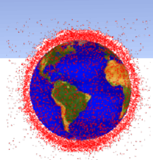
National Aeronautics and Space Administration

Orbital Debris Quarterly News

Volume 20, Issue 4
October 2016

Inside...



A publication of
the NASA Orbital
Debris Program Office

ASTRO-H Spacecraft Fragments During Payload Check-out Operations

The ASTRO-H/*Hitomi*/New X-Ray Telescope (NeXT) high energy astrophysics observatory satellite experienced an operationally-induced fragmentation event on 26 March 2016 at approximately 1:42 GMT. The spacecraft (International Designator 2016-012A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 41337), managed and operated by the Japan Aerospace Exploration Agency (JAXA) but including payloads from NASA/Goddard Space Flight Center, the Canadian Space Agency, and the European Space Agency, had concluded its Phase 0 Critical Operations Phase and was approximately 60% complete in its Initial Function Check Phase. The spacecraft had been on-orbit slightly over one month and was in a 31.0° inclination, 578 by 536 km orbit at the time of the event. JAXA abandoned the spacecraft on 28 April 2016 after repeated attempts to recover it.

Following an extensive investigation by JAXA and ASTRO-H program management, a report now is available to the public [1]. To summarize their findings, unexpected behavior of the Attitude Control System (ACS) indicated to the spacecraft that it was rotating, although it was not. On-board reaction wheels were activated to stop the rotation, which induced an actual rotation of the spacecraft. The ACS assessed the spacecraft to be in a critical situation and attempted to use the RCS to enter a Safe-Hold mode. Unfortunately, incorrect thruster control parameters led to the thrusters increasing the angular acceleration of the spacecraft. As rotational speed exceeded design parameters, several major components separated from the spacecraft, leading to mission loss. JAXA post mortem analyses

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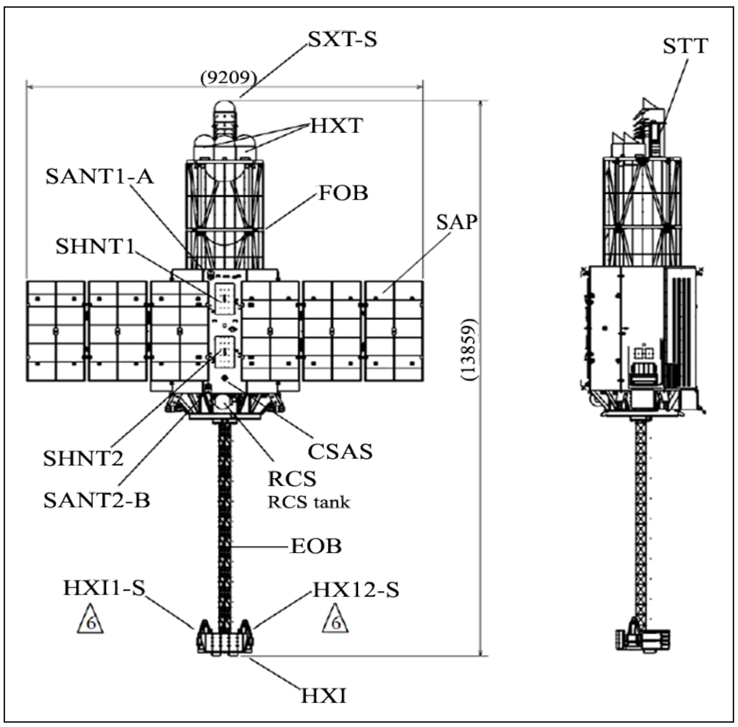

Figure 1. An exterior view of the ASTRO-H spacecraft (from Ref. 1). All dimensions are in millimeters. Relevant acronyms are Solar Array Paddles (SAP); Extensible Optical Bench (EOB), and Reaction Control System (RCS). See Ref. 1 § 2.3 for a complete list of acronyms.

ASTRO-H Fragments

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suggest that the Solar Array Paddles, the Extensible Optical Bench, and other components separated near the spacecraft body. The body was left in a quickly rotating state with depleted batteries.

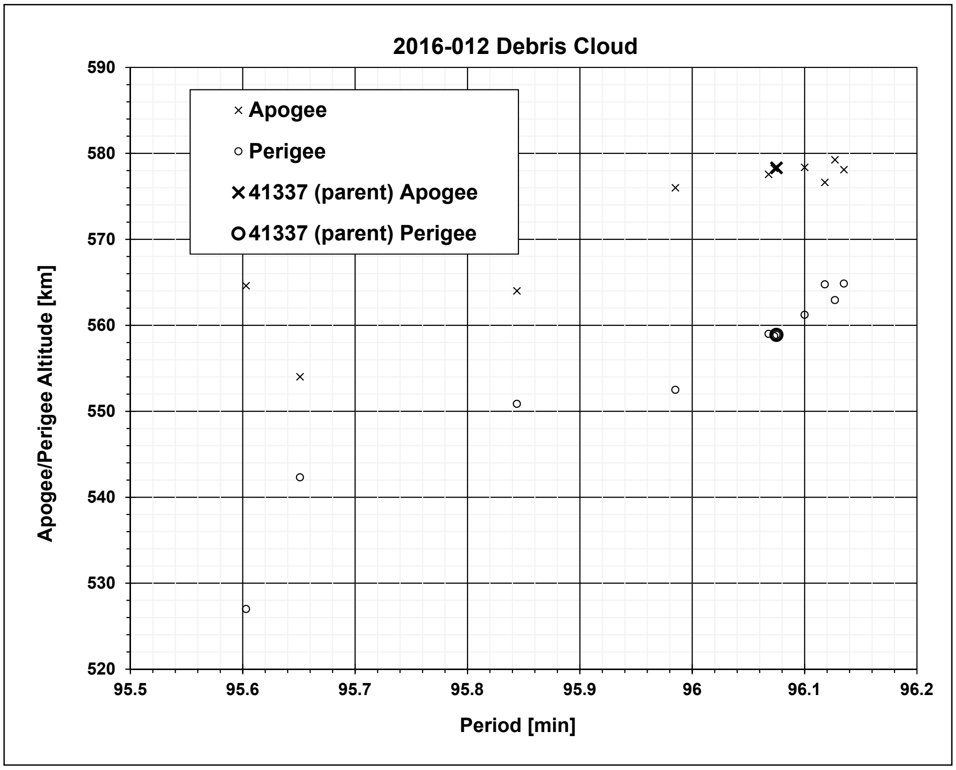

Figure 2. A Gabbard diagram for 2016-012 event-related objects.

As of 8 September 2016, 10 debris had officially entered the SSN catalog in addition to the parent object; 8 remain on orbit. Figure 2 is a Gabbard diagram for the debris cloud, including the parent body. All debris are in orbits similar to the parent object, with a maximum change in period of 0.5 minutes and change in inclination of 0.47°.

A previous rotation-induced fragmentation, occurring over 50 years before *Hitomi*, was the likely RCS-related breakup of the Titan IIIC-4 Transtage (1965-082DM, SSN #1822) in low Earth orbit during thrusting. Balloon satellites and spacecraft with long appendages are also subject to naturally-induced spin-up and spin-down. Thus the assessed loss mechanism of *Hitomi*, while contributing to a major programmatic loss to astrophysics, is not unique in the history of spaceflight.

Reference

1. JAXA, "Hitomi Experience Report: Investigation of Anomalies Affecting the X-ray Astronomy Satellite 'Hitomi' (ASTRO-H)," 8 June 2016 edition. Retrieved 1 October 2016. http://global.jaxa.jp/projects/sat/astro_h/topics.html?utm_source=dlvr.it&utm_medium=twitter#topics7815 ♦

New SOZ Breakup in July 2016

A SOZ (*Sistema Obespecheniya Zapuska*) ullage motor, or SL-12 auxiliary motor, from a Proton Block DM fourth stage fragmented at 1:19 UTC on 27 July 2016. These motors have a long history of fragmentations, this event being the 46th breakup of this class of object over its program history and the second in 2016. A total of 380 SL-12 Auxiliary Motors have been cataloged between 1970 and 2012, of which 64 remain on orbit. Of these 64, 38 are believed to be intact. Ullage motors, used to provide three-axis control to the Block DM during coast and to settle propellants prior to an engine restart, are routinely ejected after the Block DM stage ignites for the final time. This SOZ unit (International Designator 2006-062G, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 29680) is associated with the launch of the Cosmos 2424-2426 spacecraft, members of the Russian global positioning navigation system (GLONASS) constellation.

The unit fragmented into multiple pieces, though none have entered the SSN catalog as of 8 September 2016. The motor was in a highly elliptical 19088 x 426 km orbit at an inclination of 64.8° at the time of the breakup. Due to difficulties in tracking objects in deep space elliptical orbits, this event may have produced many fragmentation debris. ♦

BeiDou G2 Spacecraft Fragments in Geosynchronous Orbit

The second-generation *BeiDou* G2 navigation satellite fragmented on 29 June 2016. The object (International Designator 2009-018A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 34779) fragmented into at least five pieces. As of 8 September 2016, no fragmentation debris had officially entered the SSN catalog in addition to the parent object. At the time of the event, the spacecraft had been on-orbit 7.2 years and was in a 4.7° inclination, 36137 by 35384 km orbit.

This spacecraft was the first launch of the People's Republic of China (PRC) *BeiDou* 2nd generation regional navigation satellites in the Compass Navigation Satellite System, and is sometimes labeled as "Beidou-2 G2" to indicate

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BeiDou Fragments

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2nd generation, 2nd Geosynchronous (GEO) spacecraft (the –G1 was launched in 2010). This designation ("G") identifies it as being apart from the PRC's middle Earth orbit (MEO, "M") or inclined GEO ("IG") spacecraft constellations. The spacecraft uses the Chinese Academy of Spacecraft Technology (CAST) Dong Fang Hong 3 (DFH-3) communication satellite-heritage bus with the specialized navigational payload. Publicly available sources suggest a dry mass on the order of 1100 kg. Stored energy sources may include stored chemical energy in batteries and residual liquid bipropellants.

As seen in Fig. 1, inclination maintenance of SSN# 34779 appears to have been abandoned in mid-May 2010. Inclination can be expected to evolve to a maximum of approximately 15° before decreasing back to 0° and repeating the cycle over a period of approximately 53 years.

Figure 2 indicates that East-West longitude control ended in early- to mid-September 2010. As can be seen, at that time the subsatellite longitude changed fundamentally to a drift state. Currently, the spacecraft remains oscillating in the east geopotential well centered around 75° East longitude with a period of approximately 2.73 years. Small velocity changes [1] are sufficient for resident objects to leave the well, suggesting that any debris created in this event may leave the well and eventually propagate throughout the GEO region.

A relatively significant amount of propellant may have remained onboard following GEO insertion due to this spacecraft's relatively short operational career of less than 1.4 years. The DFH-3 490 N liquid apogee engine is the Shanghai Institute of Space Propulsion FY-25 hypergolic bipropellant engine using monomethylhydrazine as the fuel and nitrogen tetroxide as the oxidizer. The smaller reaction control thrusters employ these hypergolic propellants in a unified propulsion system [2] but the actual equipment fit and propellant storage configuration is unknown at this time. The presence of significant hypergolic residual propellants aboard BeiDou G2 is a possible failure mode.

References

1. National Research Council (U.S.) Committee on Space Debris. Orbital Debris: a Technical Assessment. National Academy Press, Washington, D.C., p. 152, (1995).

2. Liangdong, L. and L. Guo. "Adavance [*sic*] of Chinese Spacecraft Control Technologies". In Automatic Control in Aerospace 2004, Vol. 1, Ed. A. Nebylov. Elsevier Ltd., Oxford, pp. 174-5, (2005). ♦

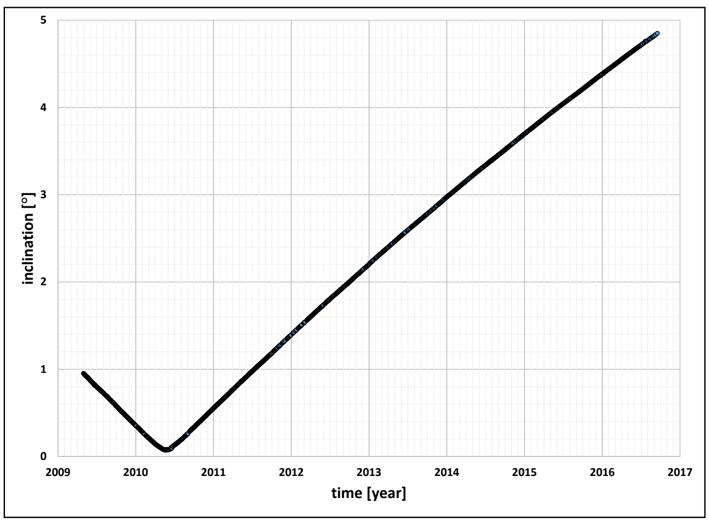

Figure 1. The inclination history of SSN# 34779 from launch to current date.

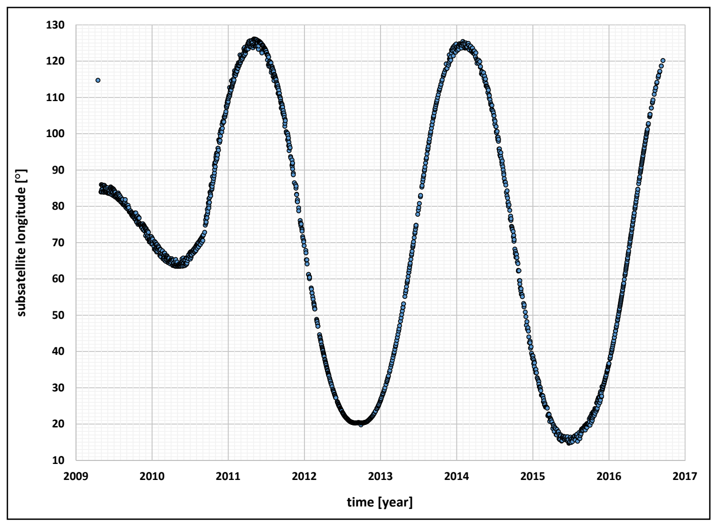

Figure 2. Subsatellite longitude history of SSN# 34779 from launch to current date.

WorldView 2 Spacecraft Fragments in July 2016

The WorldView 2 commercial Earth observation satellite, owned and operated by DigitalGlobe of Longmont, Colorado, USA, experienced a fragmentation event on 18 July 2016 at approximately 22:52 GMT. The object (International Designator 2009-055A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 35946) is based on the Ball Aerospace Ball Commercial Platform (BCP)-5000 bus and was operational at the time of the event. The spacecraft had been on-orbit over 6.7 years and was in a 98.5° inclination, 768 by 767 km orbit. Subsequent to the event, DigitalGlobe reported the spacecraft to be operational [1].

As of 8 September 2016, nine debris had officially entered the SSN catalog in addition to the parent object. All debris are in orbits similar to the parent object, with a maximum change in period of 0.8 minutes and change in inclination of 0.02°.

The figure on page 4 is the Gabbard plot for this event. The presence of debris in longer-period orbits is generally indicative of a fragmentation event, in contrast to debris shedding events, which create a debris ensemble characterized by shorter periods. In this case, a separation velocity of less than 3 m/s is consistent with the observed behavior of the longest-period debris object. At the current time, the cause of this event is unknown.

Reference

1. Gruss, M. "DigitalGlobe says WorldView-2 operational after 'debris caused event'". Space News online edition, 19 July 2016. Retrieved 1 October 2016. http://spacenews.com/u-s-air-force-digitalglobes-worldview-2-involved-in-debris-causing-event/ ♦

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WorldView2 Fragments

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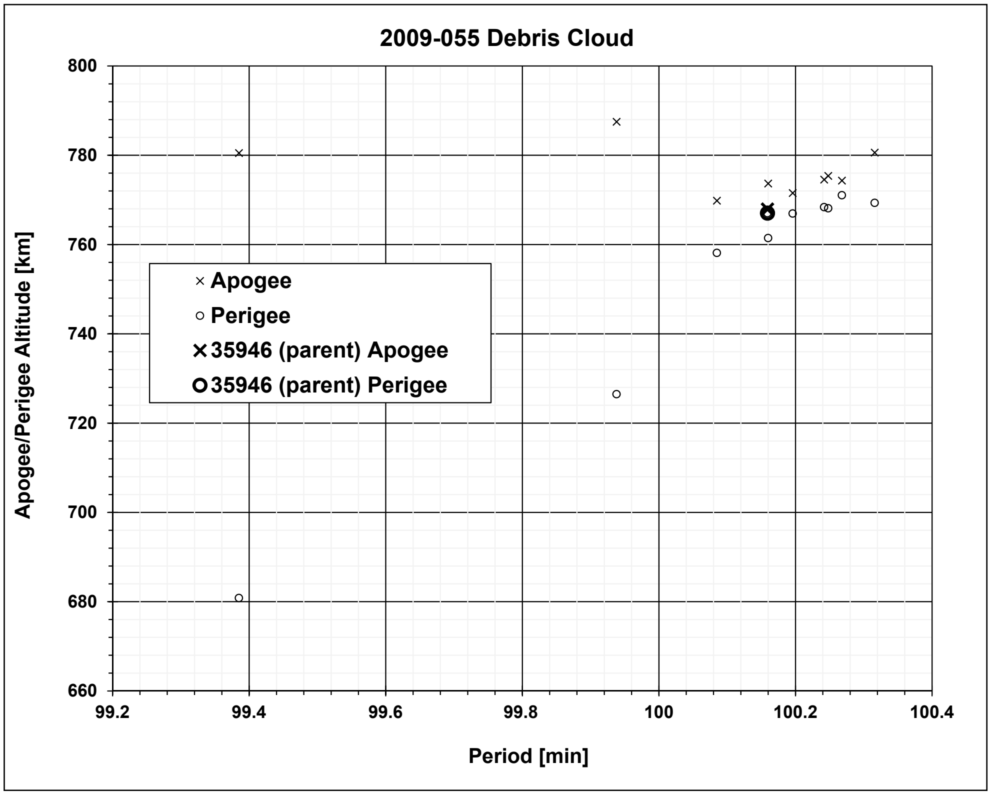

A Gabbard diagram for 2009-055 event-related objects.

DAS 2.0 NOTICE

Attention DAS 2.0 Users: an updated solar flux table is available for use with DAS 2.0. Please go to the Orbital Debris Website at https://www.orbitaldebris.jsc.nasa.gov/mitigation/das.html to download the updated table and subscribe for email alerts of future updates.

Indian RISAT-1 Spacecraft Experiences Possible Fragmentation

The Indian Radar Imaging Satellite (RISAT)-1 Earth observation satellite experienced a possible fragmentation event on 30 September 2016 between 2:00 and 6:00 GMT due to an unknown cause. The spacecraft (International Designator 2012-017A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 38248), operated by the Indian Space Research Organization (ISRO), carries a C-band microwave synthetic aperture radar. The spacecraft had been on-orbit 4.4 years and was in a 97.6° inclination, 543 by 539 km orbit at the time of the event. Stored energy sources include batteries and nine 11 N thrusters for orbit and attitude control.

No debris had entered the SSN catalog as of early October. ♦

Disposal of GOES-3

One of the longest operating satellites, Geostationary Operational Environmental Satellite 3 (GOES-3), completed its 38-year mission and conducted a series of disposal maneuvers to raise its orbit away from the geosynchronous (GEO) region in June. GOES-3 was designed and built by NASA for the National Oceanic and Atmospheric Administration (NOAA). It was launched in 1978 as a weather satellite, and then repurposed as a communications satellite for the National Science Foundation's (NSF) U.S. Antarctic Program in the late 1990s. Since GOES-3 was launched before the establishment of any orbital debris policy, it is not subject to the current orbital debris mitigation requirements. Nevertheless, the NSF project team was conscientious about the orbital debris issues before taking over the responsibility to operate GOES-3 and contacted NASA for reviews of the repurpose of the spacecraft and the eventual disposal plan.

The figure shows the disposal maneuvers in June of GOES-3 from the GEO altitude to the graveyard orbit. The NSF project team used the remaining fuel to move the spacecraft away from the GEO protection zone. The final perigee

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GOES-3

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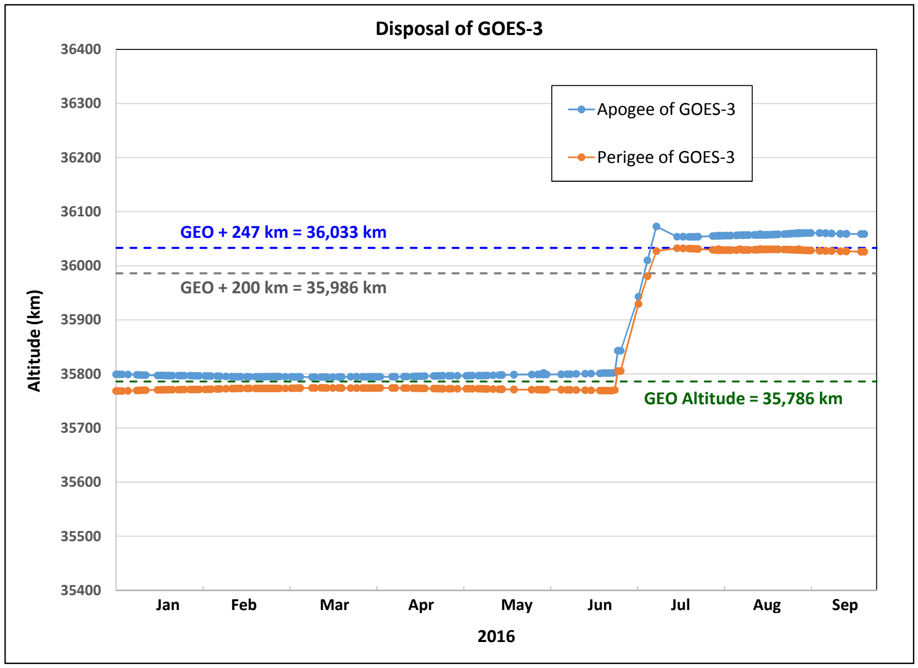
was above the GEO + 200 km requirement for NASA missions per NASA Technical Standard 8719.14A. The disposal perigee was also very close to 36,033 km, the minimum perigee altitude requirement (which depends on the area-to-mass ratio of the vehicle) specified in the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines. In addition, the final GOES-3 orbital eccentricity was about one order of magnitude below the IADC guidelines for GEO disposal. The NSF project and its supporting contractor teams and NOAA should be commended for their willingness to go above-and-beyond the original mission requirements to successfully dispose of GOES-3 to better preserve the GEO protection zone for future missions. ♦



Disposal of GOES-3. The apogee and perigee orbital data are provided by JSpOC.

UNCOPUOS Reaches Consensus on the First Set of Guidelines for the Long-term Sustainability of Outer Space Activities

During June 8-17, 2016, the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) held its annual meeting, the 59th session, in Vienna, Austria. The COPUOS is comprised of 83 Member States, including the addition of five Member States that joined the Committee in 2015: El Salvador, Israel, Oman, Qatar, Sri Lanka, and the United Arab Emirates. Dozens of organizations, including the European Space Agency, also attended the session as official observers. New Zealand submitted an application for COPUOS membership, which was endorsed by the Committee.

The Long-Term Sustainability of Outer Space Activities (LTS) Working Group (WG), established in 2010, held a 2-day intersessional meeting immediately before the COPUOS session and also held, on the margins of COPUOS, informal consultation meetings on a daily basis to continue developing an initial set of draft LTS guidelines for consideration by the Committee. After days of constructive efforts by the participating members, the WG was able to reach consensus on a first set of 12 LTS guidelines. Based on the recommendations of the WG, the Committee agreed to these 12 LTS guidelines and included them in the annex of the 2016 COPUOS report that is submitted to the UN General Assembly. The Committee also agreed to extend the mandate of the WG for two years, until 2018, to continue working on preamble text and additional proposed guidelines with the ultimate goal of completing a full compendium of LTS guidelines for agreement by the Committee and endorsement by the UN General Assembly at its 73rd session in 2018.

The first set of 12 LTS guidelines are as follows:

- Adopt, revise, and amend, as necessary, national regulatory frameworks for outer space activities
- Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities
- Supervise national space activities
- Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites
- Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
- Promote the collection, sharing and dissemination of space debris monitoring information
- Share operational space weather data and forecasts
- Develop space weather models and tools and collect established practices on the mitigation of space weather effects
- Promote and support capacity-building

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UNCOPUOS Guidelines

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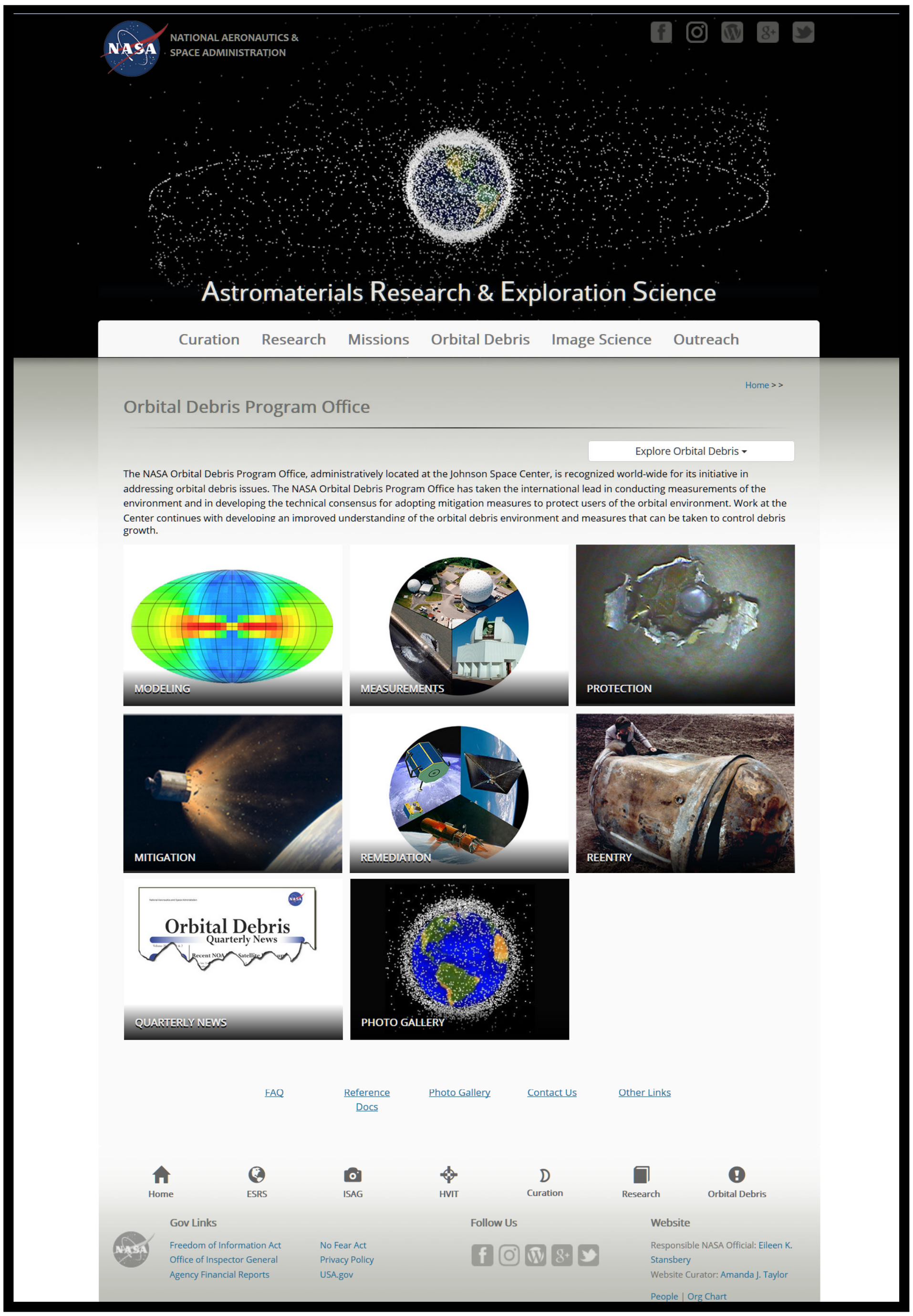
- Raise awareness of space activities
- Promote and support research on and the development of ways to support sustainable exploration and use of outer space
- Investigate and consider new measures to manage the space debris population in the long term.

Detailed narratives associated with each of these 12 LTS guidelines are available at the COPUOS website (http://www.unoosa.org/res/oosadoc/data/documents/2016/aac_1052016crp/aac_1052016crp_17_0_html/AC105_2016_CRP17E.pdf).

The completion of the first set of the LTS guidelines was a major achievement by the WG and the COPUOS Member States. These voluntary best-practice guidelines are ready for implementation by the international community to help ensure the safe and sustainable use of outer space for peaceful purposes, for the benefit of all countries. The LTS WG will continue its work on the preamble text and additional draft guidelines at a special week-long intersessional meeting in late September. ♦



Changes to the ODPO Website

The Orbital Debris Program Office (ODPO) website has a new look. Since the ODPO is part of the Astromaterials Research & Exploration Science (ARES) division at the NASA Johnson Space Center, the division name appears first when you enter the site (https://orbitaldebris.jsc.nasa.gov/). Words appearing directly below the division name lead to other areas within the ARES umbrella. However, when you use this URL, the page content is for ODPO, just as it was on the old site.

Navigate through the site by either selecting a tile or clicking on the arrow in the "Explore Orbital Debris" button above the tiles. Note that a few pages are available as links under the tiles: FAQ, Reference Docs, Photo Gallery, Contact Us, and Other Links. At the bottom of every page are a series of navigational icons that link to all of the ARES areas, including ODPO. Clicking on the Orbital Debris icon provides a quick return to the ODPO home page, without having to use the back arrow.

The Orbital Debris Quarterly News (ODQN) page (https://orbitaldebris.jsc.nasa.gov/quarterly-news/newsletter.html) remains virtually the same as its older version. An exception is the ODQN Subscription Form. Although still accessed through links in the text from the main ODQN page, the form itself now has a "CAPTCHA" field to control spam entries. Fields within the form highlighted in red text must be completed; black text signifies an optional field.

The website was updated to be more user friendly for mobile devices, and provide more security to our databases, such as the one for Orbital Debris Quarterly News subscribers. ♦

PROJECT REVIEW

International Space Station Debris Avoidance Process

BRYAN CORLEY, JSC FLIGHT OPERATIONS (GUEST AUTHOR)

Orbital debris presents one of the highest risks to the International Space Station (ISS) and its resident crewmembers. The ISS is just one of 23,000 objects currently tracked by the Space Surveillance Network (SSN) and a collision between one of these objects and the ISS could be catastrophic. The joint American and Russian flight control teams have been prepared to maneuver the ISS out of the way should the threat of a collision trigger a certain threshold since the launch of the first ISS module.

The first step in the process is detecting if there is a risk. The 18th Space Control Squadron (18SPCS) located at Joint Space Operations Center (JSpOC) Vandenberg Air Force Base routinely screens the ISS three times per day against the entire catalog of tracked space debris and notifies the ISS Trajectory Operations and Planning Officer (TOPO) if anything is predicted to pass within a ±2 (local vertical) x 25 x 25 (local horizontal) km volume within the next 72 hours. TOPO then uses data from the 18SPCS to compute the probability of collision (Pc), and based on a set of criteria, notifies the flight control teams in Houston and Moscow of the potential collision hazard. TOPO continues refining the Pc as new tracking information is received on both the ISS and the threat object. Flight rules govern when a Debris Avoidance Maneuver (DAM) should be performed to minimize the risk of a collision. The threshold for when to maneuver the ISS out of the way depends on what other activities are currently underway onboard the ISS or planned in the near future. For example, if a visiting vehicle such as a crewed Soyuz has launched and is inbound to arrive at the ISS, it takes a higher Pc (collision risk greater than 1 in 100) to warrant a DAM than if the ISS is in the middle of quiescent operations (collision risk greater than 1 in 100,000).

Over the years, many improvements have been implemented in the debris avoidance process. These range from improved coordination between the flight control teams in Houston and Moscow to improvements in the astrodynamics and risk assessment. One of the most dramatic improvements comes from reducing the amount of time it takes to plan and execute a DAM. A DAM is a small orbit raising (or lowering) maneuver that alters the ISS trajectory enough to reduce the risk of a given conjunction.

On the ISS, all the core propulsive capability is performed by the Russian segment controlled by Mission Control Center-Moscow (MCC-M). DAMs can be performed by Progress resupply vehicles or the ISS Service Module (SM) itself, depending on which ports are occupied (see Figure 1). The Automated Transfer Vehicle (ATV) was used as well when it was docked to the ISS. A Progress docked either to the SM aft or to the SM main engines are the typical methods to perform a DAM since the thrust axis is typically almost aligned with the velocity vector. Therefore, only a small attitude maneuver is needed prior to the DAM. In fact, at the expense of a little inefficiency, a dedicated attitude maneuver is not even required. A DAM can be performed from a Progress at either the Nadir or Zenith ports. This method uses different thrusters from the vehicles and requires an approximately 20-degree attitude maneuver (shown in Figure 2).

The original process required building a unique set of commands for each DAM. Once it was determined a DAM was needed, the joint Houston and Moscow trajectory teams discussed how large of a maneuver was required and when to burn it. Then MCC-Moscow flight controllers built a command script, called a "cyclogram," on the ground to be uplinked to the Russian segment of the ISS. The cyclogram was verified on the ground by running it through a test rig, which

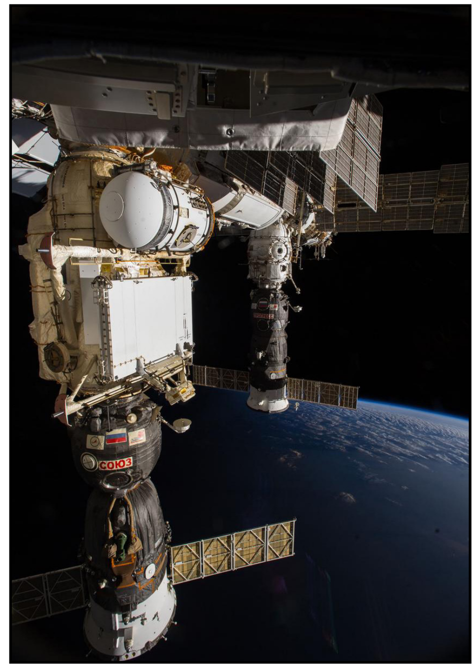


Figure 1. Earth Observation taken during a day pass by the Expedition 40 crew aboard the International Space Station (ISS). Docked Soyuz (foreground) and Progress (background) spacecraft are visible. (NASA photo ISS040e086771)

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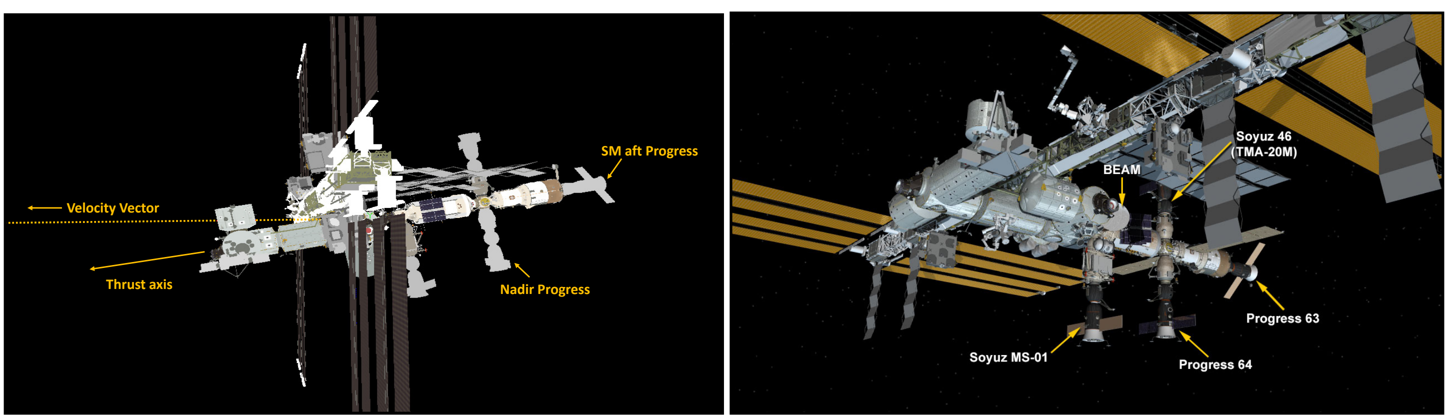

Figure 2. (left) The Torque Equilibrium Attitude (TEA) of the ISS showing the thrust axis with respect to the velocity vector. A docked Progress in both the nadir and aft positions is shown (model-produced graphic courtesy of Bryan Corley). (right) The current configuration of the ISS, with specific visiting vehicles identified, shows the capability to have several vehicles docked to the station simultaneously (NASA photo online at https://blogs.nasa.gov/spacestation/2016/07/).

ISS DAM

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could take a full day to complete. In parallel with the cyclogram build process, TOPO continued to evaluate the risk of collision, and if subsequent updates indicated the conjunction was no longer a concern, the flight control teams would jointly agree to stand down from any DAM preparation.

Objects in low-Earth orbit (LEO) near the ISS altitude regime of 400 km, where drag effects are relatively significant, can be difficult to predict. This meant that a DAM was often subsequently canceled once the risk subsided. Even more concerning, if a high risk conjunction notification came less than 24 hours until the Time of Closest Approach (TCA), there was no way for the ISS to get out of the way due to the lengthy planning process. For high concern events (collision risk greater than 1 in 10,000) without enough notice to perform a DAM, the ISS crew closed inter-module hatches and entered their respective Soyuz vehicles (safe haven) so they were best positioned to be able to depart the ISS and make it home in the event of a collision. Safe haven has been executed four times in the history of the ISS (see the table below for a complete safe haven history). As a result of the crew sheltering in March 24, 2012, the ISS Program requested an update to the onboard Russian software to allow for a quicker turn-around time to perform a DAM.

In late 2012, the Pre-determined Debris Avoidance Maneuvers (PDAM) capability became operational. PDAM is essentially a simplified version of a DAM cyclogram hard-coded onboard the Russian segment which will automatically perform the maneuver to the appropriate attitude, select the correct thrusters, and perform a 0.5 m/s PDAM exactly one hour after two commands are sent. These commands can be sent from the ground by MCC-Moscow or the crew. Adding some time to get the solar arrays appropriately positioned for the operation, it means a PDAM can be performed with as little notice as three hours. This eliminates much of the wasted effort preparing for false-alarm conjunctions and greatly reduces the likelihood of needing to perform safe haven. An enhancement to the onboard PDAM cyclogram added some flexibility by allowing selection of a few "canned" delta-velocity options (0.3, 0.5, 0.7, and 1.0) m/s. These options will assure a safe PDAM option can be found while minimizing operational consequences to the existing altitude strategy and planning of future visiting vehicles coming to or leaving the ISS.

Since the ISS was launched in 1998, it has performed 20 successful DAM or PDAMs. Four additional DAMs were performed by the Shuttle while it was docked to the ISS. While the addition of the PDAM capability does not affect the total number of DAMs expected to be performed by the ISS, it does make the planning and execution process much more efficient and tries to assure there will almost always be the capability to maneuver the ISS out of harm's way should it be required. PDAM is a critical evolution of the capability to ensure the ISS remains safe despite the ever-growing debris population in space. ♦

ISS Crew Safe Haven History

Date	Object Number	Object Name	Highest Risk (odds)	Final Miss (km)
03/12/09	25090	PAM-D Debris	1 in 4255	3.9
06/28/11	82618	Unknown	1 in 356	0.3
03/24/12	36546	COSMOS 2251 Debris	1 in 6369	16.5
07/16/15	36912	Meteor 5 Debris	1 in 870	2.4

CubeSat Post Mission Disposal by Drag Enhancement: an Operational Review

P. D. ANZ-MEADOR

A variety of post mission disposal (PMD) options are available to the CubeSat owner/operator community. One option is active or passive drag enhancement, differing only by whether the drag enhancement device can be manipulated, as sails can be reefed or oriented. This article examines the operational history of passive drag enhancement devices for CubeSat PMD and is motivated by prior work reported in ODQN articles (see ODQN, vol. 19, issues 3 and 4, July and October 2015, respectively).

While focused on the California Polytechnic State University's PolySat or Cal Poly 5 (CP5) (International Designator 2012-048F, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 38763), this work also uses the Aerospace Corporation's AeroCube 2 (2007-012R, SSN# 31133) and AeroCube 3 (2009-028E, SSN# 35005) CubeSats to provide a standard against which CP5 could be compared. All were built to the 1U CubeSat standard and were secondary payloads launched aboard Minotaur (AeroCubes) or Atlas aft-rack (CP5) deployers. The CanX-7 spacecraft, built to the 3U CubeSat standard and launched in September 2016, is of relevance but has too short an orbital history for inclusion in this study.

CP5 was a dedicated debris mitigation experiment whose goal was to demonstrate PMD by deploying a passive, spring-loaded, thin film drag enhancement device. Following launch on 13 September 2012, the deploy command was sent on 7 November 2012 with an acknowledgement packet received at 23:56:44 UTC that day. Contact with the CP5 ended shortly thereafter. AeroCube 2 was to deploy a square Kapton balloon (23 cm on edge), while AeroCube 3 was to deploy a 0.6-m diameter aluminized Mylar balloon [1]. Unfortunately, AeroCube 2 failed after one day on-orbit and did not deploy or inflate its balloon. The AeroCube 3 balloon deployed but did not inflate. However, enhanced drag was evident and shall be discussed [2].

Figure 1 depicts the evolution of the CP5 semimajor axis altitude. While a change in slope is readily apparent between 2014 and mid-2015, a comparison with observed solar activity suggests that the rate of change of semimajor axis is dependent on that solar activity. A change in decay rate on or about the deploy date is not evident.

The Two Line Element (TLE) set's canonical drag parameter, B*, was compared for CP5 and the AeroCubes. Figure 2 illustrates the time history of B*.

Unlike the CP5 experience, a secular change in B* for AeroCube 3 was observed within

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CubeSat PMD

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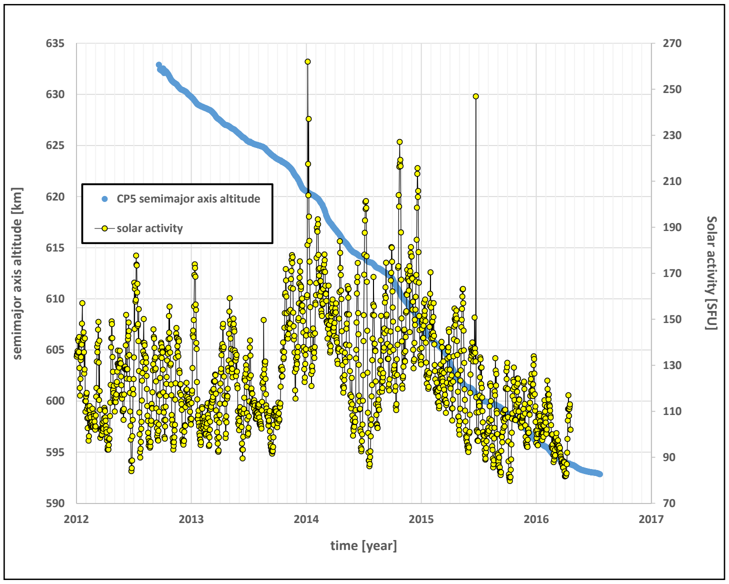

Figure 1. CP5 semimajor axis altitude compared to observed solar activity.

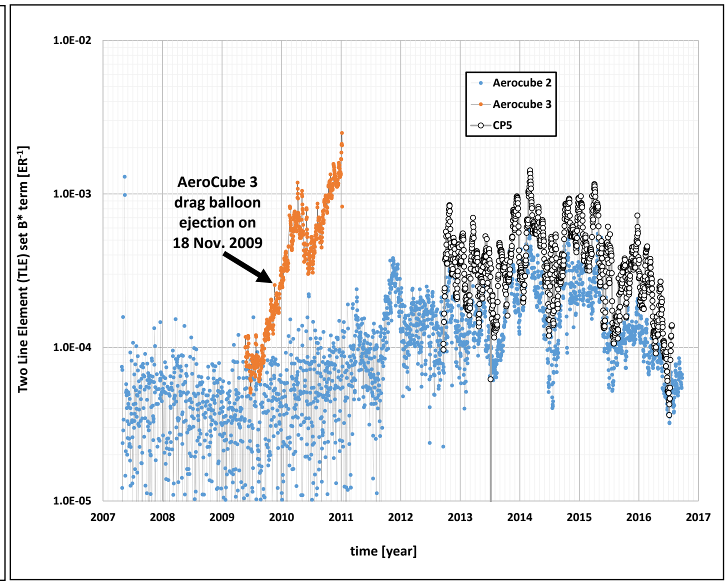

Figure 2. B time history for CP5 and AeroCubes 2 and 3. The AeroCube 3 history is consistent with that presented in Ref. 2. AeroCube 3 was launched to a much lower altitude than the other two spacecraft but this does not account for the secular growth of B* over time.*

days of the partially successful deployment on 18 November 2009. A comparison of AeroCube 2 and CP5 illustrates a high correlation with typical solar activity signatures, *e.g.*, the approximately 28-day solar rotation period. Therefore, like AeroCube 2, it is highly likely that the CP5 PMD device deployment was unsuccessful.

Given the limited operational success of this satellite ensemble, it is instructive to examine the projected orbital evolution of AeroCube 2 and CP5. This evolution is shown in Figure 3.

As seen in this figure, it is likely that CP5 will decay from orbit in late 2024. AeroCube 2, due to its higher initial altitude, is anticipated to decay in late 2047. CP5 will therefore inadvertently meet the 25-year rule, though its PMD device apparently did not deploy.

A fully successful demonstration of a passive PMD device for CubeSats remains to be seen. However, the effect of the partially successful deployment of the AeroCube 3 balloon is readily observable and suggests that passive PMD via drag enhancement is a viable option for CubeSat operators.

References

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2. Hinkley, D.A. “AeroCube 3 and AeroCube 4”. April 2010. Accessed 1 October 2016 at http://mstl.atl.calpoly.edu/~bklofas/Presentations/SummerWorkshop2012/Hinkley_AeroCube_3_4.pdf ♦

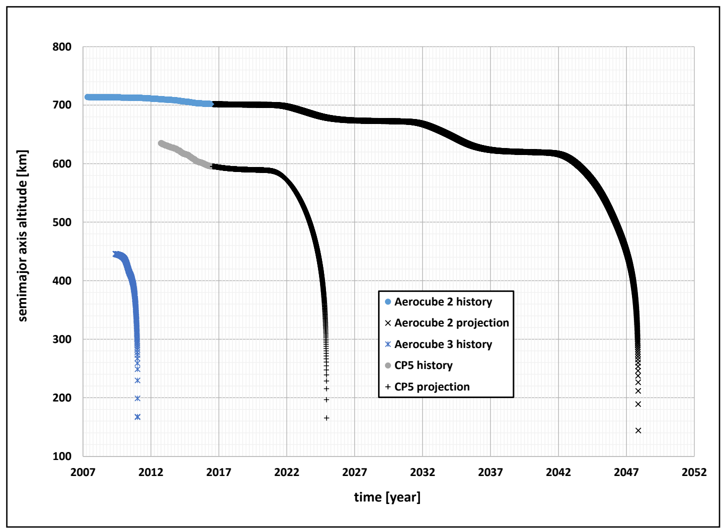

Figure 3. A comparison of the projected future evolution of the semimajor axis altitude for AeroCube 2 and CP5. The NASA Orbital Debris Program Office (ODPO) standard computer tools and models were used to estimate the historical area-to-mass ratio of these spacecraft and propagate them into the future. The latest Debris Assessment Software (DAS) solar activity file was used to model expected solar activity over the next five decades.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The 8th International Association for the Advancement of Space Safety (IAASS) Conference, 18-20 May 2016, Melbourne, Florida, USA

Statistical Issues for Calculating Reentry Hazards

J. BACON AND M. MATNEY

A number of statistical tools have been developed over the years for assessing the risk of reentering object to human populations. These tools make use of the characteristics (e.g., mass, shape, size) of debris that are predicted by aerothermal models to survive reentry. This information, combined with information on the expected ground path of the reentry, is used to compute the probability that one or more of the surviving debris might hit a person on the ground and cause one or more casualties.

The statistical portion of this analysis relies on a number of assumptions about how the debris footprint and the human population are distributed in latitude and longitude, and how to use that information to arrive at realistic risk numbers. This inevitably involves assumptions that simplify the problem and make it tractable, but it is often difficult to test the accuracy and applicability of these assumptions.

This paper builds on previous IAASS work to re-examine one of these theoretical assumptions. This study employs empirical and theoretical information to test the assumption of a fully random decay along the argument of latitude of the final orbit, and makes recommendations how to improve the accuracy of this calculation in the future. ♦

The SPIE Astronomical Telescopes and Instrumentation Conference, 26 June – 1 July, 2016, Edinburgh, Scotland, United Kingdom

The NASA/AFRL Meter Class Autonomous Telescope

H. COWARDIN, S. LEDERER, B. BUCKALEW, J. FRITH, P. HICKSON, T. GLESNE, P. ANZ-MEADOR, E. BARKER, G. STANSBERY, AND P. KERVIN

For the past decade, the NASA Orbital Debris Program Office (ODPO) has relied on using various ground-based telescopes in Chile to acquire statistical survey data as well as photometric and spectroscopic data of orbital debris in geosynchronous Earth orbit (GEO). The statistical survey data have been used to supply the Orbital Debris Engineering Model (ORDEM) v.3.0 with debris detections in GEO to better model the environment at altitudes where radar detections are limited. The data produced for the statistical survey ranged from 30 to 40 nights per year, which only accounted for ~10% of the possible observing time. Data collection was restricted by ODPO resources and weather conditions. In order to improve the statistical sampling in GEO, as well as observe and sample other orbits, NASA's ODPO with support from the Air Force Research Laboratory (AFRL), has constructed a new observatory dedicated to orbital debris – the Meter Class Autonomous Telescope (MCAT) on Ascension Island.

This location provides MCAT with the unique ability to access targets orbiting at an altitude of less than 1,000 km and low inclinations (< 20 deg). This orbital regime currently has little to no coverage by the U.S. Space Surveillance Network. Unlike previous ODPO optical assets, the ability to operate autonomously will allow rapid response observations of break-up events, an observing mode that was only available via radar tasking prior to MCAT's deployment.

The primary goal of MCAT is to statistically characterize GEO via daily tasking files uploaded from ODPO. These tasking files define which operating mode to follow, providing the field center, rates, and/or targets to observe over the entire observing period. The system is also capable of tracking fast-moving targets in low Earth orbit (LEO), middle Earth orbit (MEO), as well as highly eccentric orbits like geostationary transfer orbits.

On 25 August 2015, MCAT successfully acquired scientific first light, imaging the Bug Nebula and tracked objects in LEO, MEO, and GEO. NASA is working towards characterizing the system and thoroughly testing the integrated hardware and software control to achieve fully autonomous operations by late 2016.

This paper will review the history and current status of the MCAT project, the details of the telescope system, and its five currently manifested operating modes. ♦

Development of the NASA MCAT Auxiliary Telescope for Orbital Debris Research

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

The National Aeronautical Space Administration has deployed the Meter Class Autonomous Telescope (MCAT) to Ascension Island with plans for it to become fully operational by summer 2016. This telescope will be providing data in support of research being conducted by the Orbital Debris Program Office at the Johnson Space Center. In addition to the main observatory, a smaller, auxiliary telescope is being deployed to the same location to augment and support observations generated by MCAT. It will provide near-simultaneous photometry and astrometry of debris objects, independent measurements of the seeing conditions, and offload low priority targets from MCAT's observing queue. Its hardware and software designs are presented here. ♦

The Von Karman Institute for Fluid Dynamics Lecture Series, Space Debris Reentry and Mitigation, 12-16 September 2016, Belgium

Measuring Small Debris – What You Can't See Can Hurt You

M. MATNEY

While modeling gives us a tool to better understand the Earth orbit debris environment, it is measurements that give us "ground truth" about what is happening in space. Assets that can detect orbital debris remotely from the surface of the Earth, such as radars and telescopes, give us a statistical view of how debris are distributed in space, how they are being created, and how they are evolving over time. In addition, *in situ* detectors in space are giving us a better picture of how the small particle environment is actually damaging spacecraft today. In addition, simulation experiments on the ground help us to understand what we are seeing in orbit. This talk will summarize the history of space debris measurements, how it has changed our view of the Earth orbit environment, and how we are designing the experiments of tomorrow. ♦

Modeling of the Orbital Debris Environment Risks in the Past, Present, and Future

M. MATNEY

Despite the tireless work by space surveillance assets, much of the Earth debris environment is not easily measured or tracked. For every object that is in an orbit we can track, there are hundreds of small debris that are too small to be tracked but still large enough to damage spacecraft. In addition, even if we knew today's environment with perfect knowledge, the debris environment is dynamic and would change tomorrow. Therefore, orbital debris scientists rely on numerical modeling to understand the nature of the debris environment and its risk to space operations throughout Earth orbit and into the future. This talk will summarize the ways in which modeling complements measurements to help give us a better picture of what is occurring in Earth orbit, and helps us to better conduct current and future space operations. ♦

The 17th Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), 20-23 September 2016, Maui, Hawaii

NASA's Orbital Debris Optical and IR Ground-based Observing Program Utilizing the MCAT, UKIRT, and Magellan Telescopes

S. M. LEDERER, H. M. COWARDIN, B. BUCKALEW, J. FRITH, P. HICKSON, L. PACE, M. MATNEY, P. ANZ-MEADOR, P. SEITZER, E. STANSBERY, AND T. GLESNE

Characterizing debris in Earth-orbit has become increasingly important as the growing population of debris poses greater threats to active satellites each year. Currently, the Joint Space Operations is tracking > 23,000 objects ranging in size from 1-meter and larger in geosychronous orbits (GEO) to 10-cm and larger at low-Earth orbits (LEO). Model estimates suggest that there are hundreds of thousands of pieces of spacecraft debris smaller than 10 cm currently in orbit around the Earth. With such a small fraction of the total population being tracked, and new break-ups occurring from LEO to GEO, new assets, techniques, and approaches for characterizing this debris are needed.

With this in mind, NASA's Orbital Debris Program Office has actively tasked a suite of telescopes around the world. In 2015, the newly built 1.3-m optical Meter Class Autonomous Telescope (MCAT) came on-line on Ascension Island and is now being commissioned. MCAT is designed to track Earth-orbiting objects above 200 km, conduct surveys at GEO, and work with a co-located Raven-class commercial-off-the-shelf system, a 0.4-m telescope with a field-of-view similar to MCAT's and research-grade instrumentation designed to complement MCAT.

The 3.8-m infrared UKIRT telescope on Mauna Kea, Hawaii has been heavily tasked to collect data on individual targets and in survey modes to study both the general GEO population and a break-up event. Data collected include photometry and spectroscopy in the near-infrared (0.85 – 2.5 μm) and the mid-infrared (8-16 μm).

Finally, the 6.5-m Baade Magellan telescope at Las Campanas Observatory in Chile was used to collect optical photometric survey data in October 2015 of two GEO Titan transtage breakups, focusing on locations of possible debris concentrations as indicated by the NASA standard break-up model. ♦

The Population of Optically Faint GEO Debris

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

The 6.5-m Magellan telescope 'Walter Baade' at the Las Campanas Observatory in Chile has been used for spot surveys of the GEO orbital regime to study the population of optically faint GEO debris. The goal is to estimate the size of the population of GEO debris at sizes much smaller than can be studied with 1-meter class telescopes. Despite the small size of the field of view of the Magellan instrument (diameter 0.5-degree), a significant population of objects fainter than R = 19th magnitude have been found with angular rates consistent with circular orbits at GEO. We compare the size of this population with the numbers of GEO objects found at brighter magnitudes by smaller telescopes.

The observed detections have a wide range in characteristics starting with those appearing as short uniform streaks. But there are a substantial number of detections with variations in brightness, flashers, during the 5-second exposure. The duration of each of these flashes can be extremely brief: sometimes less than half a second. This is characteristic of a rapidly tumbling object with a quite variable projected size times albedo. If the albedo is of the order of 0.2, then the largest projected size of these objects is around 10-cm.

The data in this paper was collected over the last several years using Magellan's IMACS camera in f/2 mode. The analysis shows the brightness bins for the observed GEO population as well as the periodicity of the flashers. [*(ed.) Correlation with the catalog was attempted on all observed objects*]: the focus of the paper will be on the uncorrelated, optically faint, objects. The goal of this project is to better characterize the faint debris population in GEO that access to a 6.5-m optical telescope in a superb site can provide. ♦

Non-Resolvable SOI Working Group, 26-27 September 2016, Maui, Hawaii

Characterizing GEO Titan Transtage Fragmentations using Ground-based Measurements

H. COWARDIN AND P. ANZ-MEADOR

In a continued effort to better characterize the Geosynchronous Orbit (GEO) environment, NASA's Orbital Debris Program Office (ODPO) utilizes various ground-based optical assets to acquire photometric and spectral data of known debris associated with fragmentations in or near GEO. The Titan IIIC Transtage upper stage is known to have fragmented four times. Two of the four fragmentations were in GEO while a third Transtage fragmented in GEO transfer orbit. The forth fragmentation occurred in Low Earth Orbit.

In order to better assess what may be causing these fragmentations, the NASA ODPO recently acquired a Titan Transtage test and display article that was previously in the custody of the 309th Aerospace Maintenance and Regeneration Group (AMARG) in Tucson, Arizona. After initial inspections at AMARG demonstrated that the test article was of sufficient fidelity to be of interest, the test article was brought to JSC to continue material analysis and historical documentation of the Titan Transtage. The Transtage will be a subject of forensic analysis using spectral measurements to compare with telescopic data; as well, a scale model will be created to use in the Optical Measurement Center for photometric analysis of an intact Transtage, including a BRDF.

The following presentation will provide a review of the Titan Transtage, the current analysis that has been done to date, and the future work to be completed in support of characterizing the GEO and near GEO orbital debris environment. ♦

Infrared Studies of the Reflective Properties of Solar Cells and the HS376 Spacecraft

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

In 2015, a selection of HS-376 buses were observed photometrically with the United Kingdom Infrared Telescope (UKIRT) to explore relationships between time-on-orbit and Near Infrared (NIR) color. These buses were chosen because of their relatively simple shape, for the abundance of similar observable targets, and their surface material being primarily covered by solar cells. While the HS-376 spacecraft were all very similar in design, differences in the specific solar cells used in the construction of each model proved to be an unconstrained variable that could affect the observed reflective properties.

In 2016, samples of the solar cells used on various models of HS-376 spacecraft were obtained from Boeing and were analyzed in the Optical Measurements Center at the Johnson Space Center using a visible-near infrared field spectrometer. The laboratory-based spectra are convolved to match the photometric bands previously obtained using UKIRT and compared with the on-orbit photometry. The results and future work are discussed here. ♦

The 67th International Astronautical Congress (IAC), 26-30 September 2016, Guadalajara, Mexico

DebriSat Fragment Characterization System and Processing Status

M. RIVERO, B. SHIOTANI, M. CARRASQUILLA, N. FITZ-COY, J.-C. LIOU, M. SORGE, T. HUYNH, J. OPIELA, P. KRISKO, AND H. COWARDIN

The DebriSat project is a continuing effort sponsored by NASA and DOD to update existing break-up models using data obtained from hypervelocity impact tests performed to simulate on-orbit collisions. After the impact tests, a team at the University of Florida has been working to characterize the fragments in terms of their mass, size, shape, color and material content. The focus of the post-impact effort has been the collection of 2 mm and larger fragments resulting from the hypervelocity impact test. To date, in excess of 125K fragments have been recovered which is approximately 40K more than the 85K fragments predicted by the existing models. While the fragment collection activities continue, there has been a transition to the characterization of the recovered fragments. Since the start of the characterization effort, the focus has been on the use of automation to (i) expedite the fragment characterization process and (ii) minimize the effects of human subjectivity on the results; e.g., automated data entry processes were developed and implemented to minimize errors during transcription of the measurement data. At all steps of the process, however, there is human oversight to ensure the integrity of the data. Additionally, repeatability and reproducibility tests have been developed and implemented to ensure that the instrumentations used in the characterization process are accurate and properly calibrated. ♦

ABSTRACT FROM THE NASA HVIT GROUP

American Institute of Aeronautics and Astronautics (AIAA) 2016 Annual Technical Symposium, 6 May 2016, NASA JSC, Houston, Texas, USA

The Orion Exploration Flight Test Post Flight Solid Particle Flight Environment Inspection and Analysis

J. MILLER, HYPERVELOCITY IMPACT TECHNOLOGY (HVIT) GROUP

Orbital debris in the millimeter size range can pose a hazard to current and planned spacecraft due to the high relative impact speeds in Earth orbit. Fortunately, orbital debris has a relatively short life at lower altitudes due to atmospheric effects; however, at higher altitudes orbital debris can survive much longer and has resulted in a band of high flux around 700 to 1,500 km above the surface of the Earth. While large orbital debris objects are tracked via ground based observation, little information can be gathered about small particles except by returned surfaces, which until the Orion Exploration Flight Test number one (EFT-1), has only been possible for lower altitudes (400 to 500 km). The EFT-1 crew module backshell, which used a porous, ceramic tile system with surface coatings, has been inspected post-flight for potential micrometeoroid and orbital debris (MMOD) damage. This paper describes the pre- and post-flight activities of inspection, identification and analysis of six candidate MMOD impact craters from the EFT-1 mission. ♦

CONFERENCE AND MEETING REPORTS

NASA-DOD Working Group 2016, 11 July 2016, NASA Johnson Space Center

The annual NASA-DOD Orbital Debris Working Group (ODWG) meeting was held July 11, 2016. This annual 1-day meeting reviews activities and research in orbital debris (OD) of mutual interest to both NASA and the 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 was co-chaired by Mr. Gene Stansbery, Program Manager of NASA's Orbital Debris Program Office (ODPO) and Mr. Tim Payne, Chief, Operational Assessments Division, HQ Air Force Space Command A2/3/6Z.

During the meeting, NASA and DOD each made five presentations and one special topic was discussed. NASA Chief Scientist for Orbital Debris, Dr. J-C Liou, discussed the status and recent activities from the Inter-Agency Space Debris Coordination Committee (IADC) and debris-related issues from the United Nations/Committee on the Peaceful Uses of Outer Space. Joe Hamilton provided a summary of the Space Debris Sensor (SDS), which is a Debris Resistive/Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS) to be mounted on the International Space Station (ISS) in 2017/18. This sensor will measure size, mass, and orbital parameters of small debris up to sizes of about 0.5 mm.

Mark Matney then presented the results of a study of the long-term debris population under different traffic models of CubeSat deployments. The study shows that even under aggressive traffic scenarios, as long as CubeSats adhere to current orbital debris mitigation practices, especially post-mission disposal, the debris population stays within reasonable levels (compared to baseline projections) during the next 200 years.

Mr. John Opiela then presented status and plans for continued analysis of the DebriSat fragments. 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 120,000 fragments had been recovered. The fragments are being extracted, measured, and weighed by students at the University of Florida.

Dr. Sue Lederer presented the status of the new Meter-Class Autonomous Telescope located on Ascension Island. The telescope is a collaboration between NASA and the AFRL. The DOD showed great interest in receiving data from the telescope and in possibly tasking the telescope for some observations. It was suggested that a sub-working group be formed of the interested parties to discuss data sharing.

Following the NASA presentations, Mr. Doug Moffitt, AFSPC/A2/3/6S, presented the status and plans for the Space Surveillance Network (SSN). The SSN maintains the catalog of resident space objects and provides data for conjunction warnings with operational satellites. Of particular interest were instruments planned for SSN inclusion in the near future: the Space Surveillance Telescope and the Space Fence radar.

Mr. Gary Wilson, AFSPC/A5CS, followed up with a presentation dedicated to plans for the Space Fence. The first element of the Space Fence is currently under construction on Kwajalein Atoll in the Pacific Ocean. The Space Fence is designed to discover and track objects as small as 2 cm at ISS altitudes. Continuing the Space Fence theme, Dr. Matthew McHarg from the U.S. Air Force Academy presented plans to launch a CubeSat from the ISS that will deploy two calibration spheres, one 2-cm and one 4-cm diameter sphere, designed to verify the performance goals of the Space Fence. The consortium of groups funding and working on the project, designated the Falcon ODE (Orbital Debris Experiment), includes NASA's ODPO.

Mr. Shane Cowen, 614 AOC/SSD, presented DOD efforts to mitigate the number of SSN tracked objects that have been "lost." The lost list includes orbital objects that are in the official SSN catalog as well as "analyst" satellites. The lost list is important since lost objects cannot be included in conjunction screening. Satellites, including debris, are lost for a number of reasons including gaps in SSN coverage. Although the list continues to grow over time, the growth has slowed.

The number of cataloged objects continues to grow. The original numbering system is expected to be outgrown at some point in the near future, especially with the inclusion of the SST and the Space Fence to the SSN. Orbital elements are transmitted in a format designated as the two-line element (TLE), but this format will not be able to accommodate the new numbering system. Therefore, DOD is planning on implementing a new format utilizing three lines. Plans for the new format were presented by Lt Col Kim Gonzalez, AFSPC/A2/3/6Z.

The final topic of the Working Group was a discussion about differences in the methods used to calculate the reliability of upper stages for accidental explosions. The different results create confusion about the ability of these stages to meet orbital debris mitigation standards. Bart Lundblad and Marlon Sorge from The Aerospace Corporation presented some information on the DOD process. A follow-on meeting on this topic is scheduled for November. ♦

The 67th International Astronautical Congress (IAC), 26-30 September 2016, Guadalajara, Mexico

The 67th International Astronautical Congress (IAC) was held in Guadalajara, the second largest city in Mexico, on 26-30 September 2016. This year's congress, with a theme of "Making Space Accessible and Affordable to All Countries," was hosted by the Mexican Space Agency (AEM) and attracted more than 3000 attendees from the global aerospace community, including many government, industrial, academia, research, and media organizations.

Just like the previous IACs, the International Academy of Astronautics (IAA) organized the Symposium on Space Debris during the congress. It was one of the top and best attended symposiums during the event. The Space Debris Symposium consisted of nine oral presentation sessions and one interactive session. They covered the full spectrum of activities on space debris, ranging from measurements, modeling, risk assessments, orbit determination, hypervelocity impact and protection, and mitigation, to active debris removal, space situational awareness, and policy and legal challenges. A total of 73 papers were presented during the 9 sessions, representing the community's latest efforts to better characterize the space debris populations, model the current and future environment, improve mitigation compliance, explore innovative concepts and technologies for remediation, and address the policy and legal aspects of environment management.

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The 67th IAC

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A special plenary session dedicated to "Orbital Debris Environment in the Light of the Planned Mega-Constellation Deployments" also took place during the IAC. It was moderated by Professor Heiner Klinkrad, former Head of the ESA Space Debris Office and currently an Honorary Professor at the Institute of Space Systems of the Technical University of Braunschweig. The panelists included Dr. J.-C. Liou, NASA Chief Scientist for Orbital Debris; Dr. Holger Krag, Head of the ESA Space Debris Office; Dr. Tim Maclay, OneWeb Mission Systems Engineering Director; and Professor Stephan Hobe, Head of the Institute of Air- and Space-Law at the University of Cologne. This plenary highlighted the community's need to take preventative measures to protect the environment while continuing to use near Earth space for global telecommunications. To further the dialogues between the space debris and the small satellite communities, a potential joint session between the Symposium on Space Debris and the Symposium on Small Satellite Missions at the 68th IAC is being discussed by the symposium coordinators. ♦

The 17th Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference 20-23 September 2016, Maui, Hawaii

The 17th Advanced Maui Optical and Space Surveillance Technologies Conference was held 20-23 September. This year's conference was reported to have the largest turnout of attendees with 17 participating countries. Opening keynote speakers were Major General David D. Thompson, Vice Commander from the Air Force Space Command and Douglas L. Loverro, Deputy Assistant Secretary of Defense for U.S. Space Policy, U.S. Department of Defense. Maj. General Thompson discussed how the Space Enterprise Vision is focusing on command and control and space situational awareness to avoid conflict in space. Mr. Loverrro described the space environment as being competitive, congested, and contested. Three major tasks for remediation were outlined that included: (1) more precision on object tracking for collision avoidance, (2) active management of objects as a national issue, rather than solely relegated to the Department of Defense, and (3) reviewing the rules and implementation for objects in space, specifically the 25 year de-orbit criteria.

Eight papers were presented during the Orbital Debris Session, which was co-chaired by Tim Flohrer (ESA/ESOC Space Debris Office) and Thomas Schildknecht (Astronomical Institute University of Bern). The first session speaker, Dr. Susan Lederer (NASA\ODPO), discussed NASA's optical and infrared ground-based optical telescopes used for orbital debris observations, which include MCAT, UKIRT and Magellan. Dr. Pat Seitzer (University of Michigan) then presented a summary of the Magellan observations used to detect the faint debris population in GEO. Next, Thomas Schildknecht presented his work on observing the Briz-M fragmentation debris in GEO. Mark Shappirio (NASA\GSFC) discussed work done using satellite laser ranging techniques in support of space situational awareness. Ben Greene (Space Environmental Research Centre-Australia) delivered a proposal for space environment management using optical techniques. Next, Matthew Bold (Lockheed Martin Space Systems) presented on work done by the Space Environment Research Centre in Australia using lasers to remotely maneuver space debris. Craig Benson (UNSW Canberra-Australia) discussed using GPS satellites as bistatic radars to track low Earth orbit space debris. Finally, the last paper in the session by Masahiko Uetsuhara (Astroscale-Singapore), discussed work on IDEA OSG 1, which tracks sub-millimeter size debris.

A second set of keynote speakers presented on Thursday, including Frank Rose, Assistant Secretary of State for Arms Control, Verification, and Compliance, U.S. Department of State; and Atsushi Saito, Director of Space Policy Division, concurrently Senior Negotiator for International Security Affairs, National Security Policy Division and Director of Cyber Security Policy Division, Foreign Policy Bureau, Ministry of Foreign Affairs, Japan.

Following several Space Situational Awareness policy forum discussions, Dr. Lederer co-chaired the Instrumentation and Optical Surveillance Session with Mark Ackerman. The talks focused on GEO measurements, characterization, and ground-based measurements of GEO satellites; active debris removal; tracking debris with ground-based lasers; upgrades to the GEODSS network; and improving networks for ground-based systems in support of space situational awareness.

The last day of the conference began with the final keynote speaker, Professor Jordi Puig-Suari with Cal Poly State University, CubeSat Program and also CEO of Tyvak Nano-Satellite Systems, Inc. Another round of SSA Policy forum discussions commenced, followed by two sessions focused on astrodynamics and non-resolved object characterization.

Following the AMOS conference, the Non-Imaging Space Object Identification Workshop, hosted by Paul Kervin (AFRL), was held over a two-day span. Two presentations from ODPO were delivered: "*Characterizing GEO Titan Transtage Fragmentations Using Ground-based Measurements*" by Dr. Heather Cowardin and "*Infrared Studies of the Reflective Properties of Solar Cells and the HS376 Spacecraft*" by Dr. James Frith. ♦

30th Anniversary of Delta 180 Intercept Mission

The 30th anniversary of the launch and interception test event of USA-19 was noted on 5 September 2016. Also known as Delta 180 (the Delta booster family launch sequence) or Vector Sum, the SDIO Program name, this U.S. Strategic Defense Initiative Organization (SDIO)-sponsored test was the first powered space interception. The payload (USA-19, International Designator 1986-069A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 16937) and Delta 3920 second stage (USA-19 R/B, 1986-069B, SSN# 16938) performed a series of technical and scientific experiments before colliding at low altitude over the Kwajalein Missile Range [1].

Following on 1985's destruction of the P-78 spacecraft by an air-launched Anti-Satellite (ASAT) interceptor (ODQN, vol. 19, issue 4, October 2015, pp. 4-6), the USA-19 mission was specifically tailored to be Anti-Ballistic Missile Treaty compliant and to minimize the post-event debris hazard. SDIO safety guidelines required all debris produced in the event to reenter within 90 days. Modeling conducted by the NASA Orbital Debris Program Office

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Delta 180

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indicated that this would be the case, with the exception of an on-board fragmentation warhead's energetic debris. The fragmentation case was removed by SDIO management to eliminate this exception. The results of the tests, as compared to those of the P-78 interception test, provided the basis of the U.S. Government's position on future space tests. The Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guideline 5.2.3 "Avoidance of intentional destruction and other harmful activities," specifically "… intentional break-ups should be conducted at sufficiently low altitudes so that orbital fragments are short lived." is consistent with this position.

Testing of military and dual-use technology was and remains an important motivation for space flight. Intercept tests in particular have a long history, whether consisting of targeting a virtual point in space, a fly-by of a satellite target, or a hit-to-kill kinetic interception event; these latter have had the potential to significantly alter the debris environment in the long term. The USA-19 flight planning reflected a responsible program management team and a critical understanding of the debris environment and the hazard it poses to manned and unmanned spaceflight in a much more benign space environment than that of today.

Reference

1. Griffin, M.D. and M.J. Rendine. "Delta 180/Vector Sum: The First Powered Space Intercept". Paper AA-88-0161 presented at the AIAA 26th Aerospace Sciences Meeting, Reno, NV, 11-14 January 1988. ♦

UPCOMING MEETINGS

5-9 February 2017: 27th AAS/AIAA Space Flight Mechanics Meeting, San Antonio, Texas

The American Astronautical Society and the American Institute of Aeronautics and Astronautics (AIAA) will jointly sponsor the 27th AAS/AIAA Space Flight Mechanics Meeting in San Antonio, Texas, USA. This conference will feature sessions on various technical orbital debris topics, including orbit determination and space-surveillance tracking, orbital debris and the space environment, satellite constellations, and Space Situational Awareness, Conjunction Analysis, and collision avoidance. Additional information about this conference is available at http://www.space-flight.org/docs/2017_winter/2017_winter.html.

18-21 April 2017: 7th European Conference on Space Debris, Darmstadt, Germany

The European Space Agency's European Space Operations Center, Darmstadt, Germany, will host the 7th European Conference on Space Debris. This quadrennial event will address all fundamental, technical areas relevant to the orbital debris community, including radar, optical, and in situ measurements; space surveillance and catalogues; orbit prediction and determination; operational collision avoidance; debris environment modeling and prediction; on-orbit risk and reentry risk assessments; debris mitigation techniques and processes; active debris removal and environmental remediation concepts; proposed mega-constellation and their environmental impact; hypervelocity impacts and protection; and standardization, policies, and regulation. Abstract submission deadline is 22 November 2016. Additional information about this conference is available at https://conference.sdo.esoc.esa.int/page/welcome.

24-28 April 2017: 14th Hypervelocity Impact Symposium, Canterbury, United Kingdom

The University of Kent, Canterbury, United Kingdom, will host the 14th Hypervelocity Impact Symposium. This event will cover a broad range of technical areas relevant to the orbital debris community, including Hypervelocity Phenomenology Studies, Spacecraft Meteoroid/Debris Shielding and Failure Analyses, Fracture and Fragmentation, Theoretical/Applied Mechanics Relevant to Hypervelocity Impact. Abstract submission deadline is 18 November 2016. Additional information about the symposium is available at http://astro.kent.ac.uk/~mcp2/HVIS2017/.

5-10 August 2017: 30th Annual Small Satellite Conference, Logan, Utah, USA

Utah State University (USU) and the AIAA will sponsor the 30th Annual AIAA/USU Conference on Small Satellites at the university's Logan campus, Utah, USA. Abstract submission deadline is 9 February 2017. Additional information about the conference is available at https://smallsat.org/conference/dates.

25-29 September 2016: 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. Abstract submission eadline for the congress is 28 February 2017. Additional information for the 2017 IAC is available at: http://www.iac2017.org/.

SATELLITE BOX SCORE

(as of 4 October 2016, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	220	3562	3782
CIS	1509	4845	6354
ESA	69	54	123
FRANCE	62	467	529
INDIA	71	114	185
JAPAN	155	90	245
USA	1387	4312	5699
OTHER	784	116	900
TOTAL	4257	13560	17817

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

1 July 2016 – 30 September 2016

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2016-044A	SOYUZ MS-01	RUSSIA	400	409	51.6	1	0
2016-045A	PROGRESS MS-03	RUSSIA	400	409	51.6	1	0
2016-046A	DRAGON CRS-9	USA	391	395	51.6	0	2
2016-047A	USA 269	USA	NO ELEMS. AVAILABLE			0	0
2016-048A	TIANTONG-1 1	CHINA	35772	35800	4.9	1	0
2016-049A	GAOFEN 3	CHINA	750	752	98.4	1	0
2016-050A	JCSAT 16	JAPAN	35778	35795	0.0	1	0
2016-051A	QSS	CHINA	484	506	97.4	0	0
2016-051B	3CAT-2	SPAIN	483	506	97.4		
2016-051C	LX-1	CHINA	123	132	97.4		
2016-052A	USA 270	USA	NO ELEMS. AVAILABLE			1	0
2016-052B	USA 271	USA	NO ELEMS. AVAILABLE				
2016-053A	INTELSAT 36	INTELSAT	EN ROUTE TO GEO			1	1
2016-053B	INTELSAT 33E	INTELSAT	EN ROUTE TO GEO				
2016-054A	INSAT 3DR	INDIA	EN ROUTE TO GEO			1	0
2016-055A	OSIRIS-REX	USA	HELIOCENTRIC ORBIT			0	0
2016-056A	OFEQ 11	ISRAEL	375	536	142.0	1	0
2016-057A	TIANGONG-2	CHINA	381	390	42.8	1	5
2016-067KH	FLOCK 2EP 13	USA	396	408	51.6	0	0
2016-067KJ-KQ	(7 additional FLOCK 2EP)						
2016-058A	PERUSAT 1	PERU	697	699	98.2	0	1
2016-058B	SKYSAT C4	USA	501	503	97.4		
2016-058C	SKYSAT C5	USA	501	503	97.4		
2016-058D	SKYSAT C2	USA	499	502	97.4		
2016-058E	SKYSAT C3	USA	500	503	97.4		
2016-059A	PRATHAM	INDIA	661	707	98.2	1	1
2016-059B	OBJECT B	(TBD)	661	705	98.2		
2016-059C	OBJECT C	(TBD)	661	704	98.2		
2016-059D	OBJECT D	(TBD)	648	658	98.2		
2016-059E	ALSAT 2B	ALGERIA	661	703	98.2		
2016-059F	CANX-7	CANADA	661	702	98.2		
2016-059G	ALSAT 1N	ALGERIA	661	699	98.2		
2016-059H	SCATSAT 1	INDIA	718	733	98.2		