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Space Situational Awareness: Key Issues in an Evolving Landscape

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

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

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

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

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

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

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

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

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

The steps needed to build a decentralized STM:

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

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

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

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

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

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

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

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

Maritime Law as a Model for Space Traffic Management

Introduction

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

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

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

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

Regulation vs. Control

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

Table 1: Comparison of Maritime and Aviation Authorities

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

Components of STM

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

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

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

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

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

From a governance perspective, maritime law evolved over centuries, but global standards development became institutionalized with the advent of the United Nations. For aviation, the umbrella Chicago Convention is updated through amendment to a series of annexes, while the IMO uses a series of topic specific independent conventions that can be amended as needed. The IMO approach may prove to be more agile to accommodate technical innovation and market changes in space operations.

Debris

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

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

Conclusion

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

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Decentralized Space Traffic Management

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ABSTRACT

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

1. Introduction

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

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

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

2. Definitions

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

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

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

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

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

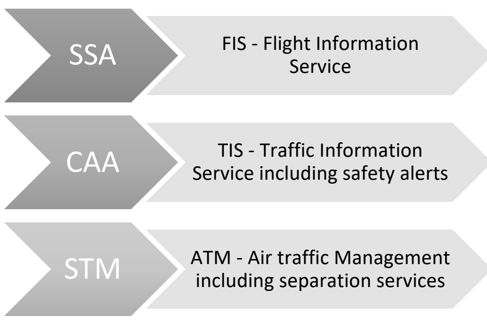

Figure 1: Comparison of terms between STM and ATM

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

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

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

3. Barriers

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

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

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

3.1. *Political*

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

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

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

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

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

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

3.2. *Policy*

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

3.3. *Regulatory Authority*

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

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

3.3.1. *Rules of the Air*

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

Figure 2: Evolution of ATM Collision Avoidance

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

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

4. Concepts for "Near Space" traffic management

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

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

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

5. Policy Model for Decentralized STM

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

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

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

Steps needed to build a decentralized STM

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

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

6. Summary and Conclusion

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

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