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INSIDE...



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# Accidental Collisions of Cataloged Satellites Identified

Personnel of the U.S. Space Surveillance Network (SSN) have identified two new cases of accidental collisions between cataloged objects from different missions. One collision is recent, having occurred in January 2005, while the other is a much older event which occurred in late 1991 but has just now been recognized.

The subjects of the recent collision were a 31-year-old U.S. rocket body (1974-015B, U.S. Satellite Number 07219) and a fragment (1999-057CV, U.S. Satellite Number 26207) from the third stage of a Chinese CZ-4 launch vehicle, which exploded in March 2000. The event occurred on 17 January 2005 at an altitude of 885 km above the south polar region (Figure 1), a regime in low Earth orbit (LEO) with an above-average satellite population density. Both objects were in similar retrograde orbits at the time of the collision.

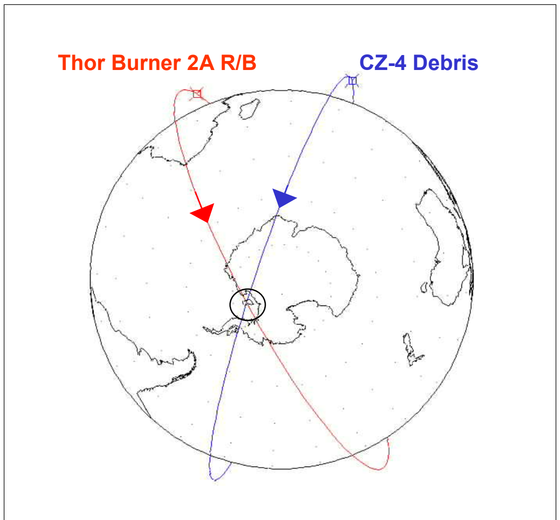



Figure 1. The accidental satellite collision occurred over the Southern Hemisphere at an altitude of 885 km.

Analysis indicates that the orbits of both objects were slightly perturbed at the same time that three debris (subsequently cataloged as U.S. Satellite Numbers 28591-28593) were released from the U.S. rocket body. The rocket body was the relatively small (1 $m^2$) upper portion of a Thor Burner 2A final stage (Figure 2). The fragment of the Chinese rocket body possessed a radar cross-section of only 0.06 $m^2$.

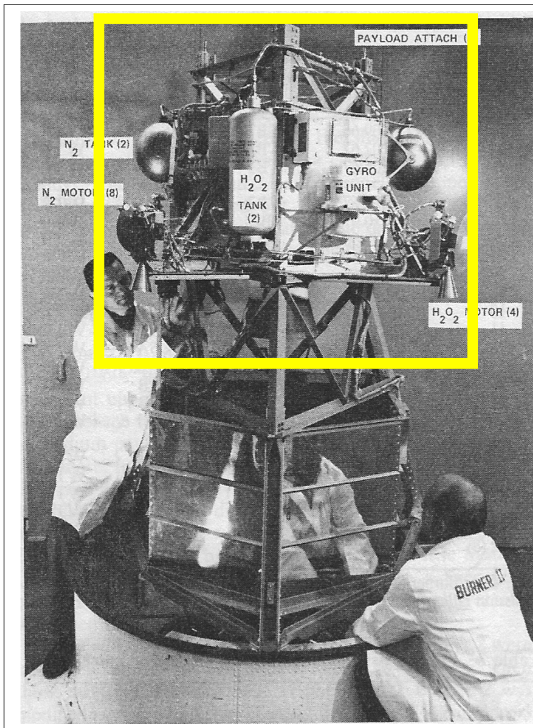



Figure 2. The highlighted portion of the Thor Burner 2A upper stage was involved in the collision with a Chinese rocket body fragment.

The recently recognized collision of late December 1991 involved a Russian non-functional navigation satellite, Cosmos 1934 (1988-023A, U.S. Satellite Number 18985) and a piece of debris from a sister spacecraft, Cosmos 926. Both objects were in similar orbits with a mean altitude of 980 km and an inclination of 83°. Two pieces of debris (1988-023C, U.S. Satellite Number 21912 and 1988-023D, U.S. Satellite Number 22919) from Cosmos 1934 were discovered by the SSN within a few weeks of the event, although they were not cataloged until later.

In this case the smaller impacting object apparently broke-up into much smaller debris and was no longer trackable by the SSN, *i.e.*, it could not be found after the collision. The event was only recognized recently when SSN specialists were examining historical tracking data.

The first recognized collision between cataloged objects from different missions involved an operational spacecraft and a fragment from a launch vehicle upper stage which had suffered a post-mission breakup. In that event, which occurred on 24 July 1996, the French CERISE spacecraft (1995-

*See Collisions on page 2*

NEWS

# Another NAVSTAR PAM-D Recovered after Reentry

For the third time in four years, a PAM-D (Payload Assist Module - Delta) solid rocket motor casing has been recovered after an uncontrolled atmospheric reentry. Coincidentally, all three reentries occurred during the month of January in the years 2001, 2004, and 2005. All were also utilized in the deployment of NAVSTAR spacecraft for the U.S. Global Positioning System (GPS).

The most recent event occurred on 13 January 2005 when the NAVSTAR 49 PAM-D (2000-071C, U.S. Satellite Number 26607) reentered over Asia. The titanium casing of the STAR-48B solid rocket motor was subsequently found near Bangkok, Thailand (Figure 1). The egg-shaped object had a diameter of 1.2 m and a mass of more than 50 kg and closely resembled the casings found in Saudi Arabia in January 2001 (*Orbital Debris Quarterly News*, 6-2, p. 1) and in Argentina in January 2004 (*Orbital Debris Quarterly News*, 8-2, p. 1).

Each launch of a NAVSTAR spacecraft left a PAM-D in a highly elliptical orbit of approximately 200 km by 20,000 km. During the period January 2001 through January 2005, a total of 10 of these rocket bodies, with ages ranging from 3 to 10 years, reentered with a 30 percent recovery rate, a rate consistent with the ratio of Earth's land to water area. Orbital inclinations of the 10 stages ranged from 22° to 39°, limiting reentries to between 39° North and 39° South latitude. ◆

Figure 1. PAM-D solid rocket motor casing that survived reentry.

# Annual United Nations Meeting on Space Debris

The Scientific and Technical Subcommittee (STSC) of the United Nation's Committee on the Peaceful Uses of Outer Space (COPUOS) held its annual discussions on space debris at the UN complex in Vienna, Austria, during 28 February – 4 March 2005. A new STSC multi-year work plan on space debris, calling for STSC space debris mitigation guidelines by 2007, was adopted.

The work plan includes the following features:

**2005**: Considerations will begin, during intersessional work, of Member States proposals for the document to be developed covering space debris mitigation. The Working Group on Space Debris will also begin discussions with Member State experts on Nuclear Power Sources (NPS) to identify issues of mutual interest.

**2006**: The review and revision of the draft STSC space debris mitigation document will be undertaken, and future processes by which the final document, if necessary, could be updated will be considered. The Working Group on Space Debris will continue, as necessary, discussions relating to the use of NPS in outer space. Member States and international organizations will continue reporting, on a voluntary basis, on space debris research programs and mitigation practices.

**2007**: The proposed space debris mitigation document will be submitted by the Working Group on Space Debris to the STSC, with the view of the later adoption of the document by the full COPUOS. Member States and international organizations will continue reporting, on a voluntary basis, on space debris research programs and mitigation practices.

The STSC guidelines are currently envisioned to be high level and not contain the specificity of the Inter-Agency Space Debris Coordination Committee (IADC) space debris mitigation guidelines, which will be referenced (www.iadc-online.org). An intersessional meeting of the STSC Working Group on Space Debris will be held 13-16 June 2005, during the next full meeting of COPUOS. ◆

# *Collisions*

*Continued from page 1*

033B, U.S. Satellite Number 23606) collided with a fragment (1986-019RF, U.S. Satellite Number 18208) from the third stage of an Ariane 1 launch vehicle, which had exploded ten years earlier.

As the number of objects in Earth orbit increases, the likelihood of accidental collisions will also increase. Currently, hundreds of close approaches (*i.e.*, passes within less than one kilometer) between cataloged objects occur on a daily basis. If future spacecraft and rocket bodies are not removed from LEO within a moderate amount of time after the end of mission, *e.g.*, within 25 years, the rate of accidental collisions will increase markedly later in this century (*Orbital Debris Quarterly News*, 5-1, pp. 1-3). ◆

# Recent Satellite Breakup

The latest observed aerodynamic breakup of a satellite occurred on 24 February, when the 15-year-old Molniya 1-77 (1990-039A, U.S. Satellite Number 20583) dropped to a very low perigee altitude before finally falling back to Earth the next day. At the time of the minor fragmentation, the orbit of the spacecraft was about 75 km by 1700 km. Such breakups, which normally include the loss of solar arrays and other appendages, occur when a satellite is decaying from a highly elliptical orbit with a perigee below 100 km. Fortunately, the debris produced in such events are usually very short-lived. In this case up to five debris were detected, and all are assessed to have decayed within a few days. However, due to their high apogees such debris do present a temporary potential risk of collision with other resident space objects in low Earth orbit.

During 2004, five satellites (three spacecraft and two rocket bodies) decaying from highly elliptical orbits were observed to breakup within a few days prior to reentry. Four of these satellites were Russian (three were launched by the former Soviet Union), and one was of U.S. origin. ◆

# 2005 NASA/DoD Orbital Debris Working Group Meeting

The eighth annual meeting of the NASA/DoD Orbital Debris Working Group was held in Colorado Springs, Colorado on 19 January 2005. Approximately 50 people attended the meeting. 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. The Working Group is an outgrowth of a recommendation from the White House Office of Science and Technology Policy (OSTP) (www.orbitaldebris.jsc.nasa.gov/library).

A summary of recent debris activities in the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nation's Committee on the Peaceful Uses of Outer Space (COPUOS) was presented with an emphasis on efforts to promote international standard practices for the minimization of orbital debris.

NASA presented status reports on several ongoing projects. Haystack/HAX radar observation results for 2003 were shown along with issues arising from data collected in 2004 and plans for data collection in 2005 and beyond. Results from the most recent 24-hr debris measurement campaign using the Cobra Dane radar were presented. The status of on-going work attempting to determine the material composition of satellites and debris using spectral measurements was shown. Status of future measurement initiatives were discussed including plans for the Meter-Class Autonomous Telescope (MCAT) and proposed measurements utilizing the Ground Based Radar - Prototype (GBR-P). NASA also presented results of a study completed last year of solid rocket motor debris (*Orbital Debris Quarterly News*, 8-4, pp. 4-5).

Air Force Space Command discussed several topics including operations at the Cobra Dane radar, status of the Eglin FPS-85 radar Service Life Extension Program, and plans for the Air Force Space Surveillance System (AFSSS, which is the new designation for what used to be known as NAVSPASUR). Also discussed were plans and the schedule for the forthcoming upgrade to Haystack. Haystack will be unavailable for approximately one year starting in the summer of 2006 while a W-band (3-mm wavelength) system is added. Optical systems upgrades discussed included CCD installation on Ground Electro-Optical Deep Space Surveillance (GEODSS) telescopes and a new Space Based Space Surveillance (SBSS) projected to be launched near the end of 2007.

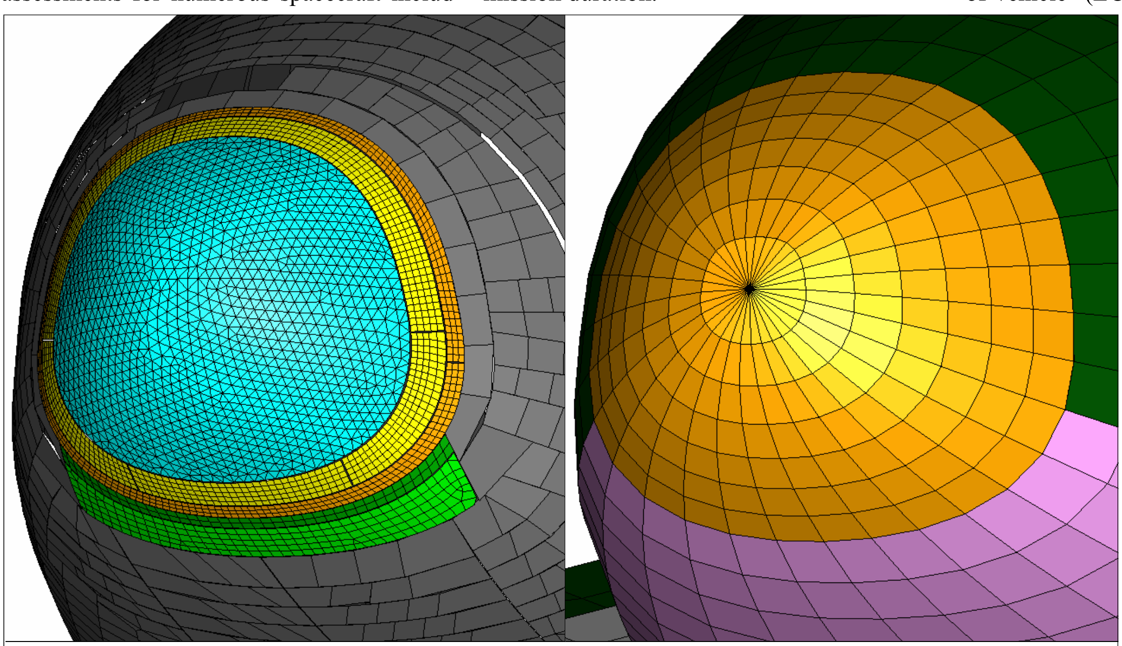
Space and Missile Systems Center (SMC) summarized debris mitigation efforts for DoD space missions and procedures for retrieving DoD hardware that survives reentry. ◆

# PROJECT REVIEWS

## Enhancement of Space Shuttle Models Used in BUMPER Micrometeoroid and Orbital Debris Risk Analyses

D. LEAR, E. CHRISTIANSEN, J. HYDE, & T. PRIOR

The NASA Johnson Space Center's Hypervelocity Impact Technology Facility (JSC/HITF) performs micrometeoroid and orbital debris (MMOD) impact risk assessments for numerous spacecraft including the Space Shuttle and International Space Station using a computer program called BUMPER. BUMPER determines MMOD risk based on spacecraft physical geometry, surface material resistance to impacts, flight altitude, orbit inclination, flight attitude, and mission duration.



***Space Shuttle Nose Cap - enhanced model (in work)*** ***Space Shuttle Nose Cap - current model***

Figure 1. Graphical comparison of nose cap region and adjacent tile acreage of Space Shuttle electronic model used in BUMPER MMOD risk analysis.

Typical BUMPER results consist of critical and functional failure risk estimates for individual spacecraft surface regions such as the crew module and payloads as well as overall risk for the entire vehicle. Critical risk is defined as damage that exceeds loss-of-vehicle (LOV) damage limits ("failure criteria"), whereas functional failure is defined as damage of a Space Shuttle component that is not critical but will require repair/refurbishment on the ground after the flight. Examples of critical risk include damage exceeding the LOV failure criteria for the wing leading edge (WLE) panels, nose cap and thermal protection system tiles covering the vehicle. Examples of functional failure risk include MMOD damage to coolant tubes in the radiator panels.

BUMPER is used to perform MMOD risk assessments for each Space Shuttle mission. An initial Cargo Integration Review (CIR) MMOD risk

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# Enhancement of Space Shuttle Models

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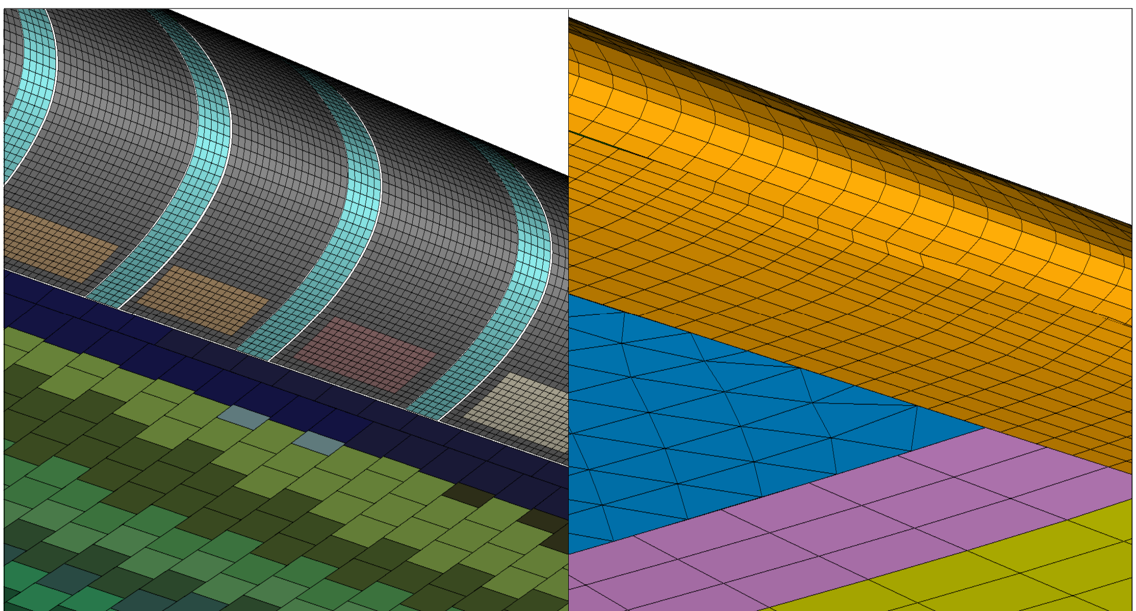
assessment is performed approximately one year prior to launch. Interim assessments are performed to update the risk estimates to account for changes in mission profile parameters such as flight attitudes and mission duration. A final pre-flight MMOD risk assessment is provided to a Flight Readiness Review (FRR) approximately two weeks prior to launch. Post-flight, a BUMPER MMOD damage assessment is performed and compared to actual MMOD damage identified on the vehicle during inspection and repair operations performed at Kennedy Space Center. Samples from several hundreds of MMOD impacts to Space Shuttle radiators, windows, WLE and other surfaces have been collected and analyzed by scanning electron microscope energy dispersive x-ray to determine damage cause (whether due to meteoroid or orbital debris).

BUMPER calculates risk for each vehicle orientation during the mission. MMOD risk is highly dependent upon spacecraft orientation in low Earth orbit, so that some Space Shuttle flight attitudes have a low MMOD risk while others have a high MMOD risk. Typical missions require the analysis of several dozen to several hundred Space Shuttle attitudes. Risks for Space Shuttle attitude on a mission specific basis are generated and provided to the Shuttle Mission Operations group. Mission specific MMOD risks are assessed because the MMOD environment is dynamic, payloads change (some contain critical components and others are inert), and flight altitude, orientation and durations differ for each mission. By reallocating exposure durations for each Space Shuttle attitude, the Mission Operations planners can assess and reduce MMOD risk while meeting overall mission objectives.

The physical geometry of the spacecraft that is input to BUMPER is specified using a finite element model (FEM). This model is provided in a specific format and consists of thousands of 3- and 4-sided polygons, or "elements." The elements are mapped over the entire surface of the vehicle and are grouped and correlated to specific surface features, material resistance, and failure criteria. BUMPER uses these elements to calculate MMOD particle flux from the space environment and the corresponding risk of damage from that flux that exceeds established failure criteria for the particular surface based on impact resistance of that surface.

The Space Shuttle Orbiter FEM has been enhanced periodically over the past decade. The enhancements have been necessary to reflect changes in failure criteria for the vehicle and to facilitate the determination of MMOD risk for very specific regions of the Space Shuttle. Another FEM upgrade is underway. The scope of the current enhancements includes mapping individual WLE Reinforced Carbon-Carbon (RCC) panels, WLE T-seals, carrier panel tiles, and nose cap RCC, as well as increasing the resolution of the model by decreasing the sizes of the individual elements. The changes are necessary to reflect the complexity of current failure criteria defined for the Space Shuttle RCC. These enhancements will also provide capability to assess MMOD risk on very specific regions of the Space Shuttle.

Two graphical comparisons between the current and enhanced Space Shuttle electronic model used for BUMPER MMOD risk analyses are shown in Figure 1 and Figure 2. Figure 1 is a comparison of the nose cap region between the enhanced and previous FEM. A similar comparison of the WLE RCC and underside tile acreage areas is shown in Figure 2. In the enhanced model, each of the underside acreage tiles is represented as an individual element. ◆

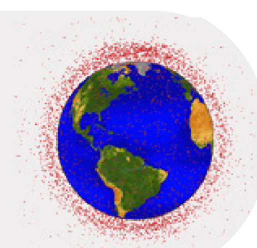


***Space Shuttle wing leading edge and underside tiles enhanced model (in work)***

***Space Shuttle wing leading edge and underside tiles current model***

Figure 2. Graphical comparison of wing leading edge composite panels region and adjacent underside tile acreage of Space Shuttle electronic model used in BUMPER MMOD risk analysis.





# A Bayesian Approach of Size Estimation for Haystack and HAX Radar Cross Section Observations

Y.-L. XU, C. STOKELY, M. MATNEY, & E. STANSBERY

The Haystack and Haystack Auxiliary (HAX) radars have been observing the orbital debris environment since the early 1990s using a staring operational mode. The Haystack and HAX measurements have provided orbital debris researchers with radar cross sections (RCS) and rough orbital elements for the debris. These radars have the ability to examine continuous size distributions for sizes ranging from cataloged objects to objects smaller than 1 cm diameter.

Characterization of the orbital debris environment involves the estimation of orbital debris sizes from the observed RCS data. The RCS-to-size conversion requires an accurate interpretation of the returned radar signals originating from the complicated interaction between electromagnetic radiation and objects, *i.e.*, the scattering of electromagnetic radiation by arbitrary scatterers. A precise theoretical prediction of radiative scattering properties from various bodies is essential for obtaining accurate information on the nature of the objects from their scattering signals. This includes a theoretical analysis of the principal and orthogonal polarization of the received signal to derive general shape parameters of a target as well as its composition. Rigorous radiative scattering solutions exist for certain types of spherical and non-spherical objects as well as for an arbitrary ensemble of these types of scatterers. Mie theory has been extensively used for more than a century to calculate the radiative scattering by homogeneous spheres. Non-spherical and irregularly shaped objects such as orbital debris possess significantly different scattering properties from spheres, the prediction of which motivates on-going research into more sophisticated radiative scattering theories such as the Generalized Multi-particle Mie-solution (GMM). GMM FORTRAN codes are publicly available at http://www.astro.ufl.edu/~xu.

The issue is complicated because many different RCS values are possible depending on the debris object's unknown shape, orientation, and composition. These issues were addressed experimentally by measuring the RCS values as a function of radar frequency and object orientation of a set of fragments taken from a hypervelocity impact test between a debris piece and a satellite mockup. These fragments are considered representative of the orbital debris environment. Since regular and irregular objects are considered, the size is defined by an "effective diameter" that is the average of three orthogonal breadth measurements. The measurements consist of the size of the longest dimension which defines the first axis; the second being the largest dimension perpendicular to the first axis; the third dimension is the size in the direction perpendicular to the first two axes.

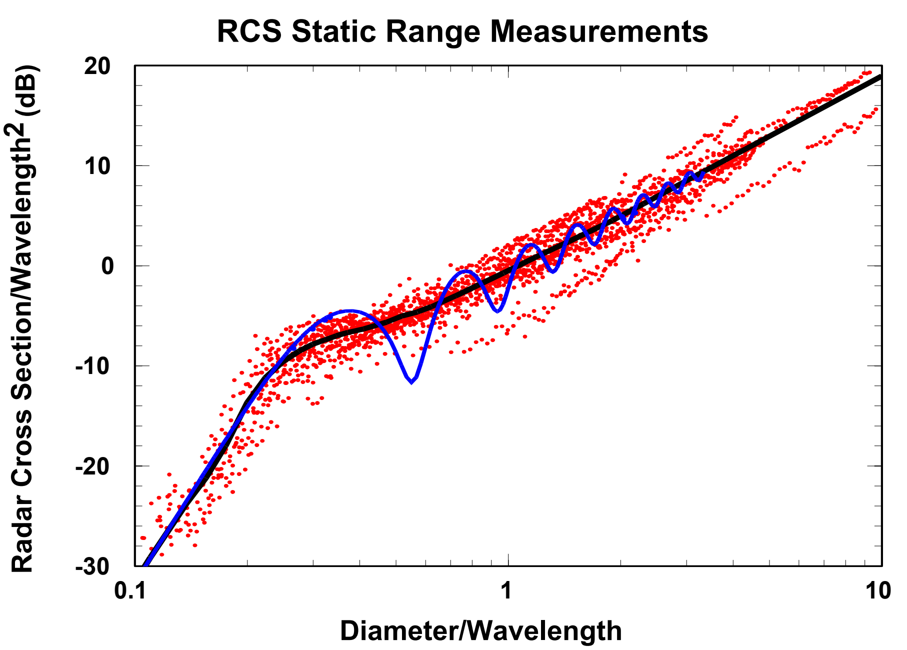



Figure 1. Results of RCS-to-Physical size measurements on 39 "representative" debris objects over the frequency range 2.0 - 18 GHz (15 - 1.67 cm wavelength). Each point represents a single object measured at a single frequency. The oscillating line is the radar cross section for a spherical conductor while the smooth line is the polynomial fit to the data.

Radar data from different wavelengths can be compared by normalizing the size by the wavelength of the measuring frequency ($x = \text{size}/\lambda$; $\lambda$ = wavelength) and the RCS by the wavelength squared ($y = \text{RCS}/\lambda^2$). Radar data from the mock debris are shown in Figure 1. The RCS parameter data at each size parameter is scattered by approximately ±3 dB, with the exception of a series of outliers that represent data from a nonmetallic printed circuit board included in the mock debris measurements. The mean of the RCS parameter data for each size parameter results in a smooth scaling curve that is the basis of the NASA size estimation model (SEM). This model provides a simple one-to-one conversion between RCS and size based on the wavelength of the radar. For comparison, the oscillatory RCS curve for a perfectly conducting sphere is also shown in Figure 1. The SEM curve approximates the sphere RCS curve for small and large size-to-wavelength ratios. Between these two size extremes, the RCS is oscillatory as a function of size parameter in the Mie resonance region. Irregularly shaped bodies have much more complicated responses than those of spheres.

The NASA SEM does not provide the uncertainties on estimated sizes. We describe here a statistical size estimation model (SSEM) based on Bayesian statistics to improve the original NASA SEM. The statistical analysis of the sizes begins with the mathematical representation of the conditional probability distributions of RCS for a given size, as derived from the SEM debris measurements by XonTech[1]. The uncertainty analysis is easy and straightforward with the Bayesian approach. In this new model a given RCS does not correspond to a unique size. The model accounts for contributions from a range of sizes. It is obvious from Figure 1 that a certain range of size may contribute to an observed RCS.

With the SSEM, the (posterior) size distribution is obtained from an iterative technique based on Bayes' rule, starting from an initial (prior) guess of the size distribution from the SEM estimate. The solution is iterated until a satisfactory convergence is achieved. This iterative solution process converges very fast, requiring usually only a few iterations. Results from the SSEM agree

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# A Bayesian Approach

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favorably with those obtained through other statistical methods, such as standard extended linear model and Bootstrap estimations. However, the Bayesian approach seems to be much more efficient.

Two different sources of uncertainties are considered in the SSEM. First, the radar detections are assumed to follow Poisson (sampling) statistics. Second, the observational errors of RCS are assumed to follow a normal distribution about a certain mean value. Based on the ODERACS experiments[2], the estimated RCS uncertainty is ± 1.5 dB. The uncertainty estimation of the size distribution is calculated by adding the errors in quadrature.

Shown in Figure 2 is a cumulative flux distribution (for the altitude range from 850 to 950 km) derived by the SSEM from the FY2002 Haystack data at 75° elevation pointing east. The cumulative flux distribution is derived from the cumulative size distribution, the radar observation time, and the area of the radar beam. For comparison, the results from the SEM are shown. The comparison shows that the size estimations derived from the SSEM and SEM are close to each other. Additional studies indicate that the agreement is generally good when the number of detections is large. The advantage of the SSEM is that in addition to the size distribution, it provides uncertainty estimates for the derived model parameters. The Bayesian approach is efficient, reliable, and easy to implement in practice.

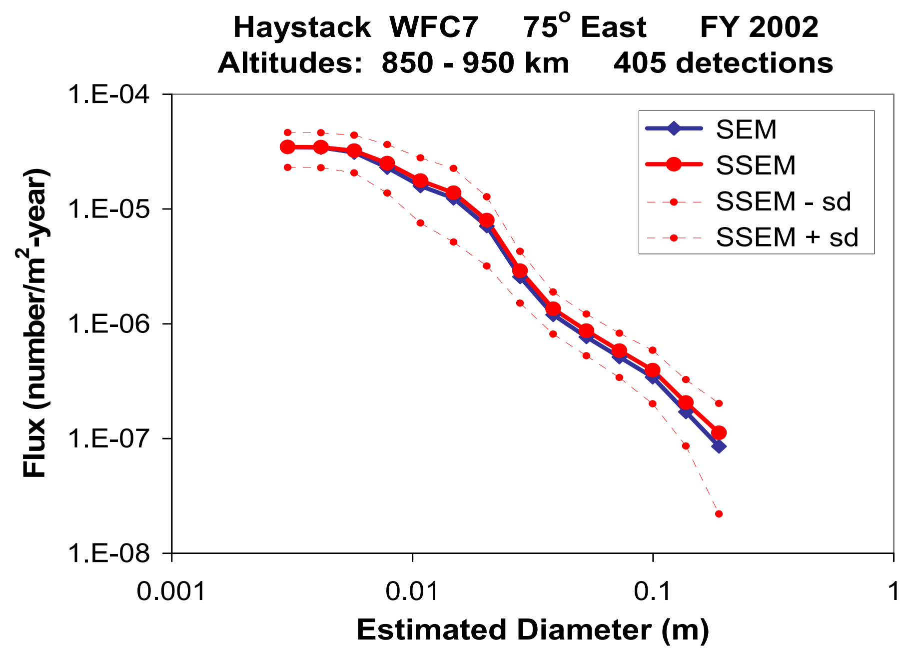


Figure 2. Cumulative flux distributions derived by SSEM and SEM from the Haystack 405 detections (FY2002, 75° east pointing) in the altitude range from 850 to 950 km.


1. Bohannon, G.E. *Comparison of Orbital Debris Size Estimation Methods Based on Radar Data*, XonTech, Inc. report 920123-BE-2048, 1992.

2. Cress, G. H., et al. *Orbital Debris Radar Calibration Spheres, Radar and Optical Ground Based Measurements*, NASA/JSC Publication JSC-27241, 1996. ◆


# No Fire from the Dragon this Year

B. COOKE & M. MATNEY

Each year in October, the Earth passes through a stream of meteoroids released from comet Giacobini-Zinner. The resulting meteor shower is called the Draconids (also known as the "October Draconids" or "Giacobinids") because to observers on the ground the meteors appear to radiate from the constellation Draco, the Dragon. The shower is easily lost in the normal rate of sporadic background meteors and is usually a real "yawner" as far as meteor showers go, with typical rates of just two per hour. Draconid meteors enter the atmosphere at the "leisurely" pace of 20 km/s, leaving only faint streaks of light to mark their passage. The unspectacular nature of the stream makes the fact that it was predicted well in advance of its discovery (1915 prediction; 1920 first visual observations) no great surprise. So why, then, is there concern about this shower causing elevated risk to spacecraft?

Part of the reason is simple: Just like the Leonids, the Draconids storm - sometimes quite spectacularly. The shower put on major shows in 1933 and 1946, with visible rates over 5000 per hour.

But it goes beyond that. Recall that Leonids enter near-Earth space with a speed of 71 km/s; at such speeds, even small meteoroids, on the order of $10^{-5}$ grams, will be visible to an observer on the ground. Now consider the Draconids; they're much slower - 20 km/s - and so only a fairly large Draconid meteor produces enough energy to leave a visible streak. A simple calculation shows that a Draconid needs to be 100 times more massive than a Leonid to produce an equivalent brightness. Fold this in with the fact that the number of shower meteors down to a given size is roughly proportional to the inverse of the meteor mass; one quickly realizes that a large number of visible Draconids means that the shower also possesses a huge number of smaller particles, too small to be seen, but big enough to

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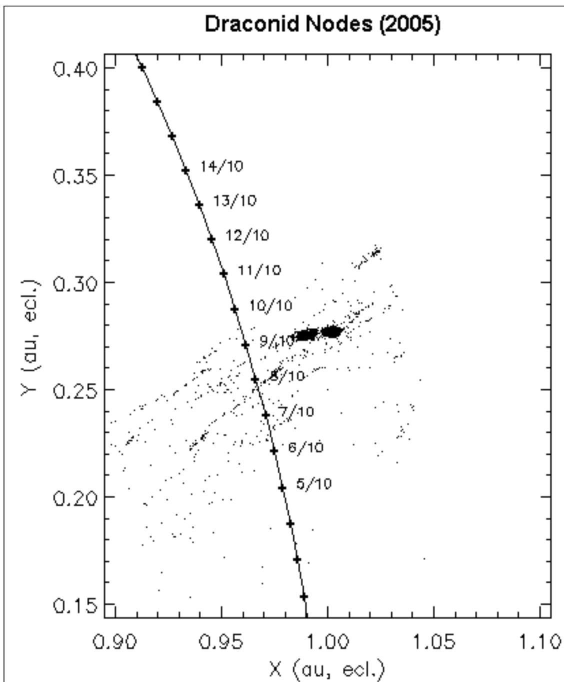


Figure 1. Nodal crossing geometry of Draconid meteors during the 2005 encounter. The points along the line indicate the position of the Earth at those dates.

# No Fire from the Dragon This Year

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damage spacecraft.

Put in terms of penetrating flux, a Draconid storm is much more of a hazard than a Leonid shower of the same visible rate by about an order of magnitude. A Draconid meteor storm with a Zenith Hourly Rate (ZHR) of 1000 has a flux exceeding that of the sporadic background by a factor of 30 (100 micron particles and larger); a Leonid storm with a ZHR of 1000 may reach twice the background level. In terms of spatial density of the meteoroid cloud, the Draconid storms early in the 20$^{th}$ century had some of the highest numbers ever recorded.

So when the traditional technique of assessing the shower's activity indicated the possibility of a 2005 Draconid outburst, or possibly even a storm, researchers took notice.

This technique, which involves comparing the distance of the node of the cometary orbit to the number of days before or after comet perihelion, indicated that circumstances in 2005 were similar to those in 1985, when a Draconid outburst with a ZHR of 700 was observed. However, the more modern and more reliable technique of meteor stream modeling that evolved during recent Leonid meteor storms shows that little or no Draconid activity should be expected this 8 October; the particle concentrations are quite far from Earth (Figure 1, by Jeremie Vaubaillon, currently a post-doctoral student at the University of Western Ontario). The peak ZHR is estimated to be about 30, which, in terms of penetrating flux, is roughly equivalent to that at the peak of the annual Geminid shower. These results need to be confirmed by other stream model calculations, but it does provide some assurance that the meteoroid flux in low Earth orbit will not be significantly elevated during this year's Draconid shower.

However, this same model indicates that we will have to face the fire from the dragon in 2011 and in 2018; Draconid storms are currently forecast for these years (Figure 2 gives the 2011 circumstances, also by Jeremie Vaubaillon). In the meantime, should you happen to be somewhere in Asia during the evening hours of 8 October of this year, look up. You may see a Draconid or two. ◆

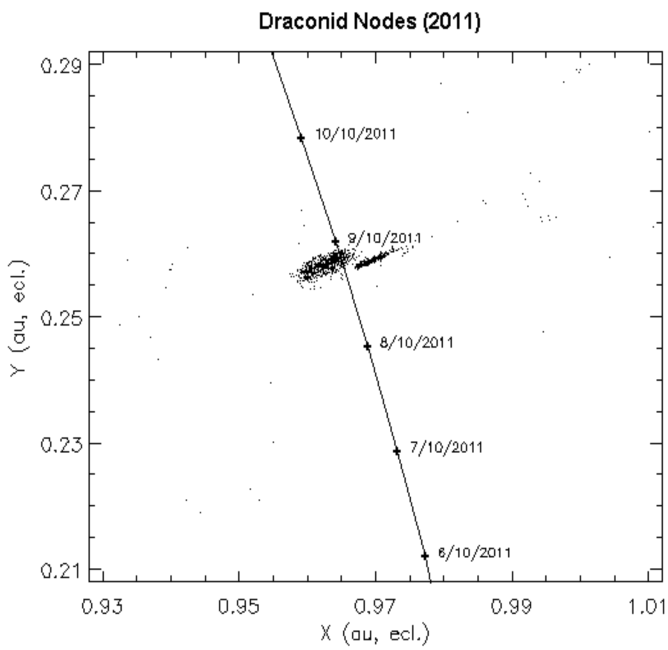



Figure 2. Nodal crossing geometry of Draconid meteors during the 2011 encounter. Note that the geometry is more favorable for enhanced activity in 2011 than in 2005.

# ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

## Fourth European Conference on Space Debris, 18-20 April 2005, Darmstadt, Germany

*Additional Abstracts from the Orbital Debris Program Office for this Conference will appear in the July 2005 Issue of the Orbital Debris Quarterly News*

### Inertial Upper Stage Surface Property Study

K. JORGENSEN-ABERCROMBY, M. GUYOTE, & J. OKADA

The Orbital Debris Program office at NASA Johnson Space Center (JSC) began a project four years ago termed NASS (NASA AMOS (Air Force Maui Optical and Supercomputing) Spectral Study) in an effort to determine the material type of orbiting objects using the slope and absorption features of reflectance spectra. The material type of these objects is important because a priori information on composition leads to better approximation of the density and thereby the mass and then the size of the object. Size estimates are necessary for the modeling of the debris environment. From our initial observations, the remote measurements increased in reflectance as the wavelength increased, a phenomenon that astronomers termed "reddening." Most objects showed the reddening, but one in particular, the United States Inertial Upper Stage (IUS), did not show the effect. The IUS is used as an upper stage launcher either from Titan rockets or from the bay of the Shuttle. In July 2004, laboratory measurements of the outer surfaces of a non-launched IUS were taken so that comparisons of similar materials could be made between similar materials observed in the laboratory and materials viewed remotely. IUS outer surfaces are mostly white paint, multi layer insulation (MLI) which is gold colored, and carbon-carbon nozzle. A model using the three materials mentioned was created that predicts the spectral response of the IUS remote measurements. Five IUS rocket bodies were observed at different points in their orbits and these spectra were compared to the predictions from the models. The spectrum due to the carbon-carbon nozzle shifts only the amplitude of the overall reflection, but not the shape or location of the absorption features. The absorption feature due to white paint (near 3500 angstroms) is apparent and strong in the remote measurements, while the main feature one would expect from the MLI is not seen in any of the samples. Due to the lack of knowledge of the orientation of the rocket bodies, it is possible that the orientation of the rocket bodies is the cause for the lack of the MLI feature. However, it is also possible that either the MLI is missing entirely or the outer, copper-colored surface suffered from environmental or mission related effects and has been damaged, thus changing the spectral response. Investigations into the possibilities and their implications will be explored. ◆

## Modeling the Meteoroid Environment with Existing *In Situ* Measurements and with Potential Future Space Experiments

J.-C. LIOU, E. CHRISTIANSEN, R. CORSARO, F. GIOVANE, P. TSOU, & E. STANSBERY

Meteoroids are known to exist throughout the Solar System. Typical meteoroids are natural objects between centimeter and micrometer sizes. The main sources of meteoroids in the inner Solar System are asteroids and comets (both long-period and short-period). It has been known since the beginning of the space age that meteoroid impacts represent a threat to space instruments, vehicles, and extravehicular activity. Of particular significance are particles about 50 µm and larger in size. Meteoroids smaller than 50 µm are generally too small to be of concern to satellite operations.

To characterize the near Earth meteoroid environment, one can utilize ground-based optical and radar observations, space-based *in situ* measurements, or the lunar crater records. There are advantages and limitations associated with each approach. The main objectives of this paper are (1) to review recent *in situ* measurement data, (2) to discuss several proposed future *in situ* experiments, and (3) to discuss how one could utilize the data to improve the near Earth meteoroid environment definition.

The impact detectors onboard Ulysses, Galileo, and Cassini have collected valuable meteoroid data in interplanetary space over the last decade. However, due to the small size of the detectors (0.1 $m^2$), the data are limited to meteoroids about 100 µm and smaller. To address the critical size regime between 100 µm and 1 mm, much larger detection area will be needed for the next generation *in situ* measurements. Several such experiments have been proposed for ISS and for other missions. Innovative designs have been developed to increase the detection areas to several meters squared and larger while keeping the mass, power, and cost requirements low. A review of these proposed experiments and how one can utilize the results to improve the understanding of the meteoroid environment are included in the paper. ◆

## A Survey for GEO Debris in High Inclination Orbits

P. SEITZER, K. JORGENSEN-ABERCROMBY, J. AFRICANO, T. PARR-THUMM, M. MATNEY, K. JARVIS, E. STANSBERY, & E. BARKER

A standard picture of the geosynchronous orbit (GEO) debris population is starting to emerge from recent optical observations. There are two families of debris. The first consists of bright objects on circular orbits with inclinations ranging up to 17°. These are uncontrolled objects whose orbits have been gravitationally perturbed by the Sun, Moon, and Earth. The second family is a fainter debris population, which appears to be on eccentric orbits. Theoretical models suggest that the observed angular motions of the faint debris can be explained if they are high area-to-mass ratio (A/M) objects which suffered significant perturbations by solar radiation pressure. If this faint debris is indeed high A/M objects at GEO, then one prediction of the models (*Orbital Debris Quarterly News*, 8-3, p. 6, and this conference) is that the orbital inclinations will range to much larger values than those expected on the basis of gravitational perturbations alone. We report the results of an ongoing optical survey at high inclinations to look for such a population of faint, possibly high A/M GEO debris. These observations were taken as part of the NASA/Michigan GEO Debris Survey, which uses **MODEST** (the **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope, a 0.6/0.9-m Schmidt telescope in Chile).

This project is supported by grants to the University of Michigan from NASA's Orbital Debris Program Office, Johnson Space Center, Houston, Texas. ◆

## Understanding Photometric Phase Angle Corrections

J. AFRICANO, D. HALL, P. SYDNEY, J. ROSS, T. PAYNE, S. GREGORY, P. KERVIN, K. JORGENSEN-ABERCROMBY, K. JARVIS, T. PARR-THUMM, E. STANSBERY, & E. BARKER

Determining the actual physical dimensions of resident space objects (RSO) from radar cross section (RCS) measurements or optical signatures has proven to be problematic. For radar, RCS is a complex function of size, shape, material, and wavelength of the radar. NASA developed the empirically derived size estimation model (SEM) to statistically relate RCS to physical size for small debris. The SEM is not appropriate for individual objects and especially intact objects. Converting optical brightness to actual object size for both known and unknown objects is a real challenge for the optical debris community. Optical signatures are complex functions of the shape, type, albedo and scattering functions of the object's surfaces. In general, surface reflectance does not behave solely as combinations of specular or Lambertian surfaces. Adding to these complexities is the fact that the objects change orientation during the observing periods due to the real or apparent rotation of the object. For uniformity, observers participating in the IADC optical debris campaigns have agreed to reduce their data using the diffuse Lambertian spherical phase function correction to 0° phase angle. A size for the RSO is then determined after the phase correction is made. It is also well understood that rocket bodies, spacecraft, debris, and most manmade objects have complex irregular shapes. These complex irregular shapes and even simple shapes produce time varying amounts of shadowing which complicate the interpretation of the photometric signatures and the resulting size estimations. This paper will address some of the limitations in using the diffuse Lambertian spherical phase angle correction. ◆

## The GEO Environment as Determined by the CDT Between 1998 and 2002

E. BARKER, K. JARVIS, J. AFRICANO, K. JORGENSEN-ABERCROMBY, T. PARR-THUMM, M. MATNEY, & E. STANSBERY

The National Aeronautics and Space Administration (NASA) obtained observations of the geosynchronous orbit (GEO) environment with the 0.6 m CCD Debris Telescope (CDT) at Cloudcroft, New Mexico between January 1998 and December 2001. This presentation will summarize the datasets of detected correlated (CTs) and uncorrelated (UCTs) targets which have been presented in a series of yearly reports, but have not been summarized in entirety to date. The final CDT dataset consists of observations totaling ~1233 on-sky hours and ~18,832 detections which are unique detections per night; (Calendar Year (CY)1998, ~488 hrs, 4606 CTs, 1159 UCTs), (CY1999, ~530 hrs, 4822 CTs, 911 UCTs), (CY2000, ~256 hrs, 2970 CTs, 429 UCTs), and

*Continued on page 9*

## The GEO Environment as Determined by the CDT Between 1998 and 2002

*Continued from page 8*

(CY2001, ~380 hrs, 3350 CTs, 689 UCTs)). The CDT was operated in a GEO stare mode reaching a limiting magnitude of 17 which corresponds to a limiting diameter for a sphere of ~60 cm (assuming a specular reflection and an albedo of 0.2).

Observational and reduction techniques have improved over the period of the CDT performance and analysis. Observed magnitudes for the previously published CDT absolute magnitudes have not been corrected for solar distance variations. A summary dataset will be presented which contains uniform data corrections for observed range, phase angle, and solar distance. The conversion of an observed brightness to a physical size requires the assumption of an albedo for the object or a model which relates the radar cross section (RCS) to a characteristic length for the object. These size conversions will be discussed in terms of the entire database and different assumed albedos. The complete GEO dataset for the CDT will be presented in context of distributions such as inclination, RAAN, mean motion, magnitude (size), and flux. Seasonal and/or trend variations of the observed fluxes for a given size range will be compared to fluxes observed by the European Space Agency (ESA) and to fluxes predicted by modeling the GEO environment. ◆

## A New Look at Nuclear Power Sources and Space Debris

N. JOHNSON

The last satellite containing a nuclear power source (NPS) and intended for operations in Earth orbit was launched in 1988. However, a renewed interest in radioisotope power systems (RPSs) and nuclear propulsion could lead to new NPS in orbit about the Earth later in this decade or the next. Today, at least eight radioisotope thermoelectric generators, 13 nuclear reactor fuel cores, and 32 nuclear reactors (one from the U.S. and 31 from the former Soviet Union) are known to be still circling the Earth in orbits below 1700 km. Previous NPS risk assessments, particularly those performed for the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful Uses of Outer Space, have employed older space debris environment models. The present paper applies current environment models and examines the potential effects of collisions between NPS satellites and space debris to both the near-Earth space environment and the terrestrial environment. The principal region of interest is between 700 and 1500 km, where the vast majority of historical NPS currently reside and where orbital lifetimes are typically long. Impacts between debris and NPS-equipped vehicles can lead to a termination of the mission or the destruction or disabling of the vehicle, which in turn could prevent proper disposal. Harmful collisions between NPS and space debris are unlikely on an annual basis, but the long durations of most NPS in disposal orbits lead to significantly higher total collision probabilities. The insertion of multiple new NPS in Earth orbit would also raise collision risks. Disposal plans for new spacecraft or orbital stages with NPS designed to remain in Earth orbit should be developed early in the design phase and should be compatible with internationally accepted space debris mitigation and NPS safety guidelines. A distinction must, therefore, be made between a disposal orbit which protects the future Earth orbital environment and one which protects the terrestrial environment from the premature reentry of space objects containing radioactive materials. ◆

## Reentry Survivability Analysis of the Hubble Space Telescope (HST)

R. SMITH, K. BLEDSOE, J. DOBARCO-OTERO, W. ROCHELLE, N. JOHNSON, A. PERGOSKY, & M. WEISS

An analysis of reentry survivability and population risk of the Hubble Space Telescope (HST) entering from orbital decay was performed using the Object Reentry Survival Analysis Tool (ORSAT). The objective was to investigate the reentry, breakup, demise, and ground impact of all objects with known properties. The analysis assumed an uncontrolled reentry from an altitude of 122 km to a breakup altitude of 78 km. Over 600 different objects from the satellite were modeled, comprising 75% of the entire spacecraft mass. A total of 2055 kg of mass is predicted by the analysis to survive reentry and produce an effective debris casualty area of 146 $m^2$. The resulting calculated risk is 1:250, corresponding to a reentry in the year 2021. The risk has been scaled to account for the unmodeled mass. ◆

# UPCOMING MEETINGS

**5-9 September 2005: Air Force Maui Optical and Supercomputing (AMOS) Technical Conference,** 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, Computational Object Identification, High Performance Computing Applications in Astronomy, Imaging Theory, Algorithms, and Performance Prediction, Laser Propagation and Laser Radar, Non-Resolved Object Characterization, Orbital Debris, Satellite Modeling, Small or Autonomous Telescope Systems, Space Situational Awareness, and Space Weather. For more information, visit http://www.maui.afmc.af.mil/conferences.html.

**17-21 October 2005: The 56th International Astronautical Congress,** Fukuoka, Japan.

The Congress will include four sessions on space debris: Measurements and Space Surveillance, Risk Analysis and Modeling, Hypervelocity Impacts and Protection, and Mitigation and Standards. Additional information on the Congress is available at http://www.iac2005.org.

## INTERNATIONAL SPACE MISSIONS
### January—March 2005

| International Designator | Payloads | Country/ Organization | Perigee (KM) | Apogee (KM) | Inclination (DEG) | Earth Orbital Rocket Bodies | Other Cataloged Debris |
|---|---|---|---|---|---|---|---|
| 2005-001A | DEEP IMPACT | USA | HELIOCENTRIC | | | 1 | 0 |
| 2005-002A | COSMOS 2414 | RUSSIA | 907 | 969 | 83.0 | 1 | 0 |
| 2005-002C | TATIANA | RUSSIA | 910 | 969 | 83.0 | | |
| 2005-003A | AMC-12 | USA | 35783 | 35798 | 0.1 | 1 | 1 |
| 2005-004A | USA 181 | USA | NO ELEM. AVAILABLE | | | 1 | 1 |
| 2005-005A | XTAR-EUR | USA | 35778 | 35795 | 0.0 | 1 | 1 |
| 2005-005B | MAQSAT/ARIANE 5 | ESA | 257 | 35453 | 6.8 | | |
| 2005-005C | SLOSHSAT | ESA | 259 | 35737 | 6.8 | | |
| 2005-006A | MTSAT-1R | JAPAN | 35777 | 35797 | 0.0 | 1 | 0 |
| 2005-007A | PROGRESS-M52 | RUSSIA | 352 | 361 | 51.7 | 1 | 0 |
| 2005-007C | TNS-0 | RUSSIA | 348 | 357 | 51.6 | | |
| 2005-008A | XM-3 | USA | 35786 | 35789 | 0.0 | 1 | 0 |
| 2005-009A | INMARSAT 4-F1 | INMARSAT | 35569 | 36006 | 3.0 | 0 | 0 |
| 2005-010A | EXPRESS AM-12 | RUSSIA | EN ROUTE TO GEO | | | 2 | 3 |

## ORBITAL BOX SCORE
### (as of 30 MAR 2005, as catalogued by US SPACE SURVEILLANCE NETWORK)

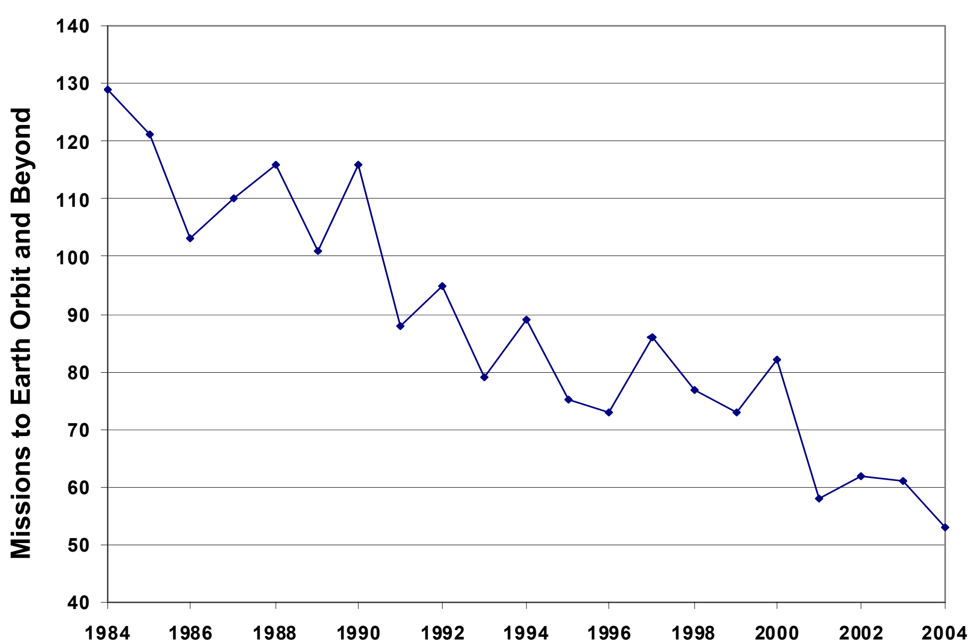
| Country/ Organization | Payloads | Rocket Bodies & Debris | Total |
|---|---|---|---|
| CHINA | 46 | 305 | 351 |
| CIS | 1358 | 2661 | 4019 |
| ESA | 34 | 32 | 66 |
| FRANCE | 42 | 295 | 337 |
| INDIA | 28 | 104 | 132 |
| JAPAN | 86 | 51 | 137 |
| US | 1003 | 2915 | 3918 |
| OTHER | 338 | 18 | 356 |
| TOTAL | 2935 | 6381 | 9316 |


**Technical Editor**
J.-C. Liou

**Managing Editor**
Sara Portman

**Correspondence concerning the ODQN can be sent to:**
Sara Portman
NASA Johnson Space Center
Orbital Debris Program Office
Mail Code JE104
Houston, Texas 77058

**sara.a.portman1@jsc.nasa.gov**


Since 1984 the rate of world-wide missions to Earth orbit and beyond has declined significantly, *i.e.*, by 60%. However, the total mass of man-made objects in Earth orbit has more than doubled during the same period, at an average rate of 150 metric tons per year.

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