The 2019 U.S. Government Orbital Debris Mitigation Standard Practices

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ABSTRACT

The rapid expansion of space traffic enabled by the SmallSat revolution has enabled unparalleled opportunity for commercial, educational, and national interests. However, it is an ongoing truth of space operations that the number of functioning spacecraft in orbit is vastly exceeded by non-functional orbital objects that can destroy them. As with any other environment, orbital space is easily polluted by human activities, and at some point the pollution can significantly degrade the usefulness of that environment. Today, there are more threats to more spacecraft than ever before, and the current accelerated growth of space activity consequently accelerates the growth of its risks.

As early as 1988, US national space policy established the priority to protect the space environment. Subsequently NASA and the US Department of Defense made first efforts on formal standard practices to control space debris as early as 1993. Their work was expanded with the participation of all involved US agencies in the publication of the first US Orbital Debris Mitigation Standard Practices (ODMSP) document in 2001. That document mandated minimum design and operations practices to best preserve the orbital environment with prudent, low-cost, mandatory steps. Subsequently, global coordination through the Interagency Debris Coordination Committee (IADC) has propagated many of these practices to all space-faring powers with varying levels of success, and has elevated orbital debris mitigation to be a global concern. Each US agency implements the standard practices within their own official regulatory/safety documents, such as NASA's standard 8719.14 and DOD's Directive 3100.10, and others.

In the last decade innovative new practices, concepts, and massive constellation proposals have opened "future space" to realities not envisioned in the 2001 standard practices document. Therefore, under Presidential Space Policy Directive #3 (June 8, 2018) all US space-related agencies were directed to coordinate a major revision to the ODMSP to reflect expected best practices for this new era in space. This revised document was approved by the National Space Council in December 2019, and is reprinted here. All US agencies with any certification or development authority over space launchers and/or spacecraft are now working to assure compliance of their internal standards with these practices. In addition, a 2025 list of recommendations (non-mandatory) from the 18th Space Wing at the Central Space Operations Center introduces addition details of design and operations that are all useful in reducing the risks in small satellite operations. This document is proposed for revision as well.

No matter the intended function of a space object or launch vehicle, its certification for flight by any US agency will now depend upon meeting the minimum set of debris mitigation practices of the 2019 ODMSP. Additionally, good recommended practices are embodied in the 2015 Recommendations for Optimal CubeSat Operations. Both documents are included with this presentation. The attached presentation slides highlight all ODMSP requirements,

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This paper consists of two exhibits: the 2019 ODMSP and the 2015 JSpOC Recommendations.

<u>TABLE 1:</u>

U.S. Government
Orbital Debris Mitigation Standard Practices, November 2019 Update

PREAMBLE

The United States Government (USG) Orbital Debris Mitigation Standard Practices (ODMSP) were established in 2001 to address the increase in orbital debris in the near-Earth space environment. The goal of the ODMSP was to limit the generation of new, long-lived debris by the control of debris released during normal operations, minimizing debris generated by accidental explosions, the selection of safe flight profile and operational configuration to minimize accidental collisions, and postmission disposal of space structures. While the original ODMSP adequately protected the space environment at the time, the USG recognizes that it is in the interest of all nations to minimize new debris and mitigate effects of existing debris. This fact, along with increasing numbers of space missions, highlights the need to update the ODMSP and to establish standards that can inform development of international practices. This 2019 update includes improvements to the original objectives as well as clarification and additional standard practices for certain classes of space operations. The improvements consist of a quantitative limit on debris released during normal operations, a probability limit on accidental explosions, probability limits on accidental collisions with large and small debris, and a reliability threshold for successful postmission disposal. The new standard practices established in the update include the preferred disposal options for immediate removal of structures from the near-Earth space environment, a low-risk geosynchronous Earth orbit (GEO) transfer disposal option, a long-term reentry option, and improved move-away-and-stay-away storage options in medium Earth orbit (MEO) and above GEO. The update also incorporates new sections to clarify and address operating practices for large constellations, rendezvous and proximity operations, small satellites, satellite servicing, and other classes of space operations. The updated standard practices are significant, meaningful, and achievable. The 2019 ODMSP, by establishing guidelines for USG activities, provides a reference to promote efficient and effective space safety practices for other domestic and international operators. The USG intends to update and refine the ODMSP as necessary in the future to address advances in both technology and policy.

The USG will follow the ODMSP, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the conduct of tests and experiments in space. When practical, operators should consider the benefits of going beyond the standard practices and take additional steps to limit the generation of orbital debris. Together with continued development of standards and best practices for space traffic management, the updated ODMSP will contribute to safe space operations and the long-term sustainability of space activities.

OBJECTIVE

1. CONTROL OF DEBRIS RELEASED DURING NORMAL OPERATIONS

Programs and projects will assess and limit the amount of debris released in a planned manner during normal operations. Objects with planned functions after release should follow standard practices set forth in Objectives 2 through 5.

MITIGATION STANDARD PRACTICES

1-1. *In all operational orbit regimes*: Spacecraft and upper stages should be designed to eliminate or minimize debris released during normal operations. Each instance of planned release of debris larger than 5 mm in any dimension that remains on orbit for more than 25 years should be evaluated and justified. For all planned released debris larger than 5 mm in any dimension, the total debris object-time product in low Earth orbit (LEO) should be less than 100 object-years per upper stage or per spacecraft. The total object-time product in LEO is the sum, over all planned released objects, of the orbit dwell time in LEO.

OBJECTIVE

2. MINIMIZING DEBRIS GENERATED BY ACCIDENTAL EXPLOSIONS

Programs and projects will assess and limit the probability of accidental explosion during and after completion of mission operations.

MITIGATION STANDARD PRACTICES

2-1. *Limiting the risk to other space systems from accidental explosions and associated orbital debris during mission operations*: In developing the design of a spacecraft or upper stage, each program should demonstrate, via commonly accepted engineering and probability assessment methods, that the integrated probability of debris-generating explosions for all credible failure modes of each spacecraft and upper stage (excluding small particle impacts) is less than 0.001 (1 in 1,000) during deployment and mission operations.

2-2. *Limiting the risk to other space systems from accidental explosions and associated orbital debris after completion of mission operations*: All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload. Propellant depletion burns and compressed gas releases should be designed to minimize the probability of subsequent accidental collision and to minimize the impact of a subsequent accidental explosion.

OBJECTIVE

3. SELECTION OF SAFE FLIGHT PROFILE AND OPERATIONAL CONFIGURATION

Programs and projects will assess and limit the probability of operating space systems becoming a source of debris by collisions with human-made objects or meteoroids.

MITIGATION STANDARD PRACTICES

3-1. *Collision with large objects during orbital lifetime*: In developing the design and mission profile for a spacecraft or upper stage, a program will estimate and limit the probability of collision with objects 10 cm and larger during orbital lifetime to less than 0.001 (1 in 1,000). For the purpose of this assessment, 100 years is used as the maximum orbital lifetime.

3-2. *Collision with small debris during mission operations*: Spacecraft design will consider and limit the probability to less than 0.01 (1 in 100) that collisions with micrometeoroids and orbital debris smaller than 1 cm will cause damage that prevents planned postmission disposal.

OBJECTIVE

4. POSTMISSION DISPOSAL OF SPACE STRUCTURES

Programs and projects will plan for disposal procedures for a structure (*i.e.*, launch vehicle components, upper stages, spacecraft, and other payloads) at the end of mission life to minimize impact on future space operations.

MITIGATION STANDARD PRACTICES

4-1. *Disposal for final mission orbits*: A spacecraft or upper stage may be disposed of by one of the following methods:

a. Direct reentry or heliocentric, Earth-escape: Maneuver to remove the structure from Earth orbit at the end of mission into (1) a reentry trajectory or (2) a heliocentric, Earth-escape orbit. These are the preferred disposal options. For direct reentry, the risk of human casualty from surviving components with impact kinetic energies greater than 15 joules should be less than 0.0001 (1 in 10,000). Design-for-demise and other measures, including reusability and targeted reentry away from landmasses, to further reduce reentry human casualty risk should be considered.

b. Atmospheric reentry: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to as short as practicable but no more than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit. The risk of human casualty from surviving components with impact kinetic energies greater than 15 joules should be less than 0.0001 (1 in 10,000).

c. Storage between LEO and GEO:
I. Maneuver to an eccentric disposal orbit (*e.g.*, GEO transfer) where (1) perigee altitude remains above the LEO zone for at least 100 years, (2) apogee altitude remains below the GEO zone for at least 100 years, and (3) the time spent by the structure between 20,182 +/- 300 km is limited to 25 years or less over 200 years; or,

II. Maneuver to a near-circular disposal orbit to (1) avoid crossing 20,182 +/- 300 km, the GEO zone, and the LEO zone for at least 100 years, and (2) limit the risk to other operational constellations, for example, by avoiding crossing the altitudes occupied by known missions of 10 or more spacecraft using near-circular orbits, for 100 years.

d. Storage above GEO: Maneuver to an orbit with perigee altitude sufficiently above 35,986 km (upper boundary of the GEO zone) to ensure the structure remains outside the GEO zone for at least 100 years.

e. Long-term reentry for structures in MEO, Tundra orbits, highly inclined GEO, and other orbits: Maneuver to a disposal orbit where orbital resonances will increase the eccentricity for long-term reentry of the structure. In developing this disposal plan, the program should (1) limit the postmission orbital lifetime to as short as practicable but no more than 200 years, (2) limit the time spent by the structure in the LEO zone, the GEO zone, and between 20,182 +/- 300 km to 25 years or less per zone; and (3) limit the probability of collisions with debris 10 cm and larger to less than 0.001 (1 in 1,000) during orbital lifetime. To limit human casualty risk from the reentry of the structure, surviving components with impact kinetic energies greater than 15 joules should have less than 7 m^2 total debris casualty area or less than 0.0001 (1 in 10,000) human casualty risk.

f. Direct retrieval: Retrieve the structure and remove it from orbit preferably at completion of mission, but no more than 5 years after completion of mission.

4-2. *Reliability of disposal*: The probability of successful postmission disposal should be no less than 0.9 with a goal of 0.99 or better.

The geosynchronous Earth orbit (GEO) zone is defined as the region between the altitudes of 35,586 and 35,986 km. The low Earth orbit (LEO) zone is defined as the region below 2000 km altitude. The medium Earth orbit (MEO) is the region between LEO and GEO.
Because of fuel gauging uncertainties near the end of mission, a program should use a maneuver strategy that reduces the risk of leaving the structure near an operational orbit regime.

OBJECTIVE

5. CLARIFICATION AND ADDITIONAL STANDARD PRACTICES FOR CERTAIN CLASSES OF SPACE OPERATIONS

These classes of space operations and structures should follow Objectives 1 through 4 plus the additional standard practices for orbital debris mitigation set forth in this section.

MITIGATION STANDARD PRACTICES

5-1. *Large Constellations*: A constellation consisting of 100 or more operational spacecraft cumulative is considered a large constellation.

a. Each spacecraft in a large constellation should have a probability of successful postmission disposal at a level greater than 0.9 with a goal of 0.99 or better. In determining the successful postmission disposal threshold, factors such as mass, collision probability, orbital location, and other relevant parameters should be considered.

b. For large constellations, Objective 4-1.a. is the preferred postmission disposal option for the spacecraft. In developing the mission profile, the program should limit the cumulative reentry human casualty risk from the constellation.

5-2. *Small satellites, including CubeSats*, should follow the standard practices set forth in Objectives 1 through 4. For spacecraft smaller than 10 cm × 10 cm × 10 cm when fully deployed:

a. Any spacecraft in LEO should be limited to an orbital lifetime as short as practicable but no more than 25 years after completion of mission.

b. The total spacecraft object-time product in LEO should be less than 100 object-years per mission.

5-3. *Rendezvous, proximity operations, and satellite servicing*: In developing the mission profile for a structure, the program should limit the risk of debris generation as an outcome of the operations. The program should (1) limit the probability of accidental collision, and (2) limit the probability of accidental explosion resulting from the operations. Any planned debris generated as a result of the operations should follow the standard practices for mission-related debris set forth in Objective 1.

TABLE 2:

JSpOC Recommendations for Optimal CubeSat Operations

1 JFCC SPACE AND THE JSPOC

The Joint Functional Component Command for SPACE (JFCC SPACE) is responsible for identifying, cataloging and tracking over 23,000 man---made objects achieving orbit. JFCC SPACE executes this mission using data collected by the U.S. Space Surveillance Network (SSN) and through the expertise of its personnel at the Joint Space Operations Center (JSpOC), located at Vandenberg Air Force Base, in California. The proliferation of CubeSats (10cm x 10cm x 10cm satellites) and associated technology, have posed unique tracking and identification challenges. In light of this evolving situation, JFCC SPACE would like to share information on the current challenges it faces and propose recommendations on how to optimize operations in coordination with the JSpOC, to support the growing government, commercial, and academic CubeSat communities of interest.

2 CURRENT CHALLENGES

In late 2013, two launches presented an unprecedented challenge for JSpOC personnel. The ORS-3 mission launched STPSAT 3 and 27 CubeSats, closely followed by a DNEPR rocket hosting 31 CubeSats. Both launches involved multiple owner/operators (O/Os) from all facets of the space community; U.S. and foreign governments, academia, and commercial entities, all of whom depend on the JSpOC to a varying degree for support functions to ensure mission success. These two independent multi---payload deployment missions presented known challenges to JSpOC processes. After---action reviews completed after the launches revealed that the JSpOC and O/Os require higher levels of collaboration in order to provide optimal pre--- and post---launch support. Notable points included:

- The JSpOC uses information provided by the launch entity and/or O/O as the truth---source. Without launch information from the launch entity and/or O/O, the JSpOC has limited data to inform tracking and cataloging, which delays delivery of information to satellite stakeholders.
- The JSpOC does not command and control satellites, communicate with satellites (passive or active), or provide telemetry of satellites. Many O/Os are unaware of this fact. The JSpOC relies on O/Os to perform this role and provide telemetry information that may assist with identification.
- The JSpOC depends on O/Os to provide detailed information on launch plans and payload deployment to ensure individual payload(s) are quickly identified upon separation or release from the payload deployer. Without this information and coordination, the JSpOC may have difficulty tracking and differentiating CubeSats. As a result, the JSpOC may be required to categorize the objects as unknown “analyst satellites” until more

data can be collected. Analyst satellites are not publicly releasable, which makes it difficult for O/Os to conduct their missions, and inhibits collaborative identification efforts between the JSpOC and the O/O.

- The JSpOC physically tracks objects and provides assessment screenings using SSN observations and O/O---provided information, both before and after launch. These services include Launch Conjunction Assessment, Early Orbit Conjunction Assessment, and On---Orbit Conjunction Assessment. The JSpOC is dedicated to supporting spaceflight safety through all mission phases, but relies on O/O---provided information to do so consistently.

3 RECOMMENDATIONS

After extensive coordination with CubeSat O/Os, the JSpOC understands that O/Os have a wide range of requirements, spanning from pre---launch mission planning to spaceflight safety support. Accordingly, the JSpOC offers the following recommendations for CubeSat launch entities and O/Os to consider as they conduct CubeSat planning.

CubeSat Development:

- Satellite identification is extremely difficult to determine without initiative taken by the launch entity and/or O/O.
    - Identification markers, either physical or signal based, should be considered and these should be different for each object deployed in a multi---payload launch. Markers should function for at least two months to provide sufficient time for object separation and maximize the likelihood of identification.
- Satellites should have some maneuver capability to facilitate conjunction avoidance on---orbit.
- Satellites should be built to allow controlled reentry or expedited uncontrolled reentry to minimize the threat of individual CubeSats beyond the satellite's mission life.

Pre---launch Planning:

- JFCC SPACE highly encourages early engagement between the launch entity and/or CubeSat O/O(s) and the JSpOC. Early engagement includes exchanging mission briefs, discussing mission support requirements, and establishing formalized communication channels prior to launch. This will allow the JSpOC to provide an honest assessment of how they can support the O/O's mission, and provide recommendations on how to best achieve mission success.
- Orbit and mission parameters should be tightly scrutinized and controlled by O/Os.
    - With some margin, operational life should be proportional to orbit life. For example, a satellite's operational life should be greater than 2/3 of the orbital life.

    - Satellites that have a projected orbit 100km or less in the radial component from the ISS should be reevaluated to identify alternatives that don't threaten the ISS or to determine if overall mission objectives and parameters outweigh the risk to Human Space Flight (HSF) objects. In general, O/Os should deploy CubeSats below or from the ISS.
    - Satellites should be placed into high inclination orbits. Early engagement will allow the JSpOC to review the launch plan, and provide recommendations that will ensure maximum sensor coverage to optimize tracking and identification, as well as spaceflight safety.

- To expedite cataloging and identification, the launch entity and/or O/O should provide the following to the JSpOC (preferably through the R---15 Form, 10---30 days prior to launch):
    - Orbital regime of the satellite(s)
    - Deployment sequence of launch vehicle and all payloads
        - Satellites should be deployed at multi---second intervals during burns to facilitate CubeSat separation and JSpOC detection/identification/tracking. Detailed development of supporting deployment scenarios such as minimum propulsion thrust (km/s) recommendations and timed satellite deployments will enable observations. This will lead to greater probability of individual CubeSat identification.
        - If deployment during boost is not an option then deployments during non--- powered flight should be no closer than 60 seconds apart.
    - Satellite characteristics, including size, maneuverability, and deployment plans (i.e. solar panels, parachutes, shedding, etc.)
- To ensure spaceflight safety, the launch entity or satellite O/O(s) should request launch conjunction assessment.
    - The launch entity should submit the launch trajectories and analysis requirements through the Form 22.
    - The JSpOC will screen the trajectories against the space catalog and inform the launch entity and/or O/O of any possible conjunctions.

Launch

- Immediately after launch, the JSpOC will use the information provided by the launch entity and/or O/O to confirm a nominal launch, and catalog and identify the launched satellites.
- If the JSpOC is able to catalog and identify a satellite according to provided information, they will provide the initial element set to the O/O.
- If cataloging and identification is complicated due to lack of information or a complex launch sequence, the JSpOC may be forced to catalog the objects as analyst satellites.
    - If the O/O pre---coordinated with the JSpOC, the JSpOC will provide information on analyst satellites and ask the O/O for assistance in identifying their asset.

    - It the O/O has not pre---coordinated, the JSpOC will maintain the object as an analyst satellite until sufficient tracking data is collected to confidently catalog the object.

Post---Launch

- For multi---payload launches, satellites that are CubeSats or smaller, or complex deployment sequences, ongoing communication with the JSpOC is critical to identifying satellites and providing timely and accurate conjunction assessment.
    - If available, O/O tracking or position data should be provided to the JSpOC to assist in identification.
    - If the O/O cannot provide tracking data, the JSpOC will provide potential positional data and ask the O/O to confirm successful communication.
- During the early orbit phase of operations, the JSpOC relies on O/O information and predicted ephemeris to provide accurate conjunction assessment for maneuverable missions.
    - The O/O can provide ephemeris pre--- and post---launch for early orbit conjunction assessment to assist in maneuver planning.
- If the CubeSat mission is non---maneuverable, the JSpOC will rely on SSN data to provide conjunction assessment. In this case, information from the launch provider and/or O/O is absolutely critical to cataloging the object as soon as possible so that the JSpOC can provide conjunction assessment based on high---accuracy catalog data.

4 GETTING STARTED

The JSpOC would like to engage as early as possible with all CubeSat launch entities and O/Os to discuss mission requirements, negotiate optimal support, and establish lasting relationships that will ensure mutual operational success.

- Visit JFCC SPACE's public website, Space-Track.org, for a description of SSA Services
    - Available at no cost to all satellite O/Os
    - https://www.space---track.org/documentation#odr
    - Includes links to all launch planning and support forms (R---15, Form 22, Orbital Data Request)
- Consider an SSA Sharing Agreement with USSTRATCOM
    - Protects proprietary information
    - Entitles signatory to advanced SSA services
    - Contact j513@stratcom.mil for more information
- Contact the JSpOC's SSA Sharing Cell to discuss your mission and coordinate immediate support
    - Email: jspoc.ssasharing@us.af.mil
    - Phone: 805-606-2675