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Promoting Space Sustainability

Conjunction Assessment (CA)

NASA

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Implementation of the Guidelines for the Long-term Sustainability (LTS) of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space

Operational Case Studies

I. Short description of the outer space activity [*1000-word max.*]

The increasing utilization of space -- including a significant increase in the volume and diversity of commercial activity -- means actors need to take responsibility for maintaining outer space as a stable, safe and sustainable environment. All nations benefit from a stable and orderly space environment that drives opportunity, creates prosperity, and ensures our security on Earth and in the vast expanse of space. To that end, this case study details NASA's experience with conjunction assessment in the hopes of sharing lessons learned with the growing space community.

In December 2020, the NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook (https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf) was published to document safety standards and best practices developed over the past 30 years that consider maneuverability, tracking, reliability, and disposal. The handbook will be updated as new conjunction assessment (CA) and on-orbit operations are developed, and NASA is seeking feedback from the community to augment the volume. Entities offering, or intending to offer or use Space Situational Awareness (SSA) or CA services should consider the information in this handbook from the perspective of augmenting or improving upon existing capabilities as the entire space industry benefits from advancing these capabilities.

Different organizations use the term "conjunction assessment" in different ways, but NASA defines a 3-step process:

1. Conjunction assessment prediction (screening) — The process of comparing trajectory data from the asset to be protected against the trajectories of the objects in the space object catalogue to predict when a close approach will occur within a chosen protective volume placed about the asset.

2. Conjunction risk assessment — The process of determining the *likelihood* of two space objects colliding and the expected *consequence* if they collide in terms of lost spacecraft and expected debris production. Risk is defined as the product of likelihood and consequence. Computing the risk determines which predicted events may represent dangerous situations and therefore require a mitigation action.

3. Conjunction mitigation — An action taken to remediate conjunction risk via a propulsive maneuver, an attitude adjustment (e.g., for differential drag or to minimize frontal area), or providing ephemeris data to the secondary owner/operator to enable them to perform an avoidance maneuver.

The NASA historical CA process is challenged by new ways of doing business. First, the proliferation of smaller satellites, i.e., smallsats and cubesats, has skewed the owner/operator (O/O) view of risk. As small satellites are relatively cheap and easy to launch, many operators are not concerned about one satellite being lost in a collision, as they can simply rely on on-orbit redundancy, or launch a replacement, in order to continue their mission. However, any collision can create debris that would threaten other owner/operators' assets, or even astronauts' lives. Further, small satellites must be tracked in order to prevent collisions. Some small satellites are smaller than US Space Force's (USSF) regular tracking threshold, meaning that CA services provided by 18th Space Control Squadron (18 SPCS) cannot include these objects. Ironically, many small satellite operators do not compute ephemerides for their assets. Often these operators rely on Two-Line Elements (TLEs) from 18 SPCS to communicate with their satellite, making 18 SPCS tracking essential to their position determination. However, if the satellite is too small to track well, TLEs are not always available.

The second challenge is the increasing use of electric propulsion, which causes spacecraft to maneuver along a non-Keplerian path for long periods of time, slowly transiting through populated regimes. Other entities are not able to track the location of such a spacecraft without having a shared ephemeris that predicts this path, making non-cooperative conjunction assessment very difficult or impossible. Therefore, sharing predicted trajectory data to a central repository such as 18 SPCS is especially critical for such missions. Satellites using electric propulsion often take longer to mitigate a close approach event because sufficient separation distance cannot be achieved by low thrust propulsion over short periods.

The third challenge is that more operators are using automation, both on the ground and onboard, driven in part by operators needing resource conservation when managing large constellations of spacecraft. For conjunction assessment, this change means that it is not always possible to contact the other O/O to coordinate maneuver planning to prevent simultaneous maneuvers that could cause a collision. Also, spacecraft that plan maneuvers onboard don't always send predicted trajectories to a central repository such as 18 SPCS to screen before the maneuvers are executed, meaning that other owner/operators have no way of knowing where these spacecraft will be, again increasing the possibility of maneuver-on-maneuver collisions.

It is important for all O/O's to be aware of these challenges, the best practices to mitigate them, and the availability of existing data and tools that can be used in mitigation. NASA is working to assist in this area by publishing a publicly-accessible manual of CA best practices and posting our conjunction risk assessment software, including source code, to a public-facing repository for anyone to download and use (**https://github.com/nasa/CARA_Analysis_Tools**). We hope that by educating space actors about these challenges and the existing capabilities that are available to help mitigate them, that even without a centralized Space Traffic Management coordination entity, advances can be made from a grass-roots level to make space flight safer.

II. Connection with the LTS Guidelines [*500-word max.*]

The USG was a strong supporter of the adoption by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) of the Preamble and 21 Guidelines for the long-term sustainability of outer space activities (LTS), as they represent best practices for the safe and responsible use of space. These voluntary guidelines mark an important milestone in ensuring that all nations can continue to benefit from the use of space for future generations. In accordance with **Guideline B.4**, which recommends **performing conjunction assessment during all orbital phases of controlled flight**, NASA performs conjunction assessment for all operational missions during their entire mission lifetime. In fact, NASA has a long history of experience with CA and was involved in developing the process that many entities use today.

Space exploration presents challenges that impact not only the U.S., but also the international community. A significant increase in the volume and diversity of activity in space means that it is becoming increasingly congested. Emerging commercial ventures such as satellite servicing, in-space manufacturing, and tourism as well as new technologies enabling small satellites and large constellations of satellites present serious challenges for safely and responsibly using space in a stable, sustainable manner.

The U.S. seeks to improve global awareness of activity in space by publicly sharing flight safety-related information and by coordinating its own on-orbit activity in a safe, responsible manner. We seek to bolster stability and reduce current and future operational on-orbit risks so that space is sustained for future generations. To this end, new and better Space Situational Awareness (SSA) capabilities are needed to keep pace with the increased congestion, and the U.S. seeks to create a dynamic environment that encourages and rewards commercial providers who improve these capabilities.

In November 2020, NASA expanded its requirements documentation to provide more detailed, lower-level CA requirements for its missions, to help them adapt to the challenges of the changing space environment. The guidance expands the Agency's required CA activities beyond just those performed after the spacecraft has launched, to include previously optional pre-launch activities, in keeping with LTS **Guideline B.5: Develop practical approaches for pre-launch conjunction assessment**. Required pre-launch activities include taking steps to avoid co-location of spacecraft to the extent practical, planning for robust communications and data sharing between co-located spacecraft when co-location is unavoidable, and analyzing planned mission trajectories to determine anticipated number of potential conjunctions, both during ascent and those expected to be regularly encountered in the final mission orbit, in order to estimate fuel usage and expected personnel activity levels.

III. Lessons learned [*500-word max.*]

The lessons learned for NASA over the many years of performing CA are documented in the NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices handbook (https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf). Several key topics are discussed here.

First, operator-to-operator communication for close approaches is critical to prevent both operators simultaneously maneuvering into each other and causing a collision. As operators move to use of onboard automated maneuvering, this coordination becomes more challenging. In order to ensure flight safety and prevent maneuver-on-maneuver collisions, it is important to build in a CA screening of planned maneuvers before they are executed onboard. This screening ensures that a representation of the planned trajectory is available to all other space operators. Methods to exchange planned automated maneuver data in near-real-time is an important area in which research and development of methods to achieve safe automation would help to advance the state of the art.

Second, conjunction assessment computations require high quality input data. Predicted ephemerides must be furnished frequently to the screening entity, span an appropriate period of predictive time, employ point spacing close enough to enable interpolation, provide a full state (position and velocity) for each ephemeris point, and provide a realistic 6 x 6 covariance matrix (with both variance and covariance terms) for each ephemeris point to enable the calculation of a Probability of Collision (Pc).

Finally, for a robust safety-of-flight process, risk assessment analysis is needed of the close approach prediction (screening) data to determine whether the close approach warrants mitigation. Many space operators use the CA screening services provided by the 18 SPCS to receive Conjunction Data Messages (CDMs) containing data on predicted close approaches. CDMs are not warnings of an impending collusion, but simply data intended to be analysed by the operator to determine the risk posed by the close approach. The key risk assessment step of the process is needed on the part of the Owner/Operator (O/O) to ensure any action taken is increasing safety, not decreasing it. The data should be analysed to determine whether the solution for the other object is stable and recent, considering the covariance (error) in the solution and other included parameters, before taking mitigation action. CA risk assessment tools are needed to perform this risk assessment, which includes calculation of Pc and other relevant information such as expected collision consequence and whether the state and covariance information is sufficiently accurate to subtend the risk assessment process.

The NASA Handbook provides descriptions of methods, rationale for choosing one method over another, and supporting analyses drawn from NASA's long history of performing CA. NASA continuously examines and actively updates its best practices for CA as the industry undergoes rapid evolution. Large constellations of satellites, for example, comprise a new and evolving paradigm for which NASA is developing in-house expertise. NASA seeks input from the space community to improve the content presented in this document. The NASA documentation and the repository of CA software is publicly available.