Written testimony of Dr. Marcus J. Holzinger
H. Joseph Smead Faculty Fellow, Associate Professor
Ann & H. J. Smead Aerospace Engineering Sciences Department
University of Colorado Boulder

U.S. Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science and Space

Hearing on Space Situational Awareness, Space Traffic Management, and Orbital Debris: Examining Solutions for Emerging Threats

July 22, 2021

Madame Chair, Senator Hickenlooper, and distinguished members of this subcommittee, I thank you for the opportunity and honor of discussing critical problems and opportunities in civil space situational awareness, space traffic management, and orbital debris.

Exponential commercial utilization of space is simultaneously inspiring and terrifying. Even with 'only' 27,000 space objects being sensed, tracked, and deconflicted at any time, the rate of close approaches – once a worrisome novelty – has steadily become a daily occurrence. Worse, there are hundreds of thousands of objects too small to be tracked that can still damage or destroy spacecraft. Human spaceflight has become outright dangerous, necessitating several International Space Station maneuvers annually. Previous National Security Space Strategy (NSSS) statements have called space "congested, contested, and competitive.' This apt phrase captures the truth of what we face in enabling vibrant, prosperous economic utilization of space.

Space Situational Awareness (SSA) and Space Traffic Management (STM) are emerging interdisciplinary fields that focus on how to use radar, telescopes, and other sensors to detect, track, characterize, determine intent, and manage on-orbit space objects. This includes disparate technical disciplines including but not limited to astrodynamics, information theory, control theory, autonomy, electro-optical and radio-frequency systems, machine learning, and human factors / cognitive engineering. Civil SSA / STM focuses on non-defense applications of these capabilities, particularly civil government and commercial spacecraft.

Perhaps a dozen on-orbit collisions have been positively identified, which, combined with anti-satellite tests (ASAT) have led to an explosion of tracked space objects over the past two decades. The number of on-orbit debris are expected to grow for the foreseeable future unless remediation methods are enacted. The overwhelming majority of current space objects are either debris from past misadventures or spacecraft malfunctions. NASA's Orbital Debris Program office suggests that removing up to five large rocket bodies each year could stabilize the debris population[1], however this figure was formed before large commercial constellations began to launch and is likely now an underestimate. Rapidly growing commercial services and resource exploration in space about Earth and near the Moon are increasing the risk of collision and further collateral damage. Our present situation is much like enduring heavy automobile or maritime traffic without a sense of 'right-of-way.'

Yet, for all these dangers, we stand at a truly thrilling precipice. Behind us we see the space domain as the sole province of a few state and commercial actors. Ahead, there are countless opportunities near the Earth, Moon, and beyond that promise economic prosperity, innovation, and rules-based international leadership. The United States government and industry possess the unique and critical means and opportunity to lead the international community in developing SSA / STM norms of behavior and 'rules

[1] https://orbitaldebris.jsc.nasa.gov/remediation/

of the road.' We have a chance to streamline our civil SSA / STM research and development enterprise, producing transformative basic research, economically impactful technology development, and the future workforce necessary to realize substantial prosperity in space. Further, with the recommended transfer of civil SSA / STM to the Department of Commerce (DoC)[2] and the formation of the United States Space Force, now is the right time to articulate clear mission authorizations and domains of responsibility for relevant government entities. Behind each of these opportunities lie shoals of challenges. However, it is my sincere belief that with bold vision and judicious action, we can set the 'rules of the road' and norms of behavior of the space frontier, ensuring a windfall of economic prosperity and peaceful interactions for the majority of this century.

Overcoming the following key challenges will be necessary for us to achieve this outcome.

1. **Rules of the Road and Norms of Behavior.** State and commercial actors in the international community have neither achieved consensus nor adopted safe and commercially viable civil rules of the road and norms of behavior. For such consensus to occur, interested parties must participate directly or indirectly in rule-making; it must be plain to state and commercial actors that such rules benefit them.
2. **Coherent, Coordinated, and Sustained Funding for SSA / STM Innovation.** Our current research funding organizations are neither sufficiently funded nor adequately coordinated to lead academia and industry in basic research, technology development, and workforce for real operational concerns and future needs. Through no fault of the cognizant organizations, the current funding structure is insufficient to solve complex systems of systems challenges in the new and developing field of SSA / STM. Coherent, impactful innovation in SSA / STM and efficient tax dollar use will require inputs from a cadre of government, industry, and academic experts, centers of excellence, and sustained congressional support.
3. **SSA / STM Beyond Earth Orbit.** A rising tide of state and civil missions will be sent to the Moon in the next 5 years. Such missions vary from high profile human spaceflight missions such as Artemis to a variety of ultra-small CubeSat missions led by universities. SpaceX has announced its intentions to send missions to Mars. Our core SSA tools, such as observation association, two-line element (TLE) orbit representation, and initial orbit determination break down in many of these cases[3]. These civil and commercial missions beyond geosynchronous Earth orbit will require any new civil SSA / STM enterprise system to seamlessly handle space objects transferring between and residing within Earth orbit and beyond.
4. **Clear Civil SSA / STM Mission Authorization.** Because of the newness of democratized space commerce activities, unclear / piecemeal SSA / STM roles and responsibilities between DOC, FCC, USSF, and NASA are unavoidable. These gaps and ambiguities impose unnecessary challenges, frictions, and costs in quickly responding to civil space needs and commercial endeavors. Clear civil SSA / STM mission authorizations must be articulated and any inter-agency connections and communications streamlined.

Details on opportunities motivated by these challenges are summarized in the following paragraphs.

---

[2] https://napawash.org/uploads/NAPA_OSC_Final_Report.pdf
[3] M. Holzinger, C. Chow, P. Garretson, A Primer on Cislunar Space, AFRL Space Vehicles Directorate, 23 June, 2021.
https://www.afrl.af.mil/Portals/90/Documents/RV/A%20Primer%20on%20Cislunar%20Space_Dist%20A_PA2021-1271.pdf?ver=vs6e0sE4PuJ51QC-15DEfg%3D%3D

Rules-Based United States Leadership in SSA / STM

How can we develop, implement, and verify compliance for sustainable SSA / STM 'rules of the road' extending to the Moon and beyond? Further, how can we ensure that international state and commercial actors will embrace such practices, rather than skirt or ignore them? Continuing unsustainable SSA / STM practices will quickly lead us to a tragedy of the commons – an unenviable scenario in which space, our common resource, is no longer usable. As with many fields of cooperation, it is clear that international state and commercial actors must ultimately agree to follow any rules of the road and clearly understand how these norms of behavior benefit them directly or indirectly. These ideas are not new, and have been most recently endorsed in a joint statement[4] at the G-7 summit in June 2021.

In the strongest terms, I recommend that the United States demonstrate continued and increasing leadership in SSA / STM. The benefits of United States leadership are manifold with few, if any, drawbacks. Fundamentally, taking this mantle of leadership reinforces and supports continuity of the rules-based system of international cooperation and commerce we have supported for nearly a century. Service and resource exploration commercial activities depend greatly upon predictable requirements, environments, and outcomes to function. With the space economy expected to grow exponentially in the coming decades we can look forward to substantial growth in quality jobs, gross domestic product, and tax base. This growth will be accelerated if the United States decisively promulgates a rules-based SSA / STM system of governance that encourages our space industry to seek commercial opportunities while also protecting the future use of space.

The late Dr. Mark Meaney, founding principal investigator for the CU Boulder Space Sustainability Initiative (SSI)[5], proposed leveraging basic existing frameworks and principles that have been highly successful in applications to other shared commons. Dr. Elinor Ostrom received the 2009 Nobel Memorial Prize in Economic Sciences for her 8-principle framework on sharing common resources (Ostrom, 1990)[6]. These principles are:

- Define clear boundaries of the common resource
- Rules governing the use of common resources should fit local needs and conditions
- As many users of the resource as possible should participate in making decisions regarding usage
- Usage of common resources must be monitored
- Sanctions for violators of the defined rules should be graduated
- Conflicts should be resolved easily and informally
- Higher-level authorities recognize the established rules and self-governance of resource users
- Common resource management should consider regional resource management

Ostrom's framework has been successfully implemented in other applications and may be an excellent set of principles for the United States to use when leading development of a rules-based system of governance.

Finally, much like real estate locations on Earth, there are unique locations in space (i.e., orbits) that can have more commercial value than other locations. This is already demonstrated with geosynchronous orbit and the resulting 'slots' organized and assigned by the International Telecommunication Union. Several researchers have proposed orbit 'slots' for spacecraft in other orbits. In addition to this

[4] http://spaceref.com/news/viewpr.html?pid=57581
[5] https://www.colorado.edu/initiative/space-and-sustainability/
[6] Ostrom, Elinor (1990). Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press. ISBN 978-0-521-40599-7.

consideration, I suggest that the SSA / STM system of governance consider mechanisms similar to real estate zoning for different types of orbits.

Innovation, Workforce Development, and Jobs in SSA / STM

While much good work has been funded by the Air Force Office of Scientific Research (AFOSR), the Air Force Research Laboratory (AFRL), the National Aeronautics and Space Administration (NASA), and others, the resources awarded to SSA / STM research have been insufficient on three fronts: 1) basic research has been chronically underfunded, 2) because of low funding in academia the resulting rates of PhD graduates with expertise in SSA / STM has been in grave deficit compared to demand, and 3) there is little coordination between funding agencies as to what research is needed and pursued. To be absolutely clear, these issues are not due to neglect or malfeasance, but stem from the newness of the SSA / STM field, sharply increasing demand for solutions, and a shortfall in coherent basic research and technology development coordination between all government entities. I have two suggestions that may help address these problems.

Firstly, whichever government entity is ultimately chosen to have mission authority over civil SSA / STM should have, as part of its mandate, some level of access, visibility, and potentially input into research pursued by other entities (such as AFOSR, AFRL, and NASA). We may consider rotating research program officers from these constituent organizations through such a coordination role to maximize knowledge transfer, buy-in, and awareness amongst government-funded research programs in SSA / STM.

Secondly, we must leverage the wisdom and technical expertise of the larger domain of SSA / STM researchers and operational experts. To do so, we should consider following NASA's lead in engaging impartial entities (e.g., the National Research Council, the National Academies, or other groups) to conduct decadal surveys identifying promising avenues of basic research and technology development. To ensure these decadal survey reports capture research opportunities and real operational needs, I propose that government, industry, and academic researchers and practitioners contribute to these reports.

In addition to functional changes in the research enterprise that could result in more quality jobs and transformative research, the following selected topics comprise a non-exhaustive list of high-impact research and operational gaps in SSA, STM, and debris mitigation.

- We must expand the SSA, STM, and debris mitigation enterprise beyond Earth orbit. For example, our core capabilities in observation association and initial orbit determination often break down in multi-body regions. This includes regions about the Earth-Moon system, Earth-Sun Lagrange points, as well as other destinations for both public and private spacecraft.
- Our space object catalog is outdated and struggles to accurately represent states, enable propagation, and represent uncertainty for all but the most traditional cases. When expanding operations beyond geosynchronous orbit, we're asking our existing algorithms to perform tasks there were never designed for. Fundamental and applied technology development is necessary to resolve this. Emphatically, any new catalog representation we choose to adopt should be able to represent all trajectory types, whether in low-Earth orbit or on an interplanetary transfer.
- New results in decision-making under uncertainty for centralized and decentralized sensor networks may fundamentally change our sensor tasking and orbit update processes. We should explore 'real-time' ingestion, fusion, and tasking of sensor data in both centralized and decentralized sensor networks. Such advances would make substantial efficiency improvements and reduce taxpayer burden and/or business overhead costs.

- Space weather has been shown to substantially impact spacecraft operations. New sensors continue to be launched that allow us improvingly timely space weather status and predictions. Integration of real-time space weather in SSA / STM methods should be pursued. An excellent example of collaboration in this topic between the Department of Commerce and academia is the CU Boulder Space Weather Technology, Research, and Education Center (SWx TREC)[7].
- It is completely appropriate for commercial enterprises to wish to retain proprietary methods for autonomous orbit maintenance and collision avoidance. However, we must still ensure safe autonomous spacecraft operations. Work in certifiable algorithms that provide basic proof of safety for autonomously maneuvering spacecraft or constellations must be performed. Such a method could protect commercial intellectual property while demonstrating necessary flight safety certificates.
- Ultimately, fused SSA / STM information must be understood and acted upon by human operators, much like in air traffic control. Our current SSA in USSF operations handle 1-2 thousand active space objects, where in the future we expect 10s of thousands of active space objects, many more of which may maneuver autonomously. Research in human factors must be performed to understand optimal operator workloads, operator algorithm supervision capacity, and trust in autonomous sensor processing, space object management, and sensor tasking systems.

Appropriate Roles for Government, Industry, and Academia

Whether implemented as a coalition in a public-private partnership or as formal elements of the DoC or other government entities, the following roles and responsibilities should reside within government, industry, and academia, respectively.

Government

- Congress needs to clearly articulate Mission Authorization and domains of responsibility for SSA / STM
- Introduce physics-informed operating requirements for different regions in space (e.g., polar sun-synch orbits, geosynchronous orbit, Lagrange points). Consider extension of principles in real estate zoning to these regions. Examples of things to change include our antiquated 20-year deorbit policy is not region-specific. Further, our geosynchronous ‘graveyard orbit’ has been shown to be unstable in the long term.[8]
- Engage with and lead the international community (other governments, industry, and academia) in adoption and acceptance of rules of the road and norms of behavior.
- Support integrated STM sensor processing, space object management, and sensor tasking / observation request system. Consider market-based options for sourcing sensor processing and tasking from 3rd parties
- Public purchase and availability of sensor observations in support of civil SSA / STM
- Streamline and maintain a coherent long-term stable funding source, including Centers of Excellence, to facilitate transformative research, workforce development, and quality job growth
- Participate in SSA / STM decadal survey activities

[7] https://www.colorado.edu/spaceweather/
[8] https://www.nature.com/articles/d41586-018-06170-1

Industry

- Participate heavily in formation and adoption of rules of road, norms of behavior
- Coordinate to propose verification standards for safe operations that don't divulge proprietary techniques & methods
- Participate in SSA / STM decadal survey activities

Academia

- Support research needs in SSA, STM, and debris mitigation for both government and industry
- Lead Centers of Excellence
- Increase PhD and MS workforce in SSA / STM allied areas for government and industry employment, as well as entrepreneurial activities
- Provide impartial algorithm verification and validation services for core SSA / STM activities
- Participate in SSA / STM decadal survey activities

Combined, these actions have real potential to ensure rules-based United States leadership in SSA / STM amongst the international community, improve relevance and efficacy of basic research and technology development efforts, and produce a thriving space economy.

With that summary, Senators Hickenlooper and Cantwell, I thank you again for the opportunity to testify on the criticality of our challenges and opportunities in SSA / STM. The subcommittee's work on this matter has the potential to substantially benefit United States and international civil space endeavors. I would be pleased to answer any questions you or the subcommittee may have.