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INSIDE...

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New NASA Policy for Limiting Orbital Debris Generation

On 27 January 2003, NASA Administrator Sean O'Keefe signed NASA Policy Directive (PD) 8710.3A, the latest revision in NASA's 10-year-old policy designed to curtail the growth of the orbital debris population. The new policy recognizes the growing importance of orbital debris mitigation, both nationally and internationally, and a need to expand the responsibilities of various organizations within NASA. Ten organizations or positions within NASA are now assigned explicit orbital debris mitigation duties, in contrast to only four organizations or positions cited in the previous policy.

The Orbital Debris Program Office, in support of the Director of the Lyndon B. Johnson Space Center, is responsible for

"(1) developing, maintaining, and updating orbital debris environment models,
(2) assisting space program/project managers in technical debris assessments,
(3) providing technical reviews of orbital debris assessment reports,
(4) reviewing end-of-mission plans for NASA spacecraft,
(5) maintaining a list of predicted reentry dates for NASA spacecraft and upper stages,
(6) providing technical and policy assistance to all NASA headquarters offices and centers, and
(7) promoting the adoption and use of international orbital debris mitigation guidelines."

For the first time, NASA orbital debris policy addresses the issue of U.S. Government coordination prior to the reentry, controlled or uncontrolled, of spacecraft and upper stages employed on NASA missions. A copy of NPD 8710.3A can be obtained via the Orbital Debris Program Office website at www.orbitaldebris.jsc.nasa.gov.

Work is now underway on a related revision to NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris*, first issued in 1995. The new standard will reflect improvements in both the technical foundation of the standard and the assessment process. Where appropriate, minor changes will also be incorporated to ensure that the standard is consistent with the latest national and international orbital debris mitigation guidelines. ◆

Satellite Fragmentations in 2003

In a further indication that world-wide passivation measures are apparently having a positive effect, satellite breakup activity in 2003 was minor and limited to two pre-reentry events, three small Soviet propulsion units launched during 1987-1990, and a low altitude intentional breakup. Meanwhile, the Hubble Space Telescope and non-operational French and American satellites each released an unexpected piece of debris in classical anomalous events.

In January 2003, the Molniya 1-66 rocket body (1985-103D, U.S. Satellite Number 16223) and Cosmos 1849 (1987-048A, U.S. Satellite Number 18083) both experienced minor breakups during the final stages of catastrophic orbital decay from highly elliptical orbits with perigees less than 120 km. In both events all debris created apparently decayed within only a few days.

Between February and August 2003, fragmentations of three Proton Block DM SOZ ullage motors, all from former Soviet navigation satellite missions, were detected by the U.S. Space Surveillance Network (SSN). All objects were in elliptical orbits with perigees of 645-755 km and apogees near 18,500-18,800 km and were launched before passivation measures were adopted in the 1990's.

The first event occurred on 21 February and involved an ullage motor from the Cosmos 2109-2111 mission (1990-110G, U.S. Satellite Number 21012). Only a few debris were detected with this breakup. The second event, which was associated with the Cosmos 1883-1885 mission (1987-079H, U.S. Satellite Number 18375), occurred on 23 April and produced about three dozen, short-lived debris. Finally, an ullage motor from the Cosmos 1970-1972 mission (1988-085F, U.S. Satellite Number 19535) apparently broke-up twice between 4 and 6 August. The first event again produced only a few dozen debris, but the second event generated up to 200 new debris.

On 9 December the Russian Cosmos 2399 spacecraft was intentionally destroyed at an altitude of only 190 km. Only 21 debris were identified by the SSN, and these were short-lived. Cosmos 2399 was the seventh of a series of spacecraft which began flights in 1989 and which are disposed of destructively at very low altitudes at the end of mission.

In August two anomalous events, i.e., small

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NEWS

Satellite Fragmentations in 2003

Continued from page 1

number of debris released at low velocities, were detected by the SSN. A piece of debris, estimated to be about 5 cm in diameter, was apparently liberated from the Hubble Space Telescope (HST) (1990-037B, U.S. Satellite Number 20580) on 5 August at an altitude of about 575 km. The nature of the debris remains unknown, but it was initially decaying at a faster rate than HST.

The French satellite SARA (1991-051E, U.S. Satellite Number 21578) was the subject of the second anomalous event in August. The object, later cataloged as 1991-050H (U. S. Satellite Number 28065), is larger than the piece from HST and might be part of one of the 5-meter-long antennas extending from SARA. One hypothesis is that one of the antennas was severed by the impact of a small meteoroid or orbital debris. Long, thin antennas on other spacecraft have suffered similar fates. The mean altitude of SARA at the time of the event was 730 km. Like the HST debris, the SARA debris is decaying at a faster rate than its parent.

Finally, on 25 November a small piece came off the NOAA 7 spacecraft (1981-059A, U.S. Satellite Number 12553) at an altitude of about 835 km. The spacecraft has previously released unexpected small debris, the first time in July 1993. ◆

2003 NASA Orbital Debris Colloquium

On 4 and 5 November 2003, the third annual NASA Orbital Debris Colloquium, hosted this year by the Orbital Debris Program Office, was held near the Lyndon B. Johnson Space Center in Houston to address a wide variety of issues related to orbital debris. Attendees included representatives from NASA Headquarters, the Goddard Space Flight Center (GSFC), the Marshall Space Flight Center (MSFC), the Kennedy Space Center (KSC), and the Jet Propulsion Laboratory (JPL), as well as JSC.

Two of the primary topics discussed were the new NASA policy directive on orbital debris limitation (NPD 8710.3A) and the draft revision of NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris.* The latter was reviewed in detail to permit agency personnel an opportunity to ask questions about proposed changes and to offer other improvements to the Standard. Reports on orbital debris mitigation efforts at GSFC, KSC, and JPL were also presented, as was a special summary of the Columbia Accident Investigation Board's final report with particular emphasis on reentry risk assessment. Finally, plans for the development and release of NASA's Debris Assessment Software (DAS), Version 2.0, were described. ◆

Orbital Debris Website Update

The NASA Orbital Debris Program Office website, www.orbitaldebris.jsc.nasa.gov, has been redesigned with a stylish layout and new navigation structure. All pages now contain a "flyover" menu system for easy traversal. The pages contain graphical indicators of where you are and quick links to related pages within the subsection. Beside the new look and feel, the original content has been updated and new content has been added.

One of the new additions to the website is the Photo Gallery. Many photos relating to orbital debris have been collected and made available. Another component added to the site is the Important Reference Documents section, which contains publicly available documents related to orbital debris and its research. Also check out the new Reentry section for information on the current orbital debris work going on in this area.

The *Orbital Debris Quarterly News* has also been given a new design layout and is incorporated in this January 2004 issue. Going to the Orbital Debris Quarterly News page of the website will give you access to this issue as well as all other *Orbital Debris Quarterly News* issues that have been published. All issues are available for viewing or downloading in Abode PDF format. Also provided for user friendliness are issue highlights that are displayed as the user positions their mouse over the specific issue. If you would like to be notified when the next issue is available, please go to the Orbital Debris Quarterly News section of the website and fill out the subscription form.◆

Chandra Observatory Possibly Hit by Small Particle

The Chandra X-Ray Observatory (CXO) was apparently hit by a small particle on 15 November at approximately 1554 UTC. A minor disturbance in the spacecraft's pointing stability was recorded during a period between scientific observations. The disturbance was automatically corrected, and no residual effects have been detected. CXO orbits the Earth in a highly elliptical orbit of about 25,000 km by 125,000 km. At the time of the event, the spacecraft was at an altitude of ~52,000 km, suggesting that the particle was probably a meteoroid, possibly a Leonid meteoroid, rather than orbital debris. CXO was launched inside Space Shuttle Columbia (STS-93) on 23 July 1999. ◆

John R. Gabbard

The orbital debris community lost one of its most venerable and well-respected members in October with the passing of John R. Gabbard at the age of 82. While working for the Analysis Directorate of the former NORAD/ADCOM in Colorado Springs, Colorado, in the 1970's, John developed the now-famous Gabbard diagram which depicts the apogee, perigee, and period of debris from a satellite fragmentation. Such diagrams are extremely useful tools in identifying objects from an explosive event and in understanding characteristics of the event. The U.S. Space Surveillance Network still uses another of John's innovations: the Gabbard system of orbit type classification.

John also made many noteworthy discoveries during his long aerospace career. One of the most important involved the post-mission explosions of Delta launch vehicle second stages. His identification of a series of major fragmentations associated with these launch vehicles led to the adoption, first in the U.S. and later around the world, of a passivation policy for all spacecraft and launch vehicles. This policy has done more to curtail the growth of the orbital debris environment during the past twenty years than any other action.

After a distinguished career as a U.S. civil servant, John continued his work for several years with Teledyne Brown Engineering, helping to educate a new generation of space analysts. John will long be remembered by his many friends not only for his ability to interpret data and to see patterns where others saw none, but also for his genuine good nature and willingness to help all. ◆

PROJECT REVIEWS

Hypervelocity Impact Survey of the Multi-Purpose Logistics Module (MPLM)

J. HYDE, R. BERNHARD, &
E. CHRISTIANSEN

The International Space Station (ISS) program has manifested a Multi-Purpose Logistics Module (MPLM) on five launch packages since 2001, with another flight scheduled for the STS-114 mission. The MPLM has been deployed each time on the nadir docking port of Node 1 by the Space Shuttle. Flight module 1 (Leonardo) and flight module 2 (Raffaello) have accumulated about 700 hours of low Earth orbit (LEO) exposure time on the ISS. This article documents the results of an on-going post-flight campaign that identifies hypervelocity impact (HVI) damage to the Meteoroid and Debris Protection System (MDPS) of the MPLM through observations, data collection and analysis.

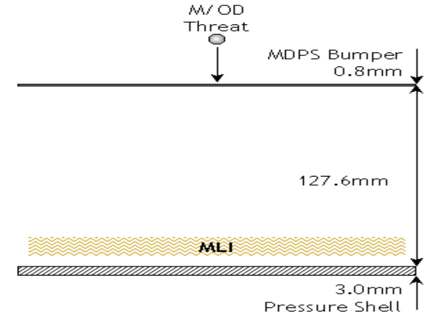

Figure 1. The typical layout of an MDPS panel in the cylinder region.

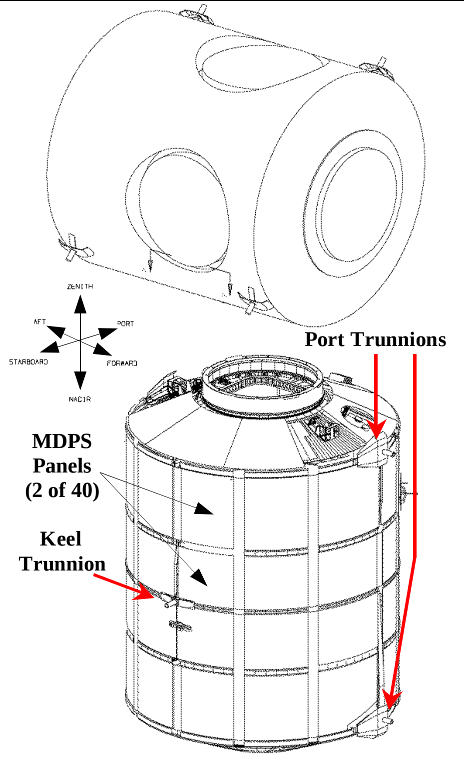

Figure 2. The orientation of the MPLM when attached to ISS Node 1.

Through five missions, there have been two perforations (i.e., complete penetrations) of the aluminum outer "bumper" wall of the MDPS and twenty-four HVI craters. The risk of bumper perforation for a typical MPLM mission was estimated to be 55% by the BUMPER risk assessment code (more information on BUMPER code can be found in ODQN Vol. 4, Iss. 3). Observed damage to MPLM (i.e., 1 outer wall perforation every 2.5 flights) and the distribution of crater damage match the BUMPER code predictions.

Forty MDPS panels protect the cylinder region of the MPLM. Each MDPS panel consists of a 0.8 mm thick aluminum alloy, also called an external "bumper", that is mounted 127.6 mm away from the 3.0 mm thick aluminum alloy pressure shell. A blanket of multi-layer insulation (MLI) is located near the pressure shell. Figure 1 depicts the typical layout of an MDPS panel in the cylinder region.

The orientation of the MPLM when attached to ISS Node 1 is shown in Figure 2. The MPLM keel trunnion is oriented in the ISS starboard direction, while the port trunnions face in the forward (velocity) direction in the ISS frame of reference. The keel trunnion will face the bottom of the Orbiter payload bay (PLB) when the MPLM is carried as cargo in the PLB.

The images in Figure 3 show the front and back side views of the bumper perforation that occurred during the initial flight of the MPLM. The maximum diameter of the crater lip was 2.45 mm and the diameter of the hole was 1.44 mm. The MDPS panel was removed and the MLI blanket below the impact point was inspected, but no damage or debris was found on the blanket itself. Sam-

See MPLM on page 13

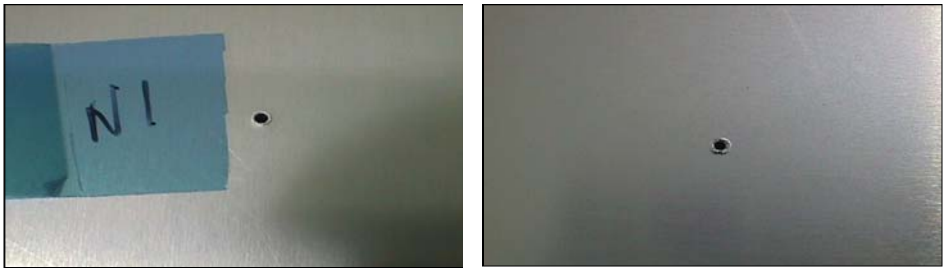

Figure 3. The front and back side views of the bumper perforation that occurred during the initial flight of the MPLM.

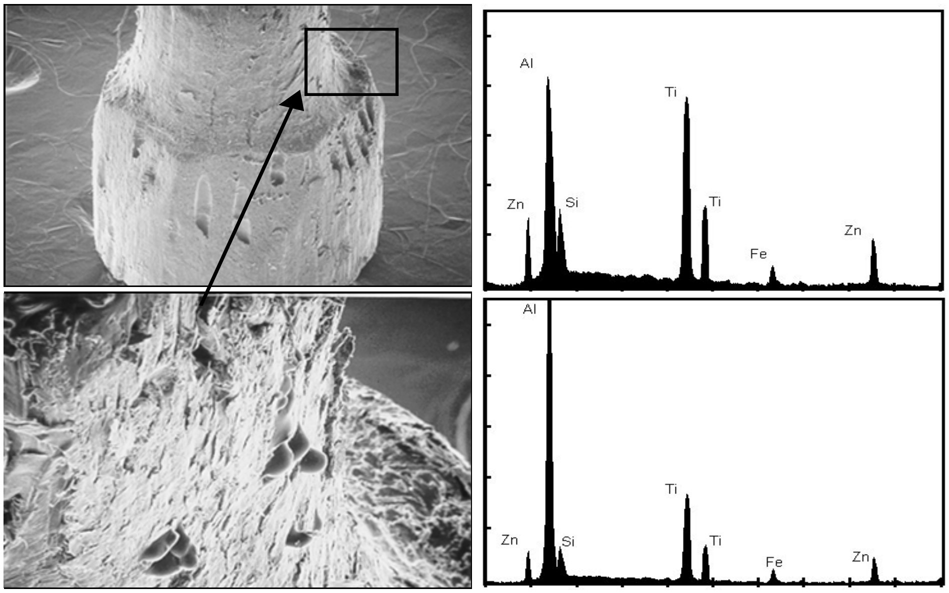

Figure 4. SEM output images and EDX spectra for samples collected from the bumper perforation.

Reentry Survivability Analysis of the Tropical Rainfall Measuring Mission (TRMM) Spacecraft

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

The joint NASA/Japanese National Space Development Agency (NASDA) spacecraft was launched in November 1997 from Tanegashima, Japan. The United States is responsible for the satellite bus, four instrument sensors, and satellite operation through NASA Goddard Space Flight Center (GSFC), Greenbelt, MD. Japan is responsible for the largest instrument (Precipitation Radar) and was responsible for the launch with a Japanese H-II launch vehicle.

A sketch of the TRMM with the solar array deployed is shown in Figure 1, showing location of the five instruments: Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible and Infrared Scanner (VIRS), Clouds and Earth's Radiant Energy System (CERES), and Lightning Imaging Sensor (LIS). The objective of the TRMM spacecraft is to measure the amount and distribution of rainfall in tropical and near-tropical areas of the Earth, using the data to predict climatic changes on a global scale.

The TRMM was launched in a 350 km altitude, 35º inclination circular orbit; however, nearly three years later, it was boosted to a 402.5 km altitude as a means of extending the mission life. Eventually, the orbital decay of the TRMM spacecraft will cause it to reenter the Earth's atmosphere, resulting in break-up and demise of most of the spacecraft components. However, due to the size, mass and material properties of some of the components, there is a possibility that some of these objects will survive the atmospheric reentry and pose a safety risk to the ground population.

In order to assess compliance with the NASA Safety Standard 1740.14 Guideline 7-1, several reentry survivability analyses were performed for the TRMM. The initial analysis was performed in early 1999 using the Miniature Object Reentry Survival Analysis Tool (MORSAT), with only 8 TRMM components. This analysis was updated in early 2001 using the ORSAT code with 35 TRMM components. The final and most complete analysis was performed in late 2002 using the ORSAT code with over 200 TRMM components, representing over 91% of the total mass of the spacecraft. This last reentry survivability analysis considered all five instruments and included all components of the structural subsystem, electrical subsystem, and high-gain antenna.

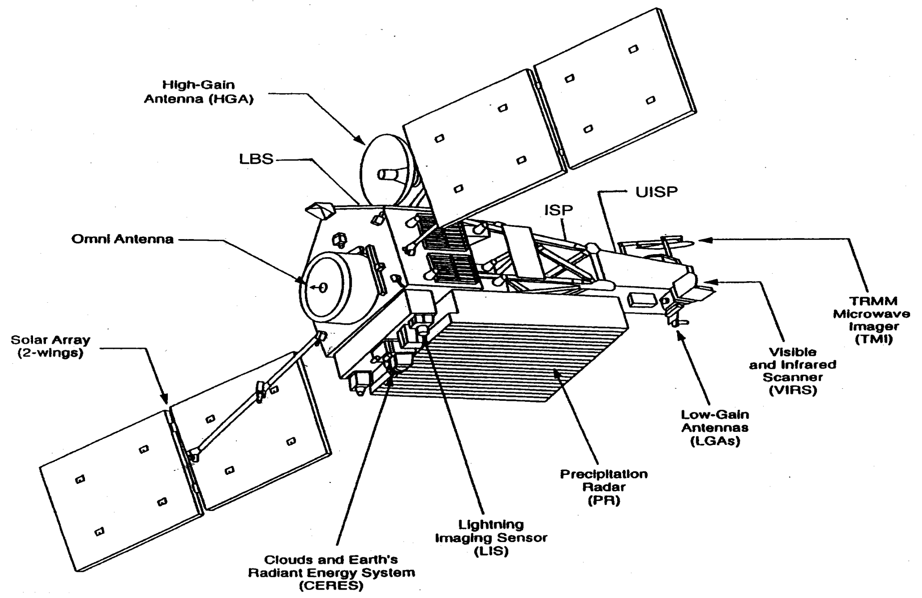

Figure 1. TRMM Spacecraft with solar arrays deployed.

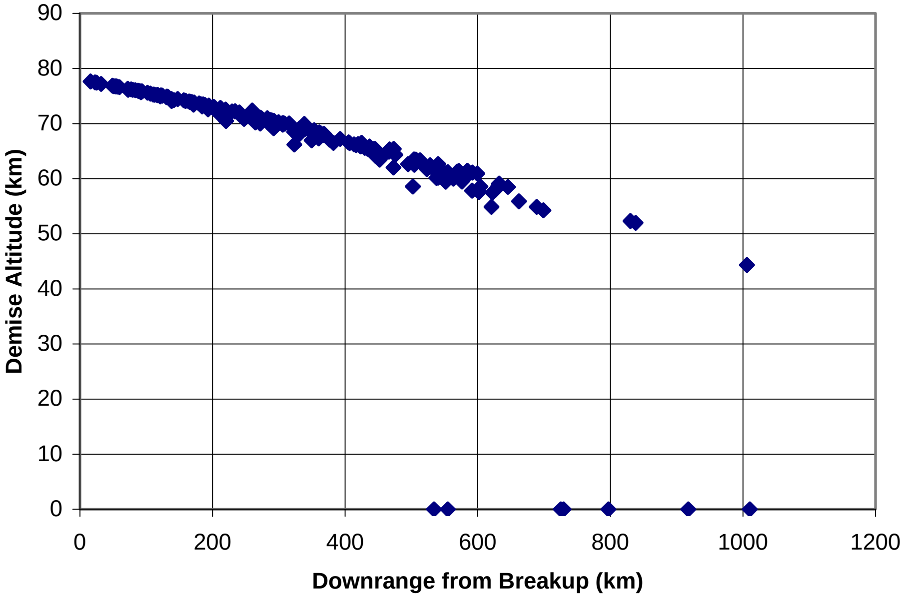

Figure 2. Demise altitude vs. downrange for all TRMM components.

The basic assumptions of this final TRMM analysis include an orbital decay entry (uncontrolled), starting at an entry interface altitude of 122 km. The initial breakup of the spacecraft was assumed to occur at 78 km. Below this break-up altitude, the primary components were assumed to split from the parent body and enter separately. In a number of cases, further fragmentation of subcomponents occurred.

The parent body of the TRMM was assumed to have a mass of 2620 kg, with box-like dimensions of length = 5.1 m, width = 3.7 m, and height = 3.0 m. Other assumptions included an initial surface temperature of 300 K for all components, an average oxidation efficiency of 0.5, and a surface emissivity of most materials of 0.3. In some cases in which a component demised at lower altitude (below about 60 km) or survived with a high demise factor (absorbed heat divided by heat of ablation) of over 90%, a parametric analysis was considered in which the initial temperature, oxidation

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Reentry Survivability Analysis of TRMM

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efficiency, and emissivity were varied from the nominal values.

Ten nodes were used in the 1-D heat conduction analysis for spheres and cylinders for nearly all TRMM components. A lumped mass model was used for all boxes and flat plates. The 1976 U. S. Standard Atmosphere model was used for all components. Fifteen different materials were used in the analysis for the approximately 210 components evaluated. The point of object demise is assumed to occur in ORSAT once the total heat absorbed (net heating rate integrated over time, multiplied by its surface area) becomes greater than the heat of ablation of the object.

Five TRMM components that either demised at a low altitude or survived with a high demise factor were evaluated in a parametric analysis in which initial temperature, surface oxidation, and/or surface emissivity were allowed to vary slightly from the nominal values. This analysis resulted in four out of these five objects demising. As a result, the final results showed seven components (all made of titanium with a high melt temperature of 1943 K) survived, or 12 components, counting multiple components of the same type, survived. This resulted in a total debris casualty area of 11.3 m^2. Using the 35°-orbit inclination with this debris casualty area and a year of reentry for the orbital decay of 2009, a risk of 1:4530 was obtained. If the TRMM spacecraft were to reenter from orbital decay in 2006, the risk would be slightly lower at 1:4600.

Figure 2 shows the demise altitude plotted vs. downrange for all the TRMM components modeled by ORSAT. There is a near linear variation of demise altitude vs. downrange until about 60 km, when some scatter occurs as some of the components begin to survive. The seven surviving components at impact (altitude = zero) are also shown on this figure, with a range between 534 km and 1010 km (or footprint length of 476 km) for the surviving components. A total mass of 112 kg was obtained for all surviving components, or a 4.3% surviving mass compared to the original mass of 2620 kg for the TRMM spacecraft. The results of this analysis were submitted to NASA GSFC to aid in assessing compliance with the NASA Safety Standard for orbital debris.

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Cube – The LEGEND Collision Probabilities Evaluation Model

J.-C. LIOU

LEGEND, a LEO-to-GEO Environment Debris model, is a new three-dimensional orbital debris evolutionary model developed by the NASA Orbital Debris Program Office at the Johnson Space Center. Since collisions are likely to dominate the future debris environment, it is critical for LEGEND to have a good model to evaluate collision probabilities among objects from LEO to GEO. The requirements for such a model include: (1) a three-dimensional model capable of capturing collision characteristics among objects with uniform and non-uniform distributions in orbital element and in precessing rate, (2) a model capable of handling a system of several hundred thousand objects, and (3) a model with manageable computer speed and space.

The classical way to evaluate collision probabilities between two orbiting objects was pioneered by Öpik [1]. This method was later generalized by Wetherill [2], Kessler [3], and Greenberg [4] to allow for non-circular orbits for the objects involved and to handle singularity problems associated with certain close encounter geometries. The fundamental assumptions of this approach are (1) the semimajor axis, eccentricity, and inclination (a, e, i, respectively) of each object remain constant, and (2) the right ascension of the ascending node, argument of perigee, and mean longitude (Ω, ω, λ, respectively) of each object are distributed randomly between 0 and 2π. Based on these assumptions, all possible close encounter geometries between any two orbiting objects can be sampled randomly or uniformly to obtain the long-term average collision probability between the two objects. This is a statistical approach based on random sampling in the physical space where collision is possible. It has been applied to estimate collisions between asteroids and comets [2, 4, 5, 6], collisions between Jovian satellites [3], and collisions between artificial satellites [7]. However, there are some systems that violate one or both of the assumptions. Examples include asteroids near mean motion resonances (non-random Ω, ω, and λ; fast changing eccentricity and/or inclination), comets (non-random Ω and/or ω), and objects under strong dissipative forces (fast changing a and e).

With the help of modern computers, it is now possible to perform numerical simulations on the orbital evolution of an N-body system. Therefore, there is a need for a collision model that can work with an orbital evolution simulation to utilize the updated information (new objects, decayed objects, orbital elements) as the system evolves in time. The Cube approach is designed to accomplish this objective. The basic assumption of the approach is that the long-term collision characteristics of a system can be represented by evaluating the collision probabilities among objects at numerous instances (snapshots) during the simulation. Instead of the classical uniform sampling in space approach, this is a uniform sampling in time approach.

The procedure to evaluate collision probabilities among objects at each instance in time is straightforward. At each snapshot the three-dimensional space is divided into many elements (cubes). The cube dimension is characterized by the short-period perturbations on the positions of the objects. The position and velocity of each object are calculated based on their orbital elements at that instance. The cube inside which each object is located is identified. When there are two objects within the same cube, the collision rate is determined by the same spatial density approach developed by Kessler [3]. On a microscopic scale, this is identical to the kinetic theory of gas approach. On a macroscopic scale, the orbital elements of objects are determined from the orbital evolution simulations. No assumptions regarding either constant (a, e, i) or uniform (Ω, ω, λ) are needed. Note that the only objects selected for collision evaluation are those within the same cube. For those identified as the only object in a cube, they are not processed any further. This is a fast and efficient way of performing pair-wise comparisons. The computation time of this approach increases with N, rather than N^2, for an N-body system. This approach can be coupled with any numerical simulations of the orbital evolution of objects (orbital debris, asteroids, comets, Kuiper Belt objects, planetesimals, etc.) to evaluate the long-term collision probability as the system evolves. At every integration time step, one needs to identify multi-object cubes and determine the collision rate of each pair of objects. A random number is then drawn to compare with the probability to determine whether or not a collision would occur. As a standard statistical sampling technique, more snapshots, or smaller time step between snapshots, are preferred. The identification of objects with non-zero collision rate and the computation time of collision probability should be small compared with the orbital

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Cube – The LEGEND Collision Probabilities Evaluation Model

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integration time of an N-body system. Therefore, the integration time step should be used to evaluate collision probabilities. In addition, the cubes have to be small enough to capture the characteristics of the true collision nature of the system. In general, a dimension of 1% or less of the average semimajor axis of objects in the system is sufficient. A time step of 5 days and 10 × 10 × 10 km^3 cubes are the default setup in LEGEND. In the extreme case where the cube is as big as the whole system, the Cube approach mimics a simple particle-in-a-box collision model.

To validate and verify the Cube model, we have applied it to various systems and compared its predictions with previously published collision probabilities between asteroids and comets, between Jovian satellites, and among LEO debris – assuming all systems obey the two Öpik's assumptions. Overall, the Cube predictions are consistent with asteroids/comets/satellites collision probabilities calculated by various authors using Öpik's approach [8]. For LEO debris comparison, the Cube predictions agree well with results using Kessler's method for objects with regular orbits (no singularities). The Cube model has no problems dealing with LEO objects with irregular orbits (overlapping at perigee or apogee) that cannot be calculated using Kessler's method. In addition, we have applied the Cube model to two objects in mean motion resonance (a non-Öpik system) and showed that the model predicted the outcome correctly.

Based on all the comparison results, we conclude that the Cube approach provides a good statistical estimate of the long-term collision probabilities among orbiting objects. When applied to an Öpik system – a system where all objects have fixed (a, e, i)'s and randomly distributed $(\Omega, \omega, \lambda)$'s, this "uniform sampling in time" approach agrees with the classical "uniform sampling in space" approach. The Cube approach is also capable of predicting the long-term collision probabilities among orbiting objects in a general (non- Öpik) system. This fast and reliable model is a critical component in LEGEND to predict the future orbital debris environment.

Reference:
[1] Öpik E.J. (1951) *Proc. Royal Irsh Acad., 54A*, 164-199. [2] Wetherill G.W. (1967) *JGR, 72*, 2429-2444. [3] Kessler D.J. (1981) *Icarus, 48*, 39-48. [4] Greenberg R. (1982) *Astron. J., 87*, 184-195. [5] Namiki N. and Binzel R.P. (1991) *Geophys. Res. Letters, 18*, 1155-1158. [6] Bottke W.F. and Greenberg R. (1993) *Geophys. Res. Letters, 20*, 879-881. [7] Kessler D.J. and Cour-Palais B.G. (1978) *JGR, 83*, 2637-2646. [8] Liou J.-C. *et al.* (2003) LPSC XXXIV, 1828. ◆

NASA's Sodium Potassium Generation and Propagation Model

P. KRISKO

Sodium potassium (NaK), used as the coolant for the nuclear reactors of the former Soviet RORSAT (Radar Ocean Reconnaissance Satellite) spacecraft, is believed to have been accidentally released during nuclear core ejection events of many of the later RORSATs. Objects identified as NaK droplets have been observed over the last decade by several NASA radars (i.e., Haystack, HAX, Goldstone) and through impacted material recovery (LDEF). This population represents an orbital debris hazard to spacecraft in low Earth orbit. Modeling efforts have been hampered in the past by lack of data and lack of knowledge as to the precise mechanism of core ejection and total NaK mass available for release. Even so, models have been developed to account for the population (i.e., ESA's MASTER model and NASA's EVOLVE NAKDEP subroutine).

NASA has recently developed its next generation NaK simulation model, NaKModule. This model is designed for compatibility with the NASA 3-D debris environment simulation model LEGEND. It makes use of two main advances in recent years, the NASA orbital propagator PROP3D and the newly processed and fitted Haystack radar data from 1994 through 2002. Though Haystack data has been used in the past for NaK identification and modeling, the routine processing of that data assigns diameters based on the NASA Size Estimation Model (SEM). The current effort makes full allowance of the fact that NaK droplets are spheres, and recasts the data droplets as spherical conductors. This results in reliable identification and size assignment. The wealth of NaK data over 8 years also increases statistical accuracy of the calculated population, displays the orbital decay of droplets over time, and leads to a cursory observation of the sublimation rate of droplets (no noticeable sublimation over the 8 year time period).

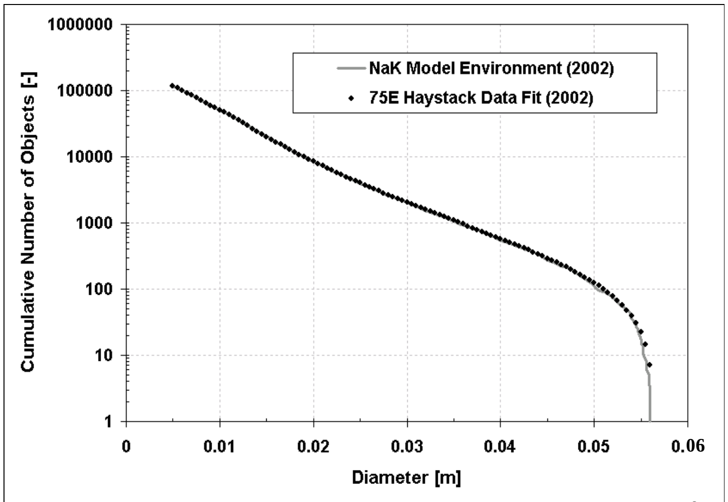

Figure 1. Cumulative number distribution with respect to diameter for the 75E Haystack dataset 2002 and the NaK model (NaKModule) at the end of 2002.

The Haystack NaK selection requirements were derived by J. L. Foster. They include objects by radar polarization (≥ 0.92), Doppler inclination (≥ 62° and ≤ 68°), and altitude (≤ 1200 km). The total inferred population as of January 1, 2003 consists of about 110,000 droplets ranging in size from 5 mm to 5.6 cm with a total mass of about 165 kg ±15 kg. Foster developed a linear regressive fit to the radar-cross-section data. This fitted function is applied to droplet diameter and modified for use in NaKModule to account for previously decayed droplets.

Though specific information on the RORSAT reactor design and ejection method is still wanting, the NaK ejection process is modeled in NaKModule by analogy with the reactor core ejection. Of 29 RORSAT upper stages boosted into collection orbits and listed in the US Satellite Catalog, 16 have performed a reactor core ejection after that end-of-life maneuver. It is believed that these 16 ejection events resulted in a concurrent release of NaK reactor coolant. By backtracking the first ejected core 2-Line Element set (TLE) to the most recent TLE of the reorbited RORSAT upper stage for all 16 events it is possible to estimate the core ejection direction and relative velocity. The cores

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NASA's Sodium Potassium Generation and Propagation Model

Continued from page 6

appear to be ejected in the upper stage ram direction at relative velocities ranging from about 6 m/s to 13 m/s. Since the observed NaK droplets do not appear to have been deposited with a significant Δv, this ejection criterion is applied to the droplets as well. It must be noted that the above result is in general agreement with that of previous models (i.e., MASTER and NAKDEP).

NaKModule generates individual droplets at the time of each of the 16 RORSAT re-orbits. Each event is unique in diameter distribution, initial Δv distribution, and initial orbital elements. Diameters and Δv's of each droplet are randomly selected within constraints noted in the previous paragraphs. Since about 110,000 droplets are calculated to exist in orbit presently, the droplets in the code are generated one at a time (i.e., no grouping is needed or used for the smaller droplets). Orbital and physical parameters of each droplet are saved in arrays, which serve as inputs to the orbital propagator. All objects are propagated from time of generation to the chosen time of completion. The output of the model, the physical and orbital characteristics of each droplet at a given time, represents a population that can be input to the NASA model, LEGEND.

The area-to-mass ratio of each modeled droplet is simply calculated, $A/m = \pi r^2/\rho(4\pi r^3/3)$, where the density of the eutectic NaK alloy (Na – 22 wt.**%,** K- 78 wt.**%)** is, $\rho = 0.9$ gm/cm^3. The natural decay of droplets leads to a modeled population that closely matches that of the Haystack dataset at the end of 2002 (Figure 1).

The model and data diameter vs. altitude at the end of 2002 are shown in Figure 2. Several important points must be made about this figure. First, the model points number the total predicted in-orbit population of 116,151. The number of identified NaK droplets in the Haystack dataset is 417 for the year 2002. This is a function of the radar beam geometry and latitude, the altitude of the detections, and the sensitivity of the radar. The estimated true population of the NaK droplets based on the 417 Haystack detections is about 115,800 for diameters down to 5 mm. Second, as noted above, Haystack data diameter values are routinely processed with the NASA SEM. The NaKModule diameters are derived from the Foster fit, which is based on the spherical conductor theory. Generally speaking, then the Haystack data diameters are misidentified using the SEM. Finally, the smallest diameters in the Haystack data (~3 mm) are not matched in the model which has a deliberate diameter floor of 5 mm. The population at NaK altitudes that is smaller than 5 mm in diameter is generally incomplete by reason of a Haystack radar 'roll off' in detection efficiency. This has been demonstrated by comparisons between the Haystack datasets and the ORDEM2000 populations. So it has been decided to restrict NaKModule to diameters larger than 5 mm for the time being. Extension of NaKModule to smaller sizes will be investigated in the future.

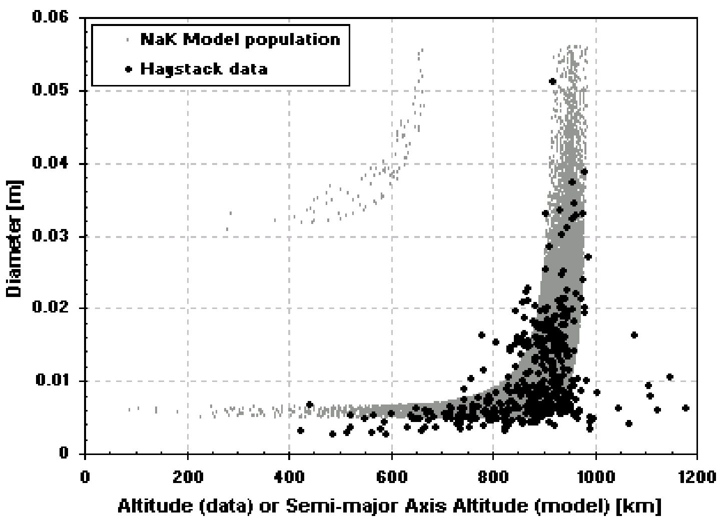

Figure 2. NaKModule vs. 75E Haystack data at end of 2002 shows the atmospheric decay of NaK droplets over time. The smallest droplets (those with the largest A/m values) decay fastest.

The comparative populations are listed below. Differences between the two Haystack columns are due to statistical variation in viewing opportunities. ◆

Parameter	Haystack Data Fit (1994-2002)	Haystack Data Fit (2002)	NaK Model
Total Number of NaK Droplets in Orbit	110,000	115,785	116,151
Total Mass [kg] of NaK Droplets in Orbit	165 ± 15	158 ± ~15	164

Table 1. Comparative values at the end of 2002.

Growth in the Number of SSN Tracked Orbital Objects

G. STANSBERY

The number of objects in Earth orbit tracked by the US Space Surveillance Network (SSN) has experienced unprecedented growth since the first of last year. On January 1, 2003, the SSN was routinely tracking ~10,870 objects in Earth orbit – ~8,860 in the regular "catalog" and ~2,020 analyst satellites. The number peaked in mid September with ~13,690 total objects (~9,030 catalog and ~4,650 analyst) and as of November 21, 2003 stood at ~13,120 total objects (~9,100 catalog and ~4,020 analyst).

This growth is primarily due to the resumption of full power/full time operation of the AN/FPS-108 Cobra Dane radar located on Shemya Island, AK (Figure 1). Cobra Dane is an L-band (23 cm wavelength) phased array radar which first became operational in 1977. The radar generates approximately 15.4 MW of peak RF power (0.92 MW average) from 96 Traveling Wave Tube (TWT) amplifiers arranged in 12 groups of 8. This power is radiated through 15,360 active array elements. Cobra Dane was a "Collateral Sensor" in the SSN until 1994 when its communication link with the Space Control Center (SCC) was closed. NASA and the Air Force conducted tests in 1999 using Cobra Dane to detect and track small debris (see ODQN Vol. 4, Iss. 4). These tests confirmed that the radar was capable of detecting and maintaining orbits on objects as small as 5 cm diameter. Subsequently, Cobra Dane was reconnected to the SSN and resumed full power/full time space surveillance operations on March 4, 2003.

The drop in the number of tracked objects from September to November does not correspond necessarily to a drop in the environment. More likely it is due to more Cobra Dane resources (time and transmit power) being used to maintain orbits of objects as

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Growth in the Number of SSN Tracked Orbital Objects

Continued from page 7

opposed to searching for new objects. Of the ~2000 objects added to the analyst satellite list, about 1300 have been tracked by other sensors in addition to Cobra Dane. The remaining 700 objects are only being tracked by Cobra Dane, according to Taft DeVere of the Air Force Space Command Space Analysis Center.

One area noted in examination of the two catalogs is an increase in the population near 65° at mean altitudes near 9000 km. A Gabbard diagram (Figure 2) of these objects shows perigees near 300-500 km altitude with apogees in the 15,000-20,000 km range. A number of known breakups of Proton-Block DM Ullage motors have occurred with these orbital parameters. However, very few objects were cataloged from these breakups. Cobra Dane is currently maintaining orbits on about 100 of these objects.

The location (52.7 N, 174.1 E) and orientation of Cobra Dane preclude it from detection of low inclination orbits. Its sensitivity and large collection area, however, have allowed it to quickly add 2000 objects to the low Earth orbit tracked debris population. ◆

Figure 1. AN/FPS-108 Cobra Dane L-band phased array radar.

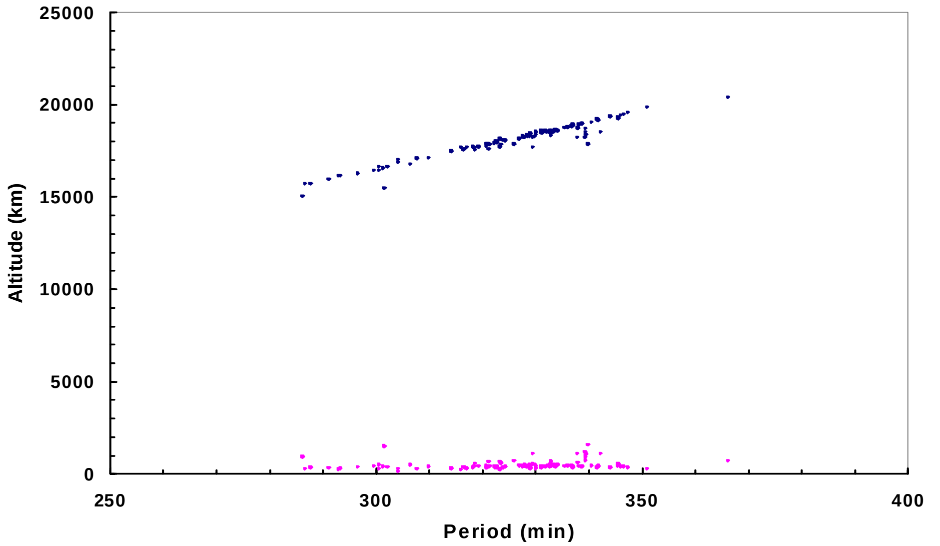

Figure 2. Gabbard diagram of "analyst" satellites with orbital inclinations between 60° - 70° and with mean altitudes between 8,000 – 11,000 km.

Results from the GEO Debris Survey with MODEST

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

Since early 2001, the University of Michigan's 0.6/0.9-m Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory, Chile, has been used in a continuing optical survey of space debris at geosynchronous orbit (GEO). This project is called **MODEST**, for **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope. The goal is to study the distribution of space debris in the geosynchronous region.

From its location in the foothills of the Chilean Andes, the telescope can cover most of the orbital slots over the continental US. Each night of observing, the telescope uses a scanning CCD to cover a strip of sky 1.3 degrees high by over 100 degrees long. A GEO object can be detected up to a maximum of 8 times as it drifts across the telescope field of view. A typical 14 night observing run covers over 1400 square degrees of sky, centered on the station-keeping ring of active satellites. Each morning a summary of the results from the previous night's observing is sent to the NASA Orbital Debris Program Office at the Johnson Space Center in Houston, Texas along with positions, angular motions and brightness estimates for all objects detected.

In this article we will highlight some results from the MODEST survey.

Figure 1 shows the magnitude distribution of a sub-sample of objects detected in 4 observing runs starting in November 2002 and ending in April 2003. We only include 510 objects which are not station-keeping in both East-West and North-South directions near the station-keeping ring. This excludes most active satellites, and only includes objects which are uncontrolled near GEO. This is a dynamical definition of orbital debris at GEO.

The figure shows a bimodal distribution of debris. Bright debris at the left side is mostly intact spacecraft and rocket bodies. Faint debris on the right side of the histogram is too faint to be in the existing catalogs of space objects, and the physical characteristics of this faint population is unknown. The cutoff at R = 18th magnitude (corresponding to a 20 cm diameter sphere) is due to system limitations, and does not reflect the true debris population. In fact, the debris population could be increasing to fainter magnitudes!

What is most interesting is the analysis of the observed motions of these 510 objects. There is a remarkable difference in the motions of the bright versus faint debris. Figure 2 shows the observed angular motions of these objects in the East-West (hour angle) and North-South (declination) directions. A true station-keeping satellite which is controlled would be at the center of these plots (0,0).

The bright objects show a very correlated motion, which is to be expected if most of them are on near-circular orbits at the same geocentric orbital radius. If everything was precisely at GEO in circular orbits, but with different orbital inclinations, then the plot would be a straight line at 0 arc-seconds/sec in HA. But the observed curvature results from the drift velocity of uncontrolled orbits, due to perturbations from the Earth's

Continued on page 9

Results from the GEO Debris Survey with MODEST

Continued from page 8

bulge, and the Sun and Moon. It is expected that this correlated motion translates into the well known relationship between RAAN (Right Ascension of the Ascending Node) and orbital inclination for GEO objects.

Faint objects show no such correlation. Physical explanations include eccentric orbits at GEO or circular orbits at a range of geocentric orbital distances, or a combination of these. The current observations (taken over a 5.2 minute time span) do not have enough information to do a full orbital solution to resolve the uncertainty. Follow-up observations over a longer time span are essential to solve this problem.

Where did all this debris come from? There are only a few explosive fragmentations known at GEO. In an effort to monitor one source of GEO debris, we regularly (once per month) observe the station-keeping ring of active satellites. The goal is to look for pieces which have very recently fallen off active satellites and thus are moving very slowly.

Figure 3 shows the brightness histogram for all observed objects within +/- 0.5 degrees of geocentric orbital latitude = 0 degrees, and with a total angular motion less than 0.1 arc-seconds/sec. This angular motion cutoff is imposed to exclude faster moving objects which are in the field of view of the system but which are on inclined orbits (and hence older). This figure shows only bright objects which are intact, operating spacecraft. The cutoff at the bright end is due to the fact that many operating satellites are too bright for the system to observe, and they saturate the detector.

We see no population of faint, slowly moving debris, which could have been recently released at zero velocity from larger spacecraft. Such debris might be solar panels, covers, insulation blankets, etc. We conclude that at least during this time span there was no significant source of debris in the station-keeping ring.

MODEST observations will continue into 2004. Improvements under way should result in being able to reach R = 19th magnitude, one magnitude fainter than the above results. We will continue to survey the GEO regime in an effort to determine the total population of objects at GEO above our sensitivity limits, and to regularly monitor for releases of debris.

The orbital debris program at the Department of Astronomy, University of Michigan, is supported through grants from NASA's Orbital Debris Program Office at the Johnson Space Center, Houston, Texas.

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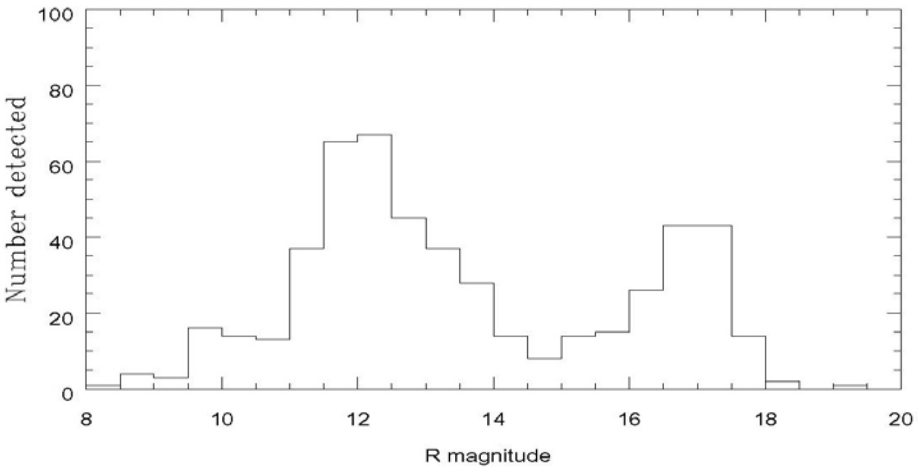

Figure 1. The brightness histogram of 510 uncontrolled objects observed from November 2002 through April 2003. Bright objects are on the left, faint on the right. The cutoff at R = 18th magnitude reflects system limitations, and not a limit to the true population of debris.

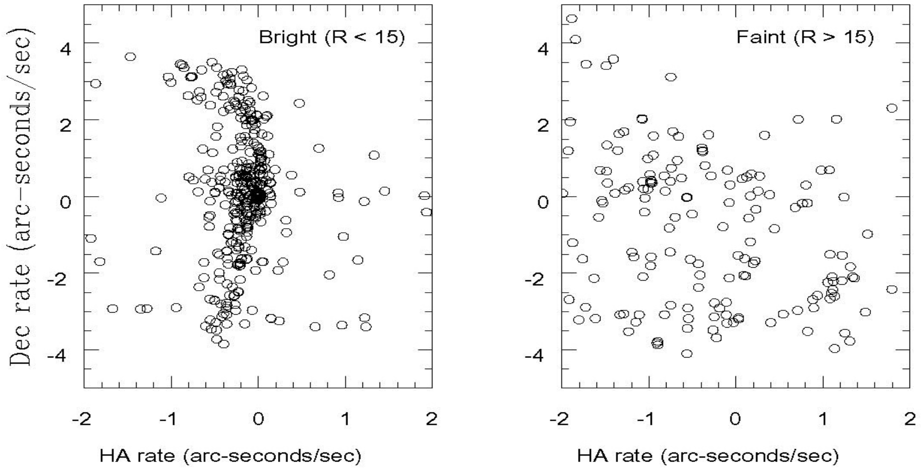

Figure 2. The observed angular motions of the 510 uncontrolled objects in Figure 1. Note the very different distributions for bright versus faint debris.

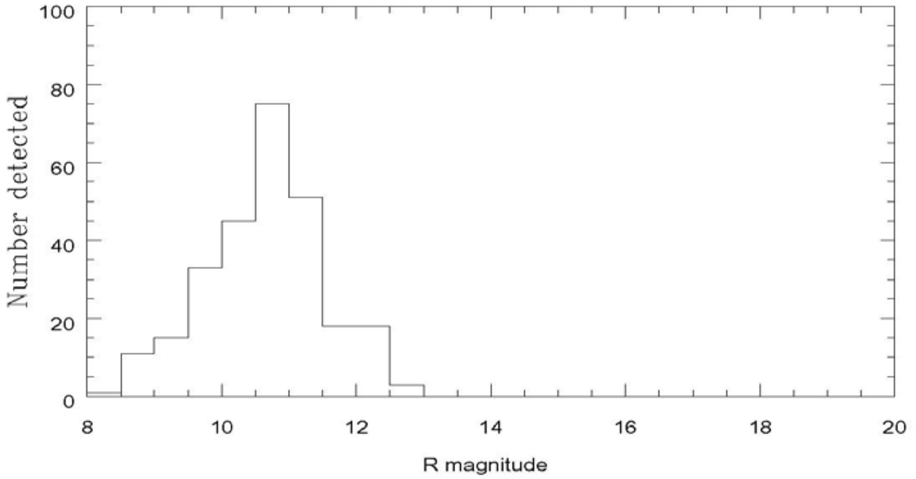

Figure 3. Brightness distribution of objects at or close to the station-keeping ring, and with a total angular motion less than 0.1 arc-seconds/second. Only bright objects are seen, nothing fainter than R = 13. These are all intact, operating spacecraft. Compare this with Figure 1, which shows a large population of debris fainter than R = 14.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

54th International Astronautical Congress
29 September—3 October 2003, Bremen, Germany

Revisions to Nasa Policy Directive and Safety Standard for Orbital Debris Mitigation

N. JOHNSON

NASA Policy Directive (NPD) 8710.3, *NASA Policy for Limiting Orbital Debris Generation*, was revised as NPD 8710.3A in January 2003, reflecting the growing importance of orbital debris mitigation and a need to identify and to expand the responsibilities of various organizations within NASA. The agency has acquired considerable experience in assessing orbital debris potential for a large number of human space flight and robotic satellite missions, and this experience indicated that more explicit guidance to NASA enterprises and centers was necessary to ensure that orbital debris mitigation issues were handled in an efficient and comprehensive manner. Work is now underway to revise the 1995 NASA Safety Standard (NSS) 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris*, to update the document and to correct deficiencies and areas of ambiguity. Although the technical elements will remain largely unchanged, some guidelines will be improved, and the document will be more consistent with the U. S. Government Orbital Debris Mitigation Standard Practices and other national and international guidelines. An important lesson in the management of orbital debris learned by NASA during the past eight years is that an effective orbital debris mitigation program requires a detailed, formal process which is supported by all agency organizations. ◆

Space Traffic Management Concepts and Practices

N. JOHNSON

Concepts of space traffic management have been discussed for many years with little progress to date due both to the complexity of the issue and to a perceived lack of urgency. Although a renewed interest in the subject has arisen in some corners of the aerospace community, the challenges of space traffic management remain unchanged. Perhaps the greatest challenge is reaching a consensus on the definition of space traffic management and its objectives. In the simplest terms, space traffic management should promote physical and electromagnetic noninterference among the multitude of operational space systems. However, contrary to popular belief, air and ground traffic control concepts and techniques offer few analogies applicable to the space environment. The value of a space traffic management system must weigh the historical and legally entrenched concept of the freedom of operation in near-Earth orbit against the potential benefits of a new regulatory regime. Most spacefaring nations do not yet exert control over the selection of orbital parameters for new space systems within their own countries, much less in an international context. The prospects for such intrusive space traffic management in the foreseeable future are not bright. ◆

Changes Seen In Three Years of Photometry for GEO Objects

K. JARVIS, J. AFRICANO,
T. PARR-THUMM, M. MATNEY,
& G. STANSBERY

The CCD Debris Telescope has collected several years worth of data of GEO objects. The database built from these observations include such information as absolute magnitude, solar declination, phase angle, range, eccentricity and, in some cases, known dimensions at time of launch. Many objects that are correlated with known SSN numbers are seen on multiple nights throughout 1998, 1999, and 2000 data. More than seventy objects have sufficient data points to study absolute magnitude variations. Brightening of objects is seen to relate to solar declination. Boxes and cylinders present different light curves and different dependence on solar declination. Average absolute magnitudes of cylinders are found to be about two magnitudes dimmer than those of boxes. A general darkening with increasing age of satellite is also seen. ◆

NAK Droplet Source Modeling

J. FOSTER, JR., P. KRISKO, M. MATNEY,
& G. STANSBERY

As part of the NASA orbital debris modeling effort, a quantitative model is developed for the large population of spherical electrically conducting objects in 65° inclination circular orbits at the disposal altitude of the Russian Radar Ocean Reconnaissance Satellite (RORSAT) spacecraft. These are believed to be droplets of liquid sodium-potassium (NaK) reactor coolant released from the RORSAT satellites. Observations of the droplets from 1990 through 2002 have shown slow orbital decay. Data from the Lincoln Laboratory Haystack and HAX radars have been examined for the time period from 1994 to 2002. Electrically conducting spheres produce a distinctive polarization signature allowing their identification, with high probability, among the other objects detected by the radars. The droplets are comparable in diameter to the radar wavelengths. This produces a size ambiguity for a given radar cross-section because of diffraction effects. Previous work, used the NASA orbital debris size estimation model that is based upon radar measurements of randomly shaped objects with the radar wavelength comparable to the object size. Here, the size distribution is estimated using the radar cross section of a conducting sphere, permitting an accurate population size distribution determination. ◆

Upgrades to Object Reentry Survival Analysis Tool (ORSAT) for Spacecraft and Launch Vehicle Upper Stage Applications

J. DOBARCO-OTERO, R. SMITH,
J. MARICHALAR, J. OPIELA,
W. ROCHELLE, & N. JOHNSON

Prediction of reentry survivability of spacecraft and upper stages of launch vehicles is necessary to determine the risk to humans upon ground impact. NASA Johnson Space Center has been developing a computer program that will predict survivability of objects reentering the Earth's atmosphere. The objectives of this study are to present updates and applications from the latest version of this code, Object Reentry Survival Analysis Tool (ORSAT) 5.8. Recent up-

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Upgrades to Object Reentry Survival Analysis Tool (ORSAT)

Continued from page 10

dates to ORSAT include addition of parametric features, heat conduction through boxes and flat plates, radiation to internal components, improved material database, drag coefficients at low speeds, higher-fidelity aeroheating algorithm, and improvement of global population database. Results of these new features include the ability to input a range of values for a specific parameter, more accurate predictions for flat plate and box-shaped objects, higher initial temperatures for internal components, improved velocity and kinetic energy predictions at impact, emissivity variations with wall temperature, real gas effects on aeroheating, and survival risk calculations out to the year 2050. This paper will present recent predictions of reentry survivability to sample spacecraft and launch vehicle upper stages using these updated features of ORSAT. ◆

Comparison of Photometric and Spectral Data from NASA'S CCD Debris Telescope (CDT) and the NASA AMOS Spectral Study (NASS) Observations

K. JORGENSEN, K. JARVIS,
K. HAMADA, T. PARR-THUMM,
J. AFRICANO, & G. STANSBERY

A comparison study was conducted between the CCD Debris Telescope (CDT) and NASA AMOS Spectral Study (NASS) observations. Photometric data was collected using the CDT during the 1998-2000 observing sessions on various GEO satellites. From 2001-2003, spectral observations were collected during NASS; several of these same objects had been observed with the CDT. By comparing the changing magnitudes of the overlapping CDT and NASS data, one can explain aspects of the spectral signature including orientation of the object, location of the main body and solar panels, and possibly anomalies seen in the spectra. Initial investigation shows that the shape of the satellite (with and without solar panels) plays a large role in the magnitudes of the object. Also, the spectral signatures show a change in location of features dependent upon shape. For this analysis, three cylindrical objects of similar size and three box satellites with varying solar panel lengths are examined and the results are discussed herein. In addition to the spectral signature, NASS converts the spectrum into photometric data, which can be compared directly to the CDT data in an effort to validate the NASS measurements. The same set of satellites observed spectrally will be discussed. ◆

NASA Long-Term Orbital Debris Modeling Comparison: LEGEND and EVOLVE

P. KRISKO & J. -C. LIOU

This paper presents examples of the long-term low Earth orbit (LEO) orbital debris environments generated by the NASA simulation models LEGEND and EVOLVE. LEGEND (LEO-to-GEO Environment Debris model) is a three-dimensional debris evolutionary model that is slated to replace the one-dimensional LEO-only EVOLVE in 2004. The β version of LEGEND is completed and is undergoing an extensive validation and verification process. The historical and projection test environments compared for this paper are part of this process. They show a great deal of similarity in the 10-cm and larger populations. The business-as-usual scenario leads to a collisionally dominated environment in LEO, as has been reported in past studies with EVOLVE. But with the additional capabilities that LEGEND provides, more details of the environments are now available, such as the dominance of the LEO-LEO collision pairs, and the inclination clustering of collision pairs. ◆

Toward A Comprehensive GEO Debris Measurement Strategy

M. MATNEY

In recent years there has been increasing interest in the effects of orbital debris on the Geosynchronous Earth Orbit (GEO) environment. This region has great economic importance that is only expected to grow stronger in the foreseeable future. The lifetime of any debris created is very long, so that there is no effective sink to remove the debris in a timely manner. Considerable resources have been brought to bear to understand the current debris environment at GEO. A number of optical telescopes in different countries are now systematically making observations of this region specifically to understand the debris population. We are now at a stage where we can begin to answer specific questions about orbital debris in these orbits, but what are these questions? Are we asking the right questions? Are the observations we are pursuing answering the most important questions? Are there changes needed in the observation techniques to better address the most important issues? Are there changes needed in the types of instruments to answer the most important questions? This paper will outline the broad questions that GEO observations should be designed to answer. I will discuss how observations so far have begun to answer those questions and where they need to concentrate in the future. This will include discussions of the benefits and limitations of the statistical sampling methodology versus the cataloguing methodology. I hope to provide a framework for future observations that will be of benefit to all GEO users. ◆

Improvements to NASA's Estimation of Ground Casualties from Reentering Space Objects

J. OPIELA & M. MATNEY

Recent improvements to NASA's long-term estimation of ground casualties from reentering space debris include refinements to the human population distribution and to the risk probability calculation. The previous human population distribution was based on a global total, with a simple scaling factor for future years. This constrained the world's population to change at the same fixed rate. The new predicted global population is based on a fixed distribution and variable total population for each country or area. All areas are then combined into the total global population as a function of latitude. This creates a more accurate population estimation based on non-uniform growth at the country/area level. The previous risk probability calculations were based on simplifying assumptions for debris that did not take into account the debris shape. The new method uses a simple procedure based on numerical calculations to include the geometry of the debris shape intersecting the human body. We use the perimeter of the debris area to arrive at a more accurate representation of the risk. These results have been tested for accuracy against Monte Carlo models that simulate how different shapes of debris could hit a person on the ground. ◆

Satellite Operations and Safety Workshop
22-23 October 2003, Westford, Massachusetts, USA

Fundamentals of Debris Collision Avoidance

J. FOSTER, JR. & G. STANSBERY

The statistical risk of a collision between a spacecraft and tracked (i.e. cataloged) space debris is generally small for a given conjunction. However, even this small risk may be unacceptable for a variety of reasons. In particular the integrated risk over time may not be so small. Collision avoidance maneuvering is one method of mitigating the risk and can be quite economically effective for some vehicles. However, maneuvering also has associated costs and risks and should not be used in all cases. An holistic approach to debris collision avoidance maneuvering is required for a safe and effective process.

A formalism for quantifying risk and residual risk based on a maneuvering strategy and position and position uncertainty for the tracked conjuncting population is developed. Position and position uncertainty predictions of the conjunction population need to be sufficiently accurate so that the cost of maneuvering a spacecraft is at least comparable to the value of the mitigated risk. A process based on an exclusion volume is compared with a process based on collision probability. The use of two line element sets for debris avoidance is also discussed.

Before adapting any debris collision avoidance strategy for any vehicle, the associated risk and residual risk should be determined. A debris avoidance process based on collision probability offers the possibility of identifying the infrequent high collision probability conjunctions for which action should be taken if at all possible. Such a process has been adopted for both the International Space Station and for the Space Shuttle. ◆

AMOS Technical Conference
8-12 September 2003, Wailea, Maui, Hawaii, USA

Obtaining Material Type of Orbiting Objects through Reflectance Spectroscopy Measurements

K. JORGENSEN, J. OKADA, D. HALL, L. BRADFORD, J. AFRICANO, K. HAMADA, G. STANSBERY, & P. KERVIN

A collaborative effort between the Air Force Maui Optical and Supercomputing (AMOS) site and NASA Johnson Space Center (JSC) began in September 2001 to study the material type of orbiting objects using the AMOS telescopes. This project, termed NASS for the NASA AMOS Spectral Study, observed large orbiting objects spectrally and compared the overall shape of the reflectance spectra as well as the location of spectral absorption features in an effort to distinguish material types. The Spica spectrometer, a sensor based on the commercial Acton Sp-500 spectrograph, which is mounted on the rear-blanchard of the AMOS 1.6 meter telescope, was the main instrument used in the study. In this paper, we will discuss the results of recent analysis of Spica data and its implications towards the determination of material type of orbiting objects, spectroscopic Space Object Identification (SOI), and effects of space weathering. In addition to the material type identification, an overall increase in reflectance has been noted in virtually all measurements of the orbiting object and it has been found not to be dependent on altitude. Investigations of material type dependence on this increase have been explored and the results will be discussed. ◆

Recent Results from NASA's GEO Debris Optical Surveys

M. MATNEY, G. STANSBERY, P. SEITZER, K. JORGENSEN, T. THUMM, K. JARVIS, & J. AFRICANO

For several years, we have been observing the geosynchronous orbit (GEO) environment using optical telescopes for NASA's Orbital Debris program. The goal has been to try to understand the population of debris objects too small to be easily tracked by the US Space Surveillance system. However, by using telescopes in a staring mode to survey the environment, it has proven very difficult to obtain orbital elements accurate enough to track an object and maintain an element set. Instead, NASA's goals have centered on characterizing the statistical distributions of objects in GEO and near-GEO orbits. In this study, we introduce calculations made with data from the University of Michigan 0.6/0.9 meter (1.3°x1.3° field of view) Curtis Schmidt telescope in Chile. By removing observation biases due to the observing geometry (i.e., where the telescope is pointed for each frame), we show how the populations of debris objects are distributed in orbit distributions and in size. From this information, it is possible to make general conclusions about the sources of debris in the GEO environment. ◆

Meter-Class Autonomous Telescope for Space Debris Research

G. STANSBERY, D. O'CONNELL, D. NISHIMOTO, J. AFRICANO, & P. KERVIN

The National Aeronautics and Space Administration (NASA) and the Air Force Research Laboratory (AFRL) Maui Optical and Supercomputing (AMOS) Site are cooperating to place a wide field of view, meter aperture telescope on Kwajalein Atoll for space debris research. The telescope system, designated the Meter-Class Autonomous Telescope (MCAT), will be deployed as part of the High Accuracy Network Orbit Determination System (HANDS) and will use the Oceanit, Inc. K-Star design. The telescope will operate in two different modes. During twilight hours it will sample low inclination orbits in a "track before detect" mode. In the middle of the night it will perform a more standard GEO search. Kwajalein Atoll was chosen as the location for MCAT because: 1) its low latitude location necessary for sampling low inclination orbits, 2) its location allows it to measure a part of the GEO belt not covered by other optical sensors, 3) it has a technically skilled workforce which can act in a caretaker capacity. ◆

MEETING REPORTS

2003 AMOS Technical Conference
8-12 September 2003, Wailea, Maui, Hawaii, USA

The AMOS Technical Conference was held at the Marriott Outrigger Wailea Resort in Wailea, Maui from 8 to 12 September, 2003. Over 400 representatives from high-tech industry, academia, and government attended the five day technical conference

Sessions included: Lasers, Adaptive Optics, High Performance Supercomputing, Astronomy, Space Weather, Metrics, Orbital Debris, and Space Object Identification.

Within the orbital debris session, seven papers were presented with speakers from around the world. Michael Oswald (Aerospace Systems, ILR) spoke on the German space debris observation in GEO. Next, NASA/JSC's Mark Matney discussed the recent results from NASA's GEO debris optical surveys, specifically the MODEST data. Following his talk, Thomas Schildknecht of the University of Berne gave a presentation on the search for small-size debris in GEO and GTO optically. Gene Stansbery (NASA/JSC) presented a talk about meter-class autonomous telescope currently in development. Mark Ackermann from Sandia National Laboratories spoke about a blind search for micro satellites in LEO, more specifically the optical signatures and search strategies. The next talk was given by Christian Tournes of Davidson Technologies which was about the prediction of orbital debris and the hazard assessments his group is working. The final talk of the session was given by the ESA's Walter Flury which detailed the activities of Europe in the area of space debris research. ◆

Satellite Operations and Safety Workshop
22-23 October 2003, Westford, Massachusetts, USA

The second annual workshop, addressing Satellite Operations, Space Weather, Close Encounter Analysis, Collision Avoidance Techniques, Spacecraft Innovations, Orbit Determination, and Space Measurements took place at the MIT Lincoln Laboratory (MIT/LL) Haystack Observatory in Westford, Massachusetts.

October 22nd: Heather Schidge of the U. S. State Department spoke on Space Law liability related to orbital debris. Steve Hunt (MIT/LL) spoke on use of radar measurements of meteor trails to determine their velocity distribution. Bill Bouchas (MIT/LL) presented the evolution of the Millstone Hill Radar from inception to present. Frank Picher (MIT/LL) discussed the Kwajalein radar assets. Angel Borja (Satellites Mexicanas) presented a study on the feasibility of using solar radiation pressure on solar panels to assist in re-orbiting satellites.

October 23rd: Dr. Rick Abbot (MIT/LL) reviewed the geostationary encounter data for the Commercial Resource Debris Avoidance (CRDA) partner satellites and presented, in detail, the issues involved. It was claimed that all recent debris avoidance maneuvers have been combined with scheduled orbit maintenance maneuvers. Drs. Carl Toews / Eric Phelps (MIT/LL) presented a statistical analysis of close approach distances at geosynchronous orbit. Dr. J. Lee Foster (GB Tech, Inc.) / Gene Stansbery (NASA/JSC) discussed the analysis leading to the current International Space Station and Space Shuttle debris avoidance procedures and stressed the need for careful analysis to determine the operational cost and effectiveness of any debris avoidance process before it is implemented. AF Lt. Brian Poller , 3rd Space Operation Squadron, Shriver AFB, proposed a debris collision avoidance procedure. Richard Hujsak (Analytic Graphics) spoke on progress toward a Turn-Key Collision Avoidance Solution using TK Solver. In the last open talk of the workshop, AF Lt. Richard Lyon (MIT/LL) made an excellent presentation on geosynchronous orbit estimation with SSN observations and improved radiative force modeling.◆

MPLM

Continued from page 3

ples were taken from around the perforation in the bumper to identify the source of the impact damage.

An examination of the crater residue samples was performed with the Scanning Electron Microscope (SEM) & Energy Dispersive X-ray (EDX) system at JSC Building 31. The primary output product of this analysis is the EDX spectra, which can be used to match the signatures of known aerospace materials. SEM output images and EDX spectra for samples collected from the bumper perforation are shown in Figure 4. The central object in the SEM image is the wooden probe that was used to collect impactor residue. EDX analysis output revealed evidence of spacecraft paint. Currently, there are 26 impacts in the HVI database for the MPLM that is maintained at the Hypervelocity Impact Technology Facility at JSC. All impact data from the 5 MPLM missions compared well with the BUMPER predictions. ◆

MITIGATION COLUMN

International Progress in Orbital Debris Mitigation

In October 2002 after a multi-year effort, the 11 members of the Inter-Agency Space Debris Coordination Committee (IADC) adopted by consensus the IADC Space Debris Mitigation Guidelines. These guidelines, which are similar to those in the U.S. and other spacefaring nations, represent the first comprehensive and internationally accepted guidance for preventing the unnecessary creation of orbital debris and for limiting its presence in Earth orbit. The four major areas covered by the guidelines are limiting debris released during normal operations, minimizing the potential for on-orbit breakups, postmission disposal of spacecraft and orbital stages, and prevention of on-orbit collisions.

In February 2003 the IADC formally presented the space debris mitigation guidelines to the Scientific and Technical Subcommittee (STSC) of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS) at the latter's annual meeting in Vienna, Austria. At the February 2004 meeting of the STSC, discussion of the guidelines will resume with the expectation that the guidelines will be endorsed in whole or in part by the STSC and will then be forwarded to the full COPUOS for approval in June.

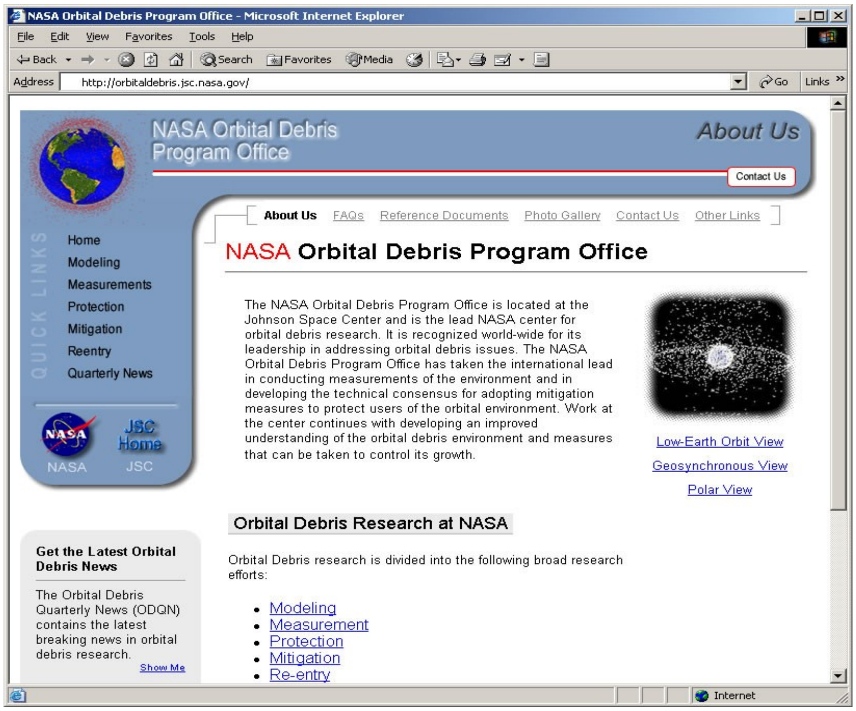
Beginning in 2005, members of the STSC are encouraged to report on their efforts to implement the IADC space debris mitigation guidelines. Meanwhile, the International Standards Organization (ISO) is drafting potential space debris mitigation standards, based primarily on the IADC space debris mitigation guidelines.

The IADC space debris mitigation guidelines can be obtained via the NASA Orbital Debris Program Office website at www.orbitaldebris.jsc.nasa.gov. ◆

INTERNATIONAL SPACE MISSIONS

October—December 2003

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2003-044A	HORIZONS 1	USA	35734	35745	0.0	1	0
2003-045A	SHENZHOU 5	CHINA	332	336	42.4	1	4
2003-045G	SZ-5 MODULE	CHINA	340	356	42.4		
2003-046A	IRS P6	INDIA	819	821	98.7	1	0
2003-047A	SOYUZ TMA 3	RUSSIA	366	374	51.6	1	0
2003-048A	DMSP 5D-3 F16	USA	842	854	98.9	0	4
2003-049A	CBERS 2	CHINA/BRAZIL	773	775	98.5	1	0
2003-049B	CHUONG XIN 1	CHINA	731	751	98.5		
2003-050A	SERVIS-1	JAPAN	984	1016	99.5	1	0
2003-051A	FSW-3 1	CHINA	195	325	63.0	1	2
2003-052A	ZHONGXING 20	CHINA	35777	35797	0.2	1	0
2003-053A	YAMAL 201	RUSSIA	EN ROUTE TO GEO			2	3
2003-053F	YAMAL 202	RUSSIA	EN ROUTE TO GEO				
2003-054A	USA 173	USA	NO ELEMS. AVAILABLE			1	1
2003-055A	GRUZOMAKET	RUSSIA	454	460	67.1	1	0
2003-056A	COSMOS 2402	RUSSIA	19018	19314	65.1	1	1
2003-056B	COSMOS 2403	RUSSIA	18963	19102	65.1		
2003-056C	COSMOS 2404	RUSSIA	18961	19104	65.1		
2003-057A	UFO 11 (USA 174)	USA	35781	35798	4.2	1	0
2003-058A	NAVSTAR 53	USA	19963	20328	55.1	2	0
2003-059A	AMOS-2	ISRAEL	EN ROUTE TO GEO			1	0
2003-060A	EXPRESS AM-22	RUSSIA	EN ROUTE TO GEO			1	1
2003-061A	DOUBLE STAR 1	CHINA/ESA	550	78955	28.2	1	0



NASA Orbital Debris Program Office

The NASA Orbital Debris Program Office is located at the Johnson Space Center and is the lead NASA center for orbital debris research. It is recognized world-wide for its leadership in addressing orbital debris issues. The NASA Orbital Debris Program Office has taken the international lead in conducting measurements of the environment and in developing the technical consensus for adopting mitigation measures to protect users of the orbital environment. Work at the center continues with developing an improved understanding of the orbital debris environment and measures that can be taken to control its growth.

Orbital Debris Research at NASA

Orbital Debris research is divided into the following broad research efforts:

- Modeling
- Measurement
- Protection
- Mitigation
- Re-entry

Get the Latest Orbital Debris News

The Orbital Debris Quarterly News (ODQN) contains the latest breaking news in orbital debris research.

Visit www.orbitaldebris.jsc.nasa.gov to see the updated NASA Orbital Debris Program Office website. For more information on updates to the website, see the article Orbital Debris Website Update on page 2 of this issue.

ORBITAL BOX SCORE

(as of 31 DEC 2003, as catalogued by US STRATEGIC COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	38	283	321
CIS	1351	2606	3957
ESA	34	305	339
INDIA	27	113	140
JAPAN	82	48	130
US	986	2795	3781
OTHER	357	32	389
TOTAL	2875	6182	9057

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 C104
Houston, Texas 77058

sara.a.portman1@jsc.nasa.gov

UPCOMING MEETING

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.

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