National Aeronautics and Space Administration

Orbital Debris Quarterly News

Volume 24, Issue 1
February 2020

Inside...

A publication of the
NASA Orbital Debris
Program Office (ODPO)

U.S. National Space Council Announces Update to the USG ODMSP

The U.S. National Space Council announced the update to the U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) in December. Originally published in 2001, this 2019 update to the ODMSP, as mandated by the Space Policy Directive-3, includes improvements to the original objectives as well as clarification and additional standard practices for certain classes of space operations. The updated ODMSP provides a reference to promote efficient and effective space safety practices for domestic and international operators. See the report on the 1st International Orbital Debris Conference (IOC) below for the official announcement. The project review on page 4 provides a summary of key new elements in the updated ODMSP. The updated ODMSP is available at: https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf. ♦

The Inaugural International Orbital Debris Conference

The inaugural International Orbital Debris Conference (IOC) was held 9-12 December 2019, in Sugar Land, Texas. This event also corresponded with the 40th anniversary of the NASA Orbital Debris Program Office (ODPO) being established at NASA Johnson Space Center (JSC) in 1979. The goal of the IOC is to promote orbital debris research activities in the United States and to foster collaborations with the international community. The first IOC attracted 288 registered participants from 21 countries.

Figure 1. Col. C. Hernandez from the U.S. National Space Council announces the update to the ODMSP. Credit: NASA

The IOC opening keynote was presented by Col. Curtis Hernandez, Director of the National Security Space Policy from the U.S. National Space Council (Figure 1). Col. Hernandez delivered the address "Driving Adaptive and Responsive Orbital Debris Policies." He endorsed the efforts of NASA on leading the update to the Orbital Debris Mitigation Standard Practices (ODMSP), as directed by Space Policy Directive-3 (SPD-3), and officially announced the ODMSP update as approved and available on the ODPO website. Originally published in 2001, this 2019 update to the ODMSP includes improvements to the original objectives as well as clarification and additional standard practices for certain classes of space operations. It provides a reference to promote efficient and effective space safety practices for domestic and international operators.

continued on page 2

1st IOC

continued from page 1

Two additional keynote addresses were given by Mr. Don Kessler, former NASA Senior Scientist for Orbital Debris, and by Professor Heiner Klinkrad of the Technical University of Braunschweig, former head of the European Space Agency (ESA) Space Debris Office. Both speakers provided a history of space debris programs at NASA and ESA, respectively.

After the opening plenary (shown in Figure 2), the IOC was conducted in two parallel oral sessions and two dedicated poster sessions over a 4-day period. A total of 162 technical papers were presented during the sessions. They covered optical, radar, laboratory and in-situ measurements, modeling, reentry, hypervelocity impacts, protection, satellite anomalies, conjunction assessments, mitigation, remediation, space situational awareness, space traffic management, policy, and meteoroids. The papers are available individually or may be downloaded as a group at https://www.hou.usra.edu/meetings/orbitaldebris2019/presenter/.

Excellent participation from the global orbital debris community, distinguished keynote speakers, contributions from the Technical Program Committee members, session chairs, and the Local Organizing Committee members, and the support of the Universities Space Research Association/Lunar and Planetary Institute made the first IOC a very successful event. ◆

Figure 2. Attendees at the 1st IOC Opening Plenary. Credit: NASA

Fifty-first SOZ Unit Breaks Up

Following the milestone 50th breakup of a SOZ (*Sistema Obespecheniya Zapuska*) ullage motor, or SL-12 auxiliary motor, in August 2019 (Orbital Debris Quarterly News [ODQN], Vol. 23, Issue 4, p. 2), the 51st fragmentation of a SOZ occurred at 1200 GMT on 23 October 2019.

Ullage motors, used to provide three-axis control to the SL-12's Block DM fourth stage during coast and to settle propellants prior to an engine restart, were routinely ejected after the Block DM stage ignited for the final time. The reader is referred to ODQN, Vol. 18, Issue 4, pp. 1-2 for an illustration and engineering drawing of a typical SOZ unit. A total of 380 SL-12 Auxiliary Motors were cataloged between 1970 and 2012, of which 64 remain on orbit as of 1 December 2019. Of these 64, 33 are now believed to be intact. The remaining 31 have fragmented and remain on-orbit while an additional 20 fragmented parent bodies are no longer on-orbit.

This recently fragmented SOZ unit (International Designator 2006-062H, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 29682), is associated with the launch of the Cosmos 2424-2426 spacecraft triplet, members of the Russian global positioning navigation system (GLONASS) constellation. Its sister unit, International Designator 2006-062G, SSN# 29680, had previously fragmented on 27 July 2016 [1], producing eight cataloged debris in addition to the parent body.

The motor was in a highly elliptical 19189 × 294 km-altitude orbit at an inclination of 64.5° at the time of the breakup. Ten objects have been observed in addition to the parent body, but none has entered the satellite catalog as of 16 December 2019. Due to difficulties in tracking objects in deep space elliptical orbits, this event may have produced many more fragmentation debris than have been observed to date. This event represents another SOZ unit fragmentation predicted by analysts of the Air Force Space Command 18th Space Control Squadron [2]. Their analysis indicates that SOZ units experience outgassing prior to the fragmentation event. This new analytical technique is useful in prompting additional surveillance of a SOZ unit prior to and post-fragmentation and assessing event time for modeling and risk assessment purposes.

References

1. Anz-Meador, P., Opiela, J., Shoots, D., *et al*. History of On-Orbit Satellite Fragmentations, 15th ed., NASA TM-2018-220037, (Nov. 2018).
2. Slatton, Z. and McKissock, D. "Methods of Predicting and Processing Breakups of Space Objects," Presented at the 7th European Conference on Space Debris, Darmstadt, Germany, April 2017.

◆

DAS 3.0 NOTICE

Attention DAS Users: DAS 2.1.1 has been updated to DAS 3.0. DAS 3.0 is optimized for Microsoft Windows 7/8/10. Previous versions of DAS should no longer be used. NASA regulations require that a Software Usage Agreement must be obtained to acquire DAS 3.0. To begin the process, click on the **Request Now!** button in the NASA Software Catalog at https://software.nasa.gov/software/MSC-26690-1. An updated solar flux table can be downloaded for use with DAS 3.0.

Russian Mystery Satellite Fragments

Cosmos 2491 (International Designator 2013-076E, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 39497) fragmented in December 2019, the final known breakup event of the year. The event is estimated to have occurred at 1302 GMT on 23 December 2019, after nearly 6 years on-orbit. The spacecraft was in an 82.5° inclined 1517 × 1485 km-altitude orbit.

As reported in the Orbital Debris Quarterly News (ODQN), vol. 19, issue 1, January 2015, p. 8, this spacecraft had initially been assumed to be debris associated with the Briz-KM upper stage. The 8 April 2014 final launch registration document for Russian late-2013 launches, submitted to the United Nations, identified the object as a spacecraft [1]. The Radio Amateur Satellite Corporation, AMSAT, further identified the spacecraft as carrying the payload Radio Sputnik (RS) 46.

The configuration of the spacecraft is unknown, though certain characteristics may be inferred. A reasonable hypothesis regarding stored energy is that the spacecraft is equipped with solar panels and an associated battery/power distribution system, at a minimum to support the RS 46 payload. Furthermore, given the demonstrated maneuvering capability of the next spacecraft in this previously-unknown series, Cosmos 2499 and Cosmos 2504, it is reasonable to surmise that Cosmos 2491 was outfitted with a thruster and on-board propellant/pressurization systems.

At the present time, the cause of this fragmentation is unknown. Two new objects (SSN #44912 and #44913) associated with this launch have entered the satellite catalog as of this writing, and the ODQN readership will be advised of developments as they arise.

References

1. Anon. Information furnished in conformity with the *Convention on Registration of Objects Launched into Outer Space*, UN Secretariat document V.14-02754 (E), ST/Sg/SER.E/709, 5 May 2014. Retrieved 6 January 2020 at http://www.unoosa.org/pdf/reports/regdocs/ser709E.pdf . ♦

Debris Assessment Software Version 3.0 Release

The Orbital Debris Program Office has released version 3.0 of the Debris Assessment Software (DAS) replacing the prior January 2017 release of DAS 2.1.1. The updated version provides data that can verify compliance of a spacecraft, rocket stage, and/or payload with NASA's requirements for debris generation, debris vulnerability, mission lifetime, and entry safety. The update assures compliance with the revised NASA Standard 8719.14 Revision B "Process for Limiting Orbital Debris," baselined April 2019. In addition to adaptations to verify against the updated requirements, DAS 3.0 incorporates updates to world population and material demise models. It also incorporates background processing for the Orbital Debris Engineering Model (ORDEM), and moves the help files to a new structure (HTMLHelp).

Successful verification of a design in DAS is guaranteed to be acceptable proof of compliance with NASA debris mitigation requirements. DAS analysis has historically been acceptable evidence to meet requirements of many other agencies in the U.S. and around the world. DAS does not address the inherent design reliability facets of NASA requirements, but addresses all Earth-related orbital debris requirements that make up the bulk of the NASA standard.

DAS is available for download. Note that download is by permission only, and requires that an application be completed via the NASA Software Catalog. To begin the process, click on the **Request Now!** button in the catalog at https://software.nasa.gov/software/MSC-26690-1. Approval for DAS is on a per project basis: approval encompasses activities and personnel working within the project scope identified in the application. A new approval form is required to download DAS 3.0, even if a current user has been approved for and has an earlier version. ♦

Orbital Debris Engineering Model (ORDEM), Version 3.1

ORDEM offers flux as a function of debris size and year. The technology can be operated in spacecraft mode or telescope mode. An upgraded user interface uses project-oriented organization and provides graphical representations of numerous output data products.

Notes:
Secure email from Repository for software download

Software Details

Reference Number	MSC-25457-1
Category	Environmental Science (Earth, Air, Space, Exoplanet)
Release Type	General Public Release
Operating System	Windows 7 or higher. Does not work on Mac or Linux.

Contact Us About This Software

Johnson Space Center
jsc-ttco-software-request@mail.nasa.gov

The NASA Software Catalog entry for ORDEM 3.1.

ORDEM 3.1 Release

The latest version of the Orbital Debris Engineering Model, ORDEM 3.1, has been released. ORDEM 3.1 uses the same model framework as its predecessor, ORDEM 3.0. It incorporates the latest high-fidelity datasets to build and validate representative orbital debris populations encompassing low Earth orbit (LEO) to geosynchronous orbit (GEO) altitudes for the years 2016-2050.

ORDEM 3.1 is appropriate for engineering solutions requiring knowledge and estimates of the Earth-related orbital debris environment (debris spatial density, flux, etc.). The model also can be used to predict ground-based debris measurement observations. ORDEM 3.1 is available from the NASA Software Catalog. To begin the process, click on the **Request Now!** button in the catalog at https://software.nasa.gov/software/MSC-25457-1, as shown in the figure. Approval for ORDEM is on a per project basis: approval encompasses activities and personnel working within the project scope identified in the application. A new approval form is required to download ORDEM 3.1, even if a current user has been approved for and has an earlier version. ♦

PROJECT REVIEW

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

J.-C. LIOU, M. KIEFFER, A. DREW, AND A. SWEET

NASA and the Department of Defense (DOD) led the development of the original U.S. Government (USG) Orbital Debris Mitigation Standard Practices (ODMSP) in 2001. As the orbital debris (OD) populations continue to increase over time, and as new technologies have driven the rapid expansion of commercial and global space activities in recent years, there is a need to update the ODMSP to promote efficient and effective practices to better mitigate the risks from OD for the safe operations of future space missions.

The 2018 U.S. Space Policy Directive-3 (SPD-3), the National Space Traffic Management Policy, specifically directs NASA to lead this effort – "*The Administrator of the National Aeronautics and Space Administration (NASA Administrator), in coordination with the Secretaries of State, Defense, Commerce, and Transportation, and the Director of National Intelligence, and in consultation with the Chairman of the Federal Communications Commission (FCC), shall lead efforts to update the U.S. Orbital Debris Mitigation Standard Practices and establish new guidelines for satellite design and operation, as appropriate and consistent with applicable law*" [1].

After more than a year's work by the interagency working group, which consisted of over 80 representatives from 7 departments and agencies, the update was completed in November 2019 (see the announcement on page 1 of this ODQN issue) [2]. This article provides a summary of the key new elements in the 2019 ODMSP and the rationale behind the changes.

Guiding Principles of Orbital Debris Mitigation

The intent of the ODMSP is to limit the generation of new, long-lived debris. Based on the historical increase of the debris populations (Figures 1 and 2), it is obvious that the foundation of OD mitigation is based on four guiding principles, reflected in the four "Objectives" of the 2001 ODMSP - limit the generation of mission-related debris, limit the generation of accidental explosion fragments, limit the generation of accidental collision fragments, and remove structures (upper stages and spacecraft) from the environment at the end of mission operations. Since the four guiding principles are as valid today as when they were first established in 2001, the 2019 update follows the same high-level objective structure as the 2001 ODMSP, but makes substantive changes within each objective.

In addition to improving the existing practices, the SPD-3 also directs the update to "…*incorporate sections to address operating practices for large constellations, rendezvous and proximity operations, small satellites, and other classes of space operations*…." Because of the mandate, a new section (Objective 5) was created to clarify and identify additional standard practices for such operations. The 2019 ODMSP also includes a preamble to provide the background of the update, summarize the key new elements, and identify necessary implementation of the ODMSP and other best practices to achieve safe space operations.

Mission-related Debris, Accidental Explosions, and Accidental Collisions

The main update for mission-related debris in Objective 1 is to add a new number-time product limit of "less than 100 object-years" for debris released during normal operations per upper stage or spacecraft in low Earth orbit (LEO). This new limit aims to reduce the long-term presence of mission-related debris in LEO.

continued on page 5

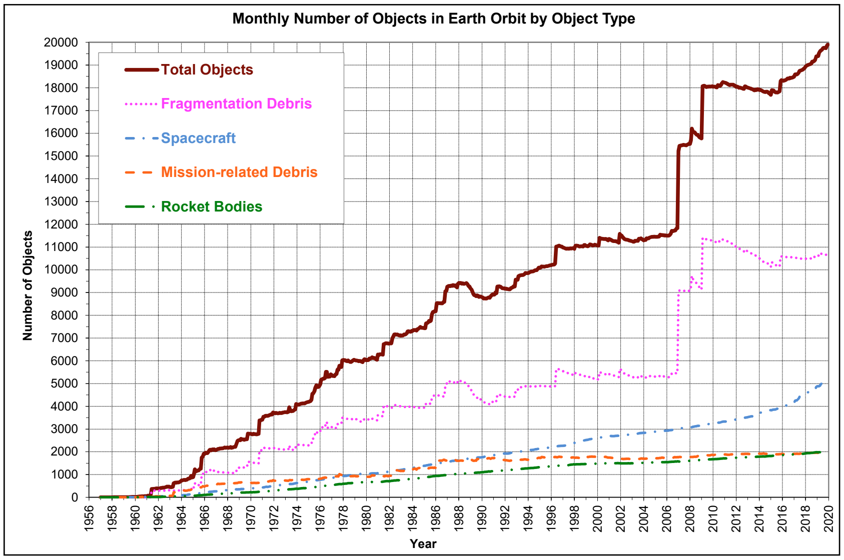

Figure 1. Monthly Number of Cataloged Objects in Earth Orbit by Object Type. This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

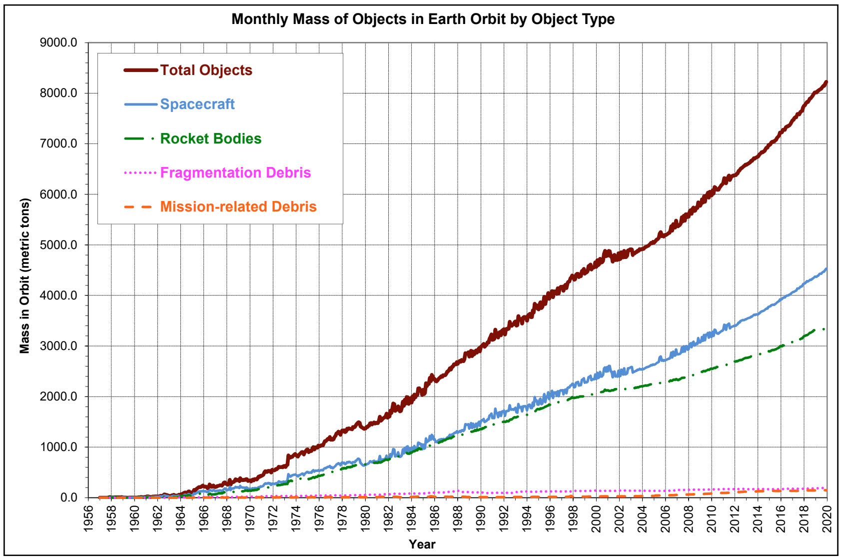

Figure 2. Monthly Mass of Objects in Earth Orbit by Object Type. This chart displays the mass of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network.

USG ODMSP

continued from page 4

Individual mission-related debris should follow the 25-year rule. If multiple mission-related debris is planned, the 100-object-years limit places an additional constraint to mitigate the risk. For example, if 10 identical mission-related debris is planned, they need to be released at an altitude where the orbital lifetime of each debris is 10 years or shorter. If 100 identical mission-related debris is planned, then it should be released at a lower altitude where the orbital lifetime of each debris is limited to 1 year or less.

For Objective 2 (“Minimizing Debris Generated by Accidental Explosions”), a new accidental explosion probability limit of “less than 0.001 (1 in 1,000) during deployment and mission operations” was added. Almost all long-lived cataloged breakup fragments before the Fengyun-1C (FY-1C) anti-satellite (ASAT) test in 2007 were explosion fragments. As of 1 January 2020, 60% of the cataloged on-orbit fragments were the outcome of accidental explosions. Limiting the probability of accidental explosions is related to the quality of the design and fabrication of the key components in an upper stage or spacecraft, such as propulsion and electrical power systems. It also is in line with mission success. The new limit in the 2019 update has been demonstrated to be achievable and meaningful in reducing the generation of accidental explosion fragments. The same limit has been adopted by NASA, the DOD, major spacefaring nations, the European Space Agency, and the International Organization for Standardization.

There are two aspects in limiting accidental collisions in Objective 3. The first is the selection of a safe flight profile, including mission altitude, background debris environment, and end of mission planning to limit the probability of accidental collisions with large objects during the orbital lifetime of a structure. A collision with a 10 cm or larger object is likely to be catastrophic, which could lead to the generation of hundreds of trackable debris and many more small debris to threaten other operational spacecraft. To better mitigate the risk, the 2019 update added a new threshold to limit the probability of a structure’s collision with objects 10 cm and larger during its orbital lifetime to less than 0.001 (1 in 1,000). For a high-altitude mission where a storage orbit is considered for postmission disposal, 100 years is used as the maximum “orbital lifetime” for collision probability calculation. Conjunction assessments and possible collision avoidance maneuvers can further limit the risk of collision with large objects.

The second aspect of Objective 3 is the proper protection of the key satellite components from small micrometeoroid and orbital debris (MMOD) impacts to ensure successful postmission disposal (PMD) operations. For example, when a propellant tank is perforated by a small, millimeter-sized MMOD, the outcome may not be a catastrophic breakup of the spacecraft, but the damage could easily cause the spacecraft to end its mission early or lose its ability to carry out disposal burns. The 2019 update added a new quantitative 0.01 (1 in 100) probability limit to address this risk. It has been demonstrated by many NASA missions that cost-effective protective shields for critical components can be designed and implemented to meet this threshold.

Postmission Disposal: from 25-year Rule to Immediate Removal

The goal of PMD is to prevent future collisions involving spent upper stages or retired spacecraft by removing them from the environment at the end of their mission operations. As more mass is added to the near-Earth space environment, it will only fuel the potential of a collision cascade effect, the so-called Kessler Syndrome. For a structure crossing LEO, lowering its orbit so that the atmospheric drag would cause its decay and eventual reentry in 25 years or less (the so-called 25-year rule) is one way to achieve this objective.

Since the introduction of the 25-year-rule in the 1990s, many organizations, including the Inter-Agency Space Debris Coordination Committee (IADC) have studied and confirmed the effectiveness of using the 25-year rule to curtail the debris growth in LEO [3]. Figure 3 is an example. Based on nominal future projection assumptions, a non-mitigation scenario (*i.e.*, “abandon in place” at the end of missions for all spacecraft and upper stages) could lead to a LEO debris population growth of approximately 330% over the next 200 years. A 90% global compliance with the 25-year rule could reduce the LEO debris population growth to approximately 110% over the next 200 years. Reducing the 25-year rule to, for example, a 5-year rule, only leads to another 10% debris reduction over 200 years, which is not a statistically significant benefit.

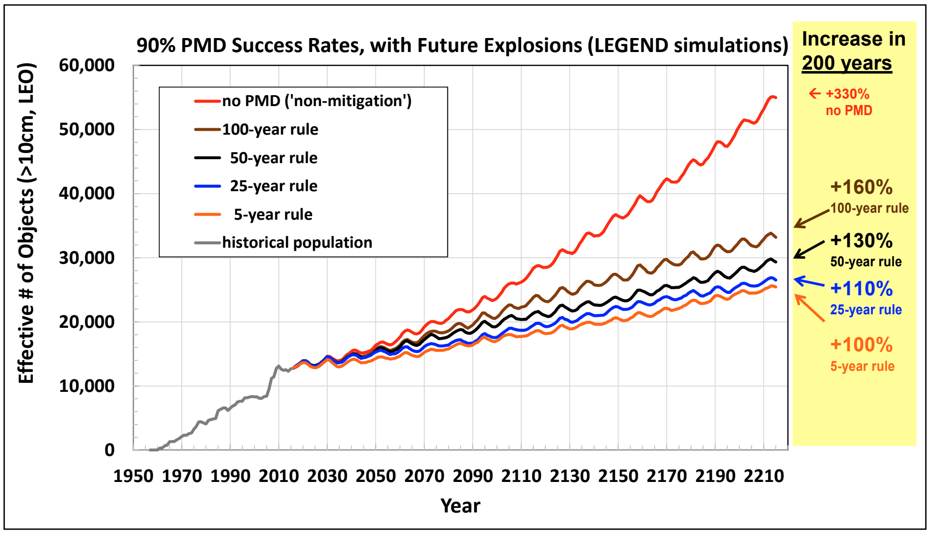

Figure 3. Effectiveness of the 25-year rule versus the non-mitigation scenario and other rules. The non-mitigation scenario assumes an 8-year traffic cycle in the future. Projection results are based on averages of 100 Monte Carlo simulations each by the NASA LEO to GEO Environment Debris (LEGEND) long-term debris environment model (https://orbitaldebris.jsc.nasa.gov/modeling/legend.html).

The cost aspect of implementing different decay rules has also been studied by many groups, including the IADC [3]. Only a modest, near-linear increase in de-orbit propellant is needed to reduce the residual lifetime to the ~50-to-25-year range. However, decreasing the postmission orbital lifetime from 25 years to a very short time, such as 5 years, will lead to a non-linear, rapid increase in fuel requirements. Therefore, the 25-year rule appears to still be a good balance between cost and benefit. Analyses of global space operations also indicate that the biggest issue in LEO is associated with the very low compliance with the 25-year rule (less than 50%) [4].

As can be seen in Figure 4, the future debris growth in LEO is more sensitive to the level of compliance than to the difference between the 25-year and the 5-year rules. Nevertheless, the 2019 update also encourages operators to go beyond the 25-year rule – “*…limit the lifetime to as short as*

continued on page 6

USG ODMSP

continued from page 5

practicable but no more than 25 years after completion of mission." In addition, Objective 4-1, for the first time, establishes "immediate removal from Earth orbit" as the preferred disposal option. This aspirational goal can be achieved by placing a structure on a direct reentry trajectory or a heliocentric, Earth-escape orbit. The latter is more cost effective for a high altitude, such as geosynchronous Earth orbit (GEO), mission. NASA has followed this preferred disposal option for some missions in the past and plans to implement it for more missions in the future (to lead by example).

For atmospheric reentry, the 2019 update excludes surviving components with impact kinetic energies less than 15 J from the calculation of human casualty risk. This improvement recognizes that such surviving components will not lead to human casualty.

PMD: Storage Options

For storage between LEO and GEO, the 2001 ODMSP established a 500 km, no-crossing, keep-out zone around the Global Positioning System (GPS). Storage orbits must be between LEO and GPS – 500 km or between GPS + 500 km and GEO. The 2019 update removes this unnecessary restriction and allows a practical, low-risk, eccentric (such as GEO transfer orbit) PMD storage option. The only conditions for this option are to limit the GPS ± 300 km zone crossing dwell time to less than 25 years over 200 years and avoid crossing LEO and GEO for 100 years, which can easily be met with a careful selection of the initial storage orbit. The 2019 update also allows near-circular PMD storage, which has been the historical practice for many Global Navigation Satellite System structures. The only conditions for this near-circular PMD storage option are to avoid crossing the GPS ± 300 km zone for 100 years and limit the risk to other operational constellations.

The above-GEO storage option in the 2001 ODMSP is to simply move a structure at the end of mission to at least 300 km above the geosynchronous altitude. Such a practice does not guarantee the disposed structure will not evolve into an orbit crossing the GEO zone later. The 2019 update adopts a move-away-and-stay-away principle to better meet the intent of this storage option and to avoid interference with spacecraft operating inside the GEO zone. Simple trajectory analyses can be performed to select a storage orbit that will meet the stay-away principle.

PMD: Long-term Reentry, Direct Retrieval, and PMD Reliability

The 2019 update includes a new long-term reentry option. It utilizes orbital resonances to increase the eccentricity of a disposed structure so that the structure's perigee will eventually be low enough to allow atmospheric drag to cause it to reenter. The advantage of this option is the removal of structures from high altitudes where reentries based on propulsion alone are cost-prohibitive. The disadvantage is that the eccentricity increase will force the disposed structures to cross the regions from LEO to GEO, generating new collision risks to operational spacecraft there. To mitigate risks associated with this new option, several conditions are established. They include: a 200-year orbital lifetime limit; less than 25-year dwell time each in LEO, GEO, and GPS ± 300 km; a less than 0.001 (1 in 1,000) probability of collisions with objects 10 cm and larger during orbital lifetime; and less than 7 m^2 total reentry debris casualty area (DCA) or 0.0001 (1 in 10,000) human casualty risk for surviving components with impact kinetic energies greater than 15 J. The DCA limit is introduced to avoid the high uncertainty in projecting global human population over a long period of time (up to 200 years). For the 2019 population, 7 m^2 DCA is approximately equivalent to the 0.0001 human casualty risk for structures with various orbital inclinations.

The 2001 ODMSP direct retrieval option is maintained in the 2019 update, but with a new condition – the retrieval must take place within 5 years of the structure's completion of mission.

A major new element in the 2019 ODMSP update is the PMD reliability. As shown in Figure 4, a high level of compliance is key to the success of using the 25-year rule to limit future debris population growth in LEO. The 90% threshold is necessary and achievable. It is also very cost-effective in long-term OD environment management when compared with active debris removal (ADR).

Clarification and Unique Classes of Space Operations

Large constellations (LC) present potential new challenges to the orbital debris community. The 2019 ODMSP highlights three additional standard practices for LC operators: (1) the PMD reliability should be at a level greater than 90% with a goal of 99% or better, (2) the PMD reliability threshold should be established based on mass, collision probability, orbital location, and other relevant parameters, and (3) immediate removal is the preferred PMD option. The second element recognizes the fact that there is not a simple one-size-fits-all number or formula for LCs. For example, an LC operating at 900 km altitude, where failed spacecraft will not naturally decay for more than 1,000 years, should follow a higher PMD reliability than an identical LC operating at 700 km altitude, where failed spacecraft will naturally decay in about 50 years. Collision probability is another factor to be considered. An LC operating at 850 km altitude should have a higher PMD reliability than an identical LC operating at 1,300 km because the collision probability with the current cataloged objects at 850 km altitude is more than 10 times higher than that at 1,300 km altitude. Thus, a failed spacecraft at 850 km altitude has a higher debris-generation potential than an identical failed spacecraft at 1,300 km altitude. Factors outlined in the second element need to be considered to establish an appropriate PMD reliability threshold for a specific LC. Many organizations have studied

continued on page 7

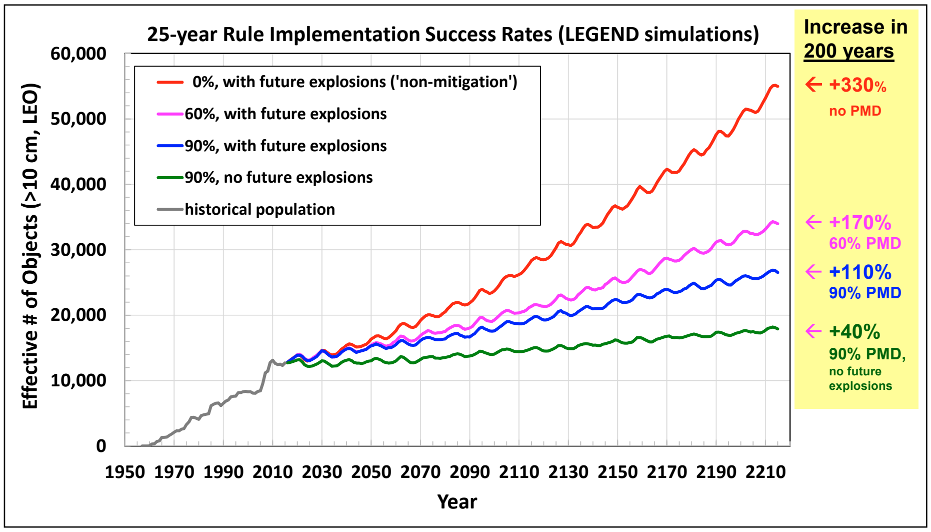

Figure 4. Future population projections based on different 25-year rule compliance levels and accidental explosions. Projection results are based on averages of 100 Monte Carlo simulations each.

USG ODMSP

continued from page 6

the potential negative effects from LCs to the environment. Based on the detailed parameters of the LCs, a 99% PMD reliability may be necessary for some large constellations [5].

Small satellites, especially CubeSats, have revolutionized access to space for the global community in recent years. However, whether or not they need to follow the same ODMSP continues to be questioned. For clarification, the 2019 update explicitly states that they should follow the ODMSP. In addition, a "less than 100 object-years" per mission limit is established for LEO spacecraft smaller than 10 cm × 10 cm × 10 cm when fully deployed. This ensures adequate risk mitigation for missions launching many (tens, hundreds, or more) very small "spacecraft."

Due to the nature of rendezvous and proximity operations (RPO), satellite servicing, and ADR, there are unique considerations to prevent debris generation associated with such operations. RPO may not lead to any physical contact with the target, but satellite servicing starts with RPO and follows by docking with and then operating on the target. Limiting the probability of accidental collision with the target during the planning and execution of RPO is a key mitigation aspect. Satellite servicing may include refueling and mechanical manipulation of hardware components, including pressurized systems, which were not designed for servicing and with unknown conditions after years in space. In general, operations on such targets are difficult to perform, even in a laboratory environment. Therefore, limiting the probability of accidental explosion resulting from these unique operations is another key aspect to preventing debris generation. In addition, objects generated as a result of operations, such as removed bolts and replaced solar arrays, should be properly disposed of and follow the standard practices established for mission-related debris.

The "Safety of ADR Operations" section in the 2019 ODMSP focuses on the mitigation aspect of the ADR operations rather than using ADR for environment remediation, which is outside the scope of the ODMSP. For the safety of ADR operations, the standard practices for satellite servicing are all applicable, with two additional mitigation practices. First, from the environment management perspective, the first principle of ADR is "do no harm." Fragmentation of the target is not a removal and should be avoided. Second, operations should be designed for the target to follow applicable postmission disposal practices for upper stages and spacecraft, including the reentry human casualty risk limit. When ADR is performed to deorbit a target with a very long orbital lifetime, the operation shifts the on-orbit collision risks to human casualty risks on Earth. It is responsible to set a reentry human casualty risk limit for such an operation, using the same rationale that the reentry human casualty risk limit is applicable to structures following the 25year rule.

Summary

The key differences between the 2001 ODMSP and the 2019 ODMSP are summarized in Table 1. The update to the ODMSP covers all aspects of orbital debris mitigation. The effort highlights the commitment of the United States to mitigate the threat from orbital debris, per SPD-3. As stated in the 2019 ODMSP Preamble, "*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…. 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*."

References

1. SPD-3. Available at https://www.govinfo.gov/content/pkg/FR-2018-06-21/pdf/2018-13521.pdf.

2. 2019 ODMSP. Available at https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf.

3. Support to the IADC Debris Mitigation Guidelines. IADC-04-06, Rev. 5.5, (May 2014).

4. Krag, H. Space Debris Mitigation Activities at ESA in 2018, presentation to the UN COPUOS/STSC, (February 2019).

5. Liou, J.-C. *et al.* "NASA ODPO's Large Constellation Study," ODQN 22-3, pp. 4-7, 2018. ♦

Table 1. Key New and Updated Elements in the 2019 ODMSP

Objectives/Elements	2001 ODMSP	2019 ODMSP
Obj 1. Mission-related debris (area-time product limit)	---	Less than 100 object-years per upper stage or spacecraft in LEO.
Obj. 2. Accidental explosion probability limit	---	Less than 0.001 during deployment and mission operations.
Obj. 3. Accidental collision probability (with large debris)	---	Less than 0.001 during orbital lifetime.
Obj. 3. Accidental collision probability (with small debris)	---	Less than 0.01 during deployment and mission operations.
Obj. 4. Preferred disposal option	---	Immediate removal from Earth orbit (direct reentry or Earth escape).
Obj. 4. PMD storage between LEO and GEO	GPS ± 500 km no-crossing, keep-out zone.	1. Allow low-risk, eccentric (such as GEO transfer orbit) PMD storage and limit GPS ± 300 km zone dwell time to less than 25 years over 200 years. 2. Allow near-circular PMD storage and avoid crossing GPS ± 300 km for 100 years and limit the risk to other operational constellations.

continued on page 8

USG ODMSP

continued from page 7

Table 1. Key New and Updated Elements in the 2019 ODMSP - continued

Objectives/Elements	2001 ODMSP	2019 ODMSP
Obj. 4. PMD storage above GEO	Maneuver to GEO + 300 km.	Maneuver to GEO + 200 km and stay away for 100 years.
Obj. 4. Long-term reentry	---	Allow a new, long-term reentry option (using orbital resonances) while limiting potential risks associated with the new option.
Obj. 4. Direct retrieval (time constraint)	As soon as practical after completion of mission	Preferably at completion of mission but no more than 5 years after completion of mission.
Obj. 4. PMD reliability	---	No less than 0.9 with a goal of 0.99 or better.
Obj. 4. Reentry human casualty risk (impact kinetic energy)	---	Exclude surviving components with impact kinetic energies less than 15 joules.
Obj. 5. Large constellations	---	Provide 2 guidelines on how to establish PMD reliability limit. Identify immediate removal as the preferred disposal option.
Obj. 5. Small satellites, including CubeSats	---	Clarify the applicability of the ODMSP to small satellites, including CubeSats. Establish a 100 object-years per mission limit for satellites smaller than 1U CubeSats.
Obj. 5. Rendezvous, proximity operations, and satellite servicing	---	Provide guidelines on mitigating unique risks associated with the operations.
Obj. 5. Safety of Active debris removal operations	---	Provide guidelines on mitigating unique risks associated with the operations.

MEETING REPORTS

The NASA-DOD Orbital Debris Working Group Meeting 2019, 2 October 2019, NASA Johnson Space Center, Houston, TX, USA

The NASA-DOD Orbital Debris Working Group (ODWG) meeting was conducted 2 October 2019 by teleconference. This annual, 1-day meeting reviews activities and research in orbital debris of mutual interest to both NASA and the Department of Defense (DOD). The ODWG originated in recommendations by interagency panels, who reviewed U.S. Government orbital debris activities in the late 1980s and early 1990s. This year's meeting marks the 22nd anniversary of the series of meetings. It was co-chaired by Dr. J.-C. Liou, NASA Chief Scientist for Orbital Debris and Program Manager of the NASA Orbital Debris Program Office (ODPO); and Mr. Tim Payne, Chief, Operational Assessments Division, HQ Air Force Space Command (AFSPC)/A2/3/6Z.

The meeting comprised 12 presentations, seven by NASA and five by DOD. In the first DOD presentation, Mr. Rob Harwick, AFSPC/A5S, presented updates on the status and plans for the Space Surveillance Telescope (SST). Developed by the Defense Advanced Research Projects Agency and transferred to AFSPC in 2016, the SST program demonstrated the fusion of advanced technologies for ground-based detection and follow-up tracking of small objects in deep space. The 3.5-meter telescope is optimized for synoptic space surveillance using short-duration/high-frequency search paradigms. Among the advanced technologies are a curved CCD focal plane camera and large telescope control technologies, yielding the most dynamically agile telescope of its size. Last light at the White Sands Missile Range was in March 2017 and the SST has been shipped and partially reinstalled in Western Australia. Australian first light is anticipated in early 2020 with an initial operational capability in 2022.

Mr. Doug Moffitt, HQ AFSPC/A2/3/6SZ, followed up with a presentation dedicated to updates of the Space Surveillance Network (SSN), including upgrades to its radar, optical, and on-orbit assets. The

continued on page 9

NASA DOD Working Group - *continued*

continued from page 8

SSN currently maintains a catalog of over 20,000 objects, including spacecraft, rocket bodies, and debris, from LEO to beyond GEO.

Mr. Gary Wilson, HQ AFSPC/A5S, delivered updates on the new Space Fence, an S-band phased array radar on Kwajalein Atoll in the Pacific Ocean. The Space Fence is designed to discover and track objects smaller than 10 cm at International Space Station (ISS) altitudes.

Mr. Zach Slatton, AFSPC/18 SPCS, reviewed the on-orbit breakups of 2019. As of 2 October, there had been eight acknowledged breakups, including six rocket bodies (one of which was the 50th breakup of a *SOZ* ullage motor [Orbital Debris Quarterly News (ODQN), vol. 23, issue 4, November 2019, pp. 1-2]).

Following the DOD presentations, Dr. J.-C. Liou discussed status and recent activities from the Inter-Agency Space Debris Coordination Committee and debris-related activities from the United Nations Committee on the Peaceful Uses of Outer Space. The latter discussion included progress by the Long Term Sustainability of Outer Space Working Group.

Dr. Sue Lederer reviewed activities of the ODPO Optical Measurements Group, including the current status of the Eugene Stansbery Meter-Class Autonomous Telescope (ES-MCAT) located at the John Africano NASA/AFRL Orbital Debris Observatory on Ascension Island. The ES-MCAT is a collaboration between NASA and the Air Force Research Laboratory (AFRL). Since the previous ODWG meeting, the main mirror of ES-MCAT was re-coated and re-installed and a new CCD chip was installed in the main camera (ODQN, vol. 23, issues 1&2, May 2019, p. 3). A new data pipeline for transmitting data from ES-MCAT to the SSN was discussed.

Dr. Tim Kennedy provided an update on the measurement of the orbital debris environment using the Haystack Ultrawideband Satellite Imaging (HUSIR), Haystack Auxiliary (HAX), and Goldstone radars. These facilities provide observations (without tracking) of particles smaller than those that are trackable by the SSN and its new Space Fence sensor.

Dr. Heather Cowardin delivered the status of the Space Debris Sensor (SDS) aboard the ISS and ODPO's continuing efforts with *in situ* measurements of the orbital debris environment. The SDS experiment has ended, and the payload was disposed on the Cygnus Northrop Grumman (NG)-12 mission in January 2020.

Dr. Mark Matney then gave the status on the development of the NASA ODPO Orbital Debris Engineering Model (ORDEM) v. 3.1. The ORDEM 3.1 version updates the radar, optical, and in situ data sets used in its predecessor, ORDEM 3.0, to better characterize the modern orbital debris environment.

Dr. Jack Bacon presented an update of the ODPO's Debris Assessment Software (DAS) from version 2.1.1 to 3.0, which incorporates general improvements as well as the changes from NASA Standard 8719.14 Revision B. A major change in DAS 3.0 is the new glass fiber-reinforced plastic and carbon fiber-reinforced plastic model.

Dr. Heather Cowardin completed the workshop's presentations with the status of the DebriSat project and the incorporation of the data into ODPO computer models of the breakup of a modern satellite, in planning for ORDEM 4.0. DebriSat was a simulated satellite constructed with modern satellite materials that was fragmented by hypervelocity impact in 2014. Fragments from the test are still being extracted from the soft-catch material that lined the vacuum chamber during the test. At the time of the presentation, more than 177,000 fragments had been recovered with 40,594 characterized. ♦

The Spacecraft Anomalies and Failures (SCAF) Workshop, 3-4 December 2019, Chantilly, Virginia, USA

The Spacecraft Anomalies and Failures (SCAF) Workshop, co-sponsored by the National Reconnaissance Office and NASA, hosted over 120 attendees and 20 presentations. The workshop highlighted that the growing trend toward proliferated architectures (i.e., constellation of smaller satellites vs single monolithic larger satellites) introduces new reliability, resiliency, and mission assurance calculations. However, just as the move to constellations will be gradual and vary by mission and customer, the need to change mission assurance paradigms will be equally as gradual. More pointedly, the "New Space" aspects add another dimension to space system performance determination but do not obviate traditional methods and metrics. In addition, the move toward a more comprehensive workshop scope next year (i.e., covering both spacecraft and ground systems as a whole) will pose some challenges; however, it is likely that benefits will outweigh liabilities.

At a high level, this new scope will reduce the possibility of system issues "falling through the cracks" but will require the integration of different communities (i.e., government, military, and commercial), operational paces, and terminology. Several presentations emphasized the importance of root cause attribution being specific enough so that correcting the observed factor will reduce or eliminate the possibility of a similar event from happening again. This requires a high-level of specificity. Dialogue throughout the workshop noted that investigators of anomalies and failures must not over-emphasize determining a single root cause as this is not normally the case. Multiple, compounding factors usually collectively influence anomalies and failures. Lastly, the lack of space threat information for commercial and civil space operators was noted; links to the four public reviews of global space threats were provided as part of the workshop summary. In the interests of the ODQN readership, these are:

1. Harrison, T., Johnson, K., and Roberts, T., "Space Threat Assessment 2019," CSIS, April 2019. https://aerospace.csis.org/wp-content/uploads/2019/04/SpaceThreatAssessment2019-compressed.pdf .
2. Weeden, B. and Samson, V., "Global Counterspace Capabilities: An Open Source Assessment," SWF, April 2019. https://swfound.org/media/206408/swf_global_counterspace_april2019_web.pdf
3. Competing in Space, https://www.nasic.af.mil/News/Article-Display/Article/1733201/usaf-nasic-releases-unclassified-competing-in-space-assessment/
4. Challenges to Security in Space, https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf . ♦

CONFERENCE ABSTRACTS FROM THE NASA HYPERVELOCITY IMPACT TECHNOLOGY TEAM

The First International Orbital Debris Conference (IOC), 9-12 December 2019, Sugar Land, Texas, USA

Authors	Abstract Title and Summary
BJORKMAN M. D. AND CHRISTIANSEN E. L.	*Aluminum Cratering Relations for In-Situ Detection of Micrometeoroid and Orbital Debris Particle Diameters* Recommended aluminum crater dimension scaling relations for interpreting observations of MMOD impact damage.
BJORKMAN M. D. AND CHRISTIANSEN E. L.	*An Astronaut's Risk of Experiencing a Critical Impact from Lunar Ejecta During Lunar EVA* Calculated an astronaut's risk from impact by lunar ejecta while performing a lunar EVA.
CHRISTIANSEN E. L. AND DAVIS B. A.	*Using Heat-Cleaned Nextel in MMOD Shielding* This paper will provide data demonstrating that hypervelocity impact protection performance is not adversely altered for shields containing heat-cleaned Nextel compared to Nextel with sizing left on the fabric to reduce fiber breakage.
DAVIS B. A., CHRISTIANSEN E. L., LEAR D. M. AND MILLER J. E.	*Composite Overwrap Pressure Vessel Hypervelocity Impact Testing* There's a limited amount of hypervelocity impact (HVI) data on pressurized composite overwrapped pressure vessels (COPV's). NASA has performed HVI tests to characterize impact conditions resulting in either leak or burst of the COPVs.
HOFFMAN K. D., HYDE J. L., CHRISTIANSEN E. L. AND LEAR D. M.	*Comparison of Risk from Orbital Debris and Meteoroid Environment Models on the Extravehicular Mobility Unit* Comparison of the updated orbital debris and meteoroid environment models (i.e. ORDEM 3.0 vs 3.1 and MEM R2 vs R3) with regards to MMOD risk to the extravehicular mobility unit (EMU) "spacesuit."
HYDE J. L., CHRISTIANSEN E. L., AND LEAR D. M.	*Observations of Micrometeoroid and Orbital Debris Impact Damage to the International Space Station* Paper will introduce the ISS Impact database, which includes nearly 1,000 direct observations of hypervelocity impact damage on spacecraft surfaces returned from ISS on the shuttle. On orbit imagery of HVI damage will also be discussed.
LEAR D. M., CHRISTIANSEN E. L., AND HYDE J. L.	*BUMPER: A Tool for Analyzing Spacecraft Micrometeoroid and Orbital Debris Risk* "Bumper" is NASA's computer program for analyzing spacecraft micrometeoroid and orbital debris (MMOD) risk. The NASA Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) Team is responsible for all aspects of the Bumper software.
MILLER J. E.	*Considerations of Oblique Impacts of Non-Spherical, Graphite-Epoxy Projectiles* This work extends recent work in the development of oblique impacts of shaped projectiles at a representative orbital speed of 7 km/s and addresses the complexities associated with that addition.

The full papers have been posted on the IOC conference website and are available for download at: https://www.hou.usra.edu/meetings/orbitaldebris2019/.

CONFERENCE ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The 20th Advanced Maui Optical and Space Surveillance Technologies Conference, 17-20 September 2019, Maui, Hawaii, USA

NASA's Orbital Debris Optical Program: ES-MCAT Operational on Ascension

S. LEDERER, B. BUCKALEW, P. HICKSON, AND H. COWARDIN

The NASA Orbital Debris Program Office at Johnson Space Center has a long history of an optical observational program. The Meter Class Autonomous Telescope, ES-MCAT, was dedicated to Eugene Stansbery in 2017. ES-MCAT, a 1.3-m DFM telescope, has a proven capability for

continued on page 11

AMOS Conference - *continued*

continued from page 10

tracking known objects from low-Earth orbit (LEO) out to geosynchronous (GEO) orbit.

Monitoring the population of the GEO belt is accomplished through surveys. A GEO survey statistically samples the GEO belt (0 to ~15 deg orbital inclinations) to detect both correlated and uncorrelated targets. A GEO survey, the initial focus for ES-MCAT, will commence in 2019 to map out the current state of the GEO population as input for the Orbital Debris Engineering Model (ORDEM 4).

If a break-up occurs, surveys of the break-up field can be followed for discovery and investigations of daughter debris fragments from the parent satellite. Discovery can be accomplished by surveying orbits near to and including the parent object's orbit. Targeted observations of debris can be taken with a suite of broadband filters for characterizing individual objects by rate-tracking their known or calculated orbital elements (two-line element sets, TLEs). These observations can be used in conjunction with NASA's Standard Satellite Break-up Model (SSBM).

In 2018, ES-MCAT's primary mirror was realuminized with a high-end, protected, enhanced silver ZeCoat and the CCD chip was replaced in the Spectral Instruments camera. With these updates completed, ES-MCAT is now on track to reach Full Operational Capability (FOC) in 2019 for its survey and rate-track capabilities. A full overview of ES-MCAT's operational state, capabilities, and mission will be discussed. ♦

The First International Orbital Debris Conference (IOC), 9-12 December 2019, Sugar Land, Texas, USA

Authors	Abstract Title and Summary
ALLEN A. AND BACON J.	*Macro-Scale Findings of the DebriSat Debris Field Obtained from X-Rays of the Catch Panels* Screening/debris-locating X-rays of catchment panels are used to generate a full 3D map of all captured particles from a hypervelocity impact, including shapes and sizes, with shedding/bending history correlated to the path through the panels.
ANZ-MEADOR P., LE L., WARD M, THOMAS-KEPRTA K., AND ROSS D.	*Analysis of WFPC-2 Core Samples for MMOD Discrimination* A selection of large cores from WFPC-2 were reexamined using a new technique to overcome some limitations of traditional crater imaging and analysis. This technique examines a polished, lateral surface area revealed by cross-sectioning a core sample.
ANZ-MEADOR P.	*Root Cause Classification of Breakup Events 1961–2018* In this paper we examine the root causes of all known fragmentation events, and the effectiveness of mitigation standard practices in managing the progenitors and the general debris environment.
ANZ-MEADOR P., WARD M., MANIS A., NORNOO K., DOLAN B., CLAUNCH C., AND RIVERA J.	*The Space Debris Sensor Experiment* This paper addresses the technical performance of the SDS during its operational lifetime and its realization of technical and scientific goals. This paper also addresses the anomalies that occurred during operation, their attribution, and resolution.
GATES D. AND ANZ-MEADOR P.	*An 82° Inclination Debris Cloud Revealed by Radar* In this paper we describe the observed cloud and model it using the NASA Standard Satellite Breakup Model. Key features of the cloud model, including source attribution and debris mass constraints, are presented to enable further observations and characterization.
HOSTETLER J. AND COWARDIN H.	*Experimentally Derived Bidirectional Reflectance Distribution Function Data in Support of the Orbital Debris Program Office* Overview of NASA's JSC Optical Measurement Center and the current capabilities for broadband bidirectional reflectance distribution measurements. Laboratory phase functions will also be presented in support of better characterizing orbital debris.
LEDERER S., BUCKALEW B., AND HICKSON P.	*NASA's Orbital Debris JAO/ES-MCAT Optical Telescope Facility on Ascension Island* NASA's orbital debris telescope, ES-MCAT, is now well on track to reach Full Operational Capability (FOC) in 2019 for its survey, TLE, and rate-track capabilities. A full overview of ES-MCAT's operational state, capabilities, and mission will be discussed.
MATNEY M., MANIS A., ANZ-MEADOR P., GATES D., SEAGO J., VAVRIN A., AND XU Y.-L.	*The NASA Orbital Debris Engineering Model 3.1: Development, Verification, and Validation* The newest version of the NASA Orbital Debris Engineering Model, ORDEM 3.1, has been developed, incorporating the latest and highest fidelity datasets available to build and validate representative orbital debris populations for LEO to GEO altitudes.

continued on page 12

NASA IOC Conference - *continued*

continued from page 11

Authors	Abstract Title and Summary
MANIS A., MATNEY M., ANZ-MEADOR P., AND COWARDIN H.	*The Updated GEO Population for ORDEM 3.1* The newest version of the NASA Orbital Debris Engineering Model, ORDEM 3.1, includes improved methods for building the GEO population, both in the assessment of fragmentation debris in the data and assignment of orbital elements within the model.
MARICHALAR J. AND OSTROM C.	*Estimating Drag and Heating Coefficients for Hollow Reentry Objects in Transitional Flow Using Direct Simulation Monte Carlo* Direct Simulation Monte Carlo is used to compute drag and aerothermal heating coefficients on hollow boxes and cylinders in rarefied flow. A preliminary model is presented for implementation in reentry survivability codes.
MATNEY M., ANZ-MEADOR P, MURRAY J., AND MILLER R.	*The NaK Population: A 2019 Status* In this paper we review the current status of the so-called NaK (Sodium-Potassium) debris population at 65 degree inclination, including potential new NaK environmental sources.
MURRAY J., COWARDIN H., LIOU J.-C., SORGE M. , FITZ-COY N., AND HUYNH T.	*Analysis of the DebriSat Fragments and Comparison to the NASA Standard Satellite Breakup Model* This paper will present the current status of the analysis of the DebriSat fragment data, including cumulative characteristic length and cumulative mass distributions, area-to-mass distributions, and characteristic length versus mass distributions.
MURRAY J., MILLER R., MATNEY M., AND KENNEDY T.	*Orbital Debris Radar Measurements from the Haystack Ultra-Wideband Satellite Imaging Radar (HUSIR): 2014–2017* Using data collected for the NASA Orbital Debris Program Office (ODPO) on the orbital debris environment, we will compare the size distributions and flux measurements of selected orbital debris populations over a four-year period (2014–2017).
MURRAY J., MILLER R., MATNEY M., ANZ-MEADOR P., AND KENNEDY T.	*Recent Results from the Goldstone Orbital Debris Radar: 2016–2017* In this paper, we present measurements and results derived from data taken during the 2016–2017 calendar years by the Goldstone Orbital Debris Radar and compare this to measurements taken by the Haystack Ultra-wideband Satellite Imaging Radar.
OSTROM C., GREENE B., SMITH A., TOLEDO-BURDETT R., MATNEY M., OPIELA J., MARICHALAR J., BACON J., AND SANCHEZ C.	*Operational and Technical Updates to the Object Reentry Survival Analysis Tool* Overview of the development of NASA ODPO reentry software package "ORSAT" over the last three years, and the subsequent effects on top-level results such as reentry ground casualty risk.
REYES J. , COWARDIN H., AND CONE D.	*Characterization of Space Related Materials Using Reflectance Spectroscopy to Assist in Orbital Debris Material Identification* Data in this study is of value to the orbital debris community with the presented reflectance spectroscopic measurements and bidirectional reflectance distribution function (BRDF) evaluations taken on selected materials used in space hardware.
SEAGO J., MATNEY M., AND VAVRIN A.	*Development of a Model for the Small-Particle Orbital Debris Population Based on the STS Impact Record* The NASA Orbital Debris Program Office (ODPO) has revisited its modeling of orbiting debris populations having characteristic sizes smaller than 1 cm. Methodologies and results for estimating and adjusting fine-particle populations are described.

continued on page 13

NASA IOC Conference - *continued*

continued from page 12

Authors	Abstract Title and Summary
SMITH A. AND GREENE B.	***Development and Analysis of the Automated Object Reentry Survival Analysis Tool's Parametric Study Wrapper*** The authors have developed a wrapper program for the ORSAT that can be used to perform Monte Carlo style analyses of object reentry demise. Results of initial studies using this tool and the development of a survivability database are presented.
VAVRIN A., MANIS A., GATES D., MATNEY M., AND LIOU J.-C.	***Risk of Increased Fragmentation Events Due to Low Altitude Large Constellation Spacecraft*** This paper will address the lower altitude constellations and the potential risk that they impose on the future space traffic. The projected future environment is generated as the average of 100 LEGEND Monte Carlo (MC) simulation runs.
WARD M. AND ANZ-MEADOR P.	***MLI Impact Phenomenology Observed on the HST Bay 5 MLI Panel*** Three HST Bay MLI blankets were obtained by ODPO to analyze impact features and develop a flux estimate. The impact feature phenomenology observed and a new method of characterization techniques used during analysis of the HST MLI is presented.
XU Y.-L., KENNEDY T., AND STANSBERY E. G.	***Radar Cross Section of Orbital Debris Objects*** RCS of a non-spherical body is orientation-dependent. Besides the probability density distributions of RCS for orbital debris objects provided in NASA SEM, theoretical tools and computer codes for predicting RCS of irregular shapes are discussed.

The full papers have been posted on the IOC conference website and are available for download at: https://www.hou.usra.edu/meetings/orbitaldebris2019/

The 2nd International Academy of Astronautics (IAA) Conference on Space Situational Awareness (ICSSA), 14-16 January 2020, Washington, D.C., USA

Recent Radar Observations of the Sub-Centimeter Orbital Debris Environment

T. KENNEDY, J. MURRAY, AND R. MILLER

The NASA Orbital Debris Program Office (ODPO) has conducted radar observations of the orbital debris environment since the early 1990's to provide measurement data that supports orbital debris models and risk mitigation activities in support of NASA mission objectives. Orbital debris radar observations are a unique mode for radar operation, employing a fixed beam configuration to statistically sample the environment. An advantage of conducting operations in this fashion is that it enables observations of smaller classes of orbital debris than would otherwise be available from the same sensor operating in a traditional tracking mode. Orbital debris-mode radar observations are used to fill in the gaps, which exist in the currently available data from the Space Surveillance Network (SSN), on small size orbital debris populations that represent significant risk to NASA programs. These gaps have typically covered orbital debris with characteristic sizes less than approximately 10 cm down to approximately 3 mm in low Earth orbit (LEO) – depending upon the altitude and sensor configuration.

The value of orbital debris radar measurements lies in the ability to extract partial orbital element information about orbital debris in the centimeter to several millimeter size regimes in low Earth orbit – which are not available from other measurement sources. This paper will discuss observations of this smaller class of orbital debris observed in recent years from the radars at the MIT Haystack Observatory in Westford, Massachusetts, and the Goldstone Solar System Radar near Barstow, California. The former radar is able to observe orbital debris down to approximately 5 mm, and the latter, orbital debris with characteristic sizes near 3 mm – at altitudes less than 1000 km. The characteristics and inferences about the current LEO orbital debris environment, and the different subpopulations that are identifiable in the observations are highlighted. ♦

UPCOMING MEETINGS

4-6 May 2020: 17th Annual Cubesat Developer's Workshop, San Luis Obispo, CA, USA

The California Polytechnic State University will host the 17th Annual Cubesat Developer's Workshop at the university's San Luis Obispo Performing Arts Center, California, USA. The abstract deadline for posters or papers passed on 10 January 2020. Additional information about the workshop is available at https://www.cubesat.org/workshop-information. In addition, the 9th Annual LunarCubes Workshop, a two-day workshop, will be hosted by Cal Poly immediately after the Developer's Workshop.

3-4 June 2020: 5th Space Debris Re-entry Workshop, Darmstadt, Germany

The European Space Operations Centre (ESOC) will host the 5th Space Debris Re-entry Workshop in June 2020. The workshop aims to address the side effects of the increased traffic to orbit, which triggered a renewed interest in the practicalities of having objects, large and small, re-entering uncontrolled after the end of mission.

The symposium style for the past events transitions this year to a workshop around the open problems burgeoning by the increase in uncontrolled re-entry "traffic": how to transition from uncertainty assessment to operational products when it comes to re-entry predictions and orbital lifetimes? Which multi-physics driven break-up processes produce predictions which can be verified on a macroscopic level to cause first fragmentation?

The submission of abstracts on those questions is encouraged, but the venue is open to other topics related to general orbital lifetime estimation, re-entry predictions on the catalogue level, low thermosphere orbit observations and orbit determination, and material and aerothermal responses of re-entering objects in the continuum regime.

Among the objectives of the workshop are linking space surveillance, astrodynamics, and re-entry physics to cover all aspects of the problem. The abstract deadline is 3 April 2020 with a registration deadline of 1 May 2020. Detailed information is available at https://reentry.esoc.esa.int/home/workshop .

15-17 June 2020: 6th International Workshop on Space Debris Modeling and Remediation, Paris, France

The National Centre for Space Studies (CNES) Headquarters will host the 6th International Workshop on Space Debris Modeling and Remediation. Topics are anticipated to include, but are not necessarily limited to, modelling, including specificities coming from small satellites and constellations; high level actions, road-maps, associated to debris remediation; remediation system studies, including those relative to small debris; design of specific concepts, including new ideas relative to just-in-time collision avoidance and proposals devoted to large constellations and small satellites; concepts derived from current space tugs initiatives; GNC aspects, rendezvous sensors and algorithms, de-spin, control during de-boost; and policy, economics, insurance, intellectual property, national security, and international cooperation aspects of debris remediation.

Workshop attendance is limited to 130. The abstract submission deadline is 15 March 2020, and additional details regarding the process are available from Mr. Christophe Bonnal at Christophe.bonnal@cnes.fr.

1-6 August 2020: 34th Annual Small Satellite Conference, Logan, UT, USA

Utah State University (USU) and the American Institute of Aeronautics and Astronautics (AIAA) will sponsor the 34th Annual AIAA/USU Conference on Small Satellites at the university's Logan campus, Utah, USA. This year's theme is "Space Mission Architectures: Infinite Possibilities", and will explore the realm of space mission architectures and how these may support the diverse needs of the global space community. Conference information is available at the organizer's website at https://smallsat.org/. The abstract submission period closed on 4 February 2020.

15-22 August 2020: COSPAR 2020, Sydney, Australia

The 43rd Committee on Space Research (COSPAR) Scientific Assembly will convene in the Sydney International Convention Center on Saturday, 15 August 2020 and run through Saturday, 22 August. The COSPAR panel Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "The Science of Human-Made Objects in Orbit: Space Debris and Sustainable Use of Space." P

EDAS.1 sessions will include advances in ground- and space-based measurements of the orbital debris environment, micrometeoroid and orbital debris environment modeling, end-of-life concepts, and solutions to fundamental operational challenges. The abstract submission period closed on 14 February 2020. Please see the COSPAR website at https://www.cospar-assembly.org/admin/session_cospar.php?session=953 and the Assembly website https://www.cospar2020.org/ for further information.

continued on page 15

UPCOMING MEETINGS - Continued

continued from page 14

17-19 September 2020: 11th International Association for the Advancement of Space Safety (IAASS) Conference, Osaka, Japan

The 11th conference of the IAASS, organized in concert with the Japan Aerospace Exploration Agency, has as its theme "Managing Risk in Space." Major debris-related topics include designing safety into space vehicles, space debris mitigation and remediation, re-entry safety, nuclear safety for space missions, safety risk management and probabilistic risk assessment, and launch and in-orbit collision risk. The conference's abstract submission deadline is 30 April 2020. Additional information for the 2020 IAASS is available at http://iaassconference2020.space-safety.org/.

15-18 September 2020: 21st Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), Maui, Hawaii, USA

The technical program of the 21st Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) is anticipated to focus on subjects that are mission critical to Space Situational Awareness. The technical sessions include papers and posters on Orbital Debris, Space Situational Awareness, Adaptive Optics & Imaging, Astrodynamics, Non-resolved Object Characterization, and related topics.

The abstract submission deadline is 1 March 2020. Additional information about the conference is available at https://amostech.com and this announcement will be updated in the ODQN as details become available.

12-16 October 2020: 71st International Astronautical Congress (IAC), Dubai, United Arab Emirates

The IAC will convene in Dubai's World Trade Centre in 2020 with a theme of "Inspire, Innovate & Discover, for the Benefit of Humankind." The abstract submission deadline is 28 February 2020. Additional information for the 2020 IAC is available at http://www.iafastro.org/events/iac/iac-2020/ and http://iac2020.org/ .

Subscribe to the ODQN or Update Your Subscription Information

To be notified by email when a new issue of the ODQN is placed online, or to update your personal information, please navigate to the ODQN Subscription Request Form located on the NASA Orbital Debris Program Office (ODPO) website at https://orbitaldebris.jsc.nasa.gov/quarterly-news/subscription.cfm .

The ODPO respects your privacy. Your email address will only be used for communication from the ODQN Managing Editor.

SATELLITE BOX SCORE

(as of 04 January 2020, cataloged by the
U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Spacecraft*	Spent Rocket Bodies & Debris	Total
CHINA	389	3718	4107
CIS	1537	5113	6650
ESA	90	58	148
FRANCE	67	509	576
INDIA	98	135	233
JAPAN	182	115	297
USA	1960	4880	6840
OTHER	978	123	1101
TOTAL	5301	14651	19952

** active and defunct*

Visit the NASA

Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

Technical Editor
Phillip Anz-Meador, Ph.D.

Managing Editor
Debi Shoots

Correspondence can be sent to:

J.D. Harrington
j.d.harrington@nasa.gov

or to:

Noah Michelsohn
noah.j.michelsohn@nasa.gov

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058

www.nasa.gov
https://orbitaldebris.jsc.nasa.gov/

INTERNATIONAL SPACE MISSIONS

01 October – 31 December 2019

Intl.* Designator	Spacecraft	Country/ Organization	Perigee Alt. (KM)	Apogee Alt. (KM)	Incli. (DEG)	Addnl. SC	Earth Orbital R/B	Other Cat. Debris
1998-067	ISS dispensed payloads	various	407	420	51.6	3	0	2
2019-066A	GAOFEN 10R	CHINA	627	629	97.8	0	1	0
2019-067A	EUTELSAT 5 WEST B	EUTELSAT	35780	35792	0.0	0	0	1
2019-067B	MEV-1	USA	EN ROUTE TO GEO			0		
2019-068A	ICON	USA	580	606	27.0	0	1	0
2019-069A	PALISADE	USA	1210	1222	87.9	0	2	1
2019-070A	TJS-4	CHINA	35777	35795	0.0	0	1	0
2019-071A	CYGNUS NG-12	USA	415	422	51.7	0	1	0
2019-072A	GAOFEN 7	CHINA	495	510	97.5	0	1	1
2019-072B	SSES-1	SUDAN	483	507	97.5			
2019-072C	HUANGPU-1	CHINA	483	506	97.5			
2019-072D	XIAOXIANG 1-08	CHINA	484	506	97.5			
2019-073A	BEIDOU 3 IGSO-3	CHINA	35682	35887	58.6	0	1	0
2019-074A	STARLINK-1007	USA	348	352	53.0	59	0	4
2019-075A	JILIN-01 GAOFEN 2A	CHINA	529	548	97.5	0	1	0
2019-076A	NINGXIA-1 1	CHINA	888	898	45.0	0	1	0
2019-076B	NINGXIA-1 2	CHINA	886	898	45.0			
2019-076C	NINGXIA-1 3	CHINA	883	898	45.0			
2019-076D	NINGXIA-1 4	CHINA	881	897	45.0			
2019-076E	NINGXIA-1 5	CHINA	880	896	45.0			
2019-077A	KL-ALPHA A	CHINA	1042	1060	88.9	0	1	0
2019-077B	KL-ALPHA B	CHINA	1044	1433	88.9			
2019-078A	BEIDOU 3M21	CHINA	21510	21546	55.0	0	2	0
2019-078B	BEIDOU 3M22	CHINA	21514	21542	55.0			
2019-079A	COSMOS 2542	RUSSIA	367	858	97.9	0	2	0
2019-079D	COSMOS 2543	RUSSIA	589	860	97.9			
2019-080A	TIBA-1	EGYPT	35778	35793	0.0	0	1	1
2019-080B	INMARSAT GX5	INMARSAT	35783	35791	0.0			
2019-081A	CARTOSAT 3	INDIA	498	521	97.5	11	0	1
2019-081C	MESHBED	USA	497	519	97.5			
2019-081D	FLOCK 4P 9	USA	498	519	97.5			
2019-082A	GAOFEN 12	CHINA	627	630	97.9	0	1	0
2019-083A	DRAGON CRS-19	USA	415	422	51.7	0	0	2
2019-084A	ALE-2	JAPAN	396	415	97.0	0	2	0
2019-084D	NOOR 1A	USA	344	402	97.0			
2019-084E	NOOR 1B	USA	340	393	97.0			
2019-084F	FOSSASAT-1	SPAIN	344	399	97.0			
2019-084G	TRSI	GERMANY	343	398	97.0			
2019-084H	ATL-1	HUNGARY	345	396	97.0			
2019-084J	SMOG-P	HUNGARY	343	397	97.0			
2019-085A	PROGRESS MS-13	RUSSIA	415	422	51.7	0	1	0
2019-086A	JILIN-01 GAOFEN 2B	CHINA	531	547	97.5	0	1	0
2019-087A	OBJECT A	CHINA	494	512	97.4	0	1	0
2019-087B	OBJECT B	CHINA	494	512	97.4			
2019-087C	OBJECT C	CHINA	494	511	97.4			
2019-087D	OBJECT D	CHINA	494	509	97.4			
2019-087E	OBJECT E	CHINA	494	510	97.4			
2019-087F	OBJECT F	CHINA	492	511	97.4			
2019-088A	COSMOS 2544 (GLONASS)	RUSSIA	19106	19154	64.8	0	1	0
2019-089A	TYVAK-0092	USA	564	573	37.0	0		
2019-089B	OBJECT B	TBD	565	574	37.0			
2019-089C	OBJECT C	TBD	565	575	37.0			
2019-089D	LEMUR 2 JPGSQUARED	USA	567	575	37.0			
2019-089E	OBJECT E	TBD	569	576	37.0			
2019-089F	OBJECT F	TBD	570	578	37.0			
2019-089G	OBJECT G	TBD	570	577	37.0			
2019-089H	OBJECT H	TBD	568	576	37.0			
2019-089J	LEMUR 2 HIMOMANDDAD	USA	567	575	37.0			
2019-089K	LEMUR 2 PAPPY	USA	567	575	37.0			
2019-089M	LEMUR 2 THEODOSIA	USA	567	575	37.0			
2019-090A	BEIDOU 3M19	CHINA	21491	21565	55.0	0	2	0
2019-090B	BEIDOU 3M20	CHINA	21532	22108	55.0			
2019-091A	JCSAT 18	JAPAN	35779	35801	0.1	0	1	0
2019-092A	CSG-1	ITALY	625	627	97.8	0		
2019-092B	CHEOPS	ESA	697	711	98.2			
2019-092D	OBJECT D	TBD	509	525	97.5			
2019-092E	OBJECT E	TBD	508	525	97.5			
2019-092F	OBJECT F	TBD	511	530	97.5			
2019-093A	OBJECT A	TBD	615	636	98.0	0		
2019-093B	OBJECT B	TBD	615	635	98.0			
2019-093C	OBJECT C	TBD	615	635	98.0			
2019-093D	OBJECT D	TBD	614	636	98.0			
2019-093E	OBJECT E	TBD	624	626	98.0			
2019-093F	OBJECT F	TBD	615	633	98.0			
2019-093G	OBJECT G	TBD	613	633	98.0			
2019-093H	OBJECT H	TBD	612	632	98.0			
2019-093J	OBJECT J	TBD	612	632	98.0			
2019-093L	OBJECT L	TBD	616	638	98.0			
2019-093M	OBJECT M	TBD	579	646	97.9			
2019-093N	OBJECT N	TBD	593	627	98.0			
2019-094A	CST-100 STARLINER	USA	246	261	51.6	0	0	0
2019-095A	ELEKTRO-L 3	RUSSIA	35373	35574	0.6	0	1	0
2019-096A	OBJECT A	RUSSIA	1498	1506	82.5	0		
2019-096B	OBJECT B	RUSSIA	1500	1507	82.5			
2019-096C	OBJECT C	RUSSIA	1501	1508	82.5			
2019-096D	OBJECT D	RUSSIA	1500	1506	82.5			
2019-097A	SJ-20	CHINA	EN ROUTE TO GEO			0	1	0

** Intl. = International; SC = Spacecraft; Alt. = Altitude; Incli. = Inclination; Addnl. = Additional; R/B = Rocket Bodies; Cat. = Cataloged*