Space Traffic Management and Orbital Debris

A Position Paper

Provided By

Association of Space Explorers

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INTRODUCTION

The Association of Space Explorers (ASE) is an international nonprofit professional and educational organization of over 400 flown astronauts and cosmonauts from 38 nations. Membership in ASE is open to individuals who have completed at least one orbit of the Earth in a spacecraft.

ASE member countries include Afghanistan, Austria, Belgium, Brazil, Bulgaria, Canada, China, Costa Rica, Cuba, Czech Republic, Denmark, France, Germany, Hungary, India, Israel, Italy, Japan, Kazakhstan, Malaysia, Mexico, Mongolia, Netherlands, Poland, Romania, Russia, Saudi Arabia, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Syria, Ukraine, United Kingdom, United States, and Vietnam.

When Sputnik was launched in 1957 there was only one man made object in orbit. Now there are over 500,000 spacecraft and space debris objects orbiting the earth. Because these objects travel at speeds on the order of 8 kilometers per second, even a very small piece of material represents a hazard to other spacecraft should a collision (conjunction) occur. Great effort is underway to better understand the orbits of all of these objects and to develop the capability to identify potential collisions.

ASE fully supports activities aimed at making operations in earth orbit safe, efficient, and collegial, and is often asked for "the astronaut's/cosmonaut's perspective" on subjects that fall under these headings. Space Traffic Management and Orbital Debris are two such topics where ASE sees the need for a coordinated, international effort to insure safe and efficient operations in earth orbit. The purpose of this paper is to outline ASE's position on these topics, as stated in the **"ASE General Statement on Space Traffic Management and Space Debris Objects"**[(1)] in September 2018:

"The ASE urges the international spacefaring nations to rapidly develop policies, technologies, protocols and/or treaties on Space Traffic Management (STM) in Low Earth Orbit (LEO) that would assess impact risk from space debris objects. Development of a US Space Traffic Management (STM) structure is a first step, but the US is only one element of a growing international launch market. Space debris objects know no international boundaries, travelling around the planet in about 90 minutes each orbit (~17,500 mph or ~28,164 km/h). Similar to the history of aviation and maritime operations, the international space sector should collaborate in order to keep the doors of space open and safe for everyone."

STATEMENT OF NEED

For those organizations currently operating spacecraft in earth orbit, the need for reducing orbital debris and implementing space traffic management is a foregone conclusion. Earth orbit is a busy place! Since the late 50's when one satellite was lifted into orbit on one booster, now over a hundred satellites ride the same rocket to space. Once a primary payload is typically deployed, the other riders are ejected from "corncob launchers" as the booster continues on its path. The number of active satellites is quickly approaching 3,000 with many commercial companies planning constellations that will easily double that figure. Unfortunately, the number of pieces

of debris has steadily increased as well. Where the debris catalog used to include around 27,000 separate pieces measuring 10 centimeters or larger, that number is in the process of being revised. Recent studies have shown that a piece of debris measuring only a few millimeters in size can be potentially lethal to an active satellite. Estimates suggest the true debris catalog of lethal objects would number near 500,000.[(2)]

Even a modest number of satellites and debris represents a significant computational challenge to avoid collisions. Because there are just simply not enough frequent observations of everything in earth orbit, the uncertainty of positions and orbits results in large error ellipsoids around the expected position of each object. When calculations are performed looking for potential conjunctions (intersecting error ellipsoids) so many "potential" collisions are identified that they are routinely ignored. It is vital that this situation be remedied before a major accident occurs.

Although individual countries may take the initial steps toward a solution, the only real answer in the end is an international partnership. Observations from all over the world need to be collected, verified, and added to a "data lake" of observations to make sure good tracks are available on everything of interest in orbit and to reduce the individual error ellipsoids as much as practical. A central body, under the auspices of the United Nations, will ultimately be needed to manage these functions and to issue warnings when viable conjunctions are predicted. Accomplishing all of this will be a major endeavor involving an expansion of tracking sites on the ground and in space, the collection of observational data, screening of the data, the addition of observations into the "data lake", the calculation of potential conjunctions in the future, and the issuance of warnings when a potential event is identified. Just coordinating all of this as an international effort will be a major undertaking!

Avoiding an incident requires one or both parties to change their orbits, if possible, to remove any possibility of a collision. Just as with ships at sea and aircraft in flight, rules are required for either a centralized coordinating body to direct a maneuver be made or for one to be made voluntarily. Further, these rules must have applicability long before satellites arrive in orbit. Policies and procedures must be in place to support mission planning, launch, post insertion, on orbit operations, and retirement/deorbit. It is imperative the work progress rapidly to field a viable Space Traffic Management and Orbital Debris (STM&OD) program before operations in earth orbit are disrupted due to an accident.

A COMPREHENSIVE SPACE TRAFFIC MANAGEMENT AND ORBITAL DEBRIS PROGRAM

There are many organizations, agencies, and individuals expressing opinions about the best way to deal with STM&OD. Only history will show who is right or wrong in this debate, but it's clear that any concerted effort will involve a large number of individual activities that will require coordination. For its part, ASE has been actively involved in articulating what a STM&OD program should look like through contributions to other publicly available papers like:

"Space Traffic Management (STM): Balancing Safety, Innovation, and Growth"[3]

- AIAA Position Paper
- October 2017

publishing our own general statement on the subject:

"ASE General Statement on Space Traffic Management and Space Debris Objects"[1]

- ASE XXXI Planetary Congress
- 14 September 2018

and by responding to US government agencies who are attempting to formulate what they think a STM&OD program should include:

"Mitigation of Orbital Debris in the New Space Age"[4]

- Federal Communications Commission Notice of Proposed Rulemaking
- 19 November 2018

"Request for Information on Commercial Capabilities in Space Situational Awareness Data and Space Traffic Management Services"[5]

- U.S Department of Commerce
- 11 April 2019

Through these writings, ASE has identified a large number of activities and subjects that will need to be addressed and integrated into an effective program. These include but are not necessarily limited to:

- **A Centralized Coordinating Body**
- **Tracking Devices for Satellites and Boosters**
- **Spacecraft and Object Categorization**
- **Assignment of Spacecraft Ownership**
- **Flight Rules (Operational Rules)**
- **Conjunction Analyses: Mission Planning**
- **Conjunction Analyses: Launch**
- **Conjunction Analyses: On Orbit**
- **Conjunction Analyses: Vehicle Retirement/Deorbit**
- **Assignment of Liability**
- **Debris Ownership**
- **Observational Frequency**
- **Communication Protocols**
- **Periodic Conjunction Studies**
- **Management Oversight**
- **Space Traffic Management Domain**
- **Financial Impacts Resulting from Liability**
- **International Applicability**
- **Licensing**

- **Issuance of Conjunction Warnings**
- **Data Collection, Verification, and Integration**

The trick of course is how to organize all of these bits and pieces into a coherent and effective program. What follows is ASE's opinion as to how a STM&OD program should be put together and transitioned from a national project to an international program.

STM&OD PROGRAM ORGANIZATION

As of this writing, it's clear the United Nations through the Committee on the Peaceful Uses of Outer Space (COPUOS) is looking for member nations to solve the space traffic management problem and then to assist in the transition of a national solution to an international one. In the United States, the Department of Commerce has been given direction to develop just such a program. There are also many who argue there is no need for any oversight organization at all. These people feel a self-regulating consortium is all that's needed to collect and share information. ASE does not share that opinion. For an STM&OD program to be successful, there will need to be licensing of spacecraft, rules governing their operation, clear lines of communication, and enforcement of any rules adopted by the community. For these reasons and more that will be explained in later sections, ASE believes there needs to be a multi-lateral, centralized coordinating body to establish and enforce best practices to mitigate the hazards presented by the growing population of space debris objects.

Coordination

A Space Traffic Management and Orbital Debris program will require a centralized coordinating body to coordinate and regulate all associated interrelated activities. Organized functionally, an STM&OD program should appear similar to that depicted in Figure 1.

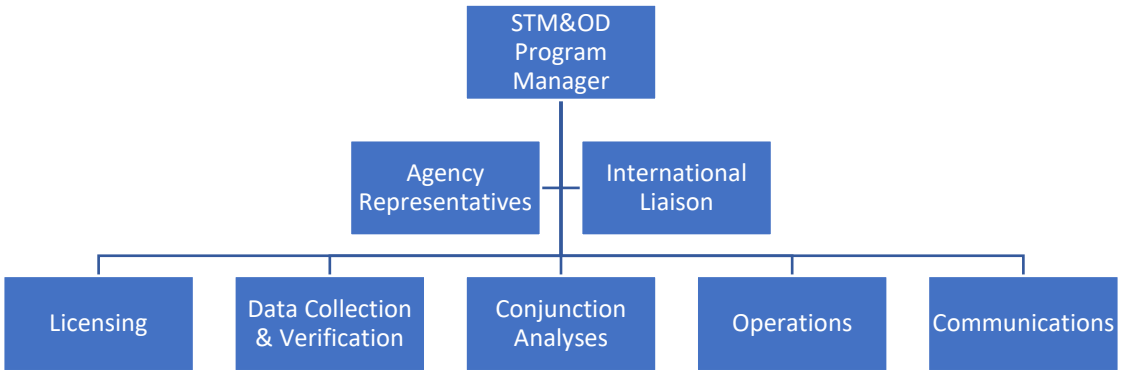

Figure 1: A Notional STM&OD Organization

Each functional block will be described in turn.

STM&OD Program Manager
The manager assigned will need to be someone with considerable experience in the space domain working with defense, government agencies, commercial companies, and entrepreneurs. In addition to being sensitive to the needs of all of these parties, this person will also need experience working in the international arena to ensure that all actions taken on the part of national interests are not inadvertently viewed as intrusions on the domains of other countries. The program manager will be personally responsible through this organization for ensuring earth orbit remains open for business.

Agency Representatives
It is vital to the success of any STM&OD program that all relevant agencies and organizations be represented.

International Liaison
It is also vital to program success that international organizations be represented from the very beginning. International participation will be needed in the development of policies and procedures, communications protocols, data collection and verification, and operations.

Licensing
Licensing needs to be expanded beyond frequency management to include, design requirements to limit the creation of orbital debris and the incorporation of passive tracking devices (e.g., corner reflectors) in all vehicles and boosters. Licensing should also be expanded to include the requirements to abide by the rules, regulations, policies, and procedures developed and adopted by the international space community.

Data Collection & Verification
It was not that long ago that the complete object catalog was on the order of 27,000 objects. Today, with a better understanding of what constitutes lethal debris to spacecraft and the dramatic increase in planned satellite launches, the catalog is expected to exceed 500,000 objects. The collection of suitable observational data for such a catalog will require not only a large number of observing systems, but also observations performed frequently to maintain orbital uncertainties within useable limits. Just verifying and integrating observational data into a catalog will be a real challenge. Further, defense agencies will be reluctant to have data on their assets included in any open database that will be used for these purposes. Although their sensitivities are understandable, the reality is that their assets are being observed and tracked today.

Another area of concern is the reliance on defense assets to perform data collection. Fortunately, great progress has been made by commercial companies like LeoLabs[(6)] to perform continuous sky surveys to generate the volume of observational data that will be needed. In addition, it has already been demonstrated by DARPA[(7)] and others that observations from disparate sensors can be validated and incorporated into an integrated catalog.

Conjunction Analyses

Another area of great concern is simply how to perform conjunction analyses with a catalog of 500,000 objects. Fortunately, great strides have been made in this area as well by academic institutions like Texas A&M[8] and commercial companies like LeoLabs who have shown that conjunction studies can be performed on catalogues of this size in a timely manner yielding viable conjunction predictions. Because there will always be uncertainty in "knowing" a satellite's orbit, every conjunction warning will of necessity involve some probability of error. As catalogue accuracy continues to improve, the number of false warnings resulting from excessive error will decline. Ideally, every warning issued will be worthy of both concern and action on the part of the parties involved.

Operations

Without a doubt, a satellite control center will be required to manage and coordinate day to day satellite operations. This would include coordination of activities during mission planning, launch, on orbit, and during satellite retirement/deorbit. When conjunctions are predicted, it will be the responsibility of Operations to issue the formal warnings and to coordinate actions as appropriate. In addition, Operations will be responsible for the sharing of data in the integrated catalog and the coordination of maneuvers to avoid unintended consequences.

Communications

The coordination of all activities involved in this enterprise will be a major communications challenge. Multiple means of communications plus the associated protocols will be needed to ensure information is passed quickly, efficiently, and in useable formats.

ESTABLISHING AN OPERATIONAL FRAMEWORK

Before beginning this next section, it is important to restate the need for a solid framework on which to build a STM&OD Program. Without any one piece of the framework, the entire program will fail. In May 2019, in response to a "Request for Information on Commercial Capabilities in Space Situational Awareness Data and Space Traffic Management Services" from the USA's Commerce Department, ASE wrote:

- If one is collecting good observation data, but there is no mechanism to validate its utility, it has little value.
- If one knows the position of all objects in earth orbit, but doesn't have the capability to calculate conjunctions, the data are of little value.
- If one knows when potential conjunctions will occur, but doesn't have the capability to communicate warnings in a timely manner to the parties involved, it is of little value.
- If two parties are advised of a potential conjunction, but they are under no obligation to alter their orbits, what good is the information?

Fortunately, great progress has been made toward collecting good observational data, validating and incorporating them into a catalog, and performing conjunction studies even with a catalog approaching 500,000 objects. Areas still needing work relate to management of the enterprise, communications, and rules to support a true operational framework. The following items should be addressed and will require a great deal of dialog and debate within the international space community.

Spacecraft and Object Categorization
A clear set of definitions are required for all objects in earth orbit. In order to establish a set of rules for operations, objects must be categorized so that a set of priorities can be formulated. An initial set of categories would be:

> **Crewed Spacecraft:** An aerospace vehicle containing human beings completing all or part of its mission in earth orbit.
>
> **Active Spacecraft:** A spacecraft operating in earth orbit capable of performing maneuvers to change its orbit. Active spacecraft, crewed and un-crewed, have the capability to use propulsive devices and consumables to effect orbit change. Spacecraft remain classified as "Active" until the capability to perform such maneuvers has been lost either due to mechanical failure or the expenditure of all propulsive consumables.
>
> **Passive Spacecraft**: A spacecraft operating in earth orbit not capable of performing maneuvers to change its orbit. Spacecraft remain in a "Passive" classification as long as they are determined to be operational. When that functionality is lost (inert objects), they are reclassified as "Space Debris".
>
> **Space Debris:** This category includes all objects in earth orbit, both natural and man-made in origin, that are not Active or Passive Spacecraft.

Spacecraft Ownership
All spacecraft have owners from the time of their manufacture, through launch, on orbit operations, and retirement/deorbit. The timeframe from manufacture through retirement/deorbit will be referred to as the spacecraft's lifetime. Ownership and responsibility exist for the entire lifetime of a spacecraft as follows:

> 1. Government developed spacecraft belong for their entire lifetime to the government that paid for their development, manufacture, and operation.
>
> 2. Commercial spacecraft (spacecraft built under contract for a commercial entity) are owned by the procuring company unless such company ceases to exist. If the procuring company no longer exists, ownership transfers to the procuring company's country of origin.
>
> 3. Spacecraft developed for an academic institution belong to that institution unless the institution ceases to exist. If the academic institution no longer exists, ownership transfers to the academic institution's country of origin.
>
> 4. Spacecraft developed for a private party belong to that party unless the private party ceases to exist. If the private party no longer exists, ownership transfers to the private party's country of origin.

5. The sale or transfer of a spacecraft from one owner to another also transfers ownership and the associated responsibilities.

Spacecraft owners are responsible for the safe operation of their vehicles for their entire lifetime. Ownership and responsibility continue even after functionality is lost due to failures or the expenditure of consumables. Spacecraft transitioning from active to passive to space debris remain the responsibility of their owners.

Flight Rules (Operational Rules)

The purpose of flight rules (operational rules) is to establish a pre-agreed to set of actions to be taken when events occur. Rules are typically based upon a scenario which requires action by one or more parties to avoid an undesirable outcome. Specific rules result from the review and debate of alternative courses of action and are ultimately agreed to by the parties involved. In that way, when a situation does occur, time is not wasted reviewing options and debating. Instead, action is taken in a timely manner to secure a positive outcome.

What follows are an initial set of flight rules (operational rules) for review and debate. The list is not intended to be complete, but simply to serve as a starting point for a more extensive effort.

General Flight Rules (Operational Rules):

1. Crewed spacecraft have priority over all other vehicles and objects in orbit.
2. Un-crewed active spacecraft shall maneuver to avoid conjunctions with crewed spacecraft, passive spacecraft, and debris.
3. Active spacecraft owners shall advise the centralized coordinating body at least 72 hours in advance of any planned maneuvers.
4. If a conjunction is predicted between two active spacecraft, the spacecraft with the longest remaining active lifetime shall maneuver.
5. The centralized coordinating body shall notify affected parties at least 72 hours in advance of any predicted conjunctions.

Mission Planning

Spacecraft owners are responsible for conducting conjunction studies in association with the centralized coordinating body to ensure no conflicts will exist during launch, post insertion, and on orbit with their primary payload, any secondary payloads, boosters, upper stages, or jettisoned hardware.

Mission Planning Flight Rules (Operational Rules):

1. Studies shall be performed during mission planning to ensure no conflicts are presented during launch, post insertion, or on orbit with Active Spacecraft, Passive Spacecraft, or Space Debris.
2. A final conjunction study shall be performed 30 days prior to flight to verify that no conflicts have developed during the planning cycle.

Launch

Spacecraft owners are responsible for conducting conjunction studies near the planned launch date in association with the centralized coordinating body to ensure no conflicts will exist during launch, post insertion, and on orbit with their primary payload, any secondary payloads, boosters, or jettisoned hardware.

Launch Flight Rules (Operational Rules):

1. One week prior to launch, a conjunction study shall be performed to ensure no conflicts will exist on launch day at any time during the launch window.
2. If the day/time of launch is changed due to weather, scheduling issues, mechanical problems, or other causes, a conjunction study shall be performed to ensure this change does not result in a conflict.
3. If a potential conflict is indicated, launch day/time shall be adjusted in conjunction with the Central Controlling Authority to avoid this conflict.

On Orbit

Spacecraft owners are responsible for conducting conjunction studies in association with the centralized coordinating body to ensure no conflicts will exist on orbit with their primary payload, any secondary payloads, boosters, or jettisoned hardware. Because spacecraft do not always end up in the orbits intended during mission planning and launch, it is necessary to perform a conjunction study once the primary payload, any secondary payloads, boosters, or jettisoned hardware reach orbit. Further, conjunction studies should be performed periodically for all objects in earth orbit to verify no conflicts have developed.

If a maneuver is planned for an Active Spacecraft, that activity shall be coordinated with the centralized coordinating body to verify the maneuver does not result in a conjunction. Once the planned maneuver has been completed, a conjunction study shall be performed to verify no conflicts were created.

On Orbit Flight Rules (Operational Rules):

1. Spacecraft owners shall perform a conjunction study in association with the centralized coordinating body once their primary payload, any secondary payloads, boosters, or jettisoned hardware have reached orbit.
2. Spacecraft owners shall advise the Central Controlling Authority of any debris placed in orbit as a result of their activities.
3. Spacecraft owners shall advise the centralized coordinating body of any planned maneuvers by their spacecraft 72 hours in advance of such activity.
4. Spacecraft owners shall perform a conjunction study in association with the centralized coordinating body before any planned maneuvers are performed to verify that no conflicts will be created.
5. Spacecraft owners shall advise the centralized coordinating body of any change in the functional status of their spacecraft.
6. Crewed spacecraft shall have priority over all other vehicles and objects in orbit.
7. Un-crewed active spacecraft shall maneuver to avoid conjunctions with crewed spacecraft, passive spacecraft, and debris.

8. If a conjunction is predicted between two active spacecraft, the spacecraft with the longest remaining active lifetime shall maneuver.
9. Every effort shall be made to notify affected parties at least 72 hours in advance of any predicted conjunctions.

Vehicle Retirement/Deorbit.
For spacecraft that are still active at the time of their retirement from service (still have maneuvering capability) they may be deorbited or placed into a "retirement orbit". In either case, such activities will be planned well in advance and coordinated with the centralized coordinating body. As with any other maneuvers performed on orbit, it is essential to avoid conjunctions with other spacecraft and debris in orbit.

Vehicle Retirement/Deorbit Flight Rules (Operational Rules):

1. Under normal circumstances, spacecraft owners shall notify the centralized coordinating body 6 months prior to any retirement/deorbit activities or immediately if circumstances require immediate action.
2. A conjunction study shall be performed in association with the centralized coordinating body to ensure the planned maneuver(s) do not result in any conjunctions.
3. As with any other on orbit maneuver, a conjunction study shall be performed post-maneuver to identify any resulting conflicts.

Assignment of Liability
The owner(s) of a spacecraft are responsible for its safe operation from launch through retirement/deorbit. These responsibilities include a free and open exchange of information as well as adherence to the flight rules (operational rules). If a collision occurs due to a failure to comply with one or more rules, the owner(s) of the offending spacecraft will be liable for damages to the other party, loss of revenue, and the damages caused by any resulting debris.

When collisions occur, a large number of pieces of debris are generated each at orbital speed in slightly different orbits. If a collision resulted from an active spacecraft owner failing to maneuver, that owner is now responsible for all debris generated as a result of the collision. Even though the owner of the offending spacecraft could argue that a maneuver was not performed due to the low probability of a collision given the size of the error ellipsoids, that will not compensate for the losses experienced by the injured parties.

It will clearly be in the best interest of all parties operating in earth orbit to reduce uncertainties in orbits and positions as soon as possible. By doing so, consumables won't be wasted on maneuvers that really aren't required thus extending mission lifetimes as long as practical and massive financial judgements will be avoided.

Debris Ownership
ASE supports the concept of orbital debris being the responsibility of the original owner just as with a spacecraft unless the debris resulted from a collision with an "offending" active spacecraft, in which case it is the offending active spacecraft that owns the debris. Further, since

spacecraft that experience failures or lose power effectively become debris, ownership and liability should be retained.

Financial Impacts Resulting from Liability

Liability in the context of this discussion can result in the payment of significant amounts of money in direct damage compensation, loss of revenue, and punitive fees. It is quite possible that the threat of legal action resulting from a collision may be the best motivator for spacecraft owners and operators to play by the rules.

International Applicability

It is the hope of ASE that the United Nations Committee for the Peaceful Uses of Outer Space and other international organizations and countries engage as partners in this endeavor. Controlling orbital debris and making Space Traffic Management work for everyone operating in earth orbit will clearly require extensive international cooperation. As with operations on the seas and in the air, this can only work if we are all in this together.

SUMMARY

The purpose of this paper was to outline the Association of Space Explorers' position on Space Traffic Management and Orbital Debris. ASE recognizes that the development of a viable STM&OD program by the United States is clearly a work in progress, but one that is vital to complete in a timely manner. ASE hopes that through this paper discussions can continue, solutions can be developed, and progress can be expedited. Solutions developed by the United States and/or other countries need to be considerate of other national interests and ultimately migrated to an international solution. The Association of Space Explorers stands ready to assist in this process in any way possible.

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