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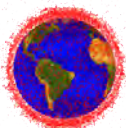
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Debris Program Office

Indian RISAT-1 Spacecraft Fragments in Late September – Update

The Indian Radar Imaging Satellite (RISAT)-1 Earth observation satellite experienced a 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.

Over 12 fragments were observed initially by the SSN. However, as of 8 November, only one piece (SSN 41797) had entered the catalog, having decayed from orbit on 12 October 2016; the remainder have decayed as well. At the current time, this event is categorized as an anomalous separation of multiple high area-to-mass ratio debris. Events like this are sometimes referred to as a shedding event. ♦

Space Debris Sensor Waiting for Launch

The Space Debris Sensor (SDS) has completed functional testing and been delivered to the Kennedy Space Center for final integration checkout with the International Space Station (ISS). From there it will go into storage until a SpaceX launch vehicle is ready to deliver it to the ISS. Launch is currently scheduled for late 2017.

The SDS is a flight demonstration of an impact sensor designed to detect and characterize impacts by small debris objects. The sensor will be attached to the ESA Columbus module facing the ISS velocity vector with one square meter of detection area. The sensor combines multiple technologies to measure the time, speed, direction, size, and density of objects greater than 50 μm in size. With this information, as well as the orbital position of each detection, the sensor should collect enough data over its intended minimum 2-year mission to update the NASA Orbital Debris Engineering Model for objects smaller than 1 mm near ISS altitudes. With lessons learned from the SDS experience, a follow-on mission to place a second-generation sensor at higher altitudes will someday provide the ability to update the risk from small debris to many operational spacecraft in low Earth orbit. ♦

Twentieth Anniversary of the ODQN

Last year marked the 20th anniversary of the NASA Orbital Debris Quarterly News (ODQN), which first published in June 1996 (the first and most recent issues are shown in the figure). Produced by the Orbital Debris Program Office (ODPO), the newsletter was developed "primarily to keep the debris community apprised of the work that is going on as a part of the research effort at NASA Johnson Space Center (JSC)" [1]. The inaugural technical editor was Dr. Robert C. Reynolds and the managing editor was Cindi A. Karpiuk. In 1996 there were 8517 tracked objects in orbit and awareness of the orbital debris problem was increasing within the U.S. government and within NASA. President Clinton's new National Space Policy included the same orbital debris passage as its precursors under presidents Reagan and Bush stating, "The United States will seek to minimize the creation of space debris" but included a revision instructing NASA and others to develop design guidelines toward this end [2].

MMOD impacts that occurred on Space Shuttle missions STS-72, STS-73 and STS-75 helped to raise awareness of the orbiter's vulnerability, leading to reinforcement of the radiators and wing leading edges (see ODQN, 2-3, July 1997, p. 9 and ODQN 3-1, January 1998, pp. 1&3. Also see multiple past issues for post-flight examination reports). Beginning in 1996, the newly released ORDEM 96 engineering model was applied to Shuttle mission risk assessment (see ODQN, vol. 2, issue 1, January 1997, pp. 6-7). STS-76 astronauts Linda Godwin and Michael Clifford installed the Mir Environmental Effects Payload (MEEP) containing the Orbital Debris Collector (ODC) experiment on the outside of the Mir shuttle docking module (ODQN 1-1, June 1996, p.1; ODQN 3-3, July 1998, p. 10; ODQN 4-2, April 1999, pp. 1-2; and ODQN 4-4, October 1999, p. 3).

Also, the Liquid Mirror Telescope began operations in Cloudcroft, New Mexico with the goal of detecting 1-cm debris objects. ODQN coverage spanned its operational lifetime (ODQN 2-4, October 1997, pp. 10-11; ODQN 3-3, July 1998, pp. 5-6; ODQN 5-1, January 2000, p. 4; ODQN 5-4, October 2000, p. 3; and ODQN 11-2, April 2007, pp. 4-7).

ODPO-related items of note in the first issue include:

• The NASA Safety Standard on Orbital Debris (NSS 1740.14) became available for general release.

• Processing of radar data from ODERACS 1 and ODERACS 2 was nearing completion.

• DAS version x.09, a beta version for user test, was released. The software ran in a DOS-PC environment and was being adapted to run under Windows 95.

• Post-flight MMOD damage to the Orbiter was compared with BUMPER code predictions as a calibration aid.

• Nick Johnson joined the ODPO staff and Don Kessler retired.

The ODQN originally was divided into four areas: modeling; measurements; risk assessment and protection; and mitigation and management. It has evolved over the years and now offers the latest events in orbital debris research, including news and statistics. With improvements in desktop publishing technology more illustrating graphs,

Twentieth Anniversary

charts, photographs, and drawings support the articles and enhance understanding of the topics. Soon after an issue is published, these illustrations often appear in scholarly publications and journals, and in media coverage. Examples where the ODQN has been referenced include Space News, Space.com, Phys.org, Universe Today, the National Geographic, the Wall Street Journal, major broadcast networks, and many other national and international news sources.

These published articles and websites often link to the ODQN webpage (https://orbitaldebris. jsc.nasa.gov/quarterly-news/newsletter.html), where each issue can be downloaded as a PDF file. Subscribers are notified by email when each issue publishes. Although the number fluctuates, in October 2016 the total number of subscribers exceeded 1700 for the first time. ODQN subscribers include scientists, engineers, and military and government policy makers with an interest in orbital debris, as well as students and individuals outside the orbital debris community. An appreciable number of subscribers are from the international space community.

References
  1. "Editor's Note," ODQN, vol. 1, issue 1, June 1996, p. 1.
  2. "The White House National Science and Technology Council," Appendix F-2, Fact Sheet National Space Policy, p. 9, September 19, 1996, accessed online November 16, 2016 at http://history.nasa.gov/appf2.pdf. See also "Key Documents in the History of Space Policy" at http://history.nasa.gov/printFriendly/spdocs.html. ◆

John Africano NASA\AFRL Orbital Debris Observatory Status and Recognition

A User Readiness Review (URR) was conducted from August through October 2016 at NASA's Johnson Space Center (JSC) for the Meter Class Autonomous Telescope (MCAT). This review certified the safe operation of the telescope and cleared the way for further development and routine operations. The MCAT is the first of two planned telescopes that will comprise the John Africano NASA/AFRL Orbital Debris Observatory (JANAODO). A second, smaller telescope, the James R. Benbrook Telescope (JRBT), is scheduled to be installed in 2017 (see Figure 1).

Both facilities are co-located on Ascension Island and will utilize various modes of operations to characterize the orbital debris environment. Data produced from the observatory instruments will be used to update and maintain the environmental models used by NASA's Orbital Debris Program Office (ODPO). ODPO's primary goal for optical measurements is to provide a distribution function for debris orbits and sizes dependent on the number of detections, brightnesses, and types of detections for the geosynchronous orbit and geostationary transfer orbit. Secondary goals of the observatory include characterization of low inclination low Earth orbits, surface material characterization via multi-band photometry, rapid response to break-up events, and the distribution functions for medium Earth orbit. Tertiary goals include supporting space situational awareness as a contributing sensor and coordination with other ground-based facilities (both radar and optical) to better define orbits and/or further investigate debris properties. ODPO will operate both telescopes autonomously by providing specific input program files that direct the telescope(s) to specific modes of operations and how to implement those requested observations.

The MCAT building was officially named in June 2015 to recognize Mr. John Africano (see Figures 2 and 3). Beginning in 1998, John worked directly with ODPO, first with the 3.0-meter Liquid Meter Telescope followed by the CCD
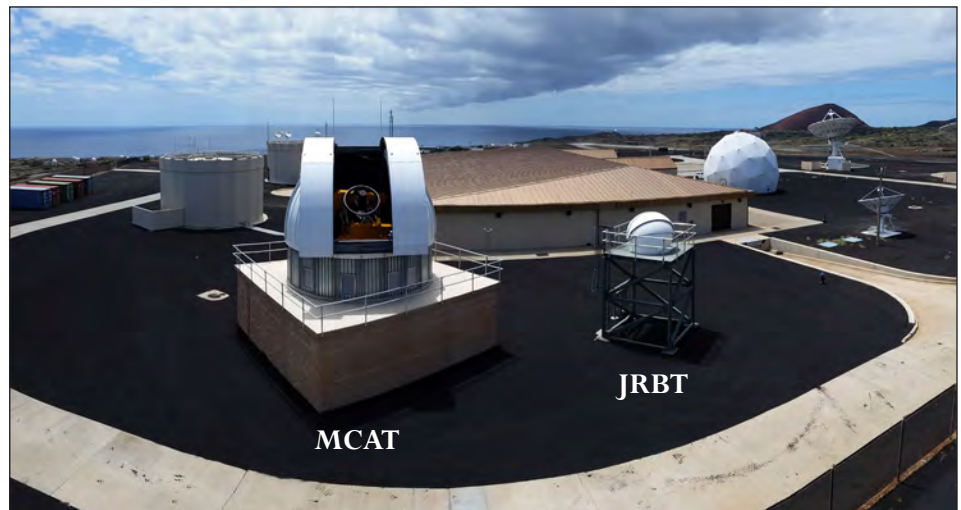
Figure 1. Overhead view of JANAODO; MCAT on left, JRBT on right.

Figure 2. John Louis Africano.

Figure 3. Plaque on MCAT Building.

Africano OD Observatory

Debris Telescope, both in Cloudcroft, New Mexico. His contributions went beyond ODPO and have been recognized by others. John served the space situational awareness, orbital debris, and astronomical communities until he passed away 26 July 2006. His dedication to these large communities helped lead to the collaborations in place today, including educating new members on the basics of photometry and astronomical instrumentation. John led and co-authored over 100 referenced publications ranging from analyses of cool stars to timing occultations, as well as space surveillance [1]. His dedication to science was acknowledged when the Jet Propulsion Laboratory
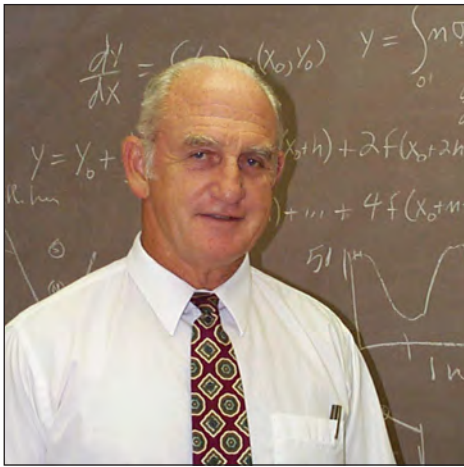

Figure 4. Prof. Jim Benbrook.

renamed Minor Planet 6391 as Africano. This year the Advanced Maui Optical and Space Surveillance (AMOS) site celebrated its 50th anniversary of operation. During the AMOS Technologies Conference, a banquet was held to celebrate the life of Mr. John Africano and his many years working at AMOS, both as an astronomer for Boeing and as a co-organizer of the annual AMOS Technologies Conference.

The second observatory, JRBT, is designed to augment and complement the observations of the primary telescope. Its primary goal is to support initial orbit determination of uncatalogued debris by immediately and persistently tracking objects of interest detected by MCAT during survey operations. JRBT is also perfectly situated to provide near-simultaneous observations of MCAT targets that, when combined with observing in different filters, will help to explore debris color-material type relationships [3].

Professor Benbrook passed away 07 February 2014 after a 40-year career teaching multiple levels of physics at the University of Houston (UH) within the College of Natural Science and Mathematics (shown in Figure 4). He was a member of the Space Physics group at UH where he participated in various test experiments including high-altitude balloon/rocket flights to study cosmic ray muons, electric fields at high altitudes during thunderstorms, and the electromagnetic radiation spectrum of lightning at high altitudes. Prof. Benbrook was also

a valuable scientist within the ODPO who worked on analyzing radar measurements acquired from the Haystack and Haystack Auxiliary radar (HAX). He was awarded two summer faculty fellowship appointments at NASA/JSC working with his previous student and ODPO program manager Gene Stansbery. The latter fellowship allowed Prof. Benbrook to bring in a UH student, Heather Cowardin, the current Orbital Debris Research and Science Operations optical measurements lead as well as the last of Professor Benbrook's students to graduate with a doctorate degree before his death. During the 2003 Faculty Fellowship Program he worked closely with the optical measurements team to support analysis on data acquired from the 3.0-meter Liquid Meter Telescope. His many contributions will be acknowledged by the dedication of the auxiliary MCAT telescope in his honor as the James R. Benbrook Telescope.

References
1. Barker, E. Obituary: John Louis Africano III, 1951-2006, Bulletin of the American Astronomical Society, v.39, issue. 4, p.1051.
2. http://www.legacy.com/obituaries/gazette/obituary.aspx?n=john-louis-africano&pid=18740550
3. Frith, J., *et al.* "Development of the NASA MCAT Auxiliary Telescope for Orbital Debris Research," SPIE 2016. ♦

PROJECT REVIEW

New Version of DAS Now Available

J. OPIELA AND A. VAVRIN

A revision of NASA's Debris Assessment Software (DAS) version 2 has been released. DAS is provided by the NASA Orbital Debris Program Office as a means of assessing, during the planning and design phase, space missions' compliance with NASA's requirements for mitigation of orbital debris. DAS is designed to assist NASA-supported programs in performing orbital debris assessments (ODA), as required by and described in NASA Technical Standard 8719.14A, Process for Limiting Orbital Debris. The software reflects the structure of the Standard and provides the user with tools to assess compliance with the requirements. If non-compliant, DAS may also be used to explore debris mitigation options to bring a program within requirements.

While DAS provides many functions useful in performing ODAs, its list of features is not exhaustive. Some analyses (*e.g.*, hardware reliability) must be performed outside DAS. The user should remember that DAS is a software tool, while the NASA Technical Standard 8719.14A contains the actual mission requirements. As with previous updates, DAS 2.1.1 includes some code changes as well as an updated software installer and User's Guide. The features of DAS have not changed with this release. The only major change is the inclusion of the latest version of the NASA Orbital Debris Engineering Model, ORDEM 3.0, which supersedes the previous NASA Orbital Debris Program Office (ODPO) model — ORDEM2000. The availability of new sensor and *in situ* data, the re-analysis of older

data, and the development of new analytical techniques has enabled the construction of this more comprehensive and sophisticated model.

New information on the debris environment comes from *in situ* sources, for debris ranging from 10 micrometers to less than 1 millimeter, and from remote sensors, for debris ranging from several millimeters to over 1 meter. These data are applied in ORDEM 3.0 using a maximum likelihood estimation as well as Bayesian and other statistical tools. The modeled debris populations are scaled in number to be compatible with the data in orbital regions where the data are collected. By extension, model debris populations are scaled in regions where no data

DAS 2.1

continued from page 4

are available (*e.g.*, sub-millimeter sizes at altitudes above the International Space Station [ISS]). Because of limitations of the future extrapolated environment, DAS 2.1.1 will assess payloads operating from the year 2010 to 2035, and objects in orbit (non-operational) from 2010 to 2070.

The higher-fidelity ORDEM 3.0 has greatly increased run-times compared to ORDEM2000. Because DAS performs an ORDEM analysis for each year an object is in orbit, these increased run-times are multiplied. DAS assessments that formerly took a few minutes will now take substantially longer. Inclusion of the ORDEM 3.0 debris population data files has also increased the hard drive space requirement to 1.6 GB.

Another important change is the updated software installer. The installer remains compatible with Microsoft Windows operating systems, both 32- and 64-bit versions. The update includes the ability to install DAS in an unprivileged (*i.e.*, non-administrator) account. As with past versions of DAS, the software must be installed in a Windows folder to which the user has both read and write access. The "Release Notes" describing these and other minor changes, as well as information on obtaining DAS 2.1.1, is available on the DAS Web page: https://orbitaldebris.jsc.nasa.gov/mitigation/das.html.

The functions of DAS are divided into three sections: Mission Editor, Requirement Assessments, and associated Science and Engineering Utilities. Other supporting features include a two-line element (TLE) converter, a user's custom material database, a plotter, and on-line help. Note that the on-line help, not updated in this version, now requires the installation of additional software (WinHlp32.exe) from Microsoft Corp. See "Error opening Help in Windows-based programs" at https://support.microsoft.com/en-us/kb/917607. Scroll to the Resolution section on the website to retrieve the appropriate download. Figure 1 shows the DAS graphical user interface (GUI) main window and the three sub-section windows.

The user enters most of the mission's information into the Mission Editor, shown in Figure 2. This part of the GUI is dominated by a data table, which the user must fill with values for each launched object. These are "high level" values, such as mission duration, operational orbit parameters, disposal orbit parameters (if applicable), mass, and area-to-mass ratio. Most of the assessments are completed using only the information in the Mission Editor.
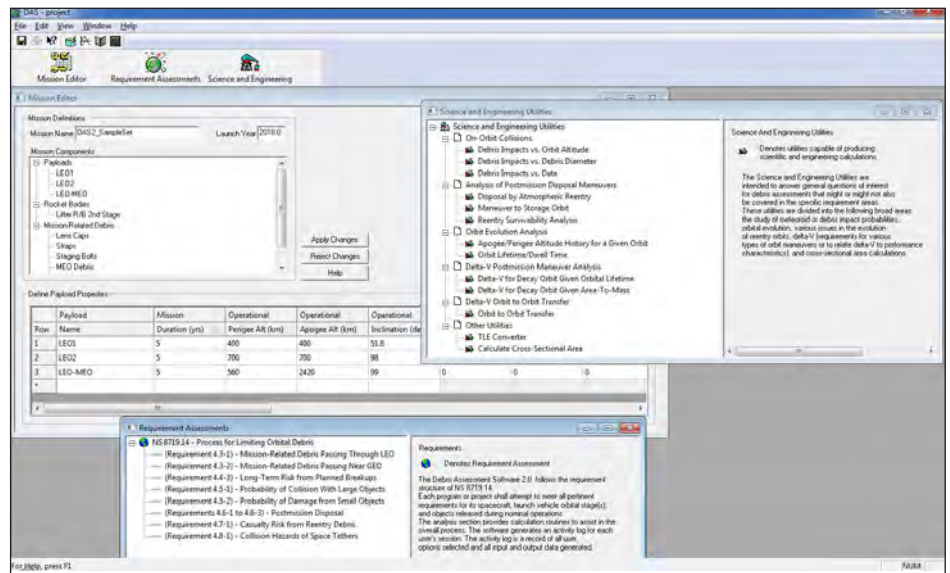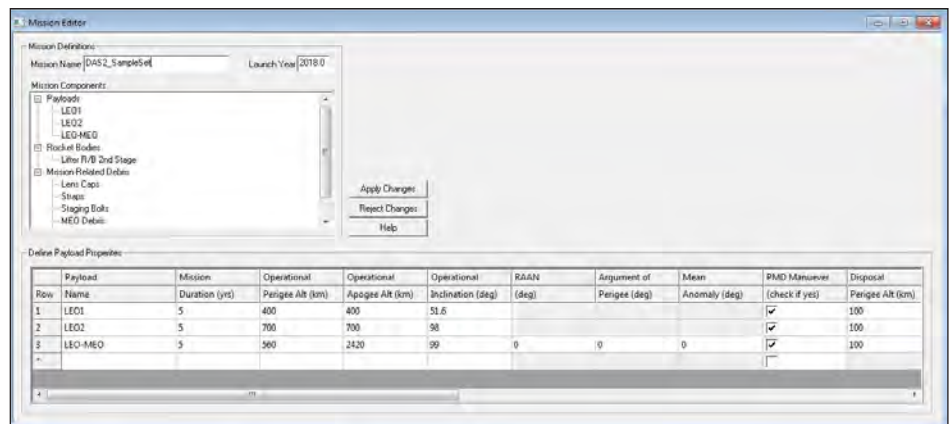
Figure 1. DAS main window.
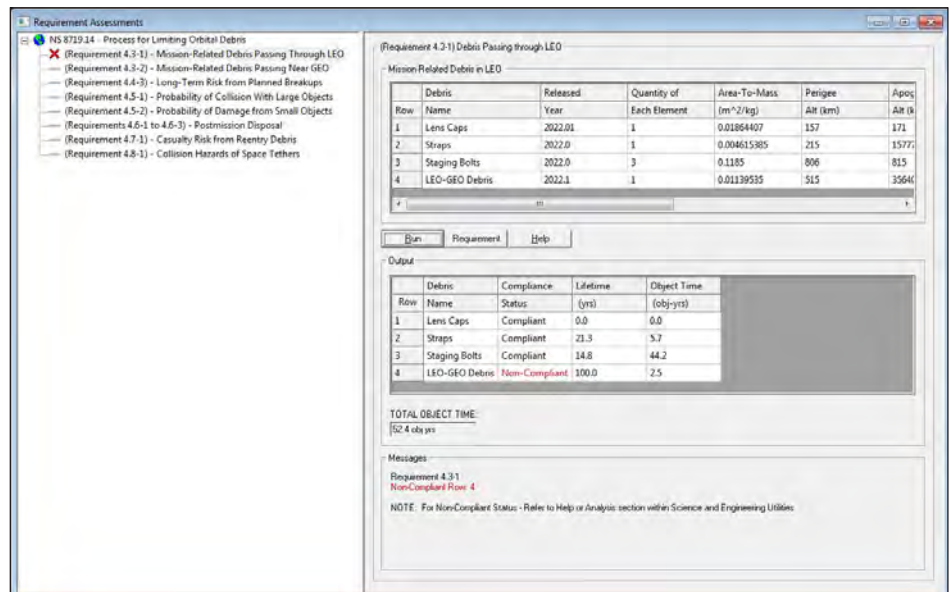

Figure 2. DAS Mission Editor.

Figure 3. DAS Requirement Assessments window.

DAS 2.1

continued from page 5

The Requirement Assessments section of DAS, shown in Figure 3, includes routines to assess the mission's compliance with most of the NASA debris-limiting requirements. The assessments do not need to be completed in sequence. Most of the assessments may be run without further input, but three of them do require the user to define the space structure in more detail. In the latter cases, the GUI provides the user with spaces and tables in which to enter the information. To assess the mission, the user selects one of the requirements from the list, enters additional information if required, and clicks the "Run" button. The results (output data and notes) then appear below the input data in the Assessments window. Any non-compliant features are flagged for the user's attention. The user may study non-compliant features using DAS's Science and Engineering Utilities. The four requirements that must be assessed using non-DAS tools/methods are 4.4-1 (limiting explosion risk due to failures during deployment and operations), 4.4-2 (design for passivation after mission), 4.4-4 (limiting short-

term risk from planned breakups), and 4.6-4 (reliability of post-mission disposal).

The Science and Engineering Utilities GUI, shown in Figure 4, provide a number of functions useful for mission planning. The utilities may aid the user in determining why some aspect of their mission failed a Requirement Assessment and help them explore options that will pass assessment. The utilities are separated into six categories: on-orbit collision, postmission disposal (PMD), orbit evolution (propagation), delta-V analysis of PMD maneuver and orbit transfer, and other utilities. The on-orbit collision routines apply the debris and meteoroid models, producing data and plots that allow the user to explore a mission's susceptibility to on-orbit impacts. Because the collision routines execute ORDEM 3.0 many times over a range of input values, these routines may require overnight run times. Analysis of PMD maneuvers includes a version of the reentry survivability analysis that may be used separately from the routine in the Requirement Assessments section. The routines for orbit evolution and delta-V analysis apply the orbit propagators and standard orbital mechanics to estimate how long an object will stay in orbit and to estimate the velocity change required for disposal. The other utilities include a simple tool for converting a two-line orbital element set (TLE) to DAS-style input values and a utility for estimating

an object's cross-sectional area. The cross-sectional area utility requires the user to "construct" a 3-dimensional (3-D) representation of the object using basic shapes. The representation may be as simple or as complex as the user requires.

The materials database editor, shown in Figure 5, simplifies the addition of materials that are not in the list of default materials provided with DAS. This allows user-specified materials to be used in the assessment of reentry survivability. The required properties must still be obtained, of course, from other reference materials. The user enters a name for the new material, and values for its density, specific heat capacity, heat of fusion, and melt temperature. (The density value is used only as a "sanity check" within the software.) This "user materials database" is stored as a comma-separated-values (CSV) file in the individual project's directory.

Though not used for requirement assessment, many of the Science and Engineering Utilities display their results as plots. The DAS plot viewer also allows the user to modify the plot properties (titles, labels, axis limits, line colors, etc.) by clicking or right clicking on plot features. Figure 6 shows a sample plot with the vertical axis properties selected. Plots may be copied directly to the Windows "clipboard" and then pasted into documents or image editors. Plots may also be saved to disk (in an internal format) and later re-loaded into the plot viewer.

All the information for a DAS session is saved in the user-specified project folder. Separate projects or cases may be stored in separate folders, which make it easy to archive or share the complete DAS project.

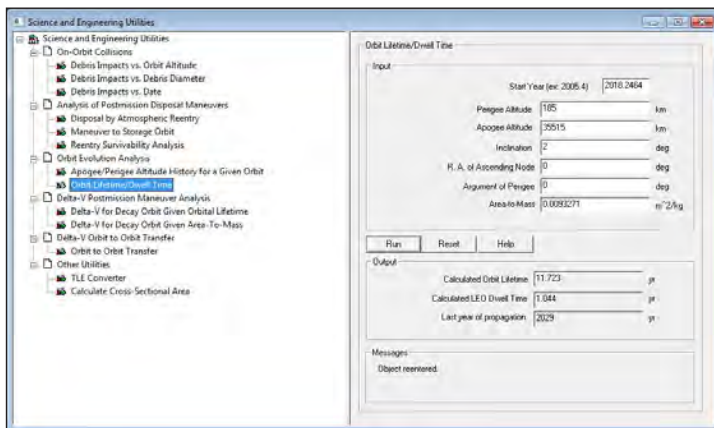DAS users should discontinue using version
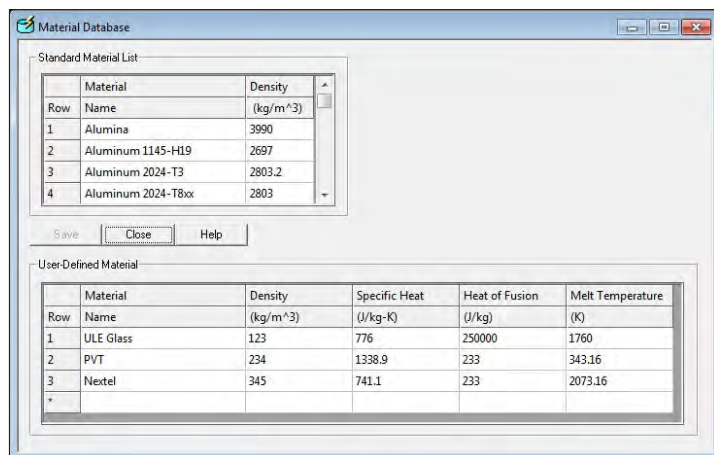
Figure 4. DAS Science and Engineering Utilities.

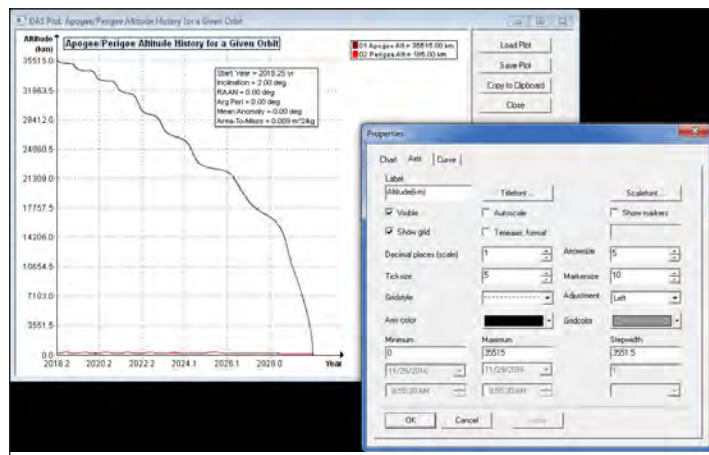*Figure 5. DAS materials database stores user-specified material properties.*

Figure 6. DAS plot viewer with axis properties selected for modification.

DAS 2.1

2.0.2 and install the new version 2.1.1. Users who have access to DAS 2.1.1 should not include results from previous versions of DAS in Orbital Debris Assessment Reports delivered to NASA. By default, the new version will install over the previous version, or users may remove the previous version using the Windows Control Panel "Add/Remove Software" feature. ♦

Reaction of Spacecraft Batteries to Hypervelocity Impact

E. L. CHRISTIANSEN, F. LYONS, B. A. DAVIS, AND D. M. LEAR

NASA has performed hypervelocity impact tests on two types of spacecraft batteries in fully charged conditions: Lithium-Ion (Li-ion) and Nickel Hydrogen (Ni-H$_2$) batteries. The impact tests were directed by the NASA Johnson Space Center Hypervelocity Impact Technology (HVIT) group in Houston Texas, and were performed at the NASA White Sands Test Facility (WSTF). The two types of batteries reacted quite differently to hypervelocity impact as described in this article, with the Li-ion batteries energetically venting their contents into the test chamber in some impact tests while the pressurized Ni-H$_2$ cells simply depressurized without major fragment release. However, neither battery ruptured or exploded in any of the hypervelocity impact tests.

The Li-ion batteries impact tested are candidates to replace the batteries used on the International Space Station (ISS) to meet energy storage requirements. The ISS battery boxes are exposed to micrometeoroid and orbital debris (MMOD) impacts and MMOD shielding on the battery boxes reduces failure risk to an acceptable level. Hypervelocity impact testing was performed to develop MMOD shields (consisting of aluminum honeycomb panel and additional fabric layers) and to verify they would protect the Li-ion battery cells, as well as to understand the consequences if an MMOD particle overwhelms the shielding and damages the battery cells. Under some conditions, thermal runaway events have been experienced in terrestrial applications of Li-ion batteries where their initial damage has propagated to neighboring cells. If thermal runaway occurs in one cell, even undamaged adjacent cells can overheat and transition into thermal runaway conditions.

Four hypervelocity impact tests were conducted on two different types of Li-ion cells to assess the consequences if the battery shielding is penetrated by MMOD. Each test article contained two fully charged Li-ion battery cells located side-by-side, although only one was targeted. A second cell was included to determine if failure could propagate to a nearby undamaged cell, and the materials surrounding each cell were representative of the battery design configuration. The impact locations were typically at the terminal end of the battery cells, although some shots to the side of the Li-ion battery were also performed. Both types of Li-ion batteries were tested with similar results. When penetrated, the impacted Li-ion battery typically increased in temperature while the cell contents were ejected and could, in some cases, auto-ignite. The neighboring cell, in most cases, increased in temperature, but in only one instance, the temperature of the undamaged cell increased to the point where it too was driven into thermal runaway.

A sequence of images of the Li-ion battery response from one test is shown in Figure 1. The projectile in this test (HITF-12143) was a 1.0-cm-diameter aluminum sphere impacting at 6.86 km/s. This test resulted in a visible deflagration as the impacted cell contents were energetically ejected over several seconds following cell penetration. Impact occurred from the bottom of the frame in Figure 1 and penetrated up through the honeycomb shielding and into one of the two side-by-side Li-ion

Figure 1. Sequence from video (1-2 seconds between frames) of hypervelocity impact test HITF-12143 on a Li-ion battery cell.

Reaction of Batteries

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Figure 2. After test imagery of shield protecting the Li-ion battery with a large 10-cm-diameter hole burned through the aluminum honeycomb panel.

Figure 3. The two Li-ion cells from HITF-12143 showing material ejected from cell interior of the impacted cell (on right), and little damage to the neighboring cell (on left) that remained operational after the test.

cells. Flame was immediately visible and about 3 seconds after impact a coherent jet of flame was seen exiting the entrance hole in the honeycomb shield, which grew in width and volume over the following 5 seconds before abruptly stopping. The aluminum honeycomb panel in front of the cell was severely melted due to the expelled cell material, which acted like a blowtorch to increase the size of the entrance hole to 10 centimeters in diameter (Figure 2). This is about four times larger than what is considered typical for this impact condition on a similar honeycomb panel without a Li-ion battery. The neighboring cell did not transition into thermal runaway. Figure 3 shows the cells after the impact test. Hundreds of metal fragments, many with dimensions greater than one centimeter, littered the target chamber floor after the test (Figure 4). Essentially all the cell contents were emptied through the impact penetration hole during the energetic aftermath of the test. Except for the penetration hole, the exterior wall of the Li-ion

Figure 4. Chamber floor after HITF-12143 showing a large number of metal fragments were ejected from the cell. Note the black and white checker-board pattern in the L-shaped ruler at the bottom of the chamber. Each block in the checker-board is 1 cm in length.

Figure 5. ISS Ni-H$_2$ cell hypervelocity test damage/perforations (on the left) Test HITF13144, 5.0-mm aluminum spherical projectile at 6.66 km/s and (on the right) HITF13165, 3.8-mm steel spherical projectile at 6.87 km/s.

Reaction of Batteries

cell remained intact. The neighboring cell was only slightly dented, but remained operational during and after the test.

Over 20 hypervelocity impact tests on fully-charged Ni-H_2 cells contained within an aluminum honeycomb panel box representative of an ISS battery box have been performed by HVIT at WSTF using steel and aluminum spherical projectile diameters of 0.3 cm to 1.0 cm at 6.6-7.2 km/s. The Ni-H_2 battery cells were constructed from Inconel 718 with minimum thicknesses in the cylinder of 0.8 mm and dome of 0.65 mm, and have a burst factor of 6 (burst pressure/operating pressure). They were fully charged and pressurized with hydrogen to 60 atm (6 MPa) prior to the impact tests. When impacted

by projectiles with sufficient size, the Ni-H_2 cell was perforated and vented. Cell voltage across the terminals declined until the cell could no longer maintain current over a load. However the cell did not rupture or fragment, nor did thermal or mechanical effects cascade to neighboring cells. In one case, the battery box cover was deformed because cell venting occurred so quickly that the box pressure increased sufficiently to deform the cover. Compared to Li-ion batteries, the Ni-H_2 cells had a much less dramatic reaction to hypervelocity impact. Figure 5 shows the results from typical tests resulting in perforation of the Ni-H_2 cell wall. ♦

Hypervelocity Impact Technology Group

SDS is Readied for Flight

The Space Debris Sensor (SDS) was developed by the Orbital Debris Program Office (ODPO) to address the lack of new data for orbital debris in the millimeter and smaller size regime. Originally named the Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor (DRAGONS), the name was changed to avoid unnecessary confusion with the SpaceX Dragon capsule, an ISS visiting vehicle that will carry the SDS to the ISS.

The SDS particle impact detection sensor is composed of two thin films located 15 cm apart with a solid back plate placed a short distance below the second thin film. Multiple acoustic impact sensors are attached to both the thin films and the back plate; however, both film surfaces also are coated with long and thin resistive lines. When a hypervelocity MMOD particle of sufficient size hits the first film, it will cut several resistive lines, travel through the film, impact the second film, pass through it, and then hit the back plate. At that point, the impact kinetic energy can be estimated from the acoustic signals received by the sensors attached to the plate.

Combining the impact timing and location data on the two films provides the impact speed and direction measurements of the impacting particle. When data from these measurements are processed and combined, information on the impact time, location, speed, direction, size of the impacting

particle, and a simple estimate of the density of the impacting particle can be collected [1, 2].

References

1. ODQN, vol. 16, issue 3, July 2012, pp. 2-3. Available at https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv16i3.pdf .

2. ODQN, vol. 19, issue 1, January 2015, pp. 2-3. Available at https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv19i1.pdf .

Captions for the images on page 10 read from left to right, top to bottom.

1. The SDS logo was inspired by a dragon image valued personally by the previous ODPO Program Manager.

2. The SDS arrives in the Space Station Processing Facility (SSPF) receiving area at Kennedy Space Center. Technicians from Jacobs-Test & Operations Support Contract (TOSC) are Richard "Chip" Chamberlain (left) and Andrew Masker (right).

3. The SDS is shown after removal from its shipping crate. TOSC technicians are Don Lisi (partially obscured on the left) and Alan Shinault (right).

4. TOSC technicians Lisi and Shinault move the SDS to the lab for final integration checkout with the ISS.

5. Bobby Ledbetter (Jacobs JETS) removes the SDS from its temporary shipping platform.

6. SDS testing in the Jacobs Engineering Development Facility in Houston, TX.

7. SDS vibration testing at NASA JSC.

8. (left to right) Chuck Claunch and Jorge Rivera (Jacobs JETS) and Joe Hamilton (NASA ODPO) perform payload rack control unit (PRCU) testing. Standing beside the SDS are (from left to right) Clay Butler (NASA), Rafael Dominguez (NASA Intern), and Rodney Ostgard (TOSC). Partially obscured individuals on the far right are Kevin Calvin (Boeing-Houston) and Santos Ribeiro (NASA).

9. The SDS electronics feature reflective tape coating for thermal management.

10. The SDS ready for flight (rear view).

11. SDS System Engineer Brian Dolan (Jacobs JETS) and the SDS ready for flight (front view).

12. Artist rendition of the future SDS location on the ISS Columbus module's External Payload Facility (EPF) Starboard-Overhead-X-axis (SOX) location, and in the SpaceX Dragon trunk. The EPF-SOX location provides SDS a field-of-regard with minimal obscuration by ISS component modules and structures. ♦

Readers should note that the ODQN publication schedule, beginning with Vol. 21, is 1 February, 1 May, 1 August, and 1 November.
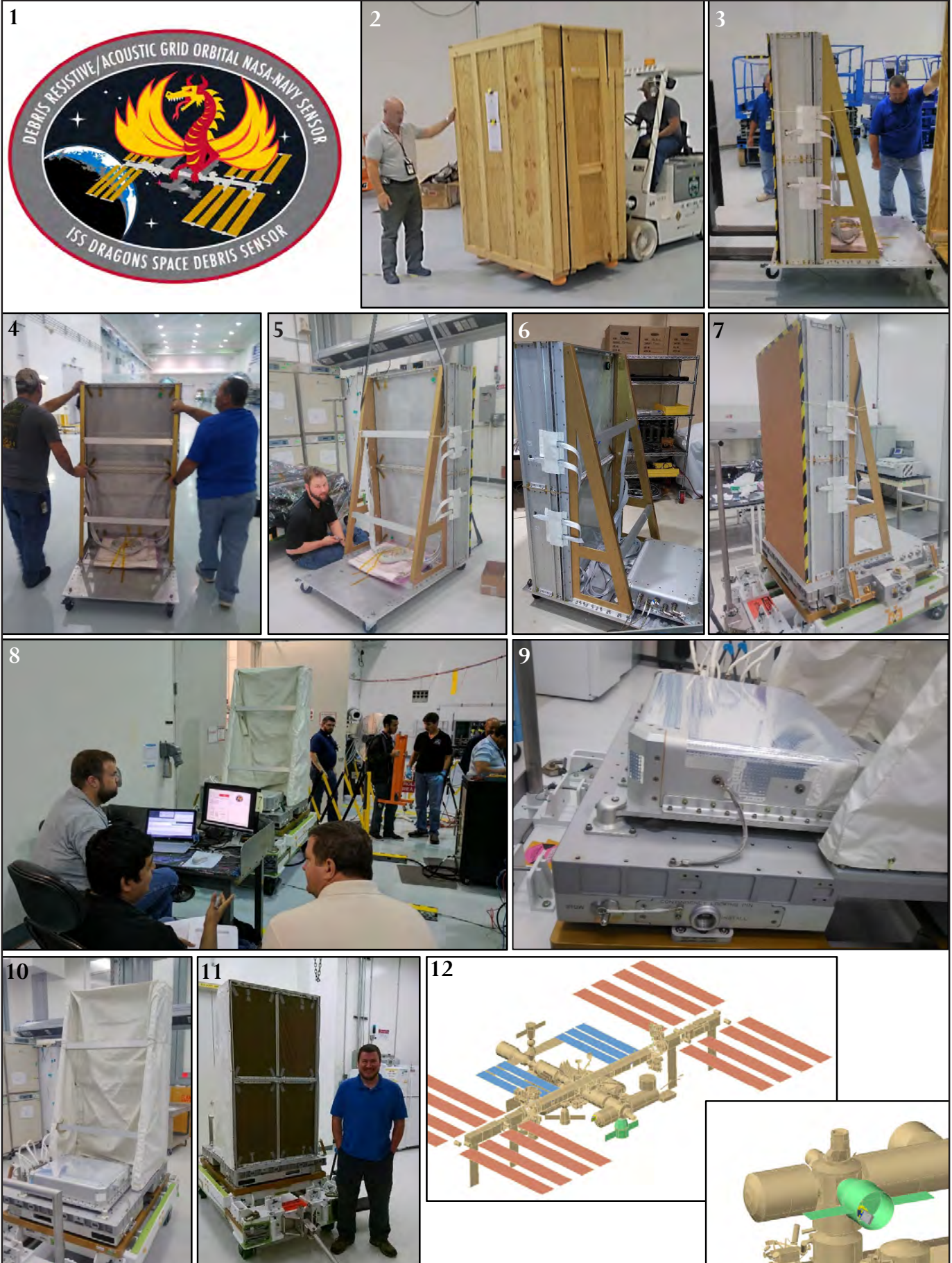
UPCOMING MEETINGS

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

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/.

26-28 April 2017: 14th Annual Developer's Workshop, San Luis Obispo, California, USA

The California Polytechnic State University will host the 14th Annual Cubesat Developer's Workshop at the university's San Luis Obispo Performing Arts Center, California, USA. Additional information about the workshop is available at http://www.cubesat.org/workshop-2017-information.

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. A side event to focus on orbital mitigation for CubeSat operators is being planned. Additional information about the conference is available at https://smallsat.org/conference/dates.

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

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

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

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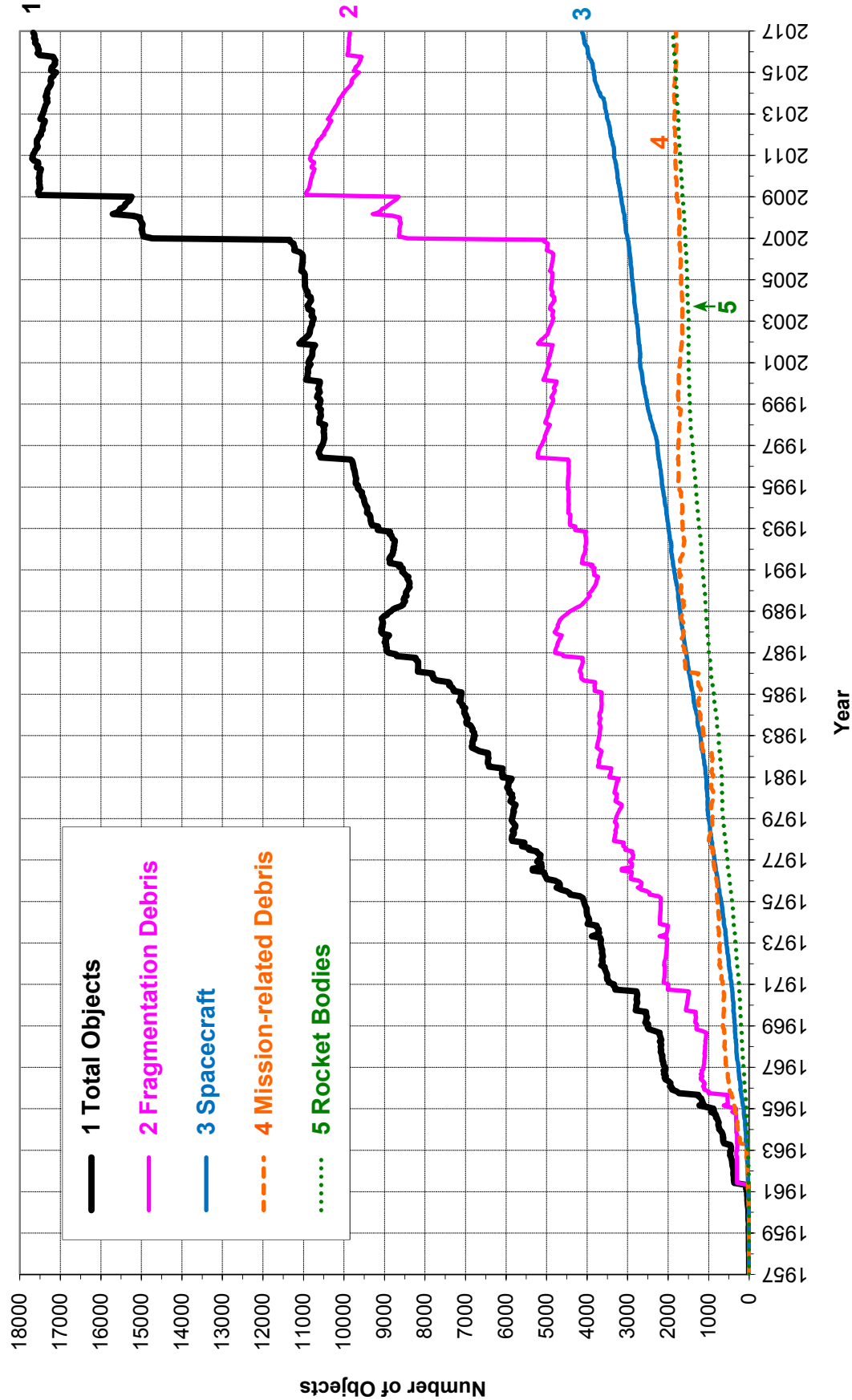
Monthly Number of Objects in Earth Orbit by Object Type

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

Monthly Mass of Objects in Earth Orbit by Object Type

Legend:
- 1 Total Objects
- 2 Spacecraft
- 3 Rocket Bodies
- 4 Fragmentation Debris
- 5 Mission-related Debris

X-axis: Year
Y-axis: Mass in Orbit (metric tons)
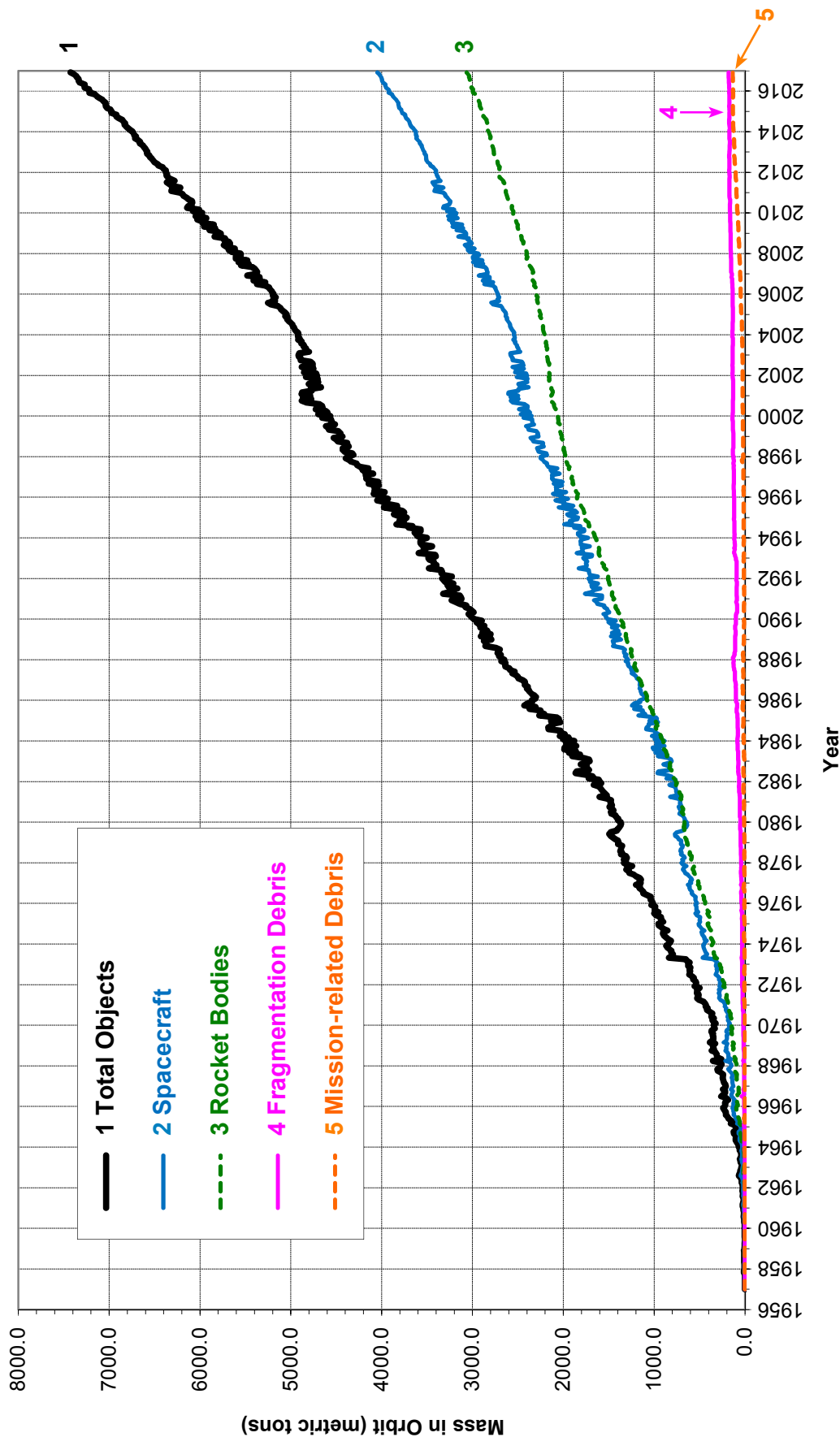
Monthly Mass of Objects in Earth Orbit by Object Type: This chart displays the mass of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network.

SATELLITE BOX SCORE

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

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	233	3573	3806
CIS	1508	4838	6346
ESA	73	60	133
FRANCE	62	470	532
INDIA	76	114	190
JAPAN	157	92	249
USA	1405	4314	5719
OTHER	789	112	901
TOTAL	4303	13573	17876

Visit the NASA
Orbital Debris Program Office
Website
www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS
1 October 2016 – 31 December 2016

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2016-060A	GSAT 18	INDIA	35773	35801	0.1	1	1
2016-060B	SKY MUSTER 2	AUSTRALIA	35777	35793	0.0		
2016-061A	SHENZHOU-11	CHINA	375	386	42.8	1	5
2016-062A	CYGNUS OA-5	USA	496	504	51.6	1	0
2016-062C	LEMUR 2 XIAOQING	USA	497	507	51.6		
2016-062D	LEMUR 2 SOKOLSKY	USA	497	507	51.6		
2016-062E	LEMUR 2 ANUBHAVTHAKUR	USA	497	508	51.6		
2016-062F	LEMUR 2 WINGO	USA	497	507	51.6		
2016-063A	SOYUZ MS-02	RUSSIA	400	410	51.6	1	0
2016-064A	HIMAWARI 9	JAPAN	35782	35793	0.0	1	0
2016-065A	SJ-17	CHINA	35758	35815	0.9	2	0
2016-066A	XPNAV-1	CHINA	491	515	97.4	1	0
2016-066B	OBJECT B	CHINA	490	512	97.4		
2016-066C	OBJECT C	CHINA	489	513	97.4		
2016-066D	OBJECT D	CHINA	489	513	97.4		
2016-066E	OBJECT E	CHINA	504	1028	98.8		
2016-066F	OBJECT F	CHINA	505	1033	98.8		
2016-066G	OBJECT G	CHINA	505	986	98.8		
2016-067A	WORLDVIEW-4	USA	614	616	98.0	1	0
2016-067B	RAVAN	USA	571	584	98.0		
2016-067C	CELTEE 1	USA	571	585	98.0		
2016-067D	OPTICUBE 04	USA	571	585	98.0		
2016-067E	AEROCUBE 8D	USA	571	587	98.0		
2016-067F	AEROCUBE 8C	USA	571	587	98.0		
2016-067G	PROMETHEUS 2-1	USA	571	588	98.0		
2016-067H	PROMETHEUS 2-3	USA	571	588	98.0		
2016-068A	YUNHAI 1	CHINA	773	792	98.5	1	0
2016-069A	GALILEO 15 (267)	ESA	23224	23250	54.6	1	0
2016-069B	GALILEO 16 (26C)	ESA	23031	23049	54.6		
2016-069C	GALILEO 17 (26D)	ESA	22965	22986	54.6		
2016-069D	GALILEO 18 (26E)	ESA	23151	23174	54.6		
2016-070A	SOYUZ MS-03	RUSSIA	400	410	51.6	1	0
2016-071A	GOES 16	US	35784	35791	0.0	1	0
2016-072A	TIANLIAN 1-04	CHINA	35782	35791	3.0	1	0
2016-073A	GOKTURK-1A	TURKEY	683	685	98.1	1	0
2016-074A	RESOURCESAT 2A	INDIA	797	843	98.7	1	0
2016-075A	WGS 8 (USA 272)	USA	EN ROUTE TO GEO			1	0
2016-076A	HTV-6	JAPAN	400	410	51.6	0	0
2016-077A	FENGYUN 4A	CHINA	35778	35799	0.3	1	0
2016-078A	CYGFM05	USA	515	538	95.2	1	0
2016-078B	CYGFM04	USA	514	536	95.1		
2016-078C	CYGFM02	USA	514	537	95.1		
2016-078D	CYGFM01	USA	515	538	95.2		
2016-078E	CYGFM08	USA	515	537	95.2		
2016-078F	CYGFM06	USA	514	535	95.1		
2016-078G	CYGFM07	USA	514	534	95.1		
2016-078H	CYGFM03	USA	514	534	95.1		
2016-079A	ECHOSTAR 19	USA	35780	35794	0.0	1	0
1998-067KR	STARS-C	USA	398	406	51.4	0	0
2016-080A	ARASE (ERG)	JAPAN	455	32113	31.4	1	0
2016-081A	TANSAT	CHINA	690	720	98.2	1	0
2016-081B	YIJIAN	CHINA	690	721	98.2		
2016-081C	SPARK 1	CHINA	690	726	98.2		
2016-081D	SPARK 2	CHINA	690	729	98.2		
2016-082A	JCSAT 15	JAPAN	35778	35796	0.0	1	1
2016-082B	STARONE D1	BRAZIL	35783	35790	0.1		
2016-083A	SUPERVIEW-1 01	CHINA	517	536	97.6	1	0
2016-083B	SUPERVIEW-1 02	CHINA	518	536	97.6		
2016-083C	BY70-1	CHINA	213	479	91.5		