National Aeronautics and Space Administration

Orbital Debris Quarterly News

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Inside...

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The Intentional Destruction of Cosmos 1408

The Russian Federation conducted a direct-ascent anti-satellite (ASAT) test in the early hours (Universal Time) of 15 November 2021. The target of the test was Cosmos 1408 (International Designator 1982-092A, Catalog Number 13552), a derelict Soviet Electronic and Signals Intelligence (ELINT) Tselina-D-class spacecraft. The 1750 kg spacecraft was launched in 1982 into a mission orbit of 666 × 636 km altitude with an inclination of 82.6 degrees. Prior to the ASAT test, Cosmos 1408 had decayed to an orbit of 490 × 465 km altitude (Figure 1).

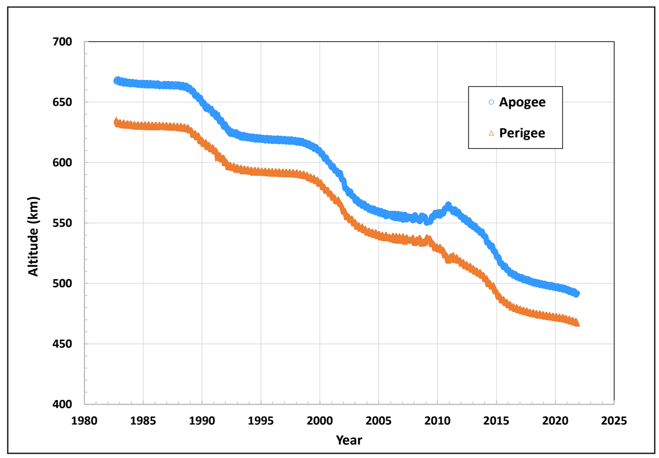

Figure 1. The apogee (top) and perigee (bottom) altitude history of the Cosmos 1408 spacecraft.

The outcome of the ASAT test was a catastrophic destruction of Cosmos 1408. The 18th Space Control Squadron (18 SPCS) of the U.S. Space Force, using the global Space Surveillance Network (SSN), identified more than 1500 pieces of large, trackable fragments associated with the breakup of Cosmos 1408 shortly after the event. As of 7 March 2022, 1604 Cosmos 1408 fragments with unique identifications and orbital element histories have been added to the U.S. Satellite Catalog [1]. More tracked Cosmos 1408 fragments are expected to be added to the catalog in the coming weeks and months. Figure 2 shows the Gabbard diagram of the cataloged Cosmos 1408

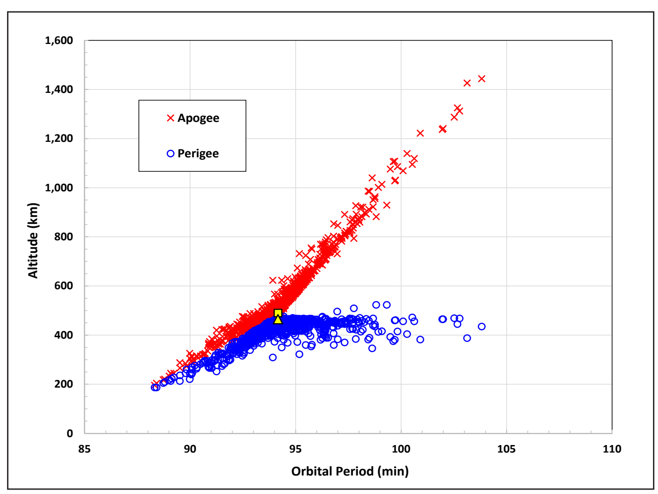

Figure 2. Gabbard diagram of the cataloged Cosmos 1408 fragments. Approximate epoch is 17 January 2022. The apogee (yellow square) and perigee (yellow triangle) altitudes of the parent object, Cosmos 1408, at the time of the breakup are also shown.

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Cosmos 1408 Break-up

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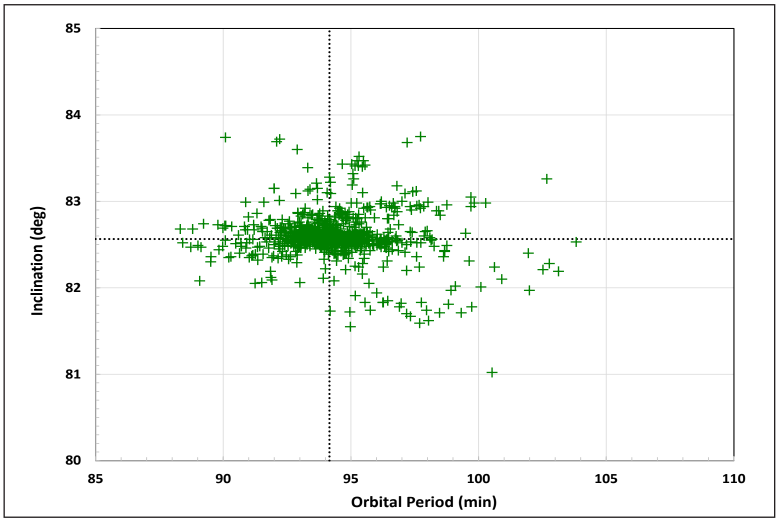

Figure 3. Inclinations vs orbital period of the cataloged Cosmos 1408 fragments, based on 17 January 2022 data. Approximately 60% of the fragments have inclinations higher than the inclination of the spacecraft prior to the ASAT test.

fragments, based on 17 January 2022 data. The apogee altitudes of some fragments reach as high as 1440 km. The lower-left part of the cross pattern indicates that the orbits of many lower altitude fragments are rapidly circularizing toward their final reentries. Figure 3 shows the orbital periods versus inclinations of the cataloged Cosmos 1408 fragments. The vertical and horizontal dotted lines indicate the period and inclination, respectively, of the Cosmos 1408 spacecraft just prior to the ASAT test. Approximately 60% of the fragments have inclinations higher than their parent spacecraft.

Figure 4 shows the historical increase of the cataloged objects. The top curve represents the total number of objects while the four curves below the total represent the population breakdown, including fragmentation debris, spacecraft, rocket bodies, and mission related debris. Fragmentation debris has dominated the historical cataloged population. The three major jumps in fragmentation debris were results of the ASAT test on Fengyun-1C conducted by China in 2007, the accidental collision between Cosmos 2251 and the operational

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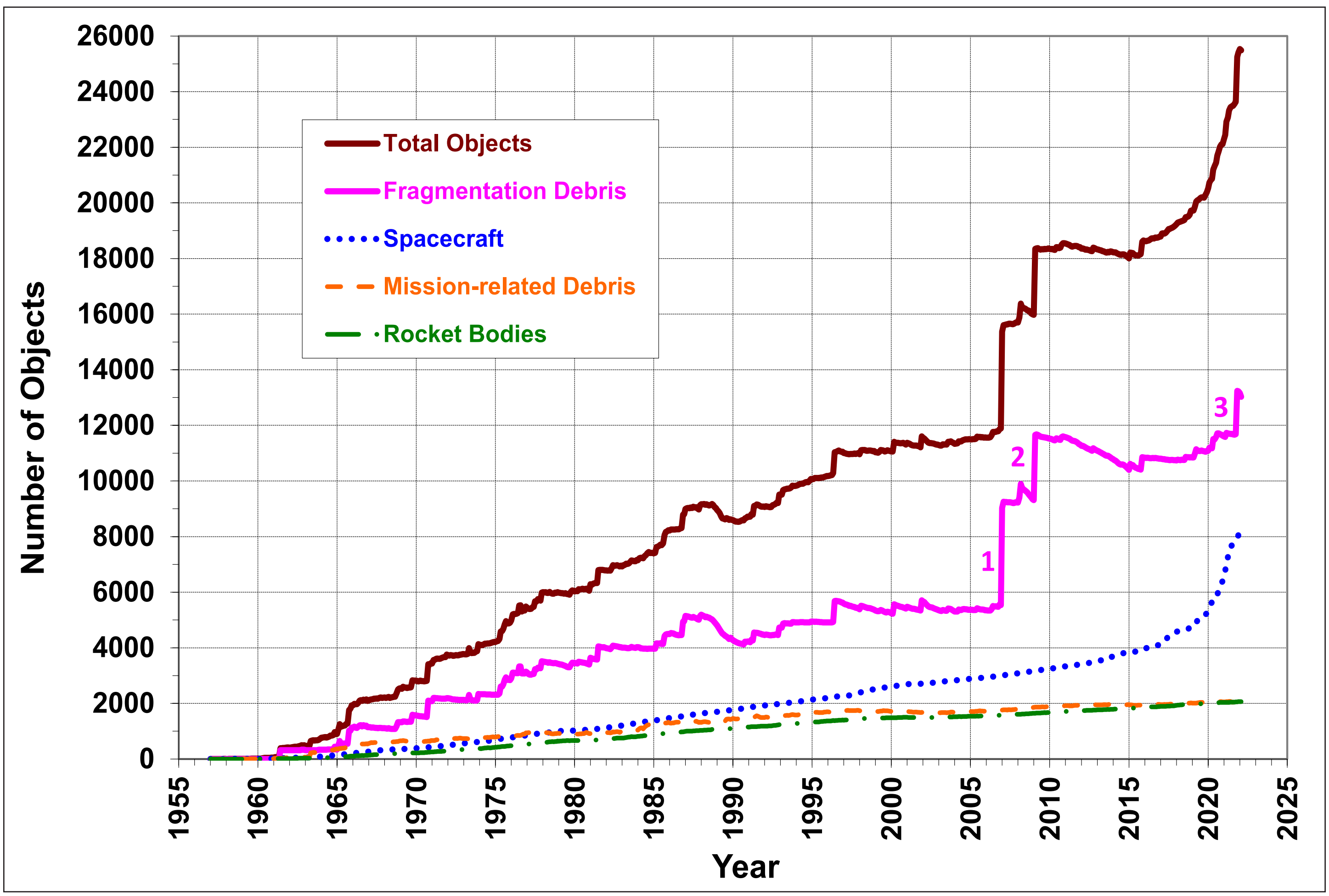

Figure 4. Historical increase of the cataloged objects based on data available on 1 March 2022. The three upward jumps in fragmentation debris correspond to (1) the ASAT test conducted by China in 2007, (2) the accidental collision between Iridium 33 and Cosmos 2251 in 2009, and (3) the ASAT test conducted by the Russian Federation in November 2021. More Cosmos 1408 fragments are expected to the added to the catalog in the coming weeks and months.

Cosmos 1408 Break-up

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Iridium 33 in 2009, and the Russian ASAT test in November 2021. Since more Cosmos 1408 fragments are expected to be added to the catalog in the near future, the jump in fragmentation debris due to this event will also increase accordingly.

Risks from Russian ASAT Fragments to NASA Assets

The NASA Orbital Debris Program Office (ODPO) has an established process to assess risks from fragments generated by a new on-orbit breakup event to the International Space Station (ISS) and critical NASA robotic assets. For the ISS, the assessment process only considers penetration risks to critical modules and components. The ISS has approximately 500 different impact shields protecting different modules and external pressure vessels, with some modules better protected than others. Consequently, the critical penetration risks to different ISS modules are driven by debris with different size thresholds, ranging from ≥ 1 cm for well-protected modules to ≥ 3 mm for less-well-protected modules [2]. In general, assessments for robotic missions focus on impact risk increases from millimeter-sized fragments since such small debris drives the mission-ending damage to most robotic assets in low Earth orbit (LEO) [3].

The risk assessment process begins with the prediction of the initial fragment cloud, including the number of fragments as a function of size, the initial spread of the fragment cloud, and the area-to-mass ratios of individual fragments, which determine the orbital lifetimes of fragments in LEO. Simulated fragments, based on the characteristics of the parent object (mass, orbit, *etc.*) are generated with the NASA Standard Satellite Breakup Model (SSBM) [4]. The simulated fragments are then propagated and incorporated into ODPO's Satellite Breakup Risk Assessment Model (SBRAM) to calculate short-term risks (days to weeks) from the new fragments to a specific space asset [5]. The new risk can also be compared with the background debris environment, based on ODPO's Orbital Debris Engineering Model (ORDEM), to calculate the risk increase over time [6].

Shortly after the Russian ASAT test, the ODPO led an effort to assess risks to the ISS and to support development of mitigation measures to protect the ISS crew from potential critical damage to the ISS modules. As the Cosmos 1408 fragment cloud dispersed, risks to the ISS decreased and reached a quasi-stable state, which was about two times the pre-ASAT level. The ODPO also evaluated risks from the Cosmos 1408 fragments to NASA robotic missions in LEO. Results indicated that the millimeter-sized fragment impact risk increased on the order of 5% for the first month after the breakup and remained at a similar level afterward. As expected, because of the sub-500 km altitude of the Cosmos 1408 spacecraft prior to its destruction, missions operating at low altitudes, such as 400 km, are affected more than missions farther away from the initial fragment cloud, such as those operating at 700 km altitude and above. The orbits of the predicted fragments can also be propagated forward in time to examine the long-term effects from the fragments to the environment. Figure 5 shows the predicted percentage of Cosmos 1408 fragments remaining in orbit as a function of time. The three curves, from top to bottom, are fragments with three different size thresholds, ≥ 10 cm, ≥ 1 cm, and ≥ 1 mm, respectively. The majority (> 90%) of the Cosmos 1408 fragments are expected to decay and reenter within 5 years.

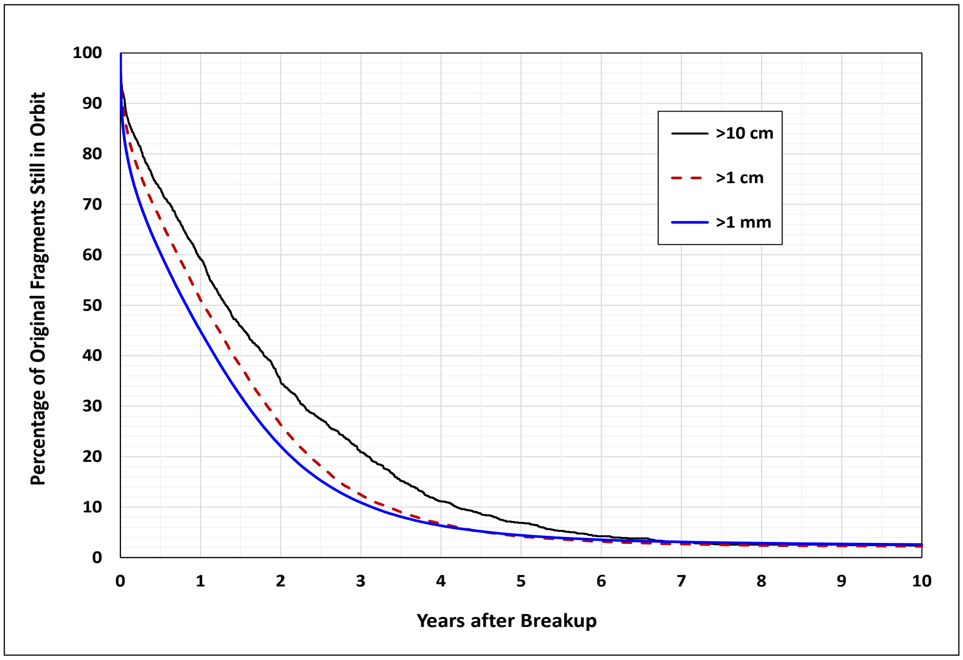

Figure 5. Predicted orbital decay of the Cosmos 1408 fragment cloud. The three curves are, from top to bottom, ≥ 10 cm fragments, ≥ 1 cm fragments, and ≥ 1 mm fragments, respectively.

Radar Measurements of Small Cosmos 1408 Fragments

The ODPO has led the characterization of the orbital debris environment below the SSN tracking capability with radars, telescopes, and in-situ measurements since the early 1990s. The cataloged data shown in Figures 2 through 4 are limited to objects approximately 10 cm and larger. Since risks to human spaceflight (ISS, *etc.*) and robotic missions are driven by fragments too small to be tracked by the SSN, direct measurement data on small debris is critical to the fidelity of the SSBM and to risk assessments.

To validate or update ODPO's Cosmos 1408 fragment risk assessments described in the section above, the ODPO initiated an effort to partner with the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) and the NASA Jet Propulsion Laboratory (JPL) to collect radar measurement data on small Cosmos 1408 fragments immediately after the ASAT test occurred. The radars used for beam park measurements were MIT/LL's Haystack Ultrawideband Satellite Imaging Radar (HUSIR) and JPL's Goldstone orbital debris radar. The measurement campaign was conducted between 16 November, the day after the ASAT

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Table 1. Summary of HUSIR and Goldstone operations for Cosmos 1408 fragment cloud measurements.

Radar	Day of Year (DOY)	Cloud Passes	Detections	Hours
HUSIR	320	2	152	1.40
HUSIR	321	2	163	0.99
HUSIR	322	2	149	1.22
HUSIR	323	2	166	1.02
HUSIR	324	1	79	0.33
HUSIR	325	2	140	1.11
Goldstone	327	1	144	1.48
Goldstone	328	1	104	0.96
HUSIR	341	1	60	0.76
HUSIR	344	1	66	0.84
Goldstone	345	1	77	4.99

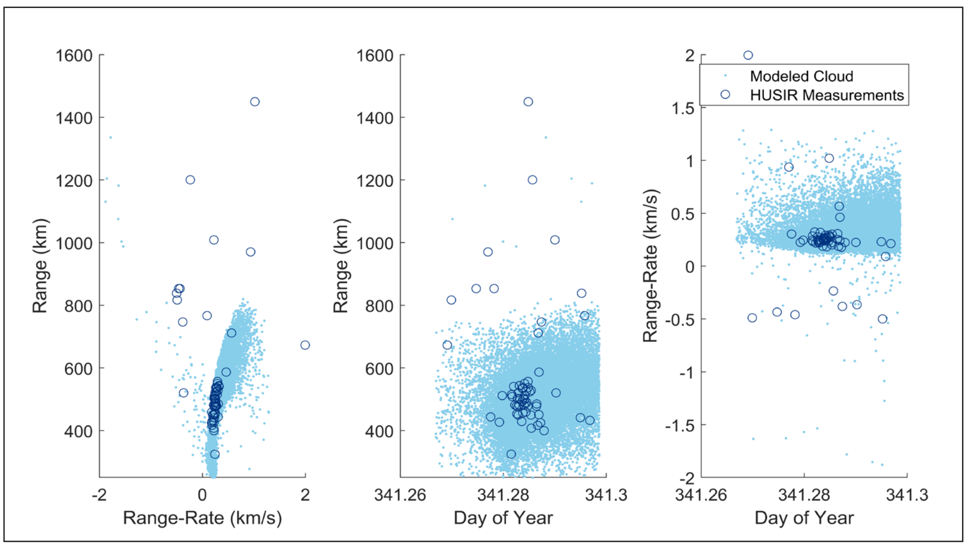

Figure 6. Range versus range-rate (left), range versus fractional DOY (middle), and range-rate versus fractional DOY (right) for detections measured by HUSIR on DOY 341.

test, and 11 December 2021. Measurements were made at times corresponding to expected passes of the Cosmos 1408 fragment cloud through the beam of the radar. Both HUSIR and Goldstone were pointed at an elevation angle of 75° and due East (75E). Table 1 summarizes the dates of data collection, number of debris cloud passes, debris counts, and observation hours. As shown in Table 1, 16 passes of the debris cloud were measured in total by the two radars.

A single pass of the fragment cloud, as measured by HUSIR on day of year (DOY) 341, is shown in Figure 6. Detections of the Cosmos 1408 fragments may be identified and distinguished from the background debris population by applying cluster analysis across measurements of range, range-rate, and time of detection. Figure 6 shows HUSIR detections, in dark blue, as they appear in range and range-rate (left plot), range and time (middle plot), and range-rate and time (right plot). An SSBM-generated debris cloud, which also includes debris objects with sizes too small to be detected by HUSIR, is shown in sky blue for reference. A significant increase in detection density within specific regions of range and range-rate can be observed in the left-most plot. These same detections are also clustered in both range and time, as well as range-rate and time, with an overall detection rate significantly higher than the background orbital debris population. This cluster of detections also correlates well to the expected timing of the highest rates of detection from the modeled cloud in range and range-rate as the ring of debris passes through the HUSIR radar beam. Similar analysis is applied to the other debris cloud passes measured by HUSIR and Goldstone to identify all detections correlated with the Cosmos 1408 fragment cloud. The size of each detected fragment was calculated from its radar cross section (RCS), based on the NASA radar Size Estimation Model (SEM) [7].

In addition to the HUSIR and Goldstone measurement data, MIT/LL, in coordination with the 18 SPCS, also generously shared a unique Space Fence data set with the ODPO. The data consists of the initial two passes of the Cosmos 1408 fragment cloud over the Space Fence on Kwajalein Atoll. The ODPO analyzed the data in a way similar to the analyses of the HUSIR and Goldstone radar data to characterize the observed population. Figure 7 is a composite plot showing the cumulative size distribution of the Cosmos 1408 fragments, from large to small, as estimated from different measurement data. Measurement uncertainties are shown as the dotted curves. The black curve is the SSBM prediction of the cumulative fragment size distribution based on the mass of the Cosmos 1408 spacecraft. Overall, the SSBM prediction matches well with the available measurement data over a wide size range, from the 10 cm and larger fragments tracked by the SSN to fragments as small as approximately 3 mm based on the Goldstone data. The good agreement between the SSBM and measurement data validates ODPO's prediction of the Cosmos 1408 ASAT fragments and ODPO's risk assessments for the ISS and NASA robotic missions in LEO.

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Model Updates

Both the ODPO's ORDEM and Debris Assessment Software (DAS) have been used by hundreds of operators (NASA, U.S. government, commercial), academia, and research groups around the world for orbital debris mission impact risk assessments and other application support. To share the characterization of the Cosmos 1408 fragments with the user community, the ODPO has developed a new Cosmos 1408 fragment component and added it to ORDEM. The updated ORDEM (version 3.2) as well as a new DAS (version 3.2.1), which incorporates ORDEM 3.2, have been released and added to the NASA Software Catalog. The links to request ORDEM and DAS can be found on page 5 (ORDEM 3.2 Release) and page 6 (DAS 3.2.1 Release), respectively.

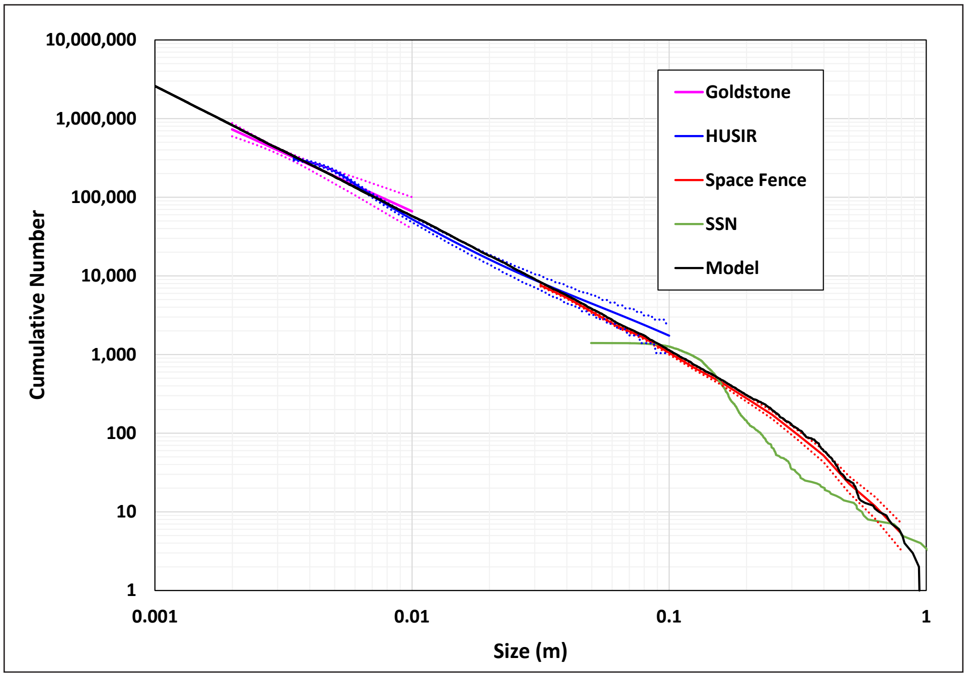

Figure 7. The cumulative size distribution of the Cosmos 1408 fragments based on different measurement data. The black curve is the NASA SSBM model prediction.

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3. Squire M., *et al.*, Joint Polar Satellite System (JPSS) Micrometeoroid and Orbital Debris (MMOD) Assessment NASA/TM-2015-218780, 2015.

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5. Gates, D. and Matney, M., Short-Term Satellite Breakup Risk Assessment Model Process, ODQN 24-3, 2020.

6. Matney, M., *et al.*, "The NASA Orbital Debris Engineering Model 3.1: Development, Verification, and Validation," 1st International Orbital Debris Conference, 2019.

7. Xu, Y.-L., *et al.*, A statistical size estimation model for Haystack and HAX radar detections, IAC-05-B6.1.02, 56th International Astronautical Congress, 2005. ♦

Orbital Debris Engineering Model 3.2 Release

The NASA Orbital Debris Program Office (ODPO) has released the latest version of the Orbital Debris Engineering Model (ORDEM), version 3.2. ORDEM 3.2 uses the same model framework as its predecessor, ORDEM 3.1, and has been updated to include fragments from the Cosmos 1408 anti-satellite (ASAT) test conducted on 15 November 2021 (see "The Intentional Destruction of Cosmos 1408" on page 1 in this issue of the ODQN). Fragments from this breakup event were added as a special population, similar to the major breakup fragment clouds from the Fengyun-1C ASAT test and the accidental collision between Iridium 33 and Cosmos 2251 [1].

Comparisons were made between the initial Cosmos 1408 fragment cloud modeled using the NASA Standard Satellite Breakup Model (SSBM) and special radar data collects from the Haystack Ultrawideband Satellite Imaging Radar, the Goldstone orbital debris radar, the Space Fence, and the U.S. Satellite Catalog. As discussed in the Cosmos 1408 news article on page 1, the initial SSBM-modeled fragment cloud matched these special radar data sets very well, indicating no additional model adjustments (*e.g.*, for overall number, area-to-mass ratio, or delta-velocity) were necessary to provide a high-fidelity model of this breakup. The initial model fragment cloud was propagated and added to each year of the ORDEM populations beginning in 2022.

ORDEM 3.2 represents the current best estimate of the dynamic orbital debris environment. As a data-driven model, ORDEM will be evaluated against newer datasets and updated periodically or, as with the ORDEM 3.2 update, as warranted by additional major breakup events. ORDEM 3.2 is available from the NASA Software Catalog at https://software.nasa.gov/software/MSC-25457-1.

References

1. Matney, M., *et al.*, "The NASA Orbital Debris Engineering Model 3.1: Development, Verification, and Validation," 1st International Orbital Debris Conference, 2019. ♦

Debris Assesment Software 3.2.1 Release

The NASA Orbital Debris Program Office has released version 3.2.1 of the Debris Assessment Software (DAS), replacing the prior January 2022 release of DAS 3.2. The updated version provides data that can verify compliance of a spacecraft, upper stage, and/or payload with NASA's requirements for limiting debris generation, spacecraft vulnerability, post-mission disposal, and reentry safety.

This release incorporates updates to the orbital debris mitigation requirements set forth in the revised NASA Technical Standard 8719.14C, released in November 2021, as well as the new version 3.2 of the Orbital Debris Engineering Model (ORDEM).

Successful verification of a design in DAS demonstrates compliance with NASA orbital debris mitigation requirements. Historically, DAS analysis has proven acceptable in meeting compliance requirements of many other agencies, in the U.S. and around the world. It does not address the inherent design reliability facets of NASA requirements, but addresses all Earth-related orbital debris requirements that make up the bulk of the requirements in the NASA Technical Standard 8719.14C. To calculate penetration risk from meteoroids, users should consult the NASA Meteoroid Environment Office and Hypervelocity Impact Technology teams for assessments.

For new users, DAS is available for download, by permission only, and requires that an application be completed via the NASA Software Catalog. To begin the process, click on the Request Software button in the catalog at https://software.nasa.gov/software/MSC-26690-1 .

Users who have already completed the software request process for earlier versions of DAS 3.x do not need to reapply for DAS 3.2.1. Simply go to your existing account on the NASA Software portal and download the latest installer. Due to file size limits, the installer has been split into several .zip archive files: the main installer and five separate files containing debris environment data. Users must download the main installer (which includes the debris environment for years 2016–2030) and additional environment files required to assess mission years beyond 2030.

Approval for DAS is on a per project basis: approval encompasses activities and personnel working within the project scope identified in the application. ♦

International Space Station Maneuvers Twice to Avoid Fragmentation Debris

The International Space Station (ISS) conducted two maneuvers in 2021's fourth quarter to avoid potential collisions with large debris tracked by the U.S. Space Command (USSPACECOM) Space Surveillance Network (SSN) on 10 November and 3 December; these were the sole ISS debris avoidance maneuvers of calendar year 2021.

The 20:15 GMT 10 November maneuver was triggered by a high-risk conjunction with a breakup fragment generated from the Fengyun-1C (FY-1C) anti-satellite test conducted by China in 2007. That fragment has an International Designator of 1999-025DKS and a Catalog Number of 35114. Beneficially, this reboost also set up downstream orbit phasing requirements originally planned for a mid-November boost. The 07:58 GMT 3 December maneuver was conducted to avoid an object with International Designator 1994-029AFN and Catalog Number 39915, which was generated in the explosion of a Pegasus launch system's fourth stage, the Hydrazine Auxiliary Propulsion System (HAPS), in 1996. Because of the conjunction's timing, the ISS Program was able to maintain launch and reentry requirements for the Soyuz mission 66 and mission 65 respectively, while also using the opportunity to decrease the delta velocity magnitude of a planned late-December deboost maneuver.

In both instances, the visiting Progress mission 79 vehicle's thrusters were used to execute the ISS Program's pre-determined debris avoidance maneuver (PDAM). PDAMs offer a standard catalog of in-plane thruster firings from which an appropriate maneuver may be selected. In these cases, the November maneuver used a +0.7 m/s PDAM while the December deboost used the -0.3 m/s PDAM option.

Presently, the ISS has conducted 30 collision avoidance maneuvers since 1999. Included among the avoided objects were three FY-1C debris and five debris from the 2009 collision between Cosmos 2251 and Iridium 33, which resulted in two and three maneuvers respectively. ♦

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Two Minor Breakup Events in Fourth Quarter of 2021

The first of two minor breakup events occurred on 23 October 2021 at 18:14 GMT ± 10 minutes when Cosmos 2499 broke up after approximately 7.4 years on orbit. At event time, the vehicle was in a 1507 × 1152 km, 82.44° orbit. The spacecraft (International Designator 2014-028E, Catalog Number 39765) is the second known fragmentation within what is apparently the first class of Russia's "satellite inspector-type" spacecraft, the first being December 2019's breakup of Cosmos 2491. Like that payload, Cosmos 2499 also hosted an amateur radio payload, specifically the Radio-Sputnik 47 (RS-47).

Though spacecraft details are unknown, the launch configuration suggests a compact vehicle with a mass on the order of 100 kg or less. This type of spacecraft has exhibited a significant maneuver capability and so likely featured batteries and power distribution subsystems, thrusters and associated propellant(s), and fine motion control subsystems in the inventory of stored energy, which could contribute to breakup processes.

In addition to the parent body, 21 debris (piece tags F-AB) have entered the publicly available U.S. Satellite Catalog. Due to the event's altitude, additional pieces may be cataloged over time. A Gabbard plot of this debris cloud is presented in Fig. 1.

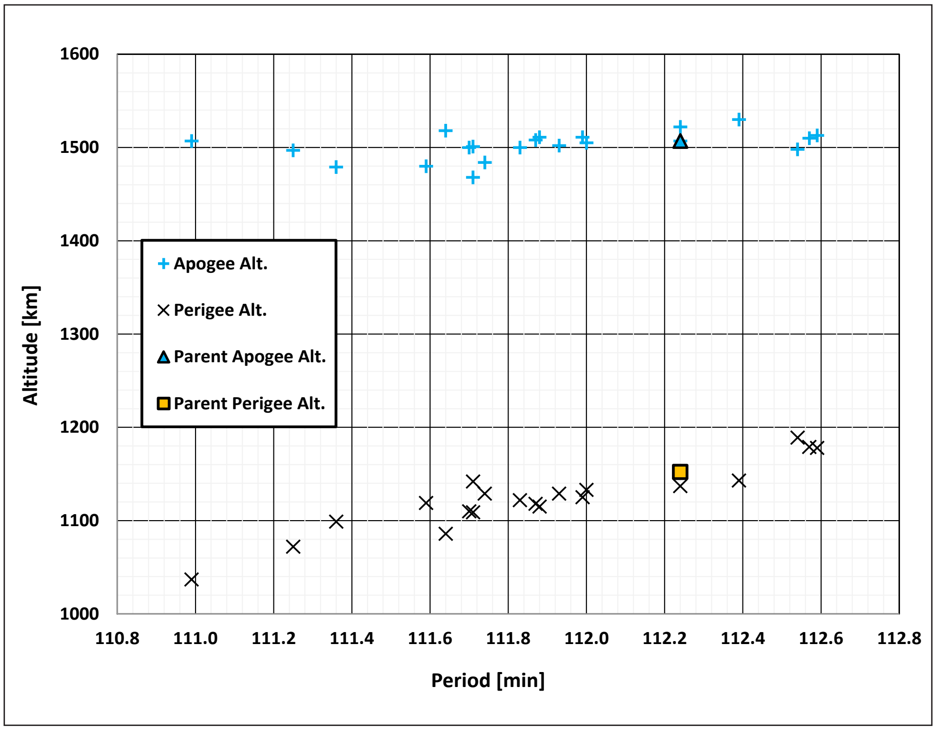

Figure 1. The Cosmos 2499 Gabbard plot. Epoch is approximately 3 January 2022. Maximum change in period is on the order of one minute while the maximum change in inclination is on the order of 0.12°.

The final known breakup event of 2021, the fragmentation of the ORBCOMM FM-5 spacecraft, was noted to have occurred between 0600-0700 GMT on 18 November. This breakup also represents the second known event for this bus/class of satellite, the first having been the 22 December 2018 fragmentation of ORBCOMM FM-16. The event occurred approximately 23.9 years after launch, with the parent spacecraft being in a 771 × 758 km, 45° orbit at the time.

The spacecraft (International Designator 1997-084F, Catalog Number 25117) is a first-generation ORBCOMM communications spacecraft; the reader is referred to the article "2018 Ends with Breakup of an ORBCOMM Constellation Spacecraft" (ODQN vol. 23, issue 1 & 2, May 2019, pp. 1-2) for a general description of this class of spacecraft, including an inventory of the on-board stored energy complement, which potentially could contribute to an energetic fragmentation event.

In addition to the parent body, eight debris (piece tags L-T) have been cataloged. A Gabbard plot for the fragments is presented in Fig. 2.

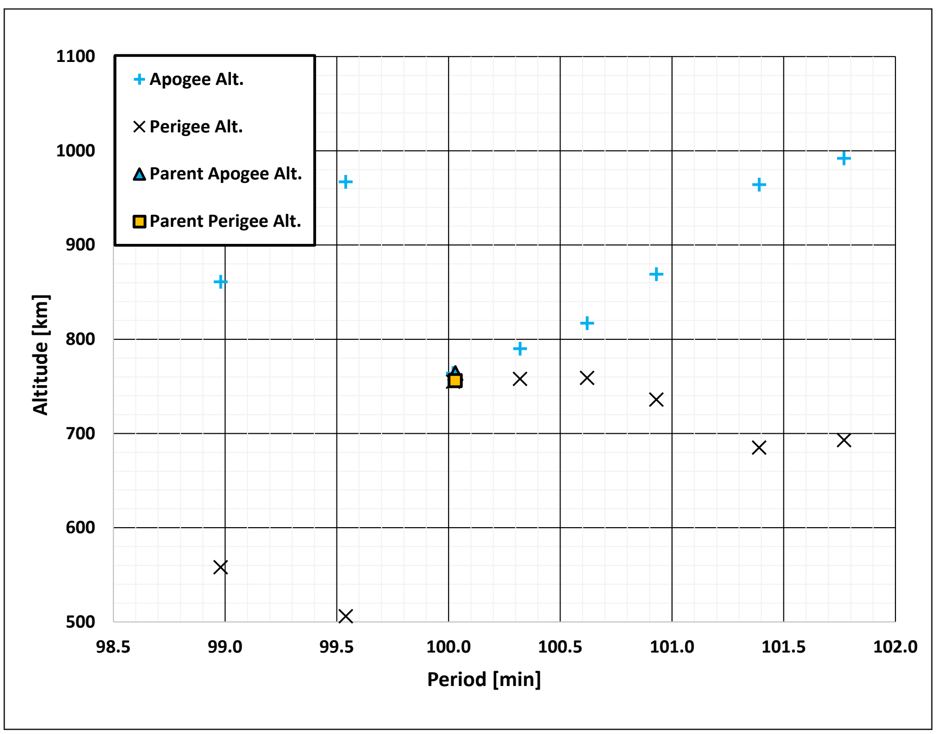

Figure 2. The ORBCOMM FM-5 Gabbard plot. Epoch is approximately 3 January 2022. Maximum change in period is on the order of 1.75 minutes. Maximum change in inclination is on the order of 0.2°.

At the time of reporting, 12 to 15 pieces have been observed by the SSN sensor network. This piece count will be updated in the ODQN and revisions to the NASA History of On-orbit Satellite Fragmentations as debris cloud cataloging develops. ♦

CONFERENCE AND WORKSHOP REPORTS

Third Applied Space Environments Conference, 1-5 November 2021

The third biennial Applied Space Environments Conference (ASEC) 2021 was held virtually 1-5 November 2021. This event was organized by the Space Environments Technical Discipline Team of NASA's Engineering and Safety Center. The ASEC is a forum for the space environment engineering and applied space science community to engage in current space programs, discuss technical needs, and actively share knowledge needed to meet future crewed and robotic space exploration goals.

The first keynote of the conference covered space weather, uncertainty of the current solar cycle 25, a high-level overview of spacecraft missions under the Heliophysics Division, and highlighted the need to measure and characterize the orbital debris environment in near-Earth space. The second keynote focused on the U.S. Space Force's current missions and disciplines, an overview of the space environment over time, and plans forward for the space environment.

This year, the conference focused on nine primary topics, including, but not limited to: 1) spacecraft charging: simulation and testing, 2) radiation effects on parts and testing, 3) instrument and measurement techniques, 4) space weather environment impacts and modeling, 5) atomic oxygen environment, effects, testing, and mitigation, 6) current and future missions, 7) the micrometeoroid and orbital debris environment, effects, testing, and mitigation, 8) in-flight observations and events, and 9) radiation effects on humans and materials. In addition to the technical discussions, a tutorial was presented on ESA's Space Environment Information System. ♦

NASA Aerospace Battery Workshop, 16-18 November 2021

The NASA Aerospace Battery Workshop was conducted virtually from 16-18 November 2021. This annual workshop is hosted by the Marshall Space Flight Center and sponsored by the NASA Engineering and Safety Center. The global battery engineering community was represented by many participants from academia, industry, and government. The workshop was held in a live, virtual format similar to last year's workshop, which allowed for a larger attendance, maintained the live question-and-answer periods, but returned scheduled breaks based on participant feedback. This year's workshop included 28 presentations covering topics such as battery health monitoring and safety; performance computer modeling and prediction; causes, modeling, and imaging of thermal runaway; new lithium-ion chemistries and capacities; specific case studies; and the state of the industry.

The NASA Orbital Debris Program Office presented "Battery Design and Orbital Debris Mitigation." The goal of presenting to this audience was to raise awareness of battery explosion, passivation, and reentry issues, as applied to orbital debris mitigation, among members of the battery research, development, and production community.

Of the many interesting and informative presentations, a sampling of those related to debris mitigation included: battery housings that prevent propagation of thermal runaway; cell materials that tolerate damage; and cell health-monitoring systems that prevent battery failures.

The NASA Aerospace Battery Workshop continues to provide a valuable opportunity for representatives from industry, academia, and government to assemble and discuss modeling capabilities, the state of battery design and performance, and future trends and expectations. Presentations from this and past workshops are available at https://www.nasa.gov/batteryworkshop. ♦

Aerothermodynamics and Design for Demise (ATD^3) Workshop 2021, 2 December 2021

The Aerothermodynamics and Design for Demise (ATD^3) Workshop 2021 was hosted by the ATD^3 working group, jointly managed by the European Space Agency and the French government space agency, CNES. The workshop was conducted in a virtual format, allowing increased participation by 163 participants across the European Union and the United States.

This workshop focused on improving our understanding of upper atmosphere dynamics (in both continuum and rarefied flow regimes), fragmentation and ablation, experimental results, material characterization, and verification and validation of models. The 1-day workshop was broken into 4 sessions, comprised of 13 presentations and 2 invited talks.

One of the invited talks was given by the NASA Orbital Debris Program Office on recent studies modeling hollow objects in reentry flows, covering background on the rarefied flow regime and previous models for drag and aeroheating, results from a previous simulation test, and a preview of the ongoing phase of the study, which will conclude with new models for implementation in Object Reentry Survival Analysis Tool 7.0.

Workshop proceedings can be found on the workshop website at https://indico.esa.int/event/389/overview. ♦

The Space Systems Anomalies and Failures (SCAF) Workshop, 11-12 January 2022

The annual 2-day Space Systems Anomalies and Failures (SCAF) workshop was held virtually on 11-12 January 2022. The NASA Engineering and Safety Center hosted the unclassified Day 1 sessions and the National Reconnaissance Office hosted the Day 2 classified sessions. There were over 260 attendees, almost double the number of participants in 2021, and 12 presentations for Day 1. Attendees and presenters included a diverse participation of U.S. and international aerospace community members including representatives from academia, industry, civil, and military space organizations. Focused on space environment interactions, this workshop provided a chance for personnel from 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.

Day 1 highlighted topics included space environment testing of deployables, insurance claims related to anomalies and failures, diagnosing anomalies with telemetry, automatically detecting hypervelocity impacts to space vehicles, and responsible disposal of satellites.

A common theme among presenters was the importance of collaboration, information sharing, and communication between space entities to achieve maximum mission success and space safety, providing opportunities to learn about useful case studies that can be applied to space mission research, development, and on-going mission support.

The organizers will be updating the acronym name for the 2023 workshop from SCAF to SSAF, to reflect the current title of Space Systems Anomalies and Failures, removing the historical reference to the Spacecraft Anomalies and Failures workshop. The workshop is expected to be held in-person in Chantilly, Virginia. ♦

UPCOMING MEETINGS

These events could be canceled or rescheduled due to the COVID-19 pandemic. All information is current at the time of publication. Please consult the respective websites for updated schedule changes.

16-24 July 2022: COSPAR 2022, Athens, Greece

The 44th Assembly of the Committee on Space Research (COSPAR) Scientific Assembly will convene in the Megaron Athens International Conference Centre. The COSPAR panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "The Science of Human-Made Objects in Orbit: Space Debris and Sustainable Use of Space." PEDAS.1 sessions will include advances in the science of human-made objects in orbit and other regions of space (Lunar and Martian regions), and will focus on data collection and processing; micrometeoroid and orbital debris environment modeling; end-of-life concepts; and solutions to fundamental operational challenges. The abstract submission period closed on 18 February 2022. Please see the PEDAS.1 session website at https://www.cospar-assembly.org/admin/sessioninfo.php?session=1114 and the Assembly website at: https://www.cospar-assembly.org/assembly.php .

18-22 September 2022: 73rd International Astronautical Congress (IAC), Paris, France

The IAC will convene in-person in 2022 with a theme of "Space for @ll." The IAC's 20th IAA Symposium on Space Debris will cover debris measurements and characterization; modeling; risk analysis; hypervelocity impact and protection; mitigation; post-mission disposal; space debris mitigation and removal; operations in space debris environment; political and legal aspects of including mitigation and removal; orbit determination and propagation; and a joint session on near Earth objects and space debris. The abstract submission closed on 7 March 2022. Additional information for the 2022 IAC is available at https://www.iafastro.org/events/iac/iac-2022/ and https://iac2022.org/.

18-22 September 2022: 16th Hypervelocity Impact Symposium, Alexandria, Virginia, USA

The Hypervelocity Impact Symposium (HVIS) is a biennial event organized by the Hypervelocity Impact Society that serves as the principal forum for the discussion, interchange, and presentation of the physics of high- and hypervelocity impact and related technical areas. Orbital debris-related presentations include fracture and fragmentation; launchers and diagnostics; penetration mechanics and target response; hypervelocity phenomenology studies; material response; meteoroid and debris shielding and failure analysis; theoretical applied mechanics relevant to hypervelocity impact; and a special session on state-of-the-art experiments enabling advances in state-of-the-art models. The abstract submission deadline passed on 15 March 2022. Additional information for the 16th Symposium is available at http://hvis2022.jhuapl.edu/.

27-30 September 2022: 23rd Advanced Maui Optical and Space Surveillance Technologies Conference, Maui, Hawai'i, USA

The technical program of the 23rd Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) will focus on subjects that are mission critical to Space Situational Awareness. The technical sessions include papers and posters on Orbital Debris; Space Situational/Space Domain Awareness; Adaptive Optics & Imaging; Astrodynamics; Non-resolved Object Characterization; and related topics. The abstract submission deadline passed on 1 March 2022. Additional information about the conference is available at https://amostech.com.

SATELLITE BOX SCORE

(as of 4 February 2022, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Spacecraft*	Spent Rocket Bodies & Other Cataloged Debris	Total
CHINA	517	3854	4371
CIS	1551	7032	8583
ESA	96	60	156
FRANCE	80	520	600
INDIA	103	114	217
JAPAN	205	117	322
UK	448	1	449
USA	4144	5216	9360
OTHER	1027	97	1124
TOTAL	8171	17011	25182

* *active and defunct*

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

01 September 2021 – 31 December 2021

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 payloads	VARIOUS	413	422	51.6	7	0	1
2021-079A	GAOFEN-5 02	PRC	700	702	98.3	0	1	1
2021-080A	CHINASAT 9B	PRC	35779	35793	0.0	0	1	0
2021-081A	COSMOS 2551	CIS	130	144	96.3	0	1	0
2021-082B	STARLINK-3096	US	357	362	70.0	50	1	4
2021-083A	ONEWEB-0292	UK	610	637	87.5	33	0	0
2021-084A	INSPIRATION-4	US	360	369	51.6	0	0	1
2021-085A	TIANZHOU 3	PRC	383	386	41.5	0	1	0
2021-086A	JILIN-01 GAOFEN 2D	PRC	530	545	97.5	0	1	0
2021-087A	SHIYAN 10 (SY-10)	PRC	1041	40155	51.1	0	1	0
2021-088A	LANDSAT 9	US	701	704	98.2	0	0	0
2021-088B	CS1	US	550	581	97.6			
2021-088C	CS2	US	548	581	97.6			
2021-088D	CUTE-LASP	US	547	575	97.6			
2021-088E	CUPID	US	548	574	97.6			
2021-089A	SOYUZ MS-19	CIS	413	423	51.7	0	1	0
2021-090A	ONEWEB-0332	UK	599	606	87.2	35	0	0
2021-091A	OBJECT A	PRC	498	520	97.5	10	0	0
2021-092A	SZ-13	PRC	383	386	41.5	0	1	0
2021-093A	LUCY	US	HELIOCENTRIC			0	0	0
2021-094A	SJ-21	PRC	35337	36185	8.3	0	2	0
2021-095A	SES 17	SES	EN ROUTE TO GEO			0	1	1
2021-095B	SYRACUSE 4A	FR	EN ROUTE TO GEO					
2021-096A	QZS-1R	JPN	32570	39012	34.2	0	1	0
2021-097A	JILIN-01 GAOFEN 2F	PRC	529	545	97.6	0	1	0
2021-098A	PROGRESS MS-18	CIS	413	423	51.7	0	1	0
2021-099A	YAOGAN-32 2A	PRC	695	697	98.1	0	1	1
2021-099B	YAOGAN-32 2B	PRC	695	697	98.1			
2021-100A	SDGSAT 1	PRC	500	515	97.5	0	0	0
2021-101A	OBJECT A	PRC	494	499	35.0	0	0	2
2021-101B	OBJECT B	PRC	493	498	35.0			
2021-101C	OBJECT C	PRC	490	496	35.0			
2021-102A	ASTERISC	JPN	557	576	97.6	8	2	0
2021-103A	DRAGON ENDURANCE	US	413	423	51.7			
2021-104A	STARLINK-3151	US	524	527	53.2	52	0	4
2021-105A	CERES 1	FR	681	686	75.0	0	1	0
2021-105B	CERES 2	FR	687	689	75.0			
2021-105C	CERES 3	FR	654	656	75.0			
2021-106A	GLOBAL-14	US	427	433	42.0	0	2	1
2021-106B	GLOBAL-15	US	425	433	42.0			
2021-107A	GAOFEN 11 3	PRC	240	626	97.4	0	1	0
2021-108A	ASTRA SATELLITE 00001	US	438	506	86.0	0	0	0
2021-109A	GAOFEN 3 02	PRC	750	752	98.4	0	1	0
2021-110A	NASA DART	US	HELIOCENTRIC					
2021-111A	PROGRESS M-UM	CIS	416	423	51.6	0	1	0
2021-112A	SHIYAN 11 (SY-11)	PRC	486	504	97.5	0	1	0
2021-113A	COSMOS 2552	CIS	1612	38748	63.8	0	1	0
2021-114A	CHINASAT 1D	PRC	35781	35793	1.8	0	1	0
2021-115A	STARLINK-3219	US	443	447	53.2	49	0	5
2021-116A	GALILEO 27 (223)	ESA	23382	23518	57.1	0	1	0
2021-116B	GALILEO 28 (224)	ESA	23308	23360	57.1			
2021-117A	OBJECT A	PRC	482	502	97.4	0	0	0
2021-117B	OBJECT B	PRC	484	502	97.4			
2021-117C	OBJECT C	PRC	482	503	97.4			
2021-117D	OBJECT D	PRC	480	503	97.4			
2021-117E	OBJECT E	PRC	476	501	97.4			
2021-118A	STPSAT-6	US	35784	35789	0.0	0	1	1
2021-118B	LDPE-1	US	35961	35990	0.1			
2021-119A	SOYUZ MS-20	CIS	417	423	51.6	0	1	0
2021-120A	GLOBAL-17	US	427	436	42.0	0	2	1
2021-120B	GLOBAL-16	US	424	436	42.0			
2021-121A	IXPE	US	588	603	0.2	0	0	0
2021-122A	SHIJIAN 6 05A (SJ-6 05A)	PRC	455	473	97.4	0	1	2
2021-122B	SHIJIAN 6 05B (SJ-6 05B)	PRC	455	473	97.4			
2021-123A	OBJECT A	CIS	EN ROUTE TO GEO			0	1	1
2021-123B	OBJECT B	CIS	EN ROUTE TO GEO					
2021-124A	TIANLIAN 2-02	PRC	35776	35796	2.9	0	1	0
2021-125A	STARLINK-3317	US	349	351	53.2	51	0	4
2021-126A	TURKSAT 5B	TURK	EN ROUTE TO GEO			0	1	0
2021-127A	DRAGON CRS-24	US	413	423	51.7	0	0	0
2021-128A	INMARSAT 6-F1	IM	EN ROUTE TO GEO			0	1	0
2021-129A	SHIYAN 12 01 (SY-12 01)	PRC	35821	35831	0.5	0	1	1
2021-129B	SHIYAN 12 02 (SY-12 02)	PRC	35821	35831	0.5			
2021-130A	JWST	ESA	HELIOCENTRIC					
2021-131A	ZY-1 02E	PRC	773	775	98.6	0	1	1
2021-131B	XW-3 (CAS 9)	PRC	761	767	98.6			
2021-132A	ONEWEB-0389	UK	495	523	87.3	35	0	0
2021-133A	IPM 3/PERSEY	CIS	108	118	63.4	0	0	3
2021-134A	OBJECT A	PRC	482	500	89.0	0	0	0
2021-134B	OBJECT B	PRC	482	500	89.0			
2021-135A	TJS-9	PRC	35773	35801	0.1	0	1	0

* *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 4 Feb. 2. Additional spacecraft on a single launch may have different orbital elements. 3. Additional uncatalogued objects may be associated with a single launch.