National Aeronautics and Space Administration

Orbital Debris Quarterly News

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Inside...

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NASA Orbital Debris
Program Office (ODPO)

The Second International Orbital Debris Conference

The Second International Orbital Debris Conference (IOC) was held on 04-07 December 2023 in Sugar Land, Texas. The NASA Orbital Debris Program Office (ODPO) established this new NASA tradition to celebrate the 40th anniversary of the ODPO in 2019. This once-every-four-year event aims to provide a focus point for information exchange and networking for the international community to address the orbital debris problem. IOC II attracted 243 registered participants from 14 countries.

Opening remarks for IOC II were provided by members of the ODPO, including Dr. J.-C. Liou, the NASA Chief Scientist for Orbital Debris and the Convenor of IOC II. He emphasized the goal of IOC II was to promote orbital debris research activities in the United States, foster collaborations with the international community, and address the orbital debris problem for long-term sustainability of near-Earth space activities. The opening remarks were followed by four invited keynote speakers. Dr. Eric Christiansen (NASA) led the first keynote addressing risks from small, untracked orbital debris. The second keynote speaker, Dr. Tim Flohrer of the European Space Agency (ESA), presented a talk on space debris activities in ESA's Space Safety Program. The next keynote was provided by Dr. A. K. Anilkumar, Indian Space Research Organization (ISRO), who shared the highlights of recent ISRO orbital debris and space situational awareness activities. Closing the plenary session, Dr. Christophe Bonnal, the *Centre National d'Etudes Spatiales* (CNES) and International Academy of Astronautics, gave the final keynote entitled "Orbital Debris: Past, Present, and Future – An International Academy of Astronautics Space Debris Committee Perspective."

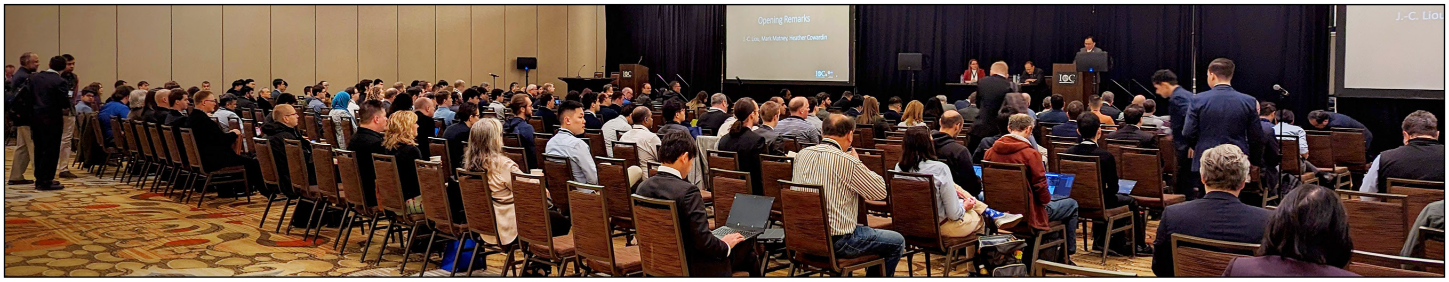
After the opening plenary, IOC II was conducted in two parallel oral sessions and two dedicated poster sessions over a four day period. A total of 124 technical papers were presented during the sessions and close to half of the papers were contributions from the international community. The papers covered optical, radar, laboratory, and *in situ* measurements; environment and risk modeling; reentry; hypervelocity impacts and protection; conjunction assessments;

IOC II

continued from page 1

mitigation and remediation; space situational awareness; space traffic coordination; and policy. They are available individually or may be downloaded as a group at https://www.hou.usra.edu/meetings/orbitaldebris2023/ to be published in the IOC II proceedings in February or March 2024.

Excellent participation from the global orbital debris community, including subject matter experts from international space agencies (ASI, CNES, DLR, ESA, ISRO, JAXA, KARI, NZ Space Agency, UKSA), the U.S. (DOD, FCC, NASA), industry, and academia, distinguished keynote speakers, contributions from the Technical Program Committee members, session chairs, the Local Organizing Committee members, organizational/logistics support of the Universities Space Research Association/Lunar and Planetary Institute, and corporate sponsors made IOC II a very successful event. ♦



ISS Maneuvers to Avoid Potential November 2023 Collision

The International Space Station (ISS) performed a Predetermined Debris Avoidance Maneuver (PDAM) on 10 November 2023 at 15:07 GMT to mitigate a projected high-risk conjunction with SL-16 debris (International Designator 1992-093KT, U.S. Satellite Catalog Number 39841). This fragment was created during one of four known breakup events; the first event occurred on 26 December 1992, within 26 hours of the 25 December launch, and the last event occurring on 30 December 1992 [1]. The breakup parent was the Cosmos 2227 rocket body, a *Zenit-2*/SL-16 second stage. The *Progress* vehicle thrusters were used to conduct a standard 0.5 m/s posigrade maneuver.

Two other *Zenit*-2 stages have experienced breakups, and one stage has experienced an anomalous event. The Ukrainian designers of the stage proactively embarked on a program to mitigate these events by investigating potential root causes, eventually focusing on residual fuel and oxidizer; in the case of the *Zenit 2* variant, approximately 900 kg of oxidizer and 450 kg of fuel may remain onboard [2] after completion of the mission. Specifically for this launch, however, 1640 kg of oxidizer was estimated to remain aboard [3]. The designers implemented a moment-free nozzle for oxidizer venting as a mitigation measure, and no further events [3, 4] have been noted through the vehicle's last flight in 2015.

This PDAM marked the 38th collision avoidance maneuver conducted by the ISS against tracked objects since 1999. The figure depicts the number of ISS collision avoidance maneuvers against objects large enough to be tracked since 1999.

References

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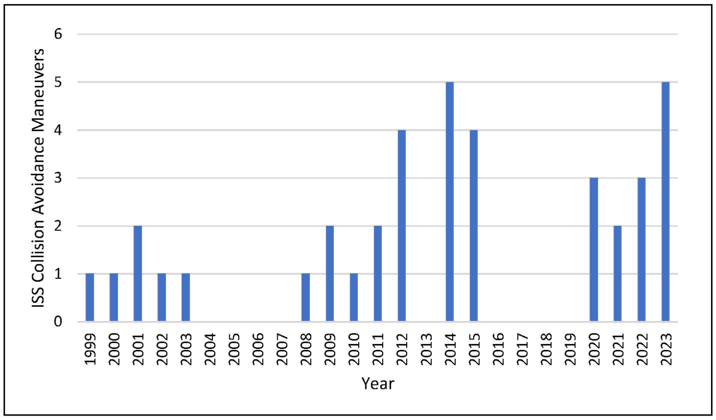

Figure. History of the ISS collision avoidance maneuvers, updated through 15 November 2023.

PROJECT REVIEW

Goldstone Radar Measurements of the Orbital Debris Environment: 2022

J. ARNOLD HEADSTREAM AND
A. MANIS

The NASA Orbital Debris Program Office (ODPO) uses several measurement data sources to statistically assess the orbital debris (OD) environment. These data are used to build, verify, and validate models of the current and future OD environment, especially the NASA Orbital Debris Engineering Model (ORDEM) [1], as well as to identify previously unknown sources of OD. Over the past 30 years, one of the instruments used to collect data by the ODPO has been the Goldstone Orbital Debris Radar (Goldstone), operated by NASA's Jet Propulsion Laboratory.

In low Earth orbit (LEO), objects with sizes larger than roughly 10 cm are tracked and cataloged by the U.S. Space Surveillance Network (SSN). Below this size, NASA uses Goldstone along with the Haystack Ultra-wideband Satellite Imaging Radar (HUSIR), operated by the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL), to measure the LEO environment. HUSIR can measure debris objects with a size as small as approximately 5 mm at an altitude of 1000 km. For smaller objects, Goldstone can extend the radar coverage to debris as small as approximately 2 mm, making it an important addition to the ODPO's measurement collection efforts. This project review presents recent Goldstone data from calendar year (CY) 2022. An in-depth report on these recent measurements remains in work.

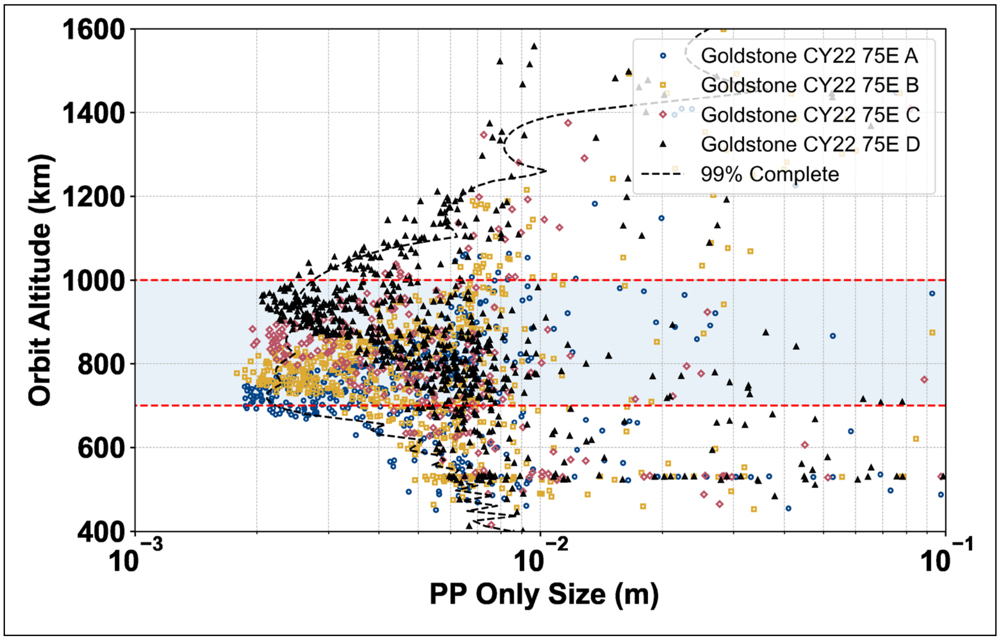

Figure 1. Orbit altitude versus SEM size of CY2022 data with 99% completeness curve overlaid (black dashed line). Altitude range of interest targeted by the Goldstone pointing plan is also identified (red dotted lines).

Goldstone is a bistatic radar that operates in a beam park mode in which the transmitter is pointed at a fixed azimuth and elevation while the receiver is pointed to intersect the transmitter beam at a targeted slant range. Objects are detected as they pass through the intersection of the transmitter and receiver beams. In early 2018, the receiver typically used for OD measurements was decommissioned and replaced with a choice between two receivers, both of which result in a greatly increased bistatic baseline from approximately 500 m to approximately 10 km. The baseline increase resulted in a significantly reduced, instantaneous, bistatic beam overlap, requiring altitudes of interest to be targeted. In response, a new pointing plan was developed and implemented in CY2020 (ODQN vol. 27, issue 1, pp. 8-9, 2023) consisting of four pointing geometries labeled *A*, *B*, *C*, and *D* that focus on altitudes between 700 km and 1000 km. This pointing plan was used throughout CY2022.

To better visualize the state of the OD environment, the more fundamental quantities measured by radar of object range, range-rate (*i.e.*, Doppler velocity), and returned power are converted to orbit altitude, inclination, and radar cross section (RCS). While it is not possible to make a complete orbit characterization given that objects are not tracked in beam park mode, inclination can be estimated by assuming a circular orbit. Furthermore, debris size can be estimated from RCS using the NASA Size Estimation Model (SEM) [2], which consists of an empirical fit to laboratory RCS data of representative debris fragments.

Typically, Goldstone records data in both the principal polarization (PP) and orthogonal polarization (OP) channels. Most of the Goldstone data received in CY2022 did not have a signal recorded in the OP channel due to hardware issues. Thus, while the conversion from RCS to debris size via the SEM typically uses the total RCS calculated from both the OP and PP channels, the SEM sizes presented here use the size converted from the PP RCS only for both CY 2021 and CY 2022. Although this underestimates the true sizes, it provides a way to consistently compare measurements on a year-to-year basis.

Targeted pointings have reduced altitude coverage compared to the historical transmitter/receiver configuration, yet they have provided an increase in sensitivity [3], resulting in a minimum completeness size of 2.7 mm at 1000 km altitude for CY2022. The completeness size represents the lower limit at which it should be possible to detect 99% of objects larger than that cut-off size.

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Goldstone Measurements

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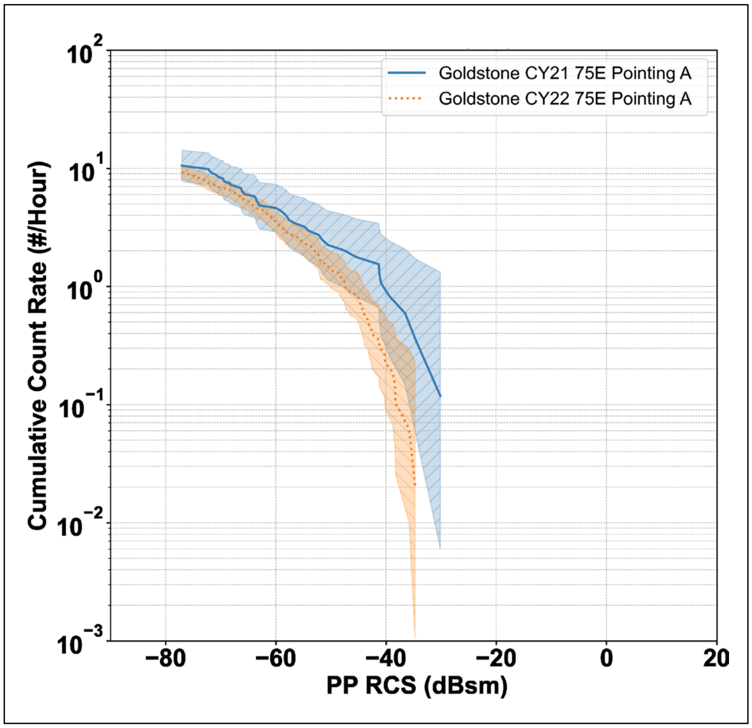

Figure 2. Cumulative count rate versus PP RCS for Goldstone in CY2021 and CY2022 restricted to orbit altitudes of 660.3 km to 806.4 km, the main beam overlap of pointing A. Shaded regions represent the 2σ Poisson uncertainties.

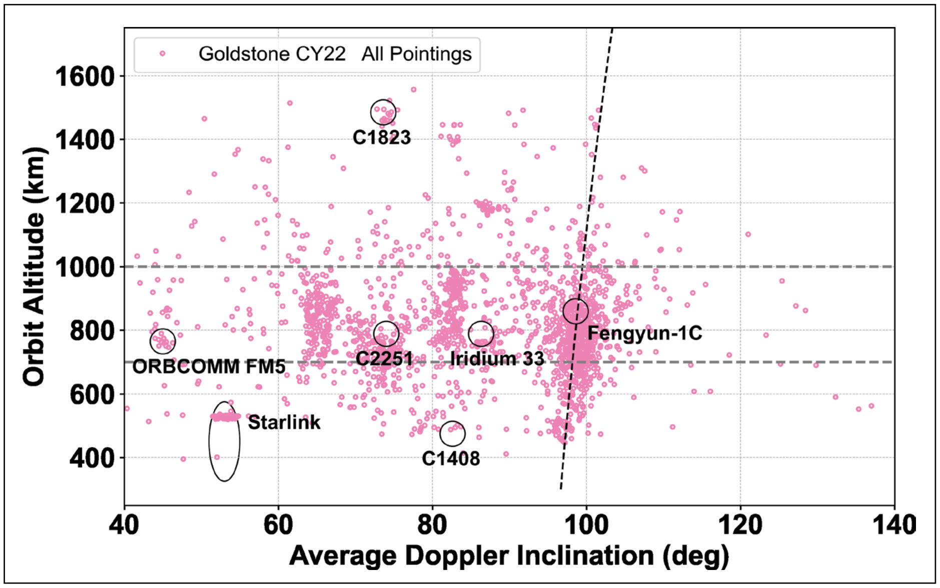

Figure 3. Orbit altitude versus average Doppler inclination for Goldstone CY2022. The Sun-synchronous condition, assuming a circular orbit, is indicated by the dashed black line. Notable debris clouds due to fragmentation events are highlighted with black circles, while detections associated with the Starlink constellation are emphasized by the black oval near 53° Doppler inclination. Altitude region of interest targeted by the Goldstone pointing plan is demarcated by the horizontal grey dashed lines.

Figure 1 shows a plot of orbit altitude versus PP-only debris size for detections measured by Goldstone in CY2022 for each pointing, with the altitude-dependent 99% completeness cut-off across all four pointings marked by the black dashed curve.

Figure 2 shows the cumulative count rate as a function of PP RCS from Goldstone pointing *A* in CY2021 and CY2022. A significant change in the OD environment may manifest as large changes in the count rate from one year to the next, or significant changes to the RCS or size distribution. Figure 2 shows that the cumulative count rate distributions for pointing *A* in CY2021 and CY2022 are similar within uncertainties. There is a larger difference in cumulative count rates for PP RCS greater than -40 dBsm due to the small number of objects detected by Goldstone at those larger RCS, leading to a larger uncertainty in the count rate. Other pointings show generally similar behavior.

Plotting orbit altitude versus inclination as in Figure 3 allows orbital families of debris to be identified. Several notable on-orbit fragmentation events are highlighted by black circles, where the center of each circle denotes the altitude and inclination of the parent body at the time of the event. These include the *Fengyun*-1C anti-satellite (ASAT) test, the breakup of Cosmos 1823 (C1823), the fragmentation of ORBCOMM FM-5, the accidental collision between Cosmos 2251 (C2251) and Iridium 33, and the Cosmos 1408 (C1408) ASAT test. Additionally, a grouping of detections associated with the Starlink constellation at 53° inclination is indicated by a black ellipse.

Due to the dynamic nature of the OD environment, it is also useful to look at year-to-year variations in the Goldstone measurements. Figure 4 shows the surface area flux as a function of altitude and inclination for Goldstone pointing *D* in CY2021 and CY2022. Flux is defined as the number of objects detected within the surface area of the radar beam per unit time (year). To aid in comparing flux in different years, which may exhibit different instrumental sensitivities, surface area flux to a limiting size is used (> 3 mm). The apparent year-over-year rise in the 500 km to 550 km altitude bin is due to the increasing number of Starlink constellation spacecraft. Even though these spacecraft operate at a lower altitude than that targeted by the *D* pointing, they show up in these higher altitude pointings as well due to sidelobe detections.

Monitoring year-to-year changes in the LEO OD environment is essential input for the continued development of ODPO models of the current state and evolution of LEO OD. Ongoing radar measurements with

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Goldstone Measurements

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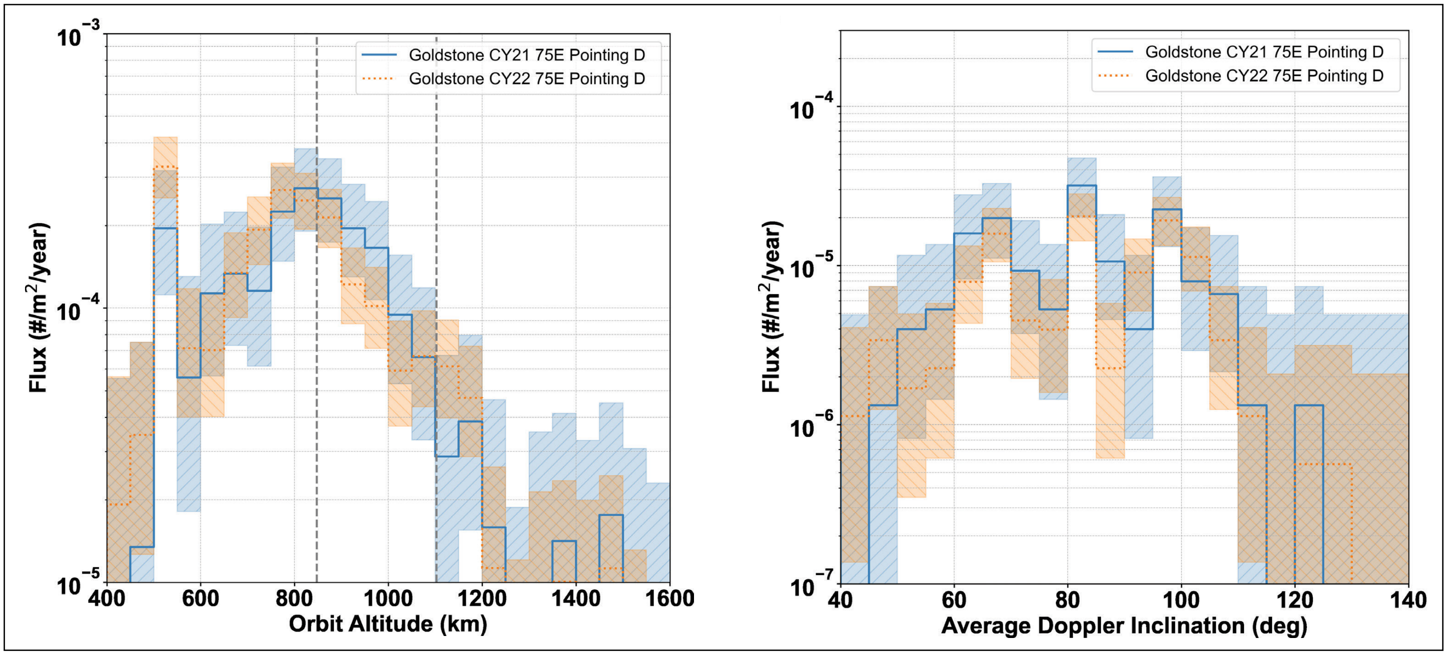

Figure 4. Flux versus orbit altitude (left) and doppler inclination (right) between Goldstone CY2021 and CY2022, at the D pointing and limited to sizes > 3 mm. The shaded regions represent the 2σ uncertainty bounds. The vertical dashed lines represent the limits of the main beam overlap for Goldstone pointing D. Flux versus Doppler inclination is restricted to orbit altitudes of 847.5 km to 1102.8 km, the main beam overlap for pointing D.

Goldstone will continue to provide valuable information on OD in the 1 mm to 5 mm size regime not covered by other sensors.

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2. Xu, Y.-L. and Stokely, C. "A Statistical Size Estimation Model for Haystack and HAX Radar Detections," 56th International Astronautical Congress, Fukuoka, Japan, (2005).
3. Murray, J., *et al*. "Optimizing altitude sampling and sensitivity with the Goldstone Orbital Debris Radar," 2nd International Orbital Debris Conference, Sugarland, TX, (2023).

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Orbital Debris Program Office Laboratory Updates

H. COWARDIN, J. OPIELA, P. ANZ-MEADOR, AND C. CRUZ

NASA's Orbital Debris Program Office (ODPO) was established at Johnson Space Center (JSC) in 1979 to conduct a full range of research on orbital debris, including environmental measurements, modeling, and mitigation policy development. Under the orbital debris measurements and modeling umbrella, the ODPO houses two primary research facilities used to support telescopic optical measurements and *in situ* analyses as well as curation of returned spacecraft hardware, hypervelocity impact fragments, and spacecraft materials for further study. Data collected in these facilities have been used to develop orbital debris models, including NASA's Orbital Debris Engineering Model (ORDEM). This article will highlight the updates and ongoing research in both the Optical Measurement Center (OMC) and the Fragment Analysis Facility (FAF).

The OMC was established in 2005 as a research facility for photometric and spectroscopic laboratory measurements of targets and materials associated with spacecraft and orbital debris. The OMC simulates space-based illumination conditions using equipment and techniques that replicate telescopic observations and source-target-sensor orientations. The OMC layout is shown in Figure 1.

For photometric measurements, the OMC utilizes a light source, a rotary arm for phase angle placement (angle defined by the illumination source-target-sensor), a charge-coupled device (CCD) detector, and a robotic arm to mount and orient targets and materials. A 75 W Xenon arc lamp simulates solar illumination over the 200 nm to 2500 nm wavelength spectrum, mounted on the rotary arm that provides the capability of

continued on page 6

Laboratory Updates

continued from page 5

rotating 360° (*i.e.*, ±180°phase angle) about the target (see Figure 1, Left, instrument layout and Figure 1, Right, measurements at 15° phase angle). A 1000 × 1500-pixel CCD collects images with a 5-filter wheel attachment that houses Johnson/Bessel or Sloan Digital Sky Survey broadband filters. A 6-degree-of-freedom robotic arm orients the mounted target or material within a 4π steradian volume and collects pseudo-bidirectional reflectance distribution function measurements that assess the magnitude of an object in various aspect angles. A field spectrometer acquires diffuse reflectance measurements over wavelengths from 350 nm to 2500 nm with 1 nm resolution. This spectrometer has also been used to acquire pre-flight measurements of spacecraft, as shown in Figure 2, and of returned, space-exposed materials. The spectral data are stored in NASA's Orbital Debris Spacecraft Materials Spectral Database, available to U.S. citizens by request.

The key objective for the OMC is to simulate telescopic observations to support updates to the ODPO's optical Size Estimation Model (oSEM), which currently assumes a spherical shape approximation. The research conducted in the OMC has characterized a variety of targets to produce light curves and assess different phase functions that could be employed in the oSEM. Recent investigations of target shapes provide a baseline for more complex fragments from hypervelocity impact experiments. In addition to measured optical data, the ODPO uses ray-tracing software to simulate the OMC set-up and targets under the same illumination conditions used in the laboratory. Incorporating the simulations allows the ODPO to verify the measurement data and any potential experimental biases and to investigate a larger number of targets with known material surface coatings.

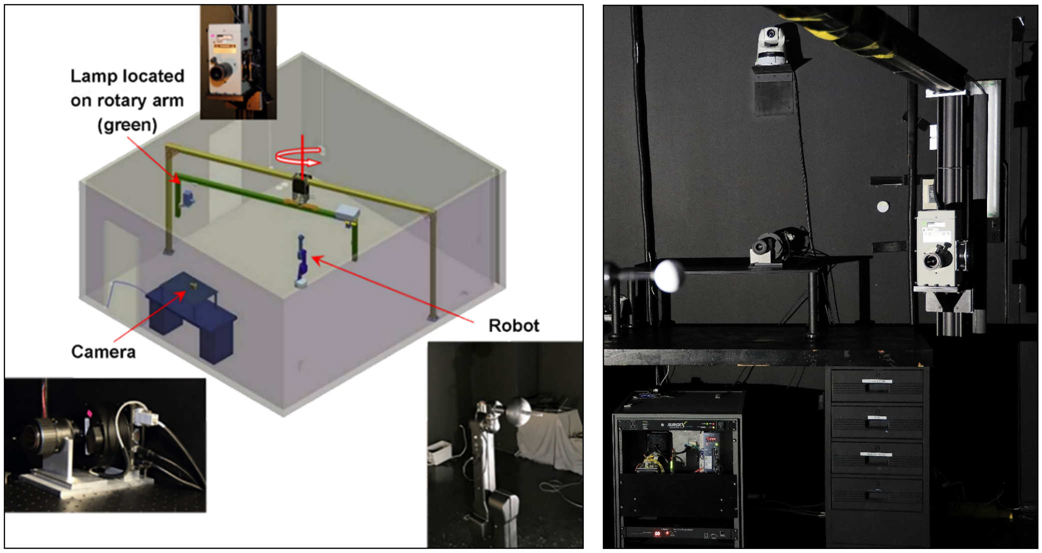

Figure 1. Left: Computer generated drawing showing the OMC instrumentation, specifically the CCD camera, illumination source mounted on the 360° rotary arm, and 6 degree-of-freedom robotic arm centered in the laboratory. Right: Digital image from target perspective on robotic arm at a 15° phase angle.

One of the most recent fragment collections undergoing analysis in the OMC is from the DebriSat project, which is a collaboration between ODPO, the Space Force Space Systems Command, The Aerospace Corporation, the University of Florida (UF), and the Air Force Arnold Engineering Development Complex (AEDC). DebriSat was designed and fabricated as a 56 kg class spacecraft representative of modern spacecraft in the low Earth orbit (LEO) environment. In 2014, a successful laboratory hypervelocity impact test was conducted at AEDC using DebriSat as the target to simulate a catastrophic fragmentation event. The DebriSat fragments were collected and continue to be assessed at UF to measure each unique fragment's size, shape, material, color, mass, and derived parameters such as cross-sectional area, area-to-mass ratio, volume, and bulk density (ODQN, vol. 13, issue 3, July, pp. 3-5). Once fragments have completed characterization at UF and the data are uploaded into the DebriSat database, the fragments are shipped to JSC for further characterization to support analyses for the oSEM as well as the NASA SEM for radar-based measurements; they are then carefully stored in the ODPO's FAF [1].

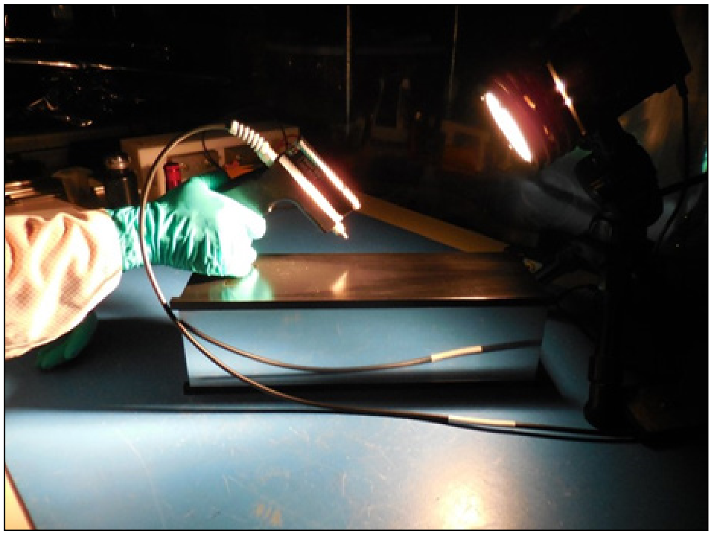

Figure 2. Image of pre-flight spectral measurements being conducted on a 6U CubeSat.

To date, the UF DebriSat team has collected and partially characterized over 275,000 fragments, a number which continues

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Laboratory Updates

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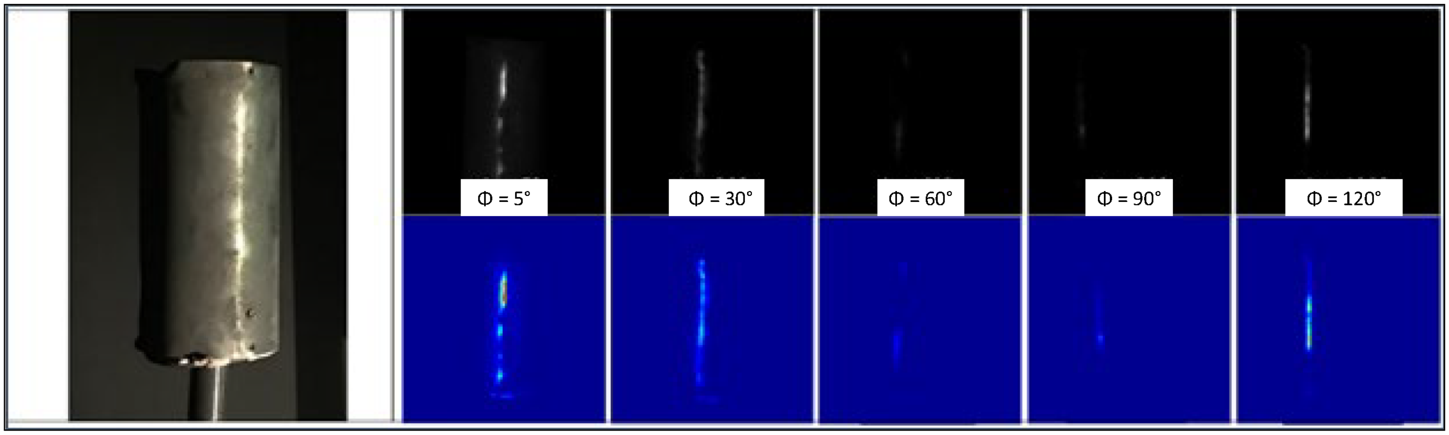

Figure 3. DebriSat fragment, telescope shell, being characterized in the OMC at various phase angles (ϕ). Top row (black and white) as viewed from CCD, bottom row, color map applied to top row for intensity characterization.

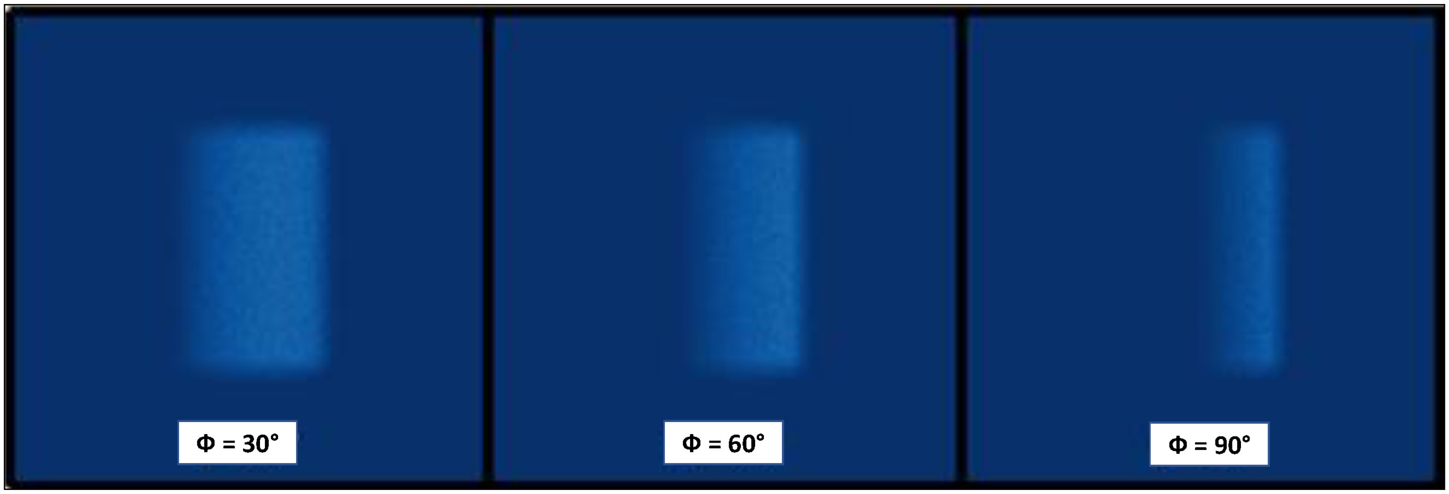

Figure 4. Simulation of cylinder with length-to-diameter ratio of 3:2 at various phase angles (ϕ).

to increase. These data are being assessed to support an update to NASA's Standard Satellite Breakup Model, which predicted a total of 85,000 fragments 2 mm and larger would be generated from the DebriSat laboratory impact experiment, based on empirical data that used legacy spacecraft construction techniques and materials. DebriSat has provided key information on material and associated shape distributions for modern-day spacecraft versus previous laboratory impact tests that did not include as many low-density materials, such as multilayer insulation (MLI), polymers, and solar cells. This shape parameterization is being assessed from a risk perspective for updating ballistic limit equations [2]. Figure 3 displays one DebriSat fragment and the data collected at various phase angles in the OMC. Figure 4 shows data from the corresponding simulation.

Another component that directly supports the sub-millimeter orbital debris measurements is *in situ* data (*i.e.*, returned surface inspections and analyses). The ODPO works closely with NASA's Hypervelocity Impact Technology (HVIT) team to analyze returned surfaces from various spacecraft. Data collections used in ORDEM development include Space Transportation System (STS or the Space Shuttle) exposed surfaces; Hubble Space Telescope (HST) MLI; and a Wide Field Planetary Camera 2 radiator [3]. These provide key data on the LEO orbital debris environment from approximately 1993 to 2011, and data analysis continues with materials returned from HST for future ORDEM development and verification and validation efforts.

To incorporate the current state of the orbital debris environment into ORDEM, the ODPO and HVIT are actively investigating returned surfaces from the International Space Station (ISS) and its visiting vehicles. The number and size of craters and penetrations allows derivation of population sizes and, via damage equations, impacting particle sizes.

To further support the inspection and characterization of these returned surfaces, the ODPO operates two state-of-the-art KEYENCE digital microscopes, the VHX-7000 and the EA-300 in its

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Laboratory Updates

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Figure 5. Overview of KEYENCE microscopes in FAF analyzing a multilayer insulation blanket that was returned from HST on STS-125.

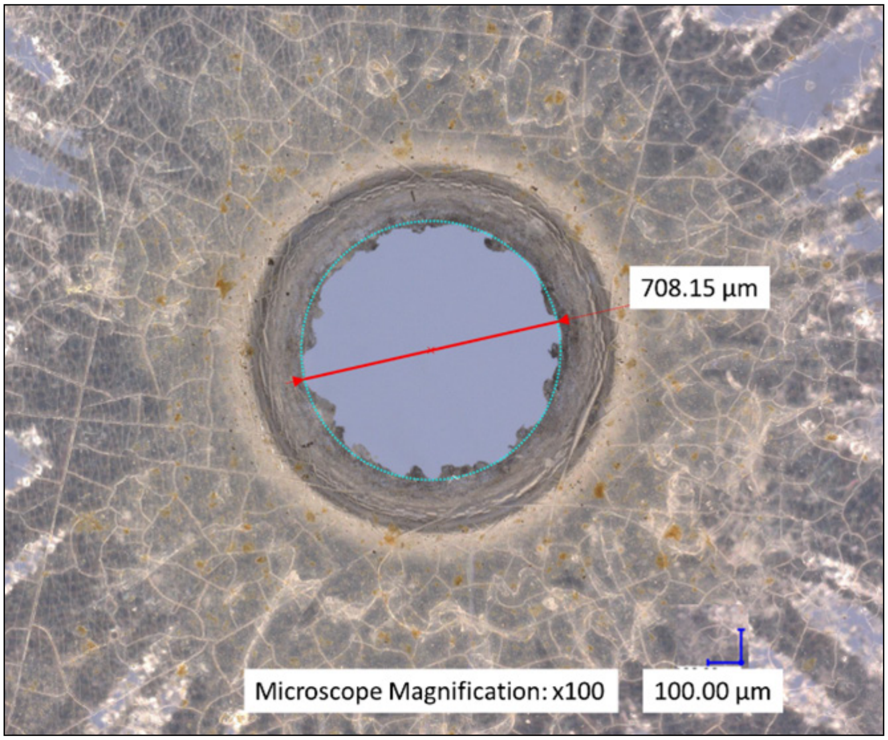

Figure 6. Example VHX-7000 image of returned HST thin-film outer surface, with impact feature.

second facility, the FAF, as shown in Figure 5. The VHX-7000 is used to characterize impact features on returned *in situ* materials that may be complex (*e.g.*, thin film polymers, as shown in Figure 6) and to image the craters so that they can be properly cut and prepared for further analysis with scanning electron microscopes available within NASA's Astromaterials Research and Exploration Science Division at JSC. Data from an electron microscope can identify any remaining projectile residue, indicating elements that are associated with orbital debris or micrometeoroids. The FAF's EA-300, an elemental analyzer, uses laser-induced breakdown spectroscopy for initial inspection to identify elements of interest. For larger materials, such as the HST MLI, the material can be mounted on a computer-controlled *x-y* gantry table in the FAF (seen in the background of Figure 5) and examined with the VHX-7000.

In addition to the scientific analyses conducted in the FAF, the facility provides a secure, environmentally controlled location for storing fragments from various impact experiments, returned surfaces, and other spacecraft materials of interest in near-pristine state (*e.g.,* solar cells and various polymers direct from manufacturers). The FAF recently completed NASA's User Readiness Review, certifying that the facility has met all NASA safety requirements and is approved for full operations.

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CONFERENCE AND WORKSHOP REPORTS

Applied Space Environments Conference 2023

The fourth biennial Applied Space Environments Conference (ASEC) 2023 was held 09-13 October in Huntsville, Alabama. ASEC 2023 was sponsored by Space Weather Solutions and organized by the NASA Engineering and Safety Center's Space Environments Technical Discipline Team. ASEC is a forum for the space environment engineering and applied space science community to report recent work on characterizing space environments and their effects on space systems, to network and develop collaboration opportunities, and to discuss the space environment discipline's ability to support current and future space programs.

Four keynote presentations were given over the first four conference days. The first covered the NASA Space Weather Program, part of NASA's Heliophysics Division, and highlighted the applied research activities, flight missions, and space weather analysis of interest to the space environment engineering and applied space science community. The second provided an overview of NASA Marshall Space Flight Center's Engineering Directorate and space weather related missions, facilities, and other activities. The third keynote focused on the National Oceanic and Atmospheric Administration's Space Weather Prediction Center efforts, including space weather effects on previous missions and the need for continued and expanded partnerships to support future missions to Earth orbit, the Moon, and Mars. The final keynote was from NASA's Planetary Protection Office, addressing the increasing need for planetary protection-related technologies and policies to prevent contamination from returned extraterrestrial samples.

The conference this year focused on eight primary topics: 1) lunar environment considerations, 2) radiation effects and modeling, 3) charging effects and modeling, 4) space environment testing and instrumentation, 5) space weather environments, 6) meteoroids and orbital debris, 7) materials in space, and 8) current and future missions. Two invited presentations from the NASA Orbital Debris Program Office were presented on "Misconceptions and Reality of Orbital Debris Risk" and "An Overview of Ground-based Radar and Optical Measurements Utilized by the NASA Orbital Debris Program Office." The ASEC2023 Book of Abstracts from the conference can be accessed at https://spaceweathersolutions.com/wp-content/uploads/2023/10/ASEC2023-Book-of-Abstracts.pdf. ♦

The 13th Ablation Workshop

The 13th Ablation Workshop was hosted and organized by NASA's Ames Research Center and Analytical Mechanical Associates from 07-09 November 2023 in Mountain View, California. Members of the NASA Orbital Debris Program Office joined over 150 participants from across the U.S. and additional representatives from Europe and Japan for this in-person workshop.

This workshop focused on improving the understanding of ablation, with presentations of analytical, experimental, and computational results; material characterization; and verification and validation of models. It was broken into 10 sessions across 3 days and comprised 43 presentations with a poster session of 29 posters.

Workshop proceedings, including presentations and past abstracts, can be found at https://ablation.engr.uky.edu/. ♦

2023 SmallSat Education Conference

The 2023 SmallSat Education Conference was conducted 27-28 October 2023 at the Center for Space Education at the Kennedy Space Center in Titusville, Florida. The global SmallSat participants were from academia, industry, and government. This year's conference had 37 presentations with topics such as research and development for SmallSat subsystems; SmallSat operation; specific case studies; and the state of SmallSat programs in secondary and tertiary schools. Special topics were covered by 13 posters and 7 workshops with university and industry leaders.

The NASA Orbital Debris Program Office presented an overview of its activities across measurements, modeling, and mitigation, including a special emphasis on the DebriSat project's goal to improve breakup models for modern spacecraft. The presentation aimed to raise awareness of orbital debris issues and new opportunities for research among members of the SmallSat research, development, and production community.

The SmallSat Education Conference allows representatives from industry, academia, and government to assemble and discuss ways to include SmallSat projects in classrooms from elementary school through postgraduate education, focused on how to build, operate, and dispose of them responsibly. Details on the topics presented and sponsors for this event are available at https://www.smallsateducation.org/. ♦

UPCOMING MEETINGS

27-28 March 2024: 2024 Spacecraft Anomalies and Failures (SCAF) Workshop

The annual two-day Spacecraft Anomalies and Failures (SCAF) workshop hosted by the NASA Engineering and Safety Center and National Reconnaissance Office will be held 27-28 March 2024. This workshop provides an opportunity to discuss a broad range of space-related areas to exchange concepts for improvements of space systems, such as anomaly and failure attribution tools and root cause analysis practices. The agenda for this workshop and logistical information can be found here: https://www.nasa.gov/nase/conferences/scaf2024.

23-25 April 2024: 2024 CubeSat Developers Workshop, San Luis Obispo, California, USA

The CubeSat Developers Workshop is an annual 3-day meeting focused on small-satellite development hosted by Cal Poly CubeSat Laboratory. The workshop provides a forum for industry professionals, small satellite developers, and students to engage on various aspects of CubeSat design, development, and operations. The abstract submission closed 16 January 2024. Additional details on the workshop can be found at the following website: https://www.cubesatdw.org/.

13-21 July 2024: Committee on Space Research (COSPAR) 2024, Bexco, Busan, Korea

The 45th Assembly of the Committee on Space Research (COSPAR) Scientific Assembly will convene in the Busan Exhibition and Convention Center, BEXCO. The COSPAR panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "A Sustainable Space Exploration: from the Mitigation of Space Debris in Earth's Orbit to the Safeguard of Planetary Environments." The main topics to be discussed in the PEDAS.1 sessions will include orbital debris observations and measurements; environmental models and databases; modeling and risk analysis; mitigation and remediation; sustainable space activities; national and international standards and guidelines; mega-constellation impact on astronomy; pollution of the Earth's atmosphere by rocket launches and re-entries; cis-lunar space; Lunar and Martian environment. The abstract submission period closes on 9 February 2024. Please see the PEDAS.1 session website at https://www.cospar-assembly.org/admin/session_cospar.php?session=1295 and the Assembly website at: https://www.cospar2024.org/.

14-18 October 2024: 74th International Astronautical Congress (IAC), Milan, Italy

The IAC will convene in 2024 with a theme of "Responsible Space for Sustainability." The IAC's 22nd IAA Symposium on Space Debris will cover space debris detection, tracking and characterization; modeling; risk analysis; hypervelocity impact and risk assessments; mitigation; post-mission disposal and space debris removal; operations in the space debris environment; political, legal, institutional, and economics aspects of mitigation and removal; and orbit determination and propagation. Interactive presentations on space debris topics will also be provided to allow more digital display capabilities for attendees. The abstract submission deadline is 28 February 2024. Additional information for the 2024 IAC is available at https://www.iafastro.org/events/iac/international-astronautical-congress-2024/ and https://www.iac2024.org/. ◆

Announcements

The ODPO has an opening for a postdoctoral fellow via the NASA Postdoctoral Progam. This position would support an *in situ* sensor in development to characterize the small (millimeter-sized) orbital debris environment in low Earth orbit. Opportunities are available to support the development of the sensor and provide oversight and analyses that directly support future flight missions. For more information on this position, please see the request.

CONFERENCE ABSTRACTS FROM THE NASA HYPERVELOCITY IMPACT TECHNOLOGY TEAM

The Second International Orbital Debris Conference (IOC), 04-07 December 2023, Sugar Land, Texas, USA

Authors	Abstract Title and Summary
E. CHRISTIANSEN, B. DAVIS, D. LEAR, AND F. LYONS	***Alternative MMOD Shielding Concepts*** This paper provides results of hypervelocity impact tests to evaluate meteoroid and orbital debris (MMOD) shielding options that offer benefits in terms of mass savings and improved safety for spacecraft MMOD protection. [6086]
E. CHRISTIANSEN, T. PRIOR, D. LEAR, AND H. COWARDIN	***The NASA JSC Hypervelocity Impact Technology (HVIT) Office*** This paper describes the capabilities of the Hypervelocity Impact Technology (HVIT) group/laboratory/office at the NASA Johnson Space Center (JSC). [6087]
K. DEIGHTON, E. CHRISTIANSEN, D. LEAR, AND J. HYDE	***Orion Artemis I As Flown MMOD Analysis*** This paper compares the prediction for MMOD impacts on the Orion capsule during the Artemis I flight to the number observed post-flight inspection to support ORDEM and MEM environment modeling. [6102]
K. DEIGHTON	***STENVI Conversion*** An Excel macro converts ORDEM 3 igloo files into the STENVI portable MMOD file format. [6103]
K. HOFFMAN, B. TULABA, J. HYDE, AND E. CHRISTIANSEN	***Micrometeoroid and Orbital Debris (MMOD) Testing, Ballistic Limit Definition and Risk Assessment of the Exploration Extravehicular Mobility Unit (xEMU)*** HVI testing, ballistic limit equation definition, and MMOD risk assessment while in low earth orbit and on the lunar surface were performed for the exploration extravehicular mobility unit (xEMU). xEMU was developed internally by NASA JSC personnel. [6100]
J. HYDE, E. CHRISTIANSEN, D. LEAR, AND M. LOZANO	***SpaceX Dragon Post Flight MMOD Inspection Campaign*** The ISS visiting vehicle MMOD impact database documents >300 impact features, primarily in thermal protection systems (TPS) surfaces. [6019]
J. MILLER, B. DAVIS, K. DEIGHTON, AND R. MCCANDLESS	***Rear Wall Perforation in Whipple Shields for Low- and High-Density Particles*** Study of survivability of Whipple shields due to long exposure to modern definitions of meteoroids. [6137]
C. SEAY, K. MULCAHEY, M. HALL, J. CLEMENTS, E. CHRISTIANSEN, *ET AL.*	***The Next Generation of Kevlar® Fiber for Improved Micrometeoroid and Orbital Debris Protection*** DuPont™ CoreMatrix™ Technology is a step-change in debris protection that allows for improving system-level performance while removing heavier portions of the system. [6013]

The NASA Orbital Debris Photo Gallery has high resolution, computer-generated images of objects in Earth orbit that are currently being tracked. Photos and graphics may be freely downloaded from the NASA ODPO webpages, unless they include a third-party credit line. In these cases, permission must be granted by the copyright owner.

CONFERENCE ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The Second International Orbital Debris Conference (IOC), 04-07 December 2023, Sugar Land, Texas, USA

Authors	Abstract Title and Summary
P. ANZ-MEADOR, M. MURRAY, J. HYDE, E. CHRISTIANSEN, AND H. COWARDIN	***A Survey of ISS and Visiting Vehicle Returned Surfaces for Environmental Characterization and Computer Model Development*** We examine the impact record of ISS-associated returned surfaces, including identifying impactor residues as MM or OD. We compare OD data with the NASA Orbital Debris Engineering Model (ORDEM) version 3.2 predictions. [6116]
J. ARNOLD, J. MURRAY, A. MANIS, AND M. MATNEY	***Radar Measurements of Orbital Debris from the Haystack Ultra-Wideband Satellite Imaging Radar (HUSIR): 2020 to 2022*** This presentation will provide an overview of recent Haystack Ultra-wideband Satellite Imaging Radar (HUSIR) measurements of the LEO debris environment for calendar years 2020 to 2022. [6020]
H. COWARDIN, P. ANZ-MEADOR, M. MURRAY, C. CRUZ, J. OPIELA, *ET AL*.	***Highlights of NASA's Orbital Debris Program Office In Situ and Laboratory Measurements*** This paper highlights the state-of-the-art facilities hosted at NASA Johnson Space Center that directly support NASA's Orbital Debris Program Office and laboratory measurements focused on ground-based impact experiments and returned surfaces. [6101]
C. CRUZ, B. BUCKALEW, J. ARNOLD, A. MANIS, AND H. COWARDIN	***The Completion of a Geosynchronous Earth Orbit Survey with the Eugene Stansbery-Meter Class Autonomous Telescope*** This paper presents GEO observational data collected by the Eugene Stansbery-Meter Class Autonomous Telescope (ES-MCAT), commencing its first GEO survey and ongoing data collections and updates. [6153]
B. GREENE, C. OSTROM, J. MARICHALAR, AND P. MENDOZA	***Recent Updates to the Object Reentry Survival Analysis Tool (ORSAT) Version 7.1*** Several additions and improvements have been included in the ORSAT 7.0 and 7.1 updates, including a new thermal demise model, a pyrolysis model for fiber-reinforced plastics, and an aerodynamic demise model. This paper will describe the updates. [6138]
P. HICKSON, B. BUCKALEW, AND C. CRUZ	***Automated Detection and Analysis of Resident Space Objects with the 1.3-Meter Eugene Stansbery-Meter Class Autonomous Telescope*** We report the results of Monte-Carlo simulations to determine the sensitivity and completeness of optical observations of RSOs obtained with the 1.3-m ES-MCAT telescope on Ascension Island. [6148]
S. HULL, T. HYDE, AND J.-C. LIOU	***NOAA-17 Break-up Engineering Investigation*** The NOAA-17 weather satellite broke up almost eight years after it was decommissioned and passivated. An investigation was made to determine the cause of the break-up. Recommendations include an update to the decommissioning procedure. [6127]
A. MANIS, J. ARNOLD, J. MURRAY, B. BUCKALEW, AND C. CRUZ	***An Overview of Ground-based Radar and Optical Measurements Utilized by the NASA Orbital Debris Program Office*** Overview of the ground-based radar and optical sensors used by the NASA Orbital Debris Program Office for a statistical sampling of the orbital debris environment and building orbital debris environment models. [6045]
M. MATNEY, P. ANZ-MEADOR, A. KING, A. MANIS, J. SEAGO, *ET AL.*	***An Overview of NASA's Newest Engineering Model, ORDEM 4.0*** This paper will present the latest work on NASA's newest orbital debris engineering model, ORDEM 4.0. It will discuss the latest data and new model capabilities, including debris shape. [6026]
P. MENDOZA, B. GREENE, AND C. OSTROM	***Development of a Composite Material Aerodynamic Demise Model for the Object Reentry Survival Analysis Tool (ORSAT)*** NASA's new material demise model for spacecraft reentry considers FRP composite shredding by aerodynamic forces, verified by analyzing fragments, and will undergo further testing for validation. [6147]

continued on page 13

NASA IOC II Conference - cont.

continued from page 12

Authors	Abstract Title and Summary
J. MURRAY, J. ARNOLD, A. MANIS, AND M. MATNEY	***Optimizing Altitude Sampling and Sensitivity with the Goldstone Orbital Debris Radar*** NASA's Goldstone radar has been measuring small debris in LEO since 1993. A new annual survey plan was developed and used in 2020-2021 to sample altitudes from 700 km to 1000 km, producing the most sensitive terrestrial radar measurements to date. [6011]
M. MURRAY, P. ANZ-MEADOR, AND H. COWARDIN	***Hypervelocity Impact Characterization on Hubble Space Telescope Multi Layer Insulation*** This paper discusses hypervelocity test conditions and parameters with resultant impact hole analyses of multi-layered insulation (MLI) samples. Damage equations and scanning electron microscopy (SEM) results are estimated and presented. [6095]
C. OSTROM, P. ANZ-MEADOR, AND J. OPIELA	***Revisiting the Effectiveness of Debris Mitigation by Back-Dating Fragmentation Events*** Back-dating fragmentation events can show a different way to understand the evolution of the orbital debris environment and the effectiveness of orbital debris mitigation measures. [6023]
C. OSTROM, J. MARICHALAR, B. GREENE, A. ANDRADE, E. HOFFMAN, *ET AL.*	***Validating Drag and Heating Coefficients for Hollow Reentry Objects in Continuum Flow Using a Mach 7 Ludwieg Tube*** Measurements of drag and heating in a hypersonic wind tunnel, in air and helium, compared to numerical smulations using continuum and rarefied CFD techniques, and their implementation in the reentry code ORSAT. [6024]
J. SEAGO, H. COWARDIN, P. ANZ-MEADOR, A. MANIS, J. MILLER, *ET AL.*	***An Approach to Shape Parameterization Using Laboratory Hypervelocity Impact Experiments*** This paper overviews the SOCIT and DebriSat impact tests, comparing their fragment parameter distributions with each other and with the NASA SSBM. The comparative analyses facilitate the potential use of data with future environmental debris models. [6145]
S. SIAM, B. GREENE, J. SIEBER, H. COWARDIN, N. FITZ-COY	***Using Machine Learning to Infer Material Properties of Debris Fragments from X-ray Images in the DebriSat Project*** ML-based approach to classify debris materials in x-ray images of foam-embedded fragments. Supervised/unsupervised techniques used, incl. CNNs, SVMs, clustering algorithms, Random Forest, and autoencoders due to limited pre-labeled data for debris <10 mm. [6154]
A. VAVRIN, A. KING, AND A. MOORHEAD	***Cloud Computing Option for Modeling the Debris Environment*** To better serve the user community and support NASA Headquarters' Digital Transformation Initiative, ORDEM is available as a cloud-based web application. [6131]
A. VAVRIN, J. SEAGO, A. KING, P. ANZ-MEADOR, AND M. MATNEY	***Statistical Approach on Utilizing Ground-based Experiments to Model Break-up Events*** A unique approach to model an on-orbit breakup event using the direct statistical sampling of the SOCIT and DebriSat data ensembles. [6139]

The full papers will be posted on the IOC II conference website and are available for download at: https://www.hou.usra.edu/meetings/orbitaldebris2023/technical_program/.

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SATELLITE BOX SCORE

(as of 04 December 2023, cataloged by the
U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Spacecraft*	Spent Rocket Bodies & Other Cataloged Debris	Total
CHINA	652	4374	5026
CIS	1566	5603	7169
ESA	97	31	128
FRANCE	86	534	620
INDIA	112	101	213
JAPAN	202	113	315
UK	695	1	696
USA	7212	5056	12268
OTHER	1185	86	1271
Total	11807	15899	27706

* active and defunct

Visit the NASA
Orbital Debris Program Office Website
https://orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

01 September 2023 – 31 October 2023

Intl.* Designator	Spacecraft	Country/ Organization	Perigee Alt. (KM)	Apogee Alt.(KM)	Incli. (DEG)	Addnl. SC	Earth Orbital R/B	Other Cat. Debris
1998-067	ISS dispensed objects	Various	415	417	51.6	1	0	2
2023-131A	STARLINK-30375	US	517	519	43.0	21	0	0
2023-132A	ADITYA-L1	IND	EN ROUTE TO SUN-EARTH L1			0	1	0
2023-133A	WILDFIRE 4	US	935	950	81.0	12	0	0
2023-134A	STARLINK-30397	US	558	560	43.0	20	0	0
2023-135A	TIANQI 21	PRC	809	828	50.0	3	1	0
2023-136A	YAOGAN-33 03	PRC	693	697	98.2	0	1	0
2023-137A	XRISM	JPN	564	578	31.0	0	1	5
2023-137D	SLIM	JPN	EN ROUTE TO MOON					
2023-138A	STARLINK-30304	US	558	560	43.0	21	0	0
2023-139A	YAOGAN-40 01A	PRC	851	854	86.0	0	2	1
2023-139C	YAOGAN-40 01B	PRC	851	854	86.0			
2023-139D	YAOGAN-40 01C	PRC	851	854	86.0			
2023-140A	USA 346	US	36184	36233	12.0	0	1	0
2023-140B	USA 347	US	36214	36234	12.0			
2023-140C	USA 348	US	36147	36231	12.0			
2023-141A	STARLINK-30285	US	509	510	53.1	20	0	0
2023-142A	VICTUS NOX	US	449	464	97.3	0	0	0
2023-143A	SOYUZ MS-24	CIS	416	418	51.6	0	1	0
2023-144A	STARLINK-30432	US	558	560	43.0	21	0	0
2023-145A	YAOGAN-39 02A	PRC	490	503	35.0	0	1	1
2023-145D	YAOGAN-39 02B	PRC	493	502	35.0			
2023-145E	YAOGAN-39 02C	PRC	489	506	35.0			
2023-146A	STARLINK-30465	US	558	560	43.0	21	0	0
2023-147A	STARLINK-30450	US	517	519	43.0	21	0	0
2023-148A	STARLINK-30712	US	509	511	53.1	20	0	0
2023-149A	YAOGAN-33 04	PRC	694	696	98.1	0	1	0
2023-150A	NOUR 03	IRAN	424	447	60.0	0	1	0
2023-151A	STARLINK-30396	US	519	522	43.0	21	0	0
2023-152A	YAOGAN-39 03A	PRC	493	501	35.0	0	1	1
2023-152C	YAOGAN-39 03B	PRC	494	501	35.0			
2023-152E	YAOGAN-39 03C	PRC	493	503	35.0			
2023-153A	STARLINK-30537	US	515	518	43.0	21	0	0
2023-154A	KUIPER-P2	US	478	498	30.0	0	0	0
2023-154B	KUIPER-P1	US	478	498	30.0			
2023-155A	T2V	THAI	623	625	97.9	9	0	0
2023-156A	STARLINK-30514	US	508	511	53.1	20	0	0
2023-157A	PSYCHE	US	HELIOCENTRIC			0	0	0
2023-158A	STARLINK-30568	US	516	520	43.0	21	0	0
2023-159A	YUNHAI 1-04	PRC	780	782	98.6	0	1	0
2023-160A	STARLINK-30604	US	517	519	43.0	21	0	0
2023-161A	STARLINK-30594	US	508	512	53.1	20	0	0
2023-162A	STARLINK-30795	US	517	519	43.0	22	0	0
2023-163A	YAOGAN-39 04A	PRC	494	502	35.0	0	1	1
2023-163C	YAOGAN-39 04B	PRC	488	509	35.0			
2023-163E	YAOGAN-39 04C	PRC	491	505	35.0			
2023-164A	SZ-17	PRC	374	384	41.5	0	1	0
2023-165A	COSMOS 2570	CIS	900	910	67.2	1	1	1
2023-166A	STARLINK-30802	US	509	510	53.1	21	0	0
2023-167A	STARLINK-30753	US	517	519	43.0	22	0	0
2023-168A	TIANHUI 5A	PRC	606	609	97.8	0	1	1
2023-168C	TIANHUI 5B	PRC	606	609	97.8			

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

Notes: 1. Orbital elements are as of data cut-off date 31 October. 2. Additional spacecraft on a single launch may have different orbital elements. 3. Additional uncatalogued objects may be associated with a single launch.