National Aeronautics and Space Administration

Orbital Debris Quarterly News

Volume 19, Issue 4
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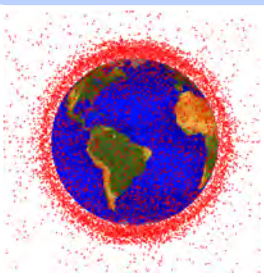
Inside...



A publication of the NASA Orbital Debris Program Office

Two More Collision Avoidance Maneuvers for the International Space Station

The 24th and 25th collision avoidance maneuvers in the history of the International Space Station (ISS) were performed this quarter. These were the 3rd and 4th of this calendar year.

The first maneuver this quarter was performed for a conjunction with a debris fragment from Iridium 33 (International Designator 1997-051EY, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 34356). The fragment was created during the February 2009 accidental collision between Cosmos 2251 and Iridium 33 (ODQN, vol. 13, issue 2, April 2009, pp. 1-2). The debris fragment was experiencing much higher drag than the ISS. Due to the high drag profile, the debris was not a concern until less than 8 hours prior to the time of closest approach. The probability of collision exceeded the red threshold for a maneuver before the initiation of the pre-determined avoidance maneuver (PDAM) on 26 July at 03:48 GMT, as shown in Fig. 1. The 0.5 m/s maneuver was executed using thrusters from the Progress 58P visiting vehicle. An update using additional tracking data from the SSN was received within a few minutes of the initiation of the PDAM, which showed that the probability of collision had fallen to acceptable levels. However, at that time the ISS was already under thruster control for attitude which could perturb the trajectory, making the risk unknown. Since there were no major consequences in performing the burn, the maneuver sequence was continued.

At the time of the second maneuver, flight controllers were tracking two potential conjunctions approximately 6 hours apart in time. Fig. 2 depicts the encounter geometry. Both objects were debris fragments. The first fragment (International Designator 1994-029AGH, USSTRATCOM SSN catalog number 40241) was created from the Hydrazine Auxiliary Propulsion System (HAPS) Pegasus fragmentation from June 1996 (ODQN, vol. 1,

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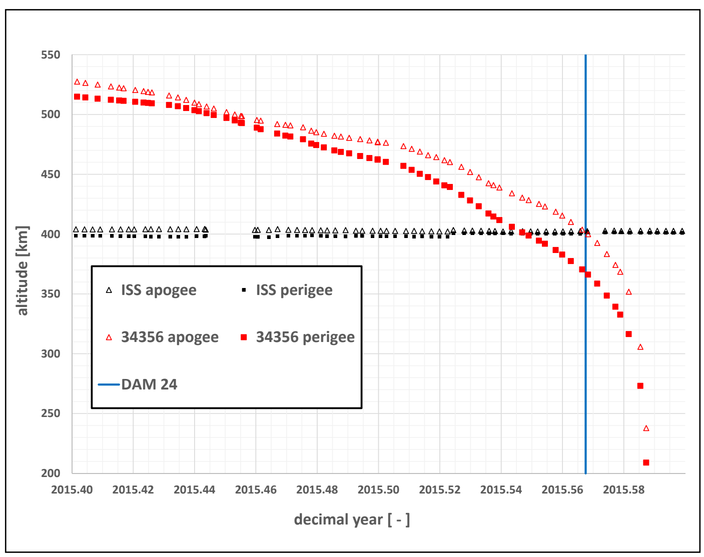

Figure 1. A view of the ISS (SSN 25544, Zarya)-34356 encounter geometry. Note the apogee of 34356 had almost cleared the ISS orbit at the time of the PDAM.

Collision Avoidance Maneuvers

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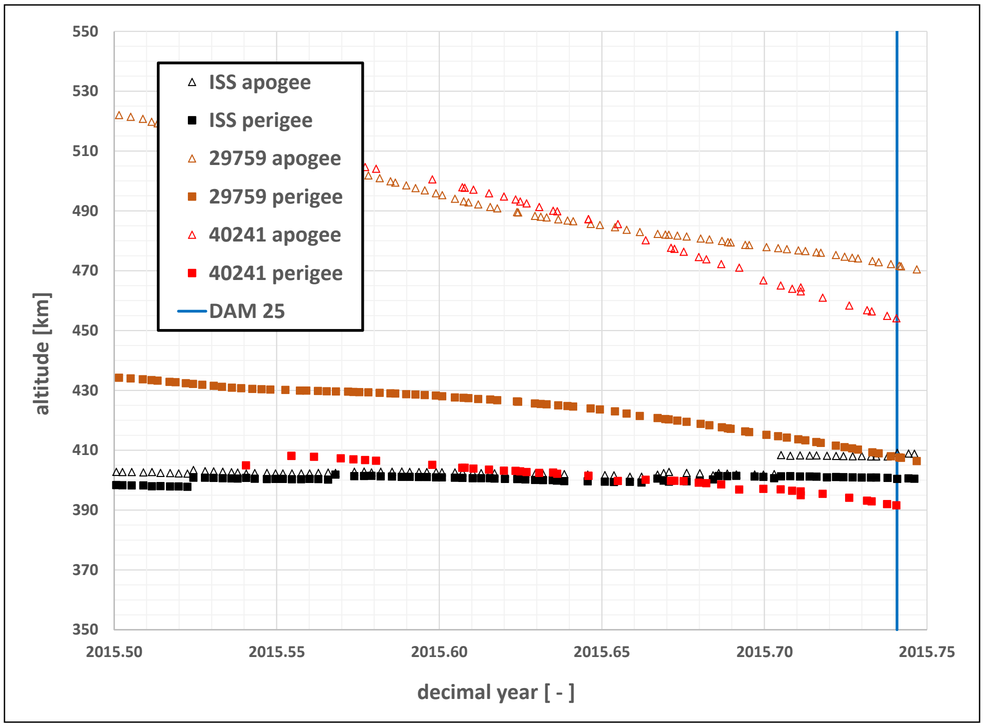


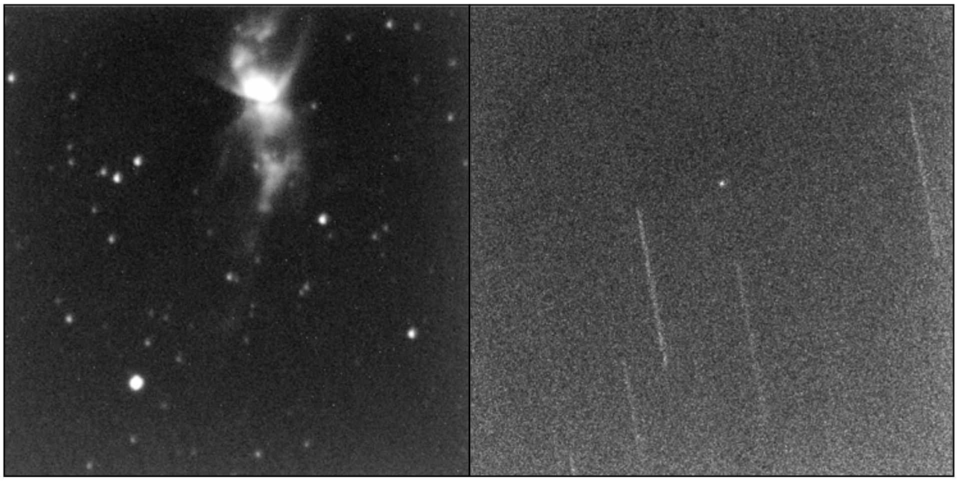
Figure 2. A view of the ISS-debris encounter geometry that prompted PDAM-25.

issue 2, September 1996, pp. 2, 11). Until the Chinese ASAT test in 2007 and the Iridium/Cosmos collision in 2009, the HAPS rocket body explosion had produced the largest number of SSN trackable breakup debris despite the stage's relatively small size.

The second debris piece being tracked was from the Chinese ASAT test target, Fengyun-1C (International Designator 1999-025AZ, USSTRATCOM SSN catalog number 29759) (ODQN, vol. 11, issue 2, April 2007, pp. 2-3). The probability of collision for conjunction with the Fengyun debris was below the threshold for performing a maneuver; however, the HAPS Pegasus debris probability exceeded the red threshold requiring a maneuver. The 0.3 m/s PDAM was performed on 27 September at 9:06 GMT using thrusters from a Progress resupply vehicle. ♦

MCAT Achieves Second First Light (a.k.a. Science First Light)

On 25 August 2015, "scientific first light" was achieved with the 1.3 m Meter Class Autonomous Telescope (MCAT) on Ascension Island when the first digital images were captured with a science-grade optical CCD camera. A fast-readout Finger Lakes Instrumentation (FLI) camera was employed to image the first astronomical object, NGC 6302, a southern hemisphere planetary nebula known as the Bug Nebula (see figure). This follows the successful deployment and MCAT's "engineering first light" on 2 June 2015, when the first photons of light were captured by human eye through an eyepiece, and has ushered in a new era of optical research by the NASA Orbital Debris Program Office's (OPDO) Optical Measurements Group.



First light images from MCAT with the Finger Lakes Instrumention Microline ML1050 camera. On the left, NGC 6302, the Bug Nebula, a southern hemisphere planetary nebula. On the right, Geostationary Operational Environmental Satellite 4 (GOES 4). Images were acquired through non-photometric conditions.

Situated at what was once a geographic blind-spot for ground-based telescopes employed by the U.S. to track debris, MCAT resides at an ideal location for sampling low-inclination, low Earth orbits (LILO). With a fast-tracking, 1.3 m DFM telescope and equally fast-tracking Observadome, MCAT is capable of tracking objects in low, medium, and geosynchronous Earth low eccentricity orbits, as well as elliptical medium Earth and geosynchronous transfer orbits (MEO and GTO, respectively) and *Molniya* orbits. During the commissioning run, MCAT proved worthy to the tasks given it for tracking objects from LEO to geosynchronous Earth orbit (GEO).

Tracking Earth-orbiting satellites was easily achieved during MCAT's scientific debut with the successful acquisition of two geosynchronous satellites, the Geostationary Operational Environmental Satellites GOES 4 and 8. Later that week, successful acquisition of a suite of eight low Earth orbit (LEO)

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MCAT Science First Light

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objects were tracked during this commission run, including six fragments from the first known breakup of a satellite in Earth-orbit. The Transit 4A rocket body, International Designator 1961-015C, U.S. Strategic Command Space Surveillance Network [SSN] catalog number 118, was perhaps appropriately the first LEO fragment tracked successfully on 3 Sept 2015. Two LEO passes, ranging from 10-20 seconds in duration, were followed on this historic piece of debris. The break-up spawning these targets occurred on 29 June 1961, when a U.S. Ablestar stage deployed three payloads, Transit 4A, Injun, and Solrad3, though the latter two did not separate from one another [1]. The upper stage did not vent its remaining 100 kg of hypergolic propellant on payload separation and propulsion-related failure modes were deemed the cause of this first debris event. Venting of all remaining propellant for future missions was recommended after a thorough investigation of this event, and set the stage for creating the modern NASA and international policies to prevent future potential orbital debris associated with accidental breakups.

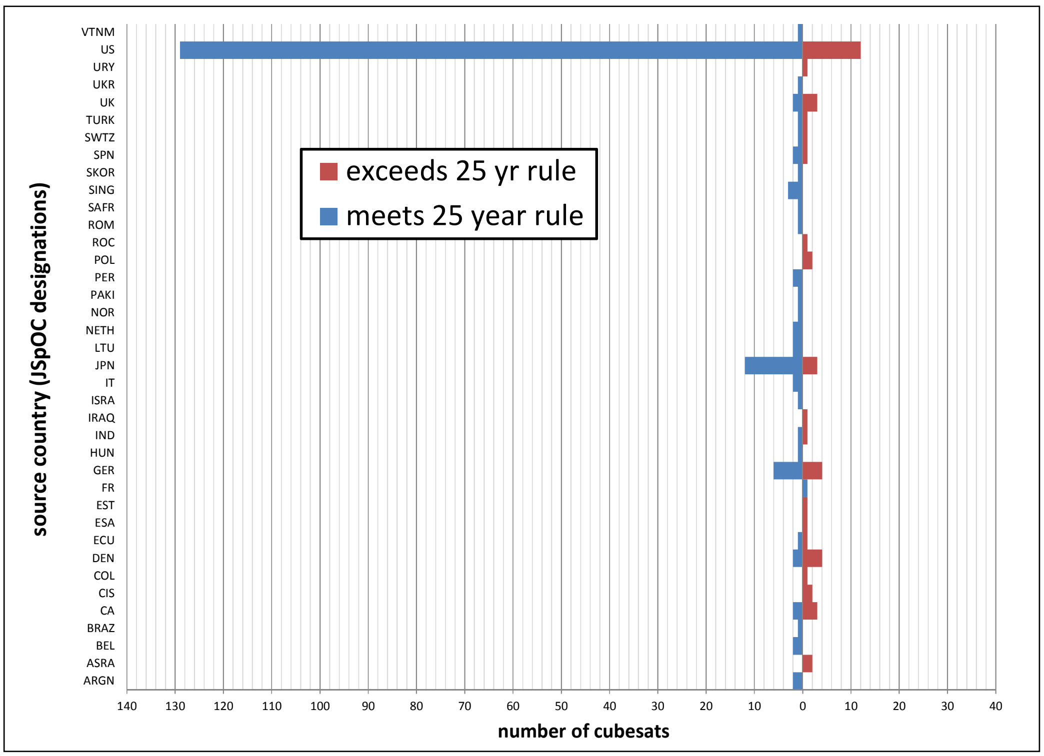
Commissioning of the GEO survey large field-of-view camera will commence in November and December of this year. The FLI camera with its fast read-out but smaller field-of-view is better suited for lightcurve studies, and is complementary to the large-format survey camera.

Reference

1. Orbital Debris Program Office. "History of On-Orbit Satellite Fragmentations: 14th Edition," NASA/TM-2008-214779, pp. 30-31, (June 2008). ♦

An Update to "A Review of Space Environment Implications of CubeSat Traffic"

The article "A Review of Space Environment Implications of CubeSat Traffic, 2003-2014," appearing in the previous ODQN (ODQN, vol. 19, issue 3, July 2015, pp. 4-6), garnered considerable interest and correspondence from readers. One item in that article of particular interest was Fig. 5, which showed the number of U.S. CubeSats listed as being "Unknown" in terms of compliance with common post-mission lifetime guidelines. As a reminder, residence in the Unknown category simply indicates that there were no publicly-available Joint Space Operations Center two line element (TLE) sets available to estimate the CubeSat's area-to-mass ratio, and thereby estimate its orbital lifetime following the (assumed) 2-year operational lifetime. Since publication, several aerospace organizations and professionals have provided information sufficient to revise the original figure, shown here.



A revised Figure 5 from the ODQN 19-3 article "A Review of Space Environment Implications of CubeSat Traffic." Of all nations that have launched CubeSats, this figure tallies their compliance with the 25-year rule. The Unknown category has been eliminated.

Between 2003 and 2014, inclusive, the U.S. launched 141 CubeSats, representing approximately 61% of all CubeSat-envelope spacecraft launched. As depicted in the figure, 129 meet the guideline referred to as the "25 year rule" while 12 do not. In this latter class are four CubeSats whose estimated lifetime excess are 4 years or less. Others, with estimated excess lifetimes of 10 years or more, may deploy drag enhancement devices to curtail their lifetimes on-orbit. Of course, all estimates are predicated upon current estimates of area-to-mass ratio derived from the observed orbital decay to-date and current projections of future solar activity. Maneuvers or deployments of drag enhancement devices can alter the CubeSat's area-to-mass ratio, reducing their nominal orbital lifetime, while differences in actual versus projected solar activity over the next century can either increase or decrease estimated lifetimes. As such, the current figure remains subject to revision, and readers are encouraged to recall the assumptions and caveats associated with it when seeking to interpret it or use it as the basis for discussions. ♦

PROJECT REVIEW

Solwind ASAT Test Retrospective

M. MATNEY AND P. ANZ-MEADOR

Thirty years ago, on 13 September 1985, U.S. Air Force Major (now retired Major General) Wilbert "Doug" Pearson flew his F-15A Eagle to an altitude of 11.6 km, and fired his ASM-135 anti-satellite (ASAT) missile at the P78 Solwind astrophysics spacecraft (Fig. 1 and 2). The orbiting target was destroyed, creating a cloud of orbiting debris. What is not generally known is that this was a watershed event in the role of NASA's orbital debris program.

In July 1985, when NASA learned of the decision to target the satellite, NASA Orbital Debris Program Office's (ODPO's) Donald Kessler met with the Department of Defense (DOD) to be briefed on the details of the planned test. There he first realized the magnitude of the orbital debris risk such an event might create. Using early NASA models, ODPO's Dr. Shin-Yi Su concluded that the high altitude of the satellite (530 km) would result in a large orbital debris cloud with a long orbital lifetime. Some of the debris was projected to remain in orbit until the 1990s. Because of this concern, Joe Loftus, (at the time the NASA Johnson Space Center [JSC]'s Assistant Director, Plans) worked with NASA Headquarters to develop alternatives for the DOD. Some of these alternatives included a lower altitude target that would not leave debris in orbit for so long. The DOD considered all options. However, with a likely U.S. Congressional prohibition on ASAT space impact testing coming in FY86 (which did happen), the DoD felt pressure to test in FY85. Since development of an alternative inflatable target was lagging behind schedule, the Solwind spacecraft was determined to be the only viable choice [1, 2].

Figure 1. The Boeing F-15A-Eagle, named "Celestial Eagle," as observed from a chase plane during the ASAT missile launch, 13 September 1985 (U.S. Air Force). The antisatellite missile is shown shortly after separation from the F-15, but before ignition. The missile will release a miniature homing vehicle to destroy the satellite on impact.

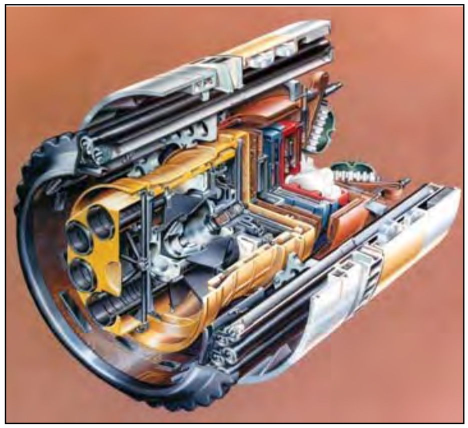


Figure 2. A cutaway view of the ASAT's miniature homing vehicle (MHV). Solid rocket motors were mounted in an outer ring around the vehicle for longitudinal and lateral control, and the infrared seeker assembly was in the center. Courtesy of Los Angeles Air Force Base military library, available online at http://www.losangeles.af.mil/shared/media/document/AFD-060912-028.pdf, Chapter VII: Other Programs, p. 64.

When President Reagan made the decision to go ahead with the ASAT test, NASA decided to use the event to learn as much as possible about the debris generated. A NASA team composed of Kessler, Dr. Andrew Potter, and John Stanley worked with the DOD to put together a measurement campaign to monitor the results of the ASAT collision. Because the satellite was in a sun-synchronous orbit, it was not ideally placed for optical observations. The only part of U.S. territory where the lighting conditions might work was in Alaska. Potter took JSC's Lenzar orbital debris telescope aloft in a Learjet flying from Anchorage toward Nome. Meanwhile, Stanley set up a smaller telescope at Circle Hot Springs on the banks of the Yukon River, and a reentry radar on the North Slope, near Barter Island [2].

The ground observations were plagued by poor weather and bright aurora, but the airborne telescope saw very few debris, prompting questions about the number of debris predicted by the models. These had predicted that the optical telescopes might see many small debris, under the assumption that the metallic pieces would be shiny. Because ground tests conducted at the U.S. Air Force Arnold Engineering Development Center had produced debris pieces that were black with soot, Potter hypothesized that the unexpected Solwind darkening was due to the vaporization of plastics inside Solwind, which condensed on the metal pieces as carbon soot. Infrared observations of the P78 debris displayed

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Figure 3. The Space Test Program spacecraft P78 was launched on 24 February 1979 with a mission to obtain scientific data from Earth- and Sun-oriented experiments. Included with its instrumentation was a white-light coronagraph and an ultraviolet imager; the combined package was designated Solwind. The platform was of the Orbiting Solar Observatory type, with a solar-oriented sail and a rotating wheel section. It remained partially operational until it was impacted during the ASAT test. Image courtesy of NASA Goddard Space Flight Center, NASA's HEASARC: Observatories. Available online at: https://heasarc.gsfc.nasa.gov/docs/heasarc/missions/p78-1.html.

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warmer/brighter signatures than was consistent with modeling the fragments as bare metallic surfaces, indicating a higher emissivity than would be expected from bare metallic surfaces but one consistent with oxidized or coated surfaces. The pieces decayed more quickly from orbit than the models predicted, implying a large area-to-mass ratio [2].

The Solwind test had three important results. (1) It raised the possibility that the debris were large and dark, not small and bright as was generally assumed. This had implications for the calibration of optical and radar orbital debris detection systems. (2) The test created a baseline event for researchers seeking a characteristic signature of a hypervelocity collision in space and for alterations to the breakup models used to predict future consequences of collision events in space. (3) The NASA protests greatly raised awareness of the orbital debris problem for the first time, especially for the DOD. This contributed to more informed conduct of DOD debris-producing activities, and prepared the way for DOD orbital debris policies. As a result, when the Strategic Defense Command (SDI) planned their Delta-180 test in 1986, where two objects were again intentionally collided in orbit, General Abrahamson, then director of SDI, ordered that the test be conducted in a manner so that all fragments were to reenter within a short time after the test.

In the end, the Solwind ASAT test had few consequences for the planned U.S. Space Station and other activities in space. For economic and political reasons unrelated to orbital debris, the station completion was pushed beyond the mid-1990s and ultimately redesigned as the current International Space Station. The record-high level of solar activity during the 1989-1991 solar maximum heated and expanded the atmosphere more than was anticipated in 1985, accelerating the decay of Solwind debris [2], as seen in Fig. 4.

Solwind's Scientific Legacy for Orbital Debris

As the previous section described the measurements and policy implications of the Solwind ASAT event, so were there other scientific benefits to be found in modeling the orbital debris environment. These were patiently developed over the years following the ASAT event by collecting and analyzing observables describing the physical characteristics and evolution of the debris cloud. Some benefits were specific to the ODPO, *e.g.*, regularly collecting and archiving orbit and radar cross-section data sets from the Joint Space Operations Center and its predecessor organizations. However, these only lay the foundation for data reduction and analysis, leading to many modeling advancements at the time. Among these advancements were the development of ballistic coefficient (area-to-mass ratio) estimation software; the development of radar cross-section (RCS) analysis software, including using the NASA Size Estimation Model (SEM) to convert, in a statistical manner, fragment RCS to characteristic length, a size characteristic; the relationship of mass and characteristic length; and a validation of power laws to describe the number-size relationship in collisions.

A precursor data product to the number-size power law is shown in Fig. 5. This figure compares the number-mass distribution of the Satellite Orbital debris Characterization Impact Test (SOCIT) debris ensemble with the P78 debris cloud. While SOCIT masses were measured directly, the on-orbit P78 debris masses are inferred from the observed orbital decay (estimate: area-to-mass ratio) and the observed RCS time histories (estimate: area, from characteristic length, from the SEM conversion of RCS to length); mass is calculated from the quotient of area to area-to mass ratio. The Solwind debris data enabled the ODPO to validate a number-size (or mass) power law relationship for collisions by demonstrating a similitude between low-fidelity ground tests, the high fidelity SOCIT test, and an on-orbit event.

The power-law fit continues in use today as a statistical representation of a collision's number-size distribution [3]. In comparison against the ASAT test conducted by the People's Republic of China against the FY-1C spacecraft in January 2007 and the accidental collision in February 2009 of the Iridium 33 and Cosmos 2251 spacecraft, the relationship proved a good fit to the Cosmos 2251 debris cloud. This is most likely due to the similarities in material and construction between the SOCIT's Transit spacecraft, the P78, and Cosmos 2251. Fits were less successful for the other two spacecraft, as both exhibit high area-

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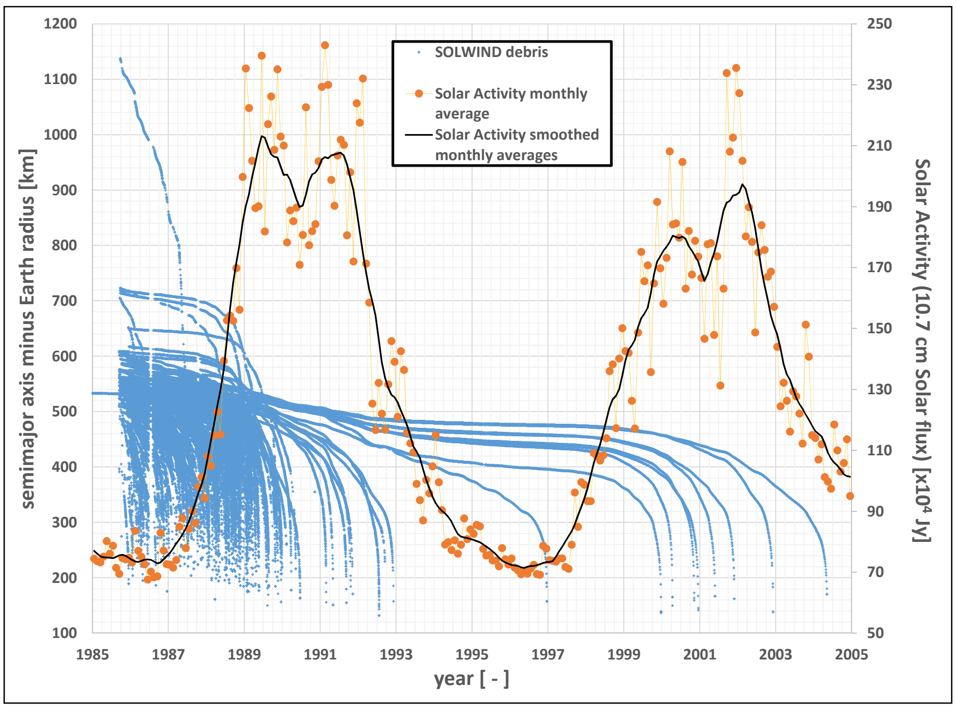

Figure 4. The orbital evolution of the P78 debris cloud over the time span 1985-2005, referenced to the left vertical axis, and accompanied by the historical solar flux, referenced to the right vertical axis. Clearly visible is the effect of high solar activity on the on-orbit lifetimes of debris cloud members. During this time span, debris cast as high as 1150 km altitude decayed, leaving no debris on-orbit by 2005. When the solar flux is high, the atmosphere is heated, expands, and increases the atmospheric drag on debris at a given altitude. As drag increases, energy is withdrawn from the orbit and it will eventually reenter.

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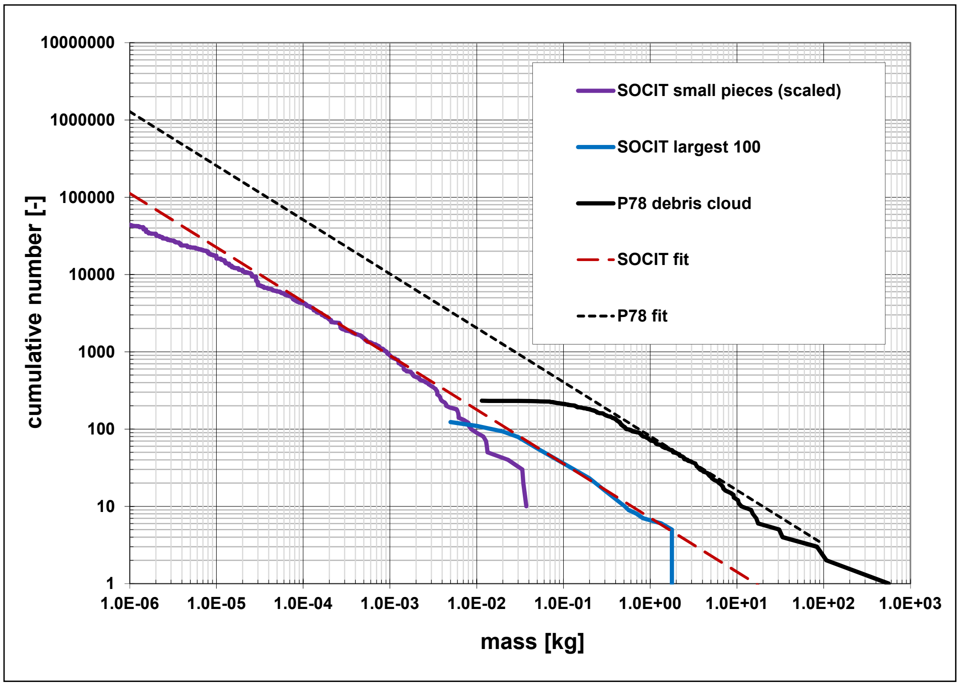

Figure 5. A comparison of the number-mass distribution for the SOCIT ground-based test and the P78 debris cloud over the mass range from one milligram to one metric ton. The small SOCIT pieces are scaled by the solid angle of the test's collecting area to a full 4π [steradian]. Note the SSN cataloging roll-off for smaller masses in the P78 cloud, and perhaps a similar effect for sieved SOCIT debris on the order of 50 [mg] and less.

to-mass components (ODQN, vol. 13, issue 3, July 2009, pp. 5-6). One or both spacecraft may also have used composites in their construction, a signal difference with more classically-constructed spacecraft.

The relatively poor match between the current power law and the FY-1C and Iridium 33 debris clouds prompted the DebriSat tests, the analysis of which is on-going at this time [4]. The ODPO anticipates an update to the current power-law-number-size distribution, specifically addressing spacecraft whose construction incorporates modern materials and techniques. However, the advances in modeling derived from analysis of the Solwind cloud will be further advanced, rather than superseded, by these new data sets, and the relationship validated by P78 will continue to serve into the foreseeable future as the law applicable to older spacecraft.

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ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The 12th Annual CubeSat Developers' Workshop 22-24 April 2015, San Luis Obispo, California, USA

Orbital Debris Mitigation

R. L. KELLEY, D. R. JARKEY, G. STANSBERY

Policies on limiting orbital debris are found throughout the US Government, many foreign space agencies, and as adopted guidelines in the United Nations. The underlying purpose of these policies is to ensure the environment remains safe for the operation of robotic and human spacecraft in near-Earth orbit. For this reason, it is important to consider orbital debris mitigation during the design of all space vehicles.

Documenting compliance with the debris mitigation guidelines occurs after the vehicle has already been designed and fabricated for many CubeSats, whereas larger satellites are evaluated throughout the design process. This paper will provide a brief explanation of the US Government Orbital Debris Mitigation Standard Practices, a discussion of international guidelines, as well as NASA's process for compliance evaluation. In addition, it will discuss the educational value of considering orbital debris mitigation requirements as a part of student built satellite design. ♦

The 30th International Symposium on Space Technology and Science (ISTS)
04-10 July 2015, Kobe-Hyogo, Japan

DRAGONS – A Micrometeoroid and Orbital Debris Impact Sensor on the ISS

J.-C. LIOU, J. HAMILTON, S. LIOLIOS, C. ANDERSON, A. SADILEK, R. CORSARO, F. GIOVANE, AND M. BURCHELL

The Debris Resistive/Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS) is intended to be a large area impact sensor for in situ measurements of micrometeoroids and orbital debris (MMOD) in the sub-millimeter to millimeter size regime in the near Earth space environment. These MMOD particles are too small to be detected by ground-based radars and optical telescopes, but still large enough to be a serious threat to human space activities and robotic missions in the low Earth orbit (LEO) region. The nominal detection area of DRAGONS is 1 m^2, consisting of four 0.5 m × 0.5 m independent panels, but the dimensions of the panels can easily be modified to accommodate different payload constraints. The approach of the DRAGONS design is to combine three particle impact detection concepts to maximize information that can be extracted from each detected impact. The first is a resistive grid consisting of 75-µm-wide resistive lines, coated in parallel and separated by 75 µm gaps on a 25-µm thin film. When a particle a few hundred micrometers or larger strikes the grid, it would penetrate the film and sever some resistive lines. The size of the damage area can be estimated from the increased resistance. The second concept is based on polyvinylidene fluoride (PVDF) acoustic impact sensors. Multiple PVDF sensors are attached to the thin film to provide the impact timing information. From the different signal arrival times at different acoustic sensors, the impact location can be calculated via triangulation algorithms. The third concept employs a dual-layer film system where a second 25-µm film is placed 15 cm behind the resistive-grid film. Multiple PVDF acoustic sensors are also attached to the second film. The combination of impact timing and location information from the two films allows for direct measurements of the impact direction and speed.

The DRAGONS technology development has been funded by several NASA organizations since 2002, first by the NASA Science Mission Directorate and the NASA Exploration Systems Mission Directorate, then by the NASA JSC Innovative Research and Development Program and the NASA Orbital Debris Program Office. The NASA Orbital Debris Program Office leads the effort with collaboration from the U.S. Naval Academy, Naval Research Laboratory, University of Kent at Canterbury in Great Britain, and Virginia Tech. The project recently reached a major milestone when DRAGONS was approved for a technology demonstration mission by the International Space Station (ISS) Program in October 2014. The plan is to deploy a 1 m^2 DRAGONS on the ISS with the detection surface facing the ram-direction for 2 to 3 years. The tentative launch schedule is in early 2017. This mission will collect data on orbital debris in the sub-millimeter size regime to better define the small orbital debris environment at the ISS altitude. The mission will also advance the DRAGONS Technology Readiness Level to 9 and greatly enhance the opportunities to deploy DRAGONS on other spacecraft to high LEO orbits in the future. ♦

Stanford Meteor Environment and Effects (SMEE) Workshop
14-16 July 2015, Stanford University, Stanford, California, USA

Using the Shuttle *In Situ* Window and Radiator Data for Meteoroid Measurements

M. MATNEY

Every time NASA's Space Shuttle flew in orbit, it was exposed to the natural meteoroid and artificial debris environment. NASA Johnson Space Center maintains a database of impact cratering data of 60 Shuttle missions flown since the mid-1990s that were inspected after flight. These represent a total net exposure time to the space environment of 2 years. Impact damage was recorded on the windows and radiators, and in many cases information on the impactor material was determined by later analysis of the crater residue. This information was used to segregate damage caused by natural meteoroids and artificial space debris. The windows represent a total area of 3.565 m^2, and were capable of resolving craters down to about 10 µm in size. The radiators represent a total area of 119.26 m^2, and saw damage from objects up to ~1 mm in diameter. These data were used extensively in the development of NASA's ORDEM 3.0 Orbital Debris Environment Model, and give a continuous picture of the orbital debris environment in material type and size ranging from about 10 µm to 1 mm. However, the meteoroid data from the Shuttles have never been fully analyzed. For the orbital debris work, special "as flown" files were created that tracked the pointing of the surface elements and their shadowing by structure (such as the ISS during docking). Unfortunately, such files for the meteoroid environment have not yet been created. This talk will introduce these unique impact data and describe how they were used for orbital debris measurements. We will then discuss some simple first-order analyses of the meteoroid data, and point the way for future analyses. ♦

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AIAA SPACE 2015 Conference and Exposition
31 August – 02 September 2015, Pasadena, California, USA

CubeSat Material Limits for Design for Demise

R. L. KELLEY AND D. R. JARKEY

The CubeSat form factor of nano-satellite (a satellite with a mass between one and ten kilograms) has grown in popularity due to their ease of construction and low development and launch costs. In particular, their use as student led payload design projects has increased due to the growing number of launch opportunities. CubeSats are often deployed as secondary or tertiary payloads on most US launch vehicles or they may be deployed from the ISS. The focus of this study will be on CubeSats launched from the ISS.

From a space safety standpoint, the development and deployment processes for CubeSats differ significantly from that of most satellites. For large satellites, extensive design reviews and documentation are completed, including assessing requirements associated with reentry survivability. Typical CubeSat missions selected for ISS deployment have a less rigorous review process that may not evaluate aspects beyond overall design feasibility. CubeSat design teams often do not have the resources to ensure their design is compliant with reentry risk requirements.

A study was conducted to examine methods to easily identify the maximum amount of a given material that can be used in the construction of a CubeSat without posing harm to persons on the ground. The results demonstrate that there is not a general equation or relationship that can be used for all materials; instead a limit can be placed on the specific heat of ablation for an object to determine if a reentry analysis is necessary for the component. In addition, the limit on specific heat of ablation for a number of generic materials that have been previously used as benchmarking materials for reentry survivability analysis tool comparison will be utilized as illustration. ♦

The 16th Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)
15-18 September 2015, Maui, Hawaii

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

K. ABERCROMBY, B. BUCKALEW, P. ABELL, AND H. COWARDIN

Presented here are the results of the Infrared Telescope Facility (IRTF) spectral observations of human-made space objects taken from 2006 to 2008. The data collected using the SpeX infrared spectrograph cover the wavelength range 0.72.5 µm. Overall, data were collected on 20 different orbiting objects at or near the geosynchronous (GEO) regime. Four of the objects are controlled spacecraft, seven are non-controlled spacecraft, five are rocket bodies, and four are cataloged as debris pieces. The remotely collected data are compared to the laboratory-collected reflectance data on typical spacecraft materials; thereby general materials are identified but not specific types. These results highlight the usefulness of observations in the infrared by focusing on features from hydrocarbons and silicon. The spacecraft, both the controlled and non-controlled, show distinct features due to the presence of solar panels whereas the rocket bodies do not. Signature variations between rocket bodies, due to the presence of various metals and paints on their surfaces, show a clear distinction from those objects with solar panels, demonstrating that one can distinguish most spacecraft from rocket bodies through infrared spectrum analysis. Finally, the debris pieces tend to show featureless, dark spectra. These results show that the laboratory data in its current state give excellent indications as to the nature of the surface materials on the objects. Further telescopic data collection and model updates to include noise, surface roughness, and material degradation are necessary to make better assessments of orbital object material types. However, based on the current state of the model, infrared spectroscopic data are adequate to classify objects in GEO as spacecraft, rocket bodies, or debris. ♦

An Analysis of 20 Years of Space Weathering Effects on the Boeing 376 Spacecraft

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

The Boeing HS-376 spin stabilized spacecraft was a popular design that was launched continuously into geosynchronous orbit starting in 1980 with the last launch occurring in 2002. Over 50 of the HS-376 buses were produced to fulfill a variety of different communication missions for countries all over the world. The design of the bus is easily approximated as a telescoping cylinder that is covered with solar cells and an Earth facing antenna that is despun at the top of the cylinder.

The similarity in design and the number of spacecraft launched over a long period of time make the HS-376 a prime target for studying the effects of solar weathering on solar panels as a function of time.

A selection of primarily non-operational HS-376 spacecraft launched over a 20-year time period were observed using the United Kingdom Infrared Telescope on Mauna Kea and multi-band near-infrared photometry produced. Each spacecraft was observed for an entire night cycling through ZYJHK filters and time-varying colors produced to compare near-infrared color as a function of launch date. The resulting analysis shown here may help in the future to set launch date constraints on the parent object of unidentified debris objects or other unknown spacecraft. ♦

Deploying the NASA Meter Class Autonomous Telescope (MCAT) on Ascension Island

S. M. LEDERER, L. PACE, P. HICKSON, H. M. COWARDIN, J. FRITH, B. BUCKALEW, T.GLESNE, R. MAEDA, D. DOUGLAS, AND D. NISHIMOTO

NASA has successfully constructed the 1.3 m Meter Class Autonomous Telescope (MCAT) facility on Ascension Island in the South Atlantic Ocean. MCAT is an optical telescope designed specifically to collect ground-based data for the statistical characterization of orbital debris ranging from Low Earth Orbit (LEO) through Middle Earth Orbits (MEO) and beyond to Geo Transfer and Geosynchronous Orbits (GTO/GEO). The location of Ascension Island has two distinct advantages. First, the near-equatorial location fills a significant longitudinal gap in the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) network of telescopes, and second, it allows access to objects in Low Inclination Low-Earth Orbits (LILO).

The MCAT facility will be controlled by a sophisticated software suite that operates the dome and telescope, assesses sky and weather conditions, conducts all necessary calibrations, defines an observing strategy (as dictated by weather, sky conditions and the observing plan for the night), and carries out the observations. It then reduces the collected data via four primary observing modes ranging from tracking previously cataloged objects to conducting general surveys for detecting uncorrelated debris. Nightly observing plans, as well as the resulting text file of reduced data, will be transferred to and from Ascension, respectively, via a satellite connection. Post-processing occurs at NASA Johnson Space Center.

Construction began in September, 2014 with dome and telescope installation occurring in April through early June, 2015. First light was achieved in June, 2015. Acceptance testing, full commissioning, and calibration of this soon-to-be fully autonomous system commenced in summer 2015. The initial characterization of the system from these tests is presented herein. ♦

An Imaging System for Satellite Hypervelocity Impact Debris Characterization

M. MORAGUEZ, K. PATANKAR, N. FITZ-COY, J.-C. LIOU, AND H. COWARDIN

This paper discusses the design of an automated imaging system for size characterization of debris produced by the DebriSat hypervelocity impact test. The goal of the DebriSat project is to update satellite breakup models. A representative LEO satellite, DebriSat, was constructed and subjected to a hypervelocity impact test. The impact produced an estimated 85,000 debris fragments. The size distribution of these fragments is required to update the current satellite breakup models.

An automated imaging system was developed for the size characterization of the debris fragments. The system uses images taken from various azimuth and elevation angles around the object to produce a 3D representation of the fragment via a space carving algorithm. The system consists of *N* number point-and-shoot cameras attached to a rigid support structure that defines the elevation angle for each camera. The debris fragment is placed on a turntable that is incrementally rotated to desired azimuth angles. The number of images acquired can be varied based on the desired resolution. Appropriate background and lighting is used for ease of object detection. The system calibration and image acquisition process are automated to result in push-button operations. However, for quality assurance reasons, the system is semi-autonomous by design to ensure operator involvement. This paper describes the imaging system setup, calibration procedure, repeatability analysis, and the results of the debris characterization. ♦

ABSTRACTS FROM THE NASA HYPERVELOCITY IMPACT TECHNOLOGY GROUP

The 13th Hypervelocity Impact Symposium (HVIS), 26-30 April 2015, Boulder, Colorado USA

Toughened Thermal Blanket for Micrometeoroid and Orbital Debris Protection

E. L. CHRISTIANSEN AND D. M. LEAR

Toughened thermal blankets have been developed that greatly improve protection from hypervelocity micrometeoroid and orbital debris (MMOD) impacts. Three types of materials were added to the thermal blanket to enhance its MMOD performance: (1) disrupter layers, near the outside of the blanket to improve breakup of the projectile, (2) standoff layers, in the middle of the blanket to provide an area or gap that the broken-up projectile can expand, and (3) stopper layers, near the back of the blanket where the projectile debris is captured and stopped. Hypervelocity impact tests were performed on candidate toughened thermal blanket configurations at the NASA White Sands Test Facility and at the University of Dayton Research Institute. From these tests the best disrupter materials were found to be beta-cloth and fiberglass fabric. Polyimide open-cell foams provide a light-weight means to increase the blanket thickness and improve MMOD protection. The best stopper material is Spectra™ 1000-952 or Kevlar™ KM2-705. These blankets can be outfitted if so desired with a reliable means to determine the location, depth and extent of MMOD impact damage by incorporating an impact sensitive piezoelectric film. ♦

Shuttle MMOD Impact Database

J. HYDE, E. CHRISTIANSEN, AND D. LEAR

The Shuttle Hypervelocity Impact Database documents damage features on each Orbiter from micrometeoroids (MM) and orbital debris (OD). Data is divided into tables for crew module windows, payload bay door radiators and thermal protection systems along with other miscellaneous regions. The database contains nearly 3000 records, with each providing impact feature dimensions, location on the vehicle and relevant mission information. Additional detail on the type and size of particle that produced the damage site is provided when sampling data and definitive spectroscopic analysis results are available. Relationships assumed when converting from observed feature sizes in different shuttle materials to particle sizes will be presented. ♦

Analytic Ballistic Performance Model of Whipple Shields

J. E.MILLER, M. D. BJORKMAN, E. L. CHRISTIANSEN, AND S. J. RYAN

The dual-wall, Whipple shield is the shield of choice for lightweight, long-duration flight. The shield uses an initial sacrificial wall to initiate fragmentation and melt an impacting threat that expands over a void before hitting a subsequent shield wall of a critical component. The key parameters to this type of shield are the rear wall and its mass which stops the debris, as well as the minimum shock wave strength generated by the threat particle impact of the sacrificial wall and the amount of room that is available for expansion. Ensuring the shock wave strength is sufficiently high to achieve large scale fragmentation/melt of the threat particle enables the expansion of the threat and reduces the momentum flux of the debris on the rear wall. Three key factors in the shock wave strength achieved are the thickness of the sacrificial wall relative to the characteristic dimension of the impacting particle, the density and material cohesion contrast of the sacrificial wall relative to the threat particle and the impact speed. The mass of the rear wall and the sacrificial wall are desirable to minimize for launch costs making it important to have an understanding of the effects of density contrast and impact speed. An analytic model is developed here, to describe the influence of these three key factors. In addition this paper develops a description of a fourth key parameter related to fragmentation and its role in establishing the onset of projectile expansion. ♦

Ballistic Performance Model of Crater Formation in Monolithic, Porous Thermal Protection Systems

J. E. MILLER, E. L. CHRISTIANSEN, B. A. DAVIS, AND K. D. DEIGHTON

Monolithic, porous, thermal protection systems were used heavily on the Apollo command module, and they are currently being used on the next generation of US manned spacecraft, Orion. These systems insulate reentry critical components of a spacecraft against the intense thermal environments of atmospheric reentry. Additionally, these materials may be highly exposed to space environment hazards like solid particle impacts. This paper discusses impact studies up to 10 km/s on nominally 0.56 g/cm3 Avcoat ablator with phenolic flexible hexcore. An impact model that describes projectile dispersion in a monolithic material is described that provides excellent agreement with observations over a broad range of impact velocities, obliquities and projectile materials. ♦

HVI Ballistic Limit Characterization of Fused Silica Thermal Panes

J. E. MILLER], W. E. BOHL, E. L. CHRISTIANSEN, B. A. DAVIS, AND K. D. DEIGHTON

Fused silica window systems are used heavily on crewed reentry vehicles, and they are currently being used on the next generation of US crewed spacecraft, Orion. These systems improve crew situational awareness and comfort, as well as, insulating the reentry critical components of a spacecraft against the intense thermal environments of atmospheric reentry. Additionally, these materials are highly exposed to space environment hazards like solid particle impacts. This paper discusses impact studies up to 10 km/s on a fused silica window system proposed for the Orion spacecraft. A ballistic limit equation that describes the threshold of perforation of a fused silica pane over a broad range of impact velocities, obliquities and projectile materials is discussed here. ♦

Multi-shock Shield Performance at 14 MJ for Catalogued Debris

J. E. MILLER, E. L. CHRISTIANSEN, B. A. DAVIS, D. M. LEAR, AND J. –C. LIOU

As the orbital debris population continues to grow significant tangible threats to robotic and crewed spacecraft have risen greatly over the last decade. These threats are currently mitigated operationally; however, an understanding of engineered solutions is useful to consider with respect to the risks and costs of operational mitigation. To this end a multi-shock shield has been designed and tested to demonstrate what it takes to stop an object that fits the energy profile of catalogued debris. A 14.25 MJ hypervelocity impact test has been performed on an enhanced, multi-shock shield at orbital speeds at the Arnold Engineering Development Complex (AEDC). The projectile was a hollow aluminum and nylon cylinder with characteristic dimensions typical of catalogued debris. The AEDC test of the shield occurred without any issues, and the shield successfully stopped the 598 g projectile at a mass penalty of 10.35 g/cm^2. ♦

CONFERENCE REPORTS

The 29th Annual American Institute of Aeronautics and Astronautics/Utah State (AIAA/USU) Conference on Small Satellites, 8-13 August 2015, Logan, Utah

The 29th Annual American Institute of Aeronautics and Astronautics/Utah State University Conference on Small Satellites was held 8-13 August in Logan, Utah. The conference hosted more than 1800 participants and 140 exhibitors from 34 countries. The topic of this year's conference was "All Systems Go! Critical Pieces for Mission Success." The NASA ODPO gave two side meeting presentations: "Overview of the Orbital Debris Problem" and "Orbital Debris Compliance Issues for Small Satellites." Many of the other presented topics focused on recently developed or upcoming small satellite technologies with little mention of debris mitigation. Several of the commercial exhibitors did advertise that their products were designed with NASA OD mitigation guidelines in mind. ♦

The AIAA Space and Astronautics Forum and Exposition (SPACE 2015) 31 August – 02 September 2014, Pasadena, California

The annual event, hosted by the American Institute of Aeronautics and Astronautics (AIAA) and cohosted by the American Astronautical Society (AAS), was held 31 August – 2 September in Pasadena, California. SPACE 2015 included more than 350 technical papers from approximately 100 government, academic, and private institution in 20 countries. The Exposition included exhibits from twenty aerospace companies, AIAA groups, and NASA.

Highlighted topics included, Atmospheric and Space Environments, Emerging Commercial Space, National Security Space, Reinventing Space, Space History, Society, and Policy, and Small Satellites. Four Plenary Session and 13 *Forum 360* panel discussions included high-level talks on such topics as the business of space, exploring the solar system, and space policy for rising aerospace leaders. ♦

The 16th Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference 15-18 September 2015, Maui, Hawaii

The Advanced Maui Optical and Space Surveillance Technologies Conference was held 15-18 September. The keynote speaker for the event was Major General Clinton E. Crosier from U.S. Strategic Command. Maj. General Crosier focused on various areas of Space Situational Awareness, including orbital debris and the U.S. government's assets in all Earth orbits.

Six papers were presented during the Orbital Debris Session; Tim Flohrer (European Space Agency) was the session chair. The first session speaker, Kohei Fujimoto, discussed statistical track-before-detect methods as they apply to faint optical observations of resident space objects using a Bernoulli filter on particle arrays. Thomas Schildknecht then presented work on a new streak detection algorithm for space debris detection using optical imagery based on templates of various lengths and angles. Next, Susan Lederer discussed the deployment and status of the NASA/AFRL Meter Class Autonomous Telescope at Ascension Island. Captain Samantha Howard discussed GEO collisional risk assessment based on analysis from the NASA-WISE data and modeling. Waldemar Bauer presented work based on environment characterization using an innovative debris detector that uses grid technology and solar cells and will be launched on the 12 month mission of TechnoSat 2016. Finally, the last paper in the session by Ronny Kanzler, discussed space debris attitude simulations using in-orbit tumbling analyses.

Although there were only six papers in this session, there were many other orbital debris-related talks in other sessions. During the Non-Resolved Optical Characterization Session, four papers were presented related to orbital debris. First, Schildknecht presented work based on photometric monitoring on non-resolved space debris and generating a database of optical lightcurves and their corresponding rotation rates. Brent Buckalew then discussed the IRTF SpeX observations of orbital objects and analyses from Kira Abercromby's unmixing algorithm used to determine material type of unknown objects. Next, Michael Pasqual presented work on active polarimetric measurements of orbital debris to acquire polarimetric bidirectional reflectance distribution functions to aid in material characterization. The last orbital debris-related paper presented in the session was by James Frith, discussing data acquired on the United Kingdom Infrared Telescope (UKIRT) focused on HS-376 bus types to characterize space weathering effects as a function of launch date over a 20-year span.

One poster paper funded by NASA ODPO was also presented. Matthew Moraguez presented a poster on an imaging system for satellite hypervelocity impact debris characterization as it relates to DebriSat.

In the Space Situational Awareness Session, a paper was presented by Barry Geldzahler discussing development and results of coherent uplink from a phased array of widely separated antennas using KaBOOM communications and radar array located at NASA/KSC.

There were also four technical short courses available at the conference. Of these, Thomas Schildknecht presented on observing and characterizing orbital debris. Following the AMOS conference, the Non-Imaging Space Object Identification Workshop, hosted by Paul Kervin, was held over a two-day span. Four presentations from ODPO were delivered including preliminary results from UKIRT spectra data by Sue Lederer; optical observation planning to observe in an orbit scan mode focused on GEO break-up events by James Frith; and initial assessment of the Space Surveillance Telescope data set by Brent Buckalew. Lastly, Heather Cowardin presented plans and status updates for characterization of orbital debris using hypervelocity ground-based tests, specifically DebriSat. ♦

MCAT Telescope Photos from Ascension Island

The collage on page 13 documents the MCAT construction process. On the top row are Tom Glesne (who oversaw the construction phase), the pier, and the dome (from left to right), while the second row continues documenting the construction process. The third row includes a photo of the facility dedication plaque flanked by opposite views of the integrated telescope. The fourth row shows MCAT during night and day operations and the last row pictures the facility from afar (arrow points to MCAT). The final figure on this row shows the MCAT auxiliary telescope (on the left) and MCAT. Refer to the ODQN, vol. 19, issue 3, July 2015, pp. 3-4 for the complete installation story.

UPCOMING MEETINGS

5-12 March 2016: 2016 IEEE Aerospace Conference, Big Sky, Montana (USA)

This conference will feature session 2.11 *Space Debris and Dust: The Environment, Risks, and Mitigation Concepts and Practices*. Conference organizers invite papers that address the space debris population and growth projections; debris and dust characteristics; impact modeling and materials testing; modeling and simulation and/or test results that can lead to quantification of the risks to spacecraft in various orbits and exploration missions; and mitigation strategies including debris removal or repositioning, spacecraft shielding, orbit selection, and spacecraft operations. Papers documenting past mission anomalies traced to space debris, and mitigation strategies employed today, are also solicited as being of critical interest. Please see the conference website: http://www.aeroconf.org/ for more details.

20-22 April 2016: 13th Annual CubeSat Developer's Workshop, San Luis Obispo, California (USA)

This workshop continues the annual series hosted by the California Polytechnic University. For updates and more information please refer to the CubeSat Project website: http://www.cubesat.org/index.php/workshops/upcoming-workshops.

16-20 May 2016: 14th International Conference on Space Operations (SpaceOps 2016), Daejon, Republic of Korea

Hosted by the Korea Aerospace Research Institute (KARI) and organized by the AIAA, the theme of SpaceOps 2016 is "Expanding the Space Community." Among the relevant sessions are *Mission Design and Management* and *Small Satellite and Commercial Space Operations*. For more information please refer to the conference website: http://www.spaceops2016.org/.

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

In cooperation with the International Space Safety Foundation (ISSF), the IAASS will host its 8th conference, themed "Safety First, Safety for All." Among the conference's topics of interest to this readership are designing safety into space vehicles, safety of extravehicular activities, space debris remediation, re-entry safety, probabilistic risk assessment, space situational awareness (SSA) and space traffic control, and launch and in-orbit collision risk. In addition to conference sessions, a set of panel sessions will address *Space Debris Reentry Safety*, *Space Traffic Management*, *Safety Standards for Commercial Human Spaceflight*, and *Human Performance and Safety on Long Duration Missions*. For more information please refer to the conference website: http://iaass.space-safety.org/.

30 May - 03 June 2016: The Small Satellite Systems and Services (4S) Symposium, Valetta, Malta
Co-sponsored by CNES and ESA

The 4S Symposium has as its theme this year "Small Satellites Go Viral". The symposium will host a cubesat workshop, and is soliciting papers on these relevant topics: mission and systems analysis; science; launchers; and new technologies. Please see the symposium website: http://congrexprojects.com/4S2016/home for further information.

30 July - 07 August 2016: 41st Committee on Space Research (COSPAR) 2016, Istanbul, Turkey

The COSPAR Scientific Assembly will convene in Istanbul's Congress Center on Saturday, 30 July 2016 and run through Sunday, 7 August. The COSPAR panel Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "Space Debris – Providing the Scientific Foundation for Action." PEDAS.1 sessions will include advances in ground- and space-based measurements of the orbital debris environment, micrometeoroid and orbital debris environment modeling, risk assessment, mitigation and remediation, hypervelocity impact range developments, and protection. Please see the COSPAR website at https://www.cospar-assembly.org/ and the Assembly website http://cospar2016.tubitak.gov.tr/ for further information.

Top and side views (day and night) of the MCAT telescope were taken by Leading Aircraftman (LAC) Hanna, Royal Air Force. All other photos were taken by NASA personnel and U.S. Air Force Research Laboratory contractors.

SATELLITE BOX SCORE

(as of 30 September 2015, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	202	3571	3773
CIS	1461	4827	6288
ESA	53	54	107
FRANCE	60	457	517
INDIA	60	109	169
JAPAN	137	72	209
USA	1276	3886	5162
OTHER	727	111	838
TOTAL	3976	13087	17063

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

1 July 2015 – 30 September 2015

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2015-031A	PROGRESS-M 28M	RUSSIA	401	409	51.6	1	0
2015-032A	DMC 3-FM1	UK	638	661	98.0	1	0
2015-032B	DMC 3-FM2	UK	639	659	98.0		
2015-032C	DMC 3-FM3	UK	637	662	98.0		
2015-032D	CARBONITE 1	UK	636	659	98.0		
2015-032E	DEORBITSAIL	UK	634	658	98.0		
1998-067GE-GT	14 Cubesats (FLOCK 1E 1-14)	USA	385	390	51.6	0	0
2015-033A	NAVSTAR 74 (USA 262)	USA	20139	20224	55.0	1	0
2015-034A	METEOSAT 11 (MSG 4)	EUMETSAT	35784	35792	3.0	1	1
2015-034B	STARONE C4	BRAZIL	35782	35790	0.0		
1998-067GU	ARKYD-3R	USA	373	377	51.6	0	0
1998-067GV	CENTENNIAL 1	USA	379	381	51.6		
1998-067GX	SERPENS	BRAZIL	394	406	51.6		
1998-067GY	S-CUBE	JAPAN	396	407	51.6		
2015-035A	SOYUZ-TMA 17M	RUSSIA	400	409	51.6	1	0
2015-036A	WGS 7 (USA 263)	USA	35782	35790	0.0	1	0
2015-037A	BEIDOU-3 M1	CHINA	21512	21544	55.0	2	0
2015-037B	BEIDOU-3 M2	CHINA	21512	21546	55.0		
2015-038A	HTV-5	JAPAN	396	404	51.6	0	0
2015-039A	INTELSAT 34	INTELSAT	35773	35801	0.1	1	1
2015-039B	EUTE 8 WEST B	EUTELSAT	35772	35801	0.1		
2015-040A	YAOGAN 27	CHINA	1194	1207	100.5	1	0
2015-041A	GSAT 6	INDIA	35749	35825	1.1	1	0
2015-042A	INMARSAT 5-F3	INMARSAT	EN ROUTE TO GEO			1	1
2015-043A	SOYUZ-TMA 18M	RUSSIA	401	409	51.6	1	0
2015-044A	MUOS 4	USA	EN ROUTE TO GEO			1	0
2015-045A	GALILEO 9 (205)	ESA	23440	23566	57.4	1	0
2015-045B	GALILEO 10 (206)	ESA	23231	23286	57.4		
2015-046A	TJS-1	CHINA	35777	35795	0.1	1	0
2015-047A	GAOFEN 9	CHINA	618	665	98.0	0	0
2015-048A	EXPRESS AM-8	RUSSIA	35784	35790	0.0	1	0
2015-049A	OBJECT A	CHINA	516	536	97.5	1	0
2015-049B	NUDT-PHONESAT	CHINA	516	536	97.5		
2015-049C	ZDPS 2A	CHINA	517	536	97.5		
2015-049D	ZDPS 2B	CHINA	518	536	97.5		
2015-049E	XW-2A	CHINA	500	533	97.5		
2015-049F	KAITUO 1A	CHINA	518	538	97.5		
2015-049G	OBJECT G	CHINA	520	541	97.5		
2015-049H	XW-2C	CHINA	519	540	97.5		
2015-049J	XW-2D	CHINA	520	540	97.5		
2015-049K	LILACSAT 2	CHINA	520	542	97.5		
2015-049L	XW-2E	CHINA	519	539	97.5		
2015-049M	XW-2F	CHINA	519	541	97.5		
2015-049N	XW-2B	CHINA	520	540	97.5		
2015-049P	KAITUO 1B	CHINA	514	536	97.5		
2015-050A	COSMOS 2507	RUSSIA	1497	1507	82.5	1	0
2015-050B	COSMOS 2508	RUSSIA	1496	1505	82.5		
2015-050C	COSMOS 2509	RUSSIA	1498	1508	82.5		
2015-051A	PUJIANG 1 (PJ-1)	CHINA	468	486	97.3	1	0
2015-051B	TIANWANG 1C (TW-1C)	CHINA	466	487	97.3		
2015-051C	TIANWANG 1B (TW-1B)	CHINA	466	485	97.3		
2015-051D	TIANWANG 1A (TW-1A)	CHINA	467	485	97.3		
2015-052A	ASTROSAT	INDIA	633	650	6.0	1	
2015-052B	LAPAN A2	INDONESIA	632	650	6.0		
2015-052C	LEMUR-2 JOEL	USA	631	650	6.0		
2015-052D	LEMUR-2 CHRIS	USA	630	650	6.0		
2015-052E	LEMUR-2 JEROEN	USA	634	650	6.0		
2015-052F	LEMUR-2 PETER	USA	635	650	6.0		
2015-052G	EXACTVIEW 9	CANADA	635	650	6.0		
2015-053A	BEIDOU I2-S	CHINA	35606	35954	55.0	1	0
2015-054A	SKY MUSTER	AUSTRALIA	35747	35773	0.0	1	1
2015-054B	ARSAT 2	ARGENTINA	EN ROUTE TO GEO				