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SPACE TRAFFIC MANAGEMENT TERMINOLOGY

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Summary

Space traffic management (STM) terminology is not universally harmonized today. The lack of a shared vocabulary stems from the continued evolution of the STM and space traffic coordination (STC) concepts. A shared vocabulary supports accurate comprehension and thus eases efficient communication. Space is international in nature, and, for managing and coordinating space traffic, a standardized vocabulary is necessary for the various actors in the space arena to achieve success.

The International Astronautical Federation (IAF) has several dedicated technical committees, including Technical Committee #26 (TC26), which deals with STM. TC26 was founded in October 2018 following a joint decision between the International Academy of Astronautics, the International Institute of Space Law, and the IAF at the International Astronautical Congress (IAC) in Bremen, Germany. TC26 is producing a white paper, with the final draft expected by the 2022 IAC in Paris, France.

To accomplish this goal, TC26 formed 14 working groups chartered to examine terminology, new means of space object monitoring, improving orbital data, reentry hazards, improving the collision avoidance process, future space operations, new technical regulations, and compliance with existing technical regulations, among other topics. This paper presents the terminology working group's contributions to TC26's white paper. Aspects of this paper may differ from the final white paper, which will be harmonized with the reports developed by the other TC26 working groups.

In the following, we summarize the significance of effective STM, present the causes of the variance in terminology, and highlight the challenges to reaching consensus. We conclude by defining STM-related terms that will inform the final white paper of TC26.

Introduction

Space traffic management (STM) is a topic of much international discussion in the aerospace community.[1,2,3,4,5,6,7,8,9] But what is STM? Various definitions abound.[10,11,12,13,14,15,16,17] We suggest an operational definition, emphasizing STM's activities, especially in comparison with related topics such as space situational awareness (SSA) and space surveillance and tracking (SST).

Context

Subgroup 1 of the International Astronautical Federation STM Technical Committee 26[18] (IAF STM TC) is tasked with STM terminology development and curation. As a quickly evolving concept, STM involves a significant degree of uncertainty and turbidity. For example, there is no formal or internationally accepted vocabulary for STM. The clarification of such concepts, and the resulting potential formation of a shared vocabulary, may help in the maturation of the STM concept and associated disciplines. It will also facilitate communication among interested parties and actors in a future STM ecosystem.[*]

Relevant Terminology

Importance of Terminology

Terminology supports accurate comprehension and thus eases efficient communication, facilitating collaboration among parties and ensuring the success of their coordinated activities. Given the international dimension and complexity of STM, standardization of its terminology is not only beneficial but essential.

Current State of STM Terminology

At present, at least 19 descriptions of STM are found in research articles, journals and conference proceedings to studies, and reports.[13] Some aspects of these descriptions overlap.[11,12,15,16,19] Two early examples are in a 2004 article by Johnson[14] and the 2006 International Academy of Astronautics (IAA) Cosmic Study report.[10]

Definitions of STM frequently include the:

- Regulation of activities.
- Establishment of rules, guidelines, norms, and recommendations.
- Coordination of orbital and orbit-access activities.
- Promotion of safety (in flight and on the ground).
- Assurance of a sustainable orbital spaceflight environment.[12]

Each of these may be expanded with further detail. For example, rules and coordination of orbital activities may include spaceflight traffic rules of the road.

Despite these commonalities, consensus on the lexicons of STM, space traffic coordination (STC), space surveillance and tracking (SST), space environment protection (SEP), space domain awareness (SDA), and SSA is still evolving. This lack of shared vocabulary stems from the continued evolution of the STM and STC concepts, their manifestation in space operations, and the challenges involved in achieving consensus among diverse parties with diverse interests, priorities, and perspectives. In effect, the terms, their definitions, interrelationships, and future concepts for STM system(s) are still being born.

Other disciplines present terms that may overlap, or otherwise be associated with, the concept of STM/STC. Most prominently, this includes astronomy and astronautics. Publications (including academic textbooks, international and regional standards, internal government documents, and private business documents) often provide organization-specific, or even document-specific, glossaries. Some context-dependent variation in the interpretation of language is inevitable, but in the case of STM, this variation is significant.

The boundaries of a potential STM/STC vocabulary can therefore be vague because related terms span a

[*]Note that although the IAF STM TC includes "STM" in its name; we are not prescribing or giving preference to the concept of management over other concepts such as coordination.

range of disciplines that include astronomy, aerospace engineering, space policy, and space law. These points were expressed by the American Institute of Aeronautics and Astronautics (AIAA) STM Working Group,[13] which is also focused on the development of an STM glossary.

In addition to the IAF STM TC26 and the AIAA STM Working Group,[20] work is ongoing to create a living catalog of key spaceflight-related terms with a focus on SSA, SST, and STM/STC.[19] The latter project also aims to provide a neutral, systematic conceptual and semantic analysis to improve existing definitions and terms, identify inaccuracies, and make suggestions for greater precision, comprehension, and consistency (with a computational aspect[21]) for the global community.

International standards development organizations (SDOs) are also focused on developing consensus STM terminology. The Consultative Committee for Space Data Systems (CCSDS) has a web-based database (the SANA registry) for the protocol registries and standards created by CCSDS.[22] The International Organization for Standardization has a web-based online browsing platform[23] that also addresses spaceflight, spacecraft operations, and space safety.[24] CCSDS and ISO's Technical Committee 20, Subcommittee 14, are now collaborating to build consensus terminology for space-related terms. The European Cooperation for Space Standardization (ECSS) has an online glossary for its documents.[25] The improvement and alignment of such vocabularies is no simple task, but collaborative engagement in the international community is already in progress to move terminology in a mutually beneficial direction.

General State of STM Terminology/ Vocabulary Development

There are many kinds of definitions: extensional, intentional, stipulative, ostensive, functional, lexical, etc. A lexical definition, for example, is one that expresses the existing meaning(s) of a word. Given the evolving meaning of STM and considering the overlap among existing definitions, we can extract common features. We can gain insight from functional definitions, which express the functions or purpose of the things denoted by the word being defined. For example, by asking the question, What are the functions of STM?, we can identify operational features that can be expressed in a definition. The same holds true for ostensive definitions, which aim to point to examples; if examples of STM are partly found in the operations of SSA/SST, for instance, we can then identify defining aspects of STM and STC.

Limitations and Challenges

Several challenges associated with terminology are worth mentioning to help manage expectations and express limitations for building consensus. Even when terms have been officially established, meanings can often shift with temporal, sociological, and regional context, both in casual and formal settings (such as technical reports, manuals, research, scientific studies, glossaries, etc.).

Ambiguity in definitions is at times desired and other times an obstacle. For example, ambiguity is exemplified in many space treaties, arguably giving rise to some open and sometimes contentious questions in space policy and law. At the same time, some may argue that ambiguity was intended and is sometimes needed. The boundaries — whether crisp or fuzzy — and the shifting aspects within the STM construct represent another challenge to terminological clarity and development.

Considering these complexities, STM is "is therefore an organizational and operational concept that involves a set of complementary means and measures to enhance the safety of on-orbit operations and to safeguard the long-term sustainability of the space operating environment."[13]

Among the similarities across "STM" definitions, *safety* is (or should be) a fundamental and internationally agreed upon objective of STM. This is a good starting point that all spacefaring nations might agree on.

Technical Description

Definitions of STM-Related Terms

IAF STM TC members recommend harmonization for the following STM-related terms:

- **Collision risk** is the product of the likelihood and consequence of space object collision, either for a single close approach event or in total (aggregated over multiple close approach events).

- **Long-term sustainability (LTS)** is "the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations."[26]

- **Space domain awareness (SDA)** is the effective identification, characterization, and understanding of any factor, passive or active, associated with the space domain (the area surrounding the Earth at altitudes equal to, or greater than, 100 km) that could affect space operations and thereby affect the security, safety, economy, or environment of a nation. (Definition adapted from "Space Power: Doctrine for Space Forces."[27])

- **Space environment preservation (SEP)** is the activity of preserving and sustaining the space operations environment, accomplished by space debris mitigation (including adherence to post-mission lifetime and disposal guidelines and rules, prevention of release of mission-related debris, and collision avoidance) and remediation (including derelict object removal, relocation, and collision prevention).

- **Space situational awareness (SSA)** is "the understanding, knowledge, characterization, and maintained awareness of the space environment: artificial space objects, including spacecraft, rocket bodies, mission-related objects and fragments; natural objects such as asteroids (including Near Earth Objects or NEOs), comets and meteoroids, effects from space weather, including solar activity and radiation[3]; and potential risks to persons and property in space, on the ground and in air space, due to accidental or intentional re-entries, on-orbit explosions and release events, on-orbit collisions, radio frequency interference, and occurrences that could disrupt missions and services." (Modified from U.S. Joint Publication 3-14, "Space Operations."[28])

- **Space surveillance and tracking (SST)** is "the detection, tracking, monitoring, cataloguing and prediction of the movement of space objects, and the identification and alerting of derived risks. It is comprised of the operation of ground-based or space-based sensors (radar, optical, passive RF) to survey, track and catalogue space objects, and the processing and analysis of orbital data to provide information and services such as conjunction analysis, analysis of space object re-entries and analysis of space object fragmentations."[29]

- **Space traffic coordination (STC)** is the cooperative planning, coordination, sharing of data and information, and on-orbit synchronization of space activities.

- **Space traffic management (STM)** is the assurance value chain that contributes to a safe and sustainable space operations environment, composed of space traffic coordination (STC) and Regulation & Licensing and dependent on a foundation of continuous space situational awareness (SSA).

Discussion

SSA provides foundational positional, electromagnetic, and situational information on objects as a function of time. It also characterizes the overall state of the space environment, including debris and space weather conditions, on which STM, STC, SDA, and SEP actions are based.

Figure 1 shows the relationships between these elements, which, taken together, constitute the space operations assurance enterprise. Space operations assurance addresses the three critical space operations aspects of **security**, **safety**, and **sustainability**. These issues are dependent on an underlying foundation of SSA capabilities, data, and information; in particular, SST.

> This paper is the effort of several authors collaborating on reaching a consensus on various terminology definitions related to STM and associated efforts. The primary language of several of the authors is not English. Their language does not necessarily differentiate between *safety* and *security; for them,* they are essentially the same word. In addition, exactly how the roles are spread among SDA, STM, and SEP can vary between countries. For example, what may be true in the United States may be slightly different in France.

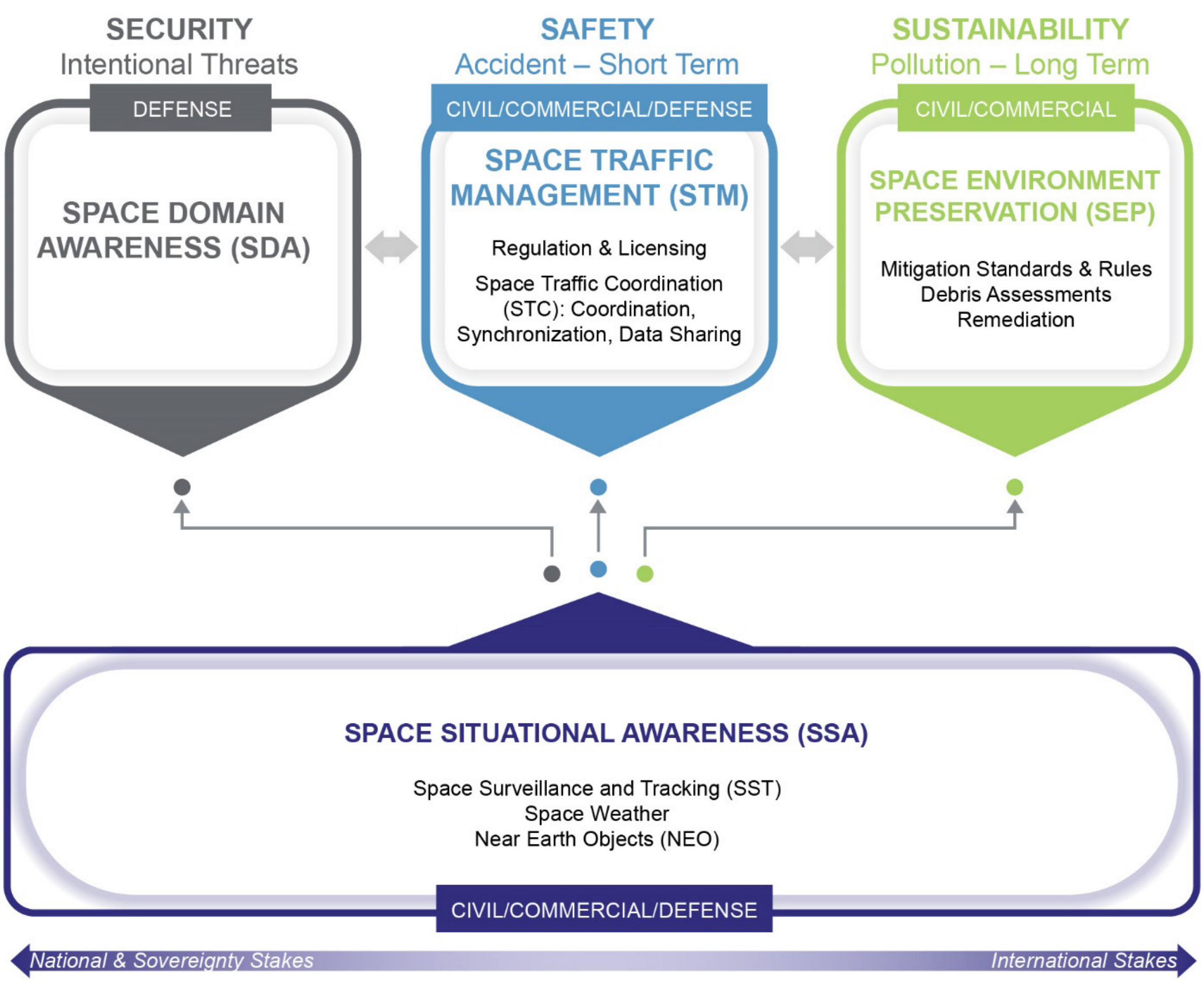

Figure 1: Relationships between SDA, STM, SEP, and SSA.

To better understand the relationships between these three aspects, consider the following. Note that these aspects—safety, sustainability, and security—may overlap in each of the STM, STC, SDA, and SEP definitions.

1. **Security** aspects primarily fall under **SDA**. Security issues could exist between any number of active spacecraft, where one or more spacecraft may intentionally pose a threat to the operational health, stability, and capabilities of other spacecraft. Security issues may not represent immediate threats to either orbital safety (STM) or space sustainability (SEP).

2. **Safety** aspects primarily fall under **STM**, existing between the many operational spacecraft as well as in their interaction with the current space debris environment and space security regimes. Safety issues would exist even in an imaginary world where space debris and intentional security threats were not present. Today, safety concerns are exacerbated by the increase in commercial space traffic associated with large constellations. Collision risk can best be mitigated through a combination of licensing, aspirational best practices,[30] international guidelines and standards,[22,24,31,32,33,34,35] national regulations, and operational synchronization via data and information sharing. Because no operator acts in isolation, **STC** provides the critical collective communications, information exchange, and coordinated actions taken by spaceflight actors to ensure the safe movement of spacecraft in orbit. To ensure compliance and accountability with the overarching goals of safety and sustainability, operators must also satisfy **regulatory and licensing** conditions established by their governing authority.

3. **Sustainability** aspects primarily fall under **SEP**. While safety (STM) and sustainability are interrelated, even in the absence of new space launches or space security threats, the debris population will continue to increase due to orbital explosions, fragmentation events and collisions between active spacecraft, debris fragments, derelict spacecraft, and upper stages. This pollution issue, stemming from past orbital traffic and end-of-life disposal practices, jeopardizes current and future space activities. Sustainability can be addressed through remediation (removal of space debris) and mitigation. Key mitigation actions include (1) improvements to spacecraft and launch system design, materials, and reliability, (2) increased capacity building, and (3) operational adoption of launch, on-orbit, and disposal guidelines,[25,31] standards,[32,33,34] and commercial best practices[30]. SEP draws on SSA to characterize the space environment and its evolution; based on this understanding, new mitigation standards and STM regulations can be developed to stabilize and remediate the problem.

These three aspects are distinct, spanning national/ sovereign interests, international interests, defense community needs, commercial interests, and civil concerns. However, as shown by the horizontal arrows in Figure 1, these areas are interrelated as the way each area is managed can favorably or adversely affect the others. STM garners high international interest because it exists at the confluence of (inter)national stakes and defense as well as civil community concerns.

Future Work

The initial work of the IAF STM Terminology Working Group will be combined with its companion working groups to be presented to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in the near future.

Conclusion

The IAF STM Terminology Working Group has, for the purposes of its Technical Committee 26 on STM, selected definitions for STM-related terms. In addition to selecting definitions for STM-related terms, this paper explores the relationships between safety, security, and sustainability.

By sharing these definitions with other stakeholders, we intend to foster consensus and encourage the use of these terms and definitions in international guidelines, standards, and agreements across the community.

To date, this terminology has been presented to the attendees of the International Association for the Advancement of Space Safety (IAASS) conference in 2021, as well as at a special session on STM at the 2021 IAC conference in Dubai, UAE. Additionally, this work has been incorporated into background references used to introduce U.S. space policy analysts to current thinking regarding STM and space safety.

The authors expect that a broader diffusion of these consensus terminology definitions will allow closer coordination and cooperation among policymakers and other actors in the space arena, across international and political boundaries.

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References

[1] Global Space Traffic Management Workshop, https://events.ph.ed.ac.uk/space-traffic2, referenced December 1, 2017.

[2] Space Traffic Management – global challenge to protect the strategic domain of space, Space Traffic Management – Global Challenge to Protect the Strategic Domain of Space , (iafastro.org) , https://www.iafastro.org/events/iac/iac-2017/plenary-programme/plenary-events/space-traffic-management-%E2%80%93-global-challenge-to-protect-the-strategic-domain-of-space.html, referenced 04/15/2021.

[3] Kaiser, S., "Legal and policy aspects of space situational awareness," In Space Policy, Vol. 31, Issue February 2015, pp. 5-12 (2015) DOI 10.1016/j.spacepol.2014.11.002.

[4] International Association for the Advancement of Space Safety (IAASS) Conference, http://iaassconference2017.space-safety.org/programme-overview/, referenced December 1, 2017.

[5] 7th Space Traffic Management Conference 2021 – IAA (iaaspace.org), referenced 16 Aug 2021.

[6] Secure World Foundation leads discussion on commercial SSA and STM, https://swfound.org/news/all-news/2017/09/swf-leads-discussions-on-commercial-ssa-and-space-traffic-management-at-2017-amos-conference, referenced 12/1/17.

[7] Space Traffic Management – Towards a Roadmap for Implementation, https://iaaspace.org/product/space-traffic-management-towards-a-roadmap-for-implementation/, referenced February 24, 2021.

[8] Space Traffic Management and Space Situational Awareness, Journal of Space Safety Engineering, Volume 6, Issue 2, Pages 63-162 (June 2019).

[9] Skinner, M.A., Jah, M.K., McKnight, D., Howard, D., Murakami, D., Schrogl, K-U., *Results of the International Association for the Advancement of Space Safety space traffic management working group*, Journal of Space Safety Engineering, Volume 6, Issue 2, June 2019, Pages 88-91.

[10] International Academy of Astronautics (IAA) Cosmic Study on Space Traffic Management. Edited by Corinne Contant-Jorgenson, Petr Lála, Kai-Uwe Schrogl. Published by the International Academy of Astronautics (IAA) BP 1268-16. https://iaaspace.org/product/space-traffic-management/, referenced 04/15/2021.

[11] Oltrogge, D.L., "Marshalling Space Traffic Management requirements and expectations in the international context" Security in Outer Space: Rising Stakes for Civilian Space Programmes, European Space Policy Institute Autumn Conference, September 28, 2018.

[12] Space Traffic Management, W. Ailor, in *Handbook of Space Security Policies, Applications and Programs*. Schrogl, K.-U., Hays, P.L., Robinson, J., Moura, D., Giannopapa, C. (Eds.), Springer-Verlag, 2015, pp. 231-255.

[13] Report 1 of AIAA Space Traffic Management Working Group Task-group 1, Rovetto, R.J., Peura, A. (November 2020), https://engage.aiaa.org/viewdocument/report-1-v2-lexicon-task-tg1?CommunityKey=29551ad4-cfbb-4fda-9c4c-a64b3dba0485&tab=librarydocuments&LibraryFolderKey=&DefaultView=folder, referenced August 16, 2021.

[14] Johnson, N. "Space traffic management concepts and practices," Acta Astronautica, Vol. 55, Issue. 3-9, pp. 803-809 (2004) DOI 10.1016/j.actaastro.2004.05.055.

[15] "ESPI Report 71 - Towards a European Approach to Space Traffic Management - Full Report," https://espi.or.at/publications/espi-public-reports/send/2-public-espi-reports/494-espi-report-71-stm, referenced August 16, 2021.

[16] Oltrogge, D.L. and Cooper, J.A., Space Situational Awareness & Space Traffic Management, chapter in book entitled, *The Space Debris Peril: Pathways to Opportunities*, CRC Publishing, 2020.

[17] Christophe Bonnal, et al., "CNES technical considerations on space traffic management," Acta Astronautica 167 (2020) 296-301, November 14, 2019.

[18] International Astronautical Federation, Technical Committee 26 - Space Traffic Management, https://www.iafastro.org/about/iaf-committees/technical-committees/space-traffic-management-committee.html, referenced February 24, 2021.

[19] Rovetto, R.J., Astronautics Terminology Catalog. GitHub webpage, https://github.com/rrovetto/Astronautics-Terminology, referenced August 16, 2021.

[20] American Institute of Aeronautics and Astronautics (AIAA) Space Traffic Management Working Group, https://engage.aiaa.org/communities/community-home?CommunityKey=bc9023a2-a293-4218-a6a9-1b949409437f, referenced August 16, 2021.

[21] Orbital Space Domain Knowledge Modeling, https://ontospace.wordpress.com, referenced August 16, 2021.

[22] The Space Assigned Numbers Authority (SANA) Registry, The Consultative Committee for Space Data Systems, https://sanaregistry.org/, referenced August 16, 2021.

[23] Online Browsing Platform, The International Organization for Standardization https://www.iso.org/obp/ui/#home, referenced August 16, 2021.

[24] International Organization for Standardization Technical Committee 20 Subcommittee 14 Space systems and operations, https://www.iso.org/committee/46614.html, referenced August 16, 2021.

[25] The European Cooperation for Space Standardization (ECSS), https://ecss.nl/glossary/, referenced August 16, 2021.

[26] UNCOPUOS LTS guidelines, 2019, paragraph 5. https://www.unoosa.org/res/oosadoc/data/documents/2019/a/a7420_0_html/V1906077.pdf, referenced August 16, 2021.

[27] "Space Power: Doctrine for Space Forces," Space Capstone Publication, https://www.spaceforce.mil/Portals/1/Space%20Capstone%20Publication_10%20Aug%202020.pdf, referenced May 2021.

[28] U.S. Joint Publication 3-14: Space Operations, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_14ch1.pdf?ver=qmkgYPyKBvsIZyrnswSMCg%3D%3D, 10 April 2018, Incorporating Change 1 on October 26, 2020, referenced May 2021.

[29] "Space Traffic Management (STM): An Opportunity To Seize For The European Space Sector," Eurospace Manifesto for a European Global Answer on STM, https://eurospace.org/wp-content/uploads/2021/03/eurospace-pp_space-traffic-management_opportunity-for-europe_final_february-2021.pdf, referenced August 16, 2021.

[30] "Best Practices for the Sustainability of Space Operations," Space Safety Coalition, https://spacesafety.org/best-practices/, as of July 1, 2021.

[31] Oltrogge, D.L. and Christensen, I.A.," Space governance in the new space era" Journal of Space Safety Engineering, https://doi.org/10.1016/j.jsse.2020.06.003, July 2020.

[32] "IADC-02-01 Space Debris Guidelines Rev 3," Inter-Agency Space Debris Coordination Committee (IADC), https://www.iadc-home.org/documents_public/file_down/id/5251, referenced August 16, 2021.

[33] Stokes, H., Bondarenko, A., Destefanis, R., Fuentes, N., Kato, A., LaCroix, A., Oltrogge, D.L., and Tang, M., "Status of The ISO Space Debris Mitigation Standards," ESA Space Debris Conference, ESDC-17-979, Darmstadt, Germany, April 24, 2017.

[34] H. Stokes et al, "Evolution of ISO's Space Debris Mitigation Standards," International Orbital Debris Conference, December 12, 2019.

[35] Consultative Committee for Space Data Systems, https://public.ccsds.org/default.aspx, referenced August 16, 2021.