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U.S. House of Representatives
"Space Situational Awareness: Key Issues in an Evolving Landscape"
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"*The price of light is less than the cost of darkness*" - Arthur C. Nielsen

1 Introduction to SSA and STM

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

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

2 Defining SSA and STM – What are they?

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

2.1 Space Situational Awareness

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

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

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

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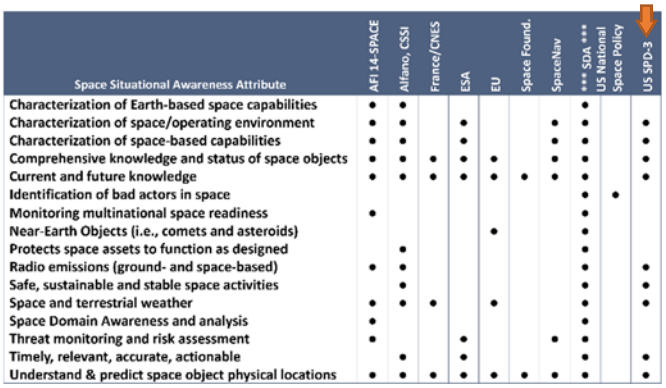
[1] National Space Policy of the United States of America, 28 June 2010.
[2] Alfano, S., Center for Space Standards and Innovation, 2018.

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

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

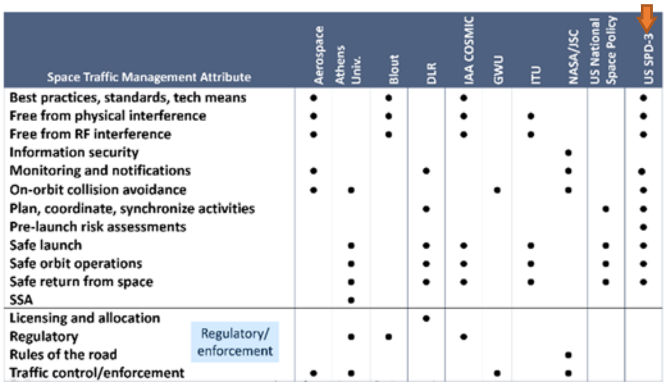
2.2 Space Traffic Management (STM)

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



Space Situational Awareness Attribute	AFI 14-SPACE	Alfano, CSSI	France/CNES	ESA	EU	Space Found.	SpaceNav	*** SDA ***	US National Space Policy	US SPD-3
Characterization of Earth-based space capabilities	●	●						●		
Characterization of space/operating environment	●	●		●			●	●		●
Characterization of space-based capabilities	●	●		●			●	●		●
Comprehensive knowledge and status of space objects	●	●	●	●	●		●	●		●
Current and future knowledge	●	●	●	●	●	●	●	●		●
Identification of bad actors in space								●	●	
Monitoring multinational space readiness	●							●		
Near-Earth Objects (i.e., comets and asteroids)					●			●		
Protects space assets to function as designed		●						●		
Radio emissions (ground- and space-based)	●	●						●		●
Safe, sustainable and stable space activities		●						●		●
Space and terrestrial weather	●	●	●		●			●		●
Space Domain Awareness and analysis	●							●		
Threat monitoring and risk assessment	●			●			●	●		
Timely, relevant, accurate, actionable		●		●				●		●
Understand & predict space object physical locations	●	●	●	●	●	●	●	●		●

Figure 1 Comparison of SSA attribute definitions by source



Space Traffic Management Attribute	Aerospace	Athens Univ.	Blout	DLR	IAA COSMIC	GWU	ITU	NASA/JSC	US National Space Policy	US SPD-3
Best practices, standards, tech means	●		●		●					●
Free from physical interference	●		●		●		●			●
Free from RF interference	●		●		●		●			●
Information security								●		
Monitoring and notifications	●			●				●		●
On-orbit collision avoidance	●	●				●		●		●
Plan, coordinate, synchronize activities				●					●	●
Pre-launch risk assessments										●
Safe launch		●		●	●		●		●	●
Safe orbit operations		●		●	●		●		●	●
Safe return from space		●		●	●		●		●	●
SSA		●								
Licensing and allocation				●						
Regulatory		●	●		●					
Rules of the road								●		
Traffic control/enforcement	●	●				●		●		

Figure 2 Comparison of STM attribute definitions by source.

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

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

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

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

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

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

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

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

3 Status of the space debris environment

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

Figure 3 Overstated space debris (source: Adobe)

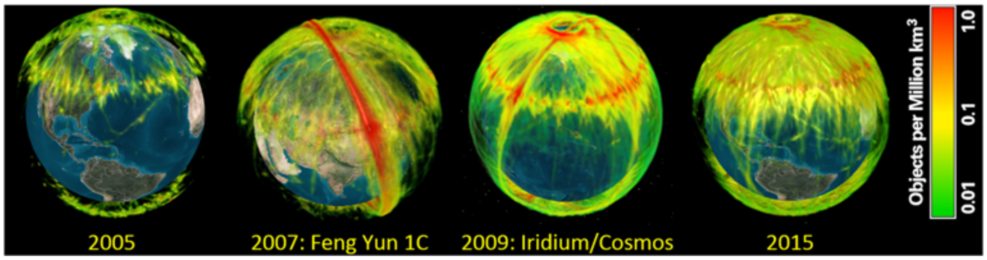

Figure 4 Comparison of STM attribute definitions by source.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

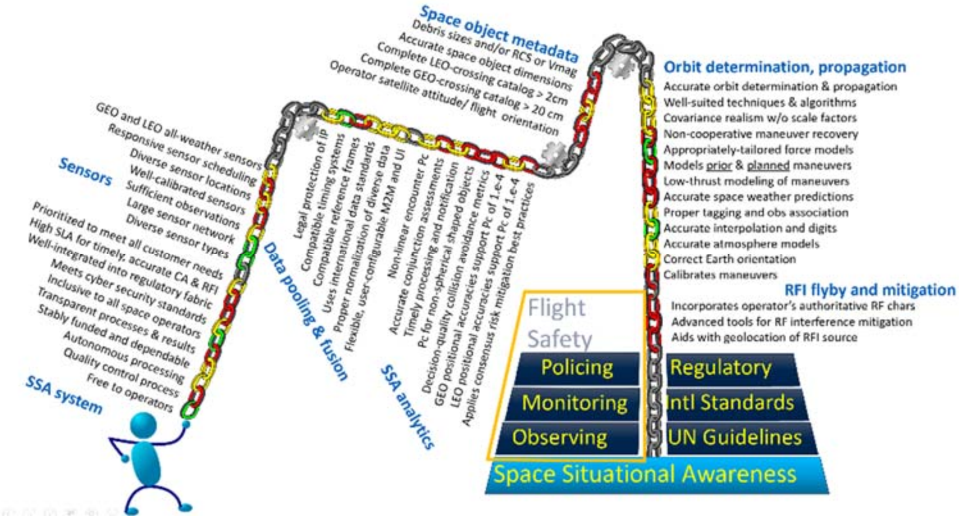

Figure 5 All the components of a comprehensive SSA and STM system

5 Who provides SSA and STM services?

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

5.1 U.S. legacy SSA and STC services

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

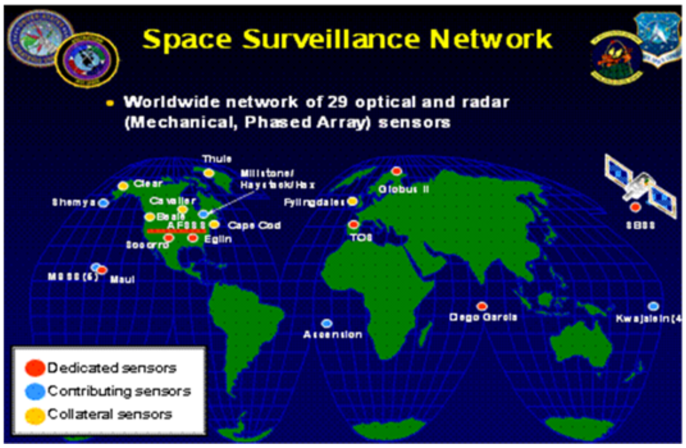

Figure 6 Space Surveillance Network configuration

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

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

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

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

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

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

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

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

5.2 Other global SSA and STC providers

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

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

5.3 Defining the commercial SSA and STM option

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

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

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

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

5.4 Emergence of SSA and STM commercial service providers

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

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

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

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

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

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

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

6 How are conjunctions assessed?

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

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

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

[11] As required by customer.

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

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

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

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

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

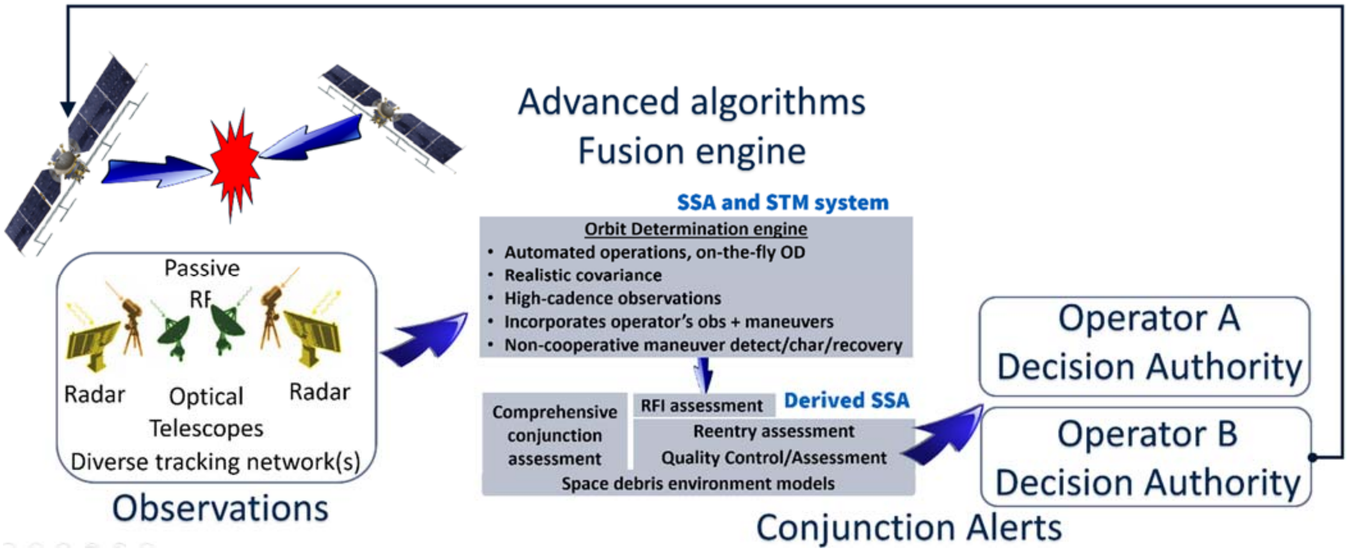

Figure 9 Potential threat, observed by SSA sensors, then orbits are solved, then any potential collision risks are identified. Operators are notified of the collision threat via a Conjunction Data Message. Operator A's mitigation of impending collision threat.

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

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

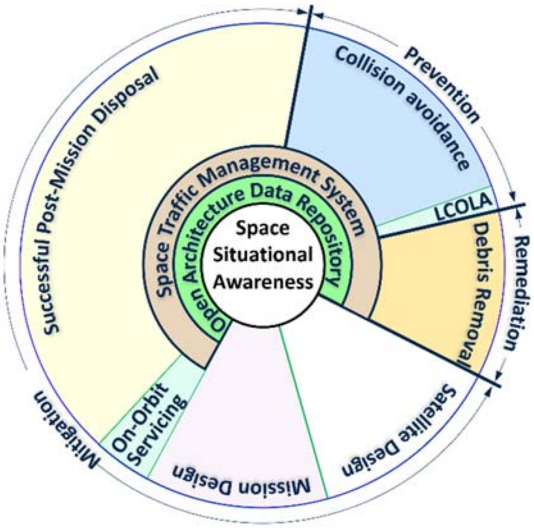

Figure 10 SSA and STM are foundational to all building blocks of long-term sustainability of space activities

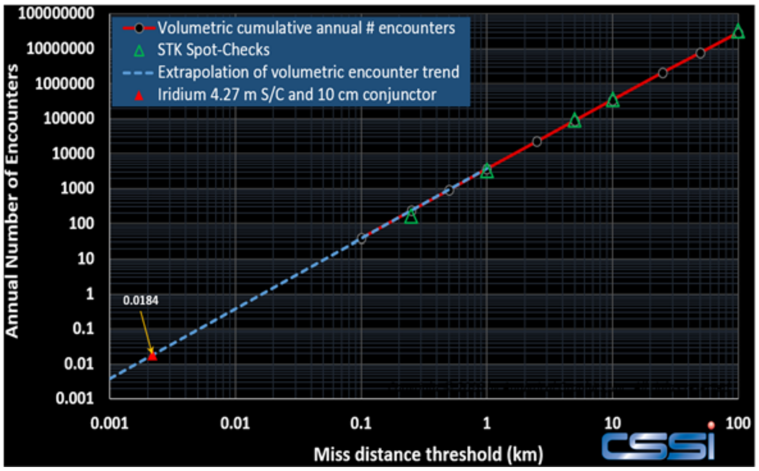

Figure 11 The number of potential threats operators must process depends exclusively upon how accurate SSA predictions are.

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

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

8.1 The current situation is unsustainable

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

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

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

8.2 Potential for a <u>tenfold increase in active satellites</u>

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

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

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

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

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

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

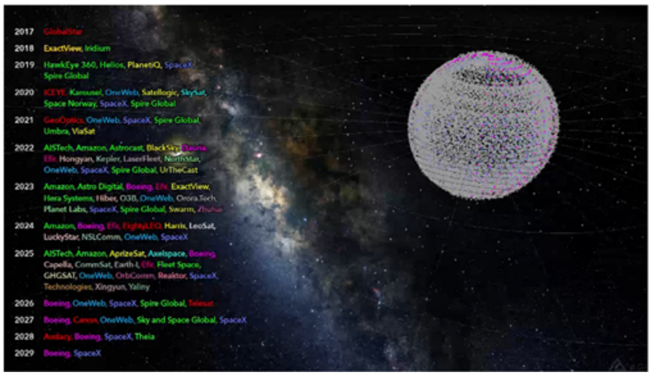
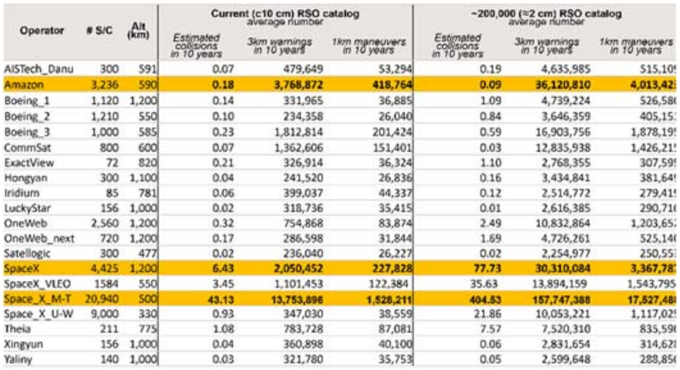


Figure 12 Top 20 large constellations at risk of collision



Operator	# S/C	Alt (km)	Current (c10 cm) RSO catalog average number			~200,000 (≈2 cm) RSO catalog average number		
			Estimated collisions in 10 years	3km warnings in 10 years	1km maneuvers in 10 years	Estimated collisions in 10 years	3km warnings in 10 years	1km maneuvers in 10 years
AISTech_Danu	300	591	0.07	479,649	53,294	0.19	4,635,985	515,10
Amazon	**3,236**	**590**	**0.18**	**3,768,872**	**418,764**	**0.09**	**36,120,810**	**4,013,42**
Boeing_1	1,120	1,200	0.14	331,965	36,885	1.09	4,739,224	526,58
Boeing_2	1,210	550	0.10	234,358	26,040	0.84	3,646,359	405,15
Boeing_3	1,000	585	0.23	1,812,814	201,424	0.59	16,903,756	1,878,19
CommSat	800	600	0.07	1,362,606	151,401	0.03	12,835,938	1,426,21
ExactView	72	820	0.21	326,914	36,324	1.10	2,768,355	307,59
Hongyan	300	1,100	0.04	241,520	26,836	0.16	3,434,841	381,64
Iridium	85	781	0.06	399,037	44,337	0.12	2,514,772	279,41
LuckyStar	156	1,000	0.02	318,736	35,415	0.01	2,616,385	290,71
OneWeb	2,560	1,200	0.32	754,868	83,874	2.49	10,832,864	1,203,65
OneWeb_next	720	1,200	0.17	286,598	31,844	1.69	4,726,261	525,14
Satellogic	300	477	0.02	236,040	26,227	0.02	2,254,977	250,55
SpaceX	**4,425**	**1,200**	**6.43**	**2,050,452**	**227,828**	**77.73**	**30,310,084**	**3,367,78**
SpaceX_VLEO	1584	550	3.45	1,101,453	122,384	35.63	13,894,159	1,543,795
Space_X_M-T	**20,940**	**500**	**43.13**	**13,753,896**	**1,528,211**	**404.53**	**157,747,388**	**17,527,48**
Space_X_U-W	9,000	330	0.93	347,030	38,559	21.86	10,053,221	1,117,02
Theia	211	775	1.08	783,728	87,081	7.57	7,520,310	835,59
Xingyun	156	1,000	0.04	360,898	40,100	0.06	2,831,654	314,62
Yaliny	140	1,000	0.03	321,780	35,753	0.05	2,599,648	288,85

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

8.3 Potential for a tenfold increase in tracked debris

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

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

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

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

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

8.5 More commercial and international space operations centers

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

8.6 Greater need to coordinate space traffic than ever before

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

8.7 More advanced SSA processing algorithms and scalable architectures

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

8.8 Increasing spacecraft and operating complexities

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

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

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

8.9 Increase in the number of space actors

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

9 What's missing in our approach today?

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

9.1 Attributes of a globally-relevant SSA and STM system

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

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

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

10 Suggested approach

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

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

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

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

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

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

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

About Dan Oltrogge

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

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

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

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

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