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INSIDE...

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The Orbital Debris Community Loses One of its Pioneers

Joseph P. Loftus, Jr., one of the most influential leaders for orbital debris research in the U.S. and the world, passed away suddenly on 4 September 2005 at the age of 75. For 25 years before his retirement from NASA in 2001, Joe, as he was universally known, was the senior proponent for orbital debris research at the Lyndon B. Johnson Space Center (JSC) and was instrumental in the establishment of the NASA Orbital Debris Program Office. He also served in leadership roles at the United Nations, the International Academy of Astronautics, the Inter-Agency Space Debris Coordination Committee, and the International Telecommunication Union on matters related to orbital debris.

Joseph P. Loftus, Jr.

Loftus completed flight training in the United States Air Force in 1957 and was serving at Wright-Patterson Air Force Base on zero-visibility landing systems in 1961 when the U.S. embarked on the Mercury man-in-space program. He was quickly assigned to work with NASA in Houston, Texas, before the Manned Spacecraft Center (later JSC) was even established. He was responsible for defining the crew accommodations and the crew control and display arrangements for the Mercury and Apollo Spacecraft. As a special task force effort, he led the design of the systems to extend the lunar landing mission stay time from 24 to 72 hours and the complementary extension of the total mission duration of the orbiting command and service modules from 9 to 12 days.

During the Space Shuttle and Space Station development programs, Loftus was responsible for nurturing the new technologies in thermal protection systems; advanced technology for bipropellant engine design and fabrication, more efficient supercritical cryogenic storage systems, higher efficiency fuel cells, large area solar cells, and advanced software developments.

In the late 1970s Joe brought the early orbital debris research work of Don Kessler and Burt Cour-Palais to the attention of senior NASA management at JSC and NASA headquarters. Although still serving in many other leadership positions, including as Assistant Director (Plans) for JSC, Loftus was known as an international spokesman for the understanding and mitigation of orbital debris for the remainder of his career at NASA. He was one of the guiding forces in the formation of the multinational Inter-Agency Space Debris Coordination Committee. He also served a leading role in the long-term study of orbital debris by the International Academy of Astronautics, in which he served for many years, including as Chairman of the Committee on International Space Policies and Plans. However, he never abandoned his engineering expertise and in the mid-1990s was the first to recognize the potential of electrodynamic tethers to remove derelict satellites from Earth orbit.

Loftus was the recipient of many awards, including the NASA Exceptional Service Medal (twice) and the NASA Distinguished Service Medal. ◆

Two NASA Spacecraft to be Retired; Debris Mitigation Plans Being Implemented

In September NASA began procedures to dispose of two old spacecraft in low Earth orbit (LEO) in accordance with the guidelines to mitigate the generation of orbital debris as called for by NASA Safety Standard (NSS) 1740.14. Both spacecraft, the Earth Radiation Budget Experiment (ERBS) and the Upper Atmosphere Research Satellite (UARS), were launched by Space Shuttles prior to NASA's adoption of an orbital debris mitigation policy. However, all older NASA missions are to comply with NSS 1740.14 disposal guidelines to the best of their abilities. Fortunately, ERBS and UARS were still capable of meeting the primary guidelines of end-of-mission passivation and reduction of orbital lifetime.

ERBS was launched by Space Shuttle Challenger in October 1984 and was inserted into an orbit near 600 km with an inclination of 57°. In 2002, when the spacecraft was then nearing its 18^{th} anniversary in space, a series of 11 maneuvers was undertaken to ensure that the spacecraft would reenter the atmos-

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Mitigation Plans

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phere within 25 years in the event of a sudden failure or its later decommissioning. This action lowered the perigee of the two-metric-ton ERBS by 60 km. The mission then continued for three more years before the program was selected for termination.

In September 2005, ERBS conducted three burns of its propulsion system with two burns lasting five hours or more. A final burn of nearly seven hours duration is planned in October, after which the spacecraft will be passivated. At the start of the maneuvers, ERBS possessed more than 80 kg of propellants. Although a degradation in its electrical power system prevented reorienting the spacecraft to conduct the most efficient altitude reduction maneuvers, from its current orbit of approximately 500 km by 550 km ERBS should fall back to Earth within 15-20 years, well within the recommended NASA, U.S. Government, and international community goal of less than 25 years.

Artist's rendering of the Earth Radiation Budget Experiment.

The larger UARS spacecraft, with a mass in excess of six metric tons, was deployed from the Space Shuttle Discovery in September 1991. Its orbit was very similar to that of ERBS with a mean altitude of slightly less than 600 km and an inclination of 57°. By September 2005 the spacecraft had naturally decayed to a mean altitude of about 550 km. From this orbit, reentry would be expected in a little more than 25 years.

As with ERBS, beginning in October UARS will conduct a series of maneuvers to achieve two objectives: (1) remove the 150 kg of residual propellants to prevent future accidental explosions and (2) reduce the orbital lifetime of the spacecraft to the greatest extent possible. These maneuvers should lower the perigee of UARS by more than 200 km, leading to a natural reentry in less than five years.

All the ERBS and UARS maneuvers are closely coordinated with the U.S. Space Surveillance Network to ensure that each maneuver would not result in the accidental collision of the spacecraft with any other cataloged resident space object. Such a collision could inadvertently create a cloud of

Artist's rendering of the Upper Atmosphere Research Satellite.

new orbital debris. During their remaining time in space, the orbits of both spacecraft will be evaluated daily for potential close approaches to Space Shuttles and the International Space Station and its logistics vehicles. Collision avoidance maneuvers would be undertaken in the extremely unlikely event that ERBS or UARS posed a significant risk to human space flight operations.

Despite the fact that ERBS and UARS are 21 and 14 years old, respectively, to date spacecraft operators at NASA's Goddard Space Flight Center, in cooperation with the U.S. Space Surveillance Network, have been able to implement retirement plans for both spacecraft safely and to meet key orbital debris mitigation objectives. ◆

PROJECT REVIEWS

Real-time Survey and Follow-up Observations of GEO Debris

P. SEITZER, K. ABERCROMBY, E. BARKER, H. RODRIGUEZ, E. STANSBERY, M. MATNEY, M. HORSTMAN, & L. FOSTER

For the past several years the University of Michigan's 0.6/0.9-m Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory in Chile has been used extensively for an optical survey of debris at geosynchronous orbit (GEO). This project is called MODEST (for **M**ichigan **O**rbital **De**bris **S**urvey **T**elescope), and to date has produced purely statistical observations of the GEO debris environment as reported in previous articles (see *Orbital Debris Quarterly News*, 9-3, p. 5 and 8-1, p. 8).

During March 2005 the telescope mechanical systems were completely modernized. New drives, encoders, and full computer control of the telescope and dome were installed. The telescope can now track at any commanded rate up to 1.25 deg/sec in both right ascension and declination. This upgrade was funded by the NASA Orbital Debris Program Office and the work was done by DFM Engineering of Longmont, Colorado.

During three nights in July 2005 MODEST was used for the first time in a real-time survey and follow-up mode to observe GEO debris. The first two hours of a night's survey data was reduced on-line at the telescope, and the positions and times of all detected objects sent to the NASA Orbital Debris Program Office in Houston, Texas. Within 45 minutes, preliminary orbits were calculated and predicted positions as a function of time for the next four hours were forwarded to the telescope. Upon receipt of these predictions survey mode was stopped and MODEST went into a follow-up mode to reacquire the initial detections. The goal is to produce much better orbits based on arcs of several hours, not just the initial five minutes. No existing datasets or catalogs were used for these orbits or predictions – only the data that was obtained at the telescope that night.

For these initial tests the telescope led the predicted position of each object in the sense that the object would drift across the field-of-view five minutes after the telescope set on the predicted position, and would continue to observe the field for five minutes after the object was predicted to have left the field-of-view. Thus we are largely insensitive to along-track errors in the predictions.

A preliminary reduction showed that we were successful in recovering at least 75% of the initial objects found. We strove to observe each object for two follow-up observations, spanning (on average) three hours of time from the first detection to last follow-up.

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GEO Debris

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Figure 1 shows our first follow-up sequence (8 detections) on a R=16th magnitude object at a Galactic latitude of 12°. Figure 2 shows a zoomed region centered on each detection.

Future work will refine this technique and concentrate on the orbits of faint, presumably high A/M, GEO debris to examine their orbits and how they change with time. ◆

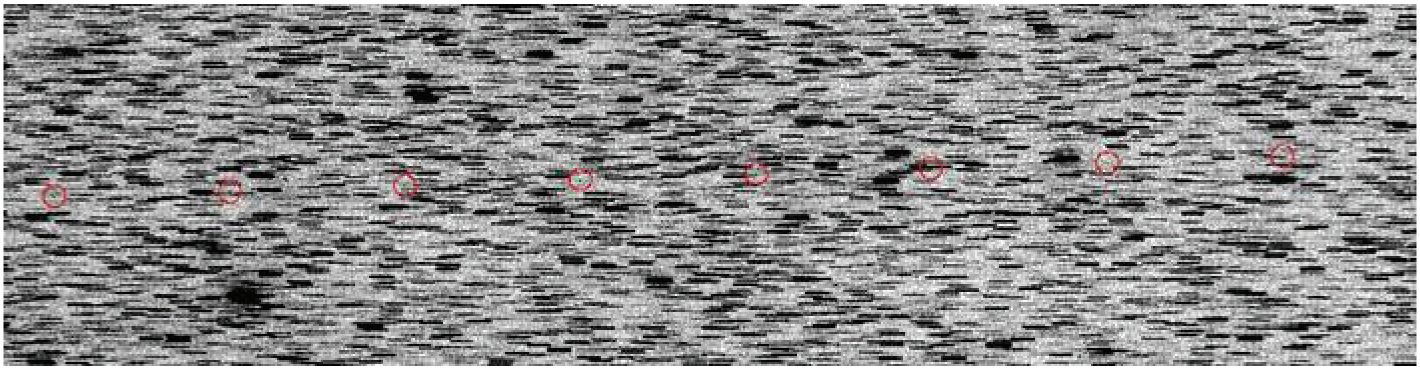

Figure 1. Sum of eight sequential follow-up observations of a R=16th magnitude object. The streaks are all background stars, and the red circles are centered on the detections of the object as it crosses the field-of-view (1.3° from left to right). These observations were obtained 2.3 hours after the initial detection, and were at the low Galactic latitude of 12°. A second set of follow-up observations were obtained 1.1 hours later, for a total time span of 3.4 hours of observations.

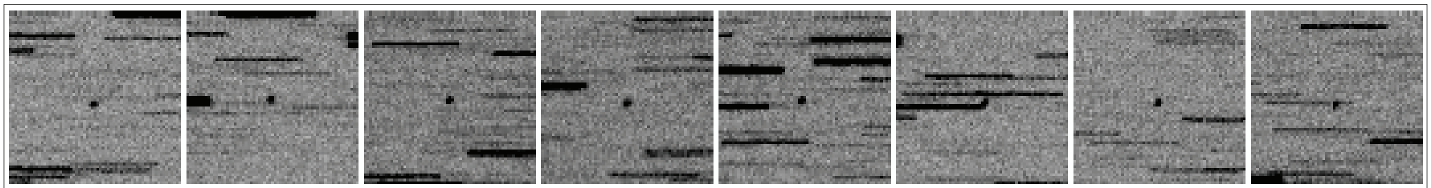

Figure 2. To show each detection better we present a zoomed region in the individual images centered on each detection. Each box is 74 x 74 arc-seconds in size.

Reentry Survivability Analysis of the Terra Satellite

R. SMITH, R. DELAUNE, & J. DOBARCO-OTERO

The Terra spacecraft (1999-068A, U.S. Satellite Number 25994) was launched on 18 December 1999 and maneuvered to an altitude of 705 km with an orbital inclination of 98.2°. Terra is part of the NASA Earth Observing System (EOS) project to study the health of the Earth by monitoring the atmosphere, oceans, and continents with unprecedented measurement accuracy. At the end of its mission, the altitude of the spacecraft will be lowered to reduce its remaining time in Earth orbit to less than 25 years, in accordance with NASA, U.S., and international orbital debris mitigation guidelines.

Engineers from the NASA Orbital Debris Program Office were tasked by the Earth Science Mission Operations Project at NASA Goddard Space Flight Center to calculate the amount of debris from the Terra spacecraft which would survive an uncontrolled reentry into the Earth's atmosphere. The reentry survivability analysis was performed with the NASA Object Reentry Survival Analysis Tool (ORSAT), version 5.8. The analysis broke the 4427 kg satellite into 280 different objects.

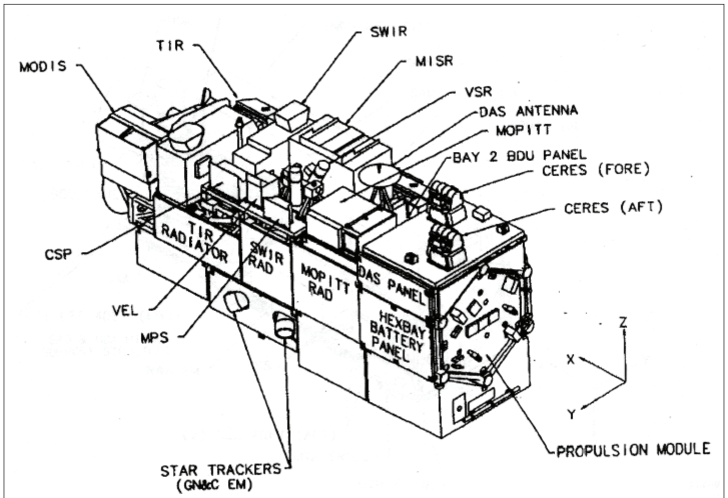

Figure 1. Nadir view of Terra satellite in stowed configuration.

This analysis assumed natural orbital decay for the spacecraft to an altitude of 122 km. The parent body (seen in Figure 1) was modeled with a length of 4.0 m, a width of 2.6 m, and a height of 1.8 m. A standard break-up altitude of 78 km was considered, at which point all the primary spacecraft components were exposed to reentry heating. In many cases, fragmentation of sub-components occurred. Approximately 90% of the total mass was analyzed and another 10% was accounted for but not modeled.

The fragments were modeled as tumbling spheres, cylinders, boxes or flat plates. The 1976 U.S. Standard Atmosphere model was used for all components. A 1-D thermal math model was used to model the heat conduction in the fragments. An object is assumed to demise when the absorbed heat (net heat rate flux integrated over time multiplied by its surface area) is greater than or equal to the heat of ablation of the object. The initial temperature and the oxidation efficiency of all components were assumed to be 300° K and 0.5, respec-

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Progress in Space Tether Sever Modeling

P. KRISKO

The usage of space tethers for enhanced orbital decay via electrodynamic drag has intrigued space users for many years and is under serious investigation by a number of groups throughout the world. The idea is appealing: fitting large satellites with low cost, expendable tether/probe packages to be deployed at satellite end-of-life. Through electrodynamic coupling with the Earth's magnetic field, the satellite-tether system experiences an additional retarding force, resulting in more rapid orbital decay. This technique can greatly decrease the time in orbit of large, spent satellites.

The implementation of a tether system carries with it a host of considerations: system-wide dynamic stability, tether and end-mass impedances, tether deployment mechanics -- all critical to the success of such missions. Of chief concern at the NASA Orbital Debris Program Office is, of course, the care which must be taken on the part of innovators to consider the artificial debris and natural meteoroid environment in their tether design criteria. The extremely long (on the order of thousands of meters) and narrow (on the order of millimeters) tether designs are particularly susceptible to severing by minuscule objects traveling at high velocity through the environment.

The NASA Orbital Debris Program Office is addressing the issue of helping designers make space debris-resistant tethers by two means. First, the development of a major upgrade to the Debris Assessment Software (DAS) package is nearing completion. The tether survival module in DAS 2.0 provides a very simple calculation of the survival probability of a single line tether in circular orbits in low Earth orbit (LEO). Second, work is underway through analysis and testing of ever-advancing techniques to determine severing probabilities of various tether designs. The most recent example is the Inter-Agency Space Debris Coordination Committee (IADC) Action Item 19.1, 'The risks and benefits of using electrodynamic tethers in space.' This task entails a comparative test of survival probabilities of electrodynamic tethers (EDTs) of different simple designs at different altitudes and inclinations during electrodynamic orbital decay.

Figure 1. Pre-launched TiPS end-masses. Spring-powered mechanism separates the end-masses at tether deployment. The masses were affectionately dubbed Ralph and Norton for the two principal characters in the classic TV series "The Honeymooners" (courtesy, Dr. Shannon Coffey, NRL).

Some of the results of this task are presented in the International Astronautical Congress (IAC) paper, IAC-05-B6.3.01[1] (see the abstract in this issue).

The NASA results compare well to the values and trends shown in studies conducted by the Italian and Japanese space agencies, ASI and JAXA, respectively. The single-line tether of 1-mm diameter or less is shown to be unlikely to survive a de-orbit mission. A double-line configuration, in which the strands remain separated by distances much greater than the strand diameters, is much more likely to survive. Also, as expected, the double-line configurations with the larger number of loops (*i.e.*, knots) have the highest survival probabilities.

Given the maturity of the study it is appropriate to test the methodology on a real tether system. The survivability calculation distinguishes between EDT and non-EDT systems simply by the time spent within altitude regions. So an acceptable test is the long-lived non-conducting Tether Physics and Survivability (TiPS) experiment, the only tether system in orbit today. This tether connects two similar end-masses, an upper mass of 37.7 kg and a lower mass of 10.8 kg (see Figure 1).

This project, sponsored by the Naval Research Laboratory, was deployed on 20 June 1996 to a near-circular orbit of 1024 km x 1019 km and 63.4° inclination and is still intact as of this writing. The tether itself is 4 km in length and ~2 mm in diameter. However, the survival probability calculation, is complicated by the tether design. Though at first glance a tether diameter of ~2 mm seems appropriate for the survival probability calculation, this leads to a survival probability of

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Terra Satellite

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tively.

A total of 559 kg of mass was assessed by the analysis to survive reentry and produce a debris casualty area of 59 m^2 and a footprint length of 848 km. A plot of demise altitude versus downrange from breakup for all Terra objects can be seen in Figure 2. Most objects are shown to demise above 50 km in altitude. Of those that survive, the objects with the lowest ballistic coefficient will comprise the heel of the footprint and the objects with the highest ballistic coefficient will comprise the toe of the footprint. A number of these objects impact with a kinetic energy below an established casualty threshold limit of 15 Joules. For the purposes of calculating risk, the casualty area contributed by these objects can be ignored. The resulting total debris casualty area for objects that impact the ground with an impact kinetic energy above the 15-J casualty limit is 48.5 m^2. ◆

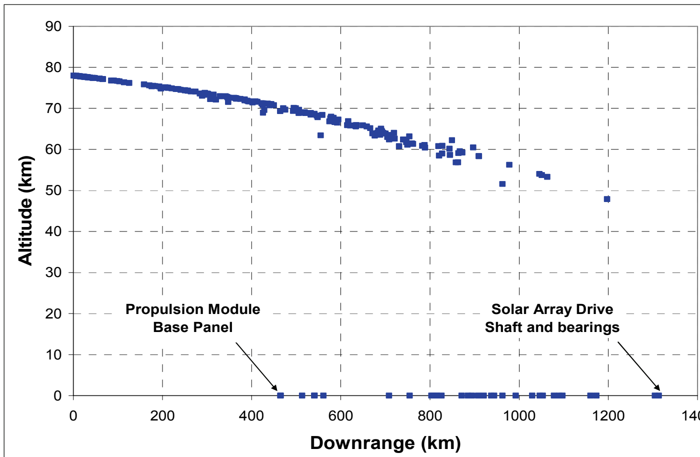

Figure 2. Demise altitude vs. downrange for analyzed Terra objects.

Space Tether

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about 1% by the end of 1999, assuming an ORDEM2000 debris flux coupled with a Grün meteoroid flux model.

However, the TiPS tether is not a monolithic single-line structure. The tether tension-bearing material is Spectra-1000 polyethylene fiber in multiple braided strands, the same material used for the SEDS-1 and SEDS-2 missions. In the case of TiPS, four ropes of acrylic yarn are inserted into a twelve-strand Spectra-1000 structure to enhance the diameter of the tether, thus improving optical tracking.[2] The yarn invariably separates the Spectra-1000 strands. Assuming that the Spectra-1000 fiber structure is identical to that of the SEDS-1 and SEDS-2 tethers, each strand is about 0.094 mm in diameter. If these strands are considered to be separated by enough distance along the surface of the yarn to be modeled as twelve distinct tethers, a survivability probability of about 99.9% is achieved through 2005 (Table 1). As expected, the survival rate is shown to decrease as the assumed number of separated strands decreases.

Tether Representation	Effective Strand Diameter	Survivability Probability Percentage through 2005
Single-line (yarn+Spectra-1000)	2 mm	0%
Double-line opposing braids separated, 6 strands per opposing braid, overlap not considered	0.563 mm (6 SEDS strands together)	0%
Quadruple-line opposing braids separated, 3 strands per opposing braid, overlap not considered	0.281 mm (3 SEDS strands together)	36%
Sextuple-line opposing braids separated, 2 strands per opposing braid, overlap not considered	0.188 mm (2 SEDS strands together)	89%
Dodecatuple-line opposing braids separated, 1 strand per opposing braid, overlap not considered	0.0938 mm (all strands separated)	99.9%

Table 1. TiPS survival for assumptions of strand separation and diameter.

1. Pardini, C., T. Hanada, P. Krisko, L. Anselmo, and H. Hirayama, *Are De-orbiting Missions Possible using Electrodynamic Tethers? Task Review from the Space Debris Perspective*, IAC-05-B6.3.01, 56th International Astronautical Congress, Fukuoka, Japan, 17-21 October 2005.

2. Dr. Shannon Coffey, Naval Research Laboratory, private communication, 2005. ◆

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

Air Force Maui Optical and Supercomputing (AMOS) Technical Conference 5-9 September 2005, Wailea, Maui, Hawaii, USA

Applying Space Weathering Models to Common Spacecraft Materials to Predict Spectral Signatures

K. ABERCROMBY, M. GUYOTE, J. OKADA, & E. BARKER

Since May 2001, spectral observations have been collected using the Spica Spectrometer on the AMOS 1.6-m telescope. These observations, when compared to laboratory spectra of similar material, are used to determine material identification, object classification, and possibly spacecraft health. From the first set of observations, an increase in reflectance as wavelength increases was noted. The increase, or reddening as it is termed in the astronomy community, appears to be material dependent and independent of orbit or age. Since the reddening is not seen upon returning to the Earth environment, the root cause of the reddening is believed to be a space environment effect. One theory is being explored currently which could explain the reddening. The theory is that oxygen vacates the surface leaving avenues for particulate contamination to attach to the space object's surface. This contamination changes the reflectance properties by altering the refractive indices of the surface material. This effect was modeled by B. Hapke for asteroids and the authors have adapted it for human-made space objects. Particle Swarm theory has been used to obtain more accurate information about the variables. This model will be explored and results shown in this paper. ◆

An Optical Survey for GEO Debris in High Inclination Orbits

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

A standard picture of the GEO debris population is starting to emerge from recent optical observations. There are two families of debris: bright objects on circular orbits with inclinations ranging up to 17 degrees, and a fainter population which appear to be on more eccentric orbits. Models suggest that observed angular motions of the fainter debris can be explained if these are high area-to-mass ratio (A/M) objects that suffer significant perturbations from solar radiation pressure. One prediction is that such objects will have orbital inclinations much greater than that expected on the basis of gravitational perturbations alone (see Liou & Weaver, ODQN Vol 8, page 6). We report the results of an optical survey designed to detect faint objects in high inclination orbits at GEO. Very few objects have been detected that are outside the spatial range observed for bright debris on circular orbits. These observations were taken as part of the NASA/Michigan survey for GEO debris with MODEST (the Michigan Orbital Debris Survey Telescope).

This work has been supported by the NASA Orbital Debris Program Office at Johnson Space Center, Houston, Texas. ◆

The LEO Environment as Determined by the LMT between 1998 and 2002

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

The National Aeronautics and Space Administration (NASA) operated the 3.0 m Liquid Mirror Telescope (LMT) at Cloudcroft, New Mexico between October 1998 and December 2002. The purpose of this presentation is to summarize datasets of detected correlated (CTs) and uncorrelated (UCTs) targets which have been presented in a series of yearly reports. Although the LMT in its zenith staring mode could monitor the orbital debris environment at altitudes up to ~40,000 km, this summary analysis will be restricted to the low Earth orbit (LEO) environment below 2100 km. The LMT dataset consists of over four years of observations totaling almost 1100 hours with 805 of those hours covering the LEO environment. Observational and reduction techniques have changed and improved over the period of the LMT performance and analysis. The observed magnitudes for the LMT database have not been corrected for solar phase angle or solar distance variations. Subsequent analysis has indicated that the detections at altitudes below 600 km are contaminated by meteor detections. A summary dataset will be presented that has uniform data corrections for observed range, phase angle, solar distance and meteor discrimination. 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. The complete LEO dataset for the LMT will be presented in terms of distributions such as inclination, size, magnitude, and flux. Seasonal and/or trend variations of the observed fluxes for a given size range will be compared to the concurrent radar fluxes and those fluxes predicted by the ORDEM2000 model. ◆

56th International Astronautical Congress
17-21 October 2005, Fukuoka, Japan

The Historical Effectiveness of Space Debris Mitigation Measures

N. JOHNSON

Nearly a quarter century has passed since a new emphasis on space debris mitigation began, following two, nearly simultaneous seminal events: the publication of “Space Debris: An AIAA Position Paper” and the realization that numerous, intense Delta second stage fragmentations had been induced by residual propellants. Since that time the major space-faring nations of the world have adopted a wide range of debris mitigation practices which have arguably reduced the rate of growth of the debris population in Earth orbit. A study has been undertaken to quantify the likely historical effects of these debris mitigation measures on the current satellite population based upon vehicle-specific launch rates. The mitigation measures addressed in the study include those associated with mission-related debris, satellite breakups, and the disposal of satellites. Mitigation measures have been classified according to their near-term and far-term consequences and to the degree of their implementation by the international aerospace community. The history of space debris mitigation measure application can be used in conjunction with long-term satellite evolutionary models to provide a more realistic expectation of the future environment. ◆

Are De-Orbiting Missions Possible Using Electrodynamic Tethers? Task Review from the Space Debris Perspective

C. PARDINI, T. HANADA, P. KRISKO, L. ANSELMO, & H. HIRAYAMA

Over 9000 satellites and other trackable objects are currently in orbit around the Earth, along with many smaller particles. As the low Earth orbit is not a limitless resource, some sort of debris mitigation measures are needed to solve the problem of unusable satellites and spent upper stages. De-orbiting devices based on the use of conducting tethers have been recently proposed as innovative solutions to mitigate the growth of orbital debris. However, electrodynamic tethers introduce unusual problems when viewed from the space debris perspective. In particular, because of their small diameter, tethers of normal design may have a high probability of being severed by impacts with relatively small meteoroids and orbital debris. This paper compares the results obtained at ISTI/CNR, the Kyushu University and NASA JSC concerning the vulnerability to debris impacts on a specific conducting tether able to de-orbit spacecraft in inclinations up to 75° and initial altitude less than 1400 km. A double line tether design has been analysed, in addition to the single wire solution, in order to reduce the tether vulnerability. The results confirm that the survivability concern is fully justified for a single line tether and no de-orbit mission, from the altitudes and inclinations considered, is possible if the tether diameter is smaller than a few millimetres. The survival probability is shown to grow for a double line configuration with a sufficiently high number of knots and loops. The results are strongly dependent on the environment model adopted and the MASTER-2001 orbital debris and meteoroids fluxes result in survival probabilities appreciably higher than those of ORDEM2000 coupled with the Grün meteoroids model. ◆

A Statistical Analysis on the Future Debris Environment

J.-C. LIOU

Modeling the future orbital debris environment is a difficult task. In addition to making reasonable assumptions on key parameters such as future launch traffic and solar activity, one needs to rely on a Monte Carlo process to evaluate future on-orbit explosions and collisions. Even with the same input parameters, the outcome of the projected debris populations could vary significantly from one Monte Carlo run to the next. A common approach to assess the growth of future debris populations is to take the average of multiple Monte Carlo runs. The number of available runs is typically between 10 and 30, depending on the speed of the simulation program and computer. However, the "mean growth" from a limited number of Monte Carlo simulations may not reveal the complete picture of what the future environment might be.

In this paper, we analyze a total of 200 Monte Carlo simulations of the future debris environment using the NASA long-term orbital debris evolutionary model LEGEND. The input parameters are identical for all the simulations. We examine the projected debris populations in terms of the mean, median, standard deviation, and uncertainty-in-the-mean. The number of runs needed to derive a stable mean population is discussed. We also analyze the distribution of the debris populations at the end of the 100-year projection. Good scenarios are compared with bad scenarios. Triggers for the worst case scenarios are identified and discussed. ◆

A Minimalist Empirical Orbital Debris/Meteoroid Hazard Model for the Space Shuttle

M. MATNEY & E. CHRISTIANSEN

Impact hazards due to orbital debris and meteoroids for the Space Shuttle and other spacecraft have been studied for many years. To date, many sophisticated environment models (such as NASA's ORDEM2000) and collision hazard models (such as NASA's BUMPER) have been developed to accurately assess the overall risk to orbiting vehicles. However, as models get progressively more complex, it is sometimes useful to assess the results at a "back-of-the-envelope" scale. This technique is necessary for those outside a narrow technical specialty to understand and critically examine the assumptions and computations of the models. In an effort to address this challenge, we present in this paper an empirical model of the Space Shuttle orbital debris/meteoroid hazard based on empirical data and a minimum of model assumptions. Data from non-critical damage on returned Space Shuttle surfaces (radiators, windows, etc.) is used to quantify the probability of critical damage in a simple calculation of the relative probability that the same impact could have occurred on certain other areas of the Space Shuttle where the impact would have caused critical damage. These empirical results will then be compared with the results of the more sophisticated models. ◆

The Object Reentry Survival Analysis Tool (ORSAT) – Version 6.0 and its Application to Spacecraft Entry

J. DOBARCO-OTERO, R. SMITH, K. BLEDSOE, R. DELAUNE, W. ROCHELLE, & N. JOHNSON

NASA Safety Standard (NSS) 1740.14 requires that each NASA reentering spacecraft and launch vehicle upper stage be assessed as a human casualty risk to the world's population upon impact of all surviving debris to the Earth. As a first approach, the risk is usually evaluated with the slightly conservative NASA Debris Assessment Software (DAS). However, if the DAS assessment of the risk does not meet the NSS guideline of 1:10,000, the higher-fidelity Object Reentry Analysis Survival Tool (ORSAT) might be required. Various versions of this code have been used in the past 10 years to perform over 20 different spacecraft reentry analyses. The object of this paper is to discuss the new features of the latest version – ORSAT 6.0. These features include replacement of the trajectory model and improvement of the gravitational model; incorporation of the GRAM atmosphere and a user-defined atmosphere model; 2-D heating rate and temperature variation around spheres, cylinders, cones, and flat plates; drag coefficients for cones; and general program improvements. Additional improvements also include a Graphical User Interface (GUI), gas cap radiation at high entry velocities, recession for non-metallic insulation materials, structural failure of solar array hinges, tank bursting, Unix/Linux plotting scripts, an expanded materials property database, and trajectory mapping on a world map. Sample results are presented for reentry of selected spacecraft using these updated features in ORSAT. ◆

Orbital Parameters for Objects Observed by the Michigan Orbital DEbris Survey Telescope (MODEST)

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

An optical survey for orbital debris at geosynchronous orbit has been conducted with the University of Michigan's 0.6/0.9-m Schmidt telescope at Cerro Tololo Inter-American Observatory in Chile. The project termed MODEST (Michigan Orbital DEbris Survey Telescope) has been collecting data since 2002. Included in this paper are 66 days of observation from calendar years 2002, 2003, 2004, 2005, which yield 100 different field locations. Combining all three years of data, MODEST observed 1014 correlated targets (unique per night) and 401 uncorrelated targets (unique per night). This paper will discuss the orbital parameters determined for correlated and uncorrelated objects based on a circular orbit assumption. The average inclination error for all correlated targets is 0.02° with a standard deviation of 0.78. The average error for right accession in ascending node (RAAN) is 0.35° but with a standard deviation of 60. However, the average error for RAAN for objects with inclinations greater than one degree increases slightly to 1.6° while the standard deviation decreases to 17.5. In addition to the orbital parameters, calculations of visual and absolute magnitude have been made. The correlated targets absolute magnitude peak is near 11 and the uncorrelated target absolute magnitude peak is near 16-17. The falloff in sensitivity of the telescope keeps the uncorrelated absolute magnitude peak from being known completely. Depending on the pointing of the telescope, the possible orbit planes in which an object can be determined. The coverage is nearing completion but is still missing one segment starting at 5° inclination through 30° within the RAAN ranges of 250 – 300°. A description of the orbits which were calculated within the possible orbital planes will be addressed. ◆

A Statistical Size Estimation Model for Haystack and HAX Radar Detections

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

The Long Range Imaging Radar (LRIR), also known as Haystack, and the Haystack Auxiliary (HAX) radar have been observing the orbital debris environment for more than a decade. One of the key radar measurements is the radar cross section (RCS) of each object detected. The conversion from RCS to target size is a complicated inverse problem especially when the size of the object is comparable to the wavelength of incident radiation, *i.e.*, in the so-called resonant region of radiative scattering. The basis of the size estimation model (SEM) NASA developed in 1991 was a static RCS measurement experiment using a set of hypervelocity impact fragments. As one of the end products of the experiment, SEM is a simple model for one-to-one RCS-to-size conversion based on the orientation- and shape-averaged RCS of the hypervelocity impact fragments as a function of size.

In this paper, we propose a Bayesian approach to improve the original NASA SEM. It takes into account the distribution of an object's RCS with shape, composition, structure, and orientation for a given size. A given RCS does not correspond to a unique size. The statistical inference of the size distribution is based on the posterior distributions obtained from the Bayes' rule. One benefit associated with this iterative statistical approach is that the uncertainty analysis becomes easy and straightforward. This new approach has been applied to recent Haystack and HAX data. Results of the Bayesian inference and comparisons with the original SEM are included in the paper. ◆

Dust in Planetary Systems
26-30 September 2005, Kauai, Hawaii, USA

Adventures in Gravitational Focusing

M. MATNEY

The forces of gravity near a planet can have a profound effect on the flux, speed, and directionality of meteoroids in space. This gravitational focusing effect selectively intensifies low-velocity meteoroid fluxes relative to high-velocity ones. This effect can lead to biases when using fluxes measured within a planet's gravitational field to understand the meteoroid sources away from the planet in interplanetary space. However, this effect can also be used creatively to extend and enhance the capability of orbiting sensors. In this paper, I review the Liouville method for computing gravitational focusing originally outlined in Matney, 2002 [1]. Then, I present examples of how planetary gravity affects meteoroid fluxes on spacecraft. I conclude with ideas and examples on how spacecraft experiments can be designed to use a planet's gravity as a giant "lens" to aid in the detection and identification of meteoroid sources.

1. Matney, M.J. *Dust in the Solar System and Other Planetary Systems*, COSPAR Colloquia Series Vol. 15, 2002, p. 359-362.◆

Characterizing the Near-Earth Cosmic Dust and Orbital Debris Environment with LAD-C

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

Introduction: A 10 m^2 aerogel and acoustic sensor system is being developed by the US Naval Research Laboratory (NRL) with main collaboration from NASA Jet Propulsion Laboratory and the NASA Orbital Debris Program Office at Johnson Space Center. This Large Area Debris Collector (LAD-C) is tentatively scheduled to be deployed by the US Department of Defense (DoD) Space Test Program (STP) on the International Space Station (ISS) in 2007. The system will be retrieved after one year. In addition to cosmic dust and orbital debris sample return, the acoustic sensors will measure important impact characteristics for potential orbit determination of the collected samples. The LAD-C science return will benefit orbital debris, cosmic dust, and satellite safety communities. This paper outlines the need for a large-area cosmic dust and orbital debris *in situ* experiment such as LAD-C, and the expected dust/debris impacts on LAD-C during the mission.

Background: Cosmic dust particles, or micrometeoroids, are known to exist throughout the Solar System. The main sources of micrometer-to-centimeter sized dust in the inner Solar System are asteroids and comets (both long-period and short-period). The Earth's accretion rate of cosmic dust is estimated to be about 15,000 to 40,000 tons per year[1,2]. In addition to cosmic dust, man-made orbital debris, from micrometer-sized solid rocket motor exhaust and satellite breakup fragments to meter-sized retired spacecraft and rocket bodies, also occupy the near-Earth space from about 100 km altitude up to the geosynchronous orbit region[3].

Justification: It is a well-known fact that meteoroid and orbital debris impacts represent a threat to space instruments, vehicles, and extravehicular activities. On average, two Space Shuttle windows are replaced per mission due to damage caused by meteoroid and orbital debris impacts. Of particular significance are particles about 50 µm and larger. Particles smaller than 50 µm are generally too small to be of concern to satellite operations. To have reliable impact risk assessments for critical space assets, a well-defined cosmic dust/orbital debris environment is needed.

The near-Earth cosmic dust flux does not vary significantly over time. On the other hand, the orbital debris populations in the 50 µm to 1 mm size regime are highly dynamic both in time and in altitude. However, there is a lack of well-designed, large surface area *in situ* measurements to better characterize the cosmic dust environment and to monitor the fast-changing small orbital debris populations since the return of the Long Duration Exposure Facility (LDEF) in 1990. There is a need for an updated mission.

Analyzing the chemical composition of the collected cosmic dust can provide clues to the origin and formation of the Solar System. The information also leads to a better understanding of the on-going physical processes (collisions, etc.) that their parents are going through. Many cosmic dust particles have been collected from the stratosphere and analyzed for their compositions[4]. However, a reliable dynamical link has not been established for any collected sample. The combined LAD-C acoustic sensors[5] and aerogel collectors[6] are designed to measure impact parameters (impact time, location, speed, direction) for large particles. With the information, the orbits of some of the collected samples can be determined for possible source identification.

What to expect: The expected number of cosmic dust and orbital debris impacts on LAD-C depends on the location of the system on ISS and the orientation of the detection surface. Both the location and orientation are limited by engineering constraints and the requirement to avoid significant ISS waste contamination. To maximize the science return for cosmic dust and orbital debris, careful planning is needed. Preliminary analysis indicates that a starboard/port-facing orientation will yield the most debris impacts while maintaining a high-level of cosmic dust impacts. In addition, a significant portion of orbital debris impacts on a starboard/port-facing surface will have impact speeds less than 7 km/sec, where the impact characteristics are better understood and the tracks embedded in aerogel are better preserved.

1. Grün et al. (1985) Icarus, 62, 244-272.

2. Love S. G. and Brownlee D.E. (1993) Science, 262, 550-553.

3. Technical Report on Space Debris (1999), Scientific and Technical Subcommittee of the United Nations, United Nations Publication No. E.99.I.17.

4. Analysis of Interplanetary Dust (1994), AIP Conference Proceedings 310 (Eds. Zolensky et al).

5. Corsaro, R. et al. (2004) NASA Orbital Debris Quarterly News, Vol 8, Issue 3, 6-7.

6. Tsou, P. et al., (2003) JGR, 108, 10.1029. ◆

INTERNATIONAL SPACE MISSIONS

July—September 2005

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2005-024A	SJ-7	CHINA	555	573	97.6	1	5
2005-025A	ASTRO E2	JAPAN	562	573	31.4	1	0
2005-026A	STS 114	USA	313	350	51.6	0	0
2005-027A	FSW-3 4	CHINA	161	331	63.0	1	7
2005-028A	IPSTAR 1	THAILAND	35782	35795	0.0	1	0
2005-029A	MRO	USA	INTERPLANETARY			0	0
2005-030A	GALAXY 14	USA	35782	35791	0.0	1	0
2005-031A	OICETS	JAPAN	596	613	97.8	1	7
2005-031B	INDEX	JAPAN	601	650	97.8		
2005-032A	MONITOR-E	RUSSIA	522	545	97.6	1	0
2005-033A	FSW-3 5	CHINA	191	259	63.0	1	2
2005-034A	COSMOS 2415	RUSSIA	202	270	64.9	1	0
2005-035A	PROGRESS-M 54	RUSSIA	347	350	51.6	1	0
2005-036A	ANIK F1-R	CANADA	35769	35800	0.1	1	1
2005-037A	STP-R1 (USA 185)	USA	294	319	96.3	1	1
2005-038A	NAVSTAR 57 (USA 183)	USA	20006	20187	55	2	0

ORBITAL BOX SCORE

(as of 05 OCT 2005, as cataloged by US SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	51	312	363
CIS	1358	2692	4050
ESA	34	32	66
FRANCE	42	295	337
INDIA	30	113	143
JAPAN	88	57	145
US	1010	2959	3969
OTHER	339	20	359
TOTAL	2952	6480	9432

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MEETING REPORT

Air Force Maui Optical and Supercomputing (AMOS) Technical Conference
5-9 September 2005, Wailea, Maui, Hawaii, USA

The 2005 Air Force Maui Optical and Supercomputing (AMOS) technical conference occurred 5-9 September 2005 in Wailea, Maui. The general topics discussed at the conference were open sessions on: imaging, non-resolved object characterization, orbital debris, metrics, instrumentation, astronomy, wide field survey systems, space weather, lasers, high performance super computing, adaptive optics, and a poster session with various topics. Below is a discussion of the orbital debris session.

Timothy Payne delivered a paper regarding a confirmation of an unintentional on-orbit collision which occurred on 17 January 2005 between a piece of debris from a Chinese rocket body and an old U.S. rocket body. The collision occurred between objects in high inclination, retrograde orbits. Edwin Barker from NASA gave a talk on the Liquid Mirror Telescope (LMT) observations from 1998-2002 and the low Earth orbit (LEO) environment determined from the observations. The LMT dataset has approximately 1100 hours of data. Patrick Seitzer presented findings on the University of Michigan/JSC NASA MODEST project which is an optical survey of geosynchronous orbit (GEO) space. This talk was aimed specifically at finding objects in high inclination orbits. Thomas Schildknect discussed a new population of objects found by the ESA telescope at Tenerife. These objects have variable eccentricities as a by-product of their high area-to-mass ratio. Follow-up measurements have been conducted. ◆

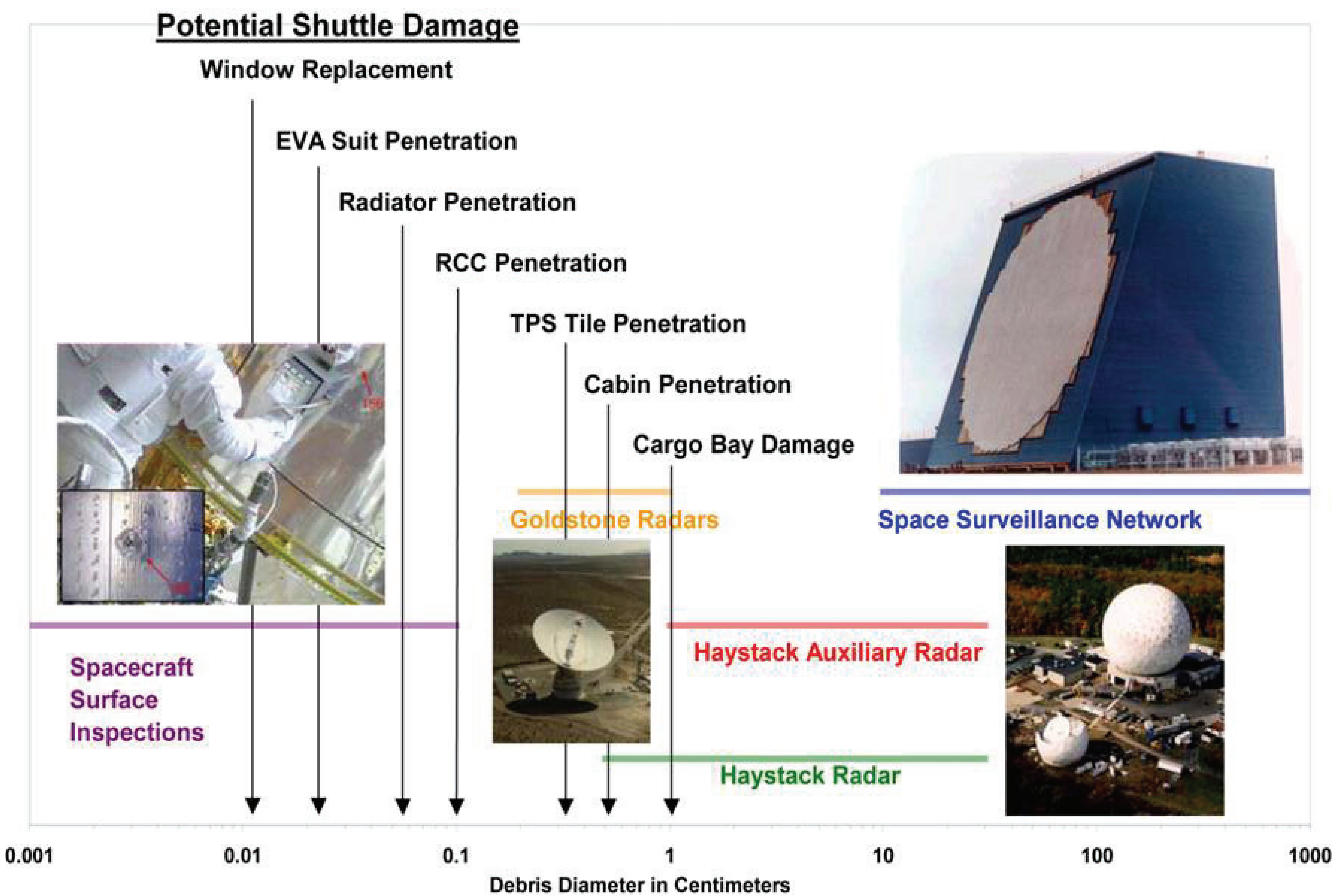
UPCOMING MEETINGS

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

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

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

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



A wide variety of ground-based sensors and spacecraft surface inspections are required to assess the full spectrum of orbital debris sizes. Debris as small as a few tenths of a millimeter can cause replacement of a Space Shuttle window or penetrate an astronaut's suit during a spacewalk.