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INSIDE...

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Rocket Body Debris Falls in Argentina

A 10-year-old rocket body reentered the atmosphere on the morning of 20 January, resulting in the recovery of a large piece of debris in Argentina. The rocket body was the third stage of a Delta II launch vehicle which placed a U.S. Global Positioning Satellite (Navstar 35) into a transfer orbit of 175 km by 20,300 km on 26 October 1993. The stage designation was PAM-D (Payload Assist Module – Delta), and the vehicle was assigned the International Designator 1993-068C and the U.S. Satellite Number 22879 by the U.S. Space Surveillance Network.

The surviving object, which was found in extreme northeastern Argentina in Corrientes Province, was the 1.2 m diameter titanium casing of the STAR-48B solid rocket motor. The mass of the casing upon landing was estimated to be about 50 kg, following the loss of part of the casing and the engine nozzle during the fiery reentry. The mass of the entire PAM-D stage prior to reentry was more than 200 kg.

During 2003 an average of one spacecraft or rocket body made uncontrolled reentries into the atmosphere each week, but fragments of such vehicles are normally not found. Just over three years before this most recent event, a STAR-48B motor casing landed in Saudi Arabia in almost identical condition (*Orbital Debris Quarterly News*, Vol. 6, Issue 2, p. 1). A week after the landing in Argentina, the Delta II second stage which placed NASA's Mars Exploration Rover Opportunity into orbit on 10 June 2003 fell back to Earth without incident. ◆

Titanium casing of the STAR-48B solid rocket motor found in northeastern Argentina.

Fragmentation of Cosmos 2383

The first satellite breakup of 2004 occurred on 28 February when the Russian Cosmos 2383 spacecraft (International Designator 2001-057A, U.S. Satellite Number 27053) fragmented into more than 50 pieces detected by the U.S. Space Surveillance Network. A total of only 13 new debris were officially cataloged, and all had decayed from orbit within a month.

The previous week the spacecraft, part of the Cosmos 699-series, had completed its primary 2-year mission in an orbit of 405 km by 415 km at an inclination of 65 degrees and had lowered its perigee to just 225 km to accelerate its fall back to Earth. This practice is common for this class of spacecraft belonging to the Russian Ministry of Defense and is often followed by a breakup event. Of the 48 spacecraft of this type placed in low Earth orbits since 1974, 21 (44%) have experienced breakups, including the last three.

At the time of the Cosmos 2383 breakup the spacecraft was in an orbit of approximately 220 km by 400 km. Since the International Space Station (ISS) was in an orbit of about 360 km by 370 km, many of the debris from Cosmos 2383 passed through the altitude regime of ISS for some days, posing a collision risk to the station and its crew. The previous spacecraft in this series, Cosmos 2347, unfortunately broke-up in its operational orbit in November 2001 just 30 km above the ISS, presenting one of the most serious threats to date to the station. ◆

Publication of the 1999-2002 Haystack/HAX Report

The 1999-2002 Haystack and HAX radar data analysis report, *Haystack and HAX Radar Measurements of the Orbital Debris Environment; 1999-2002*, JSC-49875, has been published. The report and appendices are available on CD. During the 1999-2002 collection periods, data were collected at 10° and 20° elevations pointing south and at 75° elevation pointing east. The data were taken over the maximum in the 11-year sun spot and solar particle flux cycle, which produces maximum atmospheric drag on the debris population. This report describes the radars and the data analysis and compares the 1999-2002 measurements with the NASA orbital

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PROJECT REVIEWS

NASA AMOS Spectral Study (NASS) Project Update

K. JORGENSEN

In order to characterize the space environment, the physical characteristics of orbiting objects are taken into consideration. These properties are needed for space environment models and the building of shields for spacecraft, as well as in providing base work for future environment studies. Some of these characteristics, including material type, are assumed currently. Although the material types of launched objects may be known, any debris resulting from these orbiting satellites can only be surmised. In an effort to better characterize the materials seen in the orbital debris environment, a program has been initiated to study material types of orbiting objects using reflectance spectroscopy. Each material type shows a different spectrum based on its composition. Using low-resolution reflectance spectroscopy, and comparing absorption features and overall shape of spectra, it is possible to determine material types of man-made orbiting objects in both low Earth orbits (LEO) and geosynchronous orbits (GEO).

The NASA AMOS Spectral Study (NASS) began observations in May 2001, collecting data for 23 nights. Currently, remote data on more than 60 rocket body (R/B) and spacecraft (S/C) spectra have been collected using the 1.6 m telescope at the Air Force Research Laboratory (AFRL) Maui Optical Supercomputing (AMOS) site. The remote spectra were compared to the database of spacecraft material spectra located at Johnson Space Center (JSC). Figure 1 shows the scaled reflectance spectrum of a LEO R/B (shown in black; the small spikes are noise) overlaid with the scaled reflectance spectrum of a laboratory sample (shown in red) of aluminum, painted white, that was exposed to the space environment for a long period of time (i.e., "flown"). Due to the absorption feature near 8500 angstroms, aluminum was determined to be one of the materials in the object. The absorption feature near 3900 angstroms is from white paint and therefore it was concluded that the object is white paint is another material present. It was concluded that the most likely scenario would be a white paint surface with an aluminum substrate. It is possible that the substrate is not being observed in this spectrum but rather the aluminum feature is stemming from another part of the object, however, the two materials are present in this spectrum.

Figure 2 shows the anomalous increase in intensity (termed "reddening") of R/Bs as compared to laboratory samples of common spacecraft materials. Each of the R/Bs in Figure 2 have different altitudes to show that the reddening is not dependent on range. Beginning near 7000 Angstroms, the remote spectra begin to redden and continue to do so into the near infrared. The root cause of this increase is still under investigation. Thus far, only one R/B type fails to display this reddening; the spectrum of that R/B type is shown in Figure 1. The asteroid community sees similar reddening in the spectra of asteroids. For example, S class asteroids are thought to be the parent bodies of meteorites identified as ordinary chondrites. They are spectrally similar save for the reddening seen in the spectra of the asteroids. This reddening is attributed to space weathering, specifically ion bombardment[1]. To investigate one aspect of possible space weathering, laboratory testing is being conducted to measure the effect of ion bombardment on common spacecraft materials.

The NASS project is making progress toward determining the material type of orbiting objects, the first step toward determining the material type of orbital debris. Future studies will include the remote acquisition of spectral measurements of a piece of fragmentation debris. This will move us toward a better understanding of how similar or different fragmentation pieces are as compared to intact objects.

1. Dukes, C.A., R.A. Baragiola, and L.A. McFadden. *Surface Modification of Olivine by H+ and He+ Bombardment*, J. of Geophysical Research, Vol. 104, No E1, 1999, p. 1865-1872.◆

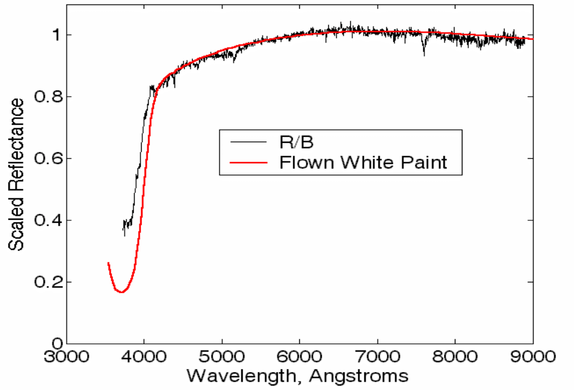

Figure 1. Comparison of a R/B remote spectrum with the laboratory sample of flown white paint.

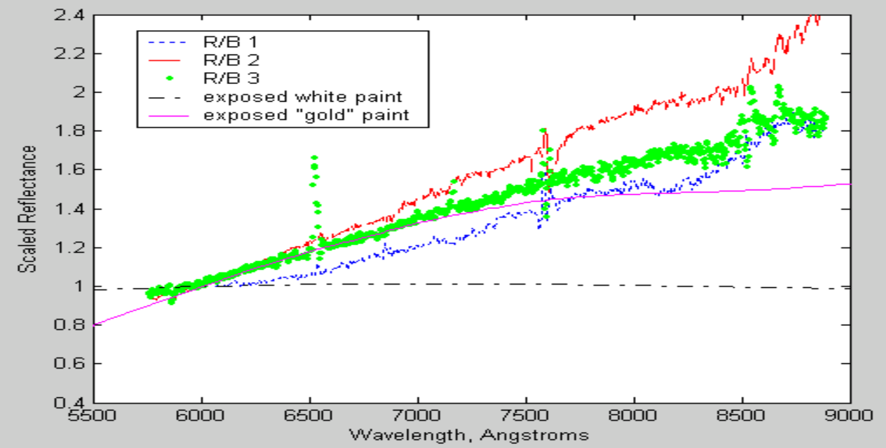

Figure 2. Comparison of three R/B remote spectra with two common spacecraft materials. This figure shows the increase in reflectance (or even intensity) as the wavelengths increase. This is termed "reddening".

Publication of the Haystack/HAX Report

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debris engineering model, ORDEM2000. A new technique for identifying breakup fragments was employed, allowing a more complete analysis. Also, a complete statistical analysis of the number and size of the RORSAT NaK droplets was carried out. Haystack and HAX have shown that the debris environment is dynamic and can change rapidly. The Haystack and HAX measurements continue to provide the ability to detect small debris from previously unknown sources and the ability to examine continuous size distributions for sizes ranging from cataloged objects to objects smaller than 1 cm diameter. ◆

Working Toward an Albedo Distribution Model: SiBAM—Size-Based Albedo Model

K. JARVIS & G. STANSBERY

Ground-based measurements of the orbital debris environment are made using both radar and optical observations in order to gain a more complete understanding of the environment. Comparing the results of the two methods is problematic, however, since neither method directly measures the size of the object. Radar measures the radar cross section (RCS) of an object. The RCS is a complicated function of not only the size of an object, but its shape, composition, orientation, and the wavelength of the radar used. Optical telescopes measure brightness which is a function, in part, of the object's albedo and phase function.

NASA measured the RCS of thirty-nine fragments from a ground hypervelocity impact test and developed the Size Estimation Model (SEM) to be used in conjunction with RCS measurements. Fragments from these ground tests typically have a dark, sooty coating. It is not known if this coating is an artifact of the ground test or if it also occurs in explosions in space. Since optical measurements rely on the brightness of an object, ground measurements analogous to the SEM have been considered impractical due to this sooty coating. NASA has planned direct albedo measurements of debris by simultaneous visual and infrared measurements using the 3.6 m telescope at the Air Force Maui Optical and Supercomputing (AMOS) site, but the instrumentation is not yet available. Therefore, researchers have had to rely on indirect measurements by comparing the optical brightness of cataloged objects with size estimates from non-simultaneous radar measurements using the SEM. There are serious issues with trying to use the SEM for this purpose. The SEM is intended to fit a distribution of small fragmentation debris. Using the SEM to assign sizes to individual objects and especially large intact satellites will likely produce very large uncertainties, if not biases. However, at the current time, it is all that is available.

In the past, the RCS to size / brightness to albedo mapping has been used to create an average albedo using intact rocket bodies, satellites and cataloged debris, and that average has been used to extrapolate sizes i.e., median diameter for smaller debris detected by large telescopes such as NASA's Liquid Mirror Telescope (LMT). Experience with the radar SEM has shown that using an average or median value where a distribution should be used will produce a biased result. As a first step toward an albedo distribution model, a size-based albedo model (SiBAM) has been developed. This model is a work in progress and is still "young" with many expected modifications as more data are processed and integrated into the model.

The Correlated Targets (CTs) from the 1998-2000 LMT data sets were sorted, choosing debris from rocket body explosions and Cosmos 1275, a satellite that is also believed to have exploded. While this type of debris is certainly not the only type of debris in the debris environment, it is hoped that the explosion debris may mimic the basic shapes of flat plates and crumpled irregular spheres of which the smaller debris are thought to consist. Several critical assumptions are made and the interpretation of results requires that the assumptions and their limitations be understood:

- Rocket body (explosion) debris represents all debris.
- The data represent a complete sample.
- Median Diameter represents ground truth diameter.
- The mapping is applied to a data set of sufficient size so as to account for the variation seen in the data.
- Absolute magnitude calculations assume a specular reflection and are based upon an orbit normalized to an altitude of 1000 km.

Additional studies of the 1999-2000 LMT data set were performed using different techniques to obtain the properly weighted average albedo of orbital debris[1]. Two different methods were utilized. Both techniques illustrated that the properly weighted average albedo is not only a function of the albedo distribution, but also a function of the relative number of small debris to large debris. When the relative number of small debris to large debris is as great as has been measured for debris (that is, that there is a much larger number of small debris as compared to large debris), the frequency of specular reflections was found to increase the proper average albedo significantly. This occurs because the dataset should have a larger number of data points in the small sizes and even a small fraction of specular reflections (hence, brighter magnitudes) will create a bias of predicting larger objects than is correct; this in turn affects the properly weighted average albedo by requiring a higher albedo at smaller sizes. SiBAM does not account for the possibility of specular reflections; but even so, the results of the properly weighted average albedo study dovetailed well with the results of SiBAM. Both studies indicate that the assumed albedo of 0.1 (a commonly assumed albedo for low Earth orbit objects) is too low. Additionally, different albedos need to be considered for intact objects versus debris objects. As SiBAM matures, better values are anticipated and ultimately SiBAM will provide a metric for the Albedo Distribution Model.

1. Kessler, D.J. and K.S. Jarvis. *Obtaining the Properly Weighted Average Albedo of Orbital Debris from Optical and Radar Data.* B1.4-0023-02, COSPAR, Houston, TX, 2002. ◆

A LEO Mitigation Study on the Duration of Spacecraft Lifetime and Postmission Disposal Success Rate

J.-C. LIOU

Postmission disposal (PMD) has been recognized as the most effective way to limit the growth of future orbital debris populations. The 1995 *NASA Safety Standard* (NSS 1740.14) recommends placing a spacecraft or upper stage passing through low Earth orbit (LEO, 200 to 2000 km altitude) in an orbit in which atmospheric drag will limit its lifetime to less than 25 years after the completion of mission. This postmission disposal practice has been known as the 25-year decay rule. However, a prolonged satellite mission lifetime will certainly decrease the effectiveness of the 25-year decay rule.

An analysis to quantify how the simulated future debris environment responded to the 25-year decay rule with different spacecraft mission lifetimes was performed. A second analysis was also done to examine how different postmission success rates affected the outcome. Both

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A LEO Mitigation Study

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analyses were based on parametric studies using the NASA orbital debris evolutionary model, LEGEND.

The first parametric study included a non-mitigation scenario in which no postmission disposal practices were applied to upper stages and spacecraft, and four test scenarios where upper stages were moved immediately to 25-year decay orbits and the mission lifetimes of spacecraft were set to 5, 10, 20, and 30 years, respectively. At the end of the mission lifetime, each spacecraft was moved to either the 25-year decay orbit or to a LEO storage orbit (above 2000 km altitude), depending on which option required the lowest velocity change for the maneuvers.

The 25-year decay orbit of a spacecraft, at the end of its mission, was determined by a simple iteration process. The orbit was propagated forward in time for 25 years. If the vehicle reentered, no modifications to its orbit were made. Otherwise, its perigee altitude was lowered by 5 km and the new orbit was propagated for 25 years. The whole process was repeated until a new orbit that would reenter in less than 25 years was reached. The postmission disposal success rates for the four mitigation cases were all set to 90%. A simple procedure based on random numbers was used to determine whether or not postmission disposal for each vehicle was to be implemented successfully. Five LEGEND simulations, one for each scenario, were completed. Each simulation included 30 Monte Carlo runs with a projection period of 100 years. Future launch traffic was simulated by repeating the 1995 to 2002 launch cycle.

Our analysis showed that at the end of the 100-year projection, the number of 10 cm and larger objects in LEO would increase with increasing spacecraft mission lifetime. This is illustrated in Figure 1. The spatial density distribution for 10 cm and larger objects at the beginning of 2003 is represented by the light blue histogram near the bottom. The projected environment for the non-mitigation scenario is indicated by the dark blue curve near the top. When compared with the non-mitigation scenario, the four mitigation cases all significantly reduce the growth of future debris populations. However, there are noticeable differences among different mitigation cases, especially around 800 km, 1000 km, and 1450 km altitudes.

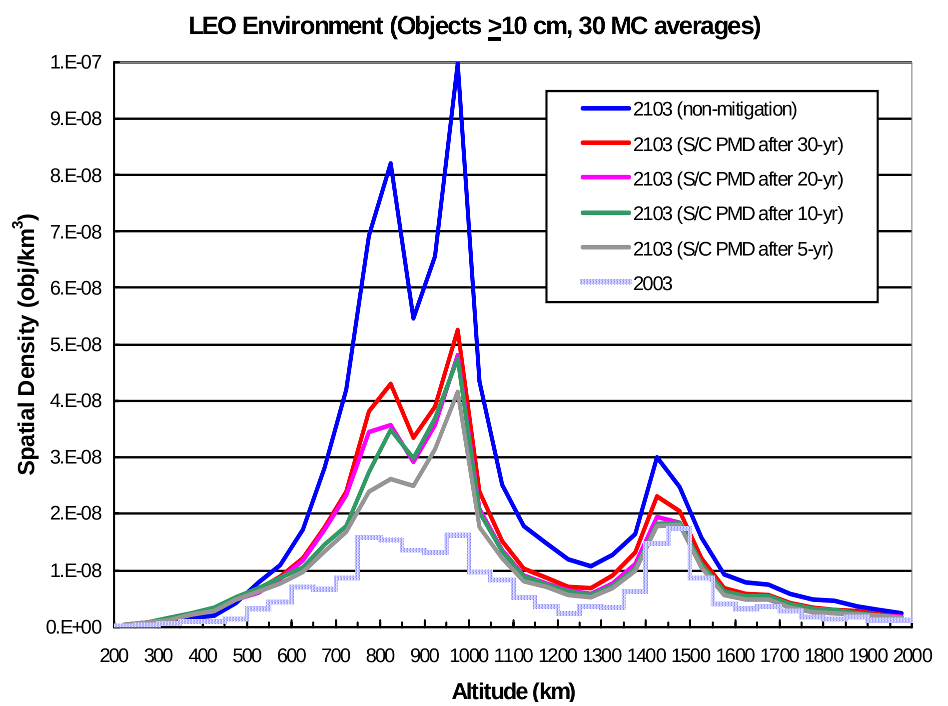

Figure 1. Spatial density distributions for objects 10 cm and larger from the non-mitigation scenario and from postmission disposal scenarios with different spacecraft mission lifetimes.

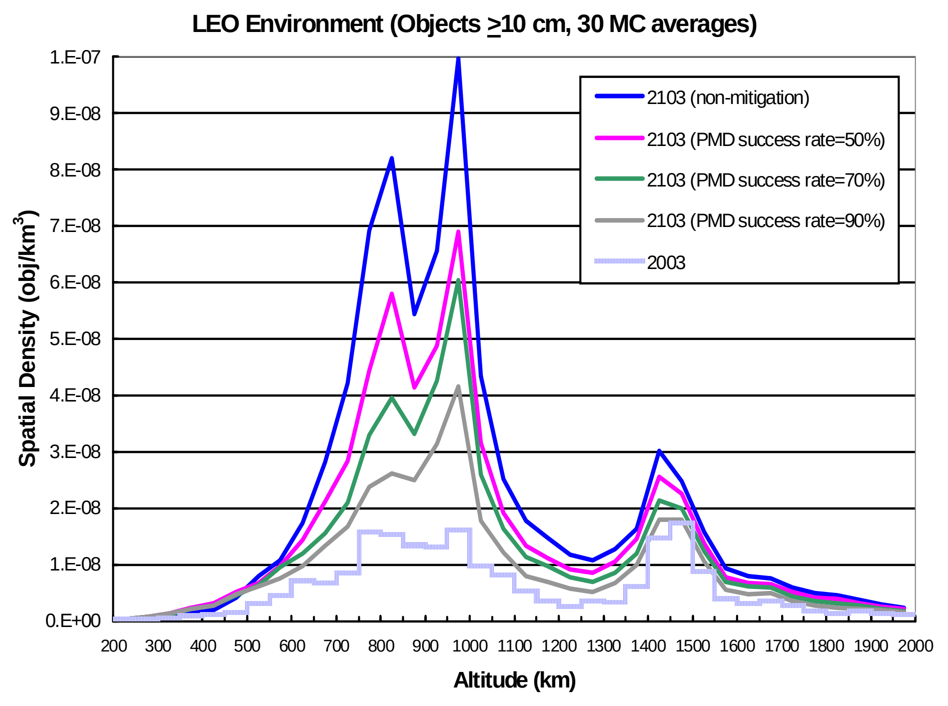

Figure 2. Spatial density distributions for objects 10 cm and larger from the non-mitigation scenario and from postmission disposal scenarios with different mitigation success rates.

The second parametric analysis included two new scenarios. Both were similar to the 5-year spacecraft mission lifetime case from the first analysis, but the postmission disposal success rates were changed to 70% and 50%, respectively. Figure 2 summarizes the non-mitigation and the three mitigation scenarios with different success rates. The results show a clear and expected trend. Note mitigation scenarios always result in a slightly higher spatial density below 500 km altitude than the environment predicted by the non-mitigation scenario. This is a direct consequence of moving on-orbit spacecraft and upper stages to the 25-year decay orbits.

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Estimation of ≥1 cm Debris Flux Uncertainty in LEO

Y.-l. XU & M. MATNEY

Models that assess orbital debris hazards to spacecraft make use of environmental models that define the orbital debris fluxes and compute the damage risk to different spacecraft elements. To assess the risk from orbital debris, it is highly desirable for a model predicting debris fluxes also to provide the uncertainties associated with the flux predictions. The NASA Orbital Debris Engineering Model, ORDEM2000, describes the orbital debris environment in the low-Earth orbit (LEO) region. It first derives debris populations from ground-based and in situ measurement data in terms of size and orbital parameters and then establishes the debris spatial density and their velocity distributions in space. What follows is a brief report on the status of computation of the ≥1 cm debris flux uncertainties for ORDEM2000.

The primary source of observational data that the ORDEM2000 uses for deriving the ≥1 cm debris population is the Haystack radar measurements. For debris observations, the Haystack radar is operated in a staring or beam park mode. Its antenna is fixed at a specific elevation and azimuth. The debris objects passing through the field-of-view are samples from the debris environment for a particular observing time and for the specific beam position. It is natural to follow a statistical approach to infer the total population of debris from the observed radar detections. A maximum likelihood estimator (MLE) is used in ORDEM2000 to model the ≥1 cm debris population distribution by using the probability that an object in a particular orbit will be detected by the Haystack radar. The spatial density, velocity distribution, and inclination distribution of the inferred debris population form the template files of ORDEM2000, which are used to calculate debris flux on an orbiting spacecraft.

To be able to provide not only the debris fluxes but also their uncertainties, the inherent uncertainties in the MLE modeling process of inferring the debris population functions need to be calculated, typically by assessing the standard deviations in the derived populations. This demands the knowledge of the covariance matrix of the model parameters and thus requires the computation of the corresponding Fisher information[1] or "expected information" matrix. To obtain the desired Fisher information matrix, we must know the observed Fisher information matrix and the explicit relation between the observed and derived Fisher information matrices.

In practice, the evaluation of the standard deviations of derived debris population functions consists of five basic steps: (1) to construct the covariance matrix of observations, using theoretical knowledge of observation techniques and instruments, (2) to invert the observation covariance matrix to get the observed Fisher information matrix, (3) to establish the relation between observed and derived Fisher information matrices from the MLE model for inferring the debris population, (4) to evaluate the Fisher information matrix of derived parameters from the observed Fisher information matrix and the relation between the two Fisher information matrices, and (5) to invert the derived Fisher information matrix. The final step results in the desired covariance matrix that contains the standard deviations of the derived population functions.

In general, observations may be correlated so that the covariance matrix of observations is not diagonal. However, for the case of Haystack measurements, it is reasonable to assume that the radar detections are independent from each other and that the Haystack count rate follows a Poisson distribution. These two assumptions greatly simplify the practical calculations in the first two steps. The MLE model used in the ORDEM2000 for deriving the ≥1 cm debris population from the Haystack data implies a linear transformation between observations and model population functions. This allows us to establish an explicit relation between the observed and derived Fisher information matrices based on the so-called delta method, also known as the theory of error propagation. Also, it is obvious from the MLE model that the covariance matrix of model parameter functions is positive definite and symmetric. This is a great advantage for the last step of getting the covariance matrix from the derived Fisher information matrix when the matrix dimensions are large. It does not require an actual inversion of the Fisher information matrix and even does not require the calculation of off-diagonal elements of the covariance matrix. In practical calculations it needs only to compute the eigenvalues and the normalized eigenvectors of the derived Fisher information matrix.

Once the ≥1 cm debris population functions and their standard deviations are derived, a Monte Carlo process can be used to obtain an estimate for the uncertainty of ≥1 cm debris fluxes. This consists of the following steps: (1) to generate randomly a set of debris populations from the derived population functions and their standard deviations (including off-axis terms in the covariance matrix), (2) to calculate a set of ORDEM2000 template files based on the debris populations obtained from the first step, (3) to compute a set of debris fluxes based on the template files, and (4) to average over the obtained fluxes to obtain the mean flux and its standard deviation. A practical example for the calculation is shown in Figure 1, which presents some preliminary results for the mean ≥1 cm debris flux and its standard

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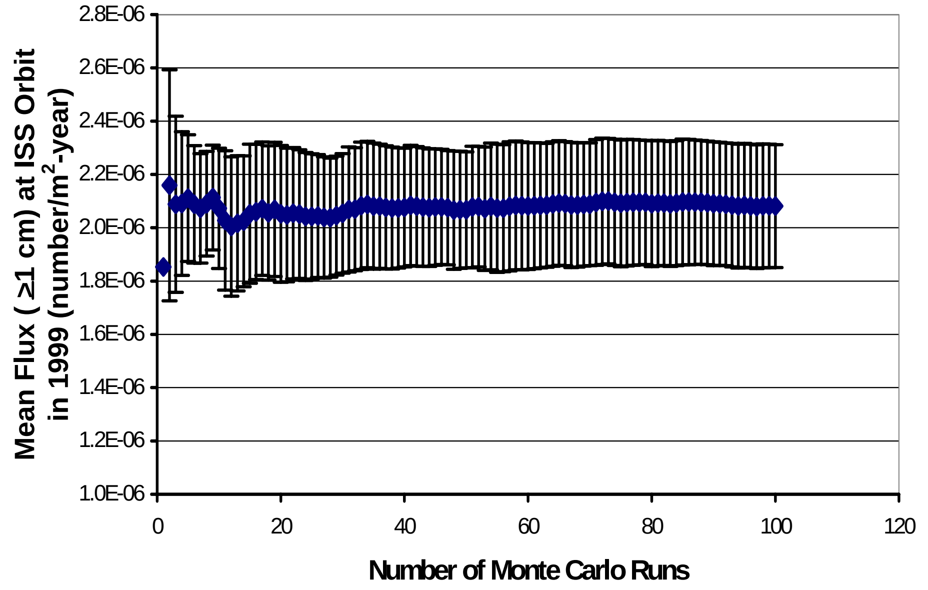


Figure 1. Example of statistical uncertainty estimates for an ISS flux calculation. The graph represents the cumulative average and standard deviation from successive Monte Carlo samples of orbital debris populations using the covariance matrix described in the text.

Reentry Survivability Analysis of Gamma-ray Large Area Space Telescope (GLAST) Satellite

R. SMITH, J. DOBARCO-OTERO, & W. ROCHELLE

The Gamma-ray Large Area Space Telescope (GLAST) is a joint project of the USA, France, Germany, Japan, Italy, and Sweden. Spectrum Astro is building the spacecraft bus for NASA Goddard Space Flight Center (GSFC), which manages the overall program. The GLAST spacecraft is scheduled to be launched in September 2006 into a 565 km circular orbit with a 28.5° inclination.

An exploded view of the spacecraft can be seen in Figure 1. The spacecraft can be divided into two general components, the Spacecraft Bus and the Large Area Telescope (LAT). The LAT is the heart of the satellite and carries the gamma-ray measuring instruments.

The reentry survivability analysis was performed with the NASA Object Reentry Survival Analysis Tool (ORSAT), version 5.8. The analysis broke the satellite into 110 different object types. The analysis was performed to assess compliance with the *NASA Safety Standard* (NSS 1740.14) Guideline 7-1.

This analysis assumed an uncontrolled reentry (orbital decay) for the satellite at an altitude of 122 km. The parent body was modeled with an estimated dry mass of 3639 kg, a length of 2.9 m, and a height and width of 1.796 m. Because of the dense construction of the GLAST spacecraft, a 73 km breakup altitude was considered, as well as the standard breakup altitude of 78 km. At either of these two breakup altitudes, all the primary spacecraft components were exposed to reentry heating. In many cases, fragmentation of sub-components occurred. The initial temperature and the oxidation efficiency of all components were assumed to be 300 K and 0.5, respectively.

The fragments were modeled as tumbling spheres, cylinders, boxes or flat plates. The 1976 U.S. Standard Atmosphere model was used for all components. A 1-D heat transfer model was used to model the heat conduction in the fragments. An object is assumed to demise when the absorbed heat (net heat rate flux integrated over time multiplied by its surface area) is greater than or equal to the heat of ablation of the object.

The preliminary total debris casualty area predicted for the standard 78 km breakup was 502 m^2. This unusually high casualty area is due to 1024 small tungsten foil objects that impact the ground with a kinetic energy above the 15 J casualty limit.

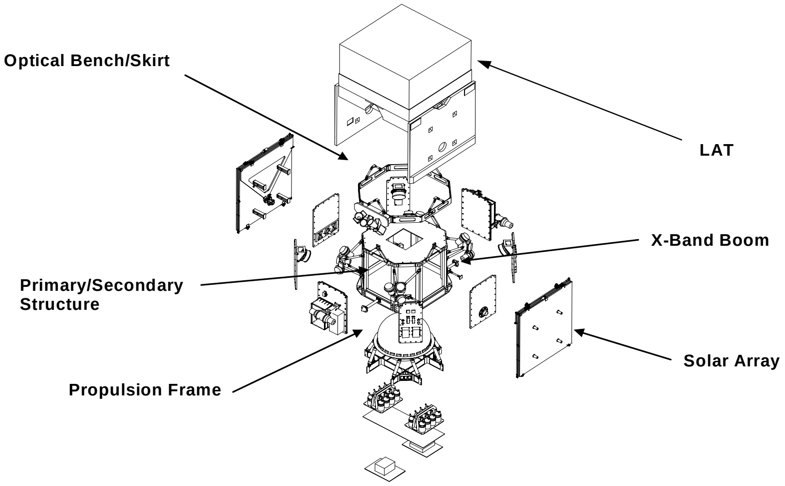


Figure 1. Exploded view – drawing of the GLAST spacecraft.

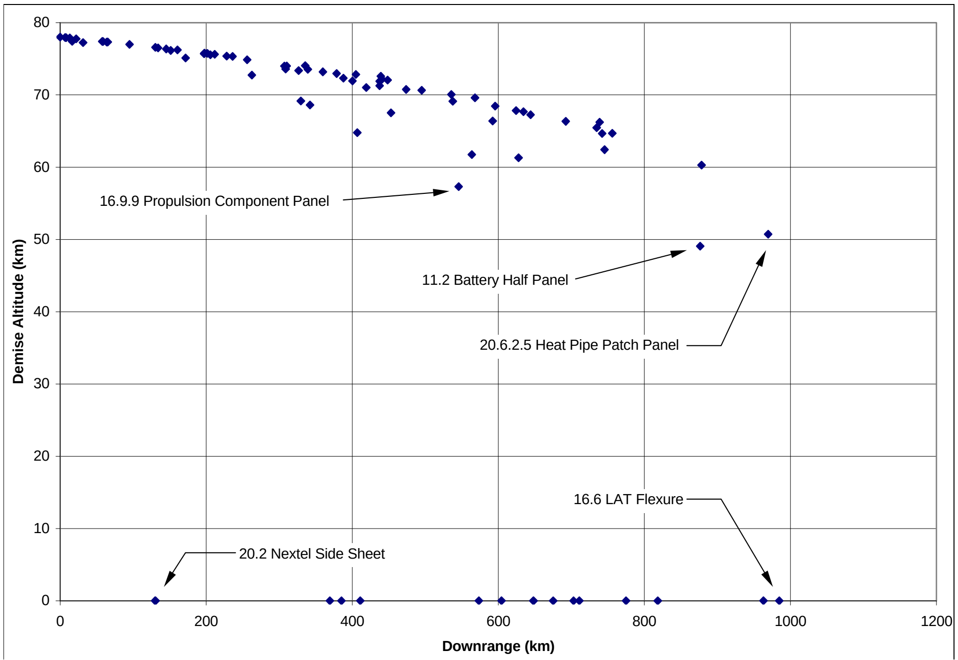


Figure 2. Demise altitude vs. downrange of all analyzed GLAST objects for 78 km breakup altitude.

However, a number of components were redesigned. These changes decreased the debris casualty area to 13.24 m^2 for both breakup altitudes. If the propulsion system is replaced by non-surviving ballast, the total debris casualty area is predicted to be only 7.18 m^2. A number of these surviving objects impact with a kinetic energy above the 15 J casualty limit but less than 25 J. The difference in human casualty risk is very small between 15 J and 25 J. Therefore, the GLAST satellite with no propulsion system would have a debris casualty area of 4.96 m^2 for objects impacting greater than 25 J.

A plot of demise altitude vs. downrange for all GLAST objects can be seen in Figure 2 for the nominal 78 km breakup assumption. Most fragments demise above 60 km. The survivors tend to be objects made of materials with high melting points such as carbon-carbon, Nextel, titanium, or tungsten. The surviving mass of all objects is about 360 kg; however, only 203 kg of these objects impact with a kinetic energy above the 15 J casualty limit.

The GLAST program is an excellent example of how the engineering community can respond positively to early reentry risk assessments by incorporating design-to-demise techniques. ◆

How to Calculate the Average Cross Sectional Area

M. MATNEY

A parameter that comes up over and over again in orbital debris applications is the proper value of the average cross sectional area. This is especially important in computing the magnitude of the atmospheric drag on an orbiting object. Historically, this value has been computed using the assumption that the object does not have a preferred orientation and is tumbling randomly. While this assumption might not hold for many operational satellites (e.g., gravity-gradient satellites), it is probably a good assumption for derelict objects, especially rocket bodies.

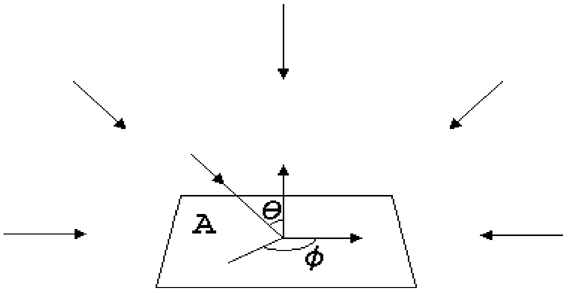
Consider a single surface on a flat plate with area **A** on one side. If the plate is tumbling randomly, then we can integrate all possible area projections of that one side over 2π sterradians (see Figure 1). The result is that the average projected area is ¼ the area of the surface being considered (note that if a two-sided plate is used, the average projected area will still work out to ¼ the total surface area of the plate). This relationship holds for any convex surface. If every surface element can "see" a full 2π sterradians of space, then the average projected area of the shape is ¼ the total surface area. Such shapes include spheres, plates, disks, cubes, rectangular boxes, cylinders, and cones.

Many objects in space, however, are not convex in shape. They have interior corners where some elements "shadow" others. A number of different schemes to account for this behavior have been devised, but none has proven satisfactory. This prompted us to write a program that computes average cross sectional areas correctly, by using computer models of spacecraft assembled from simple shapes (triangles, cylinders, and spheres). These digital models can be rotated to compute the projected area at any orientation. These orientations are integrated numerically over the complete range to compute the average cross section.

Figure 2 presents such a model for a hypothetical spacecraft. It has a cube-shaped bus with crossed square fins or solar panels (1 m on a side) and a cylindrical projection. If we were to use the total surface area of 11.571 square meters, we would naively compute an average cross sectional area of 2.893 square meters using the ¼ technique. Using the detailed procedure described above, we can assemble a digital model of this spacecraft and arrive at the correct cross sectional area of 2.328 square meters.

Using this technique, we have computed a digital model of the Hubble Space Telescope. Assuming random orientation of the telescope and random positioning of the solar panels, we get an approximate cross sectional area of 63.7 square meters.

We hope to make this program available for general use within future DAS program updates. ◆



$$\frac{1}{4\pi}\int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} \sin\theta \, d\theta \, (A\cos\theta) = \frac{A}{4}$$

Figure 1. Integration of the average projected area of a single-sided plate over the hemispherical solid angle.

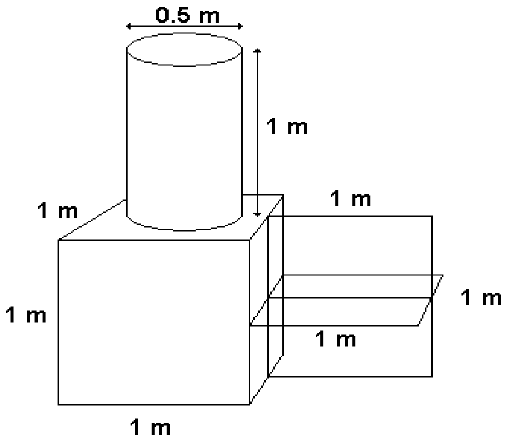


Figure 2. Design of a hypothetical spacecraft.

MEETING REPORTS

2nd Annual Non-Imaging Space Object Identification Workshop
3-4 March 2004, Kihei, Maui, Hawaii, USA

The second annual Non-Imaging Space Object Identification (SOI) Workshop was held 3-4 March 2004 in Kihei, Maui. This workshop covered various topics including space object identification, discrimination, classification, data fusion, change detection, and modeling. Overall, 50 participants shared ideas and questions regarding aspects of non-imaging. Much of the focus was on signature response from various wavelength regions and how to interpret the results. Specifically, the use of photometry to determine the type of spacecraft and tumbling rate was the topic discussed in most detail. The workshop showed the increasing interest and need for information into the arena of non-imaging techniques. ◆

7th Annual Meeting of the NASA/DoD Orbital Debris Working Group
29 January 2004, Houston, Texas, USA

The NASA/DoD Orbital Debris Working Group was formed in 1997 in response to a recommendation by the White House Office of Science and Technology Policy (OSTP) in *Interagency Report on Orbital Debris, 1995* (this report can be downloaded from the NASA orbital debris website at www.orbitaldebris.jsc.nasa.gov). Major meetings of the Working Group are held annually, alternating between Houston, Texas and Colorado Springs, Colorado. This

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7th Annual Meeting of the NASA/DoD Orbital Debris Working Group
29 January 2004, Houston, Texas, USA

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7th meeting of the Working Group was hosted by the NASA Orbital Debris Program Office at the Johnson Space Center.

The primary purpose of the Working Group is to exchange information on space surveillance activities which contribute to a common understanding of the orbital debris environment. Department of Defense representatives from U.S. Strategic Command, Air Force Space Command, and the Air Force Research Laboratory summarized current and planned space surveillance capabilities, including the recent improvement to the U.S. Space Surveillance Network (SSN) to track debris as small as 5 cm in diameter in low Earth orbits (*Orbital Debris Quarterly News*, Volume 8, Issue 1, p. 7). A proposed new S-band electronic fence might be tracking debris as small as 1-2 cm in diameter by the end of the decade.

NASA reviewed its efforts to characterize the orbital debris population down to 2 mm in diameter with the Haystack radar, the Haystack Auxiliary radar, and the Jet Propulsion Laboratory's Goldstone radars, which also support the NASA Deep Space Network. NASA also reported on observations of debris near the geosynchronous orbit in a joint effort with the University of Michigan using a telescope in Chile and on efforts to discern the composition of debris by analyzing optical signatures. NASA and the Air Force Research Laboratory are working together to deploy a new type of 1-meter-diameter telescope on the Kwajalein Atoll in the Pacific Ocean to monitor low inclination orbital debris.

The Working Group also discussed issues associated with satellite fragmentations, tracking debris shortly before its reentry into the atmosphere, and domestic and international progress in mitigating the generation of orbital debris. The next meeting of the NASA/DoD Orbital Debris Working Group is tentatively scheduled for the first quarter of 2005 in Colorado Springs. ◆

41st Session of the Scientific and Technical Subcommittee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS)
16-27 February 2004, Vienna, Austria

For the eleventh consecutive year, space debris was an agenda topic for the annual meeting of the Scientific and Technical Subcommittee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS). The subject was addressed during 23-27 February at the United Nations facility in Vienna, Austria. The principal goal of the meeting was to endorse the IADC (Inter-Agency Space Debris Coordination Committee) Space Debris Mitigation Guidelines and to forward these guidelines to the full COPUOS which will be meeting in June (*Orbital Debris Quarterly News*, Volume 7, Issue 2, p. 5).

During the meeting, a representative of IADC reviewed the basic tenets of the space debris mitigation guidelines and reported that a support document was being developed by the IADC for release as early as this year. The IADC approved the guidelines by consensus in October, 2002, and first presented them to the STSC in February, 2003. A total of 7 presentations were made by five Member States (United States, Russian Federation, Germany, France, and India), the International Academy of Astronautics, and the European Space Agency on a variety of space debris related topics.

Several Member States (Russian Federation, India, Czech Republic, Italy, and the Republic of Korea) suggested minor or significant changes to the IADC Space Debris Mitigation Guidelines during the session. Since some of the recommended changes were of a highly technical nature, the STSC concluded that the IADC should review the recommendations and report back to the STSC in 2005. The next full meeting of the IADC was scheduled to take place in Abano Terme, Italy, during 19-22 April. The IADC Steering Group has agreed to consider these recommendations at that time. ◆

UPCOMING MEETINGS

18-25 July 2004: 35th Scientific Assembly COSPAR 2004, Paris, France.

Space Debris Sessions are planned for the Assembly. These will address the following issues: advanced techniques to measure debris populations, latest modeling results, hypervelocity impact tests, debris shielding, mitigation guidelines, and other related topics. More information on the conference can be found at: http://www.copernicus.org/COSPAR/COSPAR.html.

16-21 August 2004: Meteoroids 2004, Ontario, Canada.

A broad range of meteoroid research topics, including observations, dynamics, chemistry, sources, and distribution of meteoroids in the near Earth environment and in interplanetary space will be discussed during the 5-day conference. More information can be found at: http://aquarid.physics.uwo.ca/meteoroids2004.

13-18 September 2004: Air Force Maui Optical and Supercomputing (AMOS) Technical meeting, Wailea, Maui, Hawaii, USA.

This meeting is recognized internationally as a major annual meeting for the optical, computing, and space surveillance communities. It is intended for scientists, engineers, and technical managers from academia, industry, government, and military programs. Topics include: Adaptive Optics, Astronomy, Atmospherics, High Performance Computing Applications in Astronomy, Imaging, Theory, Algorithms, and Performance Prediction, Laser Propagation and Laser Radar, Non-Resolved, Object Characterization, Orbital Debris, Orbital Prediction, Satellite Modeling, Small or Autonomous Telescope Systems, and Space Situational Awareness. For more information, visit http://www.maui.afmc.af.mil/conferences.html

4-8 October 2004: The 55th International Astronautical Congress, Vancouver, Canada.

A "Space Debris and Space Traffic Management Symposium" is planned for the congress. The Symposium will include five sessions covering space surveillance, debris measurements, modeling, risk analysis, hypervelocity tests, mitigation practices, and traffic management. More information can be found at: http://www.iac2004.ca/intro_no.html.

INTERNATIONAL SPACE MISSIONS
January—March 2004

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2004-001A	ESTRELA DU SOL-TELSTAR14	USA/BRAZIL	35779	35795	0.0	1	0
2004-002A	PROGRESS-M1 11	RUSSIA	361	376	51.6	1	0
2004-003A	AMC-10 (GE-10)	USA	35775	35797	0.0	1	0
2004-004A	USA 176	USA	NO ELEMS. AVAILABLE			3	0
2004-005A	COSMOS 2405	RUSSIA	682	39677	62.8	2	3
2004-006A	ROSETTA	ESA	HELIOCENTRIC			1	0
2004-007A	MBSAT	JAPAN	35776	35792	0.1	1	0
2004-008A	EUTELSAT W3A	EUTELSAT	35703	35797	0.0	1	1
2004-009A	NAVSTAR 54 (USA 177)	USA	20091	20276	55.1	2	1
2004-010A	COSMOS 2406	RUSSIA	EN ROUTE TO GEO			2	3

Orbital Debris Information

NASA Johnson Space Center:
http://www.orbitaldebris.jsc.nasa.gov

NASA White Sands Test Facility:
http://www.wstf.nasa.gov/Hazard/Hyper/debris.htm

NASA Marshall Space Flight Center:
http://see.msfc.nasa.gov/mod/mod.html

NASA Langley Research Center:
http://setas-www.larc.nasa.gov/index.html

NASA Hypervelocity Impact Technology Facility:
http://hitf.jsc.nasa.gov

European Space Agency:
http://www.esoc.esa.de/external/mso/debris.html

United Nations:
http://www.oosa.unvienna.org/sdnps/index.html

Inter-Agency Space Debris Coordination Committee:
http://www.IADC-online.org

Orbital Debris Documents

National Research Council, “Orbital Debris – A Technical Assessment”:
http://www.nap.edu/books/0309051258/html/

National Research Council, “Protecting the Space Station from Meteoroids and Orbital Debris”:
http://books.nap.edu/books/0309056306/html/index.html

National Research Council, “Protecting the Space Shuttle from Meteoroids and Orbital Debris”:
http://www.nap.edu/books/0309059887/html/index.html

ORBITAL BOX SCORE
(as of 31 MAR 2004, as catalogued by US SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	38	278	316
CIS	1348	2603	3951
ESA	35	28	63
FRANCE	33	291	324
INDIA	27	107	134
JAPAN	83	48	131
US	990	2810	3800
OTHER	325	7	332
TOTAL	2879	6172	9051

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Debris Flux Uncertainty

Continued from page 5

deviation at the orbit of the International Space Station (ISS) in 1999.

This approach for obtaining an estimate of the ≥1 cm debris flux uncertainty seems to be practically feasible and efficient. In principle it applies to modeling processes using other sources of observational data such as for the ≥100 µm and ≥10 µm debris fluxes derived from LDEF (Long-Duration Exposure Facility) and Space Shuttle datasets.

The procedure discussed here is for a statistical modeling process only. There are additional uncertainties for the debris fluxes caused by various known and unknown factors that are still being assessed (e.g., the uncertainties in future traffic projections). This procedure assumes that the theoretical framework of the model itself is correct, and all theoretical model assumptions are reasonable.

1. Meeker, W.Q. and L.A. Escobar. *Maximum Likelihood Methods for Fitting Parametric Statistical Models*, Methods of Experimental Physics, Vol. 28, 1994, p. 226-228. ◆