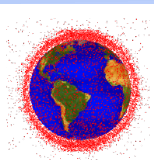
National Aeronautics and Space Administration

Orbital Debris
Quarterly News

Volume 21, Issue 2
May 2017

Inside...



A publication of the NASA Orbital Debris Program Office

Updates to NASA Procedural Requirements for Limiting Orbital Debris

An update to the NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environment (NPR 8715.6B) became official on 15 February 2017. NPR 8715.6B replaces the previous version, NPR 8715.6A with Change 1, which was released on 25 May 2012.

The purpose of this NPR is to define the roles, responsibilities, and requirements to ensure NASA, including its mission partners, providers, and contractors, take steps to preserve the near-Earth space environment, in accordance with the U.S. National Space Policy and the U.S. Government Orbital Debris Mitigation Standard Practices to mitigate the risk to space missions and human life due to orbital debris and meteoroids.

Changes in NPR 8715.6A with Change 1 to NPR 8715.6B include the following key items.

- Clarify the applicability of the NPR. It is limited to missions that do not fall under the regulatory authority of another U.S. federal department or agency.
- Clarify the process for requests for relief from requirements, including the roles and responsibilities of the Chief of Safety and Mission Assurance [SMA, *ed.*] and the evaluation elements to be considered.
- Establish a process to notify the Secretary of State for any non-compliance with the U.S. Government Orbital Debris Mitigation Standard Practices, as required by the 2010 U.S. National Space Policy.
- Clarify the roles and responsibilities of the Conjunction Assessment Risk Analysis (CARA) team and the Human Space Flight Operations team for conjunction assessments with robotic and human spaceflight missions, respectively, and their interactions with the Joint Space Operations Center (JSpOC) and other NASA organizations.
- Identify the responsible person for ensuring mission compliance for secondary payloads.
- Add the roles and responsibilities of the Meteoroid Environment Office (MEO). The roles and responsibilities of the NASA Orbital Debris program Office are also clearly defined in Section 2.1.3:

2.1.3 The NASA Orbital Debris Program Office (NASA ODPO):

a. Develops, maintains, and updates the orbital debris environment models and associated uncertainties to support the Chief, SMA, and programs and projects with the mitigation of orbital debris risk, and compliance with this NPR.

b. Conducts measurements of the orbital debris environment and conducts other research as needed to support the development of the orbital debris environment models.

c. Assists NASA mission project managers in technical orbital debris assessments by providing information and completing evaluations of the Orbital Debris Assessment Reports (ODARs) and End of Mission Plans (EOMPs) on behalf of the SMA Technical Authority.

d. Assists the Department of Defense and other U.S. Government departments and organizations on matters related to the characterization of the orbital debris

continued on page 2

Updates to NPR

continued from page 2

environment and the application of orbital debris mitigation measures and policies.

e. Contributes to the determination, adoption, and use of international orbital debris mitigation guidelines through international forums such as the United Nations Committee on the Peaceful Uses of Outer Space, the [Inter-Agency Space Debris Coordination Committee, *ed.*] IADC, and [International Standards Organization, *ed.*] ISO.

In addition to limiting the generation of orbital debris in all Earth orbits, NPR 8715.6B also states the intent to limit the generation of debris in other orbits where debris might pose a hazard to future spacecraft, including Moon, or Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points. Appropriate requirements are under development and will be included in the upcoming update to the NASA Technical Standard, NASA-STD-8719.14A, "Process for Limiting Orbital Debris."

NPR 8715.6B is available at https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8715&s=6A and the NASA Orbital Debris program Office's website: https://orbitaldebris.jsc.nasa.gov/reference-documents.html. ♦

Gene Stansbery Retires as NASA ODPO Program Manager

Figure 1. Mr. Eugene Stansbery

Mr. Gene Stansbery, NASA Program Manager for the Orbital Debris Program Office (ODPO) since 2006, retired on 28 February 2017. As the ODPO Program Manager, Gene conceived, conducted, and directed research involving all aspects of orbital debris research, risk assessments, and mitigation.

Gene started at the NASA Johnson Space Center (JSC) in 1982, working as a contractor for Lockheed Martin. In 1985, Gene received his M.S. in Physics at the University of Houston, and joined NASA the following year. His earliest work at JSC involved studying the Space Shuttle's sonic boom for its environmental impact. During his 30 years supporting ODPO, Gene specialized in ground-based and in situ debris measurement activities. As Lead Scientist for Orbital Debris Measurements, he led development of the Haystack radar project to characterize sub-centimeter debris in low Earth orbit. Gene also was coinvestigator for the OD Radar Calibration Spheres (ODERACS) payload and principal investigator for ODERACS II, which deployed spheres and dipoles to verify calibration of Haystack and other radars and optical telescopes.

In 2000, Gene conceived the idea of a meter-class autonomous telescope (MCAT) and spent the next 15 years shepherding the MCAT project, completed on Ascension Island in June 2015. To recognize his contribution, MCAT has been named the Eugene Stansbery telescope in his honor.

On 30 June 2011, Gene received the NASA Exceptional Service Medal for "dedication, leadership, and creativity in establishing international preeminence in orbital debris observation, measurement, analysis, and modeling at NASA" (see Figure 2).

Even though he has officially retired, Gene will remain an advocate for orbital debris as NASA emeritus, and will continue to offer his insight and background knowledge to the ODPO. ♦

Figure 2. Mr. Gene Stansbery (center) is presented with his NASA Exceptional Service Medal certificate by then NASA JSC Director Mike Coats (right) and Deputy Director Ellen Ochoa (left) in recognition of his service.

PROJECT REVIEW

CubeSat Post Mission Disposal by Drag Enhancement: Mission Planning for Compliance with NASA Standards

P.D. ANZ-MEADOR

NASA has developed a framework of requirements for limiting debris creation by NASA-related payloads, instruments, launch vehicles, and mission-related debris.

Post-mission disposal (PMD) is an important element in safeguarding humanity's productive and safe use of Earth orbital space, guaranteeing the benefits offered by spaceflight. The U.S. Government Mitigation Standard Practices, NASA Procedural Requirements, and NASA Technical Standard impose a burden on the spacecraft owners/operators due to the importance of protecting the space environment. The burden is made reasonable and equitable for all users by NASA's provision of the Debris Assessment Software (DAS) suite of tools and utilities and support documents developed by the NASA Orbital Debris Program Office (ODPO).

Varieties of PMD options are available to the CubeSat owner/operator community. One option is active or passive drag enhancement. In a previous article, the operational record of CubeSats so equipped was examined (see ODQN, vol. 20, issue 4, October 2016, pp. 8-9).

This article examines NASA requirements for debris mitigation by drag enhancement devices; while applicable to any resident space object, we'll again concentrate on the CubeSat form factor. As a motivation, consider the performance of the Aerospace Corporation's AeroCube 3 (International Designator 2009-028E, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 35005), a 1U CubeSat deployed from a Minotaur upper stage, with two other 1U CubeSats deployed during the same mission: Cal Poly 6 (CP6, 2009-028C, SSN# 35003) and HawkSat 1 (2009-028D, SSN# 35004). Though the AeroCube 3's inflation of the deployed drag device was unsuccessful, the device's drag was sufficient to separate it from these two similar payloads, as shown in Figs. 1 and 2.

The so-called B* parameter is an effective drag parameter for the USSTRATCOM SGP4 propagator, is resident in two line element sets, and provides a ready measure of observed drag.

continued on page 4

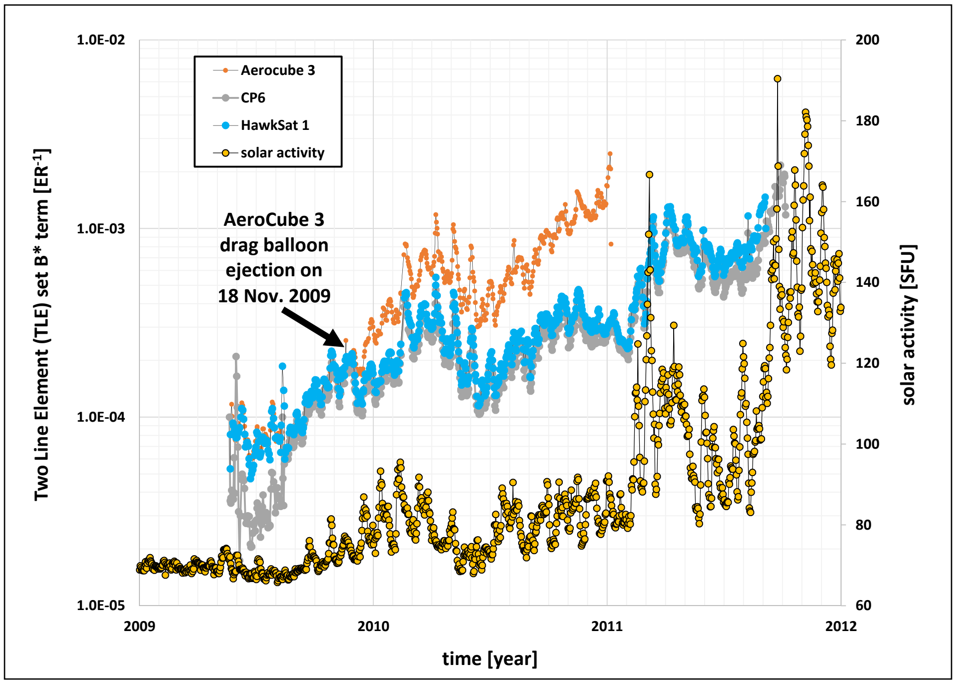


Figure 1. A time history of the two-line element set's B drag coefficient for the AeroCube 3 (test) and CP6 and HawkSat 1 (baseline) payloads compared to concurrent solar activity.*

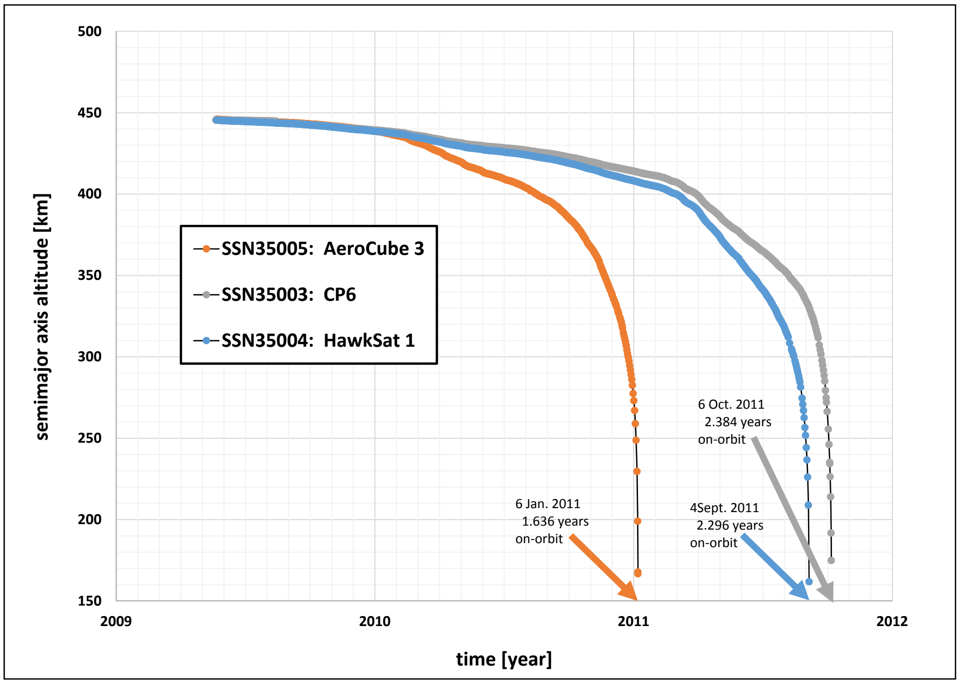


Figure 2. A time history of the semimajor axis altitude for the test and baseline CubeSats.

CubeSat PMD by Drag Enhancement

continued from page 3

While all three spacecraft B* histories shown in Fig. 1 correlate with periodic solar activity, the AeroCube 3 displays a secular growth trend in B* as compared to the baseline payloads. The variation in the baseline spacecraft lifetime shown in Fig. 2 is likely due to differences in operational area attributable to deployed solar panels, *etc*. Taking their mean time orbital duration as a standard, the AeroCube 3 demonstrated approximately a 30% reduction in on-orbit lifetime.

As these figures illustrate, even a partially successful drag enhancement device can provide a significant reduction in orbital lifetime and potentially, the collision hazard presented to other spacecraft and resident space objects. However, not all implementations of drag enhancement devices may necessarily be consistent with the overall goal of limiting the creation of new debris. For example, large areas may enhance collision probabilities with other resident space objects. The space environment may cause certain types of devices to fail prematurely, creating more debris.

The U.S. Government Orbital Debris Mitigation Standard Practices Objective 4 "Postmission Disposal of Space Structures," Section 4-1 states: *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* [1]. Furthermore, the NASA Technical Standard (hereafter referred to as the Standard), Process for Limiting Orbital Debris, Section 4.6.4.1.b states:

> Drag augmentation devices, such as inflatable balloons, increase the area-to-mass ratio of a space structure, and consequently, reduce its orbital lifetime. However, the use of such a device results in a larger collision cross-section, thereby increasing the probability of a collision during natural orbital decay. The increased collision probability should be documented in the ODAR*/EOMP**. This assessment needs to include the probable consequence of a hypervelocity impact between a resident space object, operational or non-operational, and the drag augmentation device [2].

From the Standard's Section 4.5.2.1, the compliance requirement for spacecraft in low Earth orbit (LEO) is to demonstrate that the estimated probability of accidental collision — with resident space objects 10 cm or larger in diameter — is less than 0.001.

To illustrate these requirements, this article will examine the concepts of spacecraft area-time product, the probability of collision, and the integrated mission probability of collision with large and small debris. The reader should assume that *significant* change indicates a factor of two or more.

The area-time product of a spacecraft $A_x \cdot t$, where A_x is the average cross-sectional area and t is the elapsed time on-orbit, is linear in area but non-linear in t, given a change in A_x. To understand this, consider this relationship for atmospheric drag acceleration a_D:

$$a_D = \frac{1}{2}\rho {v_r}^2 C_D \frac{A_x}{m}$$

where ρ is the atmospheric density, v_r is the velocity of the spacecraft with respect to the atmosphere, C_D is the dimensionless drag coefficient, and m is the object mass. While again linear in A_x, the quantities ρ, v_r, and C_D are non-linear functions of spacecraft orbit, solar activity, and object shape and attitude. Because orbital lifetime t depends upon the integrated drag force acting on a spacecraft, t is inherently non-linear. Third body perturbations and radiation pressure may also significantly affect the estimate of t.

The probability of collision with large objects (> 10 cm diameter) is a Poisson process, so the probability of one or more impacts is given by:

$$P_{n\geq1} = 1 - P_0 = 1 - e^{-FA_x t}$$

where F is the cumulative cross-sectional flux at a given size. The flux may be approximated by the product of the spatial density of a given size or larger and an average relative velocity; however, this simple method is generally insufficient as it cannot account for directionality and is insensitive to certain orbit parameters, particularly the inclination.

For a single year, one may examine the general effects of area enhancement versus flux by taking the total derivative of the Poisson probability $P_{n\geq1}$ and setting the resultant to zero. Since the probability of no collisions P_0 is never zero, one sees (after rearrangement) that:

$$\frac{dA_x}{A_x} = -\frac{dF}{F}$$

To maintain the same probability of one or more collisions in a given year, therefore, an increase in cross-sectional area must be offset by a decrease in the flux. This can pose problems for spacecraft above (and thus decaying through) the high spatial density peaks between approximately 800 and 1000 km altitude, as the condition may not be practically achieved. However, excepting short-life orbits, some relief is offered by the Standard's requirement that the *mission* probability be 0.001 or less. While the yearly probability may increase in certain years, offsets by reduced yearly probability and/or shorter mission lifetimes can mitigate one or more years of enhanced probability.

The integrated probability of collision over a mission's estimated lifetime of m years is computed as:

$$P_{Total} = 1 - \prod_{i=1}^{m} P_0(t_i) \approx \sum_{i=1}^{m} P_{n\geq1}(t_i)$$

if the yearly probabilities $P_{n\geq1}(t_i) \ll 1$.

Small (1 mm to 10 cm) object collisions are similarly governed by Poisson processes. The Standard requires that collisions between the on-orbit population (down to some critical size) and the drag enhancement device be evaluated using the same methodology developed for large object collisions, with the added motivation to determine if these collisions compromise both the ability to deploy the device and the effectiveness of the drag enhancement device (the Standard, §4.6.3). For example, single stranded tethers may be severed by small objects while pressurized balloons, unless rigidized mechanically or chemically, may be deflated by impacts. Depending upon the thickness of the device's material, a hypervelocity impact may shatter the impactor while transferring little energy or momentum to the device itself. This analysis requirement must be noted when preparing the ODAR/EOMP.

DAS v. 2.1 (see ODQN, vol. 21, issue 1, February 2017, pp. 4-7) incorporates the ODPO's Orbital Debris Engineering Model (ORDEM) v. 3.0 to provide the user with the latest standard space environment when addressing the requirements outlined in this article. DAS shall be used by a program or project's management (the Standard, §1.1.3) to assess compliance and enable users to tailor their spacecraft, including drag enhancement mechanisms, to comply with NASA requirements for limiting orbital debris.

As an exemplar, consider a pair of fictional U.S. university-sponsored 12U CubeSats,

continued on page 5

---

*Orbital Debris Assessment Report

**End of Mission Plan

CubeSat PMD by Drag Enhancement

continued from page 4

Humphrey and *Lauren*, launched to a circular orbit altitude of 850 km at an inclination of 51.6°. The astronomical satellites orient themselves toward celestial targets and so may be considered to be "randomly tumbling" in a local reference frame. The first challenge posed the CubeSat design team is orbital lifetime, given the relatively high operational altitude dictated by mission requirements. Figure 3 illustrates the modeled orbital lifetime of various CubeSat form factors.

As indicated by Fig. 3, our example spacecraft have an expected orbital lifetime of more than a century, based on reasonable assumptions for their area-to-mass ratio, a drag parameter. This outcome necessitates that designers incorporate a drag enhancement device into their design and ODAR and EOMP plans. The CubeSats, launched on 2016.0 (in this example), have a station-kept lifetime of 3 years, after which they deploy the required drag enhancement devices at time 2019.0. An available volume is identified in the preliminary CubeSat design, and drag device deployment electronics are mounted on the inner surface of a flat, conformal, 5 x 5-cm electronics radiator on the CubeSat's surface.

Our student analyst starts her work by executing DAS 2.1's "Science and Engineering Utilities" – Orbit Evolution Analysis – Orbit Lifetime/Dwell Time utility for this orbit. The PMD orbit starting at 2019.0 with an enhanced area-to-mass (A/m) ratio is varied until the A/m is tailored to produce an orbital lifetime of less than 25 years. In this case, an A/m of 0.146 m2/kg yields a lifetime of 24.986 years. To provide a safety factor, an A/m of 0.167 m2/kg is chosen with a corresponding lifetime of 23.496 years. This A/m corresponds to an enhanced area of 2.0 m2, ignoring the average cross-sectional area of the CubeSat itself (0.08 m2). Figure 4 summarizes the analyst's findings.

The analyst then opens the DAS "Mission Editor" and enters orbital and physical information for the CubeSat (each is evaluated individually) and any rocket bodies or associated Mission-Related Debris. The launch vehicle deploying the CubeSats performed a targeted reentry post-deployment, and there were no debris liberated by the deployment. Once defined, the analyst evaluates NS Requirement 4.5-1 "Probability of Collision with Large Objects" for the operational and PMD periods.

In the first period, the analyst defines the operational orbit and duration (3 years), checks "Station Kept," and checks "PMD Maneuver." Selecting the latter option allows the analyst to enter a final orbit and provides, in this example, a robust way to end the computational effort on the operational mission—here, a final orbit of 90-km circular altitude is entered to remove the spacecraft from orbit effectively. The "Requirements Assessments" module then computes the probability of collision, P_c,

continued on page 6

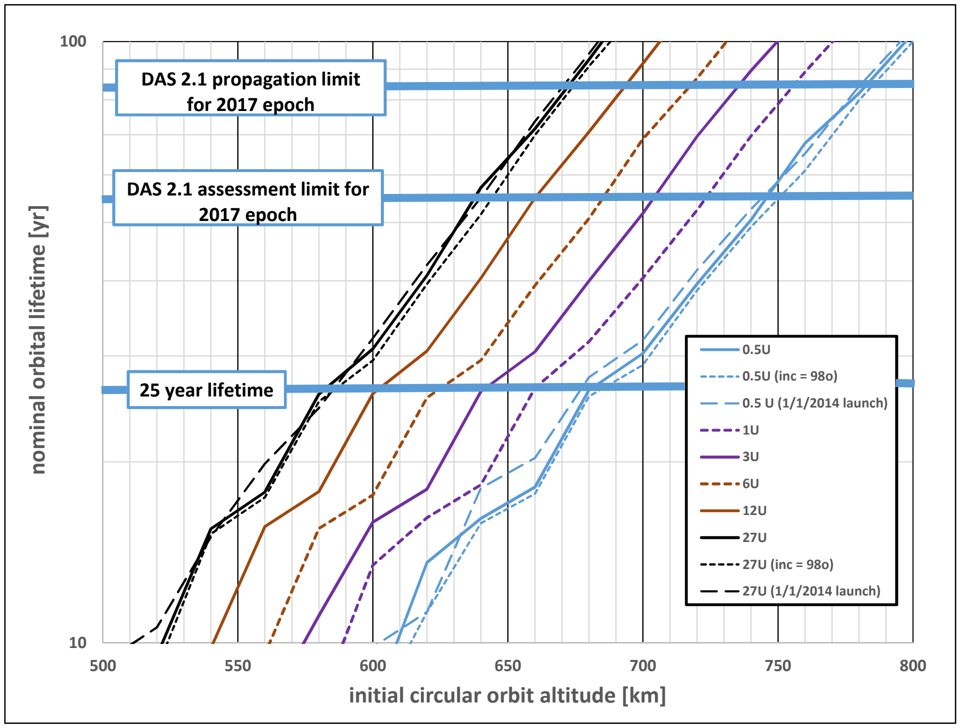


Figure 3. Orbital lifetime for CubeSat form factors, modeled using the NASA Orbital Debris Program Office (ODPO) standard propagator. Unless noted otherwise, the orbit's initial epoch is 17 April 2017, a period of relatively low solar activity, and inclination is 51.6°. The extreme form factors, the 0.5U and 27U chassis, were further modeled to illustrate lifetime variation based on either initial epoch (the high solar activity epoch 1 January 2014) or inclination, in this case a 98° inclination.

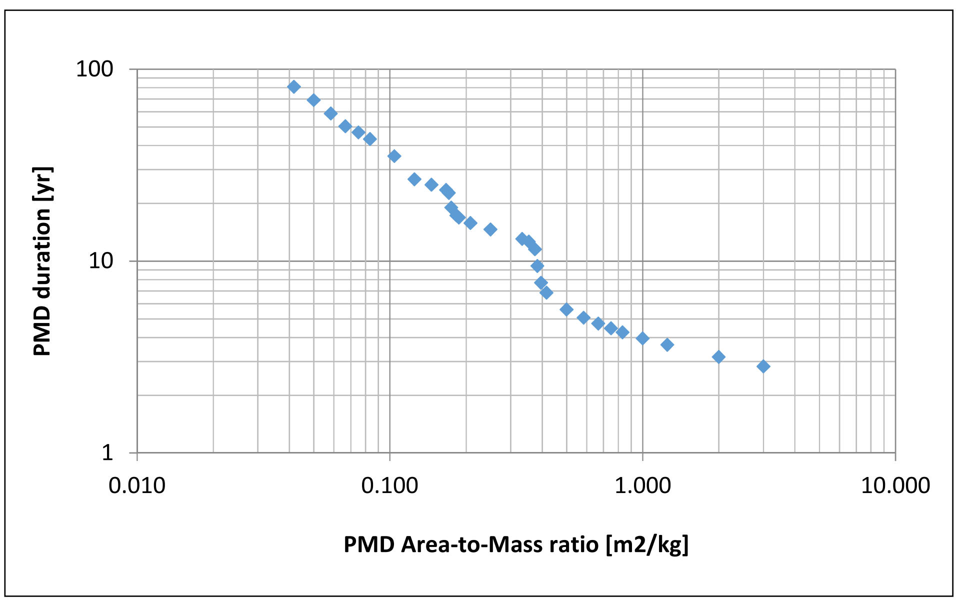


Figure 4. Post-mission lifetime as a function of A/m ratio. Modulation is due to solar cycle effects over the estimated PMD lifetime.

CubeSat PMD by Drag Enhancement

continued from page 5

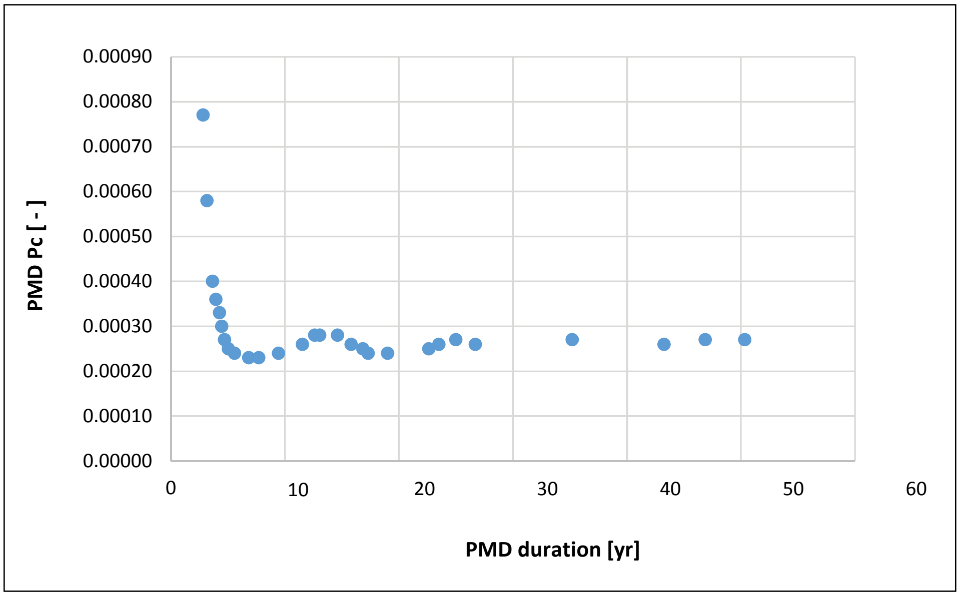


Figure 5. On-orbit probability of collision with large objects as a function of lifetime. The P_c is modulated by solar activity, spatial density, and drag enhancement area.

between the CubeSat and large objects as less than 10^{-5} over the operational mission.

The second period begins in the "Mission Editor" by unchecking these boxes, setting the initial time to 2019.0, and using the A/m ratio of 0.167 m^2/kg for the subsequent orbital evolution. The P_c over the PMD period of 23.496 years is computed to be 0.00026, well below the compliance threshold of 0.001. Figure 5 summarizes the analyst's findings. As the drag enhancement area is increased to extreme proportions to minimize orbital lifetime, it begins to interact with the local environment. Thus, the left side of Fig. 5 represents an "area-dominated" P_c region; there would be a corresponding "time-dominated" P_c region on the right side for longer timescales than are available within DAS 2.1 (limited to a final year of 2070).

In this fictional example, *Humphrey* and *Lauren's* passive drag enhancement device is a thin, aluminized Mylar sheet, which has been sized in thickness to endure atomic oxygen erosion over the PMD lifetime. As the sheet is mechanically stiffened it is not subject to small particle penetrations as a balloon would be, so no further analysis is conducted in DAS with regard to the device itself. However, the mission remains subject to the requirement that the probability of PMD device failure be less than 0.01, and the analyst uses the "Requirements Assessments"/ Requirement 4.5-2 – Probability of Damage from Small Objects module to evaluate the probability of a disabling impact and penetration on the device deployment electronics. The module allows the user to define orientation (randomly tumbling, fixed orientation, or gravity-gradient stabilized), the critical surface area (5-cm square yielding an area of 0.0025 m^2 in this example), and the surface's areal density, defined as the product of material mass density and surface thickness.

After several unsuccessful trials involving thin aluminum plates, the analyst switches the electronics radiator's material to steel. Trial and error results in a thickness of 85 mil/2.16 mm being found sufficient to reduce the probability of penetration/PMD failure over the 3-year operational orbit to 0.009349. This thickness (and attendant mass) could be reduced by removing the PMD deployment electronics from the inner surface of the radiator (a monolithic shield) to an electronics box a small distance behind the radiator—in this geometry, the radiator would act as a Whipple shield for the PMD electronics box. The DAS module can simulate this geometry.

The analyst then clicks the Requirements 4.6-1 to 4.6-3 – Postmission Disposal to confirm that her CubeSats address NASA requirements for completing post-mission disposal. This completes her PMD analysis, leaving only Requirement 4.7-1 – Casualty Risk from Reentry Debris to evaluate using DAS. A future article will address using DAS to evaluate this requirement.

References

1. U.S. Government Orbital Debris Mitigation Standard Practices (February 2001). Available at https://www.orbitaldebris.jsc.nasa.gov/reference-documents.html .

2. NASA Technical Standard Process for Limiting Orbital Debris, NASA-STD-8719.14A with Change 1 (December 2011). Available at https://www.orbitaldebris.jsc.nasa.gov/reference-documents.html . ♦

NASA ORBITAL DEBRIS PROGRAM OFFICE
ODPO

The OD Environment in Numbers

P.D. ANZ-MEADOR

Since the publication of the first edition of the History of On-Orbit Satellite Fragmentations book in August 1984, 13 later editions have chronicled the evolution of the cataloged orbital debris population [1]. With the pending publication of the 15th edition of this work, we highlight the evolution of the environment in numbers since the publication of the 14th edition in June 2008 (information cut-off date 1 August 2007). The information cut-off date for the 15th edition is 4 January 2016. Future editions will be issued on approximately a yearly basis in electronic format only. As a basis of comparison, the baseline on-orbit cataloged population in January 2016 was 17,260 resident space objects (RSOs), compared to 12,146 RSOs in January 2007. Percentages may be converted to (approximate) absolute number by multiplying the percentage by these baseline numbers.

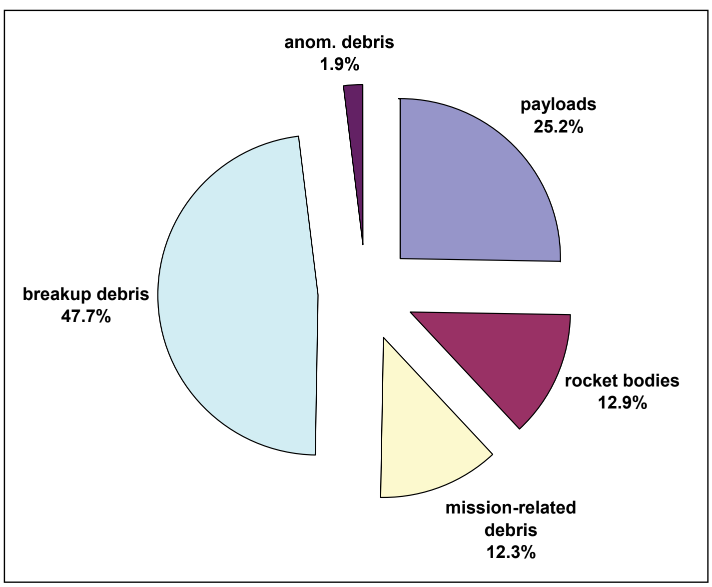
The contribution of satellite fragmentations to the growth of the Earth satellite population is complex and varied. For example, cataloged debris associated with 40% of all fragmentations have completely disappeared. On the other hand, just 10 of more than 5160 space missions flown since 1957 are responsible for 34% of all cataloged artificial Earth satellites presently in orbit (see "Top Ten Satellite Breakups Reevaluated," ODQN vol. 20, nos. 1-2 combined issue, April 2016, pp. 5-6). Moreover, the sources of 6 of these 10 fragmentations were discarded rocket bodies that had operated as designed, but later broke up. Modern debris mitigation best practices would have prevented these six events. The remaining four fragmentations are diverse in character. The oldest, the fragmentation of Cosmos 1275, is assessed by Russian authorities to have been caused by a battery fragmentation. More recently the intentional fragmentation of the Fengyun 1C meteorological payload (International Designator 1999-025) by an Anti-Satellite (ASAT) weapon and the first accidental collision of large intact spacecraft, Cosmos 2251 (1993-036) and Iridium 33 (1997-051), together account for over 25% of all cataloged RSOs. The breakup fragments associated with these three spacecraft account for almost 14% of all objects cataloged since the launch of Sputnik 1 on 4 October 1957.

The primary factors affecting the growth of the true Earth satellite population are the international space launch rate, satellite fragmentations, and solar activity. Breakup debris now comprise more than half of the cataloged Earth satellite population, as illustrated in Fig. 1. In addition, the majority of payloads are no longer operational and constitutes a separate and statistically important class of orbital debris. Rocket bodies and mission-related debris account for approximately equal proportions of the environment.

In this figure, satellite fragmentations are categorized by their assessed nature; the reader should note that assessments may change as additional information becomes available, a class of objects exhibits a consistent pattern of fragmentations, *etc*. A **satellite breakup** is the usually destructive disassociation of an orbital payload, rocket body, or structure, often with a wide range of ejecta velocities. A satellite breakup may be accidental or the result of intentional actions, *e.g.*, due to a propulsion system malfunction or a space weapons test, respectively. An **anomalous event** is the unplanned separation, usually at low velocity, of one or more detectable objects from a satellite, which remains essentially intact. Anomalous events can be caused by material deterioration of items such as thermal blankets, protective shields, or solar panels, or by the impact of small particles. From one perspective, satellite breakups may be viewed as a measure of the effects of man's activity on the environment, while anomalous events may be a measure of the effects of the environment on man-made objects.

By far the most important category of man-made, on-orbit objects is satellite breakups, which now account for over 53% of the total cataloged on-orbit Earth satellite population of 17,260 Earth-orbiting objects. Since 1957 a total of 232 satellites are believed to have broken up. The primary causes of satellite breakups (Fig. 2) are propulsion-related events and deliberate actions, although the cause for almost 25% of all breakups remains uncertain. Deliberate actions, often associated with activities related to national security, were formerly the most frequently occurring class, although only one such event occurred during the decade from 1997 until the Fengyun 1C event in January 2007.

continued on page 8



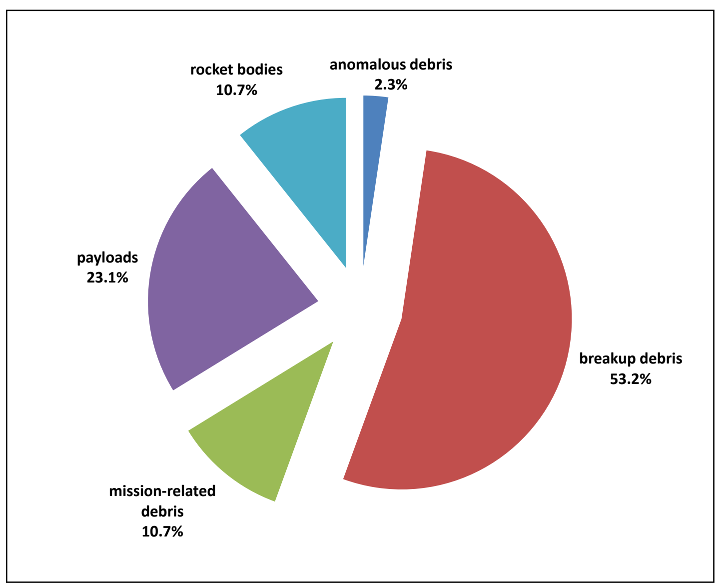


Figure 1. Relative proportions of the cataloged in-orbit Earth satellite population. A comparison of the environment as of 1 August 2007, 14th ed. (left) and 4 January 2016, 15th ed., (right).

OD Environment

continued from page 7

On average, the resulting debris from deliberate actions are short-lived (Fig. 3), the exception being Fengyun 1C. Propulsion-related breakups, currently the most frequent class, include catastrophic malfunctions during orbital injection or maneuvers, subsequent explosions based on residual propellants, and failures of active attitude control systems. Breakups of rocket bodies due to propulsion failures are usually more prolific and produce longer-lived debris than the intentional destruction of payloads, often due to the higher altitudes of the malfunctioning rocket bodies rather than the mechanics of the explosive event.

References

1. Johnson, N.L, Gabbard, J.R., DeVere, G.T. and Johnson, E.E. "History of On-Orbit Satellite Fragmentations," Teledyne Brown Engineering report CS84-BMDSC-0018, Colorado Spring, CO, August 1984.

2. Johnson, N.L., Stansbery E., Whitlock, D.O., Abercromby, K.J., and Shoots, D. "History of On-Orbit Satellite Fragmentations, 14th ed.," NASA/TM-2008-214779, June 2008. ♦

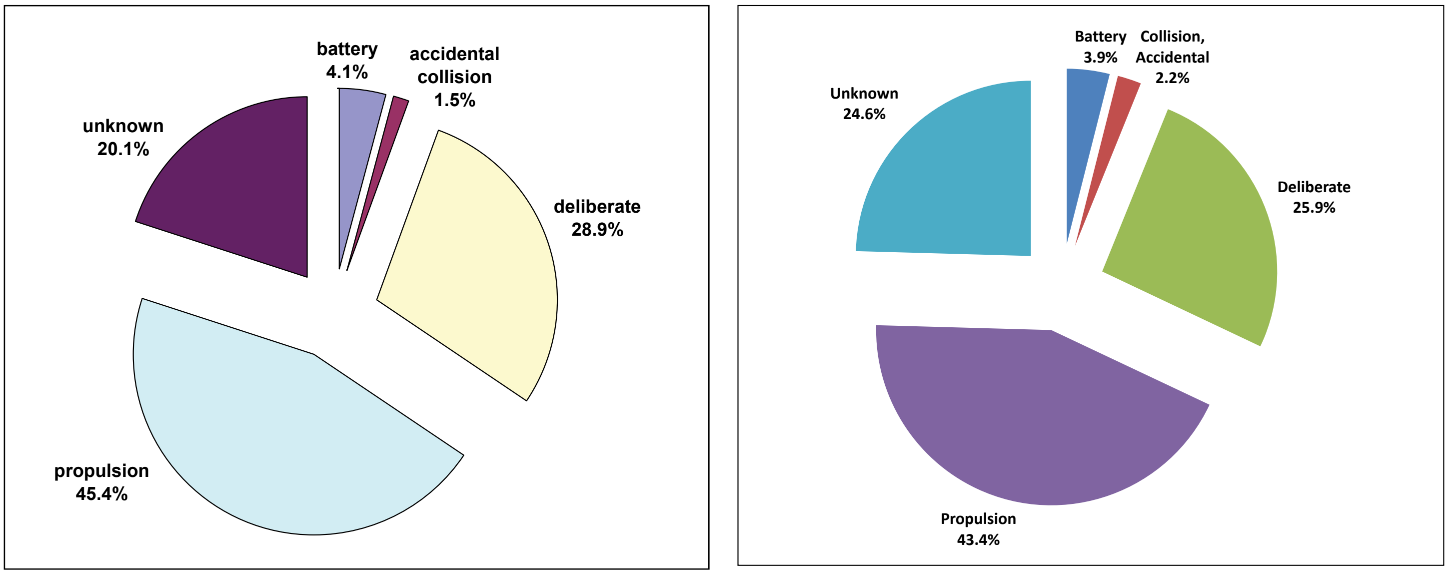


Figure 2: Causes of known satellite breakups. Compare 1 August 2007, 14th ed., (left) and 4 January 2016, 15th ed., (right) attributions.

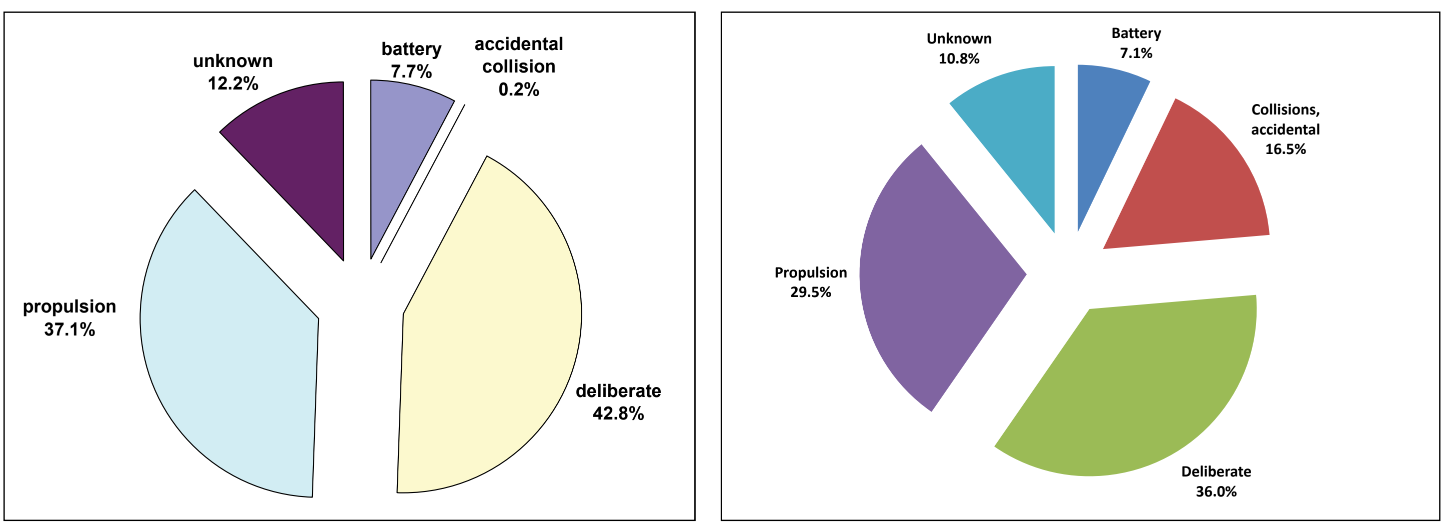


Figure 3: Proportion of cataloged satellite breakup debris remaining in orbit as of 1 August 2007, 14th ed., (left) and 4 January 2016, 15th ed., (right).

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The 7th European Conference on Space Debris, 18-21 April 2017, ESA/ESOC, Darmstadt, Germany

A Comparison of the SOCIT and DEBRISAT Experiments

E. AUSAY, B. BLAKE, C. BOYLE, A. CORNEJO, A. HORN, K. PALMA, F. PISTELLA, T. SATO, N. TODD, J. ZIMMERMAN, N. FITZ-COY, J.-C. LIOU, M. SORGE, T. HUYNH, J. OPIELA, P. KRISKO, AND H. COWARDIN

This paper explores the differences between, and shares the lessons learned from, two hypervelocity impact experiments critical to the update of orbital debris environment models. The procedures and processes of the fourth Satellite Orbital Debris Characterization Impact Test (SOCIT) were analyzed and related to the ongoing DebriSat experiment. SOCIT was the first hypervelocity impact test designed specifically for satellites in Low Earth Orbit (LEO). It targeted a 1960's U.S. Navy satellite, from which data was obtained to update pre-existing NASA and DoD breakup models. DebriSat is a comprehensive update to these satellite breakup models—necessary since the material composition and design of satellites have evolved from the time of SOCIT. Specifically, DebriSat utilized carbon fiber, a composite not commonly used in satellites during the construction of the US Navy Transit satellite used in SOCIT.

Although DebriSat is an ongoing activity, multiple points of difference are drawn between the two projects. Significantly, the hypervelocity tests were conducted with two distinct satellite models and test configurations, including projectile and chamber layout. While both hypervelocity tests utilized soft catch systems to minimize fragment damage to its post-impact shape, SOCIT only covered 65% of the projected area surrounding the satellite, whereas, DebriSat was completely surrounded cross-range and downrange by the foam panels to more completely collect fragments. Furthermore, utilizing lessons learned from SOCIT, DebriSat's post-impact processing varies in methodology (i.e., fragment collection, measurement, and characterization). For example, fragment sizes were manually determined during the SOCIT experiment, while DebriSat utilizes automated imaging systems for measuring fragments, maximizing repeatability while minimizing the potential for human error.

In addition to exploring these variations in methodologies and processes, this paper also presents the challenges DebriSat has encountered thus far and how they were addressed. Accomplishing DebriSat's goal of collecting 90% of the debris, which constitutes well over 100,000 fragments, required addressing many challenges stemming from the very large number of fragments. One of these challenges arose in identifying the foam-embedded fragments. DebriSat addressed this by X-raying all of the panels once the loose debris were removed, and applying a detection algorithm developed in-house to automate the embedded fragment identification process. It is easy to see how the amount of data being compiled would be outstanding. Creating an efficient way to catalog each fragment, as well as archiving the data for reproducibility also posed a great challenge for DebriSat. Barcodes to label each fragment were introduced with the foresight that once the characterization process began, the datasheet for each fragment would have to be accessed again quickly and efficiently.

The DebriSat experiment has benefited significantly by leveraging lessons learned from the SOCIT experiment along with the technological advancements that have occurred during the time between the experiments. The two experiments represent two ages of satellite technology and, together, demonstrate the continuous efforts to improve the experimental techniques for fragmentation debris characterization. ♦

Minimum DV for Targeted Spacecraft Disposal

J. BACON

The study analyzes the minimum capability required to dispose safely of a space object. The study considers 3-sigma (3-σ) environmental uncertainties, as well as spacecraft-specific constraints such as the available thrust, total impulse, the achievable increase or decrease in commandable frontal area under stable attitude (or stable tumble), and the final controllable altitude at which any such dV may be imparted. The study addresses the definition of the length and location of a "safe" disposal area, which is a statistical manifestation of uncertainty in this process. Some general legal concerns are raised that are unique to this prospect of low dV disposals. Future work is summarized. The goal of such research is to improve public safety by creating optimally safe disposal strategies (and potentially, applicable regulations) for low-dV and/or low-thrust spacecraft that under more traditional strategies would need to be abandoned to fully-random decay with its inherent higher risk of human casualty. ♦

United Kingdom Infrared Telescope's Spectrograph Observations of Human-Made Space Objects

B. BUCKALEW, K. ABERCROMBY, S. LEDERER, H. COWARDIN, AND J. FRITH

Presented here are the results of the United Kingdom Infrared Telescope (UKIRT) spectral observations of 17 human-made space objects (spacecraft, rocket bodies, and debris) taken in 2015. The remotely collected data are compared to the laboratory-collected reflectance data on typical spacecraft materials; thereby general materials are identified. These results highlight the usefulness of observations in the infrared by focusing on features from hydrocarbons and silicon. The model results of the spacecraft spectra show distinct features due to solar panels. These results show that the laboratory data in its current state gives excellent indications as to the nature of the surface materials on spacecraft. The model fits to rocket bodies and debris did not do as well, indicating a potential gap in the current methodology. To produce more reliable results for all space objects, we conclude with future work necessary to give logical results for both rocket bodies and debris. ♦

Characterization of Orbital Debris via Hyper-velocity Laboratory-based Tests

H. COWARDIN, J.-C. LIOU, P. ANZ-MEADOR, M. SORGE, J. OPIELA, N. FITZ-COY, T. HUYNH, AND P. KRISKO

Existing DOD and NASA satellite breakup models are based on a key laboratory test, Satellite Orbital debris Characterization Impact Test (SOCIT), which has supported many applications and matched on-orbit events involving older satellite designs reasonably well over the years. In order to update and improve these models, the NASA Orbital Debris Program Office, in collaboration with the Air Force Space and Missile Systems Center, The Aerospace Corporation, and the University of Florida, replicated a hypervelocity impact using a mock-up satellite, DebriSat, in controlled laboratory conditions. DebriSat is representative of present-day LEO satellites, built with modern spacecraft materials and construction techniques. Fragments down to 2 mm in size will be characterized by their physical and derived properties. A subset of fragments will be further analyzed in laboratory radar and optical facilities to update the existing radar-based NASA Size Estimation Model (SEM) and develop a comparable optical-based SEM.

A historical overview of the project, status of the characterization process, and plans for integrating the data into various models will be discussed herein. ♦

Observing Strategies for Focused Orbital Debris Surveys Using the Magellan Telescope

J. FRITH, H. COWARDIN, B. BUCKALEW, P. ANZ-MEADOR, S. LEDERER, AND M. MATNEY

A breakup of the Titan 3C-17 Transtage rocket body was reported to have occurred on 4 June 2014 at 02:38 UT by the Space Surveillance Network (SSN). Five objects were associated with this breakup and this is the fourth breakup known for this class of object. There are likely many more objects associated with this event that are not within the SSN's ability to detect and have not been catalogued. Several months after the breakup, observing time was obtained on the Magellan Baade 6.5 meter telescope to be used for observations of geosynchronous (GEO) space debris targets. Using the NASA Standard Satellite Breakup Model, a simulated debris cloud of the recent Transtage breakup was produced and propagated forward in time. This provided right ascension, declination, and tracking rate predictions for where debris associated with this breakup may be more likely to be detectable during the Magellan observing run. Magellan observations were then optimized using the angles and tracking rates from the model predictions to focus the search for Transtage debris. ♦

Development of the Space Debris Sensor

J. HAMILTON, J.-C. LIOU, P. ANZ-MEADOR, B. CORSARO, F. GIOVANE, M. MATNEY, AND E. CHRISTIANSEN

The Space Debris Sensor (SDS) is a NASA experiment scheduled to fly aboard the International Space Station (ISS) starting in 2017. The SDS is the first flight demonstration of the Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor (DRAGONS) developed and matured by the NASA Orbital Debris Program Office. The DRAGONS concept combines several technologies to characterize the size, speed, direction, and density of small impacting objects. With a minimum two-year operational lifetime, SDS is anticipated to collect statistically significant information on orbital debris ranging from 50 µm to 500 µm in size.

This paper describes the SDS features and how data from the ISS mission may be used to update debris environment models. Results of hypervelocity impact testing during the development of SDS and the potential for improvement on future sensors at higher altitudes will be reviewed. ♦

NASA'S Ground-Based Observing Campaigns of Rocket Bodies with the UKIRT and NASA ES-MCAT Telescopes

S. LEDERER, B. BUCKALEW, P. ANZ-MEADOR, J. FRITH, H. COWARDIN, M. MATNEY

Rocket bodies comprise a class of human-made space debris that are at the same time essential for launching every spacecraft from the Earth, but also are a significant source of debris both as intact objects, as well as fragmented debris. Unspent fuel has been long theorized as a potential cause of catastrophic rocket body break-ups. Given typical orbital speeds range from

continued on page 11

UKIRT and NASA ES-MCAT Telescopes

continued from page 10

~2-3 km/s at Geosynchronous Orbit (GEO) and up to 15 km/s in low Earth orbit (LEO), collisions with uncatalogued and undetected debris can also cause catastrophic breakups.

Understanding break-ups is a necessary step in preventing them, and one key step in that process is to correlate and characterize daughter fragments with their parent bodies. Two very different methods include (1) conducting photometric surveys to correlate an object's motion and orbital elements to the parent body, and (2) characterizing what materials comprise the target to determine whether those materials are consistent with the parent body or like objects. With this in mind, photometric data were taken shortly after the breakup of one rocket body for short-term orbital studies, and a suite of spectral data were taken of rocket bodies that are fully in tact to compare with debris fragments, for characterization studies. Targets included Titan Transtage, Briz-M, and Ariane rocket bodies and debris. Spectra of each sub-class of rocket body were very similar within their rocket body type, but differed distinctly from one type to the next, supporting the effectiveness of this approach. ♦

Highlights of Recent Research Activities at the NASA Orbital Debris Program Office

J.-C. LIOU

The NASA Orbital Debris Program Office (ODPO) was established at the NASA Johnson Space Center in 1979. The ODPO has initiated and led major orbital debris research activities over the past 38 years, including developing the first set of the NASA orbital debris mitigation requirements in 1995 and supporting the establishment of the U.S. Government Orbital Debris Mitigation Standard Practices in 2001. This paper is an overview of the recent ODPO research activities, ranging from ground-based and in-situ measurements, to laboratory tests, and to engineering and long-term orbital debris environment modeling. These activities highlight the ODPO's commitment to continuously improve the orbital debris environment definition to better protect current and future space missions from the low Earth orbit to the geosynchronous Earth orbit regions. ♦

Algorithms for the Computation of Debris Risk

M. MATNEY

Determining the risks from space debris involve a number of statistical calculations. These calculations inevitably involve assumptions about geometry - including the physical geometry of orbits and the geometry of satellites. A number of tools have been developed in NASA's Orbital Debris Program Office to handle these calculations; many of which have never been published before. These include algorithms that are used in NASA's Orbital Debris Engineering Model ORDEM 3.0, as well as other tools useful for computing orbital collision rates and ground casualty risks. This paper presents an introduction to these algorithms and the assumptions upon which they are based. ♦

The Small Size Debris Population at GEO from Optical Observations

P. SEITZER, E. BARKER, B. BUCKALEW, A. BURKHARDT, H. COWARDIN, J. FRITH, C. KALEIDA, S. LEDERER, AND C. LEE

We have observed the geosynchronous orbit (GEO) debris population at sizes smaller than 10 cm using optical observations with the 6.5-m Magellan telescope 'Walter Baade' at the Las Campanas Observatory in Chile. The IMACS f/2 imaging camera with a 0.5-degree diameter field of view has been used in small area surveys of the GEO regime to study the population of optically faint GEO debris. The goal is to estimate the population of GEO debris that is fainter than can be studied with 1-meter class telescopes. A significant population of objects fainter than R = 19th magnitude has been found. These objects have observed with angular rates consistent with circular orbits and orbital inclinations up to 15 degrees at GEO. A sizeable number of these objects have significant brightness variations ("flashes") during the 5-second exposure, which suggest rapid changes in the albedo-projected size product. ♦

Effects of CubeSat Deployments in Low-Earth Orbit

M. MATNEY, A. VAVRIN, AND A. MANIS

Long-term models, such as NASA's LEGEND (LEO-to-GEO Environment Debris) model, are used to make predictions about how space activities will affect the manner in which the debris environment evolves over time. Part of this process predicts how spacecraft and rocket bodies will be launched and remain in the future environment. This has usually been accomplished by repeating past launch history to simulate future launches.

The NASA Orbital Debris Program Office (ODPO) has conducted a series of LEGEND computations to investigate the long-term effects of adding CubeSats to the environment. These results are compared to a baseline "business-as-usual" scenario where launches are assumed to continue as in the past without major CubeSat deployments. Using these results, we make observations about the continued use of the 25-year rule and the importance of the universal application of post-mission disposal. ♦

ABSTRACT FROM THE NASA HVIT GROUP

The 7th European Conference on Space Debris, 18-21 April 2017, ESA/ESOC, Darmstadt, Germany

Surveys of ISS Returned Hardware for MMOD Impacts

J. HYDE, E. BERGER, E. CHRISTIANSEN, D. LEAR, AND K. NAGY

Since February 2001, the Hypervelocity Impact Technology (HVIT) group at the Johnson Space Center in Houston has performed 26 post-flight inspections on space exposed hardware that have been returned from the International Space Station. Data on 1,024 observations of MMOD damage have been collected from these inspections. Survey documentation typically includes impact feature location and size measurements as well as microscopic photography (25-200x). Sampling of impacts sites for projectile residue was performed for the largest features. Results of Scanning Electron Microscopy (SEM) analysis to discern impactor source is included in the database. This paper will summarize the post-flight MMOD inspections, and focus on two inspections in particular: (1) Pressurized Mating Adapter-2 (PMA2) cover returned in 2015 after 1.6 years exposure with 26 observed damages, and (2) Airlock shield panels returned in 2010 after 8.7 years exposure with 58 MMOD damages. Feature sizes from the observed data are compared to predictions using the Bumper risk assessment code. ♦

UPCOMING MEETINGS

3-9 June 2017: 31st International Symposium on Space Technology and Science, Matsuyama City, Ehime Prefecture, Japan

The IAC will return to Australia in 2017, with a theme of "Unlocking imagination, fostering innovation and strengthening security." The IAA will again organize the Symposium On Space Debris during the congress. Nine sessions are planned to cover all aspects of orbital debris activities, including measurements, modeling, hypervelocity impact, mitigation, remediation, and policy/legal/economic challenges for environment management. An additional joint session with the Symposium on Small Satellite Missions is also planned. Abstract submission deadline for the congress is 28 February 2017. Additional information for the 2017 IAC is available at: http://www.ists.or.jp/.

5-10 August 2017: 31st Annual Small Satellite Conference, Logan, Utah, USA

Utah State University (USU) and the AIAA will sponsor the 31st Annual AIAA/USU Conference on Small Satellites at the university's Logan campus, Utah, USA. With the theme of "Small Satellites – Big Data", the 31st conference will highlight the ability of small satellites to enable big data applications. Mr. Robert Cardillo, Director, National Geospatial Information Agency, is the scheduled Keynote Speaker. The abstract submission deadline passed on 9 February 2017. Additional information about the conference is available at https://smallsat.org/index.

20-24 August 2017: AAS/AIAA Astrodynamics Specialist Conference, Stevenson, WA (USA)

The American Astronautical Society (AAS) and the American Institute of Aeronautics and Astronautics (AIAA) will co-host the 2017 AAS/AIAA Astrodynamics Specialist Conference in Stevenson, Washington, USA. Technical sessions include, but are not limited to, orbit determination and space surveillance tracking; orbital debris and the space environment; orbital dynamics, perturbations, and stability; proximity operations; space situational awareness, conjunction analysis, and collision avoidance; and satellite constellations. The abstract submission deadline passed on 24 April 2017. Additional information about the conference is available at http://www.space-flight.org/docs/2017_summer/2017_summer.html.

UPCOMING MEETINGS - CONTINUED

12-14 September 2017: AIAA Space 2017, Orlando, FL (USA)

The American Institute of Aeronautics and Astronautics (AIAA) will convene the AIAA SPACE and Astronautics Forum and Exposition (AIAA SPACE 2017) in Orlando, Florida, USA. Technical sessions include Space Law and Policy and Space Operations. The abstract submission deadline passed on 23 February 2017. Additional information about the conference is available at http://space.aiaa.org/.

19-22 September 2017: 18th Advanced Maui Optical and Space Surveillance Technologies Conference, Maui, Hawaii (USA)

The technical program of the 18th Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) will 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 passed on 1 April 2017. Additional information about the conference is available at http://www.amostech.com.

25-29 September 2017: 68th International Astronautical Congress (IAC), Adelaide, Australia

The IAC will return to Australia in 2017, with a theme of "Unlocking imagination, fostering innovation and strengthening security." The IAA will again organize the Symposium On Space Debris during the congress. Nine sessions are planned to cover all aspects of orbital debris activities, including measurements, modeling, hypervelocity impact, mitigation, remediation, and policy/legal/economic challenges for environment management. An additional joint session with the Symposium on Small Satellite Missions is under consideration. The abstract submission deadline passed on 28 February 2017. Additional information for the 2017 IAC is available at: http://www.iac2017.org/.

18-20 October 2017: 9th International Association for the Advancement of Space Safety (IAASS) Conference, Toulouse, France

The 9th conference of the IAASS has as its theme "Know Safety, No Pain". Major debris-related topics include designing safety into space vehicles, space debris remediation, re-entry safety, nuclear safety for space missions, safety risk management and probabilistic risk assessment, and launch and in-orbit collision risk. In addition to the main sessions, four specialized sections will address Space Debris Reentries, Space Traffic Management, Safety Standards for Commercial Human Spaceflight, and Human Performance and Safety. Abstract submission deadline for the conference is 30 May 2017. Additional information for the 2017 IAC is available at: http://iaassconference2017.space-safety.org/.

13-15 November 2017: 1st IAA Conference on Space Situational Awareness (ICSAA), Orlando, FL (USA)

The International Academy of Astronautics (IAA) and the American Institute of Aeronautics and Astronautics (AIAA) will convene the 1st IAA Conference on Space Situational Awareness in Orlando, Florida, USA. Co-sponsors include the University of Florida, the University of Arizona, the Ohio State University, the University of Central Florida, and Texas A&M University. Technical sessions include, but are not limited to, resident space object sensing, identification, forecasting, tracking, risk assessment, debris removal, drag assisted reentry, and deorbiting technologies. The abstract submission deadline is 30 June 2017. Additional information about the conference is available at http://www.aiaa.org/icssa2017/ and http://reg.conferences.dce.ufl.edu/ICSSA/1357.

SATELLITE BOX SCORE

(as of 4 April 2017, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	235	3566	3801
CIS	1508	4993	6501
ESA	74	60	134
FRANCE	62	470	532
INDIA	79	113	192
JAPAN	162	94	256
USA	1513	4504	6017
OTHER	801	113	914
TOTAL	4434	13913	18347

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 concerning the ODQN can be sent to:

NASA Johnson Space Center
The Orbital Debris Program Office
Attn: JE104/Debi Shoots
Houston, TX 77058

debra.d.shoots@nasa.gov

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

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

INTERNATIONAL SPACE MISSIONS

1 January 2017 – 31 March 2017

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2017-001A	TJS-2	CHINA	35780	35794	0.8	1	0
2017-002A	OBJECT A*	CHINA	529	546	97.5	1	0
2017-002B	JILIN-1-03	CHINA	531	547	97.5		
2017-002C	OBJECT C*	CHINA	528	542	97.5		
2017-003A	IRIDIUM 106	USA	776	780	86.4	0	0
2017-003B	IRIDIUM 103	USA	776	779	86.4		
2017-003C	IRIDIUM 109	USA	776	779	86.4		
2017-003D	IRIDIUM 102	USA	776	779	86.4		
2017-003E	IRIDIUM 105	USA	609	623	86.7		
2017-003F	IRIDIUM 104	USA	776	780	86.4		
2017-003G	IRIDIUM 114	USA	776	780	86.4		
2017-003H	IRIDIUM 108	USA	609	623	86.7		
2017-003J	IRIDIUM 112	USA	776	779	86.4		
2017-003K	IRIDIUM 111	USA	776	779	86.4		
1998-067KS	FREEDOM	JAPAN	217	241	51.6	0	0
1998-067KU	ITF-2	JAPAN	392	400	51.6		
1998-067KV	WASEDA-SAT3	JAPAN	391	400	51.6		
1998-067KW	EGG	JAPAN	360	365	51.6		
1998-067KX	AOBA-VELOX 3	SINGAPORE	392	400	51.6		
1998-067KY	TUPOD	ITALY	378	386	51.6		
2017-004A	SBIRS GEO 3 (USA 273)	USA	EN ROUTE TO GEO			1	0
1998-067KT	TANCREDO 1	BRAZIL	381	391	51.6	0	0
1998-067KZ	OSNSAT	USA	385	395	51.6		
2017-005A	DSN-1	JAPAN	35779	35794	0	1	0
2017-006A	HISPASAT 36W-1	SPAIN	35780	35793	0	1	0
2017-007A	TELKOM 3S	INDONESIA	35785	35789	0	1	1
2017-007B	INTELSAT 32E	INTELSAT	35781	35793	0		
2017-008A	CARTOSAT 2D	INDIA	502	514	97.5	1	0
2017-008B	INS-1A	INDIA	494	510	97.5		
2017-008G	INS-1B	INDIA	494	509	97.5		
2017-008BD	BGUSAT	ISRAEL	492	507	97.5		
2017-008BE	DIDO 2	ISRAEL	493	507	97.5		
2017-008BV	PEASSS	NETHERLANDS	492	504	97.5		
2017-008BW	AL-FARABI 1	KAZAKHSTAN	492	504	97.5		
2017-008BX	NAYIF 1	UAE	492	504	97.5		
2017-008	FLOCK 3P (88 sats.)	USA	492-494	505-509	97.5		
2017-008	LEMUR 2 (8 sats.)	USA	492-493	507	97.5		
2017-009A	DRAGON CRS-10	USA	396	402	51.6	0	2
2017-010A	PROGRESS MS-05	RUSSIA	399	409	51.6	1	0
2017-011A	USA 274	USA	NO ELEMS. AVAILABLE			0	1
2017-012A	TK-1	CHINA	381	407	96.9	1	1
1998-067LA	LEMUR 2 REDFERN-GOES	USA	393	407	51.6	0	0
1998-067LB	TECHEDSAT 5	USA	386	396	51.6		
1998-067LC	LEMUR 2 TRUTNA	USA	393	405	51.6		
1998-067LD	LEMUR 2 AUSTINTACIOUS	USA	394	406	51.6		
1998-067LE	LEMUR 2 TRUTNAHD	USA	394	405	51.6		
2017-013A	SENTINEL 2B	ESA	788	790	98.6	1	0
2017-014A	ECHOSTAR 23	USA	35770	35803	0.1	1	0
2017-015A	IGS RADAR-5	JAPAN	486	489	97.4	1	1
2017-016A	WGS 9 (USA 275)	USA	EN ROUTE TO GEO			1	0
2017-017A	SES-10	SES	EN ROUTE TO GEO			1	0

** Identification of the two deployed CubeSats has not been resolved*