Automating Maneuvers: Considerations for Collision Avoidance

Lauri K. Newman
NASA Headquarters, Science Mission Directorate
300 E. St SW Washington, DC 20546; 202-358-0369
lauri.k.newman@nasa.gov

Matthew D. Hejduk
The Aerospace Corporation
2011 Crystal Dr, Arlington, VA 22202; 469-909-8121
Matthew.d.hejduk@aero.org

ABSTRACT

As more space operators implement large constellations of spacecraft, automating orbit maintenance maneuvers becomes a key feature of their operations concept to ensure that the workload is manageable. However, the practice of performing a maneuver without sharing the plan with other nearby spacecraft causes a risk that two spacecraft will collide, not only destroying the spacecraft involved, but creating debris that will affect all other spacecraft using that orbit regime. In order to share the maneuver plan, a predicted ephemeris file containing the maneuver must be sent to a central authority to screen against predicted trajectories of all other on-orbit objects to determine where and when close approaches will occur that may need to be mitigated. Currently the screening authority used by US operators is the 19th Space Defense Squadron; screenings are performed once every 8 hours, meaning that spacecraft using automated maneuvering need to allow 16 hours to share their maneuver plan via the screening process in advance of maneuver execution in case one screening is missed and the next needs to be used.

In an effort to speed up the screening process to benefit spacecraft using automated maneuvering, a prototype system for performing near-real-time screenings has been developed in support of the NASA Starling mission, a constellation of four cubesats that fly at the same altitude as the SpaceX Starlink constellation. Both of these constellations perform automated maneuvering, so without screening the planned maneuvers before execution, the two constellations would risk a collision. This paper describes the traditional conjunction assessment (CA) process, the prototype real-time CA screening capability, plans for the experiment to test the prototype, and next steps.

INTRODUCTION

In order to quickly and efficiently carry out required orbit adjustments for their spacecraft, many Owner/Operators (O/Os) are coming to rely on automated maneuver planning for their satellites; this is especially true for large constellations in order to minimize the number of support staff required to control a fleet of spacecraft. Automated maneuvering means that the spacecraft has onboard knowledge of its position and covariance (uncertainty), and uses that information to plan orbit adjustments using onboard algorithms. The maneuvers are designed to meet spacecraft constraints such as altitude or ground track control, or to perform test objectives such as evaluating new types of propulsion systems. The maneuvers are often executed shortly after being planned, without ground knowledge or intervention. As space becomes more crowded, the practice of executing a maneuver without first screening for dangerous close approaches

created by the maneuver is irresponsible, not only jeopardizing the safety of the maneuvering spacecraft, but also potentially causing a collision that would produce debris that could damage other spacecraft and/or render that region of space unusable.

This paper describes a new prototype system that has been tested by NASA and SpaceX to enable rapid screenings of planned maneuvers in order to streamline automated maneuvering while maintaining safety from collisions.

CURRENT USG CA PROCESS

In order to ensure that spacecraft don't collide, the US Government has established a process for screening predicted ephemerides for protected spacecraft assets against the Department of Defense (DOD) catalog of on-orbit objects (spacecraft and debris). Owner/Operators submit predicted ephemerides

containing planned maneuvers to the 19th Space Defense Squadron for Conjunction Assessment (CA) screening. 19 SDS compares the predicted ephemeris against the catalog and computes any close approaches that occur between the protected asset and any catalogued object over the screening timespan, typically a week. In addition to the submitted ephemerides from the Owner/Operator (O/O), the 19 SDS also maintains a solution for the protected asset generated from non-cooperative tracking data as part of the space object catalog. This DOD solution is also screened against the other catalogued objects. This screening activity is performed every 8 hours, and the resulting data are packaged in Conjunction Data Messages, files that contain state and covariance for both objects involved in a close approach at an epoch of the time of closest approach (TCA). These files are sent to the O/O, who is then responsible for analyzing the data to assess the risk presented by the close approach and taking any mitigating action as necessary. This three-step CA process of screening, risk assessment, and mitigation is described in more detail below.

Conjunction Assessment Process Definitions

Conjunction Assessment, sometimes referred to as "*screening*", involves comparing the predicted trajectories of two objects at each point in time to determine whether they come closer than a pre-defined threshold. A "screening volume" is placed around each object to represent the uncertainty in the position and velocity of the object. The sizes of the volumes are determined based on typical accuracies of that type of object in that orbit regime; large operational spacecraft have small uncertainties, while small debris objects have large uncertainties. The protected asset within its volume is then "flown" along its predicted trajectory and compared to the position of each other catalogued object, which also has an associated volume. If the two volumes intersect at any point, that intersection is defined to be a "close approach" that should be further analyzed to determine the risk of the close approach event. A Conjunction Data Message (CDM) is produced for each identified event and distributed to the O/O, who is then responsible for performing this risk analysis and making a mitigation decision.

Risk is the product of likelihood and consequence. Performing CA *risk assessment* is typically done by just computing the likelihood, since the consequence is often assumed to be undesirably disastrous. In the future, as the space environment becomes more crowded, applying consequence calculations to the risk assessment may provide a good way to triage which events to mitigate (e.g. only ones that create a large amount of debris would be mitigated) [References 2-4].

The majority of space operators compute the Probability of Collision as the likelihood metric, with most choosing a threshold for taking action of Pc > 1E-04. Pc is sometimes provided on the CDM; however it should be noted that Pc alone is often not sufficient to evaluate risk, as other factors such as conjunction geometry and quality of the orbit determination solution of the secondary object can play a large role in the actionability of the solution. These factors should be evaluated before taking action to ensure unnecessary mitigation maneuvers aren't planned and/or maneuvers aren't planned using poor quality (inactionable) data, thus making the close approach more risky.

Risk assessment is a complex undertaking that requires specialized expertise. Rather than invest in building such expertise, some programs choose to procure services of a third party to perform risk assessment on their behalf. The NASA Conjunction Assessment Risk Analysis (CARA) program is the entity who performs risk assessment on behalf of NASA non-human-spaceflight (HSF)-related assets, while NASA Johnson Space Center's Flight Operations Directorate (FOD) performs the same function for any vehicles that are part of the HSF enterprise, such as the International Space Station and any visiting vehicles. A similar entity in Europe, the European Union Space Surveillance and Tracking (EUSST), provides risk assessment services to its member operators. There are also a number of commercial entities that provide CA risk assessment services, including some providers that cater to smallsat customers with their unique needs and criteria.

Once the risk has been assessed, if **mitigation** is warranted, options are evaluated and a plan chosen. The planned maneuver must be screened before execution to ensure no additional new close approaches are created by the maneuver. Operators weigh the risk of the close approach against other risks to their spacecraft, such as thruster performance, communications options, etc. However, concern should be focused not just on the survival of the asset, but also on the potential for creating space debris from a collision. It is incumbent on all space operators to protect the integrity of the space environment to keep it usable for the future.

Resources

The National Aeronautics and Space Administration (NASA) publishes a the "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook"[1] (referred to hereafter as the CA Handbook) that reflects how NASA currently operates. The CA Handbook is intended to assist operators in developing a robust conjunction assessment operations process, as well as presenting examples of responsible

practices to consider for lowering collision risks and operating safely in space (from Low Earth Orbit [LEO] and beyond) in a stable and sustainable manner. Consideration is given to important topics such as spacecraft and constellation design; spacecraft "trackability;" pre-launch preparation and early launch activities; on-orbit collision avoidance; and automated trajectory guidance and maneuvering.

As a further resource, NASA maintains a repository of CA software along with test data to enable users to incorporate NASA algorithms easily into their systems. The repository is located at https://github.com/nasa/CARA_Analysis_Tools.

Cis-lunar and Non-Earth-Centered CA

It should be noted that the standard CA process is applicable only for spacecraft orbiting the Earth, as non-cooperatively-tracked space objects are generally only tracked at altitudes less than geosynchronous due to the limitations of ground-based tracking resources. Tracking of objects further away requires different hardware and techniques, and a consolidated plan to create a catalog of such objects for CA screening is not yet readily available despite the growing interest in cis-lunar space activities. The DOD is working on developing a cis-lunar catalog and screening capability similar to the current 19 SDS Earth-based process, but the cis-lunar capability is still in the beginning stages. In the interim, NASA has created a screening service using O/O-provided ephemerides for non-Earth-orbiting environments such as the moon, Mars, and several of the libration points. All NASA spacecraft are required to participate in this Multi-mission Automated Deep space Conjunction Assessment Process (MADCAP) process; non-NASA entities are encouraged to share ephemerides and participate in the screening service as well, since ephemeris sharing is the keystone to ensure safety for all assets flying in these environments. More information about MADCAP is available at the NASA CA website at https://nasa.gov/cara.

Autonomous Control Considerations

The use of autonomous satellite flight dynamics, including autonomous orbit maintenance maneuvers and conjunction mitigation, has increased recently. A significant factor in this increase is the growing number of large constellation O/Os who need autonomy to handle the scaling of their system. Autonomous control becomes even more complicated when both spacecraft involved in a close approach are operating autonomously. Both could be planning maneuvers that lead to a collision if the O/Os do not share their maneuver plans with each other.

If a spacecraft is being designed to perform autonomous maneuvers, care should be taken to ensure that the predicted trajectory is shared with 19 SDS and that resulting CDMs are received onboard for analysis and mitigation action, with a sufficiently large screening volume used to give the autonomously-controlled spacecraft a "snapshot" of the space catalog in its vicinity. This additional information will allow the spacecraft to determine whether any contemplated maneuvers will create problematic conjunctions with other spacecraft. For this paradigm to be workable, however, all other maneuverable spacecraft in the vicinity of the autonomously-controlled spacecraft must ensure that their predicted ephemerides fully reflect intentions and that they not change their intentions without sufficient advance notice. Advance notice would need to be early enough to allow their intended trajectory, via an ephemeris, to be forwarded to 19 SDS and the resulting CDMs to be uploaded to the autonomous spacecraft. Because of the extra burden that autonomous control involves, a different method for adjudicating these situations is desired.

Recently, NASA developed Starling, an experimental constellation built to test autonomous flight dynamics/control and constellation reconfiguration. Due to Starling's ride-share arrangement, it was planned to be essentially collocated with the Starlink constellation fielded by SpaceX, which also uses autonomous control. Thus, there became a specific identified need to develop a safety solution that could be applied to this situation. A consortium was formed among NASA CARA (the group that performs CA for NASA uncrewed spacecraft), NASA Ames (the NASA center developing the Starling mission), Emergent Space Technologies (the contractor developing the autonomous control software for the Starling mission), University of Texas at Austin (the entity providing astrodynamics consulting and services to the Starling mission), and SpaceX (the operator of the Starlink constellation) to develop an appropriate solution, build out the needed software and ground node, and test the paradigm during the planned extended mission portion of the Starling mission.

AUTOMATED SCREENING TOOL TENETS

In order to perform CA adequately with autonomously-managed constellations, certain changes in paradigm were necessary; and the first of these is to embrace a recognition that true "autonomy," such as it is, is not compatible with space spacecraft operations. In the past, autonomous operations has been loosely equated with flight dynamics calculations, planning, and option execution taking place entirely on-board the satellite. However, with modern communications paradigms such as laser cross-linking, it is often the case that all

constellation spacecraft are in contact with both the ground node and each other essentially continuously; so making a distinction between what is done "on board" and what is done "on the ground" is not particularly meaningful. The concept of autonomy instead hangs on whether the flight dynamics calculations are performed in consultation with information outside of the constellation ecosystem (e.g., with near-real-time (NRT) knowledge of other satellites' positions) and whether or not there is human review and approval of individual actions. Some large constellation operators originally supposed that decisions apart from NRT exterior information would be adequate for a safe CONOPS; but as multiple large constellations have been built out, it has been realized that the sharing of intended flight dynamics information, such as intended maneuvers and even attitude changes if they will affect future satellite positions, must be performed in order to allow safe and efficient operation for all actors. All satellite operators need both to be able to schedule last-minute trajectory changes and to bear the responsibility of making trajectory changes to resolve unsafe close approaches.

Second, the ability to make a rapid evaluation of the safety propriety of an intended orbit is extremely important, especially for those constellations that do not have continuous communications with their ground control centers. For such satellites, it is necessary to be able to download maneuver plans, have their ground centers form predicted ephemerides from these plans, submit the predicted ephemerides to a CA screening ground node, receive screening results back from the CA ground node to the satellite ground control center, and upload these results to the satellite—all during the time of a single ground contact. Much of this is of course the responsibility of the O/O; but the one centralized portion—that of the CA screening node—is external to the O/O and needs to be extremely short in duration; the performance requirement as part of the current experiment is less than one minute between receipt of a predicted ephemeris for screening and the dispatching of conjunction data messages (CDMs) documenting the results of the screening.

Third, some method is needed to determine/assign responsibility for any required CA mitigation actions. This can be as simple as providing a centralized database within which voluntarily-assumed responsibility can be logged, to an elaborate rule set that is centrally managed and imposed by the CA screening ground node. There are advantages and disadvantages across this spectrum from minimalist to elaborate, as will be discussed in the following sections.

MAJOR PROTOTYPE SYSTEM COMPONENTS

Low-latency Screening Capability

The ground node CA screening capability comprises both a database of the intended trajectories of all of the participating active satellites and the ability rapidly to screen new ephemeris submissions against the ephemeris database. (The database could also include predicted trajectories for inert space objects if these are available for screening.) Screening applications of this type use a series of first filters, based on orbital element versions of the orbits, to exclude pairs of objects that can be determined essentially to have no possibility of risky conjunction. Hoots et al. (1984) outlines a commonly-employed set of such filters, the use of which greatly increases computational efficiency. For the remaining ephemeris pairs, a direct comparison of the ephemerides is performed, both to find all of the times of closest approach (through an iterative technique) and then, via interpolation methods, to calculate both the states (position and velocity) and covariances for the two objects at the time(s) of closest approach. These state and covariance data, along with other metadata of interest (e.g., object sizes), and written into Conjunction Data Messages (CDMs) and returned from the screening node to the individual O/Os, who can then either process them within their ground control center or upload them to the spacecraft for processing and use.

Ephemeris Submission Options

There are three different ways to submit ephemerides for screening. Submitting an ephemeris as a *candidate* means that the O/O is interested speculatively in what sort of problematic close approaches the submitted ephemeris might produce; perhaps a number of different potential maneuver trajectories are being considered, and the O/O wishes to know the relative levels of close approach safety concerns that each ephemeris might introduce, which can be deduced from the produced CDMs.

In a less speculative operational situation, an O/O can submit an ephemeris, or a rank-ordered set of ephemerides, as a *candidate definitive* ephemeris. Using this paradigm, the screening ground node will screen the ephemeris and, if no serious conjunctions are discovered, will update the ground node database with this ephemeris and send the O/O back a message to this effect. In such a situation, the O/O now has a "right" to this particular trajectory but also has a responsibility to follow this trajectory unless the O/O submits a new trajectory for screening. If a ranked set of trajectories were submitted under "candidate definitive" auspices, then the screening updates the ground node database

with the highest-ranked ephemeris that sustained the screening process without producing serious conjunctions. CDMs for all submitted trajectories are returned to the O/O.

Finally, an ephemeris can be submitted as a *definitive* trajectory, meaning that the O/O intends to follow this trajectory regardless of the screening results. The payload may be non-maneuverable and simply furnishing a precision trajectory to assist others in avoiding it, the payload may be experiencing an outage or anomaly and not be capable of trajectory modification at the present time, the O/O may not wish to cooperate in close approach mitigation actions but will at the least inform those of others by furnishing an ephemeris, or the O/O may have a very rapid ability to generate alternative trajectories in response to unfavorable CDMs and prefers to iterate with multiple submissions rather than to try to submit an ordered list of possibilities from the beginning. Different O/Os can select and employ the submission option set that is best suited to their particular CONOPS.

Mitigation Action Responsibility Communication

The manner in which space traffic coordination (STC) rules are developed, communicated, and imposed on satellite O/Os is a matter of substantial debate presently, with different approaches embraced by different entities. It has been generally supposed that a government consortium would develop a set of internationally-embraced STC rules that would then be managed through a centralized ground node of sorts, via the direction of a particular O/O to perform a mitigation action in certain circumstances and the enforcement of that directive through the acceptance or rejection of submitted ephemerides. Such a solution was explored by the industrial and government consortium participating in this experiment, and after substantial discussions it was determined that an approach of this type is simply too problematic, for a number of reasons. It is actually not easy to define a robust and durable set of STC rules that apply broadly and produce a desirable solution in most of the expected actual circumstances; the context, and O/O preference, often conspire to create an extremely complex situation that is difficult to predict and regularize. Even one of the least controversial proposed STC rules—that a transiting satellite should take responsibility for mitigation when moving through a constellation of satellites occupying their approved on-orbit locations—is not an immutable rule; and large constellations have developed variants on this as different constellations' satellites interact with each other. These bilateral modifications of STC rules need to be accommodated; and if a central authority is to recognize and enforce them, then that authority will need to be constantly updating both its rule sets and the automated nature in which such rules are represented and enforced (since it is unlikely that all bilateral rule sets will be accommodated by the ground node's pre-existing software logic paradigm). Finally, a centralized enforcer of STC rules is not compatible with the federated manner in which STC is evolving. Major international entities, such as the European Union Space Surveillance and Tracking (EUSST), Australia, Japan, and India, are all building SSA/STC centers to handle the safety responsibilities for the satellites that they sponsor; and each of these entities are expected to have their own rule sets and regulatory authorities. It is highly unlikely that a single, broadly-accepted rule set can be defined among even these actors—*a fortiori* also for space actors outside of these circles, such as Russia and China. Instead, it is preferable to seek another approach that is more compatible with the political structures shaping STC.

The experiment consortium has thus embraced an approach that prescinds from assigning and enforcing rules and instead focuses on coordinating quasi-voluntary conjunction mitigation responsibility assignment. The screening ground node, in addition to maintaining an ephemeris database and providing screening information, also houses a database that allows, for each identified conjunction, the two space actors involved each to determine a particular posture towards the conjunction, choosing among the three possibilities below:

1. <u>None</u>. Neither O/O has claimed or refused responsibility for this conjunction. "None" is the default state in which all identified conjunctions of concern begin, and it indicates that neither O/O has yet taken a position. This designation actually provides useful information in that it communicates that the other O/O has not made any definitive plans to effect a mitigation; so if an O/O feels that the risk has become great and there is little time left before a decision is required, that O/O can go ahead and claim responsibility for the mitigation.

2. <u>Claimed</u>. An O/O has claimed responsibility for mitigating the conjunction, and a new ephemeris will be submitted shortly that will both mitigate the conjunction adequately and will not introduce any fresh conjunctions that exceed that O/O's standard Pc mitigation level. The non-claiming O/O should presume the conjunction will be mitigated and should refrain from introducing any fresh trajectory changes between the present time and the conjunction's TCA; or at the least the non-

claiming O/O should recognize that doing so may subject him to having to make his own subsequent mitigation maneuver if this new trajectory causes difficulties with the original mitigation action that the claiming O/O implements.

When the claiming O/O submits a new ephemeris that, based on its screening results, mitigates the main conjunction and does not introduce fresh conjunctions of concern, the conjunction will be grayed out on the screening node's conjunction board but will remain there as a visible entry (indicating the disposition result) until the TCA has passed. If space weather or other natural perturbations causes trajectories to deviate and risk to increase, the conjunction will again be marked as requiring action.

3. Refused. The responding O/O has refused responsibility for this conjunction. Such a response seems *prima facie* defiant, but there are a number of reasons that this response might be given in an overall constructive and cooperative environment:
   a. The refusing satellite inherently lacks the ability to modify its trajectory significantly enough to mitigate the conjunction—what would commonly be called a "non-maneuverable" satellite.
   b. The refusing satellite lacks the ability to modify its trajectory significantly in this case, due to hardware/software/communications failure; this could be either a temporary or permanent outage for this spacecraft.
   c. The conjunction might appear for the first time after the satellite's event horizon for that TCA has closed, meaning that insufficient time before TCA remains for the O/O to plan and execute a maneuver safely.
   d. The conjunction might not violate an O/O's safety posture, meaning the Pc is not high enough that the O/O feels compelled to pursue a mitigation action. It is to be hoped, of course, that a standard risk tolerance level could be established that all O/Os would at the least embrace (a Pc of 1E-04 is currently used by a large percentage of O/Os and thus could be considered to be such a standard); but some O/Os may wish to take a more conservative posture, and conjunctions that violate the mitigation threshold of either O/O will appear on the "Conjunction of Concern" list.
   e. The O/O may be furnishing their ephemerides as a courtesy to the orbital safety "region" overseen by a particular screening node but not intend to participate in any mitigation actions; one can imagine certain O/Os holding a position of this type. A standing "refused" response for such O/Os makes clear to all participants who will need to take action to resolve any serious conjunctions.

The methodology for facilitating the taking of responsibility for CA mitigation actions offers a number of advantages. First, it is clear to both O/Os what is actually happening with a given conjunction: because there has been explicit action—or no action—by the O/Os associated with the conjunction, each understands the current state of affairs completely. If there were standing rules that allocated the mitigation action to a particular actor, one would not necessarily know whether that actor had taken cognizance of the situation or whether a communications outage had prevented the communicating of an anomalous situation. With this explicit assignment approach, it is clear whether responsibility has been accepted; and if it has not, then the other O/O can pursue a mitigation action quickly and work to understand the details of the situation after the fact, once safety had been assured. Second, this approach allows bilateral agreements to be originated and followed without having to involve a centralized authority in the details; the central database merely keeps track of who has claimed responsibility. Large constellations may wish to develop and use specialized rule-sets for assigning mitigation responsibility for certain other constellations in certain circumstances, and this approach allows them to do this without involving anyone other than the two involved parties. Third, a method of this type works well with a federated STC system, in which different government organizations are responsible for the STC for their sponsored payloads. The ground node does not need to represent different rulesets, nor does there need to be a ground node for every participating agency; rather, a single ground node, perhaps placed in a neutral country, simply keeps track of what pairs of O/Os are doing and have done, without actually imposing or enforcing any rules. At the same time,

it actually facilitates rule enforcement by maintaining a digital audit of how each O/O handled each of their serious conjunctions. Disparate STC and licensing organizations can promulgate different rulesets for their sponsored satellite; and these organizations can use the digital audit trail, which is planned to be open-access for viewing and therefore in principle auditable by anyone, to determine whether their sponsored satellites are in compliance with the appropriate rule-sets. So while a centralized management and enforcement authority does often appear as the initial expectation of the best solution, the present proposal actually accomplishes the same goals while remaining a tractable solution with the current federated STC situation.

EXPERIMENT STATUS

The Starling-Starlink experiment was originally planned to begin in January 2024, but problems with one of the four Starling spacecraft (nicknamed "Blinky" due to its proclivity to requiring very frequent software reboots) resulted in about a five-month delay: the commencement date at the time of this writing is planned for 20 MAY and will run through the end of the calendar year (31 DEC). It will take the first couple of months to make sure that all the software pieces are in place and conduct isolated flow tests before conducting end-to-end tests with the live hardware and software and then beginning the experiment proper. Presently, the Starling constellation's altitude is at the very edge of Starlink's highest shell; if not enough appropriate conjunction events for the experiment are being produced in this configuration, the Starling constellation will be carefully lowered into the Starlink shell until the event rate is adequate for experimental conduct (it should be mentioned that all conjunctions are being monitored using the NASA CARA program to ensure against process failure). Experimental key performance parameters include conducting CA screenings through the ground node with less than one minute's turn-around time; identifying nearly all serious conjunctions on the satellite's on-board processing of conjunction data (100% identification is not needed because typically conjunctions are first identified seven days in advance of the TCA, and planning mitigation actions for nearly all of the conjunctions determined to be serious (again, multiple passes at this determination allow for an acceptable overall performance with individual performance values slightly less than 100%). If the experiment performs as expected, then the overall paradigm can be recommended to the Department of Commerce Office of Space Commerce (OSC) as an effective method for identifying, assigning responsibility for, and mitigating serious conjunctions. OSC can use these experimental results in forming the details of the operational system they are currently constructing (Tracking Coordination System for Space, or TraCSS).

NEST STEPS

The successful completion of this experiment will result in several follow-on activities:

1. The ground node capability, developed by SpaceX, will be sustained indefinitely by SpaceX in order to provide low-latency screening between O/O ephemerides. The expectation is that SpaceX will open their hosting of this algorithm to any O/O who wishes to make use of it; and if a large number of O/Os do, then this will be a very efficient method for addressing conjunction management among active payloads. If the Department of Commerce Office of Space Commerce embraces this same paradigm and stands up a system that offers it, then the capability could transfer to their auspices.

2. The Starling satellites contain on-board software that performs conjunction assessment management. If this software performs successfully during the prototype period, then both a requirements set derived from performance during the experiment as well as the source code can be furnished to the NASA Science Mission Directorate to undergo safety-critical software certification. Once it has completed this certification, it can be made available to other NASA missions and perhaps even open-sourced so that international O/Os can all make use of this improved safety approach at extremely low cost.

3. NASA maintains an extremely comprehensive orbital safety best practices document, and the paradigm arising from a successful experiment here will be thoroughly described in a future update to that document to allow the paradigm to be evaluated fully by other STC actors in the emerging federated system.

SUMMARY

Performing a maneuver without sharing the plan with other nearby spacecraft causes a risk that two spacecraft will collide, not only destroying the spacecraft involved, but creating debris that will affect all other spacecraft using that orbit regime. However the current DOD screening process only runs once every 8 hours, introducing delay that becomes problematic for missions needing fast turnaround, especially those using automated flight dynamics systems. In support of the Starling constellation, a consortium of actors have developed a prototype system to allow faster screenings

to minimize the risk of automated constellations from maneuvering into each other. Once converted from a prototype to an operational system, the Starlink/Starling near-real-time screening capability will greatly help smallsats, for example those that are planning to test propulsive capabilities, by allowing fast turnaround screening results to ensure safety from collision with other objects. Establishing a prototype system for screening close approaches in near-real-time also had the unanticipated additional benefit of developing a coordination process for assignment of mitigation action to an actor in a flexible way.

For more information on topics mentioned in this paper and other related items, visit the NASA CA website at https://www.nasa.gov/cara/.

References

1. "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook," NASA/SP-20205011276 Rev 1, February 2023, *https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf*.

2. Hejduk, M., Laporte, F., Moury, M., Kelso, T.S., Newman, L., Shepperd, R. "Consideration of Collision "Consequence" in Satellite Conjunction Assessment and Risk Analysis", International Symposium on Space Flight Dynamics, Matsuyama, Japan, 2017.

3. Lechtenberg, T. F., and Hejduk, M. D., "Assessment and Validation of Collision "Consequence" Method of Assessing Orbital Regime Risk Posed by Potential Satellite Conjunctions," Hypervelocity Impact Symposium, 2019, Destin FL, HVIS2019-061.

4. Lechtenberg, Travis F., "An Operational Algorithm For Evaluating Satellite Collision Consequence", AAS 19-669.