must be highly reliable. Realistic state uncertainty estimation is one of the most difficult problems in orbit determination and prediction, and it is presently only rarely performed well. If an ephemeris-fusion approach to data combination is to be pursued, it will be necessary to empanel a group of astrodynamics subject matter experts to evaluate the fidelity of purchased ephemerides, both in-depth initially and continuously in a monitoring capacity, to ensure that that accuracy and precision of these products continue to meet standards necessary to produce meaningful fusion-based products. In alignment with previous comments about space catalogue validation, this activity is an inherently governmental function and must be performed by individuals or groups with no financial interest in the outcome.

Finally, it is claimed in some circles that a lack of adequate SSA data is the main problem facing the orbital safety mission presently and the principal reason that orbital safety "requirements" are not being met. While it is true that more SSA data is likely to be helpful to the enterprise, the calculations needed for collision risk assessment, especially when combined with the proper logical decision framework for determining the necessity of mitigation actions, are designed to be operable at a variety of different data abundance and quality levels. There are no particular levels of SSA data supply at which the calculations suddenly become relevant or actionable. Different data levels will change the counts and ratio of serious event false alarms and missed detections, but the desirable levels for these parameters is a matter of policy and cost-benefit analysis. Because in general more data translates to better orbital safety calculations, determining when sufficient SSA data are being secured will remain a prudential judgment.

Orbital Safety Research and Development

In the last decade, orbital safety has been an active area of both academic and industrial astrodynamics research. The scope of such research has been broad, with all areas of the discipline touched: improved screening algorithms; improved risk assessment paradigms, parameters, and calculations; improved decision support constructs, especially in anticipation of much larger satellite populations; and proposed satellite norms of behavior. An orbital safety agency should certainly wish to avail itself of all of these potential improvements; but at the same time it is extremely difficult to evaluate the rectitude of the claims made in research papers and studies, especially since in many cases the proposed constructs are tested only against simulated data.

One approach to facilitating the evaluation of the results of such research is to build into the civil agency's orbital safety system an experimental subdivision to allow the hosting of proposed algorithms or tools. Within this subdivision, experimental software could be run against a historical archive of SSA data (which could be simply the operational SSA data but with an enforced posting delay of weeks or months in order to nullify any current operational relevance) and compared to baseline results, as well as the calculations from other experimental tools. Such an arrangement could substantially facilitate the evaluation of proposed replacements for the core algorithms that are part of the free orbital safety service (thus allowing the free service to evolve in accuracy and efficiency), and it could also serve as a venue for

advanced services to establish and demonstrate their capabilities to potential O/O customers. Because the space environment is changing so rapidly and the orbital safety discipline is so dynamic, it is recommended that the civil agency orbital safety system contain from its very beginning this accommodation for testing and demonstration of new capabilities.

Conclusion

There is indeed a myriad of issues associated with the transition of the USG's support of the civil and commercial orbital safety mission from the DoD to a civil agency; and for this reason, a step-based approach that deliberately avoids overreach in each such phase is seen as the most promising. The first such step is the transition of the catalogue screening and CDM generation mission from the DoD to a civil agency, using a declassified version of the DoD space catalogue and a rehosted version of this single DoD algorithm, with small modifications to place it in a modern computer architecture with a similarly modern communications interface. Once this duplication of the current DoD capability is in place, accommodation for advanced services to provide conjunction risk assessment and mitigation action planning assistance can be made, probably through the civil agency's automated communications interface and perhaps with expedited access to certain catalogue and O/O CDM data. Once this aspect of the architecture is established and working, the question of commercial data use, which will have been a subject of study in parallel with the architecture efforts described above, can be addressed in full, with appropriate data purchases and validation activities taking place contemporaneously. The study efforts will have identified which orbital regions and objects will benefit most substantially from commercial data augmentation and will have resolved the question of whether measurement data should be acquired or whether fusion of ephemerides is a viable and desirable alternative procedure. Alongside all of this activity, the roll-out of the civil agency's orbital safety system will have included an R&D physical/virtual sector, which can be used both for the commercial data study efforts mentioned above and to evaluate the benefits of improved algorithms and approaches for all of the aspects of the orbital safety enterprise. Finally, while all of these transition activities are indeed important, in many respects they are overshadowed by the great need to establish standards, guidelines, and norms of behavior for safe satellite operations. Even with a civil capability successfully producing and distributing safety alerts and data, there is no clear guidance outlining what O/Os should do with such data, how they should negotiate hazardous situations, and what data products they have an obligation to provide in order to contribute to the safety of the entire enterprise. Such a civil agency's supervening task must be to develop, in consultation with all affected parties, reasonable and analytically-grounded standards, guidelines, and norms of behavior for safe satellite operation; and they must integrate these into the launch and spectrum allocation process so that they become a formal part of an O/O's operating instructions. It is only then that space actors will both fully understand their responsibilities and be equally fully motivated to fulfill them.

Curriculum Vitæ

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EDUCATION

Ph.D., University of Dallas, Philosophy, 2006
Thesis: *Hegel, Kierkegaard, and the Limits of Rationality*
M.A., University of Dallas, Philosophy, 1998
M.T.S., Southern Methodist University, 1995, *magna cum laude*
B.S.E., Princeton University, Mechanical Engineering, 1989, *cum laude*

PROFESSIONAL EXPERIENCE

Senior Project Leader, The Aerospace Corporation (2021-present)
Current position: Chief Engineer, NASA Satellite Conjunction Analysis Risk Assessment Program
President, Astrorum Consulting LLC (www.astrorum.us), 2014 – present
Adjunct Scientist, a.i. solutions Inc., 2010 – 2014
Adjunct Scientist, SRA Inc., 2006 – 2010
Senior Systems Engineer, L3 Technologies, 2002 – 2006
Systems Engineer, SenCom Corporation, 1993 – 2002
Acquisition Officer, USAF, 1989 – 1993

RESEARCH INTERESTS

Satellite conjunction assessment techniques
Satellite radar and optical signature modeling and analysis
Estimation theory
Space Surveillance Network modeling and simulation

ARTICLES/PAPERS – LEAD AUTHOR

Hejduk, M.D., and Snow, D.E. "Satellite Conjunction 'Probability,' 'Possibility,' and 'Plausibility': A Categorization of Competing Conjunction Assessment Risk Analysis Paradigms." 2019 AAS/AIAA Astrodynamics Specialist Conference (Paper #19-652), Portland ME, August 2019.

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Hejduk, M.D. "Covariance Manipulation for Conjunction Assessment." 2016 AAS/AIAA Astrodynamics Specialist Conference, Long Beach CA, September 2016.

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Hejduk, M.D., Plakalovic, D., Newman, L.K., Ollivierre, J.C., Hametz, M.E., Beaver, B.A., and Thompson, R.C. "Recommended Risk Assessment Techniques and Thresholds for Launch COLA Operations." 2013 AAS/AIAA Space Flight Mechanics Meeting, Hilton Head, SC. August 2013.

Hejduk, M.D., Casali, S.J., Cappellucci, D.A., Ericson, N.L., and Snow, D.E. "A Catalogue-Wide Implementation of General Perturbations Orbit Determination Extrapolated from Higher-Order Theory Solutions." 2013 AAS/AIAA Space Flight Mechanics Meeting, Kauai, HI. February 2013.

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Hejduk, M.D., Cowardin, H.M., and Stansbery, E.G. "Satellite Material Type and Phase Function Determination in Support of Orbital Debris Size Estimation." 2012 AMOS Technical Conference, Kihei, HI. September 2012.

Hejduk, M.D. "Specular and Diffuse Components in Spherical Satellite Photometric Modeling." 2011 AMOS Technical Conference, Kihei, HI. September 2011.

Hejduk, M.D. and Ghrist, R.W. "Solar Radiation Pressure Binning for the Geosynchronous Orbit." 2011 AAS Astrodynamics Specialists Conference, Girdwood, AK. August 2011.

Hejduk, M.D. and DePalma, D. "Comprehensive Radar Cross-Section 'Target Typing' Investigation for Spacecraft." 2010 AAS Astrodynamics Specialists Conference, Toronto, CA. August 2010.

Hejduk, M.D. "Improved Radar Cross-Section 'Target Typing' for Spacecraft." *Advances in the Astronautical Sciences*, Vol. 135 (August 2009), pp. 3-17.

Hejduk, M.D. "Space Catalogue Accuracy Modeling Simplifications." 2008 AAS Astrodynamics Specialists Conference, Honolulu, HI, August 2008.

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Hejduk, M.D., Ericson, N.L., and Casali, S.J. "Beyond Covariance: A New Accuracy Assessment Approach for the 1SPCS Precision Satellite Catalogue." 2006 MIT / Lincoln Laboratory Space Control Conference, Bedford, MA. May 2006

Hejduk, M.D. "RCS Calculation Improvements at the Eglin FPS-85 Radar." 2005 MIT / Lincoln Laboratory Space Control Conference, Bedford, MA. April 2005.

Hejduk, M.D., Lambert, J.V., Williams, C.M, and Lambour, R.L. "Satellite Detectability Modeling for Optical Sensors." 2004 AMOS Technical Conference, Kihei, HI. September 2004.

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Hejduk, M.D., Lambert, J.V., Williams, C.M, and Lambour, R.L. "Improved Satellite Brightness Estimation Techniques." 2003 AMOS Technical Conference, Kihei, HI. September 2003.

Hejduk, M.D. and Lambert, J.V. "Statistical Distributions of Object RCS Histories." 2003 MIT / Lincoln Laboratory Space Control Conference, Bedford, MA. April 2003.

Hejduk, M.D. "Composite RCS Catalogue". 2002 MIT / Lincoln Laboratory Space Control Conference, Bedford, MA. April 2002.

Hejduk, M.D., Kervin, P.W., Lambert, J.V., Stansbery, E.G., Africano, J.L., and Pearce, E.C. "Visual Magnitude Satellite Catalogue Release 1.0." 2001 AMOS Technical Conference, Kihei, HI. September 2001.

Hejduk, M.D., Sousa, M.W., Snow, D.E., and Daw, R.S. "SP/GP Catalogue Accuracy: Technical Approach and Initial Results." 2001 MIT / Lincoln Laboratory Space Control Conference, Bedford, MA. April 2001.

Hejduk, M.D. "Region-specific Space Catalogue Growth." 15ème Symposium International: Mecanique Spatiale; Centre National d'Études Spatiales, Biarritz, France. July 2000

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Hall, D.T., Hejduk, M.D., and Johnson, L.C. "Time Dependence of Collision Probabilities during Satellite Conjunctions." 2017 AAS Space Flight Mechanics Meeting, San Antonio TX, February 2017.

Newman, L.K., Hejduk, M.D., and Johnson, L.C. "Operational Implementation of a Pc Uncertainty Construct for Conjunction Assessment Risk Analysis." 2016 AMOS Technical Conference, Kihei HI, September 2016.

Zaidi, W.H. and Hejduk, M.D. "EOS System Covariance Realism." 2016 AAS/AIAA Astrodynamics Specialist Conference, Long Beach CA, September 2016.

Vallejo, J.J., Hejduk, M.D., and Stamey, J.D. "Trending in Probability of Collision Measurements via a Bayesian Zero-Inflated Beta Mixed Model." 25th International Symposium on Space Flight Dynamics, Munich Germany, October 2015.

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Narvet, S., Frigm, R.C., and Hejduk, M.D. "Assessment of Uncertainty-based Screening Volumes for NASA Robotic Leo and GEO Conjunction Risk Assessment." 2011 AAS Astrodynamics Specialists Conference, Girdwood, AK. August 2011.

Mulrooney, M.K., Matney, M.J., Hejduk, M.D., and Barker, E.S. "An Investigation of Global Albedo Values." 2008 AMOS Technical Conference, Kihei, HI. September 2008.

Gow, C.E., Eaves, S., and Hejduk, M.D. "The Visual Magnitude Distribution and Optical Variability of LEO Space Objects." 2005 AMOS Technical Conference, Kihei, HI. September 2005.

Okada, J.M. and Hejduk, M.D. "Satellite Brightness Estimation using Kriging Optimized Interpolation." 2005 AMOS Technical Conference, Kihei, HI. September 2005

Lambert, J.V. and Hejduk, M.D. "Observed Optical Brightness Distributions of Deep Space Satellites". 2002 AMOS Technical Conference, Kihei, HI. September 2002.

Daw, R.S. and Hejduk, M.D. "Determining SSN Operational System Capability (SYSCAP)." 1999 MIT / Lincoln Laboratory Space Control Conference; Bedford, MA. April 1999.

INVITED LECTURES

Hejduk, M.D. "Effects of Atmospheric Neutral Density Mismodeling on Satellite Conjunction Assessment." NOAA 2017 Space Weather Workshop, Broomfield CO, May 2017.

Hejduk, M.D. "Approaches to Defining Uncertainty Bounds for Probability of Collision Calculations." Department of Aerospace Engineering, University of Texas at Austin. April 2016.

Hejduk, M.D. "Spacecraft Collision Probability: Problems in Uncertainty Modeling." Department of Statistics, Baylor University. September 2013.

Hejduk, M.D. and Snow, D.E. "Deterministic/Stochastic Satellite Brightness Modeling." Center for Astrophysics, Space Physics, and Engineering Research, Baylor University. February 2008.

Hejduk, M.D. "Approaches to Satellite Characterization: the Deterministic/Stochastic Divide." American Statistical Association Conference on Quantitative Methods and Statistical Applications in Defense and National Security, Santa Monica, CA. February 2006.

TEACHING EXPERIENCE

ENG 2v97: Innovation in Engineering (Baylor University), 2016
PHI 4341/5341: Continental Philosophy (Baylor University), 2008 – 2009
GTX 2302: Medieval Intellectual Tradition (Baylor University), 2008
PHI 2300: Introduction to Philosophy (University of Texas at Arlington), 2001 – 2002
PHI 1301: Philosophy and the Ethical Life (University of Dallas), 2000

PROFESSIONAL SERVICE AND ASSOCIATIONS

Technical submission evaluator, *Acta Astronautica*
Technical submission evaluator, *Advances in Space Research*
Technical submission evaluator, *Journal of the Astronautical Sciences*
Technical submission evaluator, *Journal of Guidance, Control, and Dynamics*
Technical submission evaluator, *Journal of Space Safety Engineering*
Technical submission evaluator, *Journal of Spacecraft and Rockets*
Technical submission evaluator, *Proceedings of the Royal Society A (Mathematical, Physical, and Engineering Sciences)*
Technical submission evaluator, *Space Weather: A Journal of the American Geophysical Union*
Grant application evaluator, National Sciences and Engineering Research Council of Canada
Grant application evaluator, Air Force Office of Scientific Research

Senior Member, American Institute of Aeronautics and Astronautics
Senior Member, American Astronautical Society

SENIOR COMMITTEES AND EXPERT PANELS

International Astronautical Federation Space Traffic Management Committee (2020-21)
NASA "Living with a Star" (LWS) expert panel on neutral atmospheric density modeling (2016)
Air Force Space Command Astrodynamics Innovation Committee; scientific peer review panel (2014 – 2019)
Air Force Space Command Astrodynamics Innovation Committee; working group on covariance realism (2014 – 2019)

COMMUNITY INVOLVEMENT

Undergraduate applicant interviewer, Princeton University, 2010 – present
Board of Directors member and Chairman, YMCA of Central Texas, 2011 – 2018
Volunteer of the Year, Habitat for Humanity Waco, 2016
Music Director, St. Gregory Society, Waco TX, 2007 – present

Chairman BEYER. Thank you very much, Doctor.
And we now recognize Dr. Moriba Jah for his testimony.

TESTIMONY OF DR. MORIBA JAH, ASSOCIATE PROFESSOR, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS DEPARTMENT, MRS. PEARLIE DASHIELL HENDERSON CENTENNIAL FELLOWSHIP IN ENGINEERING, ODEN INSTITUTE FOR COMPUTATIONAL ENGINEERING AND SCIENCES, THE UNIVERSITY OF TEXAS AT AUSTIN

Dr. JAH. Thank you very much, Mr. Subcommittee Chairman Beyer, Mr. Ranking Member Babin. It's good to see you again and hear your voice today, other Members of this Subcommittee. Thank you so much for the invitation to appear before you today live in from the Space Object Situation Room here at the University of Texas at Austin.

And, you know, I've testified a couple of times. I'm glad to see that we're finally able to do this today. And I love all the people here that are also witnesses with me. I know them personally and professionally, so it's great to be with them.

Let's talk about a couple of things. Look, we started launching things in 1957. We track, you know, 30,000-plus objects ranging in size from cell phone all the way to the space station. The number of operational satellites that we had just 2 years ago has doubled in the last like 2 years. So basically it's like if you look at all the operational satellites that we had, you know, somewhere around this time in 2020 and the number of operational satellites now, that's almost doubled in just 2 years. That's not a bad thing. That's good. We got some global internet. We've seen some of this—the benefits of that actually to support folks in the war in Ukraine and these sorts of things, so there's positive aspects of increasing space traffic for sure. And we're not going to stop launching satellites.

We see people going and taking suborbital flights. We see commercial entities now rendezvousing with the space station, that sort of stuff, more activity. People that have lots of resources going up to space, that's a great sign. We need to see more of that.

What are the not-so-good things? Oh, I don't know, you know, people like Russia blowing up their own satellite and basically causing all this debris that now is a hazard to human spaceflight. I've heard that the Starlink satellites that fall under the United States SpaceX have had to maneuver—I think since the Russians blew up this stuff in November, almost 2,000 times these things have had to get out of the way. That's not so good.

When people talk about conjunctions and possible collisions, all these great commercial capabilities, they're awesome but, you know, they're all opinions. So the thing is when one commercial entity says, hey, get out of the way, the DOD might say, oh, that's really, you know, a nothing burger. You know, those aren't the droids you're looking for. That's not a problem. Somebody else says, well, it's kind of a problem but not so much, so there's lots of ambiguity. There's lots of opinions. There are disparate sources of evidence. There's not a combined, aggregated pool of evidence by which to draw consistent interpretations or opinions about what's going on in space.

We see the Chinese saying, oh, you know, to the United Nations, well, you know, basically Starlinks were a hazard, U.S. saying, oh, based on our evidence, not so much. I think you kind of get the point. We see astronomers negatively impacted by space traffic and actually discovering natural phenomenon that really were satellites that were glinting at the time. I don't know, I looked at this movie, you know, *Don't Look Up,* I'm kind of worried about near-Earth asteroids because, you know, I'm allergic to things like hitting the Earth and ending all life. And our ability to detect these things is now hindered by more and more things that are reflecting sunlight getting in the way and confusing stuff.

This is all to say transitioning this to a civil entity is critical if we want to be able to sustain our way of life, if we want to be able to support space commerce, if we want to be able to support space exploration. And so one of the main goals of this transition has to be measurably making space more transparent. What's up there, who does it belong to, what can it do, making space more predictable, where are things going to be, and given any situation between two entities, can we predict how they'll behave and what they'll do with the information provided to them? And then last but not least, can we develop a body of evidence that's consistent, that is accurate, that's timely, that can be used to help people be safe, more secure, and more sustainable and hold them accountable for their behaviors in space?

That's what we need this civil entity to do. That's what we need the Office of Space Commerce to do. And that is my hope that, you know, from this gathering that we have here today and talking about these things, that we're able to advance that in a way that is very credible. Thank you very much.

[The prepared statement of Dr. Jah follows:]

Statement of
Dr. Moriba K. Jah
The University of Texas at Austin
to the
Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics
United States House of Representatives
on
Space Situational Awareness: Guiding the Transition to a Civil Capability
May 12, 2022

Mr. Subcommittee Chairman Beyer, Mr. Ranking Member Babin, and other members of this subcommittee, thank you for the invitation to appear before you today to share my perspectives regarding salient issues on guiding the transition of space situational awareness to a civil capability. It is an honor to be seated at this virtual table with these great witnesses. It has been two years since I last testified, which was to the US Senate's subcommittee on Space, Science, and Competitiveness. My name is Moriba Jah. I'm an astrodynamicist and space environmentalist. My perspectives have been shaped through an over 20-year aerospace engineering career in government, industry and academia. I started my career as a member of the technical staff of the NASA Jet Propulsion Laboratory. Whilst there, I contributed to the navigation of a variety of spacecraft to Mars and Asteroid Itokawa, and also developed advanced spacecraft navigation algorithms toward autonomy and improved orbital knowledge, beginning with Mars Global Surveyor and ending with the Mars Reconnaissance Orbiter mission. After JPL, I worked as a Civil Servant in the Air Force Research Laboratory (AFRL), where I led the design, development, and implementation of algorithms that have successfully and autonomously detected, tracked, identified, and characterized human-made objects in space, so called "Anthropogenic Space Objects," to include orbital debris. My last position within AFRL was as the Mission Lead for Space Situational Awareness. I currently serve on the faculty of the Aerospace Engineering and Engineering Mechanics Department, in the Cockrell School of Engineering at The University of Texas at Austin. At UT Austin, where I lead a transdisciplinary research program focused on delivering pragmatic solutions to problems regarding space safety, security, and sustainability. Last year I co-founded Privateer Space along with Steve Wozniak (Apple Co-Founder) and Alex Fielding (Ripcord Founder) aimed to deliver the world's most useful digital platform that supports, inter alia, space situational awareness services and capabilities. I am a Fellow of several organizations and professional societies and serve as a chair and member of several major space-related national and international technical committees. However, I am here today as an individual citizen and the views I express are mine alone.

Executive Summary

Near Earth Space is (a) geopolitically contested (b) commercially contested and (c) a finite resource in need of environmental protection.

We are of course interested in having continuing supervision of the entire set of space events and processes that occur and can happen but this set is unknowable for a myriad of reasons, not the least of which that we, as a global community, still do not widely share our observations of the space domain. If we wish to know something, we must measure it and if we want to understand something, we must predict it. This knowledge regarding causal relationships for things in space is what I call Space Situational Awareness.

If we wish to protect ourselves from extraterrestrial hazards in the form of near-Earth asteroids, space environment effects and impacts on satellites and Earth-based infrastructure, as well as space activities and services from suffering a loss, disruption, or degradation, we must have timely and actionable Space Situational Awareness. Only a few months ago, Russia destroyed one of their satellites in an on-orbit anti-satellite (ASAT) test demonstration[1]. As a result of the harmful debris that this event created, our own US based Starlink satellites have evasively maneuvered nearly 2000 times to avoid a predicted likely chance of collision. Russia claims that no harm has been done by their ASAT test. To date, there is no publicly available evidence either way. Our actions in space are not based upon truth but rather upon our perceptions, and these are uniquely driven by the evidence we have at hand which is biased, incomplete, and corrupt, to include our flawed models of reality.

As an example, just a couple of years ago, a commercial entity predicted that two dead satellites in Low Earth Orbit had an alarmingly high probability of collision[2] but these probabilities were quite varied across the space object tracking community: one entity said 1 in 10, another 1 in 100, and another 1 in 1000. These are very different from each other and the actions a satellite operator would take would also vary as such.

Several months ago, China complained to the United Nations that the Starlink satellites were a hazard to their space station and that unable to get a hold of the SpaceX operators, they had to perform two evasive maneuvers to avoid collisions[3]. The response from the United States was that based on US evidence, there was no hazard or reason for alarm. A similar incident occurred between the European Space Agency and SpaceX to coordinate an evasive maneuver but

[1] https://aerospaceamerica.aiaa.org/departments/holding-russia-accountable-for-its-asat-test/

[2] https://spacenews.com/potential-satellite-collision-shows-need-for-active-debris-removal/

[3] https://spacenews.com/esa-spacecraft-dodges-potential-collision-with-starlink-satellite/

antiquated methods (relying on email) of communication conjured a systemic obstacle in meaningful space debris mitigation. The European Space Agency maneuvered Aeolus to prevent the predicted collision. SpaceX stated in hindsight that they would not have maneuvered anyway because their Space Situational Awareness and decision threshold indicated it not sufficiently risky to them.

Once again, the decisions anyone might make given each of these opinions is obviously extremely different. One issue that this underscores is a lack of consensus regarding operational decisions which detrimentally leads us away from a common practice in space. We wish to avoid "playing chicken" in our orbital commons. We have no joint and holistic space traffic coordination framework to mitigate these inconsistencies or competing and opposed hypotheses.

Another problem calling for Space Situational Awareness is in regard to Article 6 of the Outer Space Treaty which states that States party to the treaty are responsible for providing authorization and continuing supervision of space activities of non-governmental entities. The US White House recently delivered a strategy on In-Space Servicing, Assembly, and Manufacturing[4]. The need for continuing supervision could not be more important than this developing space sector. In order to meet the needs of this community, there must be an unambiguous and distributed immutable ledger of who did what to whom when and where. As of this very testimony, I would challenge any government to demonstrate that it is currently capable of delivering such a capability. More complaints of harmful interference, damage, and threats will be raised whilst we are left ill-prepared to assemble the evidence required to assess and quantify space events and activities.

Last but not least, the global Astronomy community has taken issue with the exponential growth of anthropogenic space objects as these "corrupt" their astronomical images and negatively impact the science[5,6]. Moreover, astronomers have already misidentified natural phenomena for what was later found to be a satellite reflecting light in a way that looked like an astronomical event of interest. This doesn't even get into the fact that the added light pollution from these space objects makes it harder to detect near-earth asteroids that could be on a collision course with earth. Humanity cannot afford to suffer the consequences of these shortcomings.

A safe, secure, and sustainable space domain requires improved transparency, predictability and for us to develop an *independently corroborated* body of evidence of space activities, events, and

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[4] https://www.whitehouse.gov/wp-content/uploads/2022/04/04-2022-ISAM-National-Strategy-Final.pdf

[5] https://www.nature.com/articles/s41550-022-01655-6

[6] https://www.forbes.com/sites/startswithabang/2020/01/30/dangers-to-astronomy-intensify-with-spacexs-latest-starlink-launch/#337a38a56a57

actor behaviors that can be used to hold people accountable and can inform meaningful space policies, rules, regulations, and norms of behavior.

U.S. National Space Policy Directive #3, signed by President Trump on June 18th of 2018, laid out very succinct goals to address these issues. Its first goal is to advance Space Situational Awareness and Space Traffic Management Science and Technology. It further states that the United States should continue to engage in and enable Science and Technology research and development to support the practical applications of Space Situational Awareness and Space Traffic Management. These activities include (a) improving fundamental knowledge of the space environment, such as the characterization of Anthropogenic Space Objects, (b) advancing the Science and Technology of critical Space Situational Awareness inputs such as an openly accessible and curated set of multi-sourced observational data, algorithms, and physics-based models necessary to improve Space Situational Awareness capabilities, and (c) developing open-source software to support big-data science and analytics. In summary, we must develop the required science and technology to reliably deter, predict, operate through, recover from, or attribute cause to the loss, disruption, or degradation of any given space service, activity, or capability. This means making space transparent and predictable, and having the evidence to hold entities accountable.

Beyond examples I previously listed, I can personally attest to the fact that we are significantly behind in this endeavor as evidenced by our inability to accurately and precisely infer unique or unambiguous causal relationships between space domain events and observed satellite anomalies. You can read about these in the news frequently these days. Satellites are experiencing malfunctions where the evidence could have more than one explanation: was it the environment? was it caused by another entity? If so, was it intentional? The information tasking, collection, processing, exploitation, and dissemination requirements for Space Situational Awareness does not end with collision risk assessments or re-entry predictions; they only begin there. The much more difficult and critical requirement is to assemble the evidence of events, processes, and activities in space that would need to be used to assign fault or negligent behavior, for instance, or assessing compliance or the lack thereof with space policies. Nobody is quantifying these needs. Every domain of human activity has experienced malicious behavior and to think otherwise is naïve at best. In the face of a next "space race" or "gold rush" equivalent, driven by global space commerce, it's not a matter of if, but when. The space domain is holistically poorly monitored. We are unprepared and ill-equipped to deal with disputes resulting from space activities and events.

The U.S. is home to some of the world's top-ranked research institutions; these should be brought to bear to, once and for all, bring us out of the dark ages in terms of space domain decision-making knowledge and actualize us in order to meet the great demands of space commerce, exploration, and other activities. A well-funded and dedicated Space Situational Awareness Institute could undertake the Science and Technology research and development we desperately require. Europe and other countries are becoming leaders in these endeavors. Academia, the source of the purported workforce to meet the demands of operating so-called mega-constellations, has been mostly neglected in this area, and even decimated. As a professor at a top-tiered research university, I alone find myself turning away over a dozen qualified U.S. citizens every year, from joining my

research program due to an absence of resources and financial support to perform clearly needed research.

The National Science Foundation does not fund Space Situational Awareness research although there are many basic research problems still salient in this transdisciplinary area. The Air Force Research Laboratory and Air Force Office of Scientific Research have been the only real, and overwhelmingly underfunded, organizations making any semblance of investments in Space Situational Awareness research. I know this because I was the Mission Lead for Space Situational Awareness at the Air Force Research Laboratory for several years. The National Academies has several relevant boards that should be invoked to engage in studies that inform a nationally committed roadmap of Space Situational Awareness Science and Technology Research. I'd welcome the opportunity to serve on one or more of them. Moreover, these research outputs must be committed to being transitioned into operationally relevant environments that could directly support the U.S. Department of Commerce's stewardship of providing Basic Space Situational Awareness and Space Traffic Management services and products to the global community.

What are the next steps required to put this into effect?

- Begin collecting, curating, and exploiting multi-sourced anthropogenic space object (e.g. non-Space Surveillance Network tracking) data for orbital safety and sustainability purposes that is open and widely accessible, with multi-tiered access and dissemination (e.g. Open Architecture Data Repository).
- Create or expand the existing role of NASA to: 1) uniquely focus upon leading the **scientific and technical** requirements for a robust, effective, and meaningful Civil Space Traffic Management System, and 2) to work closely with other government agencies, industry, and academia.
    - Conjunction Analysis concerns itself with predicting so-called "close approaches" between any two Anthropogenic Space Objects[7]; it is a growing and changing field, and research into new methods is critical to keep up with the rapidly changing and marginally predictable space environment. NASA already has an effort in this area (the CARA Program at Goddard Space Flight Center) that can be leveraged along with 30+ years of developing and executing this capability for use by civil space operators. It is government's role to retire risk, invest in Science and Technology (S&T) Research and Development (R&D), and share the results with the community to encourage growth.
- Invest in and expand the role of University Affiliated Research Centers (UARCs) as foundational, dedicated, and focused government-academic partnerships to solidify science and technology (S&T) research and development for critical space-related core technical competencies and technology risk-retirement needed by the U.S. Space Exploration program and Commercial Space Industry[8].

[7] http://astriacss03.tacc.utexas.edu/ui/min.html

[8] https://www.arlut.utexas.edu

- Engage and craft mechanisms for Industry to get their investment and participation in a Civil Space Traffic Management System:
    - Satellite manufacturers
    - Satellite launch providers
    - Space Insurance Brokers and Providers
    - Commercial Space Situational Awareness Providers
    - Space Angel Investors and Venture Capitalists
    - Space Service Users

At The University of Texas at Austin, we are taking our own steps in a meaningful direction by (a) being an academic partner to the USSPACECOM in Space Situational Awareness Data Sharing, (b) collaborating with the NASA CARA program, hosting their tools at the Texas Advanced Computing Center (TACC) and leveraging our large scale computing platforms to improve current state-of-practice regarding collision risk assessments, (c) finalizing a fully executed set of Cooperative Research and Development Agreements (CRADAs) with the Department of Commerce's space weather prediction center and NOAA satellite operations facility in Suitland MD, (d) advancing the state-of-the-art in developing the world's first crowdsourced space traffic monitoring system, ASTRIAGraph, initially funded by the Federal Aviation Administration and now transitioned to Privateer Space Inc. in Wayfinder[9], (e) leading a dedicated transdisciplinary academic programs in space safety, security, and sustainability.

Mr. Chairman, we have some wicked problems to solve in near earth space and we need Congress to act now. Perfect is the enemy of good enough! We know that we won't have a perfect system at the start but let's create a system that is agile and adaptive to meet the growing demands and as a community, we will iteratively refine our tradecraft and collaboration and get better. This committee should provide the required leadership; the opportunity to act is before you.

Narrative

I recently read a draft bill titled "Space SSA Transition Act." In it, it states that the US government wants to make publicly and continually available, free of direct user fees, trusted, verified baseline space situational awareness services and information, enhanced by ongoing improvements in accuracy. I agree that this is needed but the details on this matter. Continually available means no interruption or downtime to query and access these baseline SSA services and information. The Depart of Commerce's Open Architecture Data Repository (OADR) must go beyond the current system employed by USSPACECOM whereby machine access is limited and of low bandwidth. The notion of trusted services and information is critical. There needs to be some part of the US government adequately resourced to do just this. Accuracy is also mentioned, but precision is not.

[9] http://www.privateer.com

Information that is accurate and imprecise is not useful. Accuracy relates to error and precision relates to uncertainty around this error. Decisions are made based upon precision, uncertainty. We must seek to develop a system that is optimized to remove uncertainty and ambiguity. The OADR must, *inter alia*, be an ignorance removal system. The way to remove uncertainty is by aggregating, curating, and fusing massive quantities of disparate and independent observations. The you know that you have the world's most accurate clock is because we have hundreds of them, and the weighted combination of these results in a mean time with a distribution of times that represents the uncertainty.

The Space SSA Transition Act also states the desire to make available to governmental and non-governmental space operators space safety and sustainability tools, voluntary standards, and risk mitigation practices. This is also critical. In fact, the emergent behavior we desire of the space domain is that of common operational practice. However, common practice is impossible in the absence of common knowledge, so the knowledge must be made even across the operator community. Another point made was to support research and development to promote space safety and improve space situational awareness and space traffic coordination. Truth be told, we still have a lot of science yet to be done to understand the causal relationships existing in the space domain that could then promote improved predictability. The required research and development cannot be constrained to the hard sciences because coordination of space activities is also culturally nuanced. The research and development in this area must be transdisciplinary if the outcome is to effectively meet the US governments explicit desires and needs.

The US government also states its desire to develop and support ongoing mechanisms for transitioning into operational activities the research and development. This is an area of much needed attention as there is evidence that the US government is unskilled in this regard. The OADR was designed to have a so-called "sandbox" called the Advanced Research and Collaboration Applications Development Environment (ARCADE) which would serve as a mechanism to maximize success in transitioning the salient fruits of research and development into the operational system OADR proper. This could be solved by requiring that research and development be implemented in ARCADE prior to being proposed to the OADR.

Another point made was to support the use, where validated and practicable, of commercial technologies, data, systems, and services that can supplement and enhance United States Government-provided space situational awareness services and information. This is another critical item to be addressed as there are many commercial capabilities that far exceed anything the government has or could. These should be leveraged as a system of systems. Confidence, trust, and the best interest of the public is for the government to acquire and integrate these non-government technologies into the OADR framework to augment and improve inherently government capabilities.

Regarding the desire to promote and facilitate the development, demonstration, and ongoing use of voluntary standards and best practices for space situational awareness, this can only be achieved with open and wide collaboration. There must be leadership in developing use cases or scenarios that can be leveraged to drive this development and demonstration. For instance, focusing on exchanging data and information on rocket bodies in low earth orbit could rally a community

together and the emergent result could be effective and longstanding practices with measured success in improving space safety, security, and sustainability.

With regards to leading international dialogue and collaboration toward implementing a framework for internationally harmonized space situational awareness and space traffic coordination, the US must go beyond so-called 5-Eyes and like-minded countries by leveraging its Track 2.0 Diplomacy instruments such as working with the National Academy of Sciences Committee on International Security and Arms Control (CISAC) which has a Space Security working group[10] as well as the Carnegie Endowment of International Peace (CEIP) which has a Space Project[11] dedicated to working with China, India, and Russia on theses SSA topics.

The Space SSA Transition Act mentions a Transition Plan which includes defining requirements for an Initial Operational Capability (IOC) and a Full Operational Capability (FOC) in terms of data, observations, tracking facilities, and services to be provided. Unfortunately, what is not mentioned is the need to concurrently and dynamically evaluate the data and observations in the context of so-called Dimensions of Data Quality (e.g. timeliness, accuracy, uniqueness, consistency, completeness, validity) critical to meet the needs of the community in both the IOC and FOC. This must be an inherently governmental function. In fact, given the process known as Observe-Orient-Decide-Act (OODA) pictured below, the OADR should serve principally as the Orient part of OODA. As such it should ingest, organize, curate and expose data and observations to space domain stakeholders to facilitate improved decision intelligence defined as the ability to manipulate data and information in such a way so as to maximize desired outcomes. In this case, the outcomes we seek are improved space safety, security, and sustainability by making the space domain more transparent, predictable, and developing a body of evidence that constitutes true continuing supervision.

[10] https://www.nationalacademies.org/our-work/space-security-working-group

[11] https://carnegieendowment.org/programs/technology/space/

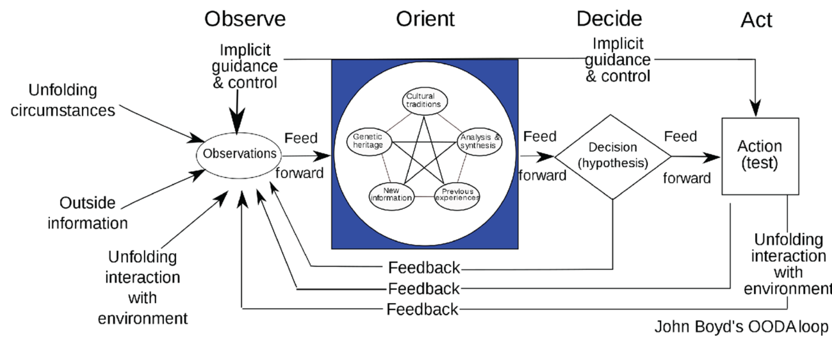

Figure 1. John Boyd's Observe-Orient-Decide-Act Framework
https://en.wikipedia.org/wiki/OODA_loop

Another way to understand this required data and information digital framework is pictured below with a snapshot of the live schema in ASTRIAgraph. There are many sources of data and observations available to the OADR which would be the yellow bubbles seen below on the left. Those in need of SSA/STM services and capabilities are the pink bubbles below on the right. These are the entities needing to make decisions and take actions. The Orient part of this resides in the middle (blue and green bubbles) below. This is what must be inherently governmental because it provides both due diligence in quality assurance ton the community and exposes the most useful and widest possibility of services and capabilities.

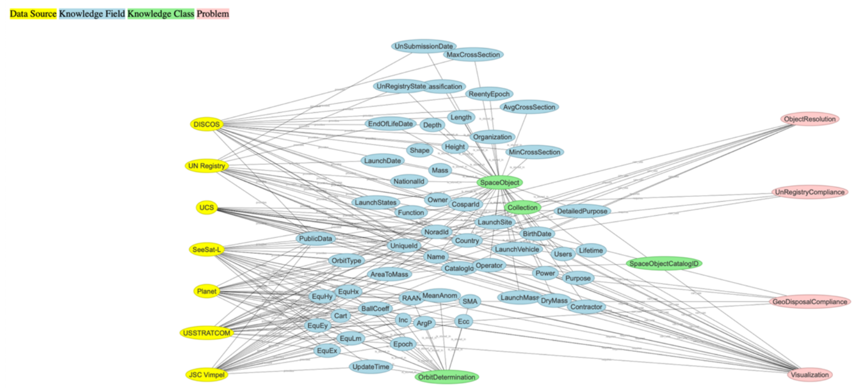

Figure 2. ASTRIAGraph's Live Schema http://astriaservices.tacc.utexas.edu/liveschema

In order to know something, one must measure it. The next figure provides a Space Domain Awareness Johari Window in terms of things we are aware of or not, and have measured or not. To wit, a Known-Known is something we are aware of having measured and this is the best place from here to make decisions and take actions. We also have thins we are aware of not having measured and for these things, Known-Unknowns, we must ascribe uncertainty to represent our ignorance and this uncertainty makes decision-making more challenging and with increased risk, but still quantifiable. The enigmas are the things we are unaware of and have not measured, making these unknowable, by definition. We have no way to protect ourselves against these things. Finally, we have the main importance of aggregating massive quantities of disparate and heterogeneous data into a properly data engineered framework, which is discovering otherwise hidden insights. These are the Unknown-Knowns or things we are unaware of having measured. Discovering this knowledge removes ignorance and improves space situational awareness and the services resultant from this.

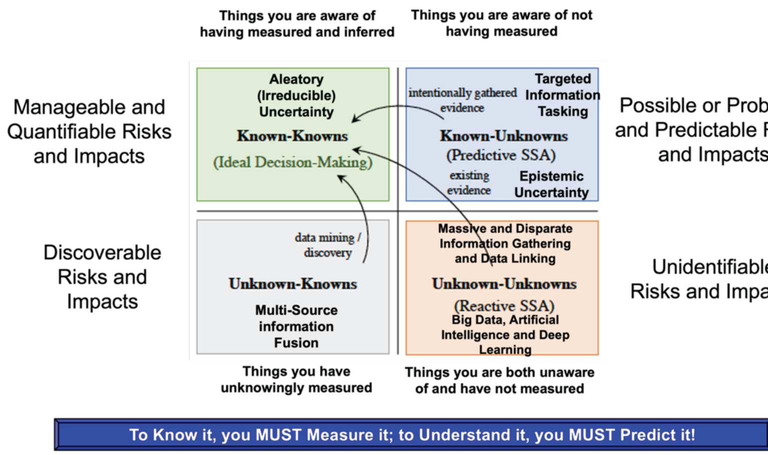

Figure 3. Space Domain Awareness Johari Window

For additional context, the US Space Command (USSPACECOM) currently has over 30,000 records active in its space situational awareness database, commonly referred to as the Department of Defense "catalog." Of these, well over 20,000 records correspond to well-tracked, well-understood Anthropogenic Space Objects in Earth-centric orbit, roughly 4,000 of which are operational satellites; the rest are so-called "space junk." The remaining records in USSPACECOM's active space situational awareness database are not as well-tracked or understood, which creates increased uncertainty when operational satellites are screened against them to identify possible orbital safety hazards, or conjunctions. The number of Anthropogenic Space Objects is increasing given an increase in launches, and on-orbit breakup events (i.e. when one Anthropogenic Space Object collides with another, a satellite explodes, or breaks on its own due to space aging and material fatigue and stresses). If we could track every detected object, we could wrap a sensible Space Traffic Management and Coordination system around that and even develop empirically-based policies and regulations. Unfortunately, it is hypothesized that we can only track a few percent of the total number of space objects that can cause loss, disruption, or degradation to critical space services, capabilities, and activities. In other words, we have an orbital iceberg equivalent of sorts. The ability to track an Anthropogenic Space Object depends on two main factors: our ability to detect the object AND our ability to uniquely identify the object. This is to underscore that an object that is detectable does not imply it is trackable, and this is a critical distinction to make moving forward.

Tracking an object means that we know where it was, a notion of where it is, and have some idea of what it is and where it will be. Think of how we track air traffic, where the aircraft is in the "custody" of someone who monitors its motion and relationship to other aircraft. The following

Figure (4) puts into perspective the problem we face in our inability to track more of the objects we can detect. It was generated from real data collected by the U.S. Space Surveillance Telescope, currently in Exmouth, Australia. It is worth mentioning that we have the long-awaited Space Fence on Kwajalein, and I've been told that the results are much like with the Space Surveillance Telescope, as seen in Figure (4). When one has an exquisite sensor and it's unique, you'll get very accurate observations during a very small part of the total orbit and you'll be observing things that other sensors will not or cannot.

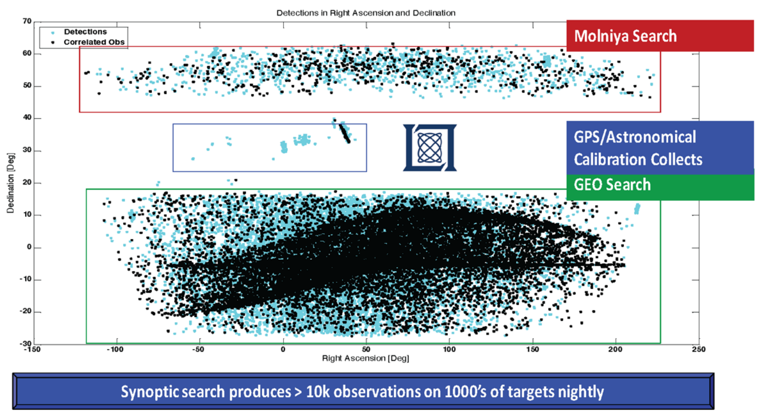

Figure 4. A Single Night's Worth of Anthropogenic Space Object (ASO Detections (for various orbital regions) from the U.S. Space Surveillance Telescope (SST) in New Mexico. Detections (dots) that are Black are those believed to be from known (cataloged) ASOs. All else (Cyan) are Detectable but Untrackable ASOs.

So, what prevents us from doing better at tracking objects in space? First, we don't have ubiquitous observations, meaning we don't persistently detect all objects all of the time. In fact, we generally have very sparse observations on any given object in space. Globally, we do not share observational data as a community. This lack of data sharing is perhaps the single biggest problem in us having a more robust space traffic monitoring and management capability. Secondly, every single object in the world's largest space object catalog (that of our DoD) is represented and modeled as a sphere, a cannonball in space. Needless to say, there aren't many human-made cannonball-shaped objects in space. Only those Anthropogenic Space Objects whose motion is not significantly different from that of a sphere in between observations, are ones we can "track." Gravity is what I call an equal opportunity accelerator: just tell me where you are and I will tell you your acceleration due to gravity, regardless of your size, shape, material constitution, orientation, etc. However, there are non-gravitational forces experienced by every single

Anthropogenic Space Object and all of these depend on the object's physical characteristics. Thus, the lack of a rigorous Anthropogenic Space Object characterization and classification scheme is a strong contributor to our inability to track more objects in space. When we wish to understand any population of things, we first "tag" individuals in that population and then "track" these individuals through time, space, frequencies, and evaluate their interaction with other individuals and their environment. We formulate hypotheses, test them, and draw conclusions based upon evidence. We do not do this, rigorously and scientifically, for Anthropogenic Space Objects, in great part because we cannot physically go to them and tag them. If we wish to someday have Norms of Behavior for Near Earth Space that led to safety, security, and sustainability, we will need to know how many classes or species of Anthropogenic Space Objects there are, and how each class or specie moves, behaves, is influenced by the local space environment, etc. Trucks carrying hazardous fuel are regulated differently than Vespa scooters, Oil Tankers on our seas are regulated differently than kayaks and canoes. So, why would we treat all Anthropogenic Space Objects as the same thing…cannonballs? The following figure (5) is a cartoon to show the difference between the limitations imposed by assuming space objects to be cannonball-like versus what they actually are like.

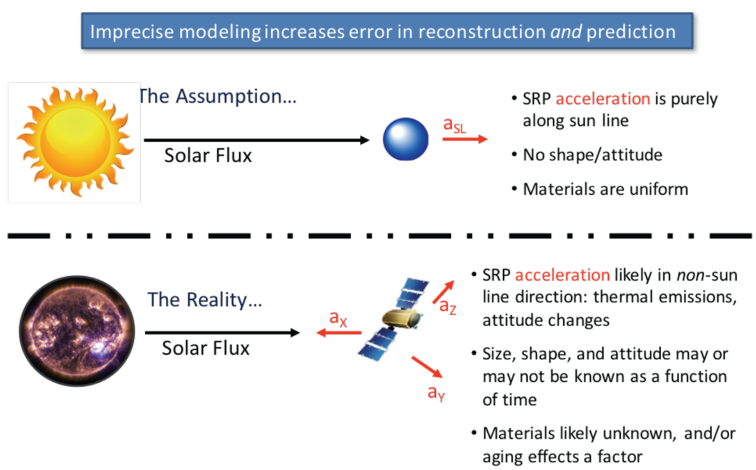

Figure 5. Difference between the motion experienced by a spherical (cannonball-like) space object and a satellite with realistic size, shape, orientation, and material properties. For the sphere, the acceleration due to the sun's effects are unidirectional. In reality, our tracking data informs us that objects experience accelerations due to the Sun's effects in 3-dimensional space (multi-directional).

Lastly, regarding our inability to track more objects in space, are the mathematics and physics we use to process the observed data and infer physical quantities regarding these objects. It really matters…call these our algorithms. Our representation of uncertainty is demonstrably and inarguably oftentimes flawed, unrealistic, and inconsistent amongst our software and tools. The following figure (6) shows a picture our current problem with having multiple detections at multiple times and having to find clever methods of uniquely identifying objects in order to make them go from detectable to trackable. Most Anthropogenic Space Objects are defunct and therefore do not self-report their identities.

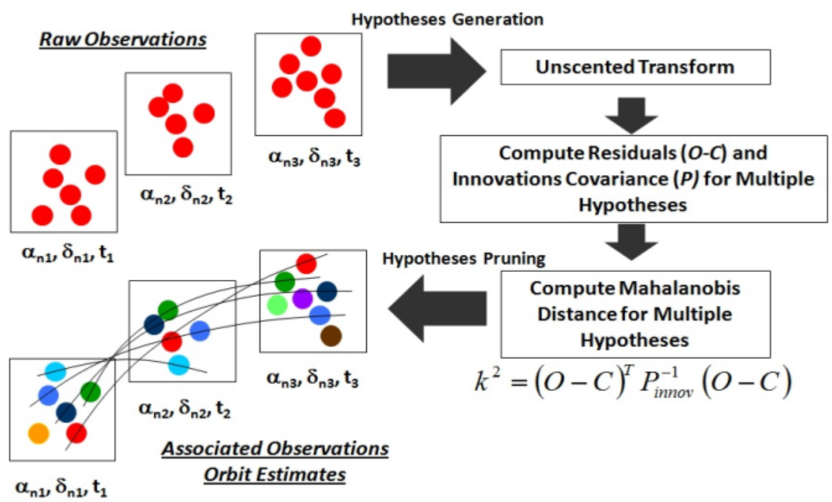

Figure 6. How to Uniquely Identify Space Objects from a Set of Unidentified Detected Objects in Order to Make Detectable Objects, Trackable. The method shown here is one of Multiple Hypothesis Testing as a mechanism to decide which detections should be paired to which objects.

If the Anthropogenic Space Object population was held constant, I'd say we'd might have more time on our hands to figure this all out. However, our global space environment is finite, getting increased traffic, and all in the absence of global governance related to safety and sustainability.

As the cost of access to space is decreasing, the number of space actors is increasing. It's like what the Transcontinental Railroad did for helping businesses explode, connecting the East Coast and Western Frontier. As was experienced in the Western Frontier of old, the environmental impact of runaway mining and prospecting was harsh and detrimental in many instances. Examples are mercury poisoning, silt in our water sources, etc. Our space environment is becoming much more

commercially driven and populated. Many "New Space" companies or start-ups are getting significant investment from Angel Investors and Venture Capitalists who are focused on getting a Return On Investment (ROI) within a few years, believing Space Traffic and Orbital Safety to be someone else's problem. I have personally found an absence of space operations expertise amongst the workforce driving some of these "New Space" ventures, causing me further concern regarding orbital safety and long-term sustainability of space activities. There is a mentality of "take risks and fail often." While this worked well for software companies in Silicon Valley, we can't afford to have this mentality in space.

We should look to so-called tenets of Traditional Ecological Knowledge (TEK) as a model for achieving space sustainability. Some of our indigenous peoples have learned how to become sustainable over many millennia. One tenet underscores the need to quantify the carrying capacity of the environment before making decisions on how to interact with it. My personal experiences have shown me that "Mother Nature" tends to seek states of equilibrium. Do we know what the carrying capacity is for different orbits? If we launch 60+ satellites every several weeks, do we know what the equilibrium state of the environment will be? We are operating in the space domain well beyond our ability to make sound and sustainable decisions, and this will be to our eventual detriment.

I fully support Congress moving to create a Civil Space Traffic Management (CSTM) system led by the Department of Commerce (as directed by national space policy) that will:

- Accelerate the pace and reduce the costs of Civil Space Traffic Management development by modernizing approaches to Space Situational Awareness and Space Traffic Management, with focus on long-term sustainability of space activities, through the creation of new federated data standards, measurement standards, models and ontologies, open source software, and big-data management and analysis techniques that aid in the scientific evaluation of the efficacy and safety of space operations, and attendant policies.
- Act as an entity that could create consortia of industry, academia, and government for collaboration and sharing of databases, computational techniques, and standards.
- Operate a Civil Space Traffic Management system that provides the accuracies and products necessary to safely enable innovative and non-traditional commercial uses of space.

The Civil Space Traffic Management Mission should be to:

- Assure the safety of operations in space.
- Maximize, encourage, and incentivize the use of commercial capabilities and data sources.
- Provide transparency, advocacy of informed guidelines, and safety services as a public good to preserve the space environment.

The Civil Space Traffic Management Primary Functions would be to:

- **Observe and Monitor:** Space Domain and Traffic Observations, Space Situational Awareness (SSA)
- **Track and Catalog:** Identify, Characterize, and Catalog Objects; Relational Statistics, Catalog Updates, Traffic Attribution, Achieve Track "Custody"
- **Analyze and Inform:** Information Dissemination, Safety Products, Conjunction Data Messages

The Tenets of a Civil Space Traffic Management system would be to provide and incentivize:

- **Open observational data** - All collected or acquired data will be made open and available for 3rd party analysis to improve learning and enable high Quality of Service domain analysis.
- **Open catalog of space objects and events** - All derived conclusions from Civil Space Traffic Management data will be made open and available for 3rd party verification and peer-review of results and conclusions.
- **Open Safety Advisory Services** - As these services are intended to be a global public good, they will be made available to the world.
- **Open and objective verification of data and analyses** - As the Civil Space Traffic Management capabilities and processes improve, impartial feedback will be made available to all service providers in the spirit of achieving increasingly effective Quality of Service.
- **Open Market** - It is not the role of the Department of Commerce to define the economics of the data and/or analysis marketplace. The intent of the Civil Space Traffic Management is to empower industry to stay involved in the provision of service to all space domain actors.
- **Open Workforce Development** - It is to the benefit of all for the specialized skills required of effective space traffic managers to proliferate globally. To this end this Civil Space Traffic Management will support mechanisms which result in the education of additional skilled space traffic managers and analysts.

The Benefits of a Civil Space Traffic Management system are that it would:

- Provide standard and benchmark data sets that enable quantifiably consistent comparative analyses between competing tools, techniques, and algorithms.
- Provide the government with a transparent mechanism to guide and exploit Civil Space Traffic Management activities and capabilities AND a sustained/focused investment in STEM education.
- Provide industry with a free foundational Civil Space Traffic Management service and a marketplace of focused, cost-shared and openly available sciences and technologies that it can "pick up" and operationalize/commercialize for its own profit.

- Provide academia with a sustained scientific and technological Civil Space Traffic Management research and educational investment, to ensure that the U.S. is stocked with capable and skilled workforce to handle the scientific and technological problems of tomorrow.

How does industry profit from such an activity, financially? It can easily wrap profit-making services around the foundational "for public good" layer of basic space situational awareness and space traffic management services and products. It lowers the bar for entry for new space initiatives as they don't need to shoulder the burden of self-providing of these basic space situational awareness and space traffic management services. It's like the benefit of the U.S. developed, owned, and operated Global Positioning System (GPS)! Think of not only the paradigm-changing science but explosion of commerce that has resulted from this U.S. Government investment and service. Many companies have developed profit-making applications which exploit the layer of foundational service provided by GPS.

I also propose that the U.S Government create the NASA Space Situational Awareness Institute using Cooperative Agreements (like the NASA Astrobiology Institute) as a mechanism under which an academic consortium could be assembled, invested in, and properly leveraged to deliver on goal #1 of Space Policy Directive #3. The funding would need to be appropriated and delivered to NASA with a strategic roadmap on how the S&T is developed and transitioned to both government and industry. Several University Affiliated Research Centers (UARCs) should also be invoked, invested in, and leveraged, to be foundational partners in this NASA Space Situational Awareness Institute. The UARCs could provide foundational capabilities and sciences to NASA and those Space Situational Awareness Institute academic members could then focus uniquely on SSA needs and requirements, working closely with the government and commercial communities.

Exploration is critical to who we are as a species; it drives our growth and evolution. When our minds and bodies are idle, we tend to self-defeating behaviors. What brings out the best in us? Rising to great challenges, and working as a nation to overcome them. What got us to the Moon and back, safely and repeatedly? Government, Industry and Academia working seamlessly, together. No one sector could do it by themselves.

The motto of my research program at UT Austin is:

Ex Coelestis, Scientia…Nihil Arcanum Est! This loosely translates to, "from the heavens, knowledge…nothing hides!"

As Ever,

Moriba Jah

Moriba K. Jah, Ph.D.

THE UNIVERSITY OF TEXAS AT AUSTIN
Cockrell School of Engineering
Resume

FULL NAME: **Moriba Kemessia Jah** **TITLE:** **Associate Professor**

DEPARTMENT: **Aerospace Engineering and Engineering Mechanics**

EDUCATION:

Embry-Riddle Aeronautical University	Aerospace Engineering	B.S.	1999
University of Colorado (Boulder)	Aerospace Engineering Sci	M.S.	2001
University of Colorado (Boulder)	Aerospace Engineering Sci	Ph.D.	2005

PROFESSIONAL REGISTRATION: **Not Registered**

CURRENT AND PREVIOUS ACADEMIC POSITIONS:

Associate Professor (with Tenure), The University of Texas at Austin,
- Department of Aerospace Engineering and Engineering Mechanics, September 2020 – present
- Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering

Affiliate Faculty, The University of Texas at Austin
- Environmental Sciences Institute, October 2019 – present

Affiliate Researcher, Massachusetts Institute of Technology
- Jan 2021 - Present

Visiting Professor, Australian National University
- Research School of Aerospace, Mechanical, and Environmental Engineering (RSAMEE), July 2019 –Jan 2021

Core Faculty, The University of Texas at Austin,
- Oden Institute for Computational Engineering and Sciences, August 2018 – present

Director, The University of Texas at Austin,
- Oden Institute Computational Astronautical Sciences and Technologies Group, August 2018 - present

Associate Professor (Tenure-Track), The University of Texas at Austin,
- Department of Aerospace Engineering and Engineering Mechanics, April 2017 – September 2020
- Statistics and Data Science Department (Courtesy), October 2017 – present

Program Lead and Distinguished Scholar, The University of Texas at Austin,
- Robert Strauss Center for International Security and Law: Space Security and Safety, March 2017 - present

SERC-Funded Visiting Fellow, Royal Melbourne Institute of Technology University (Melbourne, Australia), May 2016 and May 2017

Adjunct Professor, Royal Melbourne Institute of Technology University, School of Science, SPACE Research Centre, 2016 – Present

Associate Research Professor (Continuing-Status/Tenure-Equivalent), The University of Arizona,
- Geosciences Department (Courtesy), March 2016 – April 2017
- Aerospace and Mechanical Engineering Department (Courtesy), September 2016 – April 2017
- Electrical and Computer Engineering Department (Courtesy), April 2016 – April 2017
- College of Engineering, January 2016 – April 2017

Rector-Funded Visiting Fellow, University of New South Wales (Canberra, Australia) May-June 2014

OTHER PROFESSIONAL EXPERIENCE:

U.S. Air Force Security Police, October 1988 – October 1992 (Honorably Discharged)
NASA Space Grant Researcher, January 1996 – May 1999
Microcosm Inc., Space Mission Design and Orbital Analyst, May 1997 – May 1999
NASA Jet Propulsion Laboratory, Spacecraft Navigator, May 1999 – August 2006
Oceanit Laboratories, Maui Division, Senior Scientist, August 2006 – October 2007
Air Force Research Laboratory, Directed Energy Directorate, Team Lead, Astrodynamics Program, October 2007 – June 2010
Air Force Research Laboratory, Space Vehicles Directorate, Technical Advisor, Guidance, Navigation, & Control Program, June 2010 - September 2014
Air Force Research Laboratory, Space Vehicles Directorate, Mission Lead, Space Situational Awareness, September 2014 - January 2016
Director of Space Object Behavioral Sciences Initiative, The University of Arizona, Defense and Security Research Institute, January 2016 – April 2017
Expert Contributor "Source of the Week," National Public Radio (NPR) (2019 – present)
Contributing Writer "Jahniverse," Aerospace America, American Institute of Aeronautics and Astronautics (AIAA) (2020 – present)
Host "Space Café: Moriba's Vox Populi," SpaceWatch Global Webcast Series (2020 – present)
Executive Mentor, Patti Grace Smith Fellowship (2021 – present)
Executive Mentor, Zed Factor Fellowship (2021 – present)
Non-Resident Fellow, United Nations Institute for Disarmament Research (UNIDIR) (2019 – present)
Non-Resident Scholar, Carnegie Space Project, Carnegie Endowment for International Peace (2021 – present)
Co-Founder and Chief Scientist, Privateer Space Inc. (2021 – present)

MAJOR CONSULTING PROJECTS

Slingshot Aerospace, Technical Advisor, 2019 – Present
NorthStar Earth & Space, Technical Advisor, 2021 – Present
Privateer Space Inc., Chief Scientific Advisor, 2021 - Present

HONORS AND AWARDS:

Senior Airman "Below-the-Zone" promotion, 1990
1990 Strategic Air Command, SP Airman of the Year
National Defense Service Medal (1991)
Honorable Discharge, U.S. Air Force (1992)
2001 *NASA Group Achievement Award* and *Aviation Week & Space Technology Laurel Award* for the superb navigation of the Mars Odyssey spacecraft to Mars
2005 *NASA Group Achievement Award* for the flawless navigation of the Mars Reconnaissance Orbiter to Mars
2007 *NASA Space Act Award* "for the creative development of a scientific contribution which has been determined to be of significant value in the advancement of the space and aeronautical activities of NASA, and is entitled: Inertial Measurements for Aeroassisted Navigation (IMAN)"
2009 *NASA Group Achievement Award* for the Nanosail-D mission support

2009 *AFRL R. Earl Good Award* "for significant team contributions to the AFRL mission or image outside of AFRL and for accomplishments that have had a significant impact and enhanced the creditability of AFRL."
Hayabusa Certificate of Appreciation (2010): "in recognition of your significant contributions to the completion of Hayabusa's round trip space mission in 2010."
Elected to Senior Member of the IEEE, 2010
Elected to Associate Fellow of the AIAA, 2011
2013 *AFRL International Award*
2013 *AFRL/RV Technology Transfer/Transition Achievement Award*
Elected as Fellow of the RAS, 2014
Elected as Fellow of the AAS, 2014
Elected as Fellow of the IAASS, 2015
Elected as Fellow of the Air Force Research Laboratory (AFRL), 2015
University of Colorado Distinguished Engineering Alumni Award (DEAA), 2016
AIAA Momentum Member Spotlight – June 2016
(http://www.aiaa.org/memberspotlightJune2016/)
Elected as Corresponding Member of the IAA, 2018
Elected as Fellow of the AIAA, 2019
Selected as Fellow of TED, 2019
Elected as Member of the IISL, 2019
Selected as Fellow of The Op-Ed Project, Public Voices, 2020
Selected as Individual Member of the IAU, 2020
Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering
Elected as Full Member of the IAA, 2020
Embry-Riddle Aeronautical University Distinguished Alumni Award, 2021
Elected as Fellow of the Explorers Club, 2021
Selected as Explorers Club 50: 50 People Changing The World, 2022

MEMBERSHIPS IN PROFESSIONAL AND HONORARY SOCIETIES
Fellow, International Association for the Advancement of Space Safety (IAASS), Member 2015 - Present
Fellow, American Astronautical Society (AAS), Member 2004 - Present
Fellow, Royal Astronomical Society (RAS), Member 2014 – Present
Fellow, American Institute of Aeronautics and Astronautics (AIAA), Member 1996 - Present
Senior Member, Institute of Electrical and Electronics Engineers (IEEE), Member 2010 - Present
Member, International Society for Information Fusion (ISIF), Member 2009 – Present
Corresponding Member, International Academy of Astronautics (IAA), 2018 – 2020
Full Member, International Academy of Astronautics (IAA), 2020 – Present
Member, International Institute of Space Law (IISL), 2019 – present
Individual Member, International Astronomical Union (IAU), 2020 – present
Fellow, Explorers Club, 2021 - present

UNIVERSITY COMMITTEES/ADMINISTRATIVE ASSIGNMENTS:

Cockrell School of Engineering
Member, Diversity and Inclusivity Committee, 2017 – Present

Aerospace Engineering & Engineering Mechanics
Member Social Platform Committee 2021 - Present

PROFESSIONAL SOCIETY AND MAJOR GOVERNMENTAL COMMITTEES, EDITORIAL BOARDS, AND CONFERENCES ORGANIZED/CHAIRED:

Outside Committees
Chair, AAS Space Surveillance Technical Committee (2009 – 2016)
Chair, AIAA Astrodynamics Technical Committee (2016 – 2018)
Member, International Academy of Astronautics (IAA) Space Debris Permanent Committee (2014 - Present)
Chair, NATO SCI-ET-003 Technical Solutions to a Common Operating Picture for Space Domain Awareness Exploratory Team, (2014 – 2015)
Chair, NATO SCI-279-TG Technical Solutions to a Common Operating Picture for Space Domain Awareness Task Group, (2015 – 2018)
Member, NATO SCI-ET-036 Collaborative Space Domain Awareness Data Collection and Fusion Experiment (2017 – 2018)
Member, NATO SCI-311-RTG Collaborative Space Domain Awareness Data Collection and Fusion Experiment (2018 – Present)
Chair, NATO SCI-ET-056 Role of Data and Decisions on the Space Operations Floor Exploratory Team, (2020 – Present)
Member, International Astronautical Federation (IAF) Astrodynamics Committee (2014 - Present)
Member, International Astronautical Federation (IAF) Space Security Committee (2018 - Present)
Member, International Astronautical Federation (IAF) Space Traffic Management Committee (2020 - Present)
Member, AAS Space Flight Mechanics Technical Committee (2006 – 2011)
Technical Chair, 21st AAS/AIAA Space Flight Mechanics Meeting (2011)
Member, Research Council, Research Initiative of Sustainable Space Logistics (RISSL), Ecole Polytechnique Federale de Lausanne (EPFL) Space Center (eSpace) (2020 – Present)
Member, National Academy of Sciences Engineering and Medicine (NASEM) Committee on International Security and Arms Control (CISAC) Space Security Working Group (2020 – Present)
Chair, International Academy of Astronautics (IAA) Space Traffic Management Permanent Committee (2020 - Present)
Chair, AIAA Goddard Astronautics Award Subcommittee (2020 – present)
Member IEEE AESS Judith A. Resnik Space Award Subcommittee (2020 – present)

Conference Activities
Member, NSSDF Technical Committee (2012 – 2015)
Technical Committee Member, International Society of Information Fusion Conference (2010, 2012, 2013)
National Chairperson, Space Debris, 35th Annual AAS Guidance and Control Conference (2012)
Organizer and Moderator, 1st AAS Space Surveillance Workshop, London, UK (2011)
Session Chair, AAS; AIAA; IAC; ISIF conferences and symposia (2002 – present)

Journal Activities

Associate Editor, Advances in Space Research (Elsevier), Journal of the Committee on Space Research (COSPAR), a Scientific Committee of the International Council for Science (2017 – Present)
Co-Editor, Acta Astronautica (Elsevier), Transdisciplinary Astronautical Arts, Sciences, and Engineering, Journal of the International Academy of Astronautics (IAA) (2020 – present)
Field Editor, Journal of Space Safety Engineering (Elsevier), Journal of the International Association for the Advancement of Space Safety (IAASS) (2021 – present)
Guest Editor, AIAA Journal of Guidance, Control, and Dynamics Special Issue: Space Domain Awareness
Associate Editor, IEEE Transactions on Aerospace and Electronic Systems (2011 – 2017)
Associate Editor, IEEE Aerospace and Electronic Systems Magazine (2011 – 2017)

OTHER PROFESSIONAL HIGHLIGHTS:

Invited External Reviewer for Montana NASA EPSCoR Research Award Selection (2016)
Secretary of the Air Force Invited Member, US Air Force Science & Technology Investments 2030 Expert Recommendations Panel, Science and Technology Policy Institute, Washington DC, July (2018)
Chair, NASA Space Weather to Research (SWO2R) Satellite Drag Review Panel, Headquarters Heliophysics Science Mission Directorate (2021)

Current Review Activities:

AIAA *Journal of Guidance, Control, and Dynamics*
IAA *Acta Astronautica (Elsevier)*
COSPAR *Advances in Space Research (Elsevier)*
AFOSR Proposals

PUBLICATIONS:

Refereed Journal Publications

1. Antreasian, P. G., Baird, D. T., Border, J. S., Burkhart, P. D., Graat, E. J., **Jah, M. K.**, … Portock, B. M. (2005). 2001 Mars Odyssey orbit determination during interplanetary cruise. *Journal of Spacecraft and Rockets*, *42*(3), 394–405. http://doi.org/10.2514/1.15222
2. **Jah, M. K.**, Lisano, M. E., Born, G. H., & Axelrad, P. (2008). Mars aerobraking spacecraft state estimation by processing inertial measurement unit data. *Journal of Guidance, Control, and Dynamics*, *31*(6), 1802–1813. http://doi.org/10.2514/1.24304
3. Wetterer, C. J., & **Jah, M.** (2009). Attitude estimation from light curves. *Journal of Guidance, Control, and Dynamics*, *32*(5), 1648–1651. http://doi.org/10.2514/1.44254
4. Kelecy, T., **& Jah, M.** (2010). Detection and orbit determination of a satellite executing low thrust maneuvers. *Acta Astronautica*, *66*(5–6), 798–809. http://doi.org/10.1016/j.actaastro.2009.08.029
5. Tombasco, J., Axelrad, P., & **Jah, M.** (2010). Specialized coordinate representation for dynamic modeling and orbit estimation of geosynchronous orbits. *Journal of Guidance, Control, and Dynamics*, *33*(6), 1824–1836. http://doi.org/10.2514/1.48903
6. Kelecy, T., & **Jah, M.** (2011). Analysis of high area-to-mass ratio (HAMR) GEO space object orbit determination and prediction performance: Initial strategies to recover and

predict HAMR GEO trajectories with no a priori information. *Acta Astronautica*, *69*(7–8), 551–558. http://doi.org/10.1016/j.actaastro.2011.04.019
7. Kelecy, T., **Jah, M.**, & DeMars, K. (2012). Application of a Multiple Hypothesis Filter to near GEO high area-to-mass ratio space objects state estimation. *Acta Astronautica*, *81*(2), 435–444. http://doi.org/10.1016/j.actaastro.2012.08.006
8. DeMars, K. J., **Jah, M. K.**, & Schumacher Jr., P. W. (2012). Initial orbit determination using short-arc angle and angle rate data. *IEEE Transactions on Aerospace and Electronic Systems*, *48*(3), 2628–2637. http://doi.org/10.1109/TAES.2012.6237613
9. DeMars, K. J., & **Jah, M. K.** (2013). Probabilistic initial orbit determination using Gaussian mixture models. *Journal of Guidance, Control, and Dynamics*, *36*(5), 1324–1335. http://doi.org/10.2514/1.59844
10. DeMars, K. J., Bishop, R. H., & **Jah, M. K.** (2013). Entropy-based approach for uncertainty propagation of nonlinear dynamical systems. *Journal of Guidance, Control, and Dynamics*, *36*(4), 1047–1057. http://doi.org/10.2514/1.58987
11. Früh, C., Kelecy, T. M., & **Jah, M. K.** (2013). Coupled orbit-attitude dynamics of high area-to-mass ratio (HAMR) objects: Influence of solar radiation pressure, Earth's shadow and the visibility in light curves. *Celestial Mechanics and Dynamical Astronomy*, *117*(4), 385–404. http://doi.org/10.1007/s10569-013-9516-5
12. Früh, C., **Jah, M.**, (2013). Attitude and Orbit Propagation of High Area-to-Mass Ratio (HAMR) Objects Using a Semi-Coupled Approach. *Journal of the Astronautical Sciences*, pp. 1-19, published 9 July 2014.
13. Früh, C., & **Jah, M. K.** (2014). Coupled orbit-attitude motion of high area-to-mass ratio (HAMR) objects including efficient self-shadowing. *Acta Astronautica*, *95*(1), 227–241. http://doi.org/10.1016/j.actaastro.2013.11.017
14. Wetterer, C. J., Linares, R., Crassidis, J. L., Kelecy, T. M., Ziebart, M. K., **Jah, M. K.**, & Cefola, P. J. (2014). Refining space object radiation pressure modeling with bidirectional reflectance distribution functions. *Journal of Guidance, Control, and Dynamics*, *37*(1), 185–196. http://doi.org/10.2514/1.60577
15. Vishwajeet, K., Singla, P., & **Jah, M.** (2014). Nonlinear uncertainty propagation for perturbed two-body orbits. *Journal of Guidance, Control, and Dynamics*, *37*(5), 1415–1425. http://doi.org/10.2514/1.G000472
16. DeMars, K. J., Cheng, Y., & **Jah, M. K**. (2014). Collision probability with Gaussian mixture orbit uncertainty. *Journal of Guidance, Control, and Dynamics*, *37*(3), 979–984. http://doi.org/10.2514/1.62308
17. Linares, R., **Jah, M. K**., Crassidis, J. L., & Nebelecky, C. K. (2014). Space object shape characterization and tracking using light curve and angles data. *Journal of Guidance, Control, and Dynamics*, *37*(1), 13–25. http://doi.org/10.2514/1.62986
18. Kelecy, T., **Jah, M.,** Baldwin, J., & Stauch, J. (2014). High Area-to-Mass ratio object population assessment from data/track association. *Acta Astronautica*, *96*(1), 166–174. http://doi.org/10.1016/j.actaastro.2013.11.037
19. Linares, R., **Jah, M. K.**, Crassidis, J. L., Leve, F. A., & Kelecy, T. (2014). Astrometric and photometric data fusion for inactive space object mass and area estimation. *Acta Astronautica*, *99*(1), 1–15. http://doi.org/10.1016/j.actaastro.2013.10.018
20. Leve, F., & **Jah, M.** (2014). Spacecraft actuator alignment determination through null-motion excitation. *IEEE Transactions on Aerospace and Electronic Systems*, *50*(3), 2336–2342. http://doi.org/10.1109/TAES.2013.120187

21. Stauch, J., & **Jah, M.** (2015). Unscented schmidt-Kalman filter algorithm. *Journal of Guidance, Control, and Dynamics*, *38*(1), 117–123. http://doi.org/10.2514/1.G000467
22. DeMars, K. J., Hussein, I. I., Frueh, C., **Jah, M. K**., & Erwin, R. S. (2015). Multiple-object space surveillance tracking using finite-set statistics. *Journal of Guidance, Control, and Dynamics*, *38*(9), 1741–1756. http://doi.org/10.2514/1.G000987

Refereed Journal Publications (while in rank at UT Austin)[UT Austin students UT Austin PostDocs UT Austin Faculty]

1. Psiaki, M. L., Weisman, R., **Jah**, **M.,** (2017). Gaussian Mixture Approximation of the Angles-Only Initial Orbit Determination Likelihood Function. *Journal of Guidance, Control, and Dynamics*, Vol. 40, 2807-2819. https://doi.org/10.2514/1.G002615
2. Coder, R., Holzinger, M., **Jah**, **M.,** (2017). Space Object Active Control Mode Inference Using Light Curve Inversion. *Journal of Guidance, Control, and Dynamics, Special Issue on Space Domain Awareness*, 1-13. https://doi.org/10.2514/1.G002224
3. Coder, R., Wetterer, C., Hamada, K., **Jah**, **M.,** Holzinger, M., (2017). Inferring Active Control Mode of the Hubble Space Telescope Using a Rao-Blackwellized Particle Filter. *Journal of Guidance, Control, and Dynamics, Special Issue on Space Domain Awareness*, 1-7. https://doi.org/10.2514/1.G002223
4. Stauch, J., Bessell, T., Rutten, M., Baldwin**,** J., **Jah**, **M.,** Hill, K., (2017). Joint Probabilistic Data Association and Smoothing Applied to Multiple Space Object Tracking. *Journal of Guidance, Control, and Dynamics, Special Issue on Space Domain Awareness*, 1-15. http://arc.aiaa.org/doi/abs/10.2514/1.G002230
5. Holzinger, M., and **Jah**, **M,** (2018). Challenges and Potential in Space Domain Awareness. *Journal of Guidance, Control, and Dynamics*, Vol. 41, No. 1, pp. 15-18. https://doi.org/10.2514/1.G003483
6. Mallik, V., **Jah, M.K.**, (2018). Reconciling Space Object Observed and Solar Pressure Albedo-Areas Via Astrometric and Photometric Data Fusion. *Elsevier Advances in Space Research*, Vol. 63, Issue 1, pp 404-416. https://doi.org/10.1016/j.asr.2018.08.005
7. Delande, E., Houssineau, J., **Jah, M.**, (2018) Physics and Human-Based Information Fusion for Improved Resident Space Object Tracking. *Elsevier Advances in Space Research*, Vol. 62, Issue 7, pp 1800-1812. https://doi.org/10.1016/j.asr.2018.06.033
8. Kelecy, T., Lambert, E., Sunderland, B., Stauch, J., Mallik, V., **Jah, M.**, (2019). Automated near real-time validation and exploitation of optical sensor data for improved orbital safety, *Acta Astronautica*. https://doi.org/10.1016/j.actaastro.2018.12.043
9. Do, H., Chin, T., Moretti, N. **Jah, M.**, & Tetlow, M. (2019). Robust Computer Vision Algorithms for GEO Object Detection, *Elsevier Advances in Space Research*, Vol. 64, Issue 3, pp 733-746. https://doi.org/10.1016/j.asr.2019.03.008
10. Delande, E., Houssineau, J., Franco, J., Frueh, C., Clark, D., **Jah, M.** (2019). A New Multi-Target Tracking Algorithm for a Large Number of Orbiting Objects. *Elsevier Advances in Space Research*, Vol. 64, Issue 3, pp 645-667. https://doi.org/10.1016/j.asr.2019.04.012
11. Kucharski, D., Kirchner, G., Otsubo, T., Kunimori, H., **Jah, M.**, Koidl, F., Bennett, J., Lim, H-C., Wang, P., Steindorfer, M., Sosnica, K. (2019). Hypertemporal Photometric Measurement of Spaceborne Mirrors Specular Reflectivity for Laser Time Transfer Link Model, *Elsevier Advances in Space Research*, https://doi.org/10.1016/j.asr.2019.05.030

12. Skinner, M., **Jah, M.**, McKnight, D., Howard, D., Mukrami, D., Kai-Uwe, S. (2019). Results of the International Association for the Advancement of Space Safety Space Traffic Management Working Group, *Elsevier Journal of Space Safety Engineering*, https://doi.org/10.1016/j.jsse.2019.05.002
13. Kucharski, D., Kirchner, G., Otsubo, T., Flegel, S., Kunimori, H., **Jah, M.**, Koidl, F., Bennett, J., Steindorfer, M., Wang, P. (2020). Quanta Photogrammetry of Experimental Geodetic Satellite for remote detection of micrometeoroid and orbital debris impacts, *Acta Astronautica,* https://doi.org/10.1016/j.actaastro.2020.04.042
14. Le May, S., Carter, B., Gehly, S., Flegel, S., **Jah, M.** (2020). Representing and Querying Space Object Registration Data Using Graph Databases, *Acta Astronautica,* https://doi.org/10.1016/j.actaastro.2020.04.056
15. Cai, H., Yang, Y., Gehly, S., He, C., **Jah, M.** (2020). Sensor tasking for search and catalog maintenance of geosynchronous space objects, *Acta Astronautica*, Volume 175, October 2020, pp 234-248, https://doi.org/10.1016/j.actaastro.2020.05.063
16. Cai, H., Hussein, I., **Jah, M.** (2020). Possibilistic Admissible Region Using Outer Probability Measure Theory, *Acta Astronautica*, Volume 177, December 2020, pp 246-257, https://doi.org/10.1016/j.actaastro.2020.07.041
17. Spurbeck, J., **Jah, M.**, Kucharski, D., Bennett, J., Webb, J. (2021). Near Real Time Satellite Event Detection, Characterization, and Operational Assessment Via the Exploitation of Remote Photoacoustic Signatures, *AAS Journal of Astronautical Sciences*, https://doi.org/10.1007/s40295-021-00252-5
18. Palmroth, M., Tapio, J., Soucek, A., Perrels, A., **Jah, M.**, Lönnqvist, M., Nikulainen, M., Piaulokaite, V., Seppälä, T., Virtanen, J. (2021). Toward Sustainable Use of Space: Economic, Technological, and Legal Perspectives, *Elsevier Journal of Space Policy*, Volume 57, 2021, https://doi.org/10.1016/j.spacepol.2021.101428
19. Kucharski, D., Kirchner, G., **Jah, M.**, Bennett, J., Koidl, F., Steindorfer, M., Wang, P. (2021). Full attitude state reconstruction of tumbling space debris TOPEX/Poseidon via light-curve inversion with Quanta Photogrammetry, *Acta Astronautica*, https://doi.org/10.1016/j.actaastro.2021.06.032
20. Zucchelli, E.M., Delande, E.D., Jones, B.A., **Jah, M.K**. (2021). Multi-Fidelity Orbit Determination with Systematic Errors. *J Astronaut Sci* 68**,** 695–727. https://doi.org/10.1007/s40295-021-00267-y

Refereed Conference Proceedings

1. **Jah, M.K**., (1998). *Simulated Lunar Design and Modeling Assisted by Satellite Tool Kit (STK)*, 6th International Conference and Exposition on Engineering, Construction, and Operations in Space, held in Albuquerque, NM, April 26-30.
2. **Jah, M.K**., Potterveld, C., Rustick, J., Madler, R. (1999). *Use of Lunar Gravity Assists for Earth Orbit Plane Changes*, Part I, Advances in the Astronautical Sciences, Vol. 102, pp. 95-107, Univelt, San Diego. AAS Paper 99-107.
3. Ely, T. A., Anderson, R., Bar-Sever, Y. E., Bell, D., Guinn, J., **Jah, M**., Kallemeyn, P., Levene, E., Romans, L., Wu, S., (1999). *Mars Network Constellation Design Drivers and Strategies*, Paper AAS 99-301, AAS/AIAA Astrodynamics Specialist Conference, Girdwood, Alaska, August 16-19.

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1. Space India 2.0, Chapter on Space Situational Awareness (2016) https://www.orfonline.org/wp-content/uploads/2017/02/Space2.0_Final_23Feb.pdf
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Notable Position Papers, Reports, and Congressional Testimonies

1. O. Brown, T. Cottom, M. Gleason, M. Hallex, A. Long, E. Rivera, D. Finkleman, T. Hitchens, **M. Jah**, D. Koplow, R. Sedwick, (2016). *"Report on Space Traffic Management Assessments, Frameworks, and Recommendations,"* In Reply To: Public Law No. 114-90, "U.S. Commercial Space Launch Competitiveness Act" Title I, "Spurring Private Aerospace Competitiveness and Entrepreneurship" Section 109, "Orbital Traffic Management", 21 November.
2. **M. Jah**, Congressional Witness, invited by U.S. Senator Ted Cruz (R-Texas), chairman of the Subcommittee on Space, Science, and Competitiveness, to provide testimony at the Reopening the American Frontier: Promoting Partnerships Between Commercial Space and the U.S. Government to Advance Exploration and Settlement, 13 July 2017
3. **M. Jah**, D. Greiman, M. Sengupta, S. Magnus, P. Melroy, S. Helms, M. Brown, "*Space Traffic Management (STM): Balancing Safety, Innovation, and Growth; A Framework for a Comprehensive Space Traffic Management System,*" An Institute Position Paper, The American Institute of Aeronautics and Astronautics, October 2017
4. S. Pagano, with input from **M. Jah et al.,** "*Taking Up (Outer) Space: An Exploration of Definitional Issues: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), December 2017
5. B. Bragg, with input from **M. Jah et al.,** "*Use of the Commercial Space Industry for Military Purposes by Non-Western States: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), December 2017
6. A. Astorino-Courtois, with input from **M. Jah et al.,** "*Space and US Deterrence: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), December 2017
7. A. Astorino-Courtois, with input from **M. Jah et al.,** "*Contested Space Operations; A Strategic Multilayer Assessment: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), November 2017
8. J. Stevenson, with input from **M. Jah et al.,** "*Effectiveness of International Agreements in Space: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), February 2018
9. A. Astorino-Courtois, B. Bragg, with input from **M. Jah et al.,** "*Commercial Space Actors: Disruptors or Solid Partners for National Security: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), February 2018
10. J. Stevenson, with input from **M. Jah et al.,** "*Principles of Response to Aggression in Space: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), February 2018
11. N. Peterson, with input from **M. Jah et al.,** "*Commercial Companies' Perceptions of Security in Space: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), March 2018
12. B. Bragg, with input from **M. Jah et al.,** "*Allocation of Commercial Space Industry Components: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), April 2018

13. J. Stevenson, with input from **M. Jah et al.,** "*Effects of Investment on Pathways to Space Security: A Virtual Think Tank Report*," Produced by **NSI** in the support of the Strategic Multilayer Assessment (SMA) Office (Joint Staff, J39), April 2018
14. **M. Jah**, Congressional Witness, invited by U.S. Senator Roger Wicker (R-Miss.), chairman of the Committee on Commerce, Science, and Transportation, to provide testimony at the Space Missions of Global Importance: Planetary Defense, Space Weather Protection, and Space Situational Awareness, 12 February 2020
15. **M. Jah et al.**, *"Technical Considerations for Enabling NATO-Centric Space Domain Common Operating Picture,"* NATO STO Technical Report STO-TR-SCI-279 (2020) https://www.sto.nato.int/publications/STO%20Technical%20Reports/STO-TR-SCI-279/$$TR-SCI-279-ALL.pdf
16. Walker, C. (NSF's NOIRLab), Hall, J. (Lowell Observatory), Allen, L. (NSF's NOIRLab), Green, R. (U. Arizona,), Seitzer, P. (U. Michigan), Tyson, A. (UC Davis/Rubin Observatory), Bauer, A. (Vera C. Rubin Observatory), Krafton, K. (AAS), Lowenthal, J. (Smith College), Parriott, J. (AAS), Puxley, P. (AURA), Abbott, T. (NSF's NOIRLab), Bakos, G. (Princeton University), Barentine, J. (IDA), Bassa, C. (ASTRON), Blakeslee, J. (Gemini Observatory/NSF's NOIRLab), Bradshaw, A. (SLAC), Cooke, J. (Swinburne University), Devost, D. (Canada-France-Hawai'i Telescope), Galadí, D. (Icosaedro working group of the Spanish Astronomical Society), Haase, F. (NSF's NOIRLab), Hainaut, O. (ESO), Heathcote, S. (NSF's NOIRLab), **Jah, M**. (University of Texas at Austin), Krantz, H. (U. Arizona), Kucharski, D. (University of Texas at Austin), McDowell, J. (CfA), Mróz, P. (Caltech), Otarola, A. (ESO, TMT), Pearce, E. (U. Arizona), Rawls, M. (U. Washington/Rubin Observatory), Saunders, C. (Princeton University), Seaman, R. (Catalina Sky Survey), Siminski, J. (ESA Space Debris Office), Snyder, A. (Stanford University), Storrie-Lombardi, L. (Las Cumbres Observatory), Tregloan-Reed, J. (U. Antofagasta), Wainscoat, R. (U. Hawai'i), Williams, A. (ESO) and Yoachim, P. (U. Washington/Rubin Observatory) Appendix B and C *"Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations"* https://aas.org/sites/default/files/2020-08/SATCON1-Report.pdf and https://aas.org/sites/default/files/2020-08/SATCON1-WG-Tech-Reports_0.pdf

INVITED TALKS/LECTURES:

1. NASA Jet Propulsion Laboratory. November 2007. *Air Force Maui Optical and Supercomputing Site (AMOS)*
2. 19th AAS/AIAA Space Flight Mechanics Meeting, Savannah, GA. February 2009. *Advanced Sciences & Technology Research Institute for Astrodynamics (ASTRIA)*
3. Liceo Militar Pedro Ma. Ochoa Morales, Los Teques, Venezuela. June 2009. *Introduction to Astrodynamics and Orbit Determination*
4. Universidad Simon Bolivar, Caracas, Venezuela. June 2009. *Introduction to Astrodynamics and Orbit Determination*
5. 1st TechHui Conference, O'ahu, Hawai'i. Keynote Speaker. July 2009. *Astrodynamics and the Maui Space Surveillance Systems Branch*
6. University of Bern, Bern, Switzerland. September 2009. *Orbit Determination Performance for High Area-to-Mass Ratio Space Object Tracking Using an Adaptive Gaussian Mixtures Estimation Algorithm*

7. University College London, London, Great Britain. October 2009. *Orbit Determination Performance for High Area-to-Mass Ratio Space Object Tracking Using an Adaptive Gaussian Mixtures Estimation Algorithm*
8. 2011 European Geophysics Union Meeting, Vienna, Austria. May 2011. *Improved Methods for Tracking and Characterizing Inactive Resident Space Objects*
9. 28th International Symposium for Space Sciences and Technology, Okinawa, Japan. June 2011. *Special Panel on Space Debris*
10. 2011 Students for the Exploration and Development of Space (SEDS) conference, Boulder, CO Oct 2011. *Special Panel on Space Debris*
11. 39th COSPAR Scientific Assembly, Mysore, India. July 2012. US Keynote Speaker. *Special Panel on Space Situational Awareness*
12. 2012 AIAA GNC/Astrodynamics Conference, Minneapolis, MN Aug 2012. *Special Panel on Space Situational Awareness*
13. 1st Australian Space Situational Awareness Meeting, Canberra, Australia Apr 2013. US Keynote Speaker
14. 24th AAS/AIAA Space Flight Mechanics Meeting, Santa Fe, NM Jan 2014. *Special Panel on Air Force Space Command's Astrodynamics Innovation Committee*
15. 2nd IAA Conference on Dynamics and Control of Space Systems, Rome, Italy Mar 2014. *Special Panel on Astrodynamics Needs in Space Situational Awareness and the Air Force Space Command's Astrodynamics Innovation Committee*
16. 2nd Australian Space Situational Awareness Meeting, Canberra, Australia Jun 2014. US Keynote Speaker
17. AIAA Space 2014, San Diego, CA Aug 2014. *Mutual Application of Joint Probabilistic Data Association, Filtering, and Smoothing Techniques for Robust Multiple Space Object Tracking"* Co-authors: J. Stauch, J. Baldwin, T. Kelecy, K. Hill
18. TEDxABQ Salon, Albuquerque, NM Aug 2014. *Space Junk: The Unknown Orbital Iceberg Equivalent*
19. Space Situational Awareness 2014, London, UK, Nov. *US Representative Panelist*
20. Space Security, Wilton Park, West Sussex, UK, Mar 2015. US Space Situational Awareness technical expert
21. Space Situational Awareness 2015, Maryland, May. *Chair, Keynote Speaker, and Panelist*
22. 3rd Australian Space Situational Awareness Meeting, Canberra, Australia Sep 2015. US Keynote Speaker
23. 1st Air Force Research Laboratory (AFRL) Inspire talks, Dayton OH Oct 2015. *Space Junk: The Unknown Orbital Iceberg Equivalent*
24. Institute for Defense Analyses, Science and Technology Policy Institute: Invited lecture on Space Object Behavioral Sciences and Applications to Space Situational Awareness and Space Traffic Monitoring, Jan 2016
25. Martin Luther King Day Invited Speaker: Army Research Laboratory, Adelphi MD, Jan 2016
26. Embry-Riddle Aeronautical University Honors Lecture, Prescott, AZ. Mar 2016
27. 32nd Space Symposium Panelist on Congestion in Space, Colorado Springs CO, Apr 2016
28. Defense Strategies Institute (DSI) 2nd Annual Space Resiliency Summit, Alexandria VA, June 2016. Keynote Speaker
29. NATO SCI-292-LS Lecture Series, Lead Lecturer, Ankara (Turkey), Rome (Italy), Munich (Germany), and Washington D.C.(USA), June-July 2016. *Space Domain Awareness*

30. 2nd Space Technology and Investment Forum, San Francisco CA, July 2016. Keynote Speaker
31. NPR Arizona Science: *Episode 48 Rules of the Road are Needed in Outer Space*, https://radio.azpm.org/arizonascience/, Sep 2016
32. Space Advocates Seminar, US. House Science Committee, Washington, D.C., Oct 2016. *The Role of Academia in Space Situational Awareness and Global Space Traffic Management*
33. International Symposium for Personal and Commercial Spaceflight, Las Cruces NM, Oct 2016. Keynote Speaker
34. TEDxDayton, Dayton, OH, Oct 2016. *Space Traffic and Avoiding the Tragedy of the Commons*
35. The Space Show, http://thespaceshow.com/show/18-oct-2016/broadcast-2796-dr.-moriba-jah, Oct 2016
36. University of Texas at Austin, Aerospace Engineering and Engineering Mechanics Department, 28 Oct 2016. *Space Traffic Management and the Tragedy of the Commons*
37. University of Colorado at Boulder, Aerospace Engineering Sciences Department, 2 Feb 2017. *Adaptive Entropy-based Gaussian-mixture Information Synthesis for Improved Space Situational Awareness*
38. 3rd ORF Kalpana Chawla Space Dialogue, 15-18 Feb 2017, New Delhi, India. Invited Speaker and Panelist
39. Future In-Space Operations (FISO) seminar, 1 Mar 2017. *Space Traffic and the Tragedy of the Commons*. http://spirit.as.utexas.edu/%7Efiso/telecon.htm
40. World Space Risk Forum, Panel on Space Debris Challenges and Dangers, 15 June 2017, London, UK. Keynote Speaker
41. 29th International Summer Symposium on Science and World Affairs, Union of Concerned Scientists, 24-31 July 2017, Technical University of Darmstadt, Germany
42. 15th Reinventing Space Conference, Glasgow Scotland, Oct 24-26 2017, Keynote Speaker
43. 1st International Academy of Astronautics (IAA) Conference on Space Situational Awareness, Orlando FL, Nov 2017, Keynote Speaker.
44. Challenges in Space Traffic Management and Situational Awareness, Virginia Tech, March 9, 2018.
45. 1st Indian Workshop on Space Situational Awareness, New Delhi, June 2018, Keynote Speaker.
46. Astrodynamics Challenges for Space Situational Awareness, Space Advocates, U.S. Congressional Staff, June 2018.
47. Space Surveillance and Tracking Short Course, Shanghai Jiao Tong University, Aerospace Engineering, June 2018.
48. Space Surveillance and Tracking Short Course, Beijing Institute of Technology, Aerospace Engineering, June 2018.
49. Advanced Space Object Tracking Methods, Chinese Academy of Sciences, National Astronomical Observatories, Beijing, China, July 2018.
50. 4th Australian and New Zealand Workshop on Space Situational Awareness, UNSW/ADFA, Canberra, Australia, July 2018, Keynote Speaker.
51. 3rd Global Space Traffic Management workshop, Edinburgh, Scotland, Keynote Speaker, August 2018.
52. Space Debris Workshop, International Workshop for Laser Ranging, Canberra, Australia, Keynote Speaker, November 2018.

53. Invited Panelist, Outer Space Institute inaugural conference and meeting, University of British Columbia, Vancouver, B.C Canada, November 2018.
54. The Journey of an Astrodynamicist, McCallum High School, Austin, TX, November 2018.
55. The Journey of an Astrodynamicist, Cedar Creek High School, Houston, TX, December 2018.
56. The Journey of an Astrodynamicist, National Society of Black Engineers, The University of Austin, Austin, TX, December 2018.
57. 2018 Eilene Galloway Symposium, Keynote Speaker and Panelist, Washington D.C., December 2018.
58. The Journey of an Astrodynamicist, Molokai High School, Molokai, HI, January 2019.
59. 1st Finnish Space Sustainability Workshop, Aalto University, Espoo, Finland, February 2019, Keynote Speaker.
60. United Nations Committee On Peaceful Uses of Outer Space, Scientific and Technical Sub-Committee meetings, *AIAA Member Contributions to the Long Term Sustainability of Space*, Vienna, Austria, AIAA Representative Speaker on the United States Delegation to the United Nations, February 2019.
61. Invited Seminar Lecture, Stanford University, Aerospace Engineering Department, February 2019. *Advanced Methods of Resident Space Object Characterization and Uncertainty Quantification.*
62. Invited Seminar Lecture, Texas A&M University, Aerospace Engineering Department, February 2019. *Advanced Methods of Resident Space Object Characterization and Uncertainty Quantification.*
63. Invited Seminar Lecture, Georgia Institute of Technology, Aerospace Engineering Department, March 2019. *Advanced Methods of Resident Space Object Characterization and Uncertainty Quantification.*
64. TEDxUTAustin, Austin, TX, April 2019. *ASTRIAGraph: Space Traffic Monitoring at UT Austin.*
65. Salt Spring Forum, Salt Spring Island, B.C., April 2019. *The Journey of an Astrodynamicist: Science, Space Junk, and Environmentalism on the Final Frontier.*
66. TED, Vancouver, B.C., April 2019. *ASTRIAGraph: Towards a Crowdsourced Space Traffic Monitoring System.*
67. United Nations Disarmament Institute (UNIDIR), 2019 Space Security Conference, Geneva, Switzerland, May 2019. *ASTRIAGraph: Space Traffic Monitoring at UT Austin.*
68. US-Japan Conference on Cultural and Educational Interchange (CULCON), Beyond 2020: Paving the Way for the Next Generation and U.S.-Japan Collaboration, Speaker and Panelist, Austin, TX, June 2019. *US-Japan Areas for Scientific Collaboration Regarding Space Situational Awareness and Space Sustainability.*
69. The Journey of an Astrodynamicist, Huston-Tillotson University Elementary School Summer Program, Austin, TX, June 2019.
70. Invited Highlight Lecture, 2nd IAA/AAS SciTech Forum, Moscow, Russia, June 26-29 2019. *Advances in Space Object Characterization and Uncertainty Quantification for Space Situational Awareness.*
71. Space Traffic Management Workshop, Royal United Services Institute (RUSI), London, UK, July 2019, Keynote Speaker.
72. 10th International Workshop on Satellite Constellations and Formation Flying, Glasgow, Scotland, July 2019, Keynote Speaker.

73. ArmadilloCon 41, Austin, Texas, August 2019, The Science Guest.
74. 70th International Astronautical Congress, Washington DC, October 2019, Invited Panelist. *Artificial Intelligence in Space.*
75. 70th International Astronautical Congress, Washington DC, October 2019, Moderator. *Space Traffic Management.*
76. 70th International Astronautical Congress, Washington DC, October 2019, Invited Panelist. *34th IAA/IISL Scientific-Legal Roundtable "Mega-Constellations."*
77. 2019 swissnexDay, EPFL, Lausanne, Switzerland, December 2019, Keynote Speaker.
78. Outer Space Institute Workshop on Space Debris, Salt Spring Island, BC, Canada, January 2020
79. DLD Conference, Munich, Germany, January 2020, Invited Panelist.
80. 2020 AAAS Meeting, Seattle, WA, February 2020, Invited Topical Lecture.
81. 2020 Arizona Space Grant Symposium, 30th NASA Space Grant Anniversary, April 2020, Keynote Speaker.
82. Co-creator of the AIAA ASCEND Space Traffic Management Diverse Dozen, October 2020.
83. Given COVID-19 and use of Zoom/Teams/etc., too many to list for the remainder of 2020.
84. Guest Lecture, *"Space Environmentalism,"* Warwick University and University of Oxford Aerospace Societies, January 2021.
85. Computational Astronautics Lecture, International Space University, January 2021.
86. Chair's Distinguished Seminar Lecture, *"Traffic in Near-Earth Space: A wicked problem of a complex system requiring a transdisciplinary solution,"* University of Michigan Aerospace Engineering Department, January 2021.
87. Verification of 21st Century Arms Control Treaties, Space Security, Stanford University Guest Lecture, January 2021.
88. 2021 Data Harmony Update, Keynote, February 2021.
89. Guest Lecture, SPACE LAB at Morgan State University, February 2021.
90. 6th Japanese National Space Policy Secretariat Symposium on Ensuring the Safe and Sustainable Use of Outer Space, Invited Speaker, March 2021.
91. Global Explorers Summit (GLEX2021), Lisbon, Portugal, July 2021, Invited Panelist.

RESEARCH TOPICS

Astrodynamics
Statistical Orbit Determination and Prediction
Space Situational Awareness
Space Traffic Management
Spacecraft Navigation
Multi-Source Information Fusion
Space Surveillance and Tracking
Orbital Safety
Long-Term Sustainability of Space Activities

GRANTS AND CONTRACTS

<u>*While in rank at The University of Texas at Austin:*</u> *Total:$5,898,761 (Jah's Share: $5,019,169)*

1. "Development of a GEO Space Object Catalog," Air Force Research Laboratory via Applied Defense Solutions, $159,974 (Jah's Share $159,974), Mar 2017 – Mar 2018, Principal Investigator.
2. "Hallmark – Testbed," DARPA via Ball Aerospace, $215,000 (Jah's Share $215,000), Aug 2017 – Oct 2018, Principal Investigator.
3. "Spacecraft Navigation Independent Verification and Validation Analyses via JPL's Monte," NASA Jet Propulsion Laboratory, $101,985 (Jah's Share $101,985), Sep 2017 – Sep 2018, Principal Investigator.
4. "Space Object and Event Knowledge Graph for Space Traffic Management, Phase1" Federal Aviation Administration via NMSU, $68,896 (Jah's Share $68,896), Nov 2017 – May 2018, Principal Investigator.
5. "Space Domain Awareness Collaborative Research Infrastructure," Air Force Research Laboratory via the University of Arizona, $589,884 (Jah's share $196,628), Mar 2017 – Mar 2020, Principal Investigator (Co-Is Ryan Russell and Brandon Jones).
6. "Track Custody at GEO," Air Force Office of Scientific Research via University College London, $67,268 (Jah's Share $67,268), Jan 2020 – Jun 2020, Principal Investigator.
7. "Optical Express," Air Force Office of Scientific Research via Applied Space Solutions Ltd., $45,000 (Jah's Share $45,000), Feb 2018 – Feb 2019, Principal Investigator.
8. "AF17-CT02 Rapid Discovery of Evasive Satellite Behaviors," Air Force Research Laboratory via Applied Defense Solutions, $45,000 (Jah's Share $45,000), Apr 2018 – Jan 2019, Principal Investigator.
9. "AF17-CT02 Rapid Discovery of Evasive Satellite Behaviors," Air Force Research Laboratory via Data Fusion and Neural Networks LLC, $50,000 (Jah's Share $50,000), Apr 2018 – Jan 2019, Principal Investigator.
10. "Refinement and Validation of Radiation Pressure Models for High-Area-to-Mass-Ratio Objects for Improved Characterization, Tracking, and Orbit Prediction," Air Force Office of Scientific Research, $616,336 (Jah's Share $330,000; Co-I Renato Zanetti), Jun 2018 – Jun 2021, Principal Investigator.
11. "Deep Learning for Space Domain Awareness," Air Force Office of Scientific Research via Applied Space Solutions Ltd., $200,000 (Jah's Share $200,000), Apr 2018 – Jan 2020, Principal Investigator.
12. "Robust and Adaptive Machine Learning," Air Force Office of Scientific Research via Applied Defense Solutions, $42,600 (Jah's Share $42,600), Aug 2018 – April 2019, Principal Investigator.
13. "Improved Resident Space Object Tracking Via Advanced Estimation Methods, " Tau Technologies, $276,535 (Jah's Share $276,535), Aug 2018 – Sep 2019, Principal Investigator.
14. "Harris Advanced Space Situational Awareness Research and Development," Harris Corp., $445,000 (Jah's Share $445,000), Dec 2018 – Dec 2021, Principal Investigator.
15. "Space Object Maneuver Definition and Quantification," Air Force Research Laboratory via CUBRC Inc., $80,514 (Jah's Share $80,514), Apr 2019 – Jun 2020, Principal Investigator.
16. "AF17-CT02 Rapid Discovery of Evasive Satellite Behaviors: Phase 2," Air Force Research Laboratory via Data Fusion and Neural Networks LLC, $223,814 (Jah's Share $223,814), Nov 2019 – Aug 2021, Principal Investigator.

17. "Tactical Space Domain Awareness for Advanced and Actionable Space BMC2," Lockheed Martin Corp., $400,000 (Jah's Share $400,000), Aug 2019 – Aug 2021, Principal Investigator.
18. "Space System Modeling," Lockheed Martin Corp – Missile Fire Control, $92,289 (Jah's Share $92,289), Jun 2020 – Aug 2021, Principal Investigator.
19. "Research Fellow at Oden Institute for Computational Engineering and Sciences," SERC: Space Environment Research Centre, $80,000/year for Daniel Kucharski salary (all benefits included), June 2018 -March 2020, Research Fellow Supervisor.
20. "Robust Space Situational Awareness via Hard/Soft Information Fusion in the Presence of Epistemic Uncertainty," 2019 Moncrief Grand Challenge Faculty Award, Oden Institute for Computational Engineering and Sciences, $41,315 (Jah's Share $41,315), Spring 2020, Principal Investigator.
21. "Resident Space Object Tracking and Classification Using Methods in Geometric Statistics and Computational Topology," Air Force Office of Scientific Research, $195,000 (Jah's Share $195,000), Aug 2019 – Jul 2022, Principal Investigator.
22. "Space Object Gerontology," Air Force Office of Scientific Research, $225,000 (Jah's Share $225,000), Aug 2019 – Dec 2022, Principal Investigator.
23. "Transparency in Space Dashboard," Smith Richardson Foundation via Secure World Foundation, $87,089 (Jah's Share $87,089), Sep 2019 – Jan 2022, Principal Investigator.
24. "Space Data Prescriptive Analytics," Slingshot Aerospace, $150,000 (Jah's share $150,000), March 2020 – Feb 2023, Principal Investigator.
25. "Space Object and Event Knowledge Graph for Space Traffic Management, Phase1" Federal Aviation Administration via NMSU_Phase II, $273,430 (Jah's Share $273,430), Aug 2017 – Aug 2022, Principal Investigator.
26. "Ontology Derived Multi-Fidelity Space Object Catalog" Air Force Research Laboratory, $65,000 (Jah'sShare $65,000), Sep 2019 – Sep 2022, Co-PI.
27. "Quantification of Measurement Scheduling Effects on Orbit Determination Performance" DoD STTR via Orbit Logic Inc., $61,832 (Jah's Share $61,832), Aug 2020 – Aug 2021, Co-PI.
28. Autonomous Onboard Angles-Only Orbit Determination" Ball Aerospace Corp., $100,00 (Jah's Share $100,000), Jan 2021 – Dec 2021, Co-PI.
29. "Patterns of Life Assessment for Space" DOD STTR via O-Analytics, $150,000 (Jah's Share $150,000), Mar 2021 - Jan 2022, Principal Investigator.
30. "ACCESSED - Autopilot Commander Conjunction-assessment Enabling a Starling and a System for Exchange and Deconfliction" NASA STTR via Emergent Space Technology, $220,000 (Jah's Share $220,000), Oct 2021 – Mar 2023, Principal Investigator.
31. "Civil SSA/STM Sandbox for the OADR" Dept. of Commerce, NOAA via UT-ARL, $450,000 (Jah's Share $150,000), Dec 2021 – Dec 2022, Principal Investigator

<u>While at the Air Force Research Laboratory:</u> Total: $51,500,000 (Jah's Share: $28,000,000)

1. DARPA Orbit Outlook Program, $10M (Jah's Share $5M), Technical Lead (2014-2015).
2. Various Air Force SBIR/STTR Programs, $15M (Jah's Share $15M), Technical Lead (2010-2015).
3. DARPA Ibex Program, $20M (Jah's Share $1.5M), Technical Lead and PI (2010-2012).

4. Satellite and Missile Systems Center (SMC), $1.5M (Jah's Share $1.5M), PI (2010-2012).
5. Air Force Office of Scientific Research (AFOSR), $1.5M (Jah's Share $1.5M), PI (2009-2013).
6. AFOSR International, $1.5M (Jah's Share $1.5M), Technical Lead (2009-2013).
7. National Research Council (NRC) Research Associateship, $2M (Jah's Share $2M), Adviser (2009-2015).

PH.D. SUPERVISIONS COMPLETED:
1. Samantha Le May (co-supervised) [Royal Melbourne Institute of Technology – Australia](2021)

M.S. SUPERVISIONS COMPLETED:
1. Justin Spurbeck [University of Texas at Austin] Thesis Option (2019)
2. Marcus Bever [University of Texas at Austin] Thesis Option (2020)
3. Vivek Desai [University of Texas at Austin] (2020)
4. Vishnuu Mallik [University of Texas at Austin] (2021)
5. James Crowley [University of Texas at Austin] (2021)
6. Michael Reinhold [University of Texas at Austin] (2021)

PH.D. SUPERVISION IN PROGRESS:
1. Shiva Iyer [University of Texas at Austin] (2018 – present) [Candidacy Reached June 2019]
2. Benjamin Miller [University of Texas at Austin] (2019 – present) [Candidacy Reached June 2021]
3. Apoorva Karra [University of Texas at Austin] (2019 – present) [Candidacy Reached June 2021]
4. Nevan Simone [University of Texas at Austin] (2019 – present)
5. Tiffany Phan [University of Texas at Austin] (2021– present)
6. Keith Poletti [University of Texas at Austin] (2021– present)
7. Qing Zhu [University of Texas at Austin] (2021– present)

M.S. SUPERVISION IN PROGRESS:
N/A

PH.D. COMMITTEES:
1. Kyle DeMars, University of Texas at Austin (2010).
2. Jill Tombasco, University of Colorado at Boulder (2011).
3. Aaron Rosengren, University of Colorado at Boulder (2014).
4. Richard Linares, University of Buffalo (2014).
5. Antonella Albuja, University of Colorado (2015).
6. Ryan Coder, Georgia Institute of Technology (2016).
7. Vitali Braun, Technische Universitat Braunschweig (2016).
8. Patrick Kenneally, University of Colorado at Boulder (2019).
9. Kerianne Hobbs, Georgia Institute of Technology (2020).
10. Kirsten Tuggle, University of Texas at Austin (2020).
11. Nicholas Ravago, University of Texas at Austin (2018-present).

OTHER STUDENT RESEARCH COMMITTEES (Current):

Ph.D. Committees - 0
M.S. Committees – 0

Moriba Jah, Associate Professor

The University of Texas at Austin
Department of Aerospace Engineering and Engineering Mechanics
Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering

Dr. Moriba Jah is the Director of the Computational Astronautical Sciences and Technologies (CAST) group within the Institute for Computational Engineering and Sciences at The University of Texas at Austin, where he is also an Associate Professor of Aerospace Engineering and Engineering Mechanics in the Cockrell School of Engineering. He holds the Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering and trains a new generation of astrodynamicists and space traffic leaders through research and education at the intersection of engineering, policy, and commercialization. He has authored more than 100 scientific articles, columns, and book chapters, including a handful of op-eds. A highly sought public speaker, he has given more than 50 lectures, speeches, and invited talks in the last few years, such as testimony for hearings of U.S. Senate committees, keynotes for business meetings, plenary lectures for scientific conferences, lecture series for NATO's Science and Technology Organization, TED and TEDx talks, and the Air Force Research Laboratory's INSPIRE series. Dr. Jah has served as a member of the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS) and is the chair of the NATO SCI-279-TG activity on defining a Common NATO Space Domain Awareness Operating Picture. Dr. Jah is also the Chief Scientific Advisor for Privateer Space Inc., a company focused on delivering bespoke decision intelligence at the speed of relevance addressing space safety, security, and sustainability needs.

As a professor, Dr. Jah has taught undergraduate and graduate courses at UT Austin related to space and astronautical sciences. Dr. Jah's research focuses on the convergence of policy, technology, and security related to space traffic management and space situational awareness. Government agencies such as the Department of Defense, Air Force Research Laboratory, and others as well as non-governmental organizations and private industry have featured Dr. Jah's research in their own decision-making processes. His expertise, opinions, and research have been published, cited or featured in many media outlets, including the SpaceWatch Global, pace News, Wired, ROOM, NatGeo, NPR, BBC, ABC, and others.

Prior to being at UT Austin, Dr. Jah was the Director of the University of Arizona's Space Object Behavioral Sciences with applications to Space Domain Awareness, Space Protection, Space Traffic Monitoring, and Space Debris research. Preceding that, Dr. Jah was the lead for the Air Force Research Laboratory's (AFRL) Advanced Sciences and Technology Research Institute for Astronautics (ASTRIA) and Technical Advisor to the Guidance, Navigation, and Control Program at AFRL's Space Vehicles Directorate. He received his B.S. in Aerospace Engineering from Embry-Riddle Aeronautical University, Prescott, Arizona, and his M.S. and Ph.D. in Aerospace Engineering Sciences from the University of Colorado at Boulder specializing in astrodynamics and statistical orbit determination. Before joining AFRL in 2007, he was a spacecraft navigator for NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, serving on Mars Global Surveyor, Mars Odyssey, Mars Express (joint mission with ESA), Mars Exploration Rovers, Hayabusa (joint mission with JAXA), and the Mars Reconnaissance Orbiter. Dr. Jah founded the American Astronautical Society's (AAS) Space Surveillance Technical Committee and Chaired the AIAA Astrodynamics Technical Committee. He is a member of the Astrodynamics Committee of the International Astronautical Federation (IAF) and a permanent member of the Space Debris Committee of the International Academy of Astronautics (IAA). Dr. Jah is an elected member of the International Academy of Astronautics (IAA), a TED Fellow, a Fellow of the American Institute of Aeronautics and Astronautics (AIAA), the International Association for the Advancement of Space Safety (IAASS), the AFRL, the AAS and the Royal Astronomical Society (RAS), as well as an IEEE Senior Member, Associate Editor of Elsevier's Advances in Space Research, Acta Astronautica, and Space Safety Engineering Journals.

Chairman BEYER. Dr. Jah, thank you very much. And thank you for the graphs in your testimony, fascinating.

We'll next hear from Mr. D'Uva for his testimony.

TESTIMONY OF MR. ANDREW D'UVA, SENIOR POLICY ADVISOR, SPACE DATA ASSOCIATION

Mr. D'UVA. Thank you. Chairman Beyer, Ranking Member Babin, and distinguished Members of the Subcommittee, thank you for the opportunity to appear before you on this important topic for the United States and for the people worldwide.

Space systems are now undeniably essential to our way of life. For example, U.S. private sector capabilities effectively and affordably deliver crew and cargo to the ISS for NASA. Global public communications and remote imagery depends on commercial satellites. More than 100,000 new spacecraft applications have been filed through 2029, and 32 percent of all payloads since 1957 have been launched within the past 4 years.

As noted in my testimony, nations and operators each have reasons to avoid collisions in Earth orbit. Space situational awareness, or SSA, capabilities are foundational to managing this shared risk. In 2009, following the Iridium-Cosmos collision and lack of adequate SSA support from government agencies, commercial satellite operators established the Space Data Association, or SDA. The SDA is an open, nonprofit, risk-management entity dedicated to safety of flight and space sustainability. SDA's 30 stakeholder participants include leading fiercely competitive commercial and civil satellite communications, weather, and imagery operators.

Since 2011, SDA has offered the world's first private cooperative space traffic coordination service operating our Space Data Center, or SDC, at 99.99 percent reliability. I must stress it was developed without any government funds. The SDC now protects 769 spacecraft in multiple orbital regimes with over 50 percent of the GEO (geostationary) active spacecraft and 423 LEO and MEO (medium-Earth orbit) spacecraft participated. Operators contribute data, enabling the SDC to generate actionable, forward-looking collision warnings, deconflict plan maneuvers, and securely share SSA information.

In my testimony I note that SDA pioneered many traits that are now widely accepted as modern SSA system baselines. In fact, SDA's processes and products augmented and improved on DOD's products to the extent that NOAA and NASA became early and continuing SDA subscribers. SDA probably collaborates with and contributes operator data daily to the DOD's CSpOC (Combined Space Operations Center).

We achieve results using only U.S. commercial entities and technologies, including the foundational SSA analytics engine that fuses, normalizes, and transforms disparate data into usable knowledge. As further described in my testimony, new space operational paradigms seriously challenge legacy flight safety capabilities. Safety requires DOC to qualitatively improve on legacy DOD products for SSA in conjunction to assessment. SDA helped conceive and conduct the data fusion exercise through Space Coordination Traffic and Management in September 2020, including NOAA for participation, which indisputably demonstrated the importance

and effectiveness of U.S. private sector analytic capabilities in partnership with government.

Accordingly, SDA is disappointed that since early 2021 the Office of Space Commerce's work, informed by the strategic plan which was endorsed by the National Academy of Public Administration (NAPA) and Congress in 2020, appears to have been shelved, perpetuating unavoidable—excuse me, avoidable risks and delays. Speaking from SDA's operator support perspective, DOC have not conducted satellite operator industry days, stated how they intend to incorporate satellite operator data, and improve on DOD's products. Instead, they turned inward, taking a government system development approach with Federal research and development centers.

Developing new government systems is too risky and slow, and it's unnecessary. The DOC's prior commercial partnership vision responded to specific commercial and civil satellite needs for timely and actionable SSA data and space traffic management services. These services are essential to securing space-safe operations, preserving U.S. leadership, and enabling increased use of space.

Let me suggest three actions we take. First, we should establish a clear 1-, 5-, and 10-year vision for DOC's delivery of space traffic coordination capabilities, including fee-free based—basic services and data. Require DOC to promote not compete with U.S. private sector SSA data and analytics providers. DOC should contract existing technically mature, validated commercial capabilities to provide services, not try to develop them. We cannot risk waiting for U.S. Government development, and international competition is fierce.

Second, require DOC to qualitatively improve on today's DOD products to ensure DOC products are sufficient for safety and sustainability. For example, Congress could require DOC to use validated U.S. commercial technology to reprocess observational data from government SSA sensors such as the Space Surveillance Network and adjust operator data to drive timely and actionable information. This will leverage over $1 billion being spent annually.

And third, Congress should curtail public investments to redevelop or study needs for near-or midterm government SSA data and STM processing capabilities where private sector capabilities exist.

Thank you very much for your attention, and I look forward to answering your questions.

[The prepared statement of Mr. D'Uva follows:]

Written Testimony of Andrew R. D'Uva, Esq.
Senior Policy Advisor, Space Data Association

Before the
Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics

U.S. House of Representatives
May 12, 2022

Space Situational Awareness: Guiding the Transition to a Civil Capability

Chairman Beyer and distinguished Members of the Subcommittee, thank you for the opportunity to appear before you on this important topic for the United States and for people worldwide.

Space systems are now undeniably essential to our way of life – providing key communications infrastructure, actionable warnings of natural disasters to safeguard human lives, imagery and other remote sensing data to inform decisionmakers and the public at large of critical environmental and geopolitical developments. Due largely to U.S. commercial innovations the inherently international and dynamic space environment has never been so accessible or exciting. For example, NASA is successfully using U.S. commercial capabilities to deliver crew and cargo efficiently and effectively to the International Space Station. Interest is accelerating – applications for more than 100,000 new spacecraft have been filed through 2029, and 32 percent of all payloads since 1957 have been launched within the past 4 years.

However, collisions in Earth's orbit can create additional, exceptionally long-lived, hazardous space debris which can degrade or even render infeasible the use of critical orbits for satellites and human spaceflight. Responsible space users must avoid collisions with existing space debris or other satellites. Article VI of the Outer Space Treaty provides that subscribing Nations must provide "authorization and continuing supervision" for non-governmental space operators. In doing so, States including the United States of America bear the ultimate risk of their commercial space operations. Appropriate space situational awareness capabilities are foundational to effectively managing that risk for government and industry alike.

In 2009, facing increasing space congestion, collision of the U.S. Iridium satellite with the Russian Cosmos 2251 satellite, a growing recognition of the benefits of coordinating their space flight operations, and the lack of adequate SSA support from any U.S. or foreign government agency, competing commercial satellite operators jointly established the Space Data Association – the SDA. The SDA is an open, commercial, non-profit risk management entity

dedicated to safety of flight and space sustainability.[1] SDA's stakeholder participants are commercial, civil, and even some military satellite operators who have invested tens of billions of dollars in satellites on orbit and have come together to reduce the risk of satellite operations.

The SDA has been fully operational for almost twelve years now and was developed without any government funds. The SDA's Space Data Center (SDC), operated by a U.S. commercial company, COMSPOC, has demonstrated reliability of more than 99.99% over those twelve years. The SDA's "crowd-sourcing" model addresses proprietary and intellectual property issues, serving as a nexus for data from the U.S. government and a rich set of operator data. The SDC pioneered many traits that are now widely accepted as a baseline for a modern SSA system, including computationally and legally secure frameworks, firewalled processing to protect data, machine-to-machine interfaces, verified data normalization and conversion, operator phonebooks, data exchange and sharing, and extensive processes to maintain quality control and identify discrepancies in operator or government SSA data.

Since 2011 the SDA has combined U.S. space catalog data with measured satellite location and planned maneuver information from SDA's participants to offer the world's first private, cooperative space traffic coordination (STC) service. The SDA currently has 30 spacecraft operator members operating 769 spacecraft that span all orbital regimes, with over fifty percent of the GEO active spacecraft represented and 423 LEO and MEO spacecraft participating. These operators deliver some of the most critical communications and remote sensing capabilities today and, when not collaborating with the SDA, routinely compete as rivals. Satellite operator-contributed data allows the SDC to generate actionable, forward-looking collision warnings, deconflict planned maneuvers, and securely share selected space situational awareness data between participants.

Because SDA's products augment and improve upon existing DoD collision warning products and systems – which are generally unable to incorporate planned maneuvers into actionable predictions – NOAA and NASA quickly became early and continuing satellite operator subscribers to SDA's services.[2] SDA is proud to voluntarily aggregate, normalize, and contribute SDA member data to the U.S. Space Force and the 18th Space Defense Squadron at the Combined Space Operations Center (CSpOC) on a no-fee basis, increasing our nation's Space Domain Awareness and improving the DoD's space catalog, including notifications of discrepancies and high-risk threats. SDA has established a great partnership with the DoD.

However, as many U.S. government leaders have noted, DoD's primary space mission is not space flight safety, nor were its government systems being used to generate conjunction

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[1] For SDA, "safety of flight" means the condition where satellites are positioned and operated in a manner that preserves their long-term operational viability, the long-term operational viability of any other satellites, and the preservation of the orbital regime(s) involved.

[2] The SDC scrutinizes all operator and 18 SDS data, conjunction data messages (CDMs) and SP ephemerides to find and report irregularities, assessing their veracity, accuracy, timeliness, and completeness.

warnings designed or optimized for this use – particularly given the continuing non-transparency required to protect our national security equities.

Critically, U.S. commercial entities and technologies have always undergirded and enabled SDA's technical capabilities – including cloud-hosted compute platforms, cybersecurity, and most importantly the foundational space situational awareness analytics engine that fuses and transforms disparate data into usable knowledge for satellite operator use. That's great news for the efforts planned by the Department of Commerce (DoC), but we don't have a moment to lose. DoC needs to qualitatively improve on the legacy DoD products for SSA and conjunction assessment to enhance safety of flight.

New space operational paradigms including proliferated LEO constellations, electric propulsion with its constant low-thrust maneuvers, on-orbit servicing, space tourism, and autonomous flight operations challenge legacy flight safety capabilities. The SDA has mined its conjunction data to determine that close approaches are occurring five times more often than just five years ago. This dramatic change is due to the ever-increasing presence of orbital debris, our improving knowledge of the hazardous debris already present in orbit, and a more than doubling of the active spacecraft population over these five years. While these increases in themselves don't suggest that the sky is falling, the increasing workload on spacecraft operators, the need for substantially increased accuracy of space object positional knowledge, and the continued degradation of the space operations environment demonstrate the need to take prompt action.

Beyond DoD's longstanding efforts, the United States has been a leader in promoting space flight safety, most recently through actions including adopting the National Space Policy, publishing Space Policy Directive 3 (SPD-3), authorizing investments for the DoC, and committing to soft law approaches to establishing norms of behavior to avoid creation of additional space debris. Following publication of SPD-3 the SDA, including some of its operators, routinely engaged with the DoC leaders to provide inputs on the real-world pain points and actual needs of our satellite operator members.

SDA is fully supportive of a DoC partnership with commercial SSA service providers going forward. The SDA's founding members were unanimous in offering to support a rapid standup of a commercial SSA-based system operated by DoC to provide a basic set of SSA data and services and looked forward to the opportunity to engage with DoC to help develop a set of well-informed system requirements and capabilities to meet the needs of the spacecraft operator community.

The SDA helped conceive and conduct a data fusion exercise for Space Traffic Coordination and Management (STCM) in September 2020. NOAA, in its role as a weather satellite operator, participated in this exercise. Implemented and conducted in just four weeks, this STCM data fusion campaign demonstrated how commercial innovation and capabilities, in partnership with government data and participation, were able to achieve dramatic improvements in SSA

knowledge. For example, accuracy improvements of between ten and fifty percent in Low Earth Orbit, tenfold accuracy improvements in GEO, and as much as one thousand times improvements in the Launch and Early Orbit Phase of LEO missions were achieved. This study was unique in taking a requirements-based approach by assessing what positional accuracy requirements must be met to allow SSA data to meet the needs of operators and the way they conduct flight safety. The results of this rapid demonstration led us to conclude that such a government/industry partnership is not only effective, but imperative if we are to effectively address and facilitate enduring space sustainability.

SDA is disappointed that work achieved by the Office of Space Commerce, informed by the strategic plan which was endorsed by the National Academy of Public Administration and Congress in 2020, appears to have been shelved. This perpetuates avoidable risks and introduces substantial delays in delivering an effective capability to civil and commercial satellite operators.

The picture is confusing, but since 2021 DoC has apparently pursued an alternate approach – electing not to obtain, deploy, and manage existing U.S. commercial space traffic coordination capabilities and services to enable the basic U.S. government-derived SSA data and space traffic management services contemplated in SPD-3 and funded by Congress. They have not conducted industry days with satellite operators to survey their needs, nor discussed how or whether they intend to incorporate satellite operator data (such as ephemerides or maneuver plan) into any solutions.

From our perspective, the DoC has turned inward, taking a government system development approach, and conducted minimal outreach to the operator community. While the intentions have not been clearly signaled, the focus appears to be on developing a new start U.S. government information system, akin to a DoD program of record, to ingest "data" which may be obtained from various sources. SDA believes this "new build" approach is suboptimal, compared to the prior vision of partnering with commercial industry to address specific needs driven by commercial and civil satellite operations for timely and actionable SSA data and space traffic management services.

We note that DoC has, earlier this week, appointed a senior leader with substantial commercial and government experience to the Office of Space Commerce. We are hopeful that this additional leadership will bring a renewed and sharp focus on private sector capabilities and satellite operator equities to this mission area.

Rising concerns about congestion caused by extensive debris generating events, such as the thousands of pieces of hazardous debris caused by a November, 2021 Russian ASAT test conflicting with increasing beneficial uses of Low Earth Orbit for environmental monitoring, providing better Internet access in rural and underdeveloped areas, and other new applications, necessitate fully staffing the Office of Space Commerce to rapidly pursue a

commercial/international partnership approach to Space Situational Awareness that utilizes rather than attempts to replicate or compete with U.S. private sector capabilities.

Access to accurate, timely space traffic management services are essential to ensuring continued safe space operations for all, preserving U.S. leadership, and enabling U.S. industry to make increasing use of space. Mr. Chairman and members of the Subcommittee, as our nation continues to develop civil and commercial applications in space it is critical that we rapidly establish an effective, transparent, and enduring civil capability for space traffic coordination. To do this, we should take the following actions:

1. Establish a clear 1-, 5-, and 10-year vision for delivery of space traffic coordination capabilities, including fee-free basic services and data. Align DoC program activities in this area with national policy and consistent with DoC's mission by requiring DoC to promote – not compete with – U.S. private sector commercial interests by using today's existing, technically mature, validated, "best of class" U.S. commercial SSA capabilities, software, and analytic services, under DoC management, to meet the needs of the United States to implement an OADR, describe and provide the anticipated basic U.S. government-derived SSA data and basic STM services, and collaborate with civil and commercial space operators.

   Proven U.S. commercial SSA analytic capabilities and supplemental, multi-phenomenal SSA data from the U.S. private sector are available for deployment today to enable the Department of Commerce to deliver these basic space SSA data and STM services for a modest investment. Space development is moving too quickly for us to risk waiting for U.S. government development and international competition is fierce.

2. Ensure that any transfer from DoD responsibilities for civil and commercial support to DoC qualitatively improves on the DoD products offered today to civil and commercial users.

   For example, Congress can require DoC to use validated U.S. commercial technology to process observational data from government SSA sensors, such as the Space Surveillance Network, and ingest operator data to derive timely and actionable information specifically for civil and commercial space flight safety. This is not an unsolved technical challenge and will leverage more than $1 billion of taxpayer funds already being spent annually while protecting national security equities.

3. Congress should curtail public investments to "re-develop" or "study" the need for near and mid-term government SSA data and STM processing capabilities where U.S. private sector capabilities exist today.

> *National space policy, DoC's 2022 – 2026 Strategic Plan*[3]*, Federal acquisition regulations, prior studies, the record of U.S. government program development in this subject area, and common sense suggest that we should deploy and promote U.S. private sector commercial capabilities to solve known and mid-term anticipated challenges. Public research and development investments should be narrowly targeted to longer-term challenges where no such commercial capabilities exist and are unlikely to emerge through natural market forces.*

Thank you and I am happy to take your questions.

[3] U.S. Department of Commerce 2022 – 2026 Strategic Plan pp 25 – 27, available at https://www.commerce.gov/sites/default/files/2022-03/DOC-Strategic-Plan-2022%E2%80%932026.pdf

Andrew R. D'Uva

Andrew D'Uva is President of Providence Access Company, a government affairs, technology, and satellite consultancy. He has supported international commercial satellite and telecommunications businesses on the regulatory, policy, legal, operational, and business fronts for more than two decades, with a present emphasis on government services, space sustainability, and cybersecurity in support of commercial and national security missions. Satellite clients have included key communication satellite owner-operators, trade organizations, and U.S. Federal agencies. He led efforts to create the legal and data sharing frameworks of the Space Data Association (SDA), a non-profit space traffic management organization and has served as SDA's Strategy and Policy Advisor since its founding in 2009.

In 2014, D'Uva helped to instantiate the DoD's Commercial Integration Cell (CIC) at the Joint Space Operations Center with its commander, John "Jay" Raymond, bringing key commercial satellite operators into operational alignment on Space Situational Awareness and other space operations areas. He continues to support the CIC through U.S. industry participation at the Combined Space Operations Center (CSpOC) at Vandenberg Space Force Base.

D'Uva coordinates the activities of the SATCOM Industry Group (SIG), dedicated to improving the communications capabilities afforded in support of U.S. national security missions. D'Uva is U.S. industry chair of the Commercial Space Cryptographic Cybersecurity Working Group (CSCCWG) of the National Security Agency/United States Space Force.

He was a founding executive of the global satellite operator New Skies Satellites (now SES) where he managed its regulatory and corporate affairs. He joined New Skies from his telecommunications, media, and public markets practice at Willkie Farr & Gallagher where he represented clients at the Federal Communications Commission, International Telecommunication Union, and before the Department of Justice. He is a graduate of Georgetown University (A.B.) and the Georgetown University Law Center (J.D.). He is admitted to the bar in the District of Columbia (Active) and California (Inactive).

Chairman BEYER. Thank you, sir, very much.
We'll now hear from Mr. O'Connell for his testimony.

TESTIMONY OF MR. KEVIN M. O'CONNELL,
FOUNDER, SPACE ECONOMY RISING, LLC

Mr. O'CONNELL. Good morning, Chairman Beyer and Ranking Member Babin. Thank you for the opportunity to appear before—again before the Committee to talk about U.S. leadership in space safety and sustainability.

Today, while I'm representing my own views on this topic, I'm also a member of a group of experts organized by the American Institute of Astronautics and Aeronautics or AIAA. AIAA sent a letter to the Committee last October, and I have resubmitted it along with my prepared testimony.

Mr. Chairman, the need for the United States to create a civil SSA capability is as urgent and as compelling as ever. As part of it, there's a need to fully leverage commercial providers in the interest of making rapid progress, ensuring compatibility with space operators and allies, and the ability to leverage massive private investments in information technology and other areas. Safety is fundamental to all space operations and is the key enabler of the extraordinary opportunities we expect in the space economy. One of the most important benefits, as you've already mentioned, Mr. Chairman, is that it will free up the U.S. Space Force to focus further on its national security missions.

The Biden Administration has reaffirmed the principles in Space Policy Directive 3, which acknowledged the urgency of the problem, mandated a whole-of-government approach to mitigating it, and recognized the critical importance of working with industry and international partners.

I would like to emphasize two key points on the shift to a civil SSA system. First, it's often thought that the mission given to the Department of Commerce and SPD 3 was to replicate or simply shift the DOD system over to a civil agency. While some linkages do need to be incorporated, a civil SSA system will have to be adaptive enough to accommodate rapid changes in space over the next few years such as the projections of 100,000 satellites and new complex missions like satellite servicing. It will have to be a state-of-the-art system in order to accomplish this.

Second, there's sometimes a perception that the ultimate goal is improving conjunction warnings. While it is certainly the most immediate goal, accomplishing that will actually enable wholly new services related to space sustainability. For example, the historic decision to unlock the military GPS (Global Positioning System) signal fueled the development of commercial services that we use dozens of times every single day. Another natural beneficiary of a civil and commercial SSA system would be the space insurance industry, as more open data will inform their risk models and improve all of our understanding about risk in space.

Aside from U.S. debris mitigation policy, national space policy not only directs U.S. leadership in commercial space activities, but the Federal agencies play a key role in encouraging it. Hardly a week goes by without a major report or expert opinion expressing

concern that the government is not moving fast enough to leverage commercial capabilities.

In my prepared remarks, Mr. Chairman, I've highlighted almost 30 years of observations on commercial satellite imagery, which I might describe as a long and challenging path to government adoption. The problem is many see it on space debris is that we're out of time. We don't have 30 years to deal with this problem, and we don't want to have this conversation in the wake of a terrible accident in space.

The United States has a diverse and impressive group of companies focused on SSA and related capabilities. Some are focused on unique sensing of the space environment from Earth, and they'll soon be joined by space-based sensors to detect, track, and provide insights into the behavior of debris and other space objects. These companies are staffed with world-class talent, and all are leveraging world-class capabilities in data management, analytics, and other areas that form the basis for critical decisions in healthcare, finance, and other areas. Some are already under contract to NOAA and the Space Force. We can leverage these capabilities immediately.

International cooperation is key. Because of the growing concern about the space debris challenge, our allies in the United Kingdom and Europe and Japan are moving independently, including leveraging of and encouraging their commercial organizations. Russia and China on the other hand are advancing their own initiatives as they sense an opportunity to challenge decades of unquestioned American leadership in this area.

As we create a new civil SSA capability, simply making token commercial purchases will not be enough. There's nothing wrong with the government being a first customer so long as it's not the only customer. The large, slow, traditional government approach will not work here mainly because of the speed at which the space-based debris problem is changing. Worse, it could wind up stifling exactly the broad-based innovation that we need urgently right now.

A civil SSA system constructed with these ideas in mind will support key U.S. Government missions while also encouraging the growth of a new and important commercial—as part of this commercial space industry. At a time of great concern about America's ability to compete against our adversaries while still being able to unlock the tremendous opportunity of space, we need a new outlook and new ways to harness the speed, agility, and anticipation of the private sector.

Congress has not been silent on these issues. In the past, Congress has been pivotal in telling the executive branch not to build what it can buy in the market. This is—as I understand it, this is being discussed right now in conference as part of *U.S. Innovation and Competition Act.* I would urge Congress to fund, demand expediency, and oversee proper execution of a civil SSA capability on—that capitalizes on the themes that I've highlighted in my testimony today.

Thank you again for the invitation to participate, and I look forward to your questions.

[The prepared statement of Mr. O'Connell follows:]

TESTIMONY OF KEVIN M. O'CONNELL
FOUNDER, SPACE ECONOMY RISING
(FORMER DIRECTOR, OFFICE OF SPACE COMMERCE)

HEARING ON

SPACE SITUATIONAL AWARENESS:
GUIDING THE TRANSITION TO A CIVIL SSA CAPABILITY

BEFORE THE
US HOUSE OF REPRESENTATIVES COMMITTEE ON SCIENCE, SPACE, and TECHNOLOGY,
SUBCOMMITTEE ON SPACE AND AERONAUTICS

May 12, 2022

Good morning, Chairman Beyer, and Ranking Member Babin. Thank you for the opportunity to appear before the Committee to talk about U.S. leadership in the area of space safety and sustainability.

Today, while I'm representing my own views on this topic, I have also participated in a Coalition of experts on this topic organized by the American Institute of Aeronautics and Astronautics, or AIAA. The Coalition sent a letter to the Committee last October, and I have taken the liberty of resubmitting it along with my testimony. I'm also participating in the Commercial Space Initiative, or CSI, an organization that I recently co-founded to develop new ideas for improving predictability and sustainability in the space economy.

THE COMPELLING NEED FOR A CIVIL SSA CAPABILITY

Mr. Chairman, there remains a compelling need for the United States to create a civil SSA capability, and to accomplish it as quickly as possible. There are both positive and negative motives for doing so. Let me explain.

First, on the positive side, as I testified before Congress last July, the space economy is "accelerating and diversifying" with new market segments and services emerging all the time. While we used to focus mainly on space-based communications, remote sensing, and navigation – capabilities that continue to change – we now see markets emerging in areas ranging from space tourism to space medicine. We might consider 2022 the year of the Lunar Economy as the first landers and infrastructure capabilities arrive to ultimately enable a permanent US presence on the Moon. As a parallel to developments in the space launch business, a new wave of in-orbit activities designed to inspect, refuel, and repair satellites will again change the economics of space and enable additional new innovations in space

commerce. As space becomes more accessible, we see non-traditional space companies working to leverage it, and entities from US States to foreign countries working to more fully participate in the space economy.

Recent developments show the challenges that lie ahead. As space activities continue to improve the lives of many people on Earth, with plans to do even more, our adversaries show wanton disregard for the value of the space environment. Russia's highly irresponsible anti-satellite (ASAT) test last November generated over 1500 new debris pieces and created what have become known as "conjunction squalls" for space operators. (Think about a baseball batter at the plate who occasionally sees 1000 baseballs coming his way without knowing which one to hit or, more important, which ones might hit him). Russia and China continue to create capabilities that threaten US national security, civil, and commercial space missions. Meanwhile, by simple math alone, the space debris problem continues to grow by the day. We see this in everything from the narrowing of launch windows to the recent need to maneuver the International Space Station (ISS) to avoid space debris from the Russian ASAT test.

There are many needs and benefits, Mr. Chairman, that drive us to implement a civil SSA system as quickly as possible. Among them are to allow the US Space Force to focus on the space domain awareness that is growing in complexity and importance; to allow us to collaborate more seamlessly with our allies, partners, and the space operator community at large; to leverage state of the art technologies, and to encourage the continuing development and growth of a US space safety industry. SSA is not only seen as crucial to our immediate future in space, but to the broader development of a cislunar economy.

THE US POLICY CONTEXT: CONTINUITY OVER CHANGE

National policy discussions about the space debris problem date all the way back to the Reagan Administration, with significantly greater emphasis during the Obama, Trump, and now Biden Administrations.

Space Policy Directive -3 (Space Traffic Management; June 2018) was issued during the Trump Administration with an emphasis on three major points: that the space debris problem was urgent and getting worse; that a "whole of government" approach would be necessary to help mitigate it; and that strong cooperation with industry and international partners in dealing with it would be essential. The NAPA Report mandated by Congress in 2020 strongly endorsed the role of the Department of Commerce and the Office of Space Commerce in playing a lead role in transitioning conjunction warnings for space operators from the Department of Defense to the Department of Commerce. DoD needs to get out of the conjunction notifications business in order to focus on the more complex strategic space environment, such as assessing the capabilities and intentions of adversary space activities and in aiding our allies in protecting their capabilities.

One point that is often misunderstood there is that Commerce was to simply replicate the system developed by the Department of Defense over the decades as a derivative mission from its classified national security missions. Not correct. The idea was actually to have Commerce develop a modern system that could adapt quickly to accommodate the expected rapid growth in satellites and other complex space activities. Such a system will need to adapt rapidly as innovations like in-orbit servicing, space solar power and others enter the market. So replicating the function "as is" on the civil side would not be enough.

Improving space safety for everyone remains the immediate task. That involves a much deeper understanding of where space objects, including debris, are located and the creation of more timely and accurate warnings to all space operators. In other words, the top priority is improving conjunction analysis. But that's not the endpoint, it's actually the starting point: If executed correctly, improved conjunction warnings will serve as a pathway to new space safety services that will enhance national security and serve as a further foundation of the space economy. One of the most logical "next users" of this data, for example, will be the space insurance community, which lacks sufficient data to inform most risk models and thereby set accurate premiums. Leveraging commercial capabilities within a civil SSA system will allow us a credible mechanism to understand risks in space in much more accurate ways.

National Space Policy developed over the last three Administrations not only directs US leadership in commercial space activities, but also that federal agencies play a key role in enabling it. It directs US government organizations to encourage the US commercial space industry in developing world-class, innovative capabilities to support our national security and civil needs, as well as our rightly ambitious plans for space exploration and space commerce.

Hardly a week goes by without a new report or comments from US government officials, private sector executives, and even the Congress that the United States needs to do a much better job leveraging the talents of the private sector. Some of this concern arises from the need to innovate faster, some of it about the acquisition challenges associated with leveraging it. DoD has struggled to upgrade the current SSA system as demands have grown dramatically.

Apart from a clearly bipartisan interest to encourage a strong, vibrant, US commercial space industry, leveraging private sector innovation is one of the most important tools in fending off hostile adversaries, and addressing serious challenges like the space debris problem. A brief historical example might illustrate the point.

LESSONS FROM OTHER AREAS OF SPACE COMMERCIALIZATION

By way of background, Mr. Chairman, I have worked on space commercialization issues for almost 30 years, including from different vantage points. I began work on satellite imagery commercialization while working for the Director of Central Intelligence in 1994, served as the Executive Secretary of a Commission that assessed the National Imagery and Mapping

Agency — predecessor to the National Geospatial Intelligence Agency — and served as both member and Chairman of NOAA's federal advisory committee ACCRES. While at RAND and in the private sector, I focused my research efforts on global satellite imagery markets and their security implications, resulting in multiple studies and op-eds, including the co-authored volume "Commercial Observation Satellites: At the Leading Edge of Global Transparency." (2000, RAND/ASPRS).

With time, Mr. Chairman, we could walk through the long and sometime difficult path that it took to gain adoption of commercial remote sensing, including disbelief that such a highly technical business could be subject to commercial practices, whether it would have value for intelligence and national security purposes, and worries about the security impacts of the new transparency that it would create. Resistance isn't entirely out of the system today in spite of the demonstrated benefits from leveraging commercial remote sensing capabilities.

Today, thirty years after bold Legislative and Executive Branch action, we see the many different benefits of the government's use of commercial satellite imagery. Satellite imagery data and analytic products help intelligence organizations like NGA and NRO fulfill their national security missions and to share imagery data where the use of classified imagery is not possible. The space-based transparency that we wrote about over twenty years ago calls attention to horrific Russian atrocities in Ukraine, has helped deflate Russian disinformation and catalyzed Western government and public response. Commercial radio frequency sensing has provided other insights, such as Russian jamming of Ukrainian communications satellites. Recent policy decisions have allowed USG agencies to purchase of satellite imagery from our closest allies and partners, with substantial benefit.

I offer this example to note some of the pitfalls to avoid as we as we consider the need to leverage commercial capabilities within the creation of a civil SSA capability. While no parallel is perfect, there are also important lessons to be learned from other examples like GPS commercialization, which resulted in hundreds of applications that we use regularly. As I said many times during my time at Commerce, and since, federal agencies are doing better at leveraging commercial capabilities, but far more can still be done. Especially in the case of a civil SSA system, we will need to leverage the speed, agility, and anticipation that can only come from the private sector.

Of course, my time as Director of the Office of Space Commerce provided insights on a wide range of new space market segments, whether for purposes of linking entrepreneurs to USG programs, understanding industry trends, helping break down regulatory impediments, and otherwise advocating for the US commercial space industry per OSC's legal mandate. While the Office took on a significant responsibility for SSA/STM over the past four years, its main role is to "foster the conditions for the technological advancement and economic growth of the US commercial space industry." (Title 51 USC 50702). The role is predominantly about economic growth, competitiveness, jobs, and innovation from space and related activities,

including in the area of SSA.

THE COMMERCIAL SSA ECOSYSTEM

The United States already has a diverse and impressive ecosystem of companies focused on SSA and the broader problems of space safety and sustainability. Inspired by a challenging technical problem and growing concern about space debris, many are leveraging private investment as they come into to the market. Some of these firms are focused on unique sensing of the space environment from Earth, and they will soon be joined by space-based sensors to collect unique data about the space environment. Other companies have developed unique capabilities for detecting radio frequency interference between space objects or focus on the autonomous maneuverability required to avoid debris.

These companies are staffed with world-class talent, and are leveraging the storage, data management, analytics, visualization, and other capabilities drawn from a global IT ecosystem that supports millions of decisions daily in healthcare, global finance, and gaming, to name a few. (We might note that the US Space Command commercial strategy announced by General Dickinson last month made similar arguments and the need to leverage them).

Since leaving the US government, I have had the opportunity to work with a number of these companies, and stay connected with many others. When I look across these companies, I find their efforts to be highly complementary, and therefore an excellent basis for **immediate** participation in a civil SSA system.

Some of these companies already have US government contracts with NOAA and the US Space Force, while others are working with our allies and partners for basing sensors and to provide key support to NATO. Many of these firms are tested three times a year in the joint DoD-DoC Sprint Advanced Training Exercises, in scenarios designed to play out how Allies exchange information and how governments can work with commercial providers.

International partnerships are essential in dealing with this challenge. The SACT exercises and other DOC international outreach, in partnership with the State Department, can serve as forums for the US to work with allied and partner SSA services like the European Union's Space Surveillance and Tracking (EU/SST) partnership. This can help ensure coherent, complementary, and interoperable solutions for both civil and commercial spaceflight safety and the protection and defense of US and allied space systems.

That said, our Allies are already taking the lead in funding and leveraging commercial capabilities as part of their strategies. The European Union released a new strategy for space traffic management in February 2022 that provides funding for European companies and mandates that space operators leverage capabilities equal to or greater than the EU/SST, in other words, commercial SSA capabilities.

Back at home, a commercial demonstration at this year's Space Symposium showed the very quick work of eight different companies in developing an end-to-end assessment of the Russian ASAT test. The participants all work with government agencies in some capacity, and in the demonstration leveraged large-scale investment in imagery and SSA capabilities and the power of a massive private cloud infrastructure. This was an example, but only one example, of the kind of capability that the US government needs to leverage now within a civil SSA. The demonstration was built with company resources, not US government resources, and was completed in a number of days. I would encourage the Committee members and staff to take a look at these impressive capabilities already in the market.

Increasingly, these companies have substantial inputs from the growing space operator community. Today, a large percentage of the satellite operators in LEO are working with these firms, and the exquisite data required to connect two space objects in innovative new missions like Northrop Grumman's MEV-1 and -2 missions were provided by one company. Needless to say, these companies are making discoveries about developments in the space environment that are also helpful to our strategic understanding of the space environment.

THE PATH AHEAD

As we create a new civil SSA capability, Mr. Chairman, simply making token commercial purchases will not be enough. As a strategic imperative and as a path to creating an effective civil SSA system —from the unsustainable path that we are on to a robust public-private partnership that promotes safety and sustainability — the Office of Space Commerce needs to fully leverage the commercial capabilities now or soon to be entering the market. There is nothing wrong with the US government being a first customer, with the idea that it not be the only customer. A civil SSA system constructed with that in mind will allow for service to appropriate government missions, but also encourage the growth of this commercial sector as additional partners like space operators and our allies leverage these capabilities.

Further, to take a traditional government build path on this would effectively create a competitor to industry, put at risk the investments by these companies and their investors, and prompt an emphasis on working overseas. Given the global interest in the topic and the diverse capabilities, the USG could wind up making investments that leave the taxpayer with a legacy capability and an industry focused abroad.

To say it another way, OSC can have the advantage of using commercial capabilities without being encumbered by the existing architecture. OSC should avoid a prolonged acquisition strategy, and should consider flexible acquisition approaches, like Other Transaction Authorities, that have been proven to be helpful in the DoD acquisition cycle when urgency is called for. This comment is similar to many others calling for more flexibility and diversity in acquisition strategies, especially when the need is urgent. In the space arena, this includes the ability to leverage data buys, space as a service, and even non-conjunction analysis services.

If OSC gets anywhere near its FY2023 request, it will have sufficient resources to move out on all of these fronts, including maximum leverage of commercial capabilities.

In addition, Mr. Chairman, with over 8,000 metric tons of debris threatening space operations today, the US government needs to consider a remediation roadmap, as is suggested in recent solicitations from the US Space Force and in the Administration's new in-space servicing, assembly, and manufacturing strategy released earlier this month.

Congress is not silent on this issue. In the past, Congress has been pivotal in telling the Executive Branch not to build what it can buy in the market. Further, a hard fought consensus on the current plan, including the key role of the Department of Commerce, is codified in the SPACE ACT(s) of 2020 and 2021 and now in conference as part of the US Innovation and Competition Act. I would especially highlight the idea of a Center or Centers of Excellence on SSA that is already written into the legislation. I would urge Congress to fund, demand expediency, and oversee proper execution of the civil SSA capability in a way that capitalizes on the items outlined in this testimony.

CONCLUSION

Mr. Chairman, I appreciate the opportunity to discuss this important topic today. As the United States confronts multiple adversaries in space — one with moves with the efficiency of civil-military fusion, and another that seemingly has no due regard for anyone else's interest in space — I believe that we are at a pivotal time to extend America's leadership in space through the rapid creation of a civil SSA system. The bad news, in my opinion and the opinion of many other experts, is that we are out of time. The good news is that we have private sector tools and innovation that are available immediately to help with the current space debris problem and adapt quickly as the space environment changes.

A large, traditional government program will not work here. An effective solution requires a much more aggressive approach to leveraging private sector capabilities, not only as discussed here but by an increasing number of senior officials from within the Executive Branch, from within the Congress, and the private sector. There is no faster way to ensure rapid mitigation of the challenging space debris problem and helping keep space sustainable for our future security, exploration, civil, and space commerce interests.

Thank you, and I will look forward to your questions.

Kevin M. O'Connell
Founder and CEO, Space Economy Rising LLC

Kevin M. O'Connell is a recognized expert on space commerce, the global space economy, international intelligence and U.S. national security matters. For almost four decades, he has focused on space commercialization and technological competitiveness and how to advance them in global markets. He has also focused on how these innovations impact U.S. and allied national security.

His U.S. government assignments include the Department of Commerce (SES), The Department of Defense, The Department of State, The National Security Council, The Office of the Vice President, and The Office of the Director of Central Intelligence. Within the private sector, Mr. O'Connell was a senior research analyst at RAND and was the first Director of RAND's Intelligence Policy Center. In 2007, he founded *Innovative Analytics and Training, LLC,* a consulting firm specializing in assessing high-tech market areas including geospatial markets, cloud computing, and cyber analytics.

Mr. O'Connell's most recent role was Director of the Office of Space Commerce (OSC) within the U.S. Department of Commerce. He was the principal architect of outreach to U.S. private space companies to facilitate innovation and encourage increased market growth and viability. He focused on the growing role of the private sector in space, encouraged new space partnerships, worked to ensure the competitiveness of the U.S. commercial space industry, and advanced American leadership in space safety and sustainability. Mr. O'Connell testified before Congress on space policy and regulatory issues, American space competitiveness, and the growth of space commerce. He was awarded the Vice President's Dedicated Service Award for his support to the National Space Council.

Mr. O'Connell also expanded international outreach on space commerce issues with a wide range of U.S. allies and partners, especially to compare notes on regulation, encourage new partnerships and advance space safety and sustainability. His overseas space engagements included participation in the U.S.-Japan Comprehensive Space Dialogue, as part of a Space Delegation to Luxembourg, and including high-level discussions with the EU, India, Thailand, Singapore, Indonesia, and Commonwealth partners.

Mr. O'Connell is a recognized expert on the policy, security, and commercial aspects of satellite remote sensing technologies and markets. He served as the Executive Secretary of the Independent Commission on the National Imagery and Mapping Agency (NIMA) in 2000 and later as an advisor to the Director, National Geospatial-Intelligence Agency. He was a long-standing member of NOAA's federal advisory committee, ACCRES, including as Chair between 2012 and 2016.

Mr. O'Connell has been a regular author on space commerce issues. He contributed the foreword to "Space Policies for the New Space Age: Competing on the Final Economic Frontier," by Bruce Cahan and Mir Sadat (NewSpace New Mexico, December 2020). He co-authored Commercial Observation Satellites: at the Leading Edge of Global Transparency (ASPRS/RAND, 2000). He has an active TS/SCI security clearance with additional special accesses. He taught graduate courses in Georgetown University's School of Foreign Service and the RAND Graduate School for many years and has lectured at academic and research organizations around the world.

Chairman BEYER. Thank you, Mr. O'Connell, very much.
And finally, we'll hear from Dr. Mariel Borowitz. Dr. Borowitz?

TESTIMONY OF DR. MARIEL BOROWITZ, ASSOCIATE PROFESSOR, SAM NUNN SCHOOL OF INTERNATIONAL AFFAIRS, IVAN ALLEN COLLEGE OF LIBERAL ARTS, GEORGIA INSTITUTE OF TECHNOLOGY

Dr. BOROWITZ. Thank you. Chairman Beyer, Ranking Member Babin, and distinguished Members of the Subcommittee, I want to thank you for the opportunity to speak to you today on this important topic.

Space assets are critical to the global and U.S. economy, as well as U.S. national security, and one of the most fundamental missions for ensuring safety, security, and sustainability of space is space situational awareness, or SSA. Right now, the U.S. Department of Defense operates the most advanced SSA system in the world. With the rapid growth of activity in space and particularly commercial activity, there's been a recognition that some components of the SSA mission should be transitioned to a civil agency. However, as we've heard, there are still a number of important decisions to be made in relation to this transition. So in my testimony I want to focus on two key issues: mission definition and commercial engagement.

So with respect to mission definition, a decision needs to be made about which elements of the SSA mission will be taken on by a civil agency. SSA requires collection of raw data, data processing and fusion to create a catalog of space objects, analysis to identify potential collisions in space and determine their likelihood, and the provision of the resulting warnings to space operators around the world. At the very least, a civil agency would need to take on that last part of the mission. A civil agency would be the main point of contact and the prime interface for U.S. SSA capabilities for the world.

However, there are benefits to having a civil agency do more. A civil agency that generates its own raw data from civil or commercial sensors, generates its own independent space object catalog, and generates its own conjunction warnings can be much more open and transparent about these activities than the U.S. military. When the United States is transparent about the data and algorithms it uses, this facilitates trust and encourages international partners and commercial satellite operators to rely on U.S. data, strengthening U.S. influence and leadership in this area.

Openness and transparency also allow the United States to better leverage the commercial and academic communities. When government data is freely available, entrepreneurs can use the data as building blocks to create new and innovative products and services. Similarly, researchers with access to SSA data and algorithms can carry out research that improves U.S. space situational awareness capabilities overall. We've seen this open data model work well in weather and in remote sensing where we have open data sharing by the government and thriving commercial sectors. And it applies in the case of SSA as well.

The second issue I want to touch on is commercial engagement. A civil agency will be well-suited to leverage the strengths of the commercial SSA sector. However, it must determine how best to do so, which function, products, and services should be provided by the government and what should be done by the commercial sector. I would argue that the government should focus on providing timely, precise, and accurate conjunction warnings to all space operators globally, as well as open access to underlying data and analysis to the greatest extent possible. Some of the data needed to support these efforts should be purchased from commercial entities. Commercial entities should also provide tailored SSA services directly to customers. This division of responsibilities would best contribute to the long-term safety and sustainability of space. It would serve U.S. national interests, maximize overall socioeconomic benefits, and promote innovative—innovation in the commercial sector.

Let me tell—explain a little bit more about why I think that's the case. So nearly half of all operational objects in space are owned by the United States. The United States is the most reliant on space objects for its economy and national security, and therefore, providing these high-quality warnings that help satellite operators avoid collisions and ensure the long-term sustainability of space is really in the U.S. national interest.

Safety is also an important government mission. An example from the weather sector is useful here. The United States has a thriving commercial weather sector that's capable of producing a wide variety of products and services, and yet the government provides forecasts, severe weather watches and warnings for free. If tornado warnings had to be purchased from the private sector, surely there's lots of people that would buy them. However, the National Weather Service continues to provide the highest quality warnings free of charge. And this is because the government has a responsibility to ensure that all people have access to this critical safety information. And the same is true for SSA.

Third, and discussed earlier, open data and open science allow the United States to unleash the entrepreneurial and research communities, and that helps to maximize socioeconomic benefits. In this framework, commercial entities have a significant role to play. Commercial entities provide those tailored SSA services similar to what's done in the value-added weather center. They may also sell data to the government that can be incorporated into government SSA capabilities. And this would ensure that the U.S. Government can benefit from the innovation occurring in that sector and that that strategic sector will continue to flourish in the United States.

The transition of an SSA capability to a civil agency can enable the United States to strengthen its global leadership in this area and more effectively leverage its commercial and research communities. With an organized, efficient, and transparent civil SSA system, the United States will be able to lay the path for a safe and sustainable space environment.

Thank you again for this opportunity to testify on this important topic, and I look forward to your questions.

[The prepared statement of Dr. Borowitz follows:]

Written Statement of

Dr. Mariel Borowitz
Associate Professor
Sam Nunn School of International Affairs
Georgia Institute of Technology

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

"Space Situational Awareness: Guiding the Transition to a Civil Capability"
April 29, 2022

Chairman Beyer, Ranking Member Babin, and distinguished members of the subcommittee, I want to thank you for the opportunity to speak to you today on this important topic. As of January 2022, there were nearly 5,000 operational satellites in Earth's orbit. This number has more than doubled since January 2020 and is expected to continue growing rapidly.[1] Space assets are critical to the global and U.S. economy as well as U.S. national security. These operational systems are surrounded by tens of thousands of pieces of debris larger than a softball (10 centimeters) – large enough to destroy a spacecraft in the event of a collision.

One of the most fundamental missions for ensuring the safety, security, and sustainability of space is Space Situational Awareness (SSA). SSA involves tracking objects in space, predicting their future location, and assessing the likelihood of possible collisions. Right now, the U.S. Department of Defense operates the most advanced SSA system in the world. They collect data from a wide array of sensors and fuse that data to create a catalog of space objects. They also conduct analysis that allows them to predict the future location of these objects and provide advanced warning of potential collisions (referred to as conjunctions). The basic version of the space catalog as well as the conjunction warnings are made available free of charge to all satellite operators around the world.

With the rapid growth of activity in space – particularly commercial activity – there has been a recognition that some components of the Space Situational Awareness mission should be transitioned to a civil agency. Space Policy Directive 3 stated that the Department of Commerce should take on this mission, and a follow-up report conducted by the National Academy of Public Administration reenforced the importance of this transition. The U.S. and international space community has been enthusiastic about this effort.

However, there are still a number of important decisions to be made in relation to this transition. In my testimony, I will focus on five key questions that need to be addressed:

[1] Union of Concerned Scientists. Satellite Database. 1 October 2019.
Union of Concerned Scientists. Satellite Database. 1 January 2022.
https://www.ucsusa.org/resources/satellite-database

1. Mission Definition: Which elements of the SSA mission should be taken on by a civil agency?
2. Commercial Engagement: How should the civil agency engage with the commercial sector?
3. Quality of the Free Products: What quality of product should be provided by the civil agency free of charge?
4. International Engagement: How should the civil agency engage with the international community?
5. Preparation for the Future: How will this transition affect future developments in space, including space traffic coordination and management?

1. Which elements of the SSA mission should be taken on by a civil agency?

As mentioned above, there are many tasks associated with conducting space traffic management. Data needs to be collected by a series of sensors. That data needs to be fused to generate an understanding of where objects are located in space. This information is used to create and maintain a catalog of space objects. The data is also analyzed to determine which objects may collide in the future and calculate the likelihood of each potential collision. Finally, warnings based on this analysis are provided to satellite operators to inform their actions.

It is likely that the DoD will continue to conduct the core elements of this mission – data collection, fusion, and analysis – regardless of the activities of a civil agency, because Space Situation Awareness – or Space Domain Awareness, as the military refers to it – remains central to the national security mission. The DoD must monitor objects in space to conduct threat assessment and enable attribution. The DoD will also have requirements for intelligence information and other specialized data particularly suited to those national security missions. It would be useful for the United States to conduct a thorough analysis of the long-term vision and requirements for the military Space Domain Awareness capability. This would provide a clear understanding of exactly which elements of the system must be retained by the military long-term.

A civil agency would, at the least, be expected to take on the task of liaising with commercial and international space operators around the world: providing the catalog of space objects and conjunction warnings. The civil agency should be the main point of contact and prime interface for U.S. SSA capabilities for the world.

However, there are also benefits to having a civil agency also undertake its own analysis – generating its own catalog of space objects, separate from that created by the DoD – as well as generating its own conjunction warnings. A civil agency could even bring in its own raw data – perhaps through a combination of civil and commercial sensors, adding to any data it receives from DoD sensors. In determining which portions of the SSA mission a civil agency should engage in, the core tradeoff is between redundancy and openness.

The drawbacks of redundancy are relatively straightforward: if two U.S. agencies are conducting very similar missions, this increases the total cost to the U.S. government. Also, to the extent there is overlap in the missions or activities of the military and civil agencies, care should be taken to ensure their findings are aligned. It would be undesirable to have a situation in which

two U.S. agencies do not agree on the location of an object or the likelihood of a collision, even if the DoD predictions are no longer released publicly. Close coordination between the two agencies would be needed to ensure that this does not occur.

The benefits of giving a civil agency a larger portion of the SSA mission stem from the fact that a civil agency can be much more open and transparent in its operations than the military. This openness enables the United States to better engage with commercial and international partners, as well as the research community – goals at the heart of undertaking this transition.

While the U.S. military provides an important global service through its current provision of the space catalog and conjunction warnings, it provides very limited transparency into its processes for developing these products. The catalog consists of relatively simplistic "two-line element" data not sufficient for use in independent conjunction analyses. It does not provide access to raw data, covariance information, or algorithms underlying its analysis. While this is perhaps understandable for a national security entity, it has been a source of frustration for commercial and international partners.[2] Without this type of information, these actors have no way to independently verify the information they receive from the United States or compare it to results they receive from other systems.

When the United States is not able or willing to provide sufficient transparency from their space information systems, other nations are incentivized to develop their own independent systems, and this can erode U.S. influence and leadership. This mechanism is already at play in the SSA sector to some degree. [3] There has been an increase in the development of SSA capabilities across both international and commercial entities in recent years, with nations and regions creating SSA systems independent from the United States.[4]

By contrast, if a civil agency conducts its own analysis, independent from the U.S. military, this entity will be better able to share data and algorithms used to develop SSA products and services. This openness will facilitate trust and encourage international partners and commercial satellite operators to rely on U.S. data, maintaining U.S. influence and leadership in this area. This would also allow the United States to collaborate more closely with nations that choose to develop their own independent systems, ensuring that these developments contribute to, or at least align with, U.S. efforts. This type of cooperative engagement can increase the quality and resilience of the U.S. SSA capability.[5]

Openness also facilitates engagement with the commercial and research communities. On this topic, we can draw some useful analogies to the Earth observations and weather communities. In the early 2000s, analyses showed that the U.S. had a much larger commercial weather sector than Europe, due in part to the U.S. adoption of open data policies. Entrepreneurs were able to build

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[2] Lal, Bahvya, Asha Balakrishnan, Becaja M. Caldwell, Reina S. Buenconsejo, and Sara A. Carioscia. "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM) IDA 2018 SSA Report." Institute for Defense Analysis. Science & Technology Policy Institute. April 2018.
[3] Borowitz, Mariel. "An Interoperable Information Umbrella." *Strategic Studies Quarterly* 15.1 (2021): 116-132.
[4] Borowitz, Mariel. "Examining the Growth of the Global Space Situational Awareness Sector: A Network Analysis Approach." *Space Policy* 59 (2022): 101444.
[5] Borowitz, Mariel. "An Interoperable Information Umbrella." *Strategic Studies Quarterly* 15.1 (2021): 116-132.

on the government's basic data product to create new and innovative products and services.[6] Similarly, researchers with access to satellite data and government models could experiment easily and generate new knowledge. The resulting partnerships between government, commercial, and academic weather communities have helped the U.S. to remain a global leader in this area.[7] These effects are relevant to the SSA sector, as well. Access to SSA data and algorithms can allow entrepreneurs to develop new products and allow researchers improve U.S. approaches to analyzing and predicting the location of space objects, ultimately improving the quality of space situational awareness as a whole.

It is of course important to consider the national security implications of sharing SSA data and algorithms. However, as others have pointed out, given the rise of independent national and commercial systems, the U.S. does not have a global monopoly on SSA information. Even if the United States chooses not to share its data and algorithms, actors have an increasing number of other sources from which they can procure this information.[8] In addition, if the U.S. has both military and civil components of its SSA system, the civil agency could adopt an open data and open science model that promotes sharing and engagement, while the military retained its classified approach. The U.S. military would benefit from the innovation in the civil sector without revealing its own raw sensor data or algorithms.

2. How should the civil agency engage with the commercial sector?
As noted in the previous section, transitioning the SSA mission to a civil agency will make it easier for the government to engage with the commercial sector. However, the government still has decisions to make about how to structure this engagement: which functions, products, or services are inherently government missions, and which should be left to the commercial sector? What types of engagement, support, or public private partnerships can allow the United States to best leverage and promote the commercial SSA sector?

Commercial SSA activity has grown rapidly in the last five to ten years. A decade ago, there was relatively little commercial SSA activity, and today there are companies offering services that in some cases rival those offered by the U.S. government. Given the increasing capability of commercial entities – most of which are in the United States – it is important to consider which tasks should be undertaken by the government and which can and should be left to commercial entities. In making this decision, it's important to consider ethical responsibilities, national interest, and practical limitations to government activity.

The conjunction warnings produced as part of the SSA mission play an important role in ensuring the safety of space objects and the long-term sustainability of the space environment. Because of this safety role, particularly when human activity in space is involved, it could be argued that the United States has an ethical responsibility to provide data, even if commercial entities could conceivably make a profit by selling this product. An analogy can be drawn to the

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[6] Pira International and European Commission. Information Society DG., Commercial Exploitation of Europe's Public Sector Information: Executive Summary (Office for Official Publications of the European Communities, 2000).
[7] Borowitz, Mariel. *Open space: The global effort for open access to environmental satellite data*. MIT Press, 2017.
[8] Borowitz, Mariel. "Strategic implications of the proliferation of space situational awareness technology and information: lessons learned from the remote sensing sector." *Space Policy* 47 (2019): 18-27.

weather sector. The commercial weather industry is capable of generating tornado warnings and could conceivably sell access to these warnings. However, there is an ethical responsibility on the part of the government to ensure that citizens have access to this critical safety information free of charge. There are also benefits to ensuring there is one authoritative, trusted source for severe weather watches and warnings, rather than having many individual commercial entities release potentially conflicting guidance.

Sharing high-quality conjunction warnings is also in the U.S. national interest. Of the nearly 5,000 objects in space, more than half are affiliated with the United States.[9] While all nations rely on space assets to some extent, the United States is the most reliant on space objects for its economy and national security. Given this situation, it is in the U.S. national interest to avoid collisions among space objects to ensure the long-term sustainability in the space domain. To achieve this, it is also in the U.S. interest to ensure all space operators have access to the high-quality SSA information necessary to avoid collisions in space. Providing this information free of charge is the best way to maximize the use of this data and doing so requires government action.

In addition to continuing to provide high-quality conjunction warnings free of user fees, the United States government should also consider making raw or minimally processed data as well as high-quality space catalog data available free of charge. Currently, this type of data is not made available by the United States, since the current SSA sensors are operated by the U.S. military. However, as noted above, if civil sensors are developed, it may be possible to share data more transparently, facilitating engagement with the international, private, and academic sectors, and maximizing the socioeconomic benefits of this data. With respect to terrestrial environmental information, the National Oceanic and Atmospheric Administration (NOAA) Policy on Partnerships states that "government information is a valuable national resource, and the benefits to society are maximized when government information is available in a timely and equitable manner to all." Based on this, NOAA's policy is to provide "open and unrestricted access to publicly-funded observations, analyses, model results, forecasts, and related information products."[10] A similar policy would be appropriate for civil SSA data.

Even if the government identifies the above missions as inherently government functions, there are many opportunities for commercial entities. While the United States can and should provide information relevant to a broad community, it will not be practical to provide tailored products to individual customers. Again, there is an analogy to weather: the National Weather Service does not provide tailored weather forecasts for individual ski resorts or off-shore oil platforms – these services must be procured from the private sector. Similarly, satellite operators interested in tasking sensors to get in-depth analysis of a potential conjunction or other issues relevant to their spacecraft or constellation should turn to private SSA providers which will allow the SSA industry in the United States to flourish.

The government may also engage the commercial sector in the purchase of raw sensor data to be ingested into the civil government SSA analyses, assuming the data meets requirements for

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[9] Union of Concerned Scientists. Satellite Database. 1 January 2022.

[10] National Oceanic and Atmospheric Administration. "Policy on Partnerships in the Provision of Environmental Information." NAO 216-112. 19 January 2006. https://www.noaa.gov/work-with-us/partnership-policy

quality and reliability. This type of partnership can be more complicated, as the government must determine whether this data, like civil government data, will be shared freely with international partners and/or the public. Open sharing has many benefits, as listed above, but it makes it difficult for commercial entities to sell that data to any additional customers. NOAA is facing similar challenges in considering commercial data buys for its terrestrial weather system.

However, there are ways to overcome these challenges. One option is to purchase commercial data under an open license that sufficiently compensates the commercial entity for the impact on data sales to other customers. While more expensive, this would allow the U.S. to benefit from commercial innovation and efficiency while also promoting openness. Commercial entities could still sell value-added products and other special services. Another option is to use commercial data in data products – such as the space object catalog and conjunction warnings – which are provided for free, without releasing the underlying data. Unlike in the global weather community, there is not currently an expectation for full and open sharing of SSA sensor data. A civil entity could choose to share raw or minimally processed data from its own sensors while refraining from releasing commercial or military SSA data. The civil entity would still benefit from using all of this data in the generation of the space object catalog and the conjunction analyses, and these data products could be shared freely without compromising proprietary or classified information.

3. What quality of product should be provided by the civil agency free of charge?
Closely related to the debate on the role of the government versus commercial entities is the question of how to determine what level of quality the government should provide in its free products. As noted above, the U.S. government currently provides a space object catalog as well as conjunction warnings, and a civil government would presumably continue to do this.

Conjunction warnings are arguably the most important SSA product released by the United States, due to their direct impact on satellite operator decision making. Given the U.S. national interest in avoiding collisions, it is in the U.S. interest to ensure spacecraft operators have the best available information when making decisions about whether and how to maneuver their spacecraft to avoid a collision. This suggests that the government should seek to provide a high-quality product: one that is timely, precise, and accurate. If, for example, the United States was aware that a collision between space objects was likely, it would surely want to provide that information to the operators involved, rather than hoping those operators would procure adequate information from the private sector or another source. To return to a weather example, the United States strives to ensure that all people have access to weather information – particularly severe weather warnings and watches – and thus provides high-quality information free of charge.

However, while the United States desires that space actors have access to the highest quality information possible, there will be practical limitations – conjunction warnings will never be perfect, and the government must trade off efforts to improve these products with investments needed elsewhere. For this reason, the U.S. should, at a minimum, ensure that its product is *actionable*. This means that it is of sufficient quality that most satellite operators will trust the warning and be willing and able to make decisions based on it.

Once again, a weather analogy is helpful. The United States government provides tornado warnings. The most important aspect of these warnings is ensuring that they are clear and accurate enough that people will actually heed them. As I've seen in my own experience growing up in Minnesota, if false warnings occur too frequently, instead of heading down into the basement, people look at their weather app or check the weather radar, and often just continue on with their day.

There are many reports that we're already starting to see this type of behavior among spacecraft operators. Due to the rapidly growing number of objects in space, operators are receiving significantly more conjunction warnings. For some, it has become impractical to maneuver – or in some cases even investigate – each of these warnings. Lack of trust in the data also detracts from the willingness of operators to take action. When spacecraft operators do not find these warnings actionable, they no longer have value.

In order to ensure the freely provided conjunction warnings are actionable, the U.S. government will have to work closely with both operators and the research community – something a civil agency will be well-suited to do. Operators can help the U.S. government understand what would be required to build the trust and quality necessary to ensure they take action. The research community can help to make the improvements in the system necessary to meet these requirements. It is worth noting that this type of work requires both physical and social sciences. As demonstrated in the weather community, the impact of warnings is not just about the quality of the data and analysis, but also but the ability to communicate this information in a way that users understand and know how to respond to. We should keep in mind that satellite operators include not only large, experienced firms, but increasingly include new space actors from emerging space nations, start-up companies, universities, and even high schools.

Further, this product cannot remain static over time. Just as the space environment is changing and risks are increasing, in order to remain relevant – and actionable – the quality of the conjunction warnings must improve, as well.

With respect to the space object catalog, as well as any future civil SSA sensor data, we should think about the impact of data quality on the commercial and research communities. Data is a key building block generating new knowledge and strengthening our economy. When entrepreneurs and researchers have access to high-quality information, they find innovative ways to build new value-added products and grow the U.S. space industry and to improve our understanding of the space environment. Right now, the space object catalog provides relatively simplistic two-line element data for space objects. Basic information on space objects, such as object mass and size, is often missing. By improving the quality and scope of the information made publicly available, the U.S. government could create more opportunities for meaningful research and innovation.

4. How should the civil agency engage with the international community?

The United States is currently a global leader in space situational awareness. The United States operates the most advanced SSA system in the world, and it is the only one that makes data and services available to all users around the world, free of charge. Leadership in this area benefits the United States in practical ways – helping to avoid collisions and ensure sustainability of the

space environment – and it provides opportunities for the United States to demonstrate its commitment to peaceful engagement with nations around the world. The U.S. can and should continue to lead in this area.

Just as a civil agency will be able to open new avenues for cooperation with the commercial sector, a civil agency will be well-suited to engage international partners as well. The DoD has already begun this process through its Space Situational Awareness Data Sharing Agreements, but the civil agency can expand these partnerships both in terms of the nations involved and the opportunities for engagement and data exchange with each partner.

International activity in space situational awareness has been expanding significantly, and the United States can benefit from access to the data and analyses conducted by other nations. Close engagement can improve the quality of the U.S. SSA system. It can also help the United States to build agreement among nations and harmonize differences among systems.[11]

While the United States accounts for a large portion of activity in space, activities in this environment are inherently international – many countries share this environment and must work together to ensure it remains safe and sustainable. The United States benefits from having a system that is perceived by the global community to be accurate and reliable. Helping to harmonize the U.S. understanding of activity in space with that of other nations will be increasingly important.[12]

There are multiple different national and regional SSA systems, each using different data, relying on different algorithms, and generating different results. In some ways these differences can provide value – taking multiple approaches to solving the same problem helps improve certainty that the solution is accurate. By contrast – if we are generating significantly different findings – different understandings of where things are in space and where they're going – this is a problem. In this case, nations will have different understandings of when a collision is likely, based on which data provider they use. Nations may differ in their assessment of on-orbit interactions, potentially causing international incidents.

For example, in December 2021 China submitted a note verbale to the United Nations in which officials complained that a SpaceX Starlink satellite had come dangerously close to China's human-tended space station. The United States responded that based on data from the U.S. SSA system, the U.S. did not believe that a close approach had occurred. This may have been a politically-motivated incident, but it is also possible that this issue arose due to differences in data and analysis that led to different understandings of the relative locations of the space assets involved. There may also have been a difference in the thresholds for determining "high risk." Without better engagement between nations, it is difficult to understand the source of these types of challenges. With the additional transparency made possibly through a civil SSA agency, the United States could further elaborate on its understanding of the space environment. Continued transparency, as well as engagement with other nations will also allow the U.S. to set a standard

[11] Borowitz, Mariel. "Examining the Growth of the Global Space Situational Awareness Sector: A Network Analysis Approach." *Space Policy* 59 (2022): 101444.
[12] Borowitz, Mariel. "Legal Considerations and Future Options for Space Situational Awareness." *Georgia Journal of Internationall & Comparative. Law* 48 (2019): 695.

of behavior and can help to avoid potential misunderstandings in the future – with both partners and potential competitors.

5. How will this transition affect future developments in space, including space traffic coordination and management?

High-quality, widely-available space situational awareness information is critical, but there is more that needs to be done to ensure the safety and sustainability of space activity in the future. Space situational awareness allows us to understand what's happening in space and generate warnings when collisions may occur, but operators do not have any guidelines or requirements that govern their behavior in these cases.

This is the equivalent to telling a driver they are approaching a busy intersection, but leaving them completely in the dark as to whether they are expected to slow or stop or whether other cars are likely to do so. It is not clear whether the car on the left has the right of way or the car on the right. Every interaction must be negotiated on a case-by-case basis, and – to continue the analogy – we can't guarantee the other driver will even respond or engage in this negotiation. This is not efficient and it is not safe.

Eventually we will need to develop operational norms of behavior for outer space, just as we have for cars, ships, and aircraft. When we begin to address the issue of Space Traffic Coordination and Management, high-quality SSA information, transparency, trust, and international and commercial engagement will be more important than ever. The United States needs to take the steps described above to lay the foundation for success in this important future task. With an organized, efficient, and transparent civil SSA system that brings together military, civil, commercial, and academic communities, the United States will be able to take an international leadership role on this important issue.

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Biography
Mariel Borowitz is an Associate Professor in the Sam Nunn School of International Affairs at Georgia Tech. Her research deals with international space policy issues, including international cooperation in Earth observing satellites and satellite data sharing policies. She also focuses on strategy and developments in space security and space situational awareness. Dr. Borowitz earned a PhD in Public Policy at the University of Maryland and a Masters degree in International Science and Technology Policy from the George Washington University. She has a Bachelor of Science degree in Aerospace Engineering from the Massachusetts Institute of Technology. Dr. Borowitz completed a detail as a policy analyst for the Science Mission Directorate at NASA Headquarters in Washington, DC from 2016 to 2018. Her book, "Open Space: The Global Effort for Open Access to Environmental Satellite Data," was published by MIT Press in 2017.

Chairman BEYER. Dr. Borowitz, thank you very much.

This concludes our five presentations, and we will begin our round of questions. Let me start with Dr. Borowitz.

It's pretty clear from these five testimonies that the primary, conflict is probably too strong a word perhaps, but the thicket to work our way through is what should be the Department of Space Commerce's responsibility and what can be drawn from the private sector, the commercial thing. You mentioned that it doesn't make a lot of sense to have two U.S. agencies conducting that very similar missions. What role do you see for Department of Space Commerce or whatever civil agency ends up with the responsibility to conduct its own analysis when there apparently are a number of private sector entities capable of doing the analysis instead?

Dr. BOROWITZ. Sure. Thank you for the question. So I think that there are a lot of ways that the United States can structure the way it builds that system. And I think certainly we should be leveraging the commercial sector. The key thing is the product that comes out of it, those conjunction warnings, those need to be freely available to the operators, right? Those need to be provided without any service fee. And the other thing that I think is important to focus on is the amount of transparency that we can provide. So while I think we should leverage the commercial sector and potentially even for some elements of the analysis, I think we want to be careful about having a completely opaque system. So if it's done by a commercial entity that then can't share any of the underlying data or algorithms or things they do, that would really limit some of the benefits I think we get from moving to a civil system and being able to be more open and transparent than what we had with the military.

Chairman BEYER. Great. Thank you. Let me pivot to Mr. D'Uva on essentially the same issue. You've talked about the—what—the civilian SSA capability and how your Space Data Center has put together, you know, a great U.S. space catalog and you're willing to share this. How would you respond to the issue of the openness of the data? And I know this is a Committee where in a very bipartisan way we like as much open data as possible.

And also on the fees, is there not a structure in which the Federal Government could be paying in some cases the commercial sector to develop this and then make it free to the American public?

Mr. D'UVA. Yes, thank you for the question. I think that there—it's important that the Federal Government, Department of Commerce, Office of Space Commerce be seen as the provider of the capability, right, and that underlying capability can be provided commercially and transparently. We've seen this in the SDC where we have a lot of discussion and dialog with the users, with the satellite operators. They want to know how the processes work and how that—you know, how those warnings are derived. They also want to ensure that when they are—we are forward-looking in the SDA. We're not just looking at the sky and saying, well, what might happen. Operators also contribute maneuver data, so we can forecast what will happen based on operator intentions. And that doesn't happen anywhere else. So that's an important capability and why there needs to be a single fusion center.

But transparency and openness are critical, and it's one of the reasons that DOD needs to keep doing what it's doing with its own capabilities and the civil and commercial capability and data center has to be built from a lot of the same inputs but with more transparency while respecting national security equities.

Chairman BEYER. And, Dr. D'Uva—or Mr. D'Uva, under this responsibility, who's got the responsibility for safety issues? Is it the commercial entity that's providing the data or is the government, Department of Commerce, as the one transmitting it to the public and to the various users?

Mr. D'UVA. I believe that it should be the government itself that takes on the responsibility of ensuring that there are quality products available globally to users in space. And that derives from the fact that the United States has liability, as other nation-states do, under the relevant treaty frameworks for actions undertaken by their private-sector operators in space. It's just in the U.S. interest to ensure the highest quality safety products are made available as broadly as possible.

Chairman BEYER. Dr. Jah, you talked about accuracy is not enough, you also need to have precision. And the precision has to deal with uncertainty around how accurate things are. Is there a specific recommendation coming from this insight that's relevant to this discussion?

Dr. JAH. Absolutely. You know, there are these things called dimensions of data quality. It's a formalism, along with, again, accuracy, validity, completeness, uniqueness of the data. I think these are the things that Office of Space Commerce needs to be able to do, and it's inherently governmental, just like, you know, Andrew, you know, just said in terms of, you know, helping ensure the best quality products out there. It's not so good to just give opinions about where stuff is in space and how things might behave but there's ambiguity. And every single decision is actually made based on this ambiguity, based on this notion of uncertainty because we don't know the truth. Error is the difference between what we predict and reality, we don't necessarily know what reality is because our sources of information are biased, they're corrupt, they're incomplete.

And so I think this is really the importance of—you know, this civil SSA capability is to aggregate all these different opinions and sources of information from this aggregated set. Use this to actually remove ignorance and ambiguity so that the precision can actually converge on something that's usable in a very meaningful way.

Chairman BEYER. Great. Thank you, Dr. Jah, very much.

Let me now recognize the Congressman from Florida, Mr. Posey, for his questions, making the leap of faith that Mr. Posey is with us virtually.

OK. Let me now then turn to the other Congressman from Florida, Mr. Webster, for his questions.

Mr. WEBSTER. Thank you, Chair.

I don't know enough about this to ask a question, but I'd like to focus in, Dr. Borowitz, the—what's the specific research priorities that the Federal Government should invest in to advance SAA capabilities?

Dr. BOROWITZ. Sure. Thank you for the question. So I think there are a number of things that we can do. I think there were mentions in a number of the testimonies of some of the technical areas where we can improve the types of data, look at which types of data are most useful, look at the algorithms we're doing—using to do that data fusion, look at the algorithms we do to see if collisions are going to happen, improve, as Moriba said, both the accuracy and the precision, other kind of elements of that data. So I think there's a lot of work still that we can do there.

As someone coming from a school of international affairs, I think there's also work we can do on the social science side that will be important to look at how we organize this system both within the United States and how we engage in international cooperation in this area. It really is an inherently international issue, and it's something we want to be on the same page with other nations about, so I think there's work in both areas.

Mr. WEBSTER. So how do we ensure that this doesn't do any harm to the commercial opportunities?

Dr. BOROWITZ. Sure. So I think, you know, the United States has this really impressive SSA commercial industry already. And we certainly want to acknowledge that and build on that. So I think as this moves forward, you know, working closely with that industry, making sure we understand what the opportunities are for the industry is going to be important.

I think we do have models for doing this in a productive way. I mentioned the weather industry and remote sensing where we have the government playing a really important role. The government collects weather data, it analyzes weather data, it puts out forecasts, it puts out warnings, and yet we have a huge commercial weather industry in the United States, very successful and growing. And they work closely together, the commercial industry and the government. And so I think there is good precedent for that. It can be done. I think it should be done, you know, very purposefully and carefully, but I think we have some good models for that.

Mr. WEBSTER. Yes. So we had a—we've had a hearing on just the weather issue. It was pretty impressive. So can these items be separated out and—or do they have to work with other things, not necessarily related to weather, to make sure this all works?

Dr. BOROWITZ. Sure. So I think, you know, the SSA industry is going to be separate from the weather industry but just can have some lessons learned from the way things have been structured there. But in terms of coordinating what are the roles of the government versus commercial, I think the key thing is for the government to continue to provide the conjunction warnings, those warnings of potential collisions, to global users free of charge. And like I said in my testimony, that's in the U.S. national interest. We really don't want to have debris created in space. We won't don't want to have those collisions, so we want to make sure people have that information.

And I think beyond that, you know, tailored services, if somebody wants information very specific to that—their satellites, something maybe they're planning in the future, that's a great place to go to commercial. If the government wants to bring in more data, I think certainly we should be taking advantage of this commercial data

that's out there. That's another opportunity. So I think there's lots of places that commercial entities can still play a role, and I'm sure they'll think of more ideas as well and continue to innovate in that area. And it's really this core kind of safety product the government should do—should provide, as well as kind of general openness and transparency as much as possible.

Mr. WEBSTER. Thank you very much. I yield back. Go Jackets, by the way.

Chairman BEYER. Thank you, Congressman, very much. Now, let me recognize the senior leader of the congressional Science Committee CODEL (congressional delegation) to Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. Yes. He says that because he didn't join us in Colorado, but that's OK. You broke my heart.

So I—first, I want to thank the Chairman for putting this draft together because I think this is a very urgent matter, both understanding where the objects are, where the debris might be, where different things are, as well as providing a civilian context to really start policing, if you will, or at least cleaning and being aware of what's up there so we avoid the accidents, we avoid collisions, we avoid, you know, bad outcomes.

And so, you know, I've been supportive of moving things to the Office of Space Commerce out of the Defense Department. Maybe some of the responsibilities of NASA all reside there so that they can then develop the regulations for both commercial, as well as keep an eye on the stuff that we have up there that is just floating around as potentially dangerous.

So let me ask, to all our witnesses, what are the most critical actions that need to be taken to ensure an effective transition to a civil space situational awareness capability? And, to go along with that, what do you think Congress can do to affect a smooth transition? Anybody? Bueller, anybody?

Dr. JAH. Right, well, I'll go. Look, I think this really has to be worked as a matrixed organization, meaning recognizing that, you know, the Office of Space Commerce isn't the Lord of the Rings, is one entity to rule them all that knows how to do all this stuff. Other parts of government need to come together, coalesce to help this be successful, everything from policy and regulatory aspects to the scientific and technological that could be led by organizations such as NASA. And I think really lending an ear to the community to try to address the community needs instead of just saying, hey, how do we just take what's currently being done and give it another like storefront? That's not going to do it. We have needs that go way beyond what's currently being done. So I think——

Mr. PERLMUTTER. Like what?

Dr. JAH. Well, look, astronomy, right now, there's no capability to help astronomers predict light pollution from reflecting objects. There's nowhere to find that at this point as a for instance. We have in-space servicing and manufacturing. I just saw, you know, the White House put out something on that. All these companies that want to go service something else, the catalog that's currently maintained by the DOD represents everything as if they were cannonballs, everything's a sphere. Nothing actually looks like a satellite in their catalog. So when people want to service something,

we're not interested in servicing spheres. We're interested in servicing things that are satellites. Is it brittle? Where do I grab this thing? How is it tumbling? Does my technology work for it? We have no place to point people to to actually get that information in a way that is effective and usable.

And I'll even say one more thing. From a liability perspective if there is a satellite, let's say, operated by—I'm just going to pick some African country—Ethiopia, right, and they want it serviced by an American company, what if that satellite from Ethiopia actually shares liability with China? What does that U.S. company do? Do they just talk to the Ethiopians and service it? What if China doesn't like that so much? So——

Mr. PERLMUTTER. Yes, but here's my question to you. The—at some point we've got to have somebody who's in charge of all this. You can't have a bunch of different entities, but somebody's got to be—and it—there—maybe they're not the Lord of the Rings or the Lord of the Flies or whatever, but there's got to be a place where this resides, particularly on the commercial side of this.

And right now we've got different agencies, particularly the Air Force, maybe NASA a little bit, but this is a burgeoning area. You just mentioned two or three or four more things that I certainly hadn't thought of. I mean, doesn't somebody have to be in charge of this?

Dr. JAH. Yes, so just very quickly to let other people here talk, when I worked at JPL, which is a matrix organization, I had a project manager and a line manager. And I guess what I'm saying is that it's fine for Commerce to be the project manager, but all the line elements need to be other agencies. That's what I'm trying to propose here.

Mr. PERLMUTTER. Got you. And I think that makes sense because there are so many different potentials here. So I'll—my time is about up. I'll yield back to the Chair, and thank you for your answers.

Chairman BEYER. And, Mr. Perlmutter, Mr. Webster, we will have time for another round or two or three if you so wish. So let me move to round two.

Mr. Hejduk—Dr. Hejduk, you're a Senior Project Leader of the Aerospace Corporation. It's pretty clear already that the tension that we will have to work to overcome with setting up this responsibility—actually, let me pause because—are you ready to jump in for questions?

Mr. BABIN. Yes. Yes, sir.

Chairman BEYER. Then I will—we'll go back to round one with our Ranking Member back from solving the Conference Committee between the Senate and the House on the *COMPETES Act.* Thank you for doing that.

Mr. BABIN. Yes, sir, just came back from the Senate side.

Chairman BEYER. And the time is yours.

Mr. BABIN. OK. Thank you, Mr. Chairman. I really appreciate it. I want to say thank you to all of our expert witnesses and our panelists here.

My questions would be, No. 1, to Mr. O'Connell. The Department of Commerce's recent budget request proposes to acquire a SSA capability similar to DOD's capability. Previous testimony before this

Committee highlighted that legacy infrastructure and acquisition processes made it difficult for the Department of Defense to employ commercial approaches to modernize space situational awareness capabilities. For example, the U.S. Air Force spent billions over the last 30 years but failed to modernize its systems and still uses decades-old technology. Mr. O'Connell, what can Congress do to ensure that Commerce does not have to reinvent the wheel or adopt the same failed acquisition approach?

Mr. O'CONNELL. Congressman, nice to see you again. Thanks for the question very much.

Mr. BABIN. Yes, sir.

Mr. O'CONNELL. I think the first thing that we should say is that Congress in this area, just as in other areas, should really mandate maximum use of commercial capabilities, both to take advantage of what I see as a playing field of commercial companies that's really highly complementary when I look across all the companies that I'm aware of, and so insisting that that be a key element of this.

As I said in my testimony, we are not going to simply replicate what DOD has. We really have to create a state-of-the-art capability on the civil side for all the reasons that we've all spoken about that can keep up as the space environment changes very, very rapidly. This is going to move very quickly. There need to be new ways—and this is a common refrain in today's world—of new ways to think about acquisition. How can we creatively, credibly, competitively get money into the market in a way that we're comfortable for—on behalf of the taxpayer? I think it's very much doable in this area. The key is getting money into the market not only to use and experiment with the capabilities that are in the market or just about in the market but also to encourage this important segment of the space industry.

Mr. BABIN. Absolutely. Thank you very much. I appreciate it. I appreciate your service, too.

Mr. O'CONNELL. Thank you.

Mr. BABIN. Mr. D'Uva, the cloud-hosted Space Data Center has evolved into one of the largest clearinghouses for spacecraft operator data, which provides geographic diversity, military-grade computational security, a legal framework, high availability, ongoing forensics, data quality checks, and comparative space situational awareness analyses. The space safety coalition offers similar capabilities for low-Earth orbit. What are some of the strengths of private sector organizations in coordinating data sharing and developing best practices, and what carrots can be provided to incentivize operators to join such groups?

Mr. D'UVA. Thank you for the question. It's been an interesting journey because the SDC capabilities that you outlined were cutting-edge, but they rely on the U.S. Government data for catalog. What we saw as the gap of data capability was the lack of transparency because of national security equities. So as we looked to improve the capabilities, we investigated whether we would be able to build our own catalog and essentially provide a basic flight safety service.

And that's where we discovered that in fact only some of the satellite operators in space are interested in paying for these services. Instead, many don't know the limitations of the current—for exam-

ple, the legacy DOD products that are available publicly. And so what they don't know doesn't hurt them until there's a problem. And even one problem in orbit is too many in this area, so it's very important that we leverage those commercial capabilities that exist to transparently provide a capability under the auspices of the Department of Commerce but available to everyone. And that—I think that's what lies before us.

Mr. BABIN. Yes, sir, thank you very much. And one last question for Kevin O'Connell again. Liability significantly influences how operators act in space. How can the government leverage the insurance industry to influence safe operations without regulations?

Mr. O'CONNELL. Thanks, Congressman. Great question, and it's a topic you and I have talked about before. I think the insurance industry is—and the space insurance industry specifically is a key next user of the kinds of data that will be available on the civil side. You know, the challenge that the space insurance industry has had is that they do not have enough data for many different new things in orbit to inform their risk models. And so I think in the process they will benefit from the data that's available in a civil system and be able to characterize risk in a way that will help us all understand different aspects of risk in space.

The second point just quickly is I think an earlier question was about the kinds of research that is being done in this area or that could be done. I still think that there is an enormous amount of, if you will, economic and financial research that needs to be done. When I look at discussions about regulation, we really need to understand the economic and financial aspects of that in addition to the technical aspects.

Mr. BABIN. Thank you very much. I appreciate that. And I just have one little announcement I'd like to make, a public service if you will. I'd like to take just a moment, Mr. Chairman, to recognize Jeff O'Neil from Representative Perlmutter's office, who is here today. I've been told that this is Jeff's last Committee hearing as a staffer. This is it. Jeff has worked closely with my staff, great friends over the years. And while we may not have agreed on everything, like Jeff's boss and I, we agree on a lot. Our offices have accomplished some fantastic things together, especially for the space community, and so I want to say best of luck to you in your future endeavors, Jeff. I wish you the best. Thank you for your service and your boss's, too. God bless.

Chairman BEYER. OK. Thank you. And it's only appropriate now to recognize Mr. Perlmutter for whatever——

Mr. PERLMUTTER. If I could have——

Chairman BEYER [continuing]. Disconcerting——

Mr. PERLMUTTER. If I could have a moment of personal privilege.

Chairman BEYER. Granted.

Mr. PERLMUTTER. I'm embarrassed. Thank you, Dr. Babin, for recognizing Jeff. Jeff has been instrumental in my office for a dozen or more years now, particularly on the Science Committee where he and I have this passion for outer space and our space research and our space exploration and all of those kinds of things. The two of us have been like twins, even though we're not the same size, in terms of our love for this Committee and our love for space exploration.

And Jeff obviously has done so much more. He's handled the Rules Committee packet of things that I've got to do as well, which is a pretty busy schedule. Our office is going to miss him desperately. The constituents of the Seventh Congressional District are going to miss him desperately.

I—I've never for a second had any concern that I wasn't getting good information, that I wasn't prepared for this Committee for different things we were going to do. He helped with the Science Committee staff, and I should make a note of this. We had a fantastic trip and I tried to get everybody—Don can attest to this. We had a great trip to Colorado last week. And Jeff, together with the staff, put together a visit that I wish everybody had been part of just in terms of the science that's going on in Colorado and the laboratories and the aerospace and all that stuff.

But to my friend Jeff O'Neil, the Congress is going to miss you. I know your future endeavor at Planet will be something very exciting for you. And, you know, Brian sort of one-upped me here, but his remarks are everything that I feel and multiplied by about ten. Thank you.

Mr. BABIN. Thank you.

Chairman BEYER. Thank you, Dr. Babin, Mr. Perlmutter. And, Jeff, I know along with all the rest of us, we felt so betrayed by Representative Perlmutter's announcement of retirement that we had no choice. But we know you'll have a much better job in the years to come at Planet, so——

Mr. PERLMUTTER. Than working for me.

Chairman BEYER. Yes, exactly.

Moving on to something less serious, now let me recognize the distinguished gentleman from New Jersey, Mr. Norcross, for his questions.

Mr. NORCROSS. Thank you, Chairman. And it's good to be in the hearing room. After coming through COVID, this is literally the first time I've stepped foot in here, and it's great to see people back. So we're here to say goodbye to you, Mr. Perlmutter, but it will not be the same, and certainly our trip out West to see the assets that our country has really reinforces why we are who we are. It's just—it was great.

But let's talk about the situational awareness and something I've been focused on since my early days sitting on the HASC (House Armed Services Committee) Subcommittee on Strategic Forces where space was virtually the domain of the Defense Department and NASA mixed in. And the idea that it is now a commercial entity in addition to assets to defend nations, literally around the world, and we're seeing what Russia is doing with their space assets and Ukraine and certainly China.

But as we start to move into this area of the commercial, one of my biggest concerns—and I'd love to hear from the witnesses on this—is about how do we ensure the accuracy of the information on the commercial side, that difficult blend between, not as much the United States but certainly some of the non-friendly nations, to make sure we are being provided to the commercial side that information that will accurately indicate that there could be a potential collision or other issues? So how do we ensure that based on

a number of the proposals that we see? And I would open that up to each of our witnesses.

Dr. JAH. Can I—yes, thank you so much because I'm chomping at the bit to kind of address this. So one of the things that I guess I would ask to people there in the room is how do you know that you have the world's most accurate clock? And the answer is you have hundreds of them. That's how we tell time. We have hundreds of atomic clocks around the globe, and the United States is one entity that aggregates all these opinions about time, finds the very center, the centroid, the mean of all those opinions in a weighted sense, an ensemble of clocks to come up with what the time actually is. And then accuracy is based on the difference between that ensemble clock time and what's on your wrist.

We can do similar things for stuff in space. This is the difference where the Office of Space Commerce can step in and again aggregate all these opinions, commercial, international, that sort of stuff, look at the statistical consistency of the opinions, and then therefore be able to infer what is the best fused answer out of all of these opinions and be able to then judge how far off are other people from that centroid or very center. That is something that we know how to do. It just needs to be implemented.

Mr. NORCROSS. And certainly as you give me your answer, the standards—and we were just in Boulder talking about the standards of the world, which are so important. So for the rest of the witnesses, incorporating those standards into the accuracy.

Mr. O'CONNELL. Congressman, that's very, very important. It's another reason why the Department of Commerce needs to have a lead role in this area. The National Institute of Standards and Technology is our national expert on standards, and so to help evaluate standards, even ones that come from the bottom up as we say out of the private sector, look at new standards being evolved, that's a very important government role. When new companies come into the market, there's a role to validate the kinds of capabilities that they are saying they are providing as part of an integrated system, as Dr. Jah just said.

Mr. NORCROSS. Anyone——

Dr. HEJDUK. Yes, let me make a couple of comments about that. Validation is difficult. It takes experts, it takes time, it takes a lot of test cases, it takes exposure.

And one of the greatest impediments, I think, to using fused solutions and solutions from other entities is to go through this validation exercise. It is considerably simplified if the providing entity understands their own errors very well, but you have to get them to a level of maturity where that happens as well.

One of the reasons I've—I'm—look like the one dinosaur on this Committee here proposing the transition of some basic DOD capabilities first is because I think they represent a very good foundational level that you have to show equivalence with in order to be brought into the fold as a data provider. And we can get past the idea of what data are good enough, which data are not good enough. If you provide something of the same look and feel and heuristic quality as the DOD, you can be admitted. And that is a much easier standard to assess and certify than absolute standards

for accuracy and precision, which are much more difficult to establish and then justify.

Mr. NORCROSS. I see my time has run out, but it's also about cooperation. The United States obviously can lead the way, but unless all nations participate, we are flying with one eye closed. With that, I yield back the balance of my time.

Chairman BEYER. Thank you very much, Mr. Norcross. And now let me recognize virtually the Congressman from Florida, Mr. Posey.

Mr. POSEY. Thank you very much for having this hearing, Chairman Beyer.

Mr. O'Connell and Dr. Jah, we all understand the seriousness of space debris and the threat from the small pieces of debris that are not tracked or are difficult to track. And it seems like it's something that needs more data, continually better data, and increased resources from low-Earth and on orbit. Mr. O'Connell, how can the private sector provide augmenting data to better improve space situational awareness?

Mr. O'CONNELL. Thanks, Congressman. Nice to see you again. The—you know, this is a place where the private sector continues to innovate. We are working right now with a couple of organizations that are looking, for example, at how to use high-altitude UASs (unmanned aircraft systems) of aircraft and sensors that look up to try to deeply track and identify what is known as the lethal non-trackable space debris. And so there are a lot of people that recognize the gaps that exist in our current coverage and things that need to be understood in a much better way. The private sector is investing in those. They're innovating in them, et cetera. So, you know, again, it's another reason why we need to encourage the commercial industry forward on this topic.

Mr. POSEY. Thank you. Dr. Jah, I'm going to go back just a little bit to your last discussion here about the gaps in R&D (research and development) related to space situational awareness and how NASA and the Department of the Defense can engage or better engage with the academic community to fill those gaps.

Dr. JAH. Well, thank you so much for that question, Congressman. So, look, in terms of some technical gaps that currently exist for SSA, for one, we do need to get better measurements. If you want to know something, you have to measure it. We don't have enough eyes on the sky as it were. We certainly—the United States to this day still has no commercial space-based SSA capability for a variety of reasons that kind of maybe go beyond the scope of our conversation here that we can talk offline about. But, you know, that needs to be resolved because the United States would stand to benefit quite a bit from having a commercial space-based SSA capability.

And in terms of how to engage with academia, I have to say this is where you've hit a sore spot with me. I'm so frustrated by the absence of funding for academia in this regard. You know, the National Science Foundation doesn't consider this to be basic enough research. Everybody says it's somebody else's problem. Oh, this SSA space debris thing, it's not alluring enough, it's not interesting enough, it's—you know, it's not basic research. And so the Air Force Office of Scientific Research and the Air Force Research Lab

by and large seem to be the only people that disparately kind of care about this problem and funding it. So I think that there definitely needs to be a very serious pool of funding to allow the DOD and other entities to actually engage with academia.

And every year I'm turning away students that are U.S. citizens that want to get involved because there's not enough research support to actually get these people, you know, through the system and delivering great on science and technology. And the thing that is really the thing that really upsets me is that a lot of these companies that we're talking about helping them thrive, where's the work force coming from? They're hurting. Every day I'm getting people emailing me saying, hey, can you just send over like a dozen students? I'm like, well, they're not growing on trees. Like where do I get these students from? So this is a big problem that we need to fix.

Mr. POSEY. Yes. Where do you think we start? I mean, what would your suggestion be?

Dr. JAH. Look, I think the academic community is actually ready. It's begging. We actually—if we could have some cooperative agreements, if we could actually—you know, Congress could say this amount of money is dedicated to space situational awareness, scientific and policy research, that would be a great start. And the thing is there is no pool identified uniquely to support the research.

Mr. POSEY. Listen, thank you very much. I see my time is about to expire. I thank all the witnesses for appearing today and deeply appreciate your comments. I yield back.

Chairman BEYER. Thank you very much, Mr. Posey.

I will now go to a second round of questions. And let me begin.

Dr. Hejduk, you're in this unique role as head of—you know, Senior Project Leader at an FFRDC. If I wildly oversimplified the conversation today, on one end of the bell-shaped curve is the notion that we need to stand up a second—you know, parallel to the DOD space situational awareness within the Department of Commerce, hence, the 550 percent increase in the budget and the like. On the other end of the bell-shaped curve was the notion that our civil sector can do it all. And of course no one's argued for either of those.

But, Dr. Hejduk, in the draft legislation we have, which has not been introduced yet of course, we call for the—a mandate for the maximum use of the civilian capabilities. How do you figure we best balance that as opposed to standing up our own Department of Commerce capability?

Dr. HEJDUK. Yes, thank you for the question. In this hearing even though it's titled transition to a civil capability, we've actually talked a lot about end states and haven't talked all that much about transition. I think when—in my testimony earlier, comments when I talk about beginning with the DOD capabilities, that's in order to establish a foundation and give us a springboard from which we can move to an almost entirely commercial end state in my view. If we try to meet the timelines that are laid out in the draft legislation, we're going to have to move very quickly.

The fastest thing we can do to build confidence in the broader community is to be able to emulate what the DOD is doing presently for the CDM, Conjunction Data Message distribution. And

then what we can do is run that in parallel with other commercial proposals, some of which are actually funded by the DOC, to show how they are performing against the DOD baseline. And what that will do is provide the transparency where owner-operators out in the field will then look forward to the changeover from a DOD capability to a commercial one.

If you talk to owner-operators—and we talk to a lot of them at NASA—they—if you propose changing information that they have—well, don't change anything. We know what's there, we like it, we know how to use it. If we were suddenly to knife switch to a commercial capability, I don't think that would be received very well by the owner-operators who have spent a decade learning to use the DOD product and have written software that uses it automatically. Instead, we need to phase in these improvements.

So where am I on the bell curve? I'm well over on the commercial side. I don't think that this needs to be an indigenous, you know, government-produced acquisition product. But I do think we need a much longer transition time, and we need to show the improvements so it doesn't look like "we're from the government and here to help you."

Chairman BEYER. Thank you very much. Dr. Borowitz, a parallel question. Do you see our potential legislations use of the idea of mandating the maximum use of civilian capabilities in any way to conflict with the concerns you had laid out in your testimony?

Dr. BOROWITZ. Thank you for the question, Congressman. So I think it just depends on exactly the way those partnerships are set up. I think absolutely we want to leverage the commercial industry and the strengths that already exist there, and there are lots of different ways to structure those partnerships. If it's done in such a way that, you know, all of that data and those processes are seen as proprietary and becomes a black box, then I think we lose some of the benefit of moving to a civil agency.

And if it's done in a way, as I believe it can be, that allows us to still have some open data, some transparency even while we leverage those commercial entities, then I think we still at the key benefits we want from that civil transition. So I think, yes, it definitely is possible to leverage commercial to a very large extent if those partnerships are done in a way that still emphasize transparency.

Chairman BEYER. Thank you very much. And Mr. D'Uva, Dr. Jah complained—that's probably too strong a word—but noted there was no commercial space-based—underlying space-based SSA. Is that coming from the NDC or others?

Mr. D'UVA. Probably not unless the Congress acts to fully fund DOC activities because, as Kevin O'Connell mentioned, the government might be a good first customer of such a sensor, you know, that would cause the private sector to want to launch space-based SSA sensors and then develop the capability, but absent that, we can make pretty quick gains with just improving on the existing DOD CDMs that were mentioned just by including more data about them using a lot of the same sensor inputs that are available today.

So I think we can get a long way toward improvement by bringing modern analytics processing capabilities to some of the data

sets we already have and then augmenting those data sets with, you know, ground-based SSA capabilities that are commercial, perhaps space-based SSA capabilities, and other sensor types, not just, you know, whether it's radar, electro-optical, RF (remote frequency). There are other sensor types. So it's a combination that brings us closer and closer to a level of truth that actually becomes actionable for use by operators. And that's the key. And so that needs to be done transparently, as several of the witnesses have said. I couldn't agree more.

Chairman BEYER. Thank you very much. Now, let me recognize the Ranking Member from Texas, Dr. Babin.

Mr. BABIN. Thank you, Mr. Chairman. I've got a couple of questions for you, Kevin O'Connell. I appreciate you being here and all of you excellent witnesses, Dr. Jah, all of you. But, Mr. O'Connell, on April the 15th, 2022, NOAA published a notice of intent to issue a sole-source order for low-Earth orbit data to LEOLabs. NOAA stated that our market research has determined that LEOLabs is the only U.S. company that possesses the necessary real-time LEO space surveillance tracking data that meets OSC's requirements for its Open Architecture Data Repository. Are you aware of OSC's requirements for its Open Architecture Data Repository? And if so, are they publicly available?

Mr. O'CONNELL. Thanks, Congressman. I appreciate the question. So 16 months after having left the government, I'm not specifically aware of the new requirements as they laid out by NOAA. I suggest you hear from NOAA directly on that.

I think the thing that I would emphasize—and maybe I'm going to tie a bow around some of the last couple of comments. You know, I think was envisioned back in 2018 that as we began this transition, that we would leave everything in place until everyone was satisfied that there was technical competency on the civil side. And so there will be some duplication if you will of effort, redundancy while we do this.

And to go to Dr. Hejduk's comments a minute ago, you know, if DOD is going to continue to provide this, then the extent to which we can really experiment on the civil side with new commercial capabilities, new services, there are in fact a couple space-based SSA companies coming into the market, you know, I think it gives us a real opportunity to experiment with what's coming in the market and look at things a different way.

I did want to highlight, Congressman, I wanted to highlight an activity known as the Sprint Advanced Training Concept—Concept Training rather, or SACT as it's known, which has been a venue that the Department of Defense and the Department of Commerce have cosponsored since 2018, but it's been in existence longer than that. And this is a venue within which two things happen. When the United States works with it its allies to actually understand how to transition SSA-related information amongst allies, but more importantly to this conversation it's been a place where there has been a tremendous amount of experimentation with government transitioning custody of space-based objects to the commercial entities to see the comparative strengths and weaknesses of companies that are in the market and participating in the exercise obviously.

And so that's a tremendous learning opportunity that we already have beside—you know, with us to take advantage of here.

So on the specific question of the sole-source contract, I think I'd have to defer back to NOAA on that.

Mr. BABIN. OK. Thank you. And one last question for you as well. Fiscal year 2023 budget request from the Office of Space Commerce asks for $88 million. Do you know how that funding level was derived?

Mr. O'CONNELL. I don't, Congressman. You may recall that in the NAPA report, I think it was page 82, we had our best budget estimates just as I was going—as I was departing my role at Commerce and as—if I recall correctly, we had proposed a budget estimate of between about $40–60 million per year during the transition. But again, I don't have any detailed knowledge on the specific budget request for Fiscal Year 2023.

I would make one point that I do hope that in that budget request, given the extent of the budget growth, I do hope there's enough resources left for the other capabilities that the office is required by law to undertake. You know, SSA is the top mission, but obviously the advocacy and the regulatory and other missions will also have to be tended to as well.

Mr. BABIN. Yes, sir. And, you know, I think this just shows that we need—there's some need to know on the part of Congress about these requirements that I ask you about. And then also how this office is deriving, you know, their budget request. That's information that should be available to us. But anyway, I thank you very much. I appreciate it. And I will yield back, Mr. Chairman.

Chairman BEYER. Thank you very much, Mr. Babin—Dr. Babin.

Let me now recognize the distinguished gentleman from Colorado.

Mr. PERLMUTTER. Thank you, Mr. Chairman.

So I want to start with you, Mr. O'Connell. It's good to see you again. Since 2018, 2019, has—where there has been some initial transition, how have things been going in terms of elevating the Office of Space Commerce, ensuring that it really begins taking on this role, and is it capable of taking on kind of—I don't want to go back to the Lord of the Rings or the Lord of the Flies, but to take on a real management role with respect to particularly commercial space but space situational awareness?

Mr. O'CONNELL. So, Congressman, thank you. Good to see you again. I did refer in my testimony to the long battle on commercial imagery adoption. And I know you've been part of that battle on the right side of things, and so thank you for your leadership on that over the years.

In terms of the Office of Space Commerce, my views on this are very well known. The job is as much about economic development, job creation, innovation, and things like that, which is the job of the Department of Commerce. The extent to which the Office of Space Commerce sits within NOAA, at a minimum it has to seamlessly be able to work with all other aspects of the Department of Commerce and obviously have the attention of the Secretary and the Deputy Secretary. We wish Rich DalBello, the—you know, my successor in that role, wish him the best in that regard.

It does have the ability—the office does have the ability and it's an important ability to be the convener I think is the word used in the NAPA report and apparently in a brand-new report that's come out of NAPA to look at the issue of what the role of the convener means for the Office of Space Commerce. It does have that ability as long as it's able to tap into the rest of the Department.

Mr. PERLMUTTER. So my next question, a little different, but for you and for Dr. Borowitz, so I certainly want to see Commerce and particularly commercial efforts continue to grow in space, but I do share a concern that Dr. Borowitz brought up, and that is on sort of the open source elements of this, that we do make information available to as many people as possible. And is there a tension, do you think, between sort of developing more commercial assets up there to be aware of things that are floating around or that need to be collected and disposed of? Are we going to run into some proprietary problems, or is it going to be open source?

Mr. O'CONNELL. So I think one of the questions—one of the key questions that remains unanswered is something we were working on just as I left Commerce was the distinction between what SPD 3 called the basic service, in essence what the government would provide available free of user fees as the phrase is, and the commercial services. And I think the extent to which the government can define exactly what it is going to give away for free in the interest of national foreign policy, you know, other things like that, to define that technically would probably be a very important thing to enable the commercial industry to know where its efforts can start. And that's known as the advanced services in SPD 3.

I've thought about this a lot since I left the government. And, you know, there are different ways to think about that distinction whether in terms of the precision of the information that the government would provide, in terms of confidence levels that it has in the information, things like that. There are ways to think about this, but it's still an area where I think we need to do some work so that we can actually give confidence to industry as to where it's, you know, beginning point if you will for that emerging space safety industry is starting.

Mr. PERLMUTTER. OK. Dr. Borowitz, can you share what your concerns were——

Dr. BOROWITZ. Sure. So——

Mr. PERLMUTTER [continuing]. In terms of the open source?

Dr. BOROWITZ. Yes, absolutely. I think one of the most important things when we're moving this to a civil agency is to allow that—you know, first, the freely available conjunction warnings, to make sure those are still there, but also increasing the transparency and the availability of data. That was something—there was a 2018 report by the Institute for Defense Analysis that identified that lack of transparency as a key issue for some of our allies and others using our information. So I think that's something you can really address moving to civil.

I think it can be done well with, you know, cooperating really closely with the commercial sector but ensuring that we still get some level of transparency and openness that's sufficient. And I think Kevin's point about, you know, thinking about what is that basic product that the government is providing, I think that is a

really important element. I think it has to be a high-quality product that increases in quality over time.

You know, the—in my written testimony I compare it to tornado warnings, right? You need your tornado warning to be accurate enough to have a low enough number of false warnings that people listen to it, you know, so kind of an actionable warning. And that's what you need in space as well. We're getting too many warnings to operators or they're not accurate enough and people aren't using them, aren't finding them actionable, then that's not a high-quality enough product. So when we think about that basic product is that needs to be freely available and transparent, I think we need to make sure it's actionable.

Mr. PERLMUTTER. Thank you. My time is expired.

Chairman BEYER. I now recognize Mr. Posey from Florida for a second round of questions. I'm hoping that Mr. Posey is on board. I'll give him a minute. If not, then let me recognize——

Mr. PERLMUTTER. There he is.

Chairman BEYER. Oh, good.

Mr. POSEY. I'm still here but I'm in listening mode. Thank you.

Chairman BEYER. OK. You're in speaking mode now if you so wish.

Mr. POSEY. I'll pass, thank you.

Chairman BEYER. OK, great, thank you.

Then let me recognize Mr. Norcross to wrap us up for the day.

Mr. NORCROSS. Thank you again, Chairman.

This is fascinating as we make a transition to what is called commercial. And commercial by definition has a little bit of latitude in it. The fact that there are players in the private sector who have space situational awareness, whether they are ground-based, space-based, or a combination of each. This is something that has been around but obviously becoming more and more important, particularly when investments are going into space on the commercial side.

So the idea of always using the Department of Defense as a validator I don't think is realistic long term because, A, we don't need to give up all that information as a check and balance. But when we start talking about the Office of Space Commerce, we're making the tremendous investment in here. And the idea of going up to $87 million, that major increase, it takes time to ramp these things up.

So first to the questions, it's not as much the amount the first year but are we able to adequately incorporate this in a one-year timeframe to stand up, to start doing many of the items that we talked about? So that would be question No. 1. And when we start talking about open source or proprietary, this is going on already. We have many things up there. But when we start talking about those who want to use this information, there's—my opinion—needs to be certain ground rules called a driver's license. If we look back to when airplanes first started flying and what FAA has done, that was certainly an American-based system, but the world also followed and now we have standards.

It's a little different in space because the lines of who owns what is clearly not there, so the enforcement of whatever standards we create is really difficult. How do we punish somebody who's not

playing by the rules who says they're going to do this? And that's access to markets. And this is where commercial comes back in. If you want to use those assets to gain access to our commercial market, you have to play by the rules.

So the first question—and I would go to Dr. Borowitz—are we able to use this amount—A, is it enough for this coming year, the $87 million? And can we adequately put it into place in the first year? And then would you talk about the enforcement of any rules for space situational awareness?

Dr. BOROWITZ. Sure. So on the first question of the funding, I haven't looked in detail about exactly how that $87 million is broken down. But I will say that there is a huge community of people who have been thinking about this for years, and so I think there is a real opportunity on this issue—you know, you always have to ramp up, but there is a real ability to hit the ground running and a real desire for that around the community, so I think there is a lot that they can do even in year 1 if they get the right resources.

On your second question about how do you sort of enforce rules, so I think with space situational awareness, really you're providing information. You're providing, you know, people with a sense of where things are in space and where they're going to be in the near future. So in terms of rules, the only thing you might have is kind of the standards for people who also want to provide that type of information, so there's talk about, you know, if you're going to put out conjunction warnings as a commercial entity or provide data, we want to make sure you're meeting a certain standard of quality. And that I think, as you mentioned, the government can ensure that people are meeting that requirement when they work with the government.

When we get to action in space, then we start talking about space traffic coordination or space traffic management, and I think enforcing action there is going to be hard, but I think getting the SSA system in the United States organized and set up the way that it's going to work efficiently is going to let the United States take a leadership role in those activities. And I think that's going to make a big difference in allowing us to move forward internationally.

Mr. NORCROSS. Do any of the other witnesses have an opinion on this?

Dr. JAH. Well, I think——

Mr. D'UVA. Yes, thank you, I do.

Dr. JAH. Go ahead, Andrew.

Mr. D'UVA. Thank you. Thank you, Moriba. It's very interesting. Within the SDA context, in order to participate, operators have to communicate their maneuvers in advance and deconflict them, and the information system does this. This is obviously a voluntary activity, but with a DOC-led capability, you could actually verify that what operators say they're going to do, for example, with these autonomously maneuvering satellites, actually are doing it. So by bringing commercial sensors into the mix, which are—which can be used transparently, we start building the foundation for space traffic coordination and management by first having a robust foundational SSA capability that is driven by civil and commercial data products and data sources.

Mr. NORCROSS. But what happens if they don't adhere to that is sort of the followup question that has to be part of it?

Mr. D'UVA. I agree. What happens is that, first, we have to understand that the international framework for operations in space are such that we don't have a command-and-control environment except through the nations that authorize the launch of particular satellites. So within the United States it might be an FCC-licensed satellite. The FCC would be the—you know, for communication satellite would be the entity that would govern that. But they need to have—as regulators, they need to have actionable data on which to base those regulatory, you know, decisions.

Internationally, I think we have to start from, you know, bringing—defining what is normal, what is proper, what is improper, and then just like in aviation, over time, freedom led to well-understood norms, which eventually were codified into rules of the road that later became binding. And so we're on that same journey for space, but until we can measure and understand what's happening in space, effective regulation will be very difficult. So I think it's—there's a spectrum.

Mr. PERLMUTTER [presiding]. Thank you. The gentleman's time has expired.

The—before we bring the hearing to a close, I want to thank our witnesses for testifying before the Committee today. The record will remain open for two weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 11:42 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Matthew Hejduk

Question 1: The U.S. government plans to transition certain space situational awareness (SSA) activities from the Department of Defense (DOD) to a civil Federal agency. If a civil Federal agency were to pursue an entirely or nearly-entirely commercial solution for an SSA capability, what would a reasonable set of transition activities look like, and over what time period?

a. How might the validation of the commercial contributions be conducted?

b. And what are the greatest risks in such a transition that must be managed carefully?

Elevator Speech Response

To achieve the contemporaneous goals of a nearly-entirely-commercial SSA solution, an expedited development period, and a phased roll-out of solutions that build confidence with the O/O community, it is best to begin with the transfer and use by the commercial provider of the DoD's catalogue for orbital safety products, at the DoD's present distribution cadence: this is the fastest way to a first-phase comprehensive solution, vastly simplifies validation, and builds confidence with O/Os who are acclimated to the DoD products. The next phase adds additional orbital safety products and the flexibility for user-requested services, here furnished in near-real-time. The final phase is the use of combined DoD and commercial SSA information to improve individual CA solutions through SSA data combination. Validation of the first two phases can be accomplished via direct comparison to DoD and NASA products; validation of the third phase can involve both precision external data and DoD comparisons to show the superiority of data fusion over the DoD catalogue alone. The risks of the nearly-fully-commercial approach are too rapid a transition to a single commercial vendor who may not be prepared to perform the entire task, potentially mitigated by the phased approach with validation of each phase; and the possibility of "vendor lock," which is difficult to eliminate entirely but can be mitigated by federating parts of the process to different vendors.

Full Response

A fully commercial solution to the Office of Space Commerce (OSC)'s orbital safety mission is an extremely appealing possibility. Especially in light of government acquisition difficulties generally, and the specific problems that have been encountered in the efforts to preplace the DoD's existing SSA system, a "set and forget" approach, in which the entire set of OSC orbital safety activities is given to a single commercial contractor to manage, deserves serious consideration. Such an arrangement would contract with a single commercial provider (or perhaps a small group of providers, with the mission divided by orbit regime) to perform the following activities:

1. The maintenance of a space catalogue, resulting from the integration of DoD-sourced and commercial SSA data, to allow the production of SSA safety products that benefit from multiple sources. The activities required to maintain a space catalogue include, either directly or indirectly, the tasking of sensors for tracking data, actual tracking data

acquisition, proper tracking data association, orbit determination, and uncorrelated track (UCT) processing. If the commercial capability truly wishes to expand the catalogue beyond the objects that the DoD currently maintains, then tracking data association and UCT processing—two enduringly difficult activities to perform well—will need to be mastered commercially.

2. The production of orbital safety products, which comprises both the results from CA screenings as Conjunction Data Messages (CDMs, which are the basic product distributed to owner/operators [O/Os]) and potential ancillary products, which can include refined collision likelihood estimates, collision consequence evaluations (the amount of space debris expected to be produced should the conjunction result in a collision), event sensitivity analyses to space weather prediction uncertainties, event-specific SSA data quality evaluations (to determine whether the current information is sufficiently accurate and precise to serve as a basis for CA risk assessment), and "maneuver trade-space" presentations that allow the O/O to select an appropriate mitigation action to reduce any collision risk. Some of these risk assessment and mitigation planning products are straightforward and easy; others are more complicated and erudite. The OSC must determine which of these orbital safety products will be included as part of their free basic service and which will be considered advanced services, to be provided to O/Os on a fee-for-service basis.
3. The creation and maintenance of the data exchange mechanisms needed to receive predicted ephemerides and other requests from O/Os and to forward them CDMs and other orbital safety products.

Of the three sets of activities given above, the core of the entire enterprise, and certainly the most difficult to accomplish, is the maintenance of the space catalogue. One could argue that, given its foundational nature, one should begin with this and work out to the more peripheral activities in ## 2 and 3 above; but in addition to the SPD-3 mandate to make substantial use of commercial SSA capabilities, there is also an exhortation to try to field a new civil STM capability as quickly as possible. If one wishes to honor both of these imperatives within the context of an entirely- or nearly-entirely-commercial solution, the following set of transition activities is proposed:

a) One should begin by arranging for the export of the DoD precision catalogue and supporting data to a chosen commercial actor, either at their own facility or on a Cloud instance secured by OSC, and transitioning the capability to propagate the DoD catalogue, produce CDMs that look exactly like the CDMs produced by the DoD presently, and provide them at the DoD's present delivery cadence. At the same time, the commercial actor can create the build-out of the public-facing portion of the OADR (Open Architecture Data Repository, which is the OSC's concept for sharing data interactively with O/Os) to handle the basic data exchange of receiving O/O ephemerides and distributing CDMs. This first transition step, which could be considered an IOC, would relieve the DoD of the orbital safety mission, allowing them to concentrate on space protection; would build confidence with the O/Os that the OSC can assume and execute the mission at least as well as the DoD, and will allow more time for validation activities to evaluate commercial and fused SSA products without delaying the roll-out of an initial capability.

b) After the IOC described in a) above has been reached, one can concentrate on two types of enhancements. The first is an improvement in CDM availability by performing more frequent full-catalogue screenings and updates, and allowing on-demand ephemeris screenings in support of maneuver and trajectory modification planning. When O/Os issue complaints about the DoD orbital safety service, they rarely complain about the quality of the data and products (although they acknowledge that they are not perfect); instead, their dissatisfactions focus on the relative infrequency of screenings and the lack of on-demand interaction with the DoD system that would allow products to be requested and obtained in near-real-time. It should not be difficult to develop the OADR automated interface to interact with the needed CA applications to provide these service improvements. The second enhancement type is the incorporation of additional CA risk assessment applications to provide a more robust basic orbital safety service. This activity is also not seen as difficult; NASA has posted the source code for such tools on a public-facing repository for anyone to download freely, and many commercial vendors have similar tools already developed and integrated into their CA systems. Of course, these development efforts should proceed in parallel with the activities in a) above, so it should be possible to release this new functionality shortly after the release in a).
c) In parallel with all of the efforts in a) and b) above, the OSC will conduct an extended validation effort of the commercial vendor's space catalogue, in whatever form they are prepared to offer it. Such a catalogue could be composed of entirely commercial data, created from blended commercial and DoD metric observations, or assembled from fused data products. It could consist of blended commercial data and solutions from multiple vendors, if the commercial entity has made arrangements for this. It could be for just a single orbital region or attempt to represent all of earth orbital space. Because full-catalogue validation is difficult (see the response to Question 3 for a more elaborate treatment of the validation question), and because it is unlikely that all aspects of the catalogue will pass validation initially and thus iterative evaluation will be required, at least a full year of calendar time should probably be allocated to this activity (again, conducted in parallel with the activities in a) and b) above). Validation is often construed as a severe, vertical, rigid evaluation exercise; what is envisioned here is much more collaborative, in which the validation group and the commercial provider work interactively to create a commercial-Government catalogue that is an improvement over the DoD catalogue taken alone and can therefore serve as an attractive basis for the orbital safety mission. It is quite possible that a certain orbital region for which commercial data are more prevalent and the orbital dynamics less complicated, such as GEO, might sustain validation more quickly, while other, more complicated regions, such as LEO, could take much longer. One can thus imagine a segmented transition of different orbital regions to a composite commercial-Government catalogue at different times, governed principally by the degree to which commercial industry can provide a desirable catalogue offering for that orbital regime. The advantage of this approach is that transition to a commercially-infused catalogue can take place quickly, with the only real impediment being the industry's ability to furnish such a catalogue at reasonable cost.

It should be emphasized that the above set of transitional steps constitutes a proposed way forward should the OSC wish to pursue an entirely- or nearly-entirely-commercial solution. If,

alternatively, the OSC wishes to purchase individual services from individual vendors and host all of these on the OADR to work in an integrated manner, then a somewhat different series of steps would be appropriate. The original written testimony outlined a proposed way forward for such a case.

The conduct of the numerical validation for each of the proposed stages above would be tailored to the types of products each stage is offering. For the stage described in a), in which the transitioned DoD catalogue is being repropagated and CA screenings executed, direct comparison to the DoD propagated ephemerides and DoD CDMs is the appropriate way to determine that this re-hosting effort (although the CA screening algorithm will be a commercial product) is producing satisfactory results. For the stage described in b), the CA risk assessment results can be assessed for the NASA protected satellites, with outputs from NASA's CA operational system compared to the outputs from the OADR. For the stage described in c), a much more elaborate validation approach is needed that considers comparison to external truth ephemerides as well as DoD internal reference ephemerides. Question 3 addresses this issue of validation directly, and in greater detail.

There are a number of risks presented by a fully commercial solution, in which perhaps a single vendor is contracted to perform the entire orbital safety mission for the OSC. Of these, the following three deserve special mention:

- The commercial sector may not be fully prepared to offer competitive services with the DoD in all orbital regions. As mentioned previously, some orbital regimes are presently better serviced by commercial SSA data and present simpler orbital dynamics situations; others encounter more difficult tracking problems and require more complicated dynamical models. To mitigate this risk, it is proposed that the OSC program be configured so as to allow the use of commercial catalogue products for a subset of orbital regions, determined by which region's products can sustain numerical validation. The desired end-state is one in which a commercial or commercial-Government blended catalogue is available for all orbital regimes; but the segregated approach proposed here allows incremental steps towards that goal while not delaying the timely deployment of an initial OSC capability. Similarly, if commercial pricing for a particular region is prohibitively high, one can delay the transition for that region until additional competition produces a more affordable cost-point.
- The issue of "vendor lock" arises with some frequency in this context, and the potential problems that this phenomenon can engender must be taken seriously. Because there are so few large-scale customers for SSA data and products (especially given the US Government's commitment to providing a free SSA service), it is not difficult to imagine that the recipient of a full-service OADR contract from the OSC could push non-successful competitors out of business, both securing a monopoly for the prevailing vendor and eliminating what is presently a thriving set of small businesses that provide niche orbital safety services. There would also no longer be any other industrial competitor prepared to take on so large an activity, so the victorious vendor could increase costs and erode services, while remaining substantially insulated from repercussions. If one chooses an acquisition approach that selects a single vendor for the entire OADR project, there is no real way to structure that acquisition to insulate against

this possibility of vendor lock. “Piecemeal” vendor contracting, in which different parts of the orbital safety service set are intentionally obtained from different vendors, is viewed as an attractive alternative for this reason.

- Because both the space catalogue and derivative products would be coming from a single source, a robust and continuous validation activity would be required in order to assure continued product fidelity. A competitive environment would not be preserved in which problems or discrepancies would naturally be revealed and in which individual vendors would be incentivized to self-police their products in order to preserve their professional reputation and competitive edge.

Such risks can of course be mitigated, but they should be given full consideration when selecting an acquisition strategy and, if selected, during the implementation of a fully- or nearly-fully-commercial solution.

Question 2: When is the earliest a full operational civil space situational awareness capability could be up and running? What are the main drivers of that timeline?

Elevator Speech Response

Leaving aside the programmatic aspects and addressing only development and test time, to emulate what the DoD is doing now, add some additional safety functions, and allow O/O access through the OADR could probably be done in one year; these tasks are straightforward enough that this minimalist implementation, which is based heavily on current DoD and NASA activities, can be achieved rapidly because little system engineering and CONOPS development is required. To incorporate commercial data by having a single commercial provider integrate the DoD and commercial data into a competing catalogue, an additional year might be necessary to learn to use the DoD data, get full catalogue maintenance working well, and sustain a full numerical validation. If a federated approach is used that integrates multiple vendors' solutions, then an additional six to twelve months would need to be added for additional system engineering and integration activities, and more complicated validation.

Full Response

To this question, only a short response will be offered because it is simply too difficult to prognosticate on actual development schedules. In principle, speed of system production can be increased by assigning a larger amount of resources and personnel to the task (although a productivity ceiling is eventually reached); it is not known how long it would take to assemble the bureaucratic apparatus needed to oversee a project of this type, get an acquisition strategy approved, and actually solicit and execute the needed contractual actions; and the requirements for and delays associated with obtaining the necessary information assurance certifications to operate a public-facing, Cloud-based portal that reaches back to ITAR algorithms and data can only be guessed at. Because of this, the commentary here will be limited to descriptions of the technical tasks to provide at least that input to the overall question of schedule.

As part of the response to Question 1, a multi-step process was outlined to pursue an entirely- or nearly-entirely-commercial orbital safety capability. Even though a capability such as this should be essentially ready at present, there is probably at least a year of calendar time required to complete phases a) and b) of that plan, namely to integrate DoD data into the commercial provider's software, incorporate the full desired array of orbital safety functions, and set up the public-facing portal to meet all OSC requirements and obtain the needed certifications. There is then probably a second year of calendar time required to perform validation activities for the full space catalogue with integrated DoD-commercial solutions and incorporate any ancillary requirements needed to reach FOC. Some parts of this process might proceed more rapidly than supposed, but others will probably be more protracted. The largest unknown element for this approach is the degree of effort required for the numerical validation. If the commercial products perform well for all orbit regimes essentially right away, then the schedule can probably be accelerated; if problems are encountered, then resolving these problems and re-accomplishing portions of the validation will introduce potentially substantial delays. The LEO

orbital regime is particularly concerning from this point of view, as it presents the most difficult orbits from an astrodynamics perspective and contains greatest portion of the space catalogue, both for debris and active payloads.

If a more federated approach is pursued, in which the OSC contracts with different vendors for different discrete services and then assembles all of these individual services into processing chains in a Cloud-based environment that the OSC secures, the development schedule stretches out because, in addition to all the activities described in the above paragraph, explicit software integration of the individual services now needs to be performed and tested. This could be expected to add another six to twelve months to the development timeline. However, if a phased approach similar to that described in the response to Question 1 were followed, namely that the first phase be simply a re-accomplishment and fielding of the DoD's approach, then with that delivery a number of immediate objectives could be satisfied: the DoD could obtain early relief from the orbital safety mission, O/Os would continue to obtain the products they are used to receiving but from the OSC rather than the DoD (thus building confidence in the OSC's stewardship of the mission), and the OSC could proceed with the development their full OADR vision with a somewhat less frenetic pacing. To reach this first phase as an IOC, namely to stand up an ability to emulate the DoD's CDM generation (based on their exported catalogue and using the DoD propagation and orbital safety software), along with a public-facing portal to perform the kind of basic data exchange that the DoD presently accomplishes with Space-Track.org, should require about one year's technical effort.

Question 3: During the question and answer portion of the hearing, you said that new data from commercial sources can be included in SSA capabilities and that comparing them to legacy DOD data would be a good way to validate the data. What are some other potential methods that could be used to validate new SSA data in a civilian system?

Elevator Speech Response

For a number of reasons, astrodynamics validation works well only by comparing the data under examination to precision truth data. Such truth data outside of DoD do exist, consisting of both specialized calibration satellites and precision O/O ephemerides; and these data sources can be used to validate a number of products from commercial providers. However, the truly difficult class of objects to maintain are small debris objects, especially in LEO; and these objects cause the majority of CA events and are therefore very important. The only present validation avenue to evaluate maintenance of such objects is by comparison to the DoD catalogue's constructed reference orbits for them.

Full Response

Astrodynamics data validation is one of the most vexing issues in the SSA mission area. A number of different approaches have been attempted over the years to perform this difficult task, but it is fair to categorize them into two basic types:

- To compare the "submitted" orbital data (that is, the data undergoing validation) to a "precision" result obtained from some other source, for which there is good reason to believe that this source is substantially more accurate than the "regular" SSA data that are being submitted. In such a situation, the error in the precision data can be reasonably presumed to be negligible, and a comparison between the submitted and precision data can be taken as a statement of the submitted data's actual error. One must decide, of course, how large of an error is acceptable; but in principle the error tolerance can be derived from the requirements for the intended astrodynamics application.
- To look for in-family behavior among the submitted data and a number of additional, independent data sources. This "crowd-sourcing" method of validation presumes that a number of different data providers have essentially the same capabilities so that errant information will stand apart from the "crowd" of other data, perhaps confirmed as outliers through a formal statistical test. No actual statement of submitted data error is produced here, but some would see that as precisely the virtue of this approach, namely that it purports to distinguish good from bad data without the need of a direct error calculation against an established truth criterion.

The second of the above approaches seems initially more attractive, but in the context of actual SSA validation it has generally proven problematic. First, in order to attempt it at all, one must have a number of different data reporting sources for a particular object in order to compare them in ensemble fashion to try to determine in-family behavior. For the GEO orbit regime, in which there are presently multiple commercial data vendors, this approach might be possible, although it should be emphasized that one truly needs many submissions, not just two or three, in order

durably to establish in-family behavior and therefore outliers. In the LEO orbit regime, at least at present, there are not enough available, independent sources of SSA data for space debris, which is the most prevalent type of secondary object encountered during conjunction assessment and the object type for which additional data are most strongly needed, to make this approach possible. Since it is LEO that presents the greatest risk for conjunction assessment mishaps, an approach that is not applicable to this orbital region cannot truly serve as the basis for an ecumenical validation method. Second, and more fundamental, "outliers," such as they are, sometimes represent not errant information but a more advanced and accurate measurement or prediction. An innovative technique that, for example, identifies and removes measurement or systematic errors can represent an advance over competitors and therefore produce a notably different result; such data would at first appear as outliers but after more specialized analysis might be shown to be the most accurate. This phenomenon has been borne out at the Sprint Advanced Concept Training (SAC-T) exercises (sponsored by US Space Command and OSC), in which for certain taskings more innovative commercial actors have submitted superior solutions to those from the remainder of the participants; these submissions initially appeared errant but after more thorough inspection were ultimately established as superior. Finally, the characterization of results as in-family or out-of-family, though grounded in statistical analysis, will in the end be a matter of judgment by a subject matter expert because that individual must set the in-family/out-of-family thresholds for the statistical tests applied; so there is a level of subjectivity in this approach that cannot be eliminated. For these reasons, ensemble analysis historically has not promoted itself as the method of choice for SSA validation.

One is thus inclined to return to the first method proposed above, namely the comparison of submitted data to external precision data. Sources of precision data outside of the DoD space catalogue do exist, and in fact they are used by the DoD for calibration activities for its own sensors and processes. The best known of these is a set of designated calibration satellites deployed to be tracked by the International Laser Ranging Service (ILRS). The highly-accurate laser-ranged observations produced by this international consortium of trackers on these specialized satellites produce ephemerides of centimeter-level accuracy (accurate enough to be used by the Earth crustal dynamics community to measure continental drift), which are ideal for assessing sensor measurement errors and ephemeris errors for these particular satellites. A less accurate, but still quite serviceable, source of external precision data is the definitive ephemerides for certain operational spacecraft that possess high-quality on-board GPS receivers; these ephemerides can often be generated to meters of accuracy. The owners of such spacecraft must, of course, be willing to produce and share these ephemerides; but there are a number of civil and commercial satellites that do this regularly. These two precision data sources can be used to establish a quite attractive set of reference ephemerides, apart from any DoD data, for the evaluation of commercial SSA measurements and commercially-provided definitive/predicted ephemerides.

While an excellent start on a collection of precision data for a validation activity, these external data do have unfortunate limits, especially in LEO. The number of ILRS satellites in LEO is on the order of 25, and presently-available civil/commercial ephemerides for validation might be as large as 50, for a total of 75 objects. While this may seem like a large number, in fact it is a rather small number when one considers that these spacecraft tend to be large (thus easy to track) and placed in more easily-maintained orbits. The true test of a credible space

catalogue is its ability to maintain space debris, which are small, dim, in unusual orbits, and have unfavorable area-to-mass ratios that substantially complicate the non-conservative force solutions; objects of this type are both hard to track and, even if tracked, difficult to model astrodynamically. Small debris constitutes the majority object type in the LEO space catalogue, the debris field from the 2007 Chinese ASAT test is starting more substantially to decay down into more populated orbital regions, and any additional major collision in LEO can be expected to produce several thousand more such objects. Any validation or evaluation of a commercial SSA capability must place its emphasis on the vendor's ability to maintain objects of this type.

At present, the only viable approach to conduct an evaluation of commercial data for such objects is to compare commercial sensor measurements and constructed orbits for representative debris objects to those produced by the DoD. The DoD catalogue is often broadly maligned in the critical and commercial literature; but on the whole, the catalogue, though not perfect, is of a very high quality, and this fact is commonly recognized in the national and international CA community (the response to Question 10 speaks to this issue at much greater length). Additionally, to monitor the quality of its catalogue, the DoD has deployed a capability to construct a reference orbit for every catalogued object (fusing ephemeris data taken from the fit-spans of moving-window orbit corrections); and while these orbits are not as accurate as ILRS or owner-operator reference orbits, they are nearly always accurate enough to allow the evaluation of predicted ephemerides, to wit: the prediction error for, say, a two-day forward satellite position prediction is so much larger than the error in these constructed reference orbits that one can largely neglect the reference orbits' inherent error. It is thus possible to evaluate commercial SSA predicted orbits, and DoD predicted orbits as well, against these DoD reference orbits, giving evaluation information both in an absolute sense and in comparison to the DoD predictive capability. Because all of the orbital safety calculations take place in prediction (that is, one is always calculating which conjunctions will take place some period of time in the future—a necessary approach so that an owner/operator could actually take action to mitigate them), and because most conjunctions take place with space debris as the secondary object, the most meaningful validation test for commercial SSA products is to evaluate the performance of predicted states and covariances for debris objects. The DoD catalogue's constructed reference orbits on debris objects are at present the only large-scale source of the quasi-truth data required for this evaluation.

In summary, there are indeed data sources outside of the DoD that can serve as a basis for a full validation activity of commercial sensor measurement data and a partial validation of commercial SSA predicted ephemeris construction. However, for a full validation of commercial SSA performance for the most prevalent and problematic LEO orbits, the only viable approach at present is to look to DoD catalogue products.

Question 4: What have been the barriers or challenges to updating federal SSA capabilities at the DOD, and how might they be overcome as SSA functions are transitioned to a civilian agency?

Elevator Speech Response

The DoD SSA capabilities for expanded orbital safety fall short of what might be fully desired in two ways: first, their sensor certification process is too protracted and monolithic, impeding the use of commercial tracking data in cases where it would be helpful; and second, their data classification management approach prevents customer-driven requests and near-real-time furnishing of products. Because the OSC system will incorporate a more flexible data evaluation process, which should allow more rapid initial certification and regular evaluation of commercial submissions, and because their system will work only with unclassified information, which will allow direct interaction between the user portal and the astrodynamics algorithm locus, neither of these difficulties should inhere with the OSC instantiation.

Full Response

The myriad difficulties in upgrading the DoD space catalogue maintenance system have been considerable; and a full treatment of this subject would be a substantial undertaking yet only tangentially relevant to the current discussion—except for the main conclusion that fielding SSA systems is more of an algorithmic than a computer science problem and must be treated as such. But in limiting the discussion to orbital safety, there are two areas in which the DoD framework has encountered difficulties: in a very narrow sense regarding product quality, and in a much grander sense regarding tool and product availability. Each of these areas is discussed separately below.

As has been stated with some frequency in this testimony, the quality of the DoD orbital safety products is in general very good; and this view is broadly endorsed by both US and international CA operators. One area, however, in which difficulties can be encountered is the tracking of small debris objects. Because these objects themselves are small and often difficult to acquire, and because they often occupy unusual orbits for which orbit maintenance is more difficult, they remain the purview of more sensitive tracking sensors and tend to receive tracking less frequently. This difficulty is not encountered with larger objects, which are trackable by nearly all of the SSN sensors and usually observed close to the point at which a CA risk mitigation maneuver decision must be made (the maneuver commitment point, or MCP); so for conjunctions between large objects, additional commercial tracking data is likely to be only occasionally helpful. The opposite is true for conjunctions with small debris as the secondary object; in these cases, additional commercial tracking data would be extremely welcome and often allow an earlier dismissal of potentially problematic events. It would be very helpful for the DoD to make use of commercial SSA data in such cases, but the methodology the DoD presently employs for certifying external data is too burdensome and protracted to make this possible: their certification process, which is tailored for occasional addition of SSN sensors who will then be part of the SSN for a long period, is monolithic, manual in approach, and not configured for regular revisit and efficient evaluations. Similarly, because submitted SSA

measurement data require regular sensor calibration to be fully useful in orbit determination, another process problem is encountered: the current DoD sensor calibration toolsets are operated by analysts and require a manual calibration solution for each sensor. Because some commercial SSA data providers furnish information from hundreds of sensors, the current DoD system is not equipped to manage commercial SSA data from such sources.

Fortunately, neither of these impediments should apply to an OSC STM system. Because a military mission is not in play, the OSC can take a more flexible approach to data validation and certification so as to ensure no data degradation, performing less expansive (and automation-enabled) validation activities and conducting them at regular intervals, rather than merely at system onboarding and then never formally revisited. An external contractor can be secured to conduct these validation activities, allowing them to be more routine. Similarly, either a more automated approach to sensor calibration can be developed (the DoD is already in the process of securing one), or part of the commercial data purchase process can include sensor calibration, so long as that process be reviewed and supervised in some way by the OSC in order to ensure data integrity. In short, the main impediment to improved DoD orbital safety product quality, which is the need for additional tracking for small debris objects, can be addressed by the OSC without expecting to encounter the same retarding forces as the DoD.

Regarding orbital safety tool and product availability, the principal impediment to producing orbital safety products more frequently (and ideally on demand) is the classification disjunction between the unclassified portal for data exchange (www.Space-Track.org) and the classified DoD processing system on which SSN data reside and on which all calculations are performed. The DoD's air-gap classification management approach for orbital safety products is an effective data protection mechanism, but it has engendered a batch-run approach to product production, thus resulting in less frequent updates and difficulties in responding in near-real-time to O/O support requests. These shortcomings, such as they are, arise not due to deficiencies in the DoD processing *per se* but the way in which the orbital safety data transfer to and from their operational system is handled.

Beginning with an unclassified dataset, as the OSC intends to do by requiring declassification of DoD data before receiving them on their STM system, should allow all of these particular problems to be avoided. Regardless of whether the SSA data are on the front-door system that interacts with users or on a more remote system, so long as both systems be unclassified, gateways between them can be established to allow the automated moving of data, requesting of services, and export of outputs. Similarly, there is no algorithmic reason why software applications such as CA screenings or CA risk assessment evaluations cannot be invoked on an on-demand basis; it is merely a question of configuring the OSC software to be able to operate in this way.

In short, the impediments that have prevented the DoD from moving to a more data-rich, responsive STM system are artifacts of both military policies and the DoD data classification system, neither of which will be in play on an unclassified civil system. While miscarriage is always a live possibility with a government acquisition, the basic parameters of how the civil system wishes to operate should obviate most of the difficulties that have presented the DoD from realizing a more elaborate and responsive orbital safety system.

Question 5: Given NASA's role in conducting SSA for its own space assets, how important is NASA's expertise to helping inform the transition to a civil SSA capability? How might NASA contribute to or be involved in the transition to a civil SSA capability?

Elevator Speech Response

NASA began modern orbital safety operations in 1992 under the Shuttle program, and for almost twenty years it has performed, at the enterprise level, CA / orbital safety operations, CA operational system maintenance, and CA research and development. NASA is already retained by OSC through an IAA to provide technical support and IV&V for their STM effort. Their role in supporting the development of the OSC's SSA capability could be as the acquisition authority (the standard arrangement by which NOAA, the OSC's parent organization, obtains their satellites) or as the system engineer and IV&V for an OSC-managed acquisition. In both cases, the expected activity is to obtain and integrate commercial capabilities rather than perform traditional custom development.

Full Response

While in principle the OSC could attempt to develop an STM capability without NASA's assistance, it would be a great mistake to do so; for NASA possesses unique experience and capabilities to assist with such an effort. The particular areas in which NASA has much to offer the STM initiative include the following:

- Long CA history. Conjunction assessment began at NASA more than thirty years ago with the Shuttle program, for which many of the basic CA algorithms and practices were developed. NASA CA practice was extended beyond human space flight (HSF) assets to all NASA satellites more than fifteen years ago. Key individuals presently serving in both the NASA HSF and uncrewed object CA enterprises have occupied roles in these groups since the projects' inceptions and thus have a rich corporate knowledge of this mission area.
- Significant CA operations. NASA presently protects over eighty active payloads in all of the major orbit regimes, and its continuous period of CA operations has allowed the development of robust CA best practices. Many of these practices are now documented in the *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook* (2020), but there are other aspects of the mission that are not formally documented and are preserved only as "oral history." It will be very helpful to have access to the individuals who possess this knowledge, as the OSC (NOAA) does not indigenously protect their own satellites, presently relying on NASA and specialty contractors for this service.
- Deep CA research and development bench. NASA HSF and uncrewed CA projects have published dozens of peer-reviewed journal articles and conference papers on CA topics. All the major CA algorithms that NASA uses, along with drivers and test cases, have been posted on a public-facing, open-source software repository for anyone to download, free of charge—this is the main mechanism for sharing the results of NASA CA research

to improve safety-of-flight for all space operators. NASA possesses the subject matter experts to evaluate industry-proposed algorithms and thus enable prudent acquisition decisions, as well as perform the numerical validation required to allow operational certification of commercial algorithms. Finally, if there is to be a continuous research and development aspect to the OSC STM effort, there would be a certain wisdom in asking NASA to serve as the direct management for this effort; as an agency that oversees and executes basic and applied research as part of its mission, NASA is well equipped to perform this function and already has decades of experience in commissioning and executing CA R&D activities.

- CA operational system development experience. The NASA CARA project has developed an operational system (Conjunction Analysis System, or CAS) to perform CA risk assessment and event management, including interfacing with individual NASA owners/operators. Recently, this system was refactored to allow it to perform its operational support functions from the Cloud, and current operations are now being conducted from this Cloud instantiation. NASA is thus poised to support all phases of a CA system acquisition: requirements definition, algorithm selection, software integration, and test/validation, all within a Cloud-based framework.

For all of these reasons, it is recommended that NASA be heavily involved in the process of defining, obtaining, and validating the OSC STM system.

While there are a number of different forms that NASA involvement could take, there are two possibilities that would seem the most compatible with current NASA structures:

- NASA-managed acquisition. It is a regular arrangement for NOAA satellites to be acquired for the Department of Commerce by NASA. NOAA provides the basic requirements for the spacecraft and the appropriate funding to NASA, and NASA develops the full set of requirements, performs the system engineering, awards a development contract, manages the development, verifies the system and accepts it from the contractor, and operates the system for an initial exercise period before turning it over formally to NOAA. A similar arrangement could be followed for an STM system, although instead of a custom development of a complete system it would constitute the development of a framework into which commercial software would be selected and hosted. NASA would also assist in the selection, integration, and validation of the commercial software.
- NASA system engineering. If OSC prefers to manage the acquisition themselves or hire an integrating contractor to perform this role, then NASA's involvement would be more modest. However, it is still recommended that NASA contribute heavily to the system technical requirements definition, participate as an advisor in the system engineering process directing the acquisition, and be the appointed independent numerical validation authority for the initial and subsequent major deliveries until the system reaches FOC.

Question 6: In your written testimony, you highlight the need for improvement in orbital safety for autonomously-operated satellites. What issues do autonomously operated satellites present for SSA and orbital safety?

a. How should a transition to a civil SSA capability plan and prepare for challenges related to autonomously-operated satellites?
b. What technical or R&D solutions could be explored to help resolve these issues?

Elevator Speech Response

Autonomously-controlled satellites break current orbital safety paradigms, especially when two different, autonomously-controlled satellites operate in proximity to each other. NASA is presently leading a government-industry partnership (which includes SpaceX, the operator of the large, autonomously-controlled Starlink constellation) to develop an orbital safety solution for this particular problem and will exercise it during an extended-mission experimental period for the upcoming NASA Starling mission—a small, autonomously-controlled constellation to be collocated with Starlink. There are two different solution types presently under consideration. To choose definitively the best solution and refine it appropriately for operations, a medium-fidelity STM simulation is required; this would be an excellent OSC R&D activity.

Full Response

The question of autonomous CA was treated in abbreviated form in the written testimony, but a more complete statement of the situation will be given here so that the full import of the issues can be explicated and discussed.

For satellites with traditional, ground-based, human-overseen flight dynamics, CA mitigation actions are presently handled in a manner that allows for active coordination with other O/Os and confirmatory actions with the screening authority (typically the 18 SDS). For conjunctions between a protected active satellite and a secondary object that is a piece of space debris, if a mitigation action is warranted there is obviously no need for active coordination with the secondary object. However, because the CDM information used to inform the choice of a mitigation action is always subject to last-minute update (if, for example, new tracking information has been very recently received), and in any case is derived from analysis of the present nominal orbit and not one that includes the contemplated mitigation action, it is a recommended best practice to form an ephemeris that contains the proposed mitigation action (usually a maneuver) and submit this ephemeris for CA screening before executing the mitigation action. Screening the maneuver before it is executed ensures that the proposed mitigation action fully mitigates the main conjunction and that this intended trajectory change not introduce any new problematic conjunctions with other objects. When the secondary object is, instead of a debris object, itself an active payload, direct coordination between the two owner/operators is necessary to determine which of the two will act to mitigate the conjunction and what sort of mitigation action will be selected. Failure to pursue this latter coordination could result in the two owners/operators choosing maneuvers that cause the two satellites to

collide. As noted in the written testimony, a version of this scenario is what actually took place in the well-known 2009 Iridium-COSMOS collision, in which the Iridium satellite maneuvered into the COSMOS trajectory.

The flight control paradigm for autonomously-controlled spacecraft, in which all flight dynamics decisions are made on board the satellite, with no necessary pre-approval from the ground station (and often notification of actions to the ground station after maneuvers have already been executed), is not directly compatible with the above CA approach. For serious conjunctions with a debris object as the secondary, an autonomously-controlled satellite can select and execute mitigation actions without any ground contact at all, and therefore certainly without a pre-screening of the maneuver ephemeris to ensure its efficacy and safety. It is true that, if the screening volume used to produce CDMs is sufficiently large, then the autonomous spacecraft should have through these CDMs a temporary snapshot of the space catalogue in its immediate vicinity. Therefore, any maneuvers it plans can be evaluated against the secondary object states in this set of CDMs to ensure that no fresh serious conjunctions will be produced by the satellite's intended trajectory change. The success of this approach, however, relies on a low-latency transfer of updated CDM information to the autonomous spacecraft. When the secondary object is a non-autonomous active satellite, then additional special procedures are required: namely, this active secondary will need to refrain from any trajectory changes within about 24 hours (given current data latency times) to the time of closest approach (TCA) in order to be sure that the autonomously-controlled spacecraft possess the secondary object's correct position information upon which to base any mitigation actions. This procedure, while broadly functional, is often seen as an imposition on the active secondary object, which must now restrict its flight trajectory options for the convenience of the autonomous satellite. It is also an imprecise approach in that only the autonomous satellite has a complete sense of its own present and future position, so it is not always completely clear to the O/O of the active secondary object whether and when to implement a position freeze.

But when both primary and secondary objects are autonomously-controlled satellites, as would be the case should two constellations that employ autonomous control ever be present in the same orbit regime, then the problem becomes intractable. Because there is no direct communication of maneuver intentions, two such satellites could each maneuver to avoid separate pieces of debris and maneuver into each other. Similarly, if two such satellites each determine they have a conjunction with each other, they could both select mitigation actions that subsequently cause a collision between them. Again, maneuvering into another satellite's oncoming trajectory is not a mere phantasm of overzealous safety engineers—it is in large measure what transpired to produce the Iridium-COSMOS collision.

As the question implies, the OSC must prepare its STM system and CONOPS to address all the parts of the particular safety problem that autonomous satellite control introduces. The process has, however, been jump-started by the problem's having arisen practically and somewhat ironically (especially given the nomenclature): a NASA experimental constellation built by NASA's Space Technology Mission Directorate to test autonomous flight dynamics/control and autonomous constellation reconfiguration (the "Starling" mission) will, due to its planned ride-share, be essentially collocated with the "Starlink" constellation fielded by SpaceX, which also uses autonomous control. There is thus a specific identified need to

develop a safety solution that can be applied to this particular situation, which is also serving as a prescient opportunity to see if the fielded solution can be expanded to the more general case and thus serve as a pathfinder to a broader solution that the OSC can adopt.

To address this problem, a consortium was formed among NASA CARA (the group that performs CA for NASA uncrewed spacecraft), NASA Ames (the NASA center developing the Starling mission), Emergent Space Technologies (the contractor developing the autonomous control software for the Starling mission), UT Austin (the entity providing astrodynamics consulting and services to the Starling mission), and SpaceX (the operator of the Starlink constellation) to develop an appropriate solution, build out the needed software and ground node, and test the paradigm during the planned extended mission portion of the Starling mission. This consortium is an excellent example of a public-private partnership to develop STM solutions that will work well for both government and industrial space actors. The OSC has participated in plenary meetings of this consortium in an observer capacity. While the consortium has not yet reached any durable decisions, they have identified two principal, but rather different, approaches to addressing the problem.

The first approach focuses on mediated coordination among autonomous spacecraft. When an autonomous spacecraft wishes to make a trajectory change, the desired change is packaged into an ephemeris and submitted to a ground node that contains all of the predicted ephemerides for all of the participating autonomously-controlled satellites. The ground node rapidly screens this newly-submitted ephemeris; and if no serious conjunctions are found between it and any of the other ephemerides in its repository, it "certifies" the submitted ephemeris and communicates this certification to the satellite. That satellite now has both a right to follow this new ephemeris and, accordingly, also an obligation to follow it unless the satellite submits a different ephemeris and has that different ephemeris certified. If, alternatively, a serious conjunction is found during the screening, then the ephemeris is rejected; and the satellite cannot perform the desired maneuver and must choose another and submit that for certification. This approach appears to be robust at its core; but it requires not a small amount of supporting infrastructure, both on the part of the autonomous systems (namely the production and processing external permission requirements and needed frequent communication with their ground stations) and the "ground node" required to perform rapid screenings and manage ephemeris certifications/rejections.

A second approach is a rather different kind of solution: it seeks to define rules for spacecraft encounters that would render all expected trajectory changes predictable, obviating the need for direct communication of spacecraft intention. Foundational to this approach is a broad exchange of spacecraft ephemerides and CDMs so that each autonomous satellite would know the nominal future positions in all of the conjunctions for all other such spacecraft. Rules would then be defined that would govern, with great precision, how an autonomous spacecraft would perform their own orbit maintenance and respond to conjunctions with debris objects, active spacecraft, and autonomous spacecraft. Because each autonomous spacecraft would know precisely how every other autonomous spacecraft would respond to conjunctions with debris and with each other, courses of action can be selected that can be known to be safe without the need for communication of intention. This approach is much simpler regarding communications and adjudication infrastructure, but it is substantially more complicated in that each autonomous

satellite now needs to perform CA computations for all other autonomous satellites rather than relying on a central authority such as the OSC, meaning that each operator would need the infrastructure to do its own screenings. This would be a large technical and resource burden on each operator, many of which are small companies or educational entities who may not have the needed resources. It is also not clear whether a rule set can be developed that properly accommodates all conjunction possibilities.

By participating as an observer in the consortium's technical activities, the OSC is already properly preparing themselves to accommodate a solution to the autonomous satellite CA question within their STM system. The general question of autonomously-controlled satellite orbital safety would, however, be an excellent funded R&D project for a university or national laboratory. One particular item that the consortium's work has revealed is the utility of—actually, the compelling need for—a medium- to high-fidelity STM simulation in which different proposals and rule sets for problems such as these can be defined and then simulated to reveal their efficacy, burdens, and unintended consequences. No research group is presently known to have a mature model of this type, although some do have more embryonic versions. It is expected that such a simulation, in addition to playing an important role in the development of a solution to the question of autonomously-controlled satellite orbital safety, would be extremely useful for nearly all of the technical and policy questions that need to be addressed in order to develop a robust STM capability. Its development should be a major initiative in the OSC's R&D portfolio.

Question 7: During the hearing, the issue of proprietary SSA commercial data and transparency was discussed. What, in your view, are the key factors that need to be considered regarding commercial data and transparency, and how might those factors be addressed?

Elevator Speech Response

An excessive proprietary posture by commercial SSA providers can cause difficulties in two ways. First it can lead these providers to sell only SSA products, not measurement data (which they consider proprietary); and there is no good technical solution at present for fusing SSA products (rather than measurements) from multiple vendors into an ensemble solution. Second, it can lead providers to limit insight into their product generation algorithm base (viewing it as a trade secret) and thus perpetuating an objection presently levied on the DoD. There is no straightforward approach to mitigating the effects of an excessive proprietary posture in either of these areas; but in the latter case, rigorous validation could decrease the need for more algorithmic insight by demonstrating that the algorithms work well in all contexts.

Full Response

The question of proprietary SSA data and transparency has two different aspects. One strain of the problem is an impetus within some parts of the commercial SSA industry to sell only high-level products and services, with the actual commercial SSA measurement data not available for sale and thus retained as a proprietary holding. A second aspect is the proprietary nature of commercial SSA algorithms and a resulting lack of transparency into how calculations are actually performed. These two aspects of the question will be discussed separately below.

The DoD collects a large amount of SSA data and produces a large number of related products; and while they are not without error or occasional corruption, on the whole the DoD measurement data and precision product set is quite good. The best use of all the data that the USG may acquire, both DoD and commercial, is to combine these datasets to produce single integrated set of orbital safety products, thus obtaining the full benefit of both datasets. The broad consensus among astrodynamicists is that the best way to combine SSA data is at the measurement level. In a sense, this is what the DoD is already doing when it combines data from many different SSN sensors into a single orbit determination (OD) run; and so long as the sensor data are well calibrated, the OD takes account of the relative quality of different measurements in generating an optimized orbit fit. This same procedure is easily extended to the combination of SSN and commercial SSA measurement data: so long as both data types be well calibrated, they can be combined into a single OD, with a single and known set of force models, to produce a single vector that can then be predicted into the future with the propagator associated with the OD (it is important to propagate vectors with the exact same force modeling used during the orbit determination).

While a straightforward and astrodynamically-preferable solution, the sale of measurement data cuts against the business model of many commercial SSA data providers. Selling the measurement data ends the supply chain, especially if these data are then used by the

USG to produce products that are given out as a free service. Selling products and services can allow the reuse of these same measurement data for many different applications, each of which produces a marketable product. If the commercial SSA sector declines to sell measurement data as a matter of policy, then the OSC will need to explore other methods to try to realize the advantages of combining DoD and commercial data.

Unfortunately, at least given the present state of the research, the outlook for such methods is not particularly sanguine. There are proposals in the scientific literature for methods of combining SSA products, such as ephemerides, into a single, more accurate ephemeris; but these approaches remain largely untested, and they require as a prerequisite that the covariances contained in the ephemerides be extremely accurate, which is a standard not consistently met in the SSA community. One can step away from requiring a single solution and attempt "ensemble solutions," in which the multiple solutions are all displayed and the owner/operator is left to navigate these unitegrated items. It is not at all clear how an owner/operator should go about doing this. If all of the solutions indicate a single course of action—perhaps for a given event all show a probability of collision (Pc) above a threshold that would require mitigation—then the situation is straightforward; but it is also true that the decision would not have been any different had only one of those solutions been purchased, rather than many. If the solution set is divided—perhaps two results counsel mitigation and three do not—does one go with the majority? To be conservative, if even one solution counsels mitigation, should that constitute the course of action? Given that outliers and errant solutions are not uncommon in SSA, this level of conservatism will produce a large number of unnecessary CA mitigation actions; and one of the stated goals of a new civil STM system is to reduce the number of false alarms and thus unnecessary maneuvering. Finally, one could try to develop more complex order-of-precedence logic to determine which solution should be favored in which circumstance; but this would require a significant validation effort, and it is not at all unlikely that a single source would consistently emerge the winner, making all the other submitted solutions essentially without value, since they would not be helpful or heeded in virtually all cases.

The conclusion from the above is that if it is not possible to obtain SSA measurement data from multiple sources but only products, then there is not a clear technical and operational way forward to use multiple products in a helpful way. The processing and operational use of multiple independent solutions is another ripe area for a university or national laboratory research and development effort. It would, however, not be responsible to move forward with a STM concept of operations grounded on acquiring multiple solutions until a viable method for adjudicating such situations meaningfully and consistently has been established.

* * *

A second aspect to commercial SSA transparency is algorithmic transparency, in which users be given appropriate insight into the algorithms used to produce SSA data and products. On this score, DoD CDM production has been the subject of much criticism. Indeed, the DoD has not been publicly forthcoming about the details of their astrodynamics algorithm set—and they scarcely could be, given that many of the algorithms are categorized as ITAR and/or CUI—but it should be remarked that nonetheless there is a surprising amount of information in the

CDM describing the astroydnamics situation for each of the two satellites, including tracking densities, force model applications, parameter values, and correction goodness-of-fit indices. At the same time, there is a certain justice to the broader criticism that it is often difficult to know precisely how to interpret the DoD data because so little is publicly available describing the approaches and algorithms used in its generation.

Ironically, the position of some commercial providers is not appreciably different. Algorithmic details are considered proprietary, and only very general algorithmic descriptions are available to users. Because of the considerable investment in developing specialized astrodynamics algorithms, such a posture is understandable; but it only complicates the civil STM goal of transparency. While the curious would of course wish access to all the details of a provider's algorithm set, and while there is no method for establishing a clear boundary between reasonable and excessive degrees of insight, the two principles described below can perhaps offer some assistance.

First, the more detailed the uncertainty statement accompanying a product, the less one is required to say about the product's generating mechanisms. If, for example, each measurement from a SSA phased-array radar sensor includes a formation covariance that indicates the estimation variances in each observable and their correlations, and this formation covariance can be shown to be representative, then the precise methods the radar uses for initiating track, the number of radar hits used before forming an observation, the degree to which the measurement is off the radar boresight, &c. become far less concerning. In the past, this kind of amplifying information was used to try to gauge the overall quality of the data and the possibility of outliers; with a robust error/uncertainty statement, such insight is no longer necessary. A similar situation inheres with orbit determination products, such as vectors and ephemerides. To be sure, it is very helpful to have certain basic data, such as the kind of information presently provided in the CDM; and the basics of the algorithm used to perform the orbit determination are also appropriate (*e.g.*, the type of filter used, the type of integrator applied, &c.); but if the covariance coming out of the OD can be shown to be realistic, then there is much less strong of a case for requiring the revelation of algorithm specifics. The DoD could in principle address the question of transparency this way; but because it is not permitted to demonstrate publicly the proprietary of its covariances due to data circulation restrictions, this avenue is not available practically. Lower-level processes, such as tracking data association, are probably remote enough from the circulated products themselves that there would not be any abiding expectation to describe these algorithms in detail.

Second, the better the provider fares at meeting delivery expectations, the less need be said about the details of the generating algorithms. For example, if a commercial provider asked to furnish tracking data on particular satellites at certain time-points nearly always meets these requirements, then there is little standing for a user to be given details of the provider's sensor scheduling algorithms. If, however, the provider often fails to meet such requirements, then insight into their scheduling approach is a much more reasonable request in order to understand whether these failures to deliver were in fact unavoidable outcomes or instead due to network mismanagement. Such a dynamic generally arises naturally as providers wish to explain their performance to customers.

These two principles do not, of course, produce direct guidance regarding the amount of transparency that SSA data providers need to furnish; but they do establish a framework by which a provider who wishes to retain substantial proprietary holdings can understand the level of performance he will need to demonstrate, in terms of uncertainty quantification and customer product responsiveness, in order to make a heavy proprietary posture reasonable.

Question 8: NOAA provided a public demonstration of an Open Access Data Repository (OADR) prototype, which comprised past data, over a two-month period, on debris objects and active satellites orbiting Earth. What are the technical challenges of transitioning from a single demonstration of a finite period of time to a system that can accommodate real-time ingestion of tracking data, rapid collision risk analysis, and collision risk notification?

Elevator Speech Response

The OADR prototype was never more than a modest demonstration activity to establish that there are no substantial technical hurdles to performing basic orbital safety calculations in a Cloud-based environment using available astrodynamics algorithms. Because private industry was and is already doing this, namely working within a Cloud environment to take in tracking data, update orbits, and generate orbital safety products rapidly based on user requests, it is clear there are no basic technical challenges that stand in the way of fielding such a capability. The OADR prototype does, however, can serve a useful role in risk reduction: it can be used to work out the regular/rapid declassification and transfer of DoD data, it can identify architecture paradigms that will satisfactorily accommodate different commercial products working together in one Cloud-based system, and it can facilitate the development of a "proving ground" R&D environment to allow rapid evaluation and on-boarding of new commercial capabilities.

Full Response

The OADR prototype that was publicly demonstrated earlier this year was, deliberately, an exercise in modesty. Its purpose was simply to show that the basic technical activity chain of taking DoD SSA data, generating propagated ephemerides, performing CA screenings, and producing warning messages and CA graphical products does not involve any particularly demanding technical challenges. The selected architecture, and the software wrapping activities (such as containerization) used to deploy the multiple algorithms needed to perform the basic safety calculations, were chosen to demonstrate that software in different computer languages from multiple originating sources can be assembled into an appropriate processing chain and execute correctly in a modern, Cloud-based environment. These outcomes were not surprising to individuals who have been involved for some years in the CA enterprise, but it was seen as important to demonstrate these facts more broadly. The prototype is quite ill-suited to serve as the basis for an operational system; and it was never the intent of the assemblers, who represent FFRDCs and therefore are statutorily prohibited from competing directly with commercial industry, to advance or promote it for such a function.

At the same time, the prototype baseline can be used in the near-term to perform helpful risk-reduction activities that will need to be addressed regardless of the final architecture. For example, while the OADR prototype did process DoD data, it did not do so at a meaningful operational cadence, with fresh (declassified) updates received and processed frequently. The declassification and export of SSA information, including both vectors and tracking data, from

the classified DoD system to an unclassified system to be operated by the OSC, and the efficient reconstitution of ephemerides on the unclassified system (since predicted satellite ephemerides are far too large to export and transfer efficiently), are challenging activities that require prolonged experience with the DoD data types and current operational system to resolve effectively. There is thus wisdom in working out this data transfer and reconstitution mechanism in advance of commercial participation in the OADR, if for no other reason to remove DoD data and process familiarity from the expertise that any particular vendor needs to possess in order to offer a competitive solution. Additionally, the hosting of multiple astrodynamics packages on a single system creates interoperability challenges; so if this is the solution that the OSC ultimately embraces (namely the purchase of different commercial solutions for different parts of the CA problem), it is necessary to determine how one might assemble such a solution architecturally. The JMS program (a recent attempt to replace the existing DoD SSA system) attempted such a solution and encountered architecture-related difficulties, so it makes sense to work through such problems in a prototype environment in order to guide development of the future OSC operational system, or at the least to be able to identify and choose the best architectural solution among those offered by industrial respondents.

The degree of "transition," therefore, from this prototype system, such as it is, to the framework for the OSC operational system is highly dependent on the acquisition approach that the OSC ultimately chooses to take. If they elect to contract out the entire job to a commercial enterprise, then the prototype will have rather little relevance to the final solution; it will have been helpful in working through the DoD data declassification and transfer mechanism and perhaps presented some architectural findings for the commercial provider to consider, but there will be no transition as such from the prototype to the operational solution. If the OSC elects to assemble its basic service from commercial components but keep the basic service rather modest—along the lines of what the DoD provides presently—then the prototype effort will have been helpful as a pathfinder for the function interface and astrodynamics data interoperability issues presented by the integration of multi-vendor astrodynamics products (these issues tend to be more complex than at first it would appear). If the OSC pursues a component-based commercial products solution and takes an expansive view of the basic service, namely to include CA risk assessment and CA mitigation planning functions, then the number of algorithms to integrate is notably larger; and the prototype may now serve the additional role of testbed for some of these algorithms before the IOC or FOC OSC system.

In all of the above cases, however, the role of this prototype system is minor. It was not constructed to address in any comprehensive way the majority of the architectural problems that must be solved to field an interactive, responsive STM system; and it did not have to, because these problems are not particularly vexing and have been solved already. Commercial vendors have already fielded systems that receive and distribute SSA data and orbital safety products in an automated manner in near-real time, and additionally provide on-demand CA services, such as ephemeris screening and CA risk assessment. Complications arise when one wishes to extract and include complete DoD SSA data (which no commercial entity is presently processing), or when one attempts to assemble commercial software, with proprietary restrictions on viewing/using source code, into a calculation chain that once assembled does not suffer from interoperability issues. These are the types of problems appropriate for the FFRDC prototype effort; but its relevance to the broader solution is limited. Instead, because the general

architectural problems have been solved already in the commercial sphere, both for this mission area and in the wider industry, one can contract for such an architecture framework directly.

Question 9: The Office of Space Commerce plans to take a cloud-based approach to its SSA function through the OADR. What are the opportunities and challenges of a cloud-based approach, and what should be considered in pursuing such an approach? a. What cybersecurity issues should be taken into account?

Elevator Speech Response

NASA moved its orbital safety activities to the Cloud in order to realize the benefits of externally-managed hardware and software tech refresh, dynamically-available processing capability, and inherent hardware fail-over and data backup. The one major cybersecurity issue is the maintenance of two Cloud instances—one on the commercial Cloud for customer interface and product exchange, and one on the Government Cloud to host CUI data and algorithms subject to ITAR restrictions—and an automated gateway between them to ensure unidirectional flow of data while allowing backflow of certain products. Because this gateway does not manage classified but only controlled information, the implementation is reasonably straightforward.

Full Response

There are many advantages to placing an orbital safety operational system in the Cloud rather than on "terrestrial" (meaning "on premises") hardware; in fact, the NASA Conjunction Analysis Risk Assessment program, which provides the orbital safety support for uncrewed NASA space assets, recently refactored their orbital safety operational system to host it on a Cloud platform. The advantages they realized through this action include the following:

- The programmatic and practical burdens of operating system software and hardware tech refresh are eliminated. The Cloud provider keeps the operating system software up to date with patches and, when necessary, operating system upgrades; and they similarly keep hardware repaired and replace aging units with new ones when they have reached the end of their useful life.
- Additional processors can be spun up and spun down as operational processing demands require. With terrestrial hardware, one must physically possess all of the processors that will be needed to meet peak processing demands, meaning that many purchased machines remain idle much of the time. On the Cloud, additional processing can be marshalled when necessary, with usage fees reflecting actual processor use. One can, of course, purchase standing hardware in the Cloud that is not shared in this way; but it is not difficult to design software to manage dynamic processing requirements and thus realize often substantial cost savings.
- Cloud providers can furnish both processing and data back-up, with a large number of different options available depending on how much lag time one is willing to endure in moving from a prime system to a backup system once a failure has been experienced. Data can also be backed up both within a Cloud data center and mirrored at a physically-separated different center, the latter ensuring against loss should an entire Cloud data center experience catastrophic failure. This service obviates the need for an enterprise to create its own non-colocated backup system and ensure that the backup system's database is always current.

- Because the physical processing occurs at a distant center, the operations center can be placed anywhere and run from laptop computers. This allows rapid relocation should an operational center fail, and it easily accommodates telework arrangements.

The main disadvantages are higher costs (in some cases anyway) and perhaps greater cybersecurity requirements; more about the latter will be said presently. But one question that arises *en passant* is why the OSC has felt it necessary to specify peremptorily, before a formal set of requirements has been assembled and analyzed, that their architecture will be Cloud-based. As is implied by the set of advantages catalogued above, a Cloud-based architecture has much to recommend it and indeed is probably the best choice for this particular application; but it would seem preferable to let a requirements-based analysis determine what the best architecture solution will be rather than specifying at the very beginning of an acquisition process what in all honesty is a detail of implementation.

Before discussing the issue of cybersecurity directly, it is helpful to point out that the OSC's Cloud-based implementation is likely to be a two-tiered Cloud solution, with a public-facing portion placed on the commercial Cloud and a private portion hosted on the Government Cloud. The Government Cloud will probably be the entity of choice for storage and processing of DoD data: the DoD is likely to require at least this level of data protection for bulk storage of DoD precision catalogue and metric observations; and because a DoD propagator will be required for forward prediction of DoD vectors (theory compatibility between vector and propagator is necessary in order to produce fully accurate products) and this propagator is ITAR, the Government Cloud is a necessary platform to host and use this software. At the same time, it is not possible to place the entire system on the Government Cloud because a large number of OADR users will be foreign nationals, and foreign nationals cannot access the Government Cloud. NASA CARA has adopted a two-tier Cloud solution due to these same issues: ITAR software is required for certain calculations, but NASA also has joint missions with foreign space agencies who need to access the NASA system for orbital safety products.

If, therefore, one presumes that a two-tiered system will be implemented by OSC, then the cybersecurity concerns are greatly lessened. The public-facing Cloud system, placed on the commercial Cloud, will not contain restricted data or algorithms; these will reside on the Government Cloud system. To be sure, there will need to be a software gateway between these two systems to transfer data and processing requests to the calculation side and to return orbital safety products to the public-facing side. However, given that only certain formatted products will be coming back from the Government Cloud to the commercial Cloud, the construction of such a gateway is not seen to be a particularly difficult activity, especially because it is not part of a formal multi-level solution between different data classification levels but rather adjudicating different levels of releasability. Protocols exist to address the cybersecurity issues that this arrangement presents.

Question 10: You describe in your written testimony that receiving the position, velocity, and error information on satellites directly from satellite operators is "substantially superior, one might even say essential, for the orbital safety mission." While DOD currently accepts these data from owner-operators, they only do so on a voluntary basis and without any form of quality checking or validation.

a. What would be the added value of a robust validation capability in a civil SSA function, and what would be needed to implement it?

b. To what extent would including satellite owner/operator data on location and velocity in a civil SSA catalogue be advantageous, and what technical capabilities would be needed to accomplish it?

Elevator Speech Response

The main advantage to the use of O/O data in orbital safety calculations is their ability to include future planned maneuvers in their satellite's predicted ephemerides; calculations based on data that do not include these large planned changes in trajectory are of essentially no value for CA. At the same time, the quality of maneuvering satellites' O/O ephemerides is highly variable; and when they are poor, there is no good future position information for such satellites. A validation capability that can certify an O/O's ephemerides to be reliable will allow CA risk assessors to favor solutions based on these ephemerides, which are the only way reliably to perform CA for maneuvering satellites. The validation approach for such ephemerides is straightforward and is described at some length in the response to Question 3; and the OSC has already funded NASA to develop paradigms and toolsets for this purpose, to be used either by OSC themselves or by NASA as the OSC's validation agent.

Full Response

There are two components to producing a good forward-prediction of a satellite's state and covariance. First, the satellite orbit solution, which is typically updated from a previous solution using tracking data, itself needs to be good: there needs to be an acceptable density of quality tracking data, the force modeling and configuration of the correction needs to be properly set up, and there needs to be appropriate goodness-of-fit indices to identify problem fits and require their re-execution. Second, the state propagation approach needs to be robust: it needs to be compatible with the routines that produced the satellite orbit solution it is propagating, it needs to include enough of the force models to produce a high-fidelity product, and covariance propagation needs both to be properly propagated and to be tuned for realism through the application of process noise or consider parameters.

A satellite owner/operator is in a better position to see to the above requirements for their particular spacecraft than is a catalogue maintenance entity (such as the 18 SDS or a commercial SSA provider), who is not intimately familiar with the satellite and does not operate it. First, as most spacecraft possess on-board GPS receivers, they receive nearly-continuous information on the spacecraft's position and velocity—a much higher data rate (and data accuracy) than would

be provided by an SSA sensor observing the satellite. This GPS information can quite straightforwardly be fed into an orbit determination engine to produce a high-fidelity solution for the satellite's orbit, essentially as frequently as the spacecraft operator desires. The accurate state vector and covariance generated by this orbit determination routine can serve as the starting point for the prediction part of the process. For the prediction part as well, the owner/operator has advantages over a catalogue maintenance facility. The modeling of the atmospheric drag that the satellite will encounter (which is the greatest source of prediction error in LEO) is governed by a parameter called the ballistic coefficient—an ensemble parameter that includes the satellite mass, the satellite frontal area, and the degree to which the satellite's surface materials will interact with the gases at the intended orbital altitude (this last item is represented by C_D, the drag coefficient). The owner/operator knows the mass and frontal area quite precisely and can consult established tables to get a good estimate of the C_D; a catalogue maintenance entity would not know any of this and would have to estimate the entire ensemble parameter. By this, the satellite O/O can bring more precision to the satellite drag estimation and in principle obtain a better solution for this (although they will also need an accurate atmospheric density model as well, which is unfortunately not commonly incorporated in satellite O/O's orbit determination routines—this issue is treated at greater length in the response to Question 11).

While the above potential improvements are important, by far the most compelling consideration is the O/O's ability to include planned maneuvers in their predicted ephemerides. If, say, an O/O is planning an impulsive maneuver at 1200 Zulu the next day, the ephemeris point for 1201 Zulu, and all subsequent ephemeris points, will properly represent the new trajectory with this impulsive change included. An ephemeris that does not include this maneuver and one that contains it will diverge more and more widely as the prediction time is increased until the two trajectories become completely different. Because the precise times and sizes of future maneuvers are not known by a catalogue maintenance entity, it is not possible to produce predictions that include these significant perturbations. It is a regular experience at NASA CARA to encounter an ephemeris pair in which CA results from the O/O ephemeris indicate a high-risk conjunction and results from the DoD solution indicate low risk, and vice versa; in most cases, such a divergence is due to the inclusion of a planned maneuver in the O/O ephemeris.

To address Part B of the above question first, the preceding treatment outlines the substantial potential advantages conveyed by the presence of an O/O ephemeris. Indeed, these advantages are very familiar to both NASA and the DoD, who for some years now have been receiving such ephemerides and using them in the CA process. For orbital safety applications, there are no fresh technical capabilities required for their use: given that CA screening routines typically work from satellite ephemerides anyway (to the degree that when DoD solutions are used in CA an ephemeris must first be produced for such solutions), it is straightforward simply to select the O/O ephemeris to represent that satellite's future position rather than an ephemeris generated from a DoD (or commercial SSA provider's) solution. The use of O/O data is thus part of the current enterprise, and commercial providers include these data in their production of orbital safety products much as the DoD does.

Part A of the above question, however, points to what has been an enduring problem: while O/Os are in an excellent position to provide accurate and precise predictive state and

covariance information for their satellites, a full realization of this potential is unfortunately more the exception than the rule. Historically, the principal purpose of on-board navigation (typically via GPS) for most satellites is simply to allow re-acquisition of the satellite by their telemetry systems, an application that does not require a very accurate future prediction and can be performed without producing any uncertainty (covariance) information at all; so the production of accurate predictive position products is not an established part of O/O culture. Additionally, the 18 SDS has not forced the issue because O/O ephemerides are used only for the CA mission (rather than to inform its own internal estimates, for space protection purposes, of these satellites' future positions), and even then the CA results are simply sent to the affected missions to interpret and use—recall that as a matter of policy and liability management the 18 SDS does not perform CA risk assessment; rather, they perform certain enabling calculations and simply forward those data to O/Os for their consideration. Even within NASA, which is an organization that well understands satellite orbit determination and prediction, the predictive ephemerides produced by individual NASA missions often fall short of a quality that makes them suitable for use in CA, sometimes substantially so; and dedicated validation activities and interaction with such missions are necessary in order to improve these products to a level at which they become useful for CA.

Because, as indicated above, the CA results calculated from an O/O ephemeris can differ substantially from those derived from the DoD solution, but at the same time many O/O ephemerides are not actually providing trustworthy future position predictions, it is imperative that some sort of ephemeris validation program be in place so that a CA risk assessor can determine whether to favor the O/O or DoD solution (the same situation would arise, and require the same adjudication, between the O/O solution and the solution generated by a commercial SSA provider). To be sure, given the fact that the O/O solution has the positioning to be a superior solution, the desire is to favor that input; but given the history of poor O/O ephemerides, this desire cannot be indulged without validation results that indicate it is a prudent choice. The DoD solution set has been thoroughly evaluated, and in fact there is an operationally-deployed tool that performs an evaluation of every vector produced by that system for every satellite, at multiple prediction states up to seven days' prediction; so there is an enormous amount of validation data on the DoD catalogue that is routinely examined and used to guide settings changes and processing enhancements (this capability is described at somewhat greater length in the response to Question 3). This does not mean, of course, that every DoD orbit determination update is fully satisfactory from a CA perspective; but it has allowed both a thorough understanding of the products' accuracy and precision and a recognition of which situations tend to be extremely well modeled and which tend to encounter more difficulties.

The good news is that this type of validation has been performed for some time, so there are established methodologies and toolsets for its conduct. The OSC has presently funded NASA to develop, document, and transition a toolset, rubrics, and historical validation scenarios to the OSC so that O/O ephemerides, as well as commercial SSA products, can be evaluated and their ability to contribute to CA risk assessment determined. The OSC may choose to retain NASA as a neutral validation authority, may assume the validation activity indigenously, or may hire a commercial contractor to perform validation. Historically, it has been easier to have government entities perform validation due to the proprietary and sensitive nature of some of the

products under evaluation; but with the proper data protections, these activities could be performed by a number of different entities or actors.

The OSC will also face a policy decision similar to that of the DoD, namely whether they will merely receive, perform calculations, and return results based on O/O ephemerides without inquiry into or regard for their rectitude; or whether they will require a certain level of predicted ephemeris fidelity even to receive and process such ephemerides. Requiring at least a minimum degree of accuracy and precision of O/O ephemerides in order to participate in the CA process, and therefore a level of O/O accountability that at present is not required and often not observed, would bring a needed sense of discipline to the enterprise that would both be salutary for its own sake and can be expected have a spill-over effect into other orbital safety areas—with an increased focus on safety with regard to O/O ephemerides, one could expect a culture of safety-of-flight considerations to promote such thinking in other areas, such as general satellite design. Furthermore, if the OSC will (eventually!) embrace the activity of defining satellite "rules of the road" for safe space operations, such norms have as their foundation an O/O's robust sense of its own future position and the uncertainty of that prediction; so the articulation of at least minimum O/O ephemeris standards early in the process sets up the situation well for the development and promulgation of expected satellite norms of behavior.

Question 11: What are the limitations of the current DOD space object catalogue, and can a civil SSA system address and improve the catalogue? If so, how?

Elevator Speech Response

The current space catalogue is by some renderings incomplete because, due largely to sensing limitations, it has a broad-catalogue size limit of 10cm in LEO; but because objects need to be larger than ~10cm to create collisions that generate large amounts of debris, adding objects in the 3-10cm size range will not appreciably reduce space debris production. Orbit accuracies at the time of update can be improved by adding commercial SSA data; this will be especially helpful in deep-space orbits (MEO, GEO, and some HEO) and for small debris objects in LEO. However, because orbital safety calculations are always performed in prediction, in LEO usable accuracy is also governed by atmospheric density prediction and error modeling; and here the DoD has the best such models currently in operations. Therefore, increased tracking through commercial providers will improve orbital safety in LEO only if at the same time satellite lead times for CA mitigation are shortened to minimize the prediction time for CA products and atmospheric density forecast error can be kept under tight(er) rein.

Full Response

There are three basic ways a space catalogue could be considered deficient. First, a catalogue can lack completeness, meaning that there are space objects of consequence that, for whatever reason, are not included in the catalogue. Generally, this is due to the objects' being too small to obtain the regular sensor tracking that would enable their routine maintenance, but it can also come about intentionally by redacting from the catalogue objects of a certain type or ownership. Second, the state estimates for satellite positions and velocities that the catalogue contains can be insufficiently accurate, or have unrealistic accompanying statements of their estimation error, or both. These state estimates are called epoch states, and the accompanying estimation error statements epoch covariances, because they give the state and uncertainty at a particular epoch time, usually the time of the last sensor observation in the dataset that was used to update the satellite's orbit. The epoch state also represents an "accuracy ceiling" for a given object because the errors will only increase as the object's state is predicted forward in time. Third, the catalogue's forward-predicted orbital products can be insufficiently accurate, and the accompanying covariance can be insufficiently representative, especially in failing to consider errors that are not present during the orbit determination fit but that will arise during orbit prediction. The present treatment will discuss the DoD catalogue with respect to each of the above three areas of potential deficiency, as well as discussing improvement possibilities for each case.

Catalogue Completeness

According to the NASA's space debris website, the DoD space catalogue can be presumed to be complete to object sizes of about 10cm in LEO and about 1m in GEO, although it is known that some SSN sensors are capable of tracking objects smaller than these size thresholds. Certain commercial sensors are similarly capable; and with this commercial capability it is possible to detect, regularly track, and maintain small objects that do not presently appear in the DoD catalogue. Supplementing the DoD catalogue with such objects is called *catalogue augmentation*, and it would allow CA processes to be run against additional orbital hazards and therefore could provide more comprehensive orbital safety protection than using the DoD catalogue alone, without these augmenting objects.

Such an advantage, however, must be placed in a more comprehensive context. It is unlikely in LEO that commercial tracking will ever enable the regular tracking and maintenance of objects smaller than about 2cm—the power, operating frequency, and number of radars necessary to enable such a capability render that possibility cost-prohibitive; at the same time, spacecraft generally can be shielded against impacts from objects only up to 1cm in size without the shielding approaches becoming both mission-crippling and themselves cost-prohibitive. So it is likely that, regardless of the degree of space catalogue augmentation pursued (commercially or otherwise), there will remain a gap between the 1cm shielding threshold and the 2-3cm threshold of objects that can be tracked without extremely expensive radar technology. Based on debris catalogues created by NASA's Orbital Debris Program Office, it is estimated that 70-80% of the space objects larger than 1cm fall in the 1-3cm range, with something on the order of 93% of such objects falling in the 1-10cm range.

These facts create an interesting context for evaluating the orbital safety advantage to augmenting the satellite catalogue. Given that, out of all the objects that could create a lethal conjunction with a protected satellite, only 7% are in the current space catalogue (because only 7% of all the objects larger than the shielding size of 1cm are also larger than 10cm and thus certain to be present in the DoD catalogue), one is prompted to pursue catalogue augmentation to try to increase this rather small percentage. At the same time, however, if ~75% of the objects larger than 1cm and thus able to create a mission-ending collision are themselves smaller than 2-3 cm and thus unlikely ever to be tracked with sufficient regularity to be maintained in a catalogue, then the best one can do via catalogue augmentation is improve the overall percentage value from ~7% to perhaps ~17% (by including all objects down to 2-3cm). This improvement would more than double the number of objects that would be included as part of active CA, and therefore such a move would seem attractive; but even with such a change, it would remain the case that 75% of the objects that could create mission-terminating collisions will not be in any space catalogue and thus cannot be reduced—they constitute a risk that must simply be accepted by flying a satellite. Because this remaining accepted risk is so large, the cost-benefit of pursuing an augmented catalogue for CA would need to be scrutinized carefully. If all of the untracked debris above the level of shielding (1cm) could be added to this catalogue, thus removing the unmitigable risk that they present, there would be a straightforward case for pursuing catalogue augmentation and paying the associated cost; but because even after catalogue augmentation the accepted risk still remains so high, one wonders whether the benefit of reducing that percentage would be worth the cost. This question is especially pressing

because, in most cases, a collision with a satellite smaller than 10cm will not produce a large amount of space debris. If the objective of the OSC's orbital safety role is to protect the space environment from excessive debris pollution in order to preserve its perpetual use, this can be accomplished without a catalogue augmentation: because these "augmentation" objects will not produce large amounts of space debris, then adding them to the catalogue and performing active collision mitigation against them will not appreciably reduce the amount of orbital corridor debris pollution. If the OSC's orbital safety objectives extend beyond this to include mission preservation, then one could justify pursuing catalogue augmentation; but one would want to ask why the US taxpayer is underwriting mission preservation for all satellites, including international satellites, when CA against augmented catalogue objects could be purchased from the commercial providers by the O/Os themselves as an advanced service. It is not a necessary component of a strategy to ensure preservation of the space environment.

Epoch State Error

The accuracy of catalogue objects' state estimate updates is governed by two inputs: suitable modeling of all of the forces that determine the satellite's orbit, and the availability of sufficient tracking data. Because adequate force models for determining satellite precision orbits are available publicly (and often in open-source software), it can be concluded that any commercial SSA provider will have acceptable models for correcting satellite epoch states. Increases in quality are, therefore, principally driven by the amount and quality of tracking data that can be obtained. Any expected improvement over the DoD catalogue would be governed by a commercial provider's ability to improve on the tracking collections by the SSN.

In this forum, one cannot comment in detail on the SSN's performance, but certain general considerations can help to illuminate the overall situation; and the first of these is that the positioning of the commercial sector to provide substantial additional tracking differs by orbit regime. For tracking what in SSA are called "deep space" orbits, meaning MEO, GEO, and most of HEO, the DoD possesses three ground-based optical complexes, a couple of observing satellites, and access to a couple of deep-space radars, whereas some commercial entities have access to hundreds of ground-based telescopes, dispersed around the world to allow both full-orbit tracking and weather redundancy. Based on this difference alone, it would be expected that commercial SSA could provide both augmenting tracking for CA events in progress (especially to fill in gaps where certain parts of a critical orbit might not have coverage) and regularly increased tracking for all objects. Because the size of the covariance is generally inversely proportional to the square root of the number of observations, a notable increase in the tracking density for GEO objects would serve to shrink covariances and, if the shrinking is large enough, allow more CA events to be certified as low-risk and thus discarded.

In LEO, at present the situation is different. The DoD has about ten large-aperture, high-capacity phased-array radars for tracking LEO objects, a notable subgroup of which are able to perform high-capacity small object tracking. Present commercial industry has only a subset of such holdings, and they are less powerful; but they do have the advantage of better worldwide dispersion, for the DoD holdings are mostly in the continental United States. The DoD's considerable radar portfolio means that largish objects in LEO are extremely well tracked, and

for such objects additional commercial tracking is unlikely to make any substantial improvement to orbital safety applications. This is not so much the case for small debris: because these objects are not tracked as frequently and tend to be in orbits that are more difficult to maintain, additional tracking data would here be helpful for small object maintenance; but this advantage would inhere only if the commercial and DoD tracking data were combined, as neither DoD nor commercial SSA will obtain on their own enough data to be fully satisfied with the result.

Overall, supplementary tracking data for satellites in deep-space orbits, and for small debris objects in LEO, would help to improve the DoD catalogue's ability to support certain orbital safety applications. This is not to say that the DoD's solutions for most of these objects are deficient: in nearly all cases, these solutions are good enough both to support sensor reacquisition (the principal accuracy criterion for maintaining a space catalogue) and to enable CA adequately. However, with the supplementary tracking data mentioned above, additional CA events could be determined ultimately to be low-risk and thus dismissed, avoiding superfluous mitigation actions by O/Os.

Prediction Error

It is important to recall that orbital safety calculations, which would include CA screening results and risk assessment parameters such as the probability of collision, are always calculated for the future, not the present: there is little to be gained by informing an O/O that a collision is imminent; instead, a certain amount of warning time is needed in order for the O/O to determine how to react, plan a mitigation action, upload that action to the spacecraft, and execute the action in advance of the potential collision. With older satellites, for which maneuver processing was heavily manual, several days' warning time was required. With modern LEO satellites, the so-called maneuver commitment point (MCP) is now about 12 hours before the predicted time of closest approach (TCA), so typical warning times are now 24-36 hours before TCA to give time for risk analysis and mitigation action selection. This prediction interval is not long by SSA standards; but in those orbits in which atmospheric drag holds a significant presence, predictions of this length will present challenges.

It is true that a satellite's state accuracy at epoch establishes an accuracy ceiling in the sense that forward-predicting that state will only erode the accuracy, never improve it; so it is important to begin with a reasonably-accurate epoch state if one wishes to produce an accurate state in prediction. However, it is also frequently the case that the prediction error, especially for orbits more heavily influenced by atmospheric drag, is so much larger than epoch error that minor, and sometimes even major, improvements in epoch error do not result in an appreciable improvement in prediction error. One must thus be careful in evaluating claims of improvements wrought by supplying increased tracking data: additional tracking data may indeed improve epoch accuracy, but in many orbit regimes this will not meaningfully improve performance in prediction, which is the mode in which orbital safety calculations are performed.

To this end, reducing and quantifying prediction error in the presence of atmospheric drag is one area in which, to improve its performance for orbital safety calculations, the DoD has

made considerable investment. The following three features of the DoD LEO prediction capability do not appear to exist in other precision catalogues:

- Atmospheric density prediction debiasing. A major improvement to the standard atmospheric density models is the application of a debiasing technique called HASDM (High-Accuracy Satellite Drag Model). In the immediate past (*i.e.*, in the last couple of days before the current time), when the actual atmospheric density values are more precisely known, debiasing coefficients to correct the atmospheric density model are solved for, and these coefficients can through a regression technique be applied to the immediate future, thus correcting near-term prediction of the atmospheric density and improving prediction fidelity.[1]
- Atmospheric density forecast error. Despite the debiasing technique described above, it is still very difficult to predict future density values reliably because the density models are fed by space weather indices that describe the level of activity of the sun, and at present these indices are predicted very poorly. It is important, when generating the error estimates (covariances) that describe spacecraft predicted future states, that these covariances include the expected error from mis-guessing the future space weather indices. The DoD has developed a technique for situationally characterizing these errors and applying appropriate corrections to the predicted covariance.[2]
- Satellite Frontal Area Uncertainty. One of the parameters that governs satellite drag acceleration is the satellite's frontal area (as presented to the atmosphere along the orbit). Debris objects that are precessing or rotating are often constantly changing their presented frontal area; and if the rate of precession achieves a certain resonance with the length of the period of data that was used to correct the orbit, the frontal area presented during the fit (and that produced the epoch state) can be quite different from the frontal area that will be presented during prediction, creating a not insignificant error in the drag forecasting. The DoD has developed a technique for identifying such situations and adjusting the predicted covariance appropriately.

The three features discussed above show that prediction accuracy is not a necessary byproduct of increased tracking; instead, the proper astrodynamics modeling must be in place in order improve and properly quantify prediction errors.

An encapsulation of all of this discussion might be that the DoD catalogue, while not perfect, is actually very good; and it is open to notable improvement only in certain bounded areas. It is not as complete as some commercial catalogues may be, but the orbital safety benefit of a somewhat more complete catalogue, at least in terms of protecting orbital corridors from debris pollution, is questionable. Epoch accuracies could be improved by the introduction of commercial SSA data for deep-space orbits (MEO, HEO, GEO) and for small debris objects in LEO; and in some cases the additional accuracy brought by these additional data would allow

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[1] Casali, S.J. and Barker, W.N. "Dynamic Calibration Atmosphere (DCA) for the High Accuracy Satellite Drag Model (HASDM). 2002 AAS/AIAA Astrodynamics Specialist Conference (Paper # 2002-4888), Monterey CA, August 2002.

[2] Casali, S., Hall, D., Snow, D., Hejduk, M., Johnson, L., Skrehart, B., and Baars, L. "Effect of Cross-Correlation of Orbital Error on Probability of Collision Determination." 2018 AAS/AIAA Astrodynamics Specialist Conference (Paper #18-272), Snowbird UT, August 2018.

serious CA events to be dismissed, thus eliminating unnecessary mitigation actions. At the same time, because CA is always performed in prediction, of at least equal importance to reducing epoch error is implementing algorithms and approaches to minimize and characterize prediction error; these approaches vary in method and importance depending on the orbital regime, but in many cases they will supplant increased tracking data in their efficacy in improving state estimates and covariances in propagation. A holistic approach is thus required to improve catalogue accuracy and thus orbital safety products, and it requires both supplemental commercial tracking targeted to particular areas of need and the appropriate algorithms to exploit the benefits of additional tracking fully in state prediction. At present, only a melding of the DoD and commercial approaches could achieve this desired outcome.

Acronym List

Acronym	Definition (and, occasionally, brief explanation)
SSA	Space Situational Awareness
DoD	Department of Defense
CA	Conjunction Assessment; includes screening for conjunctions, collision risk assessment, and collision mitigation planning
O/O	Owner/Operator
OSC	Office of Space Commerce
UCT	Uncorrelated Track
CDM	Conjunction Data Message, the main mechanism for giving conjunction-related information to satellite owners/operators
STM	Space Traffic Management
SPD-3	Space Policy Directive #3
IOC	Initial Operational Capability
OADR	Open Architecture Data Repository
GEO	Geosynchronous orbit, for DoD use defined by an orbital period of 1300 to 1700 minutes, an eccentricity < 0.2, and an inclination < 35 degrees
LEO	Low-Earth Orbit, for DoD use defined by an orbital period < 225 minutes
MEO	Medium-Earth Orbit, for DoD use without a strict definition but generally containing those orbits with an eccentricity < 0.2 and not LEO or GEO (or higher than GEO)
HEO	Highly-Elliptical Orbit, for DoD use defined as an orbit with an eccentricity greater than 0.2.
ITAR	International Traffic in Arms Regulations
CONOPS	Concept of Operations
FOC	Full Operational Capability
SAC-T	Spring Advanced Concept Training
ILRS	International Laser Ranging Service
GPS	Global Positioning System
MCP	Maneuver Commitment Point
SSN	Space Surveillance Network
IV&V	Independent Validation and Verification
IAA	Inter-Agency Agreement
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
HSF	Human Spaceflight
R&D	Research and Development
18 SDS	Eighteenth Space Defense Squadron
TCA	Time of Closest Approach
OD	Orbit Determination
Pc	Probability of Collision
CUI	Controlled Unclassified Information

FFRDC	Federally-Funded Research and Development Center
JMS	JSpOC Mission System
HASDM	High-Accuracy Satellite Drag Model

Responses by Dr. Moriba Jah

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Chairman Beyer
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
Questions for the Record:
7/10/2022

1. *During the question-and-answer portion of the hearing, you spoke about fusing data from many sources to validate and derive accurate space situational awareness (SSA) data. How should SSA data be vetted given the important safety role in which they would be used? Are there existing standards for the data and best practices for validation?*
   Response:
   "Yes. There are existing standards and the formalism is called dimensions of data quality. My recommendation is that whatever the US Government does, specifically through the Department of Commerce, Office of Space Commerce and this open architecture data repository, that two things be done. First, a knowledge graph technology be deployed to do the proper data engineering that can ingest, aggregate, store, manage and curate the required data information and an information provenance schema or ontology be included in this to keep tabs on where data and information came from, which processes touch said data and information, what was done to each piece of data or information, so on and so forth. Along with that information provenance, dimensions of data quality must be applied to all of the data and information within the knowledge graph database for space based objects and events. Examples of these dimensions of data quality would be things like timeliness, accuracy, completeness, uniqueness, consistency and so on and so forth. So, whatever data and information exists in this open architecture data repository represented digitally by means of a knowledge graph database, at least the enterprise level, that the information provenance schema or ontology be implemented and deployed and that each entity, each piece of data or information in said knowledge graph database, be scored against these dimensions of data quality so that the user who then queries this knowledge graph for a variety of reasons, services applications, that sort of stuff related to space situational awareness and space traffic, can know how to actually properly utilize and trust any given piece of data and information within this open architecture data repository. An example of how this has already been done is with AstriaGraph, something that was funded initially by the FA that I developed at the University of Texas at Austin and that has also been successfully transitioned to Privateer Space through WayFinder."

2. *What have been the barriers or challenges to updating federal SSA capabilities at the Department of Defense (DOD), and how might they be overcome as certain SSA functions are planned to be transitioned to a civilian agency?*
   Response:
   "I believe that some of the barriers for updating federal SSA capabilities at the Department of Defense, in no order of importance, are issues with security classification, meaning there may be capabilities that can be developed in completely unclassified environments that could then be implemented in classified environments, but because it's the Department of Defense and there are national security issues, the connotation of the Department of Defense doing research in certain capabilities lead some to feel that there already is a compromise to National Security. I think the Department of Defense can pursue some of these SSA capabilities through a civil entity

that communicates very effectively with it, so then it can get the best of the smartest minds out there with something that was developed with a lot more freedom for innovation. The other thing that I see as a problem in updating the SSA capabilities for the Department of Defense is that the acquisitions process is extremely lethargic. It tends to play by favoritism. The evaluation process for proposals tends to be ad hoc, not rigorous, not comprehensive, and many times done by people who do not have the subject matter expertise or competence to actually review the proposed technology solutions. I'll also say that research and development at the Department of Defense tends to be done in mutual exclusivity from the actual operational systems and products; and because of that, there's inconsistency in the output of the research and development to be able to transition effectively to update SSA capabilities for the DOD. These are reasons that I think hinder the DOD from getting updated SSA capabilities in general. I feel that a civil entity, like the Department of Commerce, could get around some of these things, certainly the classification aspect of things, because it can do things without necessarily all these issues regarding national security, per se, but certainly I also think that the Department of Commerce has an opportunity to engage with the industry and the academic community in such a way to bypass some of this cronyism and the 'Valley of Death' between research and development and implementation of capabilities into products and operational services."

3. *Given NASA's role in conducting SSA for its own space assets, how important is NASA's expertise to helping inform the transition to a civil SSA capability? How might NASA contribute to or be involved in the transition to a civil SSA capability?*
   Response:
   "If I define SSA as being the knowledge required to deter, avoid, operate through, recover from, or attribute cause to the loss, disruption, or degradation of space services, capabilities, or activities, if I define it as such, clearly NASA has done work in this regard to its own assets and I think that experience can definitely be of extreme value added to having a civil SSA capability. I believe that NASA has mostly done this in the context of effects and impacts of the space environment on their assets and in the context of how I just defined SSA and even the human or anthropogenic input to the environment with other satellites and debris. I think that is a knowledge base that's critical to a successful civil SSA capability that NASA brings to bear. I also believe that NASA's role in seeing a successful transition to this SSA civil entity could be in as much as NASA being able to administer an SSA institute and we have precedence for this, and that NASA administers an astrobiology institute whereby research organizations and institutions can be brought into the astrobiology institute for up to 5 years, and renewable depending on measures of performance and these sorts of things, but NASA administers this astrobiology institute where these research institutes and organizations can comprise the membership and perform the work of the institute. I would highly encourage NASA to instantiate an SSA institute much like the astrobiology institute to support the successful transition and long term success of this civil SSA capability."

4. *Low Earth orbit is only becoming more crowded, especially as satellite operators pursue socalled "mega-constellations," systems of hundreds or even thousands of satellites. You mention orbital "carrying capacity" in your written testimony. What is our current understanding of how many satellites can safely operate in a single orbit and the minimum safe separation distance between active satellites? What informs those capacity and separation distance estimates? a. What research is being carried out to examine these issues? b. Are there other considerations specific to mega-constellations for establishing a civil SSA capability?*

Response:
"With regards to orbital carrying capacity, we should define two sustainability metrics. I'll say that space environmentalism and space sustainability are not one in the same thing. When I talk about space environmentalism, I mean looking at the space environment much like an ecosystem: land, air, ocean. So, we can say land, air, ocean and space. This is an environment naturally and with anthropogenic input but basically its the long term preservation of the environment, as an environment itself. Whereas space sustainability really is about humanity's ability to utilize space in peaceful, harmonious ways in perpetuity. So what behaviors lend themselves to achieving that? That said, two sustainability metrics that I'd like to introduce are a space traffic footprint and orbital carrying capacity. The space traffic footprint can be loosely understood as the burden that any given space object poses on the safety and sustainability of everything else. This could be a composite index of multiple factors that come together to basically quantify what this burden is. In essence, if I'm in my car and I start the engine as soon as I put my vehicle in reverse to get out of my driveway, I am now a burden to pedestrians and other drivers. Even if they can predict exactly what my move is going to be and where I am, the fact that they have to account for my existence in order to keep themselves safe constitutes that burden. So it's kind of like a carbon footprint analog, but a composite index that represents that burden. We'll call it a space traffic footprint. The next thing that I'd like to introduce is orbital carrying capacity and this orbital carrying capacity would also have several elements that would go into quantifying it but let's think about what it is that we want for this capacity to represent. In essence, it talks about usability, the ability to utilize orbital space as a resource. So the orbital carrying capacity is saturated or exceeded when our actions and decisions are no longer able to prevent some level of undesirable outcome over some interval of time. For instance, if we do everything in our power to avoid colliding with things and let's say our threshold for collisions is one collison a year, if we pass that threshold where were getting more than one collison a year, even if we try our hardest to avoid it, than we can say that our orbital carrying capacity for that orbit has been exceeded or is saturated. So really, it's a metric that really involves the community to come together to define that threshold for where it gets exceeded or what saturation looks like and that might be orbit regime or orbital highway dependent and so because of that, it's not just about the number of objects, even in the context of so called mega constellations, but it's also the uncertainty with which we understand and can know what those objects are and where they're going to be. So it's really dominated not just by the number of objects, but the uncertainty, the ambiguity or the ignorance in our ability to predict the behaviors of these objects over time and space. I would say those two metrics need to be defined. Is there research going into that? Not much. I'll say that there is work being done by myself at the University of Texas at Austin for sure into these things, some work mostly unfunded. There's some of that also happening at MIT with Professor Danielle Wood and Richard Linares and some initial papers out on that as well. Aside from that, there's some folks at the University of Colorado at Boulder interested in space sustainability where maybe some of this has been brought to their attention as well. That's about it. There is an absence of research in developing these sustainability metrics. I will say that both MIT, Bryce Technologies, and the University of Texas at Austin were part of the inaugural team that worked on the space sustainability rating led by the World Economic Forum now in phase two being led out of the EPFL in Switzerland. Basically, the space sustainability rating incorporates some of these concepts like the space traffic footprint, called the mission index, and carrying capacity, which may be defined a little bit differently. Again, because these are

sustainability metrics, the orbital carrying capacity really needs to measurably demonstrate or be in the context of our ability to utilize any given orbital highway freely, unhindered and in a safe way. It's not about just a number of objects but it's the uncertainties and ability to predict and keep ourselves safe.

5. *During the question-and-answer portion of the hearing, you indicated that the lack of dedicated funding for SSA research constrains the amount of research being done in this area, and that "there definitely needs to be a very serious pool of funding to allow the DOD and other entities to actually engage with academia." What, in your view, has led to the lack of funding for SSA research in the past, and what are the advantages of having a dedicated funding source for SSA research? What level of funding would you estimate is needed for start-up research and development activities?*
Response:
"In my opinion, and given my experience, I will say that what I believe has contributed to the lack of funding in SSA research is that SSA, by and large, is a transdisciplinary problem. Meaning that the solutions have to go across disciplinary boundaries and don't belong in any one given discipline, and so because of that policy work, there hasn't been a lot of research from policy that feeds into SSA even though there are serious policy implications with regards to SSA. The National Science Foundation doesn't admit that SSA has fundamental or basic research questions that need to be addressed which is completely myopic and wrong, actually, because SSA has lots of basic research problems that need to be addressed. NASA has not been given a mandate to conduct SSA research per se, only to do SSA operationally and that sort of thing. So it has suffered because of that. The DOD is really the only real funding in SSA and that funding has been diluted, disparate, and uncoordinated at best. The 'spray and pray' model sort of thing. The DoD research is mostly via SBIR and STTR programs, different organizations, the left hand doesn't know what the right hand is doing, sort of thing. So basically the Airforce Research Lab and the Airforce Office of Scientific Research sort of have been the only real organizations investing in some level of SSA research. That is a very small percentage of the President's budget. Going into these R&D dollars, 3600 colored money kind of stuff. So, that is clearly insufficient. There is also a need to bring in not just the hard sciences but the soft sciences, social science, anthropology, because the behavior of satellites is also driven by humans on the ground which come from different cultures and have different beliefs and different values for utilizing space and that has pretty much been absent from SSA research as well. So this is all to say that yes there needs to be a dedicated pool for SSA research that needs to be transdisciplinary. It needs to have inputs from multiple organizations or entities like an advisory board into the research. It could be done as something like the astrobiology institute that NASA administers; it could be an SSA institute that NASA could also administer since it has a strong science and technology foundation and mandate. I would say funding to the tune of 15 million dollars per year would actually make great advancements in SSA research. I would say that would be the floor of funding, no less than 15 million dollars a year. A lot of good could come as a consequence of that. There is also something called the Critical Path Institute which is a public-private partnership mostly for FDA, Big Pharma and how to accelerate pharmaceutical research to end up in people's medicine cabinets sort of thing. It's had a lot of success and I would also consider that as a model for this SSA institute, this public-private partnership."

6. *Why are standards and best practices for SSA important? a. Who should be involved in standard-setting?*

Response:
"I feel that standards and so-called best practices, which by the way I really dislike the term 'best practices'. I feel that it actually alienates other folks. I prefer to say 'effective' practices instead of 'best' because best says maybe there is nothing better by definition and for the people that aren't doing those things, it says they're not doing best thing, and who gets to define that? I think 'effective practices' is a better term to use. It is a lot more inclusive. So standards and effective practices are important because it helps with transparency, predictability, and the ability to hold people accountable for their behavior. It helps with those three things. Transparency, predictability and accountability all feed into measurable improvements in space safety, security and sustainability. That is why they are important. I don't feel that a group of people should just get together and say what those are, in terms of who sets them. I think it should be set by the community of space operators and practitioners mostly, but certainly informed by other people across humanity that have a stake in space. They should be able to have some input. Just because you don't operate a satellite doesn't mean you have zero say in how space gets utilized when it comes to that, but it is mostly driven by the people that have to operate in that environment. I would say that in order to get to common practice, we need common knowledge and I think that is very uneven across humanity. Out of all those who are space operators, knowledge of space operations is not common. It is very uneven and with huge disparities in ability to do that. I kind of equate it to driver's education. We don't necessarily give everybody who wants to get a driver's license a Lamborghini or anything like that, but we sure try to give them Driver's Education so that the knowledge of driving is common, which can lead toward common practice. Clearly, not every driver has the same skill, so I'm not by any stretch of the imagination saying we need to make sure that all space operators are equally skilled. That is never going to happen, but the knowledge about how to operate efficiently, effectively, and safely, that knowledge should be common across all space operators. That is missing and that is what capacity building, as defined by the United Nations, would aim to do. So the best way, in my opinion, to get to common practice, determining standards, and effective practices for space operations that measurably lead to a space environment that is sustainable, that is safer and more secure, is to get common knowledge to all space operators."

7. What are the limitations of the current DOD space object catalogue, and can a civil SSA system address and improve the catalogue? If so, how?
Response:
"The current DOD space object catalog was never meant to design to, intended to serve the needs of space traffic coordination and management. In fact, the DOD space catalog pretty much represents all objects based on their orbit where possible, of course, something about the country, the operator and that sort of stuff. But, every object is represented effectively as a sphere. All of them are modeled as cannon balls or spheres. Most of these human made objects are not cannon balls or spheres. That is to say that the space object catalog that the DOD has does not in any way shape or form really address the orientation and time history of orientation of objects which makes a difference in how they actually behave and their capabilities and that sort of stuff. It doesn't say much about the size, shape and material properties of these objects. It has a ballistic factor that still represents things as a cannonball not as something that has different shapes, configurations, appendages and that sort of thing. I'll tell you, in one industry or potential industry, that actually needs information about size, shape, material, properties, physical traits, functional, operational, characteristics of space

objects is the In Space Service Assembly and Manufacturing (ISAM) which the White House just put out from the Office of Science and Technology Policy, there was a recent document that came out from the White House on that. That industry has no chance of actually developing and thriving in the absence of a catalog that does not have these characteristics because the technology for in-space servicing assembly and manufacturing will greatly depend on materials, these physical characteristics. What is the structural integrity of something that's been up there 30 years? If I grab it, does it disassemble? That would be bad news. There is no one technology to rule them all like Lord of the Rings. Certain technologies only work for certain tumble rates of objects, for physical traits and characteristics, and there's no place to look that up now. From a policy perspective, the DOD catalog also does not have associated launching states with each country to understand based on international space law codified in conventions and treaties with the United Nations, who is or who is not liable and even jointly liable for any damage or harm that any one of these objects could pose. There's no place to look that up either. So these are all extra parameters or what I would call essential elements of information to support regulation policy and these emerging space commerce markets that we'd love to see exist and thrive. That foundational amount of data and information is missing from the DOD catalog and rightly so, because it was not meant to be that. But, one that could be developed by a civil entity that the Department of Commerce could very much and must, I believe it's critical, that it develop this catalog with all these additional essential elements of information. By the way, in order to actually—because we don't have most of that information, physical characteristics, traits, operational and functional, for most of the human made objects in space that requires dedicated sensors to actually measure and infer these things because if you want to know something, you have to measure it. That means that space object characterization, as understood in the DOD to some extent, there needs to be more work, research and operations dedicated to space object characterization and identification using multimodal sensing both electro optical and radio frequency sensing hypertemporal hyperspectral measurements that can help us infer physical characteristics size shape material properties orientation structural integrity and as well as operational and functional capabilities of these objects to develop this catalog."

Responses by Mr. Andrew D'Uva

Mr. Andrew D'Uva

Answers to Questions for the Record

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

In re: May 12, 2022 hearing entitled

Space Situational Awareness: Guiding the Transition to a Civil Capability

Questions Submitted by Chairman Beyer

1. In your written testimony, you discussed how one of the key interests in moving to a civil space situational awareness (SSA) capability appears to be in establishing a system that can easily accept data from other government, commercial, and international sources. How should these data be vetted given the important safety role in which they would be used?

It's essential that sensor data used to derive "truth" of any solutions be well understood before being used by operators or governments to make decisions in a safety context. This is one reason why, in the long run, reliance on all global operators to "self-report" their locations should be augmented by independent, well-understood sensors, as done today by the U.S. Space Surveillance Network (albeit for non-safety purposes). Today the commercial spacecraft operator and SSA communities have developed best practices, not yet codified into government or international operations or standards, that allow for the validation of sensor observations, orbital ephemerides (positional data), maneuvers, close approaches, neighborhood watch, and Rendezvous and Proximity Operations scenarios. For example:

- The SSA process ingests sensor observations and estimates orbits from them, and innovative sequential filter algorithms are used commercially that inherently identify and automatically de-weight outlier data. This vetting process ensures that out-of-family sensor observations are automatically flagged for further investigation and if necessary, recalibration or quarantine.
- The Space Data Association (SDA) operates its Space Data Center (SDC), which extensively conducts comparative SSA analyses that assess the differences between a wide variety of SSA products and sources to once again flag outliers and notify the spacecraft operator and SSA providers of any identified discrepancies. Often, the cause of such discrepancies is unknown maneuvers which the spacecraft operator conducted, but which the SSA provider(s) were unaware of and did not model.
- SSA providers can also routinely compare their catalog orbit solutions with positionally well-known (or "truth") orbits (such as laser calibration spheres, Wide

Area Augmentation System (WAAS) satellites, and PNT satellites). Such comparisons, while for only a small subset of the overall space population, nevertheless provide valuable insights into the performance and accuracy of SSA systems and data. One must be careful to ensure that such reference orbits are not used in the SSA system's calibration process, which may introduce a confirmation bias into later comparisons.

a. Are there existing standards for the data and for validating it?

Yes. There are two basic ways to ingest data: (1) the Data Lake model, and (2) the standardization approach. While our ultimate goal should be to standardize data formats, terminology, and required elements of information, the fact is that today's flight safety systems are on a "journey" that will require analysis systems to employ both of these methods until such time as all SSA and spacecraft mission systems have adopted an internationally standardized approach. Many spacecraft operators obtain data generated by 3rd party spacecraft mission systems that are essentially a "black box" to some operators, and some lack flexibility or expertise to change data formats, reference frames, etc. This necessarily introduces a long lead time in the ultimate goal of achieving full adoption of standardized space data messages.

The SDC, now in its twelfth year of operations, uses a Data Lake model, which "meets operators where they are" by adopting and ingesting the operator's data in whatever basic or raw format(s) they have natively available. The SDC Operations Team has developed, tested, and operationally maintains approximately forty disparate ephemeris "normalization" converters. Testing by the SDC operators compares spacecraft operator data with independent ephemeris data obtained from 18th Space Defense Squadron to ensure an effective conversion process.

Incorporating a variety of sensor observation formats can also be accomplished via the Data Lake model by U.S. commercial SSA experts; for example, COMSPOC Corporation's ability to ingest observations in any format presented is well-known. This is of particular importance, given that the standardization of observation formats seems to be lagging that of other SSA data format standards while new sensor availability rises.

Meanwhile, numerous standards (sample list below) are already published and freely available, developed collaboratively by government (i.e., NASA) and commercial industry, under the auspices of the Consultative Committee for Space Data Systems (CCSDS). These common set of space data message standards provide a foundational framework for data sharing and exchange by defining the formats, reference frames, timing systems, element sets, conjunction conditions, and spacecraft elements of information that are critical to space safety analyses and decision making.

Table 1 STC-relevant data conveyance needs and standards

	Existing CCSDS messages and related standards										
	Attitude Data Message	Conjunction Data Message	Digital Motion Imagery	Events Message*	Orbit Data Message	Pointing Request Message	Radio Freq & Mod. Systems	Re-entry Data Message	Space Data Link Security Stds	Time Code Formats	Tracking Data Message
Attitude	•				•	•				•	
Conjunctions	•	•			•					•	
Maneuvers					•					•	
Orbit & errors					•					•	
"Phonebook"					•						
Reentry								•			
RF, RFI, Geoloc							•				
RPO/OOS			•		•		•		•		•
Space catalog					•	•				•	•
Space events	•	•		•	•			•		•	•
S/C chars, SoH					•					•	
Sensor trk, obs						•				•	•
STC system									•		

b. What would be the opportunities and challenges of using multiple sources of data in a civil SSA system?

The key opportunity provided is that inaccurate or potentially intentionally misleading data can be immediately discerned and addressed by using multiple sources of data. This single benefit, while seemingly trivial, can often be the critical aspect of obtaining actionable, decision-quality SSA data.

The challenge of using multiple sources of data is that the normalization of such data must be accomplished before it can be used for flight safety purposes. Such normalization must carefully address the different formats used, differences in definitions and terminology, differences in Earth Orientation Parameters (EOP), disparate timing systems and coordinate frames, and differences in units.

2. During the hearing, you indicated that a civilian SSA capability would need to be transparent. How would the potential use of commercial data and services, including any proprietary aspects of those data and services, affect the transparency of a civil SSA capability?

SDA's experience in providing services suggests that transparency across many SSA aspects will be a prerequisite to an adoption by the global space community of any space safety system. Often, reluctance to use a particular solution arises from concern over a lack of transparency regarding its technical algorithms. However, SDA has found through satellite operator discussions that the following areas are of even higher importance for transparency:

- SSA analysis processes and schedules
- Data sources
- Error metrics
- SSA analysis inputs and outputs
- SSA solution quality
- Status of SSA analyses and operations (including outages, upcoming maintenance)

The algorithms used inside of an SSA analysis system can be transparently described in an accompanying math specification which describes the orbit determination, conjunction assessment, and probability estimation functions, while still respecting and protecting the elements of the SSA system that are truly proprietary in nature.

A commercial SSA system can describe the type, quality, and nature of the commercial sensors being used to acquire data as well as the data calibration and processing capabilities without implicating any security concerns that might be associated with a dual-use system (e.g., the Space Surveillance Network).

a. What are the implications of a commercially-based civil SSA system for international data sharing, agreements, and coordination on SSA?

The commercial community has successfully established data sharing arrangements between international operators, governments, and NGOs. Commercial actors can rely on private law agreements (i.e., contracts) to govern arrangements, allocate risk, and rely on well-established dispute resolution forums such as courts or binding arbitration arrangements. A commercially-based civil SSA system can have the positive effect of rapidly enabling and empowering data sharing and coordination. For example, the SDA have operated the SDC system with very high reliability and successfully supported the international community for over a decade, finding that a commercially-led space safety enterprise helps "open doors" to information sharing that military systems are often unable to accomplish due to security or other geopolitical factors.

However, commercial SSA system operators are self-optimizing for efficiency and must remain economically feasible to operate; SDA's experience suggests that for safety-related SSA a pure commercial market, unsupported by public resources, is likely to prove inadequate since a minority of satellite operators have proven unwilling to finance protection of the global space environment. Thus, in my testimony I called for a publicly funded and managed civil SSA capability which would be delivered using established industry capabilities, including commercially-developed software for key SSA functionality.

Numerous sources have described the benefits of using commercially-developed software, when compared with end-user or program-developed software. These include shorter time to operational capability, increased productivity, substantially lower costs, and a very high return on investment.

3. To what extent does the Space Data Association perform quality assessment or validation of submitted space operator data?

Please see my responses above for examples.

To ensure that submitted data is accurate, the SDC has employed a diverse combination of comparative SSA, multi-source identification of outliers, comparison with reference orbits, and application of sequential filters and data fusion for demonstrated advanced OD capabilities. I would be happy to provide further details if desired.

The SDA/COMSPOC/USG/commercial operator/academia collaboration that resulted in a SDA co-authored STCM demonstration paper[1] was, in my opinion, groundbreaking in that it demonstrated (a) the ability to fuse data from government, commercial operators, and commercial SSA providers in order to obtain the best possible accuracy, timeliness, and transparency; (b) the comparison between achieved accuracy and required accuracy, which we have yet to see elsewhere; and (c) the importance of incorporating, as a direct input to the OD and propagation phase of SSA, the operator's planned maneuvers.

4. To what extent are industry organizations supporting the development of standards for space situational awareness data and best practices for related validation, verification, and conjunction analysis?

Industry, particularly in COMSPOC Corporation's Center for Space Standards and Innovation (CSSI) and several of SDA's members, has played a central role in the development of space standards. Those standards mentioned above, originally designed to meet U.S. government agency needs, have now pivoted to ensure that SSA and STC needs (which have not been of primary concern to NASA previously) are addressed as well.

[1] Available at https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/263/SDC8-paper263.pdf

Industry today serves in positions as:

- Head of Delegation for ISO TC20/SC14 (Space Systems)
- Lead author of the draft Space Traffic Coordination (STC) standard;
- Lead author of the Large Constellation Technical Specification;
- Project Lead for and author of the Orbit Data message;
- Co-Project Lead for and co-author of the Conjunction Data Message
- Driving force behind the CCSDS Navigation Working Group's transition to an online set of normative content on the SANA registry (sanaregistry.org).
- Proponent of the future concept for a "super-message" to accommodate the diverse needs for message content within a single message.
- Driving force behind making standardized space data messages "leaner" through the extensive use of optional content.

Question Submitted by Mrs. Kim

1. What are the strengths of non-governmental groups when it comes to facilitating data-sharing between companies? Is the international community more likely to partner with a NGO or the Federal Government?

NGOs have a demonstrated ability to rapidly bring governments and industry to the table -- e.g., to discuss data sharing and proposing new and powerful ways to share data. I highlighted the pathfinding achievements of the Space Data Association, an NGO, in attracting civil, military, and competitive commercial satellite operators to contribute and share data and protect that exchange through a contractual mechanism.

Arguably the leading international SSA conference, AMOS, has been hosted annually for decades by the Maui Economic Development Board, a U.S. 501(c)(3) organization, and is widely attended by U.S. and foreign civil government, military, industry, and academic representatives.[2] AMOS also serves to host a number of critical sidebars and "off the record" quasi-diplomatic sessions. NGOs can often move faster than governments in establishing partnerships as pathfinders for enduring government partnership programs which can be better resourced.

International actors seek to collaborate among peers. My experience suggests that while governments are willing to support NGO activities, enduring partnerships on critical issues tend to be established on a nation-to-nation level. In the space area the U.S. government has a longstanding record of international partnerships and collaboration, particularly through the Departments of State and Commerce, NASA, and, for security matters, the Department of Defense. Ultimately, I expect members of the international community to partner with both the Federal Government and NGOs as each bring different characteristics and solutions.

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[2] See https://amostech.com/

Responses by Mr. Kevin M. O'Connell

Questions for the Record to

Mr. Kevin O'Connell

Submitted by Chairman Beyer

Q: One of the key interests in moving to a civil space situational awareness (SSA) capability appears to be in establishing a system that can easily accept data from other government, commercial, and international sources. How would these data be vetted given the important safety role in which they would be used? Are there existing standards for the data and best practices for validation? What would be the opportunities and challenges of using multiple sources of data in a civil SSA system?

A: One of the most compelling reasons to move to a civil space situational awareness (SSA) capability is the ability to incorporate US government, commercial, and international sources. The primary opportunity is to leverage multiple data sources that are pertinent to spaceflight operations and an improved understanding of how objects behave in space. This is important because of the overwhelming volume of non-maneuverable debris that populates the space environment. The ease of applying state-of-the-art data management and analytic tools in an agile fashion is another, especially as the space environment grows more complex.

The US government has experience establishing third-party standards and validation techniques. As mentioned in my testimony, the Joint Agency Commercial Imagery Evaluation, or JACIE, was established in 2000 between NASA, NGA, and the USGS (Agriculture and NOAA subsequently joined the group) to establish the quality and technical capabilities of commercial imagery satellites to see if they can satisfy important USG missions. The same kind of approach could be applied to SSA for USG missions, such as incorporation into the narrowly scoped "basic" service envisioned in Space Policy Directive -3 (2018).

Any data that becomes incorporated into USG systems (or into commercial systems, for that matter) needs to be vetted and validated for technical accuracy (is the data what it is claimed to be? Are there known errors or uncertainties surrounding the data?) as well as cyber hygiene. Commerce could decide not to purchase data that does not meet minimum cybersecurity and data integrity standards.

One way to do data validation is to have NIST publish continuous co-variance estimates among all publicly available data, including those available on space-track.org. NIST, in partnership with other federal agencies, could also be asked to assess the relative performance of different data sources in different contexts.

No SSA data provider should be required to meet government certification before they can sell data commercially, especially on accuracy and availability. The market will quickly react to those criteria on a commercial basis.

Finally, as we shift from the SSA mission from the US national security community to the US civil community, mainly through the Department of Commerce, it should be noted that the transition will not be considered complete until US government and possibly other stakeholders are completely satisfied with the new system. This is exactly the reason why we should use this moment for maximum experimentation and innovation through leverage of the incredible US commercial ecosystem I described in my testimony.

Submitted by Mrs. Kim

Q: The US government is currently partnering with the private sector to develop best practices, standards, and nonbinding "rules of the road" in two separate areas - commercial human spaceflight safety and rendezvous and proximity operations associated with satellite servicing. Can these models be used for SSA? What is working with these processes and what is not working?

A: The requirement for the US government to partner with the private sector is especially important in areas where the technology is very rapidly outstripping policy and regulatory standards. The United States is one of a few countries where this kind of dialogue is mandated by law. For all parties, the challenge will be to create standards and "rules of the road" that are agile enough to adapt to the blisteringly fast progress of space technologies and the newest space market segments.

From my perspective, the two areas cited in your question are areas where the dialogue is going well, although it should be recognized that consensus – either within industry groups or between the US government and industry – can be complex and hard to achieve. Companies at different maturity levels may have different views of how these best practices and standards either impede or encourage continued growth, whether for their own business or the broader space economy.

The United States has a mature ecosystem of public and private standards organizations, starting with the National Institute of Standards and Technology, or NIST, within the Commerce Department, which has a growing set of capabilities pertinent to space activities. Private and semi-private organizations like the American National Standards Institute, ASTM International, and the Consultative Committee for Space Data Systems are just a few of the organizations that can be leveraged to inform processes on SSA and on the higher-level space traffic management (STM). Active American participation in overseas organizations like the International Organization for Standardization (ISO) on behalf of US and allied interests is also very important.

Q: How could consensus-based standards and best practices be used to influence behavior in space, and what types of voluntary standards, best practices, or norms of behavior would be the easiest to find consensus on?

A: The current tensions caused by Russian aggression in Ukraine, and space-based hostile activities by Russia and China make international agreement on space safety and sustainability unlikely in the United Nations and other diplomatic forums. Ideally, private sector developed standards can establish practical rules for space operators that can ultimately serve as the basis for international diplomatic agreements.

The most urgent kinds of consensus-based standards center around data sharing (e.g., ephemeris, space object design), communications between space operators at risk of collision, protection against inadvertent and purposeful RF interference, and "right of way" rules for different kinds of space objects that are in conjunction. The concept of space traffic management – sometimes referred to as space traffic coordination and management – is as much about allowing space operators to reconcile possible safety hazards on their own or in concert with other space operators as it is about some form of centralized government control function. Extensive international coordination will still be required on a framework for standards, best practices, and norms, however.

Responses by Dr. Mariel Borowitz

Dr. Mariel Borowitz
Associate Professor
Sam Nunn School of International Affairs
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Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
United States House of Representatives

"Space Situational Awareness: Guiding the Transition to a Civil Capability"
April 29, 2022

Questions for the Record

1. What are the factors that should be considered in establishing a civil space situational awareness (SSA) capability that would facilitate coordination with other nations and international entities?
a. What are the current challenges in international coordination and cooperation in space situational awareness and space traffic coordination, and can they be addressed differently in civil versus a Department of Defense (DOD) SSA capability?

One of the challenges in international coordination and cooperation in space situational awareness and space traffic coordination today is the lack of transparency. While the DoD shares a significant amount of information – including the catalog of space objects and conjunction warnings – many international partners find this information insufficient because they don't have insight into how it was generated. The two-line element (TLE) data included in the public catalog is widely recognized as not being of sufficient quality to enable independent conjunction analyses, so its operational value is limited. While conjunction warnings are important, without information on how the warning was produced or the ability to carry out further independent analysis, some satellite operators – particularly those in other nations – are hesitant to rely on these. This has driven some nations to build or improve their own national or regional space situational awareness capabilities. Despite these issues, the DoD has been hesitant to increase transparency in this area. This is not surprising – as an agency focused on national security, providing transparency into its underlying processes and data is not straightforward.

A civil agency, operating a system separate from the DoD, could operate in a much more transparent manner. Because some data will likely still come from the security community, we would not expect to see full transparency. However, with respect to data collected from civil or commercial systems, sharing may be more feasible. Greater transparency with respect to algorithms and models for predicting conjunctions will also be possible. This not only helps to build trust and enable greater cooperation with international partners, it will also allow the United States to better leverage expertise in the academic sector. This transparency with regard to SSA will help to enable greater cooperation with respect to space traffic management, which must operate on a foundation of trusted SSA information.

The DoD has also struggled to develop interoperability standards and capabilities to allow the U.S. military system to efficiently and effectively ingest data from other sources, such as ephemeris data from satellite operators and data from commercial SSA providers, that could significantly improve accuracy. These challenges are related to limitations of the technical systems currently used to analyze this data as well as barriers due to the sensitive security nature of these systems.

Once again, a civil agency developing a new infrastructure to achieve this mission can design its system from the beginning to ingest these types of data. This will allow the civil system to bypass many of the technical challenges that have limited DoD progress on this issue. In addition, although this system will still need to have high standards for data quality and data security, it will not have the same level of security barriers as a system operated by the U.S. military. In this way, it is more akin to our civil weather system – it is a safety-critical operational system, but not a core national security system.

b. How can we leverage international SSA activities to help meet the SSA requirements of US operators?

Accurate space situational awareness information relies on data – data collected from systems in different locations on the ground and in space and systems using different types of technologies. Including more data of more different types improves the capabilities of the system. The United States already ingests data from some international systems, particularly those of close allies, such as the United Kingdom. The U.S. has also been proactive in setting up SSA data sharing agreements with 30 other nations. However, the current agreements primarily focus on facilitating access to U.S. data and enabling better communication. Moving forward, it would be useful to identify options for reciprocal sharing, in which the U.S. would receive and integrate foreign data into its systems. Furthermore, there are opportunities to increase the number of data sharing agreements, both with traditional partners, such as countries in Europe, as well as non-traditional partners, such as nations in South America and Africa that have invested in space surveillance capabilities.

A civil agency will have a greater ability to focus its efforts on building these types of broad international cooperative agreements. As noted in part a, above, a civil agency developing a new SSA system can also specifically design this system to safety and efficiently ingest foreign and commercial data. Improving the U.S. system in this way will improve the quality of services to U.S. operators. In addition, by improving the quality of data and warnings that the U.S. provides global operators, it will help to preserve the U.S. position as the preeminent actor in this space and as the provider of a critical global utility. Finally, more accurate data and warnings ultimately result in fewer in-space collisions and a more safe and sustainable space environment for all space actors.

2. What, in your opinion, can be done to increase and sustain trust among international actors in SSA particularly when countries may estimate collision predictions differently?
a. To what extent will the transition from a DOD to a civilian SSA capability affect the ability of the US to promote trust among international operators?

First, it is worth revisiting the current situation and why it is desirable to increase trust among international actors in SSA. There are currently a wide variety of independent SSA systems, including those run by the United States, the European Union, Russia, China, and India, among others. A number of commercial entities also operate independent SSA systems. Prior research has shown that these systems do not produce the same results in terms of the location of space objects nor the likelihood of collisions among objects. This difference in the estimated location of space objects suggests there are inaccuracies in the existing systems. We should collaborate to minimize these inaccuracies and ensure that the United States provides global spacecraft operators with the best possible data to avoid collisions in space, thus ensuring space safety and sustainability in the near-term.

Looking forward, it is recognized that the growing amount of space activity requires the development of an international space traffic management system, including right of way rules, in the near future. This effort will require a trusted source of SSA data. There must be one authoritative source for generating conjunction warnings and for determining when a conjunction passes a threshold at which a collision avoidance maneuver is required. (If you didn't have this, one actor involved in a potential conjunction might believe action is necessary while another disagrees, thus making quick coordination and action impossible.) Because the United States is the only nation currently providing free global SSA services, it is in a good position to leverage this system as the trusted source underpinning future space traffic management agreements. Thus, generating trust in the U.S. system is a significant step forward in enabling global space traffic management.

From a security perspective, different understandings of activities in space can lead to misinterpretations and miscalculations. For example, it is possible that the diplomatic incident between the United States and China in December 2021 could ultimately be traced to differences in their understanding of the relative location of key space objects. Similar differences in understanding could continue to lead to international issues going forward.

Given these goals, the question is how to improve trust in these systems and how to move toward the development of one trusted system. Increasing trust among international actors can best be achieved through transparency and close collaboration. Engaging in transparency with regard to data and algorithms – following an open science model – allows other actors to understand how SSA data is produced and to verify that the results can be trusted. A civil agency will be better-suited than the U.S. military to develop an SSA system that emphasizes transparency to the greatest extent possible.

However, because a civil system will likely continue to receive at least some data from the U.S. military, full transparency may not be possible. In this case, close collaboration offers another method for generating trust. The U.S. should work closely with other nations – beginning with allies and partners in Europe and India – to compare the results of their national SSA systems and to work together to understand and minimize discrepancies. In science, the ability to independently generate similar results – even using different methods and approaches – is a cornerstone of building confidence in scientific results. The same is true with respect to SSA. By showing that even these independently developed systems are aligned in their perception of outer space activity, partners could generate greater trust in these systems.

Validation activities, carried out transparently through collaboration with international and commercial SSA providers can also contribute to increased trust in the U.S. system. Validation might involve, for example, the United States partnering with a commercial operator to collect high-resolution data of particular objects or locations to validate that the U.S. SSA model had accurately predicted satellite location and/or potential conjunctions. This type of model validation, done in cooperation with other nations, helps to improve trust in the system.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

LETTER SUBMITTED BY REPRESENTATIVE DON BEYER

COMMERCIAL SPACEFLIGHT FEDERATION

May 12, 2022

The Honorable Don Beyer Chair Subcommittee on Space and Aeronautics Committee on Science, Space and Technology U.S. House of Representatives Washington, DC 20515	The Honorable Brian Babin Ranking Member Subcommittee on Space and Aeronautics Committee on Science, Space and Technology U.S. House of Representatives Washington, DC 20515

Dear Chair Beyer and Ranking Member Babin,

The Commercial Spaceflight Federation (CSF) is the leading national trade association for the commercial space industry, with nearly 100 member companies and organizations across the United States. Founded in 2006, CSF is focused on fostering a sustainable and growing space economy that democratizes access to space and space capabilities for scientists, students, civilians, businesses and decision makers. CSF members are responsible for creating tens of thousands of high-tech U.S. jobs driven by billions of dollars in private investment. We appreciate the opportunity to present our members' views on space situational awareness and the importance of space safety and a sustainable space environment.

The U.S. commercial space industry is leading the world today, thanks in part to the public-private partnerships that this Committee has repeatedly supported over the years and continues to support. We are grateful for your ongoing commitment to expanding and maturing this important industry, which is a key element of U.S. technological leadership and global competitiveness.

As a result of private sector innovation, the U.S. is seeing a marked increase in both the number of launches from the United States and the number of satellites—which provide critical capabilities, including broadband internet, earth mapping and environmental monitoring, and many other important services—deployed to orbit. In this domain, our competition is primarily China. With the U.S. now the center of both launch capability—leading the world in commercial launch market share—and the space services market, the importance of ensuring a global commitment to space safety and space sustainability has never been more important.

Space Situational Awareness

Access to accurate and timely space situational awareness (SSA) information is essential to ensuring continued safe operations in space for all users. The U.S. Space Force 18th Space Defense Squadron (18 SDS) collects data from U.S. government sensors worldwide to support a catalogue of over 26,000 objects. 18 SDS supports U.S. government spacecraft operations and publicly releases an unclassified Satellite Catalog along with associated orbit description and positional information for spacecraft and debris as small as 10 centimeters or four inches in diameter. 18 SDS also provides spacecraft operators, both foreign and domestic, with Conjunction Data Messages (CDMs) that indicate potential collision between two objects.

The private sector now surpasses the government in timeliness and actionable information. The commercial and civil space safety mission is, as it should be, a secondary mission for the military systems, which need to be focused on security of space and protecting national assets in space from intentional adversary actions.

To better align agency focus, the Space Force and independent technical authorities, including the National Academy of Public Administration, have recommended that 18 SDS transition unclassified SSA activities for non-U.S.-government users to a separate, civil entity; specifically, the Department of Commerce (DOC). Space Policy Directive-3 (SPD-3) issued guidance four years ago for this transition.

CSF fully endorses this recommendation, as has Congress via recent appropriations bills. The space situational awareness mission is separate and distinct from the regulatory activities performed by the Federal Aviation Administration (FAA), the Federal Communications Commission (FCC), and the National Oceanic and Atmospheric Administration (NOAA), and should be managed by a separate civilian agency. The Department of Commerce has developed a model open architecture data repository (OADR), which was previewed in February 2022.

CSF is disappointed that the Department of Commerce is taking a government development approach instead of embracing and leveraging what private industry has developed over the last decade or more. Today, private industry delivers cargo to the International Space Station, carries astronauts to the ISS, provides imagery to the intelligence community, and is providing timely information on the frontlines of the war in Ukraine. Private industry is more than capable of supporting the space situational awareness mission too.

CSF is also disappointed at the pace of development given the urgency and importance of the mission, but is optimistic that the Department of Commerce will utilize industry inputs on this subject to develop a robust operational capability that fully leverages, rather than competes with, existing commercial capabilities to successfully incorporate

commercially available OADR systems as well as curate, ingest, and fuse both government and commercial data.

Debris Mitigation

CSF is committed to ensuring a sustainable environment in space. Our members are leading the world in developing and safely operating commercial satellites across a variety of orbits. This includes incorporating advanced technologies and procedures such as autonomous collision avoidance, low operating altitudes to minimize persistent debris, and more stringent deorbit timelines than the current 25-year standard.

Despite commercial industry's strong record of sustainable operations, the challenge of orbital debris continues to grow as a direct result of foreign actors, specifically Russia, China, and India. These countries have conducted multiple anti-satellite (ASAT) weapons tests that have contributed thousands of pieces of persistent debris in key orbits. For example, the China's 2007 ASAT test and Russia's 2021 test added more than 5,200 pieces of tracked debris.[1,2] No government should deliberately create space debris. CSF applauds the Administration's recent commitment to not conduct direct ascent, destructive ASAT missile tests and looks forward to working with the United States government moving forward to address space sustainability.

Additionally, these countries routinely fail to passivate rocket stages in orbit or deorbit them at mission conclusion—a requirement levied on all FAA-licensed providers operating from the United States. This negligence results in rocket stages exploding in orbit, sometimes years after a mission nominally ends. These events have also contributed thousands of pieces of problematic debris. Responsible actors, including domestic commercial entities and NASA, have had to engage in hundreds to thousands of maneuvers to avoid debris created by irresponsible actors. CSF respectfully urges the Committee to devote attention to this international element. Any realistic effort to ensure space sustainability must recognize that this shared space must be governed with a uniform set of requirements.

It is also important to note that the Federal Communications Commission (FCC) maintains a role defining orbital debris regulations for U.S.-licensed communications systems. The United States has the most robust orbital debris requirements in the world. CSF encourages the FCC to close the regulatory loophole that enables foreign-licensed systems to waive into the U.S. market without complying with FCC orbital debris regulations. This situation increases risk for all satellite operators—both commercial and government—and an effective space traffic management (STM) regime would be incomplete without a uniform requirement on all companies serving the U.S. market, regardless of country of licensing.

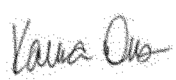
[1] https://celestrak.com/publications/AMOS/2007/AMOS-2007.pdf
[2] https://www.theverge.com/2021/11/19/22791176/russia-asat-satellite-test-space-debris-visualizations

Recommendations

CSF is grateful to the Committee for the opportunity to provide consensus recommendations on these important issues, and we look forward to a continued dialogue to meet our shared goal of a sustainable environment in space.

1. The Department of Commerce should rapidly transition from its current OADR model to an operational system that utilizes existing private sector capabilities instead of competing with the commercial market. Additional delays to this effort could create additional uncertainty for both the U.S. government and commercial users and stands to threaten critical national space-based assets. We encourage Congress to provide the necessary financial resources to the Office of Space Commerce to carry out this mission.
2. In providing SSA services, the Department of Commerce must offer a basic service tier at no cost to the end user, while also ensuring it is not competing with the private sector for more advanced space safety services. This approach represents a commitment to space safety, while also providing commercial companies the opportunity to develop innovative tools that will advance our understanding of space operations and ensure space is sustainable for generations to come.
3. The FCC should close the regulatory loophole that enables foreign-flagged satellite operators serving the U.S. market to avoid complying with strict domestic orbital debris requirements.

Sincerely,



Karina Drees

LETTER SUBMITTED BY MR. KEVIN M. O'CONNELL

October 19, 2021

The Honorable Eddie Bernice Johnson
Chair
Science, Space, and Technology Committee
United States House of Representatives
Washington, DC 20515

The Honorable Frank Lucas
Ranking Member
Science, Space, and Technology Committee
United States House of Representatives
Washington, DC 20515

The Honorable Don Beyer
Chair
Space and Aeronautics Subcommittee
United States House of Representatives
Washington, DC 20515

The Honorable Brian Babin
Ranking Member
Space and Aeronautics Subcommittee
United States House of Representatives
Washington, DC 20515

Re: Congress Needs to Act on Space Traffic Management

Dear Chairwoman Johnson, Ranking Member Lucas, Chairman Beyer, and Ranking Member Babin:

Over the past ten years, two successive U.S. presidential administrations have affirmed the need for the United States to develop a national space traffic management regime. While a few initial steps have been taken, critical elements remain unresolved, which hinders the ability of U.S. industry to anticipate what will be required for the responsible use of space. This is an unacceptable situation only Congress can solve. For example, multiple private companies are at various stages of deploying large constellations of satellites in low Earth orbit. The energy and innovation that private industry is bringing to bear in the expanding economic sphere of low Earth orbit complicates and emphasizes the importance of tracking, management, and coordination not only for other satellites in similar orbits and human spaceflight activities, but also for ensuring that global windows for new space launches and existing air traffic are well understood. In parallel with the exploding commercial interest in orbital activities, adversaries have increased their engagement in space requiring the Department of Defense to focus on a smaller number of orbital events without a corresponding alternative for the commercial sector to draw upon. As space continues to grow in importance as a domain of increasing economic activity, the U.S. government urgently needs to separate the critical national security mission from a civil approach focused on ensuring that science, climate monitoring, commercial development, and human spaceflight activities can flourish in a safe and efficient manner.

The undersigned organizations strongly back implementation of Space Policy Directive-3, which designates the Office of Space Commerce (OSC) in the Department of Commerce as the authoritative government agency to assume the civil role for space traffic management and coordination. The Department of Commerce has a unique mix of capabilities for economic analysis, standards development, and financial tools, such as insurance and tax policies that incent future investment, as well as technical excellence in space weather, cybersecurity, and artificial intelligence, that can comprehensively be brought to bear on this challenge. Several expert studies have also supported this approach and the Department of Commerce has already been given initial authorities and funding to lay the groundwork.

Furthermore, while the public discussions so far have mainly focused on transitioning space situational awareness capabilities, the ultimate goal of enabling a future space economy requires additional actions. Congress also should affirm the Department of Commerce's ability to provide a Mission Authorization function, as outlined in the 2020 National Space Policy. Doing so would create a light touch oversight framework that can say "yes" to the growing number of new and

innovative commercial space activities while ensuring they operate in a safe, responsible, and sustainable manner and also meet U.S. obligations under the Outer Space Treaty.

Finally, for the Office of Space Commerce to be successful in taking on this expanded role, it needs the gravitas and agility to work within the Department of Commerce and across government agencies at the highest levels to coordinate and establish a civil space traffic management regime domestically as well as authoritatively engage in multilateral discussions abroad. To that end, Congress should affirm its support to elevate OSC to report directly to the Office of the Secretary of Commerce and be funded to the appropriate level. Congressional action is urgently needed to provide stability and certainty so that the commercial sector can continue to innovate and experiment with new ventures that create a robust space economy.

Sincerely,

Dan Dumbacher, Executive Director, American Institute of Aeronautics and Astronautics

Ken Hodgkins, President, International Space Enterprise Consultants

Chris Kunstadter, Global Head of Space, AXA XL

Kevin O'Connell, Chief Executive Officer, Space Economy Rising

Steve Oswald, President, Association of Space Explorers – USA

Jeremy Schiel, Vice-Chair, CONFERS Executive Committee

Chris Stone, Senior Fellow for Space Studies, Mitchell Institute for Aerospace Studies

Thomas Stroup, President, Satellite Industry Association

Brian Weeden, Director of Program Planning, Secure World Foundation