



Orbital Debris Quarterly News

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Instability of the Current Orbital Debris Population

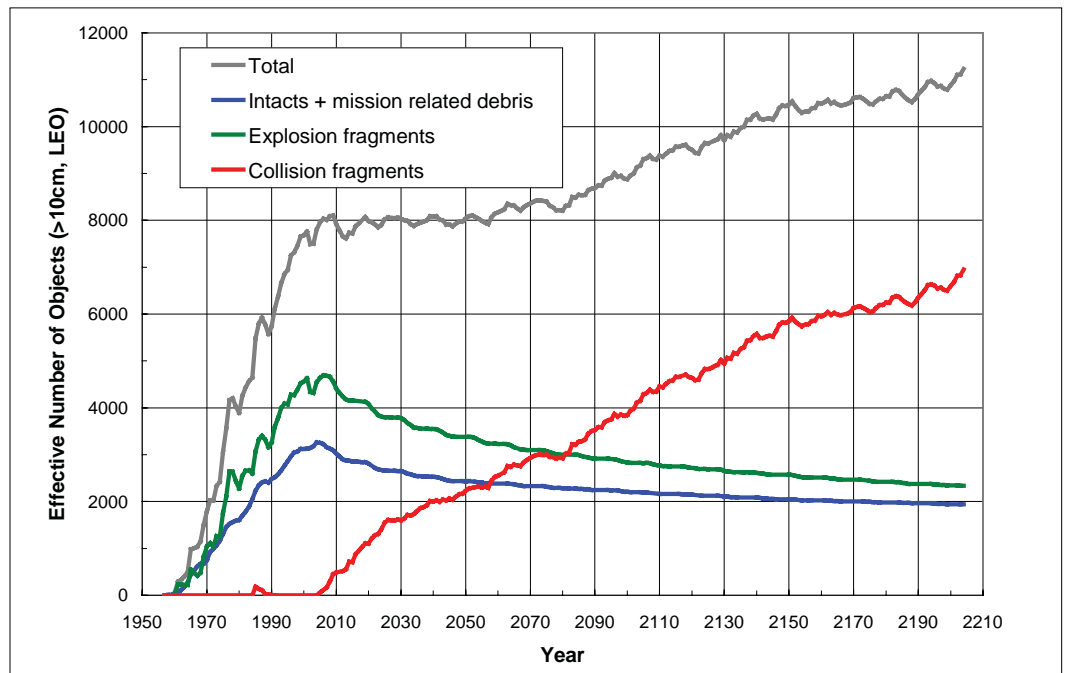
A paper addressing the inevitable growth of future debris populations was published by *Science* in its 20 January 2006 issue. The paper, written by J.-C. Liou and N. L. Johnson, summarized the results of recent research by the NASA Orbital Debris Program Office. Currently more than 9000 objects, with a combined mass exceeding 5 million kilograms, are tracked by the U.S. Space Surveillance Network and maintained in the U.S. satellite catalog. Several environment projection studies conducted between 1991 and 2001 indicate that with various assumed future launch rates, the debris populations at some altitudes in low Earth orbit (LEO) will become unstable. Collisions will take over as the dominant debris generation mechanism, and the debris generated will feed back to the environment and induce more collisions.

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The simulated 10 cm and larger LEO population indicates that collision fragments replace other decaying debris (due to atmospheric drag) through 2055, keeping the total LEO populations approximately constant. Beyond 2055, however, new col-

In addition to using a recently developed high

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Effective number of LEO objects, 10 cm and larger, from the simulation. The effective number is defined as the fractional time, per orbital period, an object spends between 200 and 2000 km altitudes. The future projection parts of the curves (years 2005 to 2204) are averages from 50 Monte Carlo runs. Intacts are rocket bodies and spacecraft that have not experienced breakups.



A publication of

The NASA Orbital Debris Program Office

Debris Population

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lision fragments outnumber decaying debris, and force the total population to increase. Detailed analysis shows that the predicted future catastrophic collisions and the resulting population increase are non-uniform throughout LEO. The most active region is between 900

and 1000 km altitudes. Even without any new launches, this region is highly unstable. Debris populations in this “red zone” will approximately triple in the next 200 years, leading to a factor of 10 increase in collision probability.

In reality, the future debris environment is likely to be worse than the study suggested,

as satellites continue to be launched into space. The paper concludes that to better limit the growth of future debris populations, active removal of objects from space needs to be considered. ♦

Draft United Nations Space Debris Mitigation Guidelines

The Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) held its annual meeting at the UN complex in Vienna, Austria, during 20 February – 3 March 2006. Since 1994 space debris has been a topic on the Subcommittee’s agenda, and the first work plan culminated with the 1999 publication of *Technical Report on Space Debris*.

The current work plan for the years 2005-2007 calls upon a special Space Debris Working Group to prepare for the Subcommittee a space debris mitigation document with high-level guidelines consistent with the more de-

tailed Space Debris Mitigation Guidelines of the Inter-Agency Space Debris Coordination Committee (IADC). After meetings in Vienna in February and June of 2005, the Space Debris Working Group met again on 23 February 2006 and completed its primary task on 1 March, when it officially presented the Subcommittee with the draft document entitled *UN COPUOS STSC Space Debris Mitigation Guidelines*.

The concise document contains seven numbered guidelines addressing debris released intentionally or unintentionally during deployment, operations, and post-disposal in all altitude regimes. STSC Member States were requested

to review the document carefully during 2006 with the objective of adopting the guidelines in their current or revised form at the 44th meeting of the Subcommittee in February 2007.

During this session of the STSC, a special workshop on nuclear power sources in space was held under the joint sponsorship of COPUOS and the International Atomic Energy Agency (IAEA). A presentation prepared by the STSC Space Debris Working Group on special space debris issues associated with space nuclear power sources was delivered. ♦

Disposal of Geosynchronous Spacecraft in 2005

One of oldest space debris mitigation guidelines addresses the disposal of spacecraft operating in the geosynchronous (GEO) regime. Today, the space debris mitigation guidelines of all major space-faring nations and the Inter-Agency Space Debris Coordination Committee (IADC), as well as a recommendation of the International Telecommunication Union, call for transferring GEO spacecraft at the end of their mission into disposal orbits above the GEO region, which is normally defined as the region within 200 km of the geosynchronous altitude, *i.e.*, approximately 35,786 km. Moreover, these disposal orbits should be sufficiently stable that the derelict spacecraft are not driven back within the GEO region by natural orbital

perturbations for a very long time.

The purpose of maneuvering spacecraft out of the GEO region is to prevent their possible future collision with operational spacecraft. Not only could the operational spacecraft be severely damaged in such a collision, but also new orbital debris could be created, which, in turn, could pose a threat to other spacecraft.

A total of 22 GEO spacecraft, a larger number than usual, terminated their missions during 2005. Unfortunately, two of these spacecraft, INTELSAT 804 and UFO 3, suffered unexpected, catastrophic failures while still in GEO and could not be maneuvered at all. However, of the remaining 20 spacecraft, all were maneuvered to higher altitude disposal

orbits, and 17 (85%) reached orbits at least 200 km above GEO.

All seven U.S. spacecraft (four government-owned and three commercial) which were moved into disposal orbits achieved the objective of non-interference with GEO for at least 100 years. In fact, the oldest GEO spacecraft to be retired in 2005 belonged to the U.S., was 21 years old, and was able to reach one of the highest disposal orbits of the year, with its lowest point more than 400 km above GEO.

The international aerospace community is increasingly demonstrating its commitment to following GEO spacecraft disposal guidelines and to protecting the unique GEO regime. ♦

PROJECT REVIEWS

Flux Comparisons from the Goldstone, Haystack, and HAX Radars

C. STOKELY

The continual monitoring of the low Earth orbit (LEO) environment using highly sensitive radars is essential for an accurate characterization of the dynamic debris environment. This environment is continually changing or evolving since there are new debris sources and debris loss mechanisms that are dependent on the dynamic space environment. Radar data are used to supplement, update, and validate existing

orbital debris models.

NASA has been utilizing radar observations of the debris environment for over a decade from three complementary radars: the NASA JPL Goldstone Radar, the MIT Lincoln Laboratory (MIT/LL) Long Range Imaging Radar (known as the Haystack radar), and the MIT/LL Haystack Auxiliary Radar (HAX). All of these systems are high power radars that operate in a fixed staring mode to statistically sample

orbital debris in the LEO environment. The Goldstone radar is a bistatic X-band radar located in the Mojave desert in California at a latitude of 35.2°. The Haystack and HAX radars are, respectively, X-band and Ku-band monopulse tracking radars located in Tyngsboro, Massachusetts at a latitude of 42.6°. The monopulse capability of the Haystack and HAX radars allows a measurement of the position of the de-

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Flux Comparisons

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bris within the beam, thus ensuring a more accurate estimate of the radar cross section (RCS). Each of these radars is ideally suited to measure debris within a specific size region. The Goldstone radar generally observes objects with sizes from 2 mm to 1 cm. The Haystack radar generally measures from 5 mm to several meters. The HAX radar generally measures from 2 cm to several meters. These overlapping size regions allow a continuous measurement of cumulative debris flux versus diameter from 2 mm to several meters for a given altitude window.

Immediately before the start of FY2003, 1 October 2002, MIT/LL had changed their Processing and Control System (PACS) used for debris detection and near-realtime processing. This entailed replacing the analog components of their processing system with digital components along with accompanying software adjustments. After the transition, anomalous debris data was identified in early 2005 by the NASA Orbital Debris Program Office, revealing errors in the PACS. These errors reduced the capability of the Haystack radar to detect debris less than 1 cm, and the HAX radar to detect debris less than 4 cm. The errors in the PACS were identified and corrected by MIT/LL before the FY2006 debris observations began in November 2005. Despite the limitations of the radars imposed by the PACS errors, the excellent statistics provided by 633.3 hours of Haystack data and 542.1 hours of HAX data during FY2003 have greatly helped in characterizing the small debris environment.

After a three-year hiatus on debris observations caused by funding constraints and antenna refurbishments, the Goldstone radar collected 118.2 hours of data throughout 2005. The Goldstone radar provides valuable data for size, radial speed, and altitude that can be incorporated into various orbital debris models. There are experimental caveats that must be realized though when interpreting the data and making error estimates for debris fluxes. The Goldstone system does not have a monopulse capability that could be used to determine where the debris passes relative to the center of the beam. This leads to inherent uncertainties of RCS measurements. There is no correction for this, and, therefore, the quoted diameters are a lower limit since the particles do not necessarily go through the center of the beam.

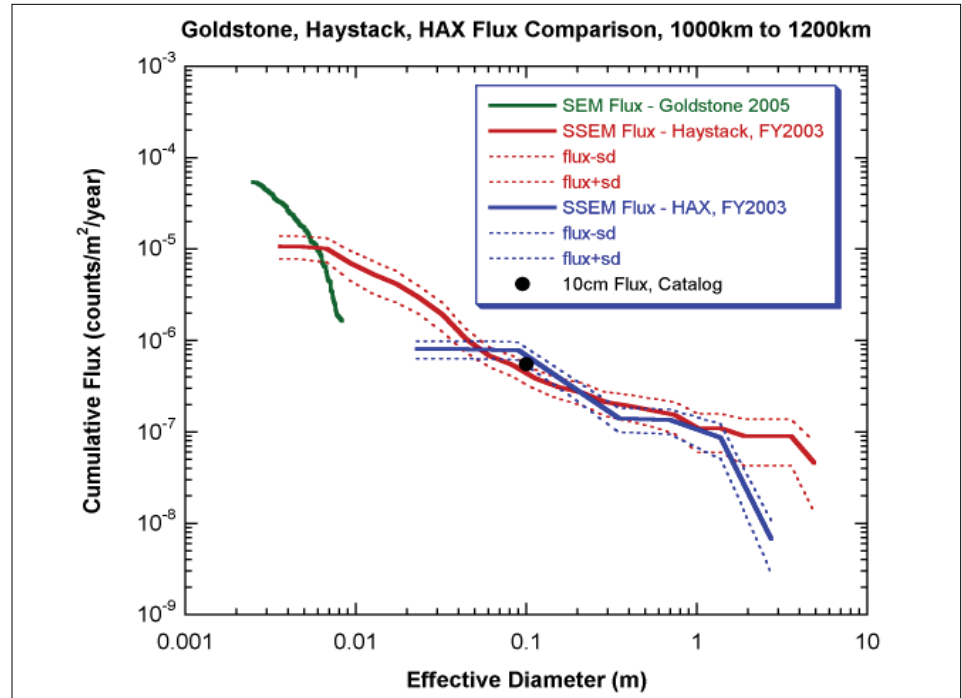


Figure 1. The measured debris flux between an altitude of 1000 km to 1200 km using NASA's primary debris observation radars. Use of all the radars provides data for debris sizes from 2 mm to several meters.

Because the Goldstone radar can measure only the principal polarization of the radar return signal, the measured RCS is slightly lower than the true RCS. This will result in the quoted diameters being slightly smaller than the true diameters.

The NASA Orbital Debris Program Office is now responsible for processing the raw Goldstone data. Three corrections are applied to the data: a doppler correction for the matched filtering, a time-in-beam correction, and a correction for the antenna gain pattern as a function of altitude. These corrections are detailed in Reference 1.

Shown in Figure 1 is the cumulative debris (conic frustum) flux versus the debris (equivalent) diameter between 1000 km to 1200 km using data from the Goldstone, Haystack, and HAX radars. The Goldstone radar was pointed near the zenith with an elevation of 88.5°. The Haystack and HAX radars were pointed at 75° east. The debris flux for the Goldstone radar is derived using the one-to-one relation between RCS and size as given by the NASA Size Estimation Model (SEM). Errors are not quoted for the Goldstone radar since the systematic errors are difficult to estimate. The debris flux for the Haystack and HAX radars are derived using the NASA Statistical Size Estimation (SSEM) model². The error bars for the Haystack and HAX data are one sigma statistical errors and do not incor-

porate any estimates of systematic errors. As a benchmark, the cumulative flux of the catalogued 10 cm population is shown and is in excellent agreement with both Haystack and HAX observations. The debris flux observed by the Goldstone radar abruptly drops above 8 mm compared to the Haystack data. This is believed to be a consequence of a signal saturation problem of the data acquisition system at the Goldstone radar that limits the maximum size visible at a particular altitude. The Goldstone data between 2 mm and 8 mm are believed to be accurate even with systematic limitations described above.

The very large coverage in debris sizes allowed by utilizing the three complementary radars is vital for assessing and understanding the debris environment. Moreover, this data is crucial for modeling and simulation efforts to better understand the long-term and short-term evolution of this environment.

1. Goldstein, R.M. and S.J. Goldstein, Jr., *Flux of Millimetric Space Debris*, The *Astronomical Journal*, Vol. 110, No. 3, 1995.
2. Xu, Y.-l., et al., *A Statistical Size Estimation Model for Haystack and HAX Radar Detections*, 56th International Astronautical Congress, Fukuoka, Japan, 2005. ♦

Modeling the Effect of High Solar Activity on the Orbital Debris Environment

D. WHITLOCK

The rate at which orbiting objects in low Earth orbit (LEO) decay due to atmospheric drag is a function of the density of the atmosphere. Variations in atmospheric density are primarily driven by variations in solar activity. The basic 11-year cycle of solar activity is well-known, but there is a considerable variation in intensity of the peak solar activity from cycle-to-cycle. Models attempting to predict future solar activity become an unavoidable error source when forecasting the orbital lifetime of debris and intact objects. While historic solar flux values measured during periods of low so-

lar activity show only slight variance from modeled values, solar flux activity measurements during high solar activity vary as much as 50% from the predictive models. Furthermore, most solar models predict a maximum flux value at or near 200 solar flux units (sfu, one solar flux unit = $10^{-22} * W * M^2 * Hz^{-1}$). Each of the past six solar cycles has contained an average of 95 days with measured flux in excess of 250 sfu. In addition, the effect of increased atmospheric drag due to high solar activity is non-linear in nature, meaning that as the deviance between the modeled and actual values increases, the consequent discrepancy in orbital behavior is exacerbated.

The actual period of the solar cycle is not constant either, and varies between cycles, such that the 11-year cycle is itself only an approximation.

The primary tool used at the NASA Orbital Debris Program Office for orbital lifetime prediction is Prop3D, which was designed specifically for long-term orbital debris evolutionary models such as EVOLVE and LEGEND (LEO-to-GEO Environment Debris model). As solar flux activity can be one of the most important factors in determining orbital lifetime, and consequently the number of objects in orbit, a table of daily flux values is needed as a primary input into Prop3D within LEGEND. The solar flux table used by Prop3D combines historical measured daily flux values (1957 to present), short term flux forecasts (present to 2007), and predicted future flux values based upon the historic measurement data. The historic daily measured flux and short term flux forecasts are made available by the National Oceanic and Atmospheric Administration, Space Environmental Center (NOAA/SEC). For epochs beyond the near term (2008 and later), a curve-fit technique using sixth order sine and cosine terms was performed to fit historical daily solar flux values from 1947 through September 2005 and then use this curve-fit equation to generate future flux predictions. The fitting technique simultaneously determines 14 coefficients. These include 12 sine/cosine terms plus the average period and a constant average flux term.

The form of the fitting curve forces the solution to have a single average periodicity representing an average value over the data set used. The current value of this base period is 3900 days (= 10.7 years). The flux fit is forced to be the same each cycle, with no attempt to predict high and low cycles, and no weighting of more recent data over old.

Only days in which there are actual solar flux values were fit, as for some days, there was no recorded flux measurement from NOAA/SEC. The fitting is done by minimizing the residuals of the sum of the square of the differences between the actual flux value and the flux calculated from the equation. It was seen that using higher order sine and cosine terms did not significantly improve the quality of the curve-fit, while using less than six terms provided an inferior fit.

The least squares solution produces a very reasonable approximation, given the inherent variability in daily solar flux (see Figure 1), particularly during periods of high activity.

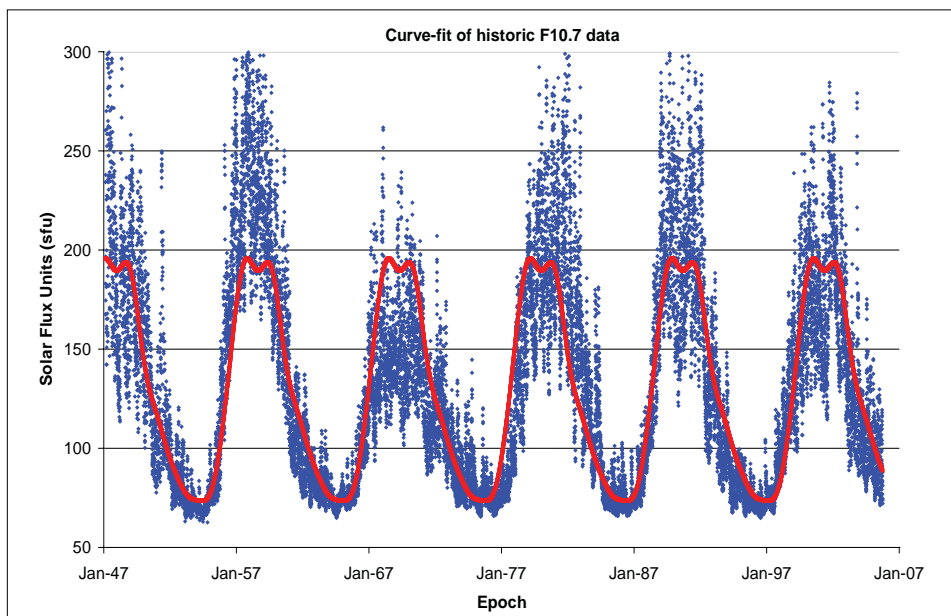


Figure 1. Least squares curve-fit solution of F10.7 historic data.

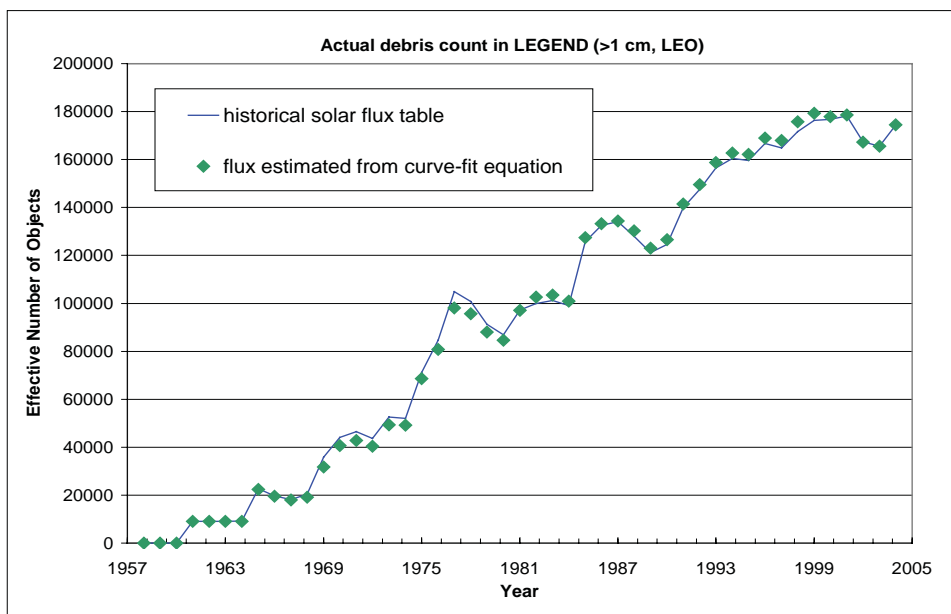


Figure 2. LEGEND effective number of objects using historic flux and curve-fit equation.

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Solar Activity

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While in practice, the equation will be used solely to generate future flux predictions, a comparison with historically measured flux can be made in order to measure the effect of the inherent inaccuracies of flux. LEGEND was used to simulate the historical debris environment from 1957 to present, using two distinct solar flux models. The first model contained historical daily solar flux measurement data with interpolated values for any days in which there were no measurements. The second model used the flux values generated by the curve-fit equation. The rest of the input variables for LEGEND were the same for both cases, and the overall count of debris greater than 1 cm was compared. It is important to note that a comparison is not being made with the true debris environment (NaK and solid rocket motor slag were not included in LEGEND), but rather the results from LEGEND given two different solar flux table inputs. Figure 2 shows the simulated debris count from 1957 through 2005 for both solar flux model inputs. Figure 3 displays the percentage difference between the debris count approximated when using flux calculated from the equation, and the debris count approximated when using the actual flux. It appears the maximum overestimation of debris (about 2% - 3%) were at the time of highest solar activity around 1980 and 2001. But it is important to note that the discrepancy appears to be short-lived, as the LEGEND debris count tends

to correct itself and become equal between the two models shortly after each peak cycle.

The primary discrepancy in debris count occurs as a result of solar cycle #20 (1965 – 1976) which had much less solar activity than the other cycles. This lower activity leads to an underestimation of debris of nearly 12% when using the empirical equation to approximate solar activity. However, this temporary underestimation is corrected by 1981, near the approximate peak of cycle #21. Again, despite in-

accuracies in the solar flux prediction, the global debris count estimation is not adversely affected in the long term.

Given that there is not yet a reliable technique to accurately forecast daily solar flux values, using a curve-fit approximation of previous cycles, in order to derive future flux values, should lead to an approximate maximum of 3% in debris count overestimation, with no apparent long term drift over several solar flux cycles.

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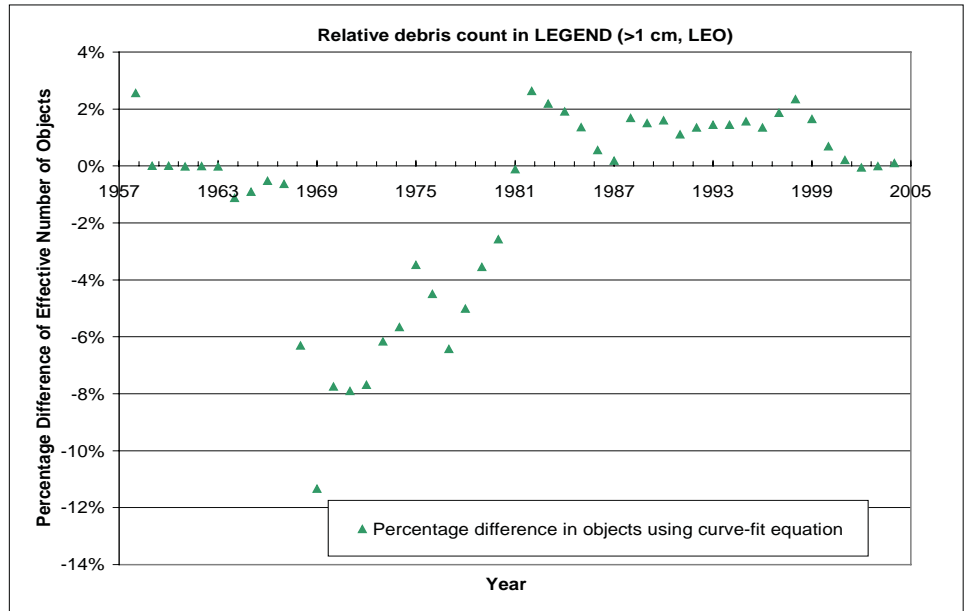


Figure 3. LEGEND effective number of objects using curve-fit equation as a percentage of LEGEND effective number of objects using historical flux.

Orbital Debris Photometric Study

H. RODRIGUEZ, K. ABERCROMBY, K. JARVIS, & E. BARKER

Beginning with the launch of Sputnik in 1957, man-made debris have been orbiting our Earth. Estimating the size of orbital debris has been a common interest in the science community ever since. To obtain a size from optical measurements, the current practice is to assume an albedo, use the brightness from the measurements, and convert to optical size. However, assuming a single albedo value may not be valid for all objects or orbit types. Radar determines a radar cross section (RCS) which can be converted to size, but it is still unknown if a direct comparison between radar and optical signals will yield the same size estimate. Objects observed in the optical regime can appear bright or dark due to material type and orientation rather than being a true assessment of its optical cross section (OCS). Albedos often used for optical size conversions are 0.2 for objects in geosynchronous Earth

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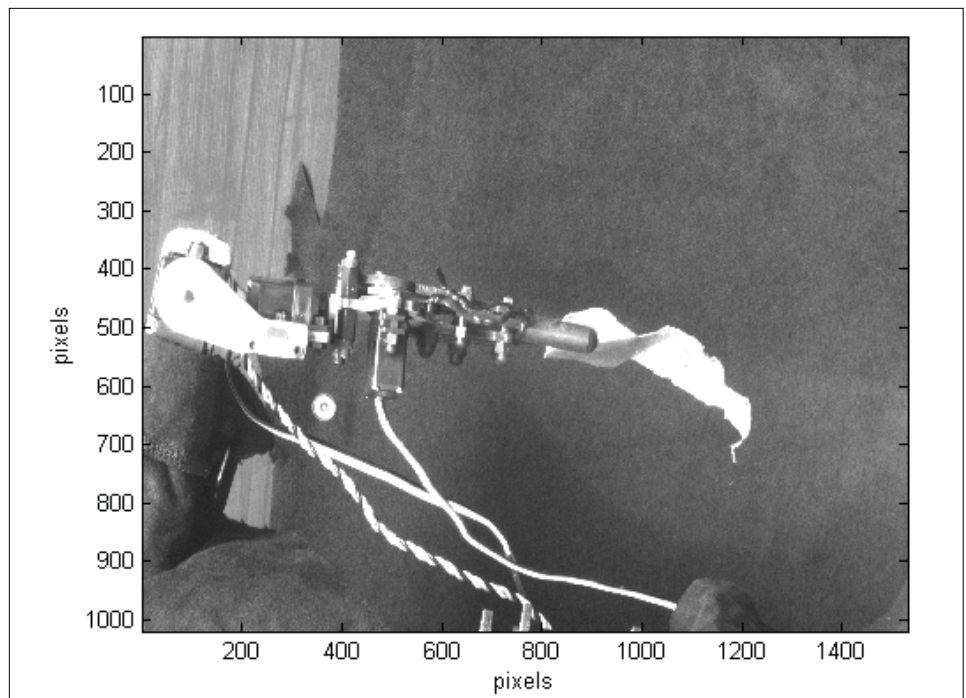


Figure 1. Picture of robot arm holding a piece of debris from ESOC2 test.

Photometric Study

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orbits (GEO)¹ and 0.1 in lower Earth orbit (LEO)². An optical size estimation model is needed so that assuming an albedo is only necessary in special circumstances.

In an effort to better understand the differences between optical and radar size estimates of orbital debris, a study of photometric response of debris pieces in the optical portion of the electromagnetic spectrum has begun. Our study takes brightness measurements of debris of various shapes and sizes at different phase angles and orientations to determine the effect of size, shape and orientation on these measurements. The debris pieces used originated from a ground test explosion of a mock satellite from European Space Operations Centre's ESOC2 test³. Each debris piece is made of an aluminum alloy and the mass is limited to 113 g or less because of robot hardware constraints.

The experiment uses a Xenon lamp to simulate solar illumination, a CCD camera to digitally record all images, and a programmable robot arm to vary the object's orientation and phase angle. The light source is a 300 W Xenon, Ozone-Free source with a 3.3 cm collimated beam defined in the spectral range of 200 to 2500 nm. The current set-up uses two apertures (the first approximately 7.5 cm and the second 3.3 cm in diameter) in the light path to help reduce off-axis scattered light from the incoming beam. Attached to the second aperture are two low density filters (ND2 and ND4) to reduce the intensity of the light. The CCD camera is a SBIG 512 x 512 ST8X MEI CCD with a filter wheel containing standard Johnson filters

(red, green, blue, clear, and ultraviolet filters defining specific bandpasses in the electromagnetic spectrum). The Lynx 6 robotic arm has five degrees of freedom (base rotation, shoulder, elbow, wrist, and wrist rotate) in addition to having a functional gripper. The height of the robot arm when in stow position is 14 cm and reaches up to 45.7 cm when fully extended. The arm reach forward is 36.8 cm and the gripper has a full opening of 5.1 cm.

The robotic arm (Figure 1) has been programmed with three different programs: "x-rotation," "y-rotation," and "full_rotation." The "x-rotation" and "y-rotation" rotate 180° in 5° increments about their corresponding axis. The "full_rotation" applies both programs (rotation about x-axis 180° in 5° increments, then lifts 5° in the y-axis and repeats the x-axis rotation). Currently the "full_rotation" is programmed only to 35° rotation on the y-axis for testing; future experiments will be programmed for the full 180° rotation.

Using the CCD software, a dark and then an illuminated image are taken for the same exposure times at each phase angle position described above. By subtracting the dark from the illuminated, or raw, image, the system corrects for any bias of thermal signals. In addition to the dark and raw images, a series of flat images are taken of a white poster board at the same exposure. These pictures are summed together and used to remove any pixel variations and any non-uniform illumination. The final image, shown in Figure 2, is produced using the following formula:

$$\text{Final Processed Image} = (\text{Raw} - \text{Dark}) / \text{Flat}$$

A MATLAB script is used to determine the intensity of the final processed images at the various orientations and phase angles. To avoid contamination from the background, the background levels are determined and set to zero. By summing the remaining counts (CCD output is in AD units or counts) in the image, the intensity is determined for each image. In the future, a white ball will be used to define a reference intensity or zero point for a magnitude system. An example of how the intensity changes with orientation is shown in Figure 3.

From these results, we can begin to understand the variations in brightness due to size and shape of an object as well as orientation. Eventually, a correlation between the brightness and the size will be determined and result in an optical size estimation model.

1. Talent, D.L. et al., *A Search for Debris in GEO*, Proceedings of the Second European Conference on Space Debris, Darmstadt, Germany, 1997.

2. Henize, K. and J. Stanley, *Optical Observations of Space Debris*, AIAA, Baltimore, MD, p. 99-1340, 1990.

3. Fucke, W. and H. Sdunnus, *Population Model of Small Size Space Debris*, ESOC Contract No. 9266/90/D/MD, Battelle-Institut, BF-R 67.698-5, 1993. ♦

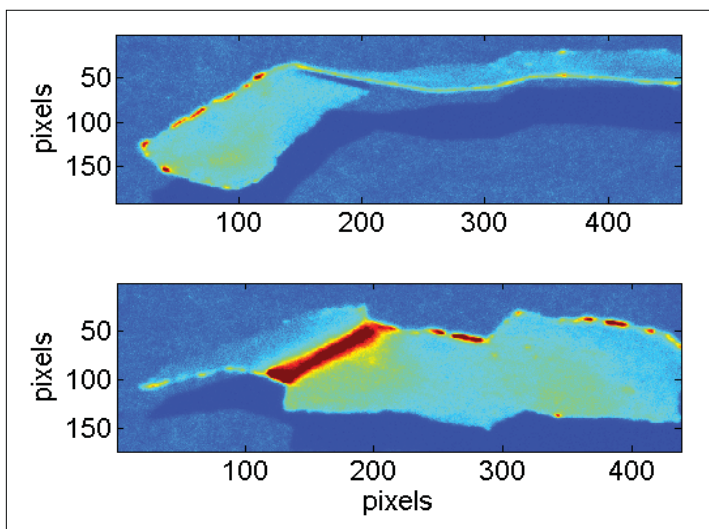


Figure 2. Small Image of a debris piece at 40° (top) and 170° (bottom) in the x-rotation. The background has not been removed from this image so the shadow is still apparent.

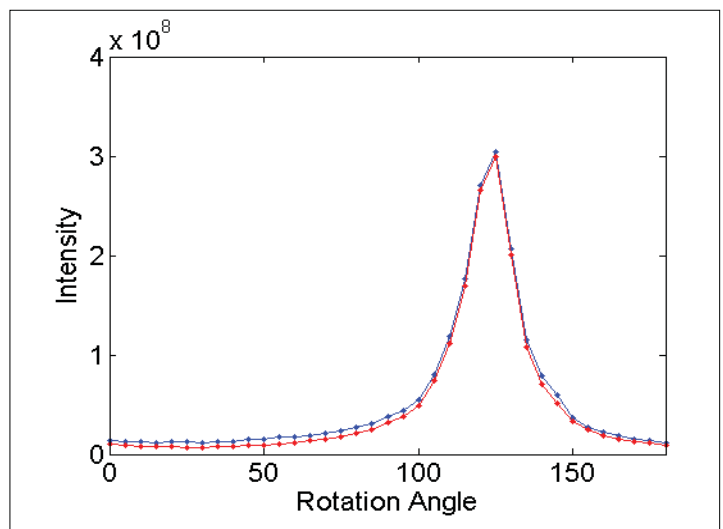


Figure 3. Intensity Profile for a debris piece for rotation angles ranging from 0 to 180°. Notice the peak intensity at 130°, which was when the piece showed the most area to the CCD. The Blue data set represents the total signal and the Red data set represents the same background set with the signal removed.

Developing a Mass Density Distribution for Breakup Debris

J. OPIELA

Introduction

Debris mass density is an important factor in studying orbital debris, as it directly affects the damage predictions of hypervelocity impact models. The purpose of the overarching study is to develop a mass density distribution (or set of distributions) for all types of orbital debris, as a function of debris size. The distribution could then be integrated into debris environment and risk models. The current study focuses on breakup debris only.

Breakup debris covers a wide range of sizes and materials, and depends on the type of parent object and breakup mechanism. The first step in characterizing breakup debris is to quantify past on-orbit breakups. Using updated source material from the *History of On-Orbit Satellite Fragmentations*¹, the sources of cataloged fragmentation debris currently in orbit may be determined. A total of 10,308 breakup debris objects were cataloged before the year 2006. Figure 1 shows the cataloged breakup debris still in orbit at the end of December 2005. A total of 3455 breakup debris objects were in orbit at that time. These debris can be further characterized by orbit. Figure 2 shows the Gabbard-style plot for the breakup debris in

orbit in January 2006.

For determination of debris material types, three data types are being considered: design-related data on launched objects, results from a ground-based breakup test, and results from the study of surfaces returned from space. Unfortunately, most of the design-related information is very general, user- or observer-type information. Information on specific, older objects is desirable for the purpose of modeling current breakup debris. There is a small amount of detailed information, on upper stages, in a 1991 study². The NASA Orbital Debris Program Office also has some detailed information on newer payloads and rockets, used for reentry hazard analyses. The more recent information, while interesting, does not contribute to the current debris environment.

Valuable ground-based payload breakup data are those from the Satellite Orbital Debris Characterization Impact Test (SOCIT) shot #4. This test was performed in January 1992. The test was sponsored by the Department of Defense, and took place at the Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee. In this test, a 150-g aluminum projectile, travelling at 6 km/s, struck an actual (surplus) Transit/

OSCAR spacecraft (Oscar 22)³. The results (fragments) of this test have been studied by several organizations. The results used here are primarily from the data tables provided by the Kaman Sciences report⁴.

Surfaces that have been returned from space within our study period (post 1995) are a Hubble Space Telescope (HST) solar array and Space Shuttle windows, radiators, and other surfaces. The Space Shuttle windows provide the best data on particle composition, but only for the smallest particles. The Space Shuttle radiators provide data on larger particles. The HST solar arrays, being composed of many materials, do not provide good information on debris particle composition. The impact database⁵, compiled by the NASA Johnson Space Center's Hypervelocity Impact Test Facility, contains detailed information about all recorded debris impacts on Space Shuttle missions STS-50 through STS-113.

Analysis of the Data

The process of studying both the Space Shuttle and SOCIT data involved sorting the data by material type and counting ("binning") the particles by size. Since there were a total of eleven materials, it was decided to simplify the results by grouping (summing) materials with similar densities. Observing the spread of density values, it appeared that the best simplification would include three density groups: low, medium, and high. Materials with densities below 2.0 g/cm³ fall into the "low density" group: fiberglass, plastic, binders, and "other". Materials with densities between 2 and 6 g/cm³ fall into the "medium density" group: titanium, aluminum, and paint. Materials with densities above 6 g/cm³ fall into the "high density" group: solder, steel, copper, and silver.

Conclusion

The current state of this study is that the density of breakup debris may be separated into three groups: low, medium, and high density materials. The typical material of each density group is plastic, aluminum, and steel, respectively. These data will contribute to the overall debris density distributions over a wide size range. Although the data sources do not always overlap, and each contains its own unique biases, we believe that the information can be scaled and combined into a single model.

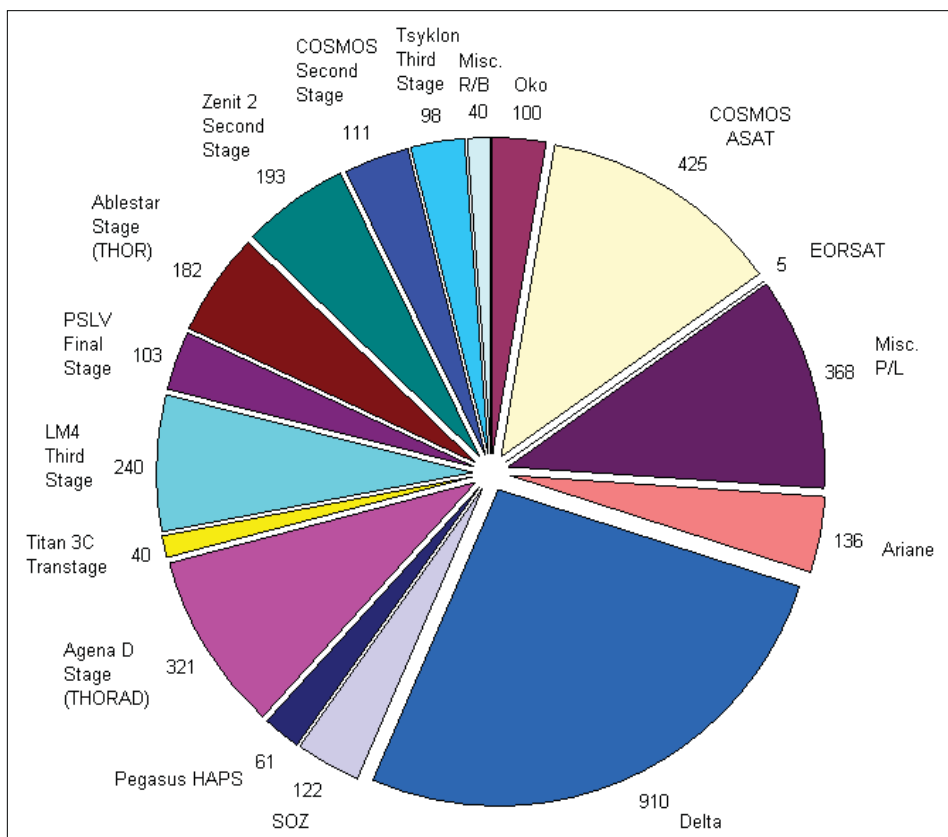


Figure 1. Number and type of cataloged breakup debris in orbit, December 2005.

1. *History of On-Orbit Satellite Fragmentations*,

Density Distribution

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13th Edition (JSC 62530), NASA JSC, Houston, TX, 2004.

2. Gehan, J., *Rocket Upper Stage Composition Survey*, TM-B91MS-031-019 (Transmittal Memo to NASA JSC), McDonnell Douglas Space Systems Co. Space Station Div., 1991.

3. Baker, D. (ed.), *Transit/NNSS (US Navy Oscar) Series*, Jane's Space Directory 2004-2005, Jane's Information Group Ltd., Coulsdon, UK, 2004.

4. McKnight, D.S., et al., *Satellite Orbital Debris Characterization Impact Test (SOCIT) Series Data Collection Report*, Kaman Sciences Corporation, Alexandria, VA, 1995.

5. Hyde, J. (curator), *Shuttle Hypervelocity Impact Database (MS-Excel file)*, ESCG, Houston, TX, February 2005. ♦

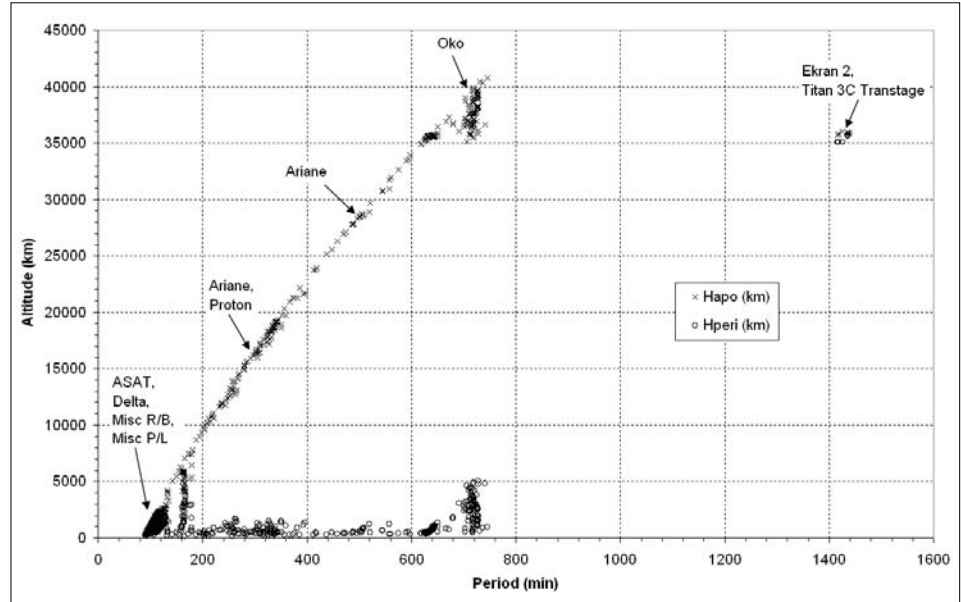


Figure 2. Cataloged fragmentation debris still in Earth orbit as of January 2006.

MEETING REPORT

2006 NASA/DoD Orbital Debris Working Group Meeting 1 February 2006, Houston, Texas, USA

The NASA/DoD Orbital Debris Working Group, formed in 1997, is an outgrowth of a recommendation from the White House Office of Science and Technology Policy (OSTP). Its primary purpose is to exchange information on space surveillance activities which contribute to a common understanding of the orbital debris environment. The 9th meeting of the Working Group was hosted by the NASA Orbital Debris Program Office in Houston, Texas on 1 February 2006.

Air Force Space Command (AFSPC) presented status and future plans for the Space Surveillance Network (SSN) including Service Life Extension Program (SLEP) for the Eglin radar to allow it to continue operations through at least 2025. They reported that the Deep Stare enhancements have been completed for the Ground Electro-Optical Deep Space Surveillance (GEODSS) telescopes with resulting improvements in throughput, sensitivity, and metric accuracy. A follow-on SLEP is also planned for GEODSS. Other planned improvements to the SSN include the new Space Surveillance Telescope (SST), the

Space Based Space Surveillance (SBSS) satellite, the S-band upgrade to the Air Force Space Surveillance System (AFSSS), and the Haystack Ultra-wideband Satellite Imaging Radar (HUSIR) upgrade to Haystack. This last upgrade will interrupt the NASA orbital debris measurements at Haystack for about one calendar year while the antenna is refurbished to handle W-band wavelengths.

Space and Missile Command (SMC) presented alternative end-of-life disposal options for geosynchronous spacecraft using modified sun-pointing perigee for spacecraft with low or uncertain fuel reserves.

The Naval Research Laboratory (NRL) reported on the Large Area Debris Collector (LAD-C) which was chosen by the DoD Space Test Program (STP) for flight on the International Space Station (ISS). LAD-C will deploy 10 m² of aerogel cells with acoustic sensors which will allow identification of time-of-impact and trajectory information.

NASA presented the status of its debris measurement projects including the resolution of a problem with Haystack and HAX debris data. A new all-digital Process-

ing and Control System (PACS) at Haystack utilizes a dual buffer system in its real time processing. One of the buffers was not being properly written resulting in missed detections for targets below 10 dB signal-to-noise ratio (SNR). Although individual detections appeared normal, the problem manifested itself when statistics on large datasets were examined. The problem has now been corrected. Other results from the Goldstone radar, the Michigan Orbital Debris Survey Telescope (MODEST), and spectral measurements of satellites and debris were presented.

Other NASA presentations covered the Satellite Breakup Risk Assessment Model (SBRAM), the policy (currently in signature cycle) for jettisoning of objects from the ISS, and a study published in *Science* on the instability of the debris environment at some altitudes. This study concluded that even if no future launches were conducted, the debris population would continue to grow at these altitudes from collisions of satellites and debris already in orbit. ♦

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

INTERNATIONAL SPACE MISSIONS January - March 2006

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2006-001A	NEW HORIZONS	USA	HELIOCENTRIC			0	0
2006-002A	ALOS	JAPAN	692	697	98.2	1	0
2006-003A	ECHOSTAR 10	USA	35784	35791	0.0	1	0
2006-004A	MTSAT-2	JAPAN	35776	35798	0.0	1	0
2006-005A	ASTRO F (AKARI)	JAPAN	697	712	98.2	1	1
2006-005C	CUTE 1.7	JAPAN	299	707	98.2		
2006-006A	ARABSAT 4	ARABSAT	REENTERED			1	0
2006-007A	SPAINSAT	SPAIN	35775	35795	0.1	1	1
2006-007B	HOT BIRD 7A	EUTELSAT	35745	35825	0.1		
2006-008A	ST5-FWD	USA	304	4552	105.6	1	0
2006-008B	ST5-MID	USA	303	4550	105.6		
2006-008C	ST5-AFT	USA	303	4554	105.6		

ORBITAL BOX SCORE

(as of 22 MAR 2006, as cataloged by US SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	51	308	359
CIS	1356	2706	4062
ESA	36	33	69
FRANCE	43	302	345
INDIA	31	109	140
JAPAN	94	59	153
US	1015	2945	3960
OTHER	349	21	370
TOTAL	2975	6483	9458

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UPCOMING MEETINGS

4-11 June 2006: The 25th International Space Technology and Science (ISTS) Conference, Kanazawa, Japan.

The conference will include technical sessions on space debris and a panel discussion session on international space law of space debris. Additional information on the Conference is available at <http://www.ists.or.jp>.

16-23 July 2006: The 36th Scientific Assembly COSPAR 2006, Beijing, China.

Three Space Debris Sessions are planned for the Assembly. They will address the following issues (1) advanced ground-based radar and optical, and space-based *in-situ* measurements, (2) population and environment modeling, (3) debris mitigation measures, (4) reentry tracking and survival analysis, and (5) hypervelocity impact testing and shielding design. The meeting will also discuss new developments toward national and international standards and guidelines. More information for the conference can be found at <http://www.cospar2006.org>.

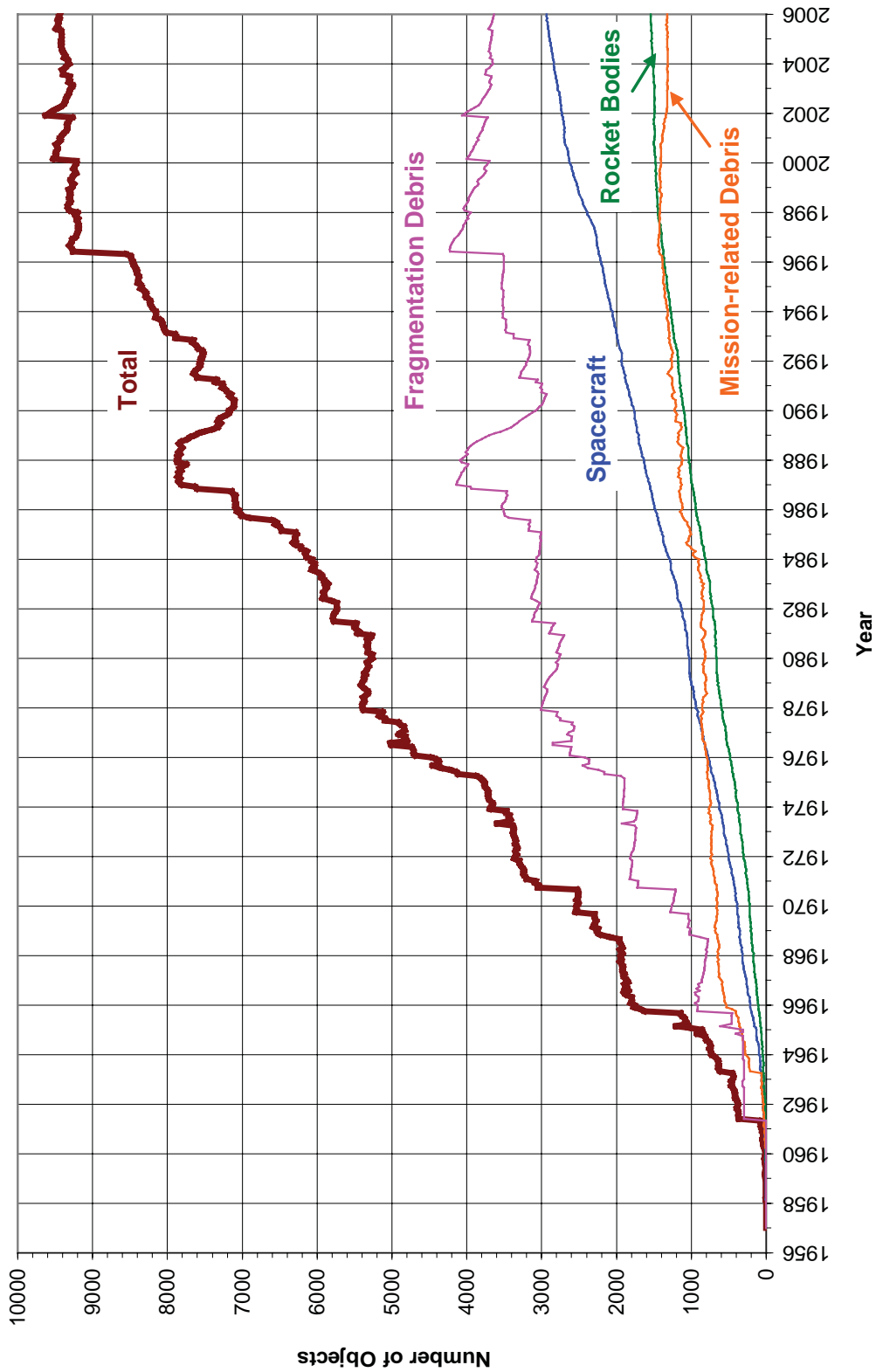
10-14 September 2006: The 7th Air Force Maui Optical and Supercomputing (AMOS) Technical Conference, Wailea, Maui, Hawaii, USA.

The 2006 AMOS Conference will cover various topics in space surveillance, imaging processing, optics, and computer simulations. One orbital debris session is planned for the conference. Additional information on the conference is available at <http://www.maui.afmc.af.mil/conferences.html>.

2-6 October 2006: The 57th International Astronautical Congress, Valencia, Spain.

A Space Debris Symposium is planned for the congress. The four scheduled sessions will address the complete spectrum of technical issues of space debris, including measurements and space surveillance, modeling, risk assessment, reentry, hypervelocity impacts, protection, mitigation, and standards. Additional information on the Congress is available at <http://www.iac2006.org>.

Monthly Number of Cataloged 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.

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