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NEWS

PAM-D Debris Falls in Saudi Arabia

After nearly eight years in orbit, a PAM-D (Payload Assist Module - Delta) upper stage reentered on 12 January 2001 with one main fragment being recovered in Saudi Arabia. The stage (US Satellite Number 22659, International Designator 1993-032C) along with a GPS spacecraft (USA-91) was launched 13 May 1993 and left in an orbit of 180 km by 20,340 km with an inclination of 34.9 degrees. The heart of the PAM-D is a STAR-48B solid rocket motor (SRM) manufactured by Thiokol Corporation. After burn-out the STAR-48B has a mass of about 130 kg, a length of 2.0 m, and a diameter of 1.2 m.

The stage had been undergoing rapid catastrophic orbital decay since the first of the year, dropping from an orbit of 145 km by 800 km during the last week. The evening (~1900 local time) reentry over the sparsely populated desert was observed, and one large fragment was found about 240 km from the capital of Riyadh. The object, about 70 kg in mass, was the main titanium casing of the STAR-48B, although most of the phenolic nozzle had broken off or burned away. A Boeing part number was clearly visible on the casing, further substantiating the identification.

This was the second known Delta stage to partially survive reentry in less than a year. On 27 April 2000 a Delta 2 second stage (US Satellite Number 23834, International Designator 1996-019B), also from a GPS mission, reentered the atmosphere over the Atlantic Ocean. Three objects were recovered in South Africa after the event: a stainless steel propellant tank (~260 kg), a titanium pressurant sphere (33 kg), and a tapered cylinder (30 kg) which served as part of the main engine nozzle assembly. A propellant tank and pressurant sphere were found in very similar condition after the reentry of a Delta 2 second stage over Texas in January 1997 (Orbital Debris Quarterly News, Apr-Jun 1997). ❖

Molniya Breakup

The year 2001's second fragmentation event was that of the Molniya 3-26 spacecraft, 1985-091A, 16112. Launched from the Plesetsk Cosmodrome on 3 October 1985 at 0726 UT aboard an SL-6 (Molniya) rocket; this fragmentation event occurred on 21 February after approximately 5620 days on-orbit. Two single track elsets were created.

The Molniya 3 series of spacecraft are communication payloads, the signal feature of which is the orbit pioneered and employed by these vehicles. This event was the second such event in as many years. The Molniya 3-36 vehicle (1989-094A, 20338) fragmented under similar circumstances on 19 May 2000. Both were undergoing catastrophic decay at the time, *i.e.* perigee height was low enough that significant aerodynamic forces were present, resulting in probable ablative heating and subsequent breakup. ❖

Inside...

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The Environmental Implications of Small Satellites Deployed in LEO

P. Anz-Meador

Small satellites have historically made important contributions to Earth and space science, biology, communications, and technology. However, innovative concepts are being proposed which would significantly reduce the size of spacecraft while increasing the coverage and, hence, the number of small satellites deployed on-orbit. This article will examine current and projected small satellite projects in terms of their physical characteristics and the overall environmental implications of small satellite utilization.

The Russian delegation to the 18th IADC meeting (June 2000, Colorado Springs) presented a comprehensive overview of current and projected small satellite traffic; these data, as well as general nomenclature, are available online at Surrey Satellite Technology's web site, and so will not be discussed at length here. While most are on the order of 10 kg or greater in mass, several satellites possess masses on the order of 0.2 kg and a linear dimension as small as 2 cm. Further, the NASA New Millenium Program foresees so-called "femtosatellites" with masses on the order of grams and dimensions on the order of 2 cm and smaller. Constellations of such satellites, with numbers in the hundreds of operational satellites, are envisaged for space science, communications, and remote sensing work. The Russian analysis of small satellite traffic indicates that these vehicles would differ in several major respects from the current population. For example, the vehicle mass density portrayed in Figure 1 is in certain cases a factor of 4 larger than that of a corresponding "classic" satellite. Here, individual data points are compared to the general relation, first derived by Kessler, for mass density of intact satellites. This leads to an enhanced orbital lifetime since atmospheric drag is inversely proportional to mass density. Enhanced orbital lifetimes lead to a larger spatial density at a given altitude and a longer exposure time for other members of the on-orbit population.

Operational experience indicates that current small satellites may be difficult to track or collect radar cross section (RCS) data on; future small satellites may therefore present considerable difficulties for the deterministic tracking task. Tracking may be enhanced using active beacons (operational vehicles only) or passive dipoles or corner reflectors. However, this is unregulated and not implemented (with the exception of a dipole in the tether connecting the Picosat 1 and 2 vehicles) at present. The small sizes of current vehicles, coupled with their geometries and power requirements, result in (a) a short operational lifetime and (b) minimal, if any, maneuver capability. Both factors preclude either active collision avoidance or self-disposal. Considering these characteristics *in toto*, small satellites are analogous in many aspects to orbital debris clouds.

One means of assessing the environmental impact of a large constellation of small satellites is to compare the spatial density of the constellation to the expected spatial density of a new on-orbit breakup. Figure 2 depicts such a breakup debris cloud. This figure (courtesy of P. Krisko), generated using the current EVOLVE 4.0 breakup model, portrays the modeled spatial density of the LANDSAT 1 rocket body debris cloud shortly after the event. The spatial density of any constellation may therefore be ratioed to the size-dependent debris spatial density for a readily understood figure of merit. A suggested means of expressing this ratio is via units of Kesslers, abbreviated [Ks]. A unit ratio is 1 Ks, a constellation density for 2 cm characteristic length picosats twice that of the modeled LANDSAT spatial density would be 2 Ks, and so on. Of obvious import is that relatively few constellation vehicles can combine to create the same effective spatial density as a larger number of objects in elliptical orbits. Not perhaps apparent in this chart, however, is the long-term effect. Whereas the debris cloud will disperse and eventually decay, the small satellite constellation may be both strictly maintained in orbital parameters and replenished at regular intervals. Thus, a maintained constellation may be considered to be equivalent to satellite breakups at regular intervals, the intervals being determined by the competing factors of natural decay (orbital debris) versus decay and replenishment (small satellites).

In summary, small satellites may differ considerably from their larger cousins not only in terms of dimensional and mass magnitude, but also their orbital lifetimes. Conversely, the operational lifetime of these vehicles are, at present, extremely short. This leads, therefore, to scenarios involving large numbers of small, derelict satellites. These are in many ways analogous to a young debris cloud, and large constellations composed of very small satellites may be characterized as such in estimating environmental impact. It is not too early to begin educating small satellite owner/operators as to the consequences of their activities, so as to both minimize environmental impact while yet maximizing their effectiveness. ❖

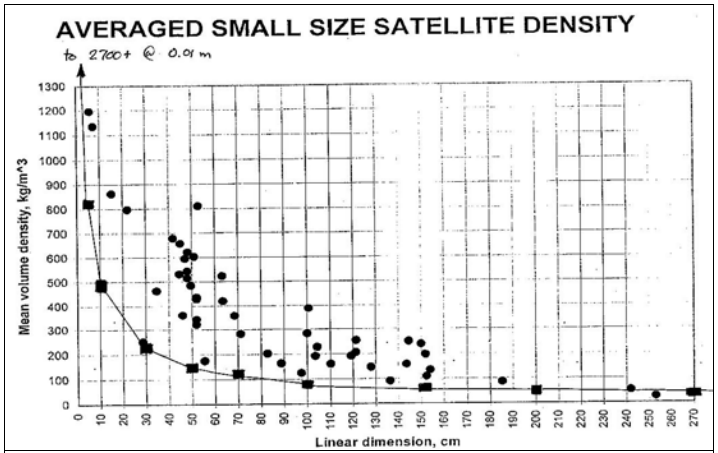

Figure 1. Small satellite mass densities (represented by dots) compared to that of "normal" vehicles (represented by the line).

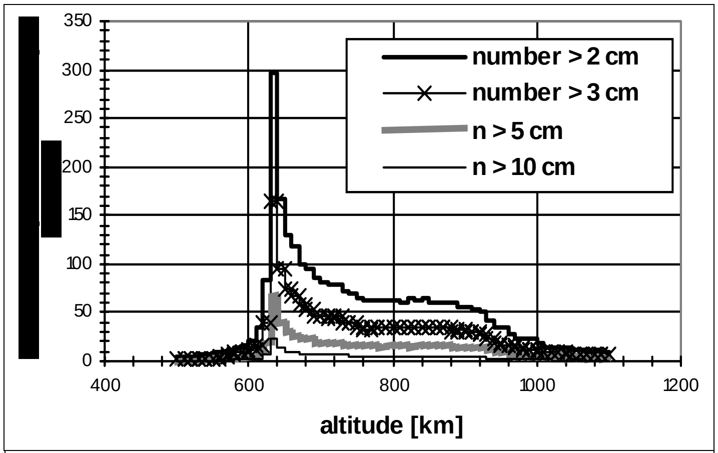

Figure 2. The modeled LANDSAT 1 R/B debris cloud for various debris sizes.

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ISS Space Shuttles Examined for Debris Impacts

Two Space Shuttles, Discovery (OV-103) and Endeavour (OV-105), have recently been examined for orbital debris and meteoroid impacts following missions to the International Space Station (ISS) late last year. Both exhibited numerous impacts on a variety of inspected orbiter surfaces, covering more than 200 m^2.

Discovery visited ISS last year on the STS-92 mission for seven days of its 13-day flight in October 2000. A total of 38 impacts were identified on the orbiter window thermal panes from orbital debris (9), meteoroid (7), and unknown (22) particles. The largest impact feature with a diameter of nearly 1 cm was apparently caused by collision with a small paint particle. Three of Discovery's thermal panes were subsequently replaced.

Six impacts (3 orbital debris, 1 meteoroid, and 2 unknown) were found on the radiators with three of these achieving penetration. The largest radiator impact site was approximately three-quarters of a millimeter in extent and was caused by a meteoroid strike. Four other impacts were also discovered: three on the flexible reusable surface insulation (FRSI) covering the external payload bay doors and one on the vertical stabilizer. Of these, two were meteoroids, one was orbital debris, and one was of unknown material.

In December Endeavour conducted the 11-day STS-97 mission, which again included seven days docked to ISS. Although the number of identified window impacts decreased to 30, the number of impacts to the radiators and the FRSI (12 and 6, respectively) actually increased compared to the longer duration STS-92. A total of two windows were replaced. Of the 12 radiator impacts, only one penetrated the thin aluminum sheet, but two struck the silver-teflon-aluminum doubler installed recently to protect the radiator coolant loops. Four additional impact sites were found on the leading edges of the orbiter wings, two from orbital debris particles and two from unknown sources.

Overall, the number of identified impactors of all sizes is roughly evenly divided between orbital debris and meteoroids. However, a significant number of impactors cannot be identified by type, particularly for the smaller window strikes. Complete inspection details are provided in "STS-92 Orbiter Meteoroid/Orbital Debris Impact Damage Analysis", JSC-29318, January 2001, and "STS-97 Orbiter Meteoroid/Orbital Debris Impact Damage Analysis", JSC-29373, March 2001. ❖

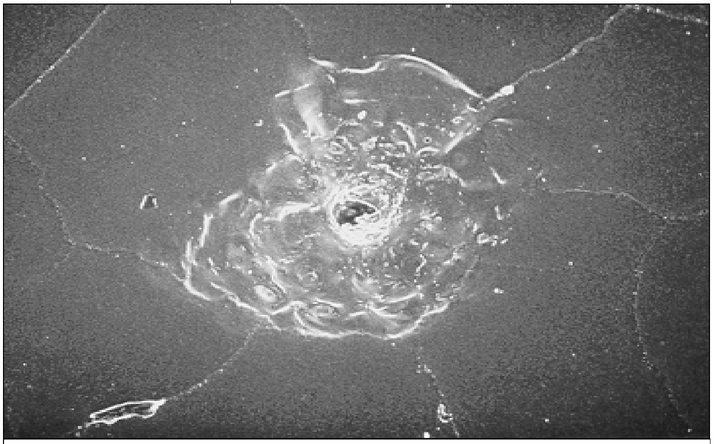

Figure 1. Impact damage from a stainless steel debris particle on the STS-97 right cabin window.

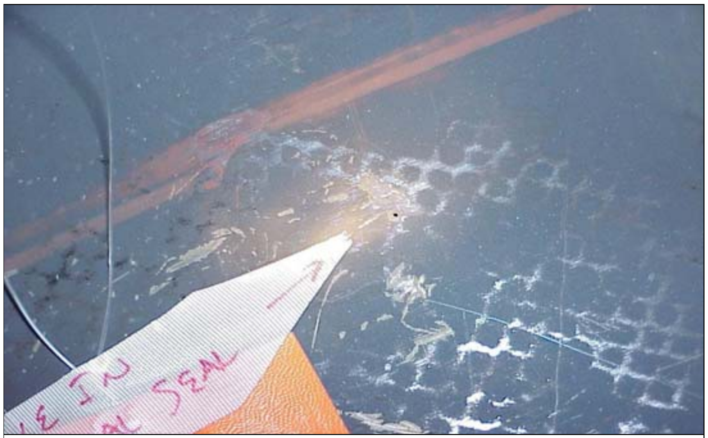

Figure 2. Close-up of hole in the STS-92 vertical stabilizer caused by collision with a stainless steel debris particle.

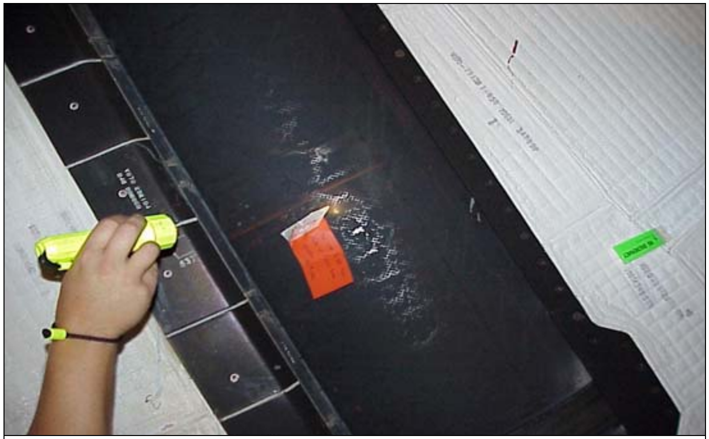

Figure 3. Overview of the STS-92 vertical stabilizer impact area.

Supporting Role of the NASA Orbital Debris Program Office in the Deorbiting of the Mir Space Station

After 15 years of historic operations, the Russian Mir space station was successfully deorbited over the South Pacific on 23 March 2001. NASA JSC played a supporting role by facilitating the exchange of tracking data on the 135 metric ton complex among the U.S., Russia, Germany, France, and the European Space Agency.

On 19 January Yuri Koptev, the Director General of Rosaviakosmos (Russian Aviation and Space Agency), sent a letter to the NASA Administrator asking for his assistance in providing space surveillance tracking information on Mir and solar activity data in the final days before the reentry of Mir. A similar agreement was signed between Rosaviakosmos and the European Space Agency on 23 January. In response to this request, the U.S. government agreed to submit the requested data through the established communications lines between the

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Supporting Role of the NASA Orbital Debris Program Office in the Deorbiting of the Mir Space Station, Continued

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International Space Station Mission Control Centers in Houston and Moscow. In return, Russia pledged to provide the U.S. with Mir deorbit plans, including the schedule and characteristics of the planned Mir maneuvers.

In February, NASA reached an agreement with the German space agency DLR and the French space agency CNES to exchange tracking data on Mir in a similar manner. The Orbital Debris Program Office at JSC served as the central node in this real-time exchange which began on 19 March and concluded with the reentry of Mir four days later. Tracking data in the form of two-line element sets (TLEs) from the U.S. Space Surveillance Network (SSN) were transmitted from JSC to DLR, CNES, and the European Space Agency. The same data were also posted on NASA Goddard Space Flight Center's Orbital Information Group (OIG) website for access by the public at large, including all the nations of the world. In return, DLR and CNES forwarded to the Orbital Debris Program Office tracking data on Mir acquired by their respective national resources. More than 70 different TLEs were exchanged in this manner during the final 96 hours of Mir's existence. ❖

Project Reviews

International Space Station Debris Avoidance Operations

L. Foster, J. Frisbee, M. Wortham, and L. Howorth

A debris avoidance process based upon collision probability has been developed for the International Space Station (ISS) using covariance information supplied by the United States Space Command (USSPACECOM). Given the debris flux and the distribution of debris covariances for conjuncting debris, it is possible to estimate risk reduction, fractional residual risk and maneuver rate for the ISS as a function of chosen maneuver threshold collision probability.

Orbiting objects larger than about 10 cm in size are tracked both by radar and optically by a number of agencies, which maintain the orbital elements for these objects. The flux of tracked objects is small compared with the flux of objects, large enough that space vehicle shielding is ineffective, but too small to be tracked. However the monetary value of the annual collision risk between tracked debris and the International Space Station is sufficiently large that the development and maintenance of a debris avoidance process is very cost effective. Further the flux of tracked debris is expected to increase significantly in coming years due to anticipated improvement to the U.S. Space Surveillance Network.

The simplest debris avoidance method, adopted by the Space Shuttle Program, is that of an exclusion volume in which a maneuver is considered or performed if a conjunction is expected to occur within some predefined volume about a space vehicle. However, based on the known tracked flux, this procedure would result in from 10 to 15 maneuvers per year for the International Space Station (ISS), too many maneuvers for a micro-gravity laboratory, and the risk reduction is not quantified.

USSPACECOM maintains Cartesian state vectors for all objects with perigees below 600 km, on a special Astrodynamics Workstation (ASW). If a conjunction is predicted within a 40x80x80 (u, v, w) km pizza box about ISS, conjunctor tasking is increased and the object is watched. The Johnson Space Center (JSC) flight controllers are notified if the object is predicted to come within a 4x50x50 km box, 72 hours from conjunction. If the collision probability is greater than 10-4 and the conjunction geometry has remained stable for three of the last 4 state vector updates prior to the time an avoidance maneuver decision must be made, a maneuver is performed if operationally feasible.

In its orbit determination process, USSPACECOM uses a weighted batch least squares computer code to obtain a state vector and a state vector uncertainty in the form of a covariance. A nominal 36-hour fit orbit determination interval is used for low to moderate drag objects, with a shorter fit interval for high drag objects. No process noise is used over the orbit determination interval. The covariance is an a priori covariance based on observation geometries, sensor noise and bias values for individual sensors, from continuous sensor calibration using satellite laser ranging. The propagated covariance is in agreement with observation statistics for objects experiencing low atmospheric drag, but the calculated covariances of higher drag objects are underestimated due to poor atmospheric drag modeling. A noise term of 12% of the energy dissipation rate due to atmospheric drag is included as a consider parameter in the propagation outside of the orbit determination interval. The propagated covariances are scaled to compensate for drag error over the fit interval.

For conjunctions with non-zero relative velocity, the seemingly difficult task of calculating a collision probability reduces, in general, to a simple two-dimensional problem. At time of conjunction, if the relative velocity vector is large compared with its uncertainty, the conjunction will take place in a plane perpendicular to the relative velocity vector, called the collision plane. The three dimensional position covariances of the conjuncting objects can be rotated into the same coordinate frame and added. If the contributions of the velocity uncertainties over the time of the conjunction do not contribute materially to the combined position uncertainty, the position of the conjunction on the collision plane will not change over the time of the conjunction. The problem is reduced to two dimensions with the effective covariance being the projection of the three-dimensional combined covariance on to the collision plane. For a large space vehicle such as ISS, it is necessary to integrate the collision probability density function over the projected vehicle area and the collision probability becomes

$$P_C = \frac{1}{2\pi\sqrt{|C|}} \int_{area} e^{-\frac{1}{2}(\vec{r}-\vec{r}_d)^T C^{-1} (\vec{r}-\vec{r}_d)} d\vec{r} \ .$$

Where $\vec{r}_d$ is the debris position in the collision plane and $\vec{r}$ is another point in the collision plane within the ISS area. The

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position covariance matrix is denoted by C with |C| its determinate. A 60-meter radius sphere approximates the ISS.

The average position covariances of 63 objects over 105 days, for 8 and 24-hour propagation, were determined from observation statistics. This covariance data was fit to a linear combination of power functions of tracks per day (TPD) and energy dissipation rate (EDR) providing an expression for an estimated UVW position uncertainty as a function of time for every tracked object.

For every object crossing the ISS altitude band, the Kessler Flux Model, which averages over argument of perigee and right ascension of ascending node, was used to calculate a flux and an average directionality with respect to the ISS velocity vector, using a catalog of orbital elements.

We may choose a collision probability Pc = Pm for which, if the collision probability is exceeded, the vehicle will always maneuver but otherwise will not. Then given a covariance and an average flux and directionality for each object it is straightforward to calculate an *anticipated maneuver rate*, *an anticipated risk reduction* and *an anticipated residual risk* for any given choice of collision probability maneuver threshold, Pm.

Fig. 1 shows the approximately elliptical contours of debris position for constant collision probability about ISS from a given direction. The ISS is represented as a 60-meter radius sphere at the center of the figure.

Clearly the total annual collision probability for a space vehicle is the sum of the fluxes of the individual conjuncting objects, multiplied by the area of the space vehicle. The total annual collision probability must also be the integral out to infinity of the collision probability per unit area associated with constant collision probability contours. The annual ISS maneuver rate for a single object is the area within the Pm contour for that object times the associated flux. The total annual maneuver rate, M_A, is the sum of the single object maneuver rate over all objects. The annual collision probability is

$$\sum_j F_j\, A_{\otimes} = \sum_j \int_{A=0}^{\infty} PF_j\, dA =$$

$$\sum_j \int_{A=0}^{A(Pm)} PF_j\, dA + \sum_j \int_{A(Pm)}^{\infty} PF_j\, dA\,.$$

Associating sums on the left with Total Risk P_T, the first sum on the right with risk reduction Q and the second sum on the right with residual risk R, we see $P_T = Q + R$. Dividing through by P_T and identifying Q/P_T as Fractional Risk Reduction (FRD) and R/P_T as Fractional Residual Risk (FRR), FRD + FRR = 1. If FRR << 1 and the maneuver rate is acceptable, then the adopted strategy is effective. Fig. 2 shows the fractional residual risk as a function of annual maneuver rate for 8 and 24-hour propagation from orbit determination epoch.

For a maneuver threshold of Pm = 10^{-4}, based on the January 1999 space debris catalog, we anticipate two maneuvers per year either for 8 or 24 hour state vector propagation. The fractional residual risk for an 8-hour propagation is about 0.15. That for a 24-hour propagation is about 0.22.

In conclusion, a debris avoidance system for ISS has been implemented which allows assessment of risk reduction, minimizes maneuvers, and is very cost effective. The method requires accurate estimates of the state vector and state vector covariance estimate for both the space vehicle and the conjuncting object. The covariance data from the orbit determination software matches observation statistics for low drag objects. The covariance from the orbit determination software is scaled for high drag objects. With the current debris avoidance system, there is a risk reduction of from 80 to 85 percent with about 2 maneuvers per year. Improvements continue to be made to the system. ❖

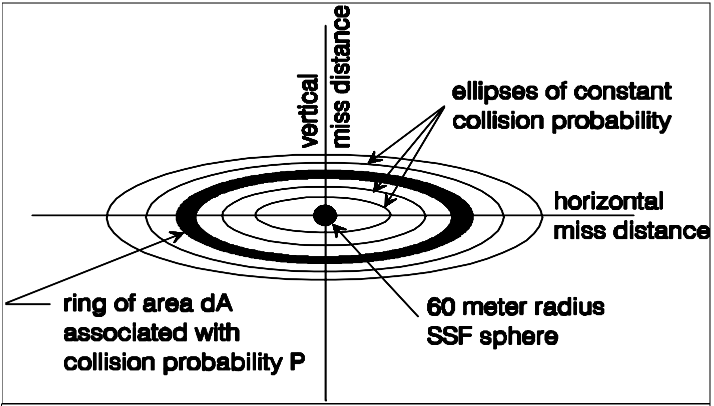

Figure 1. Contours of constant collision probability about ISS.

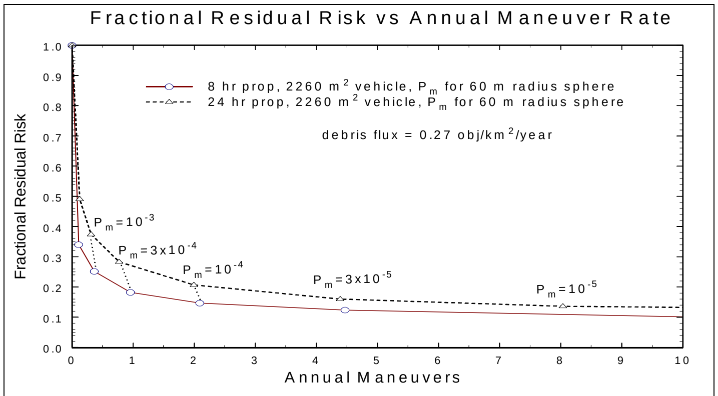

Figure 2. Fractional residual risk versus maneuver rate for 8 and 24-hour state vector propagation from epoch.

Overview of the NASA/JSC Debris Assessment Software (DAS) – Version 1.5

R. O'Hara and M. Jansen

The NASA Johnson Space Center Debris Assessment Software (DAS) originated in late 1995 as a tool to aid NASA programs in performing mission orbital debris risk assessments, in accordance with NASA NMI 1700.8. The layout of the software is parallel to the NASA Safety Standard 1740.14, which makes operation of the software easier for determining guideline compliance. There are 5 main assessment modules: Analysis of Debris Released During Normal Operations (Guideline 3.x), Analysis of Accidental Explosions/ Intentional Breakups (Guideline 4.x), Analysis of Debris Generated by On-Orbit Collisions (Guideline 5.x), Analysis of Postmission Disposal of Space Structures (Guideline 6.x), Analysis of Debris Reentry Risk after Postmission Disposal (Guideline 7.x). The software also provides tools for detailed analysis when necessary.

The DAS software was recently determined to be in need of updates to make it more user friendly. The ultimate goal of the update was to move DAS from a DOS based platform to a Windows platform. The program display still appears the same as the original DAS 1.0 with the exception of a menu tool bar located at the top of the window. Inputs to DAS are also now entered in a separate window, as seen in Figure 1.

Furthermore, the original DAS compiler

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Overview of the NASA/JSC Debris Assessment Software (DAS) – Version 1.5, Cont'd

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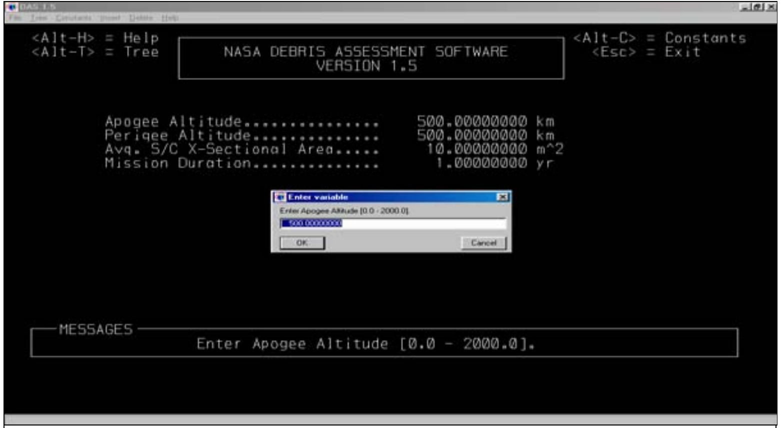
had become obsolete and it was necessary to port the program to a current FORTRAN environment. The Lahey/Fujitsu Fortran 95 compiler, commonly used by the JSC Orbital Debris Program Office, was chosen for the revision of the DAS program. The recent updates to DAS also enabled the print functions, which were not functional in the previous versions of DAS.

In addition to the graphical user interface modifications to DAS, there were also two computational changes to the source code.

The update to the windows environment, combined with the use of an updated FORTRAN platform, has increased the ease of use of the DAS software. All the changes have made DAS 1.5 a more robust and improved orbital debris assessment tool. DAS 1.5 is planned for release for public use in April 2001 once documentation has been completed. ❖



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<Alt-H> = Help                                          <Alt-C> = Constants
<Alt-T> = Tree       NASA DEBRIS ASSESSMENT SOFTWARE       <Esc> = Exit
                              VERSION 1.5

        Apogee Altitude...............     500.00000000 km
        Perigee Altitude..............     500.00000000 km
        Avg. S/C X-Sectional Area.....      10.00000000 m^2
        Mission Duration..............       1.00000000 yr

Enter Apogee Altitude [0.0 - 2000.0]
500.000000000

MESSAGES
                 Enter Apogee Altitude [0.0 - 2000.0].
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Figure 1. Example of new DAS 1.5 GUI

Meeting Report

Third European Conference on Space Debris 19-21 March 2001, Darmstadt, Germany
19th IADC Meeting 22-23 March 2001, Cologne, Germany

The Third European Conference on Space Debris was held at ESOC in Darmstadt Germany on 19-21 March. Over 200 participants from the world over attended 16 sessions and made a total of 159 technical presentations. Professor Walter Flury and the organizing committee assembled a program that covered virtually every aspect of space debris research and policy. Topics included measurements, modeling, protection, mitigation, re-entry, legal issues, risk analysis, standards and databases. The conference concluded with a round table discussion and press conference. For information regarding conference proceedings, contact Professor Flury at wflury@esoc.esa.de.

19th Inter-Agency Space Debris Coordination (IADC) Committee Meeting was hosted by the Deutsches Zentrum fur Luft- und Raumfahrt (DLR) at their facility near Cologne, Germany, on 22-23 March. Convened to follow the 3rd European Debris Conference, 111 participants focused on their collaborative activities such as joint measurement campaigns, environment model comparisons, the protection manual and draft mitigation guidelines. The eleven members of the IADC represent the space agencies of China, France, Germany, India, Italy, Japan, Russia, the Ukraine, the United Kingdom, the United States, and the European Space Agency. ❖

Scientific and Technical Subcommittee of the United Nations' COPUOS
12-23 February 2001, Vienna, Austria

The 38th Session of the Scientific and Technical Subcommittee (STSC) of the Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations was held in Vienna, Austria, 12-23 February 2001. This was the eighth consecutive year that the topic of space debris had been on the agenda of the STSC. The original multi-year work plan on space debris (1996-1999) concluded with a comprehensive assessment of the state of the near-Earth space debris environment and the principal space debris mitigation measures practiced by various space agencies and organizations. This summary was accepted by the full COPUOS and published as "Technical Report on Space Debris" (A/AC.105/720).

In the years 2000 and 2001 the STSC addressed specific topics related to space debris, namely space debris mitigation in the geosynchronous orbital regime and by launch vehicles, respectively. At this year's session Gene Stansbery of the NASA JSC Orbital Debris Program Office represented the U.S. with a presentation on the reentry of the Compton Gamma Ray Observatory and launch vehicle debris mitigation practices in the design and operation of U.S. launch vehicles. A detailed summary of these practices by launch vehicle was submitted by the U.S. and published in "National research on space debris, safety of space objects with nuclear power sources on board and problems of their collisions with space debris" (A/AC.105/751/Add.1).

Based upon multilateral discussions held in Berlin in December, 2000, and a proposal jointly submitted to the STSC by Canada, China, France, Germany, India, the Russian Federation, the United Kingdom, and the United States, a new multi-year work plan (2002-2005) was adopted. In 2002 the STSC member states will address space debris impact hazards and shielding as a special topic. The following year the STSC anticipates receiving a consensus set of space debris mitigation guidelines prepared by the Inter-Agency Space Debris Coordination Committee (IADC). During 2003 and 2004 the STSC will review the IADC guidelines and will seek to adopt similar guidelines to be implemented on a voluntary basis through national mechanisms. Member states may begin reporting the national implementation of space debris mitigation guidelines in 2005. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

A Solar-Flux Temperature Relationship Derived from Multiple-Satellite Orbital Decay

D. Hall and P. Anz-Meador

We report an analysis of the orbital decay rates of 95 satellites to determine the best-fit relationship between solar 10.7cm flux (*$F_{10.7cm}$*) and Earth's globally-averaged exospheric temperature (T_∞). The analysis focuses on reproducing atmospheric drag rates observed over a period spanning nearly 3 solar cycles, and yields globally-averaged exospheric temperatures appropriate for use in models that project Earth's satellite and orbital debris populations many decades into the future. Exospheric temperatures derived using an oblate-Earth/rotating atmosphere drag model are uniformly larger than best-fit temperatures derived using a spherical-Earth/non-rotating atmosphere model, an effect that should be included in long-term orbital debris projection models. ❖

A Decade of Growth

P. Anz-Meador and N. Johnson

This paper examines the Space Surveillance Network catalog's growth in low Earth orbit (LEO) and the geosynchronous Earth orbit (GEO) over the decade 1990-2000. During this time, innovative space utilization concepts, *e.g.* the Iridium and Globalstar commercial communication satellite constellations, have increased the public's consciousness of space. At the same time, however, these constellations have increased spatial density per 10 km altitude bin by factors of two and three respectively. While not displaying as spectacular a growth in spatial density, other regions of space have grown steadily in terms of number, mass, size, and operational lifetime. In this work we categorize launch traffic by type (*e.g.* payload, rocket body, operational debris, fragmentation debris, or anomalous debris), mass, and size so as to present the observed growth numerically, in terms of mass, and in terms of cross-sectional area. GEO traffic is further categorized by operational longitude. Because growth itself defines only the instantaneous environment, we also examine the higher-order derivatives of growth. In addition, we compare the last decade's growth with modeling results to illustrate the subtle effects of inclination, eccentricity, and size, in addition to spatial densities, on estimating the collision probability. We identify those regions of space most subject to accidental collision. ❖

Critical Number Of Spacecraft In Low Earth Orbit: Using Satellite Fragmentation Data to Evaluate the Stability of the Orbital Debris

D. Kessler and P. Anz-Meador

Previous studies have concluded that fragments from random collisions in low Earth orbit will cause the orbital debris population to increase despite efforts to minimize the accumulation of debris. New data from the orbital history of fragments in space and the laboratory hypervelocity breakup of a payload more accurately confirms this conclusion. The conclusions are reached that the orbital debris environment for much of low Earth orbit is unstable and will seek a higher equilibrium even if no new debris is added to the environment. Some regions may be slightly above a runaway level, where no equilibrium is possible as long as the number of intact objects remains constant. The rate of increase for collision fragments is currently low, but would increase rapidly with increases in the intact population. ❖

Spectral Measurements of Returned Spacecraft Surfaces and the Implications for Space Debris Material Measurements

K. Jorgensen, R. Culp, and R. Clark

Knowledge of the physical properties of orbital debris is necessary for modeling the debris environment. Current methods determine the size and mass of orbital debris based on knowledge or assumption of the material type of the piece. By using spectroscopy, one can determine the material type of the piece by comparing the absorption features of its spectra to that of lab spectra for given materials. By isolating three wavelength regions, material types can be placed into three main categories: aluminum, other metals, and plastics. Using these three categories, one can make better-educated assumptions of the material type. The goal of this research is not to improve the models themselves, but to improve the information others use to make the models.

In order to determine the effects of the space environment on the reflectance spectra of spacecraft materials, researchers measured materials from returned spacecraft. Measurements of material degradation for the Long Duration Exposure Facility (LDEF) are documented herein. The measurements gave insight to the effect of thermal coatings and paints on the reflectance spectra of various materials. When the spectra of returned spacecraft materials were compared with the pre-flight laboratory spectra degradation in the samples were seen mostly in the visible wavelengths, while the samples showed similar features in the near-infrared. Overall, the results displayed less degradation on the spaceflight samples than anticipated.

In conclusion, the effects of the space environment on the spacecraft materials did not drastically change the absorption features. It was difficult to assess which portions of the space environment were responsible for the degradation seen. Slight shifts in the aluminum absorption features were observed in some of the LDEF materials. Coatings used on the various metals greatly affect the depth and width of absorption features and should be explored in greater detail. A total change in reflectance was measured in most of the samples tested; however, the changes were not consistent from one sample to the next. The spectral measurements of returned spacecraft materials lent credence to continuing the study of determining the material type of orbital debris using spectroscopy. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

Re-Entry Survivability Risk Assessment of the Extreme Ultraviolet Explorer

R. O'Hara and N. Johnson

A reentry analysis of the Extreme Ultraviolet Explorer (EUVE) spacecraft was performed using the Object Reentry Survival Analysis Tool (ORSAT) - Version 5.0. The analysis was done in response to a request by NASA Headquarters and Goddard Space Flight Center (GSFC) after a preliminary assessment using the NASA Johnson Space Center Debris Assessment Software (DAS) - Version 1.0 had shown that the EUVE reentry may produce a debris area greater than the limit set within the NASA Safety Standard 1740.14 guidelines. DAS predicted that an uncontrolled reentry of the EUVE spacecraft would result in a total casualty area of 12.41 m^2, which exceeds the 8 m^2 limit set in the NASA standards and implies a potential human casualty risk of approximately 1 in 5300. The ORSAT model enabled a higher fidelity thermal analysis of the EUVE spacecraft, utilizing sophisticated material and thermal properties such as emissivity, heat of oxidation, thermal conductivity, and material thickness inputs, which provided a foundation for a more in depth analysis of the reentering objects. Due to the conservative nature of the DAS study, it was reasonable to run ORSAT for only the ten objects shown to survive in the original DAS analysis. The result of the ORSAT study was a reduced casualty area of only 5.95 m^2, well within NASA safety limits. With the risk to human life now acceptably low, NASA can avoid having to take mitigation measures and allow EUVE to reenter the Earth's atmosphere uncontrolled. ❖

The New NASA Orbital Debris Engineering Model ORDEM2000

J.-C. Liou, P. Anz-Meador, M. Matney, D. Kessler, and J. Theall

In 1996, NASA released the first computer-based orbital debris engineering model ORDEM96. The objective was to provide a mathematical description of the low Earth orbit (LEO) debris environment between 200 and 2000 km altitude. Over the years ORDEM96 has become a standard model widely used by the international space community to evaluate the debris environment and to perform collisional risk assessment for various satellites and spacecraft.

The motivation to build a new model to replace ORDEM96 is two-fold. First, the LEO debris environment is an evolving environment. It is essential to update an engineering model, such as ORDEM96, on a regular basis. Secondly, more LEO debris observations and measurements are available now than when ORDEM96 was developed. One should certainly take advantage of the newly available data to improve the fidelity of the model. In addition, computers are much faster now than they were 5 years ago. Faster computers allow us to develop a more rigorous and less restricted modeling method.

The data sources used to build ORDEM2000 and to validate the model results include (1) US Space Surveillance Network (SSN) catalog, (2) Haystack, HAX, and Goldstone radar observations, (3) Liquid Mirror Telescope data, (4) Long Duration Exposure Facility (LDEF) data, (5) recent measurements by the European Retrievable Carrier, Hubble Space Telescope solar array, Japanese Space Flyer Unit, Mir, and Shuttle impact data. The 10 cm and greater debris population is derived from the SSN catalog. The 1 cm and greater debris population is derived from the Haystack data based on the Maximum Likelihood Estimator (MLE) algorithm. The 10 mm and 100 mm and greater debris populations are derived from the LDEF data using the same MLE method. The 1 mm and greater population is based on the interpolation between 100 mm and 1 cm populations and the Goldstone data.

Once debris populations are derived from the data, a new method is used to build their spatial density, velocity, and inclination distributions between 200 and 2000 km altitude. This new method has the advantage of being able to handle a larger number of orbit types. It eliminates several assumptions used in ORDEM96 regarding the orientation of debris particles and their eccentricity and inclination distributions.

The new model has been tested thoroughly and compared with all available data. Overall, it provides a very good description of the current debris environment. In addition, the model comes with a user-friendly graphical user interface that allows users to select different modes and modify input parameters. The model also provides detailed output tables and figures. ❖

Activities on Space Debris in the U.S.

N. Johnson

In the U.S. space debris activities are addressed at all government levels, from the Executive Office of the President to the individual federal agencies to specialized centers, laboratories, organizations, and research groups. U.S. Space Policy specifically challenges government agencies to seek to minimize the creation of space debris and to promote debris minimization practices both domestically and internationally. A set of space debris mitigation standard practices has been developed and adopted by relevant US government agencies, and their application by the commercial aerospace community is highly encouraged. A growing number of US government agencies have issued their own space debris mitigation policies, directives, regulations, and standards.

Space debris research, including the definition and modeling of the current and future near-Earth space environment and the development of debris protection technologies, is principally conducted by NASA and the Department of Defense. The U.S. Space Surveillance Network continues to provide the most complete and timely characterization of the population of space debris larger than 10 cm. During the past several years major advancements have been achieved in extending this environment definition in LEO to include particles as small as only a few millimeters. The inspection of returned spacecraft surfaces continues to shed light on the even smaller debris population. With improvements in computer technology, new and more capable programs have been and are being developed to solve a number of operational and research problems.

Finally, the academic and industrial sectors of the U.S. are also increasing their participation in and contributions to space debris operations and research. The cooperation of satellite and launch vehicle developers and operators is essential to the U.S. objective of promoting the preservation of the space environment for future generations. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

Observations of the Geosynchronous Earth Orbital Debris Environment Using NASA's CCD Debris Telescope

K. Jarvis, J. Africano, P. Sydney, E. Stansbery, T. Thumm, K. Jorgensen, and M. Mulronney

The National Aeronautics and Space Administration (NASA) has been using the Charged Coupled Device (CCD) Debris Telescope (CDT), a transportable 32-cm Schmidt telescope located near Cloudcroft, NM, to help characterize the debris environment in Geosynchronous Earth Orbit (GEO). The CDT is equipped with a SITe 512 X 512 CCD camera. The pixels are 24 microns square (12.5 arcseconds) resulting in a 1.7 by 1.7 degree field-of-view. The CDT system is capable of detecting 17th magnitude objects in a 20 second integration which corresponds to a ~0.6-meter diameter, 0.20 albedo object at 36,000 km. The telescope pointing and CCD operation are computer controlled to automatically collect data for an entire night. Since February 1998, researchers have collected more than 1500 hours of data using the CDT. This report describes the collection, reduction procedures, and analysis of 58 nights of data collected during 1998.

The CDT uses an optimized search strategy by collecting data at low solar phase angle. By observing near the GEO belt, all uncontrolled objects will sooner or later pass through the field-of-view. Specifically, the search strategy used by the CDT was to observe a strip of GEO space eight degrees tall, centered at minus five degrees declination. This strip either leads or follows the Earth's shadow by about ten degrees. The actual length of the strip depends upon the length of the night and the elevation of the Earth's shadow.

Data from the CDT is processed using a software package called 'astro' originally developed for the "Raven" class telescope by the Air Force Research Laboratory (AFRL) but modified to account for instrumental differences between the two systems. Correlation software was written to determine which of the detections correlated with catalog objects and also automatically processes the astro results. For this data set, 80% of all detections were within five arcminutes of the predicted position while 92 %were within ten arcminutes. Since November 1999 the astro code has been modified to include correlation software written by the Space Warfare Center such that detections are correlated now in individual frames.

Estimates can be made on the errors associated with the derived quantities of range, inclination, and RAAN from the correlated objects. For objects in near circular orbits and having inclinations greater than one degree the average range error is –140 km (0.4%), the average inclination error is –0.4 degrees and the average RAAN error is 12 degrees. Contributing to the error in each quantity is the length of time the object was observed. The largest errors occur for objects observed in only one frame. Overall, these are good results and give credibility to the UCT results.

The UCT distributions for mean motion, inclination, and RAAN are very similar to the correlated population. The peak of the absolute magnitude distribution for the correlated targets corresponds to objects having average diameters of 4.5 meters, paralleling known sizes of intact objects. The peak of the absolute magnitude distribution for the UCTs corresponds to objects having 1.1 meter diameters. The roll off in the distribution reflects the detection capability of the CDT and does not reflect the true nature of the population.

In summary, the CDT technology, like other small telescope programs, has proven itself to be a cost effective way of providing large amounts of data on objects as small as 60 cm in diameter in GEO. ❖

What are Radar Observations Telling Us About the Low-Earth Orbital Debris Environment?

M. Matney and E. Stansbery

NASA has been observing the low-Earth orbital debris environment with high power radars for more than a decade, and the observations continue to reveal valuable information about the character of the debris particles. Instruments such as the Haystack, Haystack Auxiliary (HAX), and Goldstone radars have been used to observe debris particles smaller than are normally visible using only the US Space Command resources. Haystack can routinely detect objects less than 1 cm in size in LEO. HAX can routinely detect debris objects less than about 3 cm in LEO. Goldstone, while limited in capability compared to HAX and Haystack, can detect objects only a few millimeters in size in LEO.

By making statistical observations of the debris, however, we have given up the possibility of tracking these objects. So, in order to enhance our information on the orbital distribution of debris in LEO, several unusual radar geometries have been employed. These have been used to identify families of orbital debris with similar orbital inclinations and altitude distributions. In addition, polarization measurements have allowed us to probe the characteristics of the debris – primarily the shape of the particles. New statistical data analysis techniques reveal information on the elliptical orbit distributions, and allow us to make the first direct estimates of the contributions of elliptical orbits of centimeter objects to the flux in LEO and to characterize the sources of these debris.

This paper updates the results of measurements made by the Haystack, Haystack Auxiliary, and Goldstone radars and how NASA is finding new ways to use these instruments to answer questions about the orbital debris environment. ❖

The Critical Density Theory in LEO as Analyzed by EVOLVE 4.0

P. Krisko, J. Opiela, and D. Kessler

The critical density theory is revisited with NASA's long-term debris environment model, EVOLVE 4.0. Previous studies were based on incomplete data and simplifying assumptions. Recent data of ground-test and on-orbit breakups and fragment decay have been utilized within the EVOLVE 4.0 structure to realistically model the low Earth orbit (LEO) debris environment. This study concludes that, in the gross sense, the critical density theory is verified in the EVOLVE 4.0 environment. However, phenomena neglected in the theory such as collisions between fragments and the random variability built into EVOLVE 4.0, complicate the results. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

Space Debris Modeling at NASA

N. Johnson

Since the Second European Conference on Space Debris in 1997, the Orbital Debris Program Office at the NASA Johnson Space Center has undertaken a major effort to update and improve the principal software tools employed to model the space debris environment and to evaluate mission risks. NASA's orbital debris engineering model, ORDEM, represents the current and near-term Earth orbital debris population from the largest spacecraft to the smallest debris in a manner which permits spacecraft engineers and experimenters to estimate the frequency and velocity with which a satellite may be struck by debris of different sizes. Using expanded databases and a new program design, ORDEM2000 provides a more accurate environment definition combined with a much broader array of output products in comparison with its predecessor, ORDEM96. Studies of the potential long-term space debris environment are now conducted with EVOLVE 4.0, which incorporates significant advances in debris characterization and breakup modeling. An adjunct to EVOLVE 4.0, GEO EVOLVE has been created to examine debris issues near the geosynchronous orbital regime.

In support of NASA Safety Standard 1740.14, which establishes debris mitigation guidelines for all NASA space programs, a set of evaluation tools called the Debris Assessment Software (DAS) is specifically designed for program offices to determine whether they are in compliance with NASA debris mitigation guidelines. DAS 1.5 has recently been released with improved WINDOWS compatibility and graphics functions. DAS 2.0 will incorporate guideline changes in a forthcoming revision to NASA Safety Standard 1740.14. Whereas DAS contains a simplified model to calculate possible risks associated with satellite reentries, NASA's higher fidelity Object Reentry Survival Analysis Tool (ORSAT) has been upgraded to Version 5.0. With the growing awareness of the potential risks posed by uncontrolled satellite reentries to people and property on Earth, the application of both DAS and ORSAT has increased markedly in the past two years. ❖

Preliminary Results from the U.S. Participation in the 2000 Beam Park Experiment

G. Stansbery

The United States participated in the 2000 Beam Park Experiment (BPE) conducted in late October, 2000 under the auspices of the Inter-Agency Space Debris Coordination Committee (IADC). The U.S. participated using several sensors which have participated in previous campaigns: Haystack, TRADEX, and COBRA DANE radars, and the Liquid Mirror Telescope. New to the BPE experiments this time are the GBR-P radar located at Kwajalein Atoll and the Haystack Auxiliary (HAX) radar located in Massachusetts. ❖

A History of Meteoroid and Orbital Debris Impacts on the Space Shuttle

J. Hyde, R. Bernhard, E. Christiansen, and J. Kerr

NASA's Space Transportation System Orbiter has been in near continuous service since 1981. In that time, there have been over 100 missions. The vehicles have accumulated approximately 21,150 hours (2.41 years) of on-orbit exposure time. Orbital inclinations have ranged from 28.5° to 62° and operational altitudes have ranged from 138 miles (222 km) to 380 miles (612 km).

The reusable nature of the orbiter has necessitated detailed post-flight inspections of exterior thermal protection system surfaces. Since 1992, post flight inspections have included a forensic component in selected areas of the vehicle. Hypervelocity impact sites on the crew module windows, payload bay door radiators, payload bay door exterior insulation and wing leading edge surfaces have been subjected to postflight data collection and analysis. One of the final products of the postflight inspection is the determination of impactor source (meteoroid or orbital debris) and type. This is accomplished by comparing the relative amounts of constituent elements in the impactor residue to a "chemical signature" catalog of potential impactors.

This report will compile, analyze and comment on the orbiter post-flight inspection data that has been collected since 1992. The distribution of environmental sources (meteoroid and orbital debris) on the vehicle surfaces will be presented. The allocation of orbital debris types (i.e., aluminum, spacecraft paint, stainless steel, etc.) will also be discussed. ❖

Evidence for Historical Satellite Fragmentations in and Near the Geosynchronous Regime

N. Johnson

Satellite fragmentations are well known to be the principal source of debris larger than 1 cm in low Earth orbit (LEO). Since 1963, over 500 missions have placed more than 830 spacecraft and upper stages in or near the geosynchronous (GEO) regime. If the historical non-GEO breakup rate for other than deliberate or aerodynamic causes is applied to GEO, then as many as 15 breakups might be expected near GEO. Some space surveillance specialists have interpreted specific GEO satellite orbital perturbations as evidence for collisions or explosions for up to two dozen GEO satellites. Moreover, recent searches for small (20-100 cm diameter) objects near GEO have been undertaken in the US and Europe, and preliminary results suggest a significant small debris population. However, to date only two GEO regime breakups have been identified with confidence.

This paper summarizes a study of potential indicators of GEO satellite breakups and a review of the two known GEO breakups and of satellites which have been the subject of breakup speculation. Recent GEO debris observations have not revealed obvious breakup clouds which would support these hypotheses. Although some of the detected debris may be of breakup origin, some debris may well have originated from non-fragmentation sources. A LEO non-fragmentation analog may explain some of the observed orbital perturbations in GEO. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

In-Situ Detections of a Satellite Breakup by the SPADUS Experiment

A. Tuzzolino, R. McKibben, J. Simpson, S. BenZvi, H. Voss, H. Gursky, and N. Johnson

For the first time, a particle detector in Earth orbit has provided evidence to directly link sub-millimeter orbital debris to a specific satellite breakup. The University of Chicago's Space Dust instrument (SPADUS), on the U.S. Air Force's Advanced Research and Global Observation Satellite (ARGOS), has been operating in a nearly polar orbit at an altitude of about 830 km since soon after its launch on 23 February 1999. The experiment was designed primarily to detect small natural and man-made particles less than 100 microns in diameter. Using a dual-plane Polyvinylidene Fluoride (PVDF)-based detection system, SPADUS can measure dust particle flux, mass distribution, velocity, and trajectory.

During its first year in orbit, SPADUS recorded 195 impacts, about one impact every two days. In late March 2000 the instrument detection rate soared by approximately an order of magnitude, suggesting a potential encounter with a cloud or stream of debris. A review of the impact times and ARGOS orbital characteristics indicated that most of the detections occurred at multiples of half-revolution intervals deep in the northern and southern hemispheres, with a clear majority of impacts found in the latter. Orbital analyses linked these impact events to the orbital plane intersections of ARGOS and the debris cloud of a Chinese orbital stage (International Designator 1999-057C, US Satellite Number 25942) which had undergone a severe fragmentation on 11 March 2000 at an altitude 100 km below that of ARGOS. Approximately 40 of the SPADUS detections during the period 25 March – 1 April could be associated with the postulated Chinese debris cloud. Other periods of high impact flux on SPADUS may be related to debris clouds from different sources. ❖

The Analytic Basis for Debris Avoidance Operations for the International Space Station and the Space Shuttle

J. Foster

A debris avoidance process based upon collision probability has been developed for the International Space Station (ISS) using covariance information supplied by the United States Space Command (USSPACECOM). Given the debris flux and the distribution of debris covariances for conjuncting debris, it is possible to estimate risk reduction, fractional residual risk and maneuver rate for the ISS as a function of chosen maneuver threshold collision probability.

The USSPACECOM batch least squares orbit determination software produces state vectors and covariances for both ISS and conjuncting debris. The collision probability is calculated from the projected relative miss distance and the summed covariances. The summed covariances are projected onto a plane perpendicular to the relative velocity vector between the debris object and the space vehicle. This plane is called the collision plane. The collision probability is the integral of the two-dimensional joint probability density distribution over the projection of the vehicle area onto the collision plane. Because of inherent model error over the fit and propagation intervals, the covariances are currently scaled from the values produced by the software. Tables of scale factors relate the true covariance size to the orbital drag or energy dissipation rate (EDR) experienced by the satellite or the ISS. These tables were developed by comparing the propagated state vector prediction with the actual observed position, for a large number of objects over representative prediction intervals.

Operational experience has shown successive predictions for both the individual states and the conjunctions to be, generally, in statistical agreement. Even so, the collision probability may vary by about an order of magnitude from state vector update to state vector update. The collision probability at the time a maneuver decision must be made is, nonetheless, the best information available at that time. To date, two ISS debris avoidance maneuvers have been performed, with both maneuvers using this process.

Debris avoidance for the Space Shuttle is currently based on exclusion volumes. A probability-based process is currently under development and should be implemented in late 2000 or early 2001. The batch least squares orbit determination with covariance scaling generally requires a standard fit interval of over a day. While orbiting, the Space Shuttle generally maintains attitude with control jets , which exert a net thrust on the vehicle, even when no maneuvers are being performed. Because of the dynamic nature of the Shuttle, screening boxes for the Shuttle may be larger than those for ISS. Also because of this dynamic nature, the Shuttle state vector covariance produced by USSPACECOM is not adequate for collision avoidance purposes. Additional studies have been carried out to determine a statistical covariance for use in Shuttle debris avoidance operations. ❖

The Space Debris Environment for the ISS Orbit

J. Theall, J.-C. Liou, M. Matney, D. Kessler

Recent work at the Johnson Space Center has focused on updating the existing space debris models. The Orbital Debris Engineering Model (ORDEM) has been restructured to take advantage of state-of-the-art desktop computing capability and revised with recent measurements from Haystack, HAX, and Goldstone radars, additional analysis of LDEF and Space Shuttle impacts, and the most recent Space Surveillance Network catalog. The new model also contains the capability to extrapolate the current environment in time to the year 2030. A revised meteoroid model that includes the meteor showers for Earth orbit has also been developed. This paper quantifies the space debris environment for the ISS orbit from anthropogenic and natural sources. Particle flux and velocity distributions as functions of size and angle are given for particles 10 microns and larger. The environment is projected forward in time until 2030. ❖

Abstracts from Papers presented at the Third European Conference on Space Debris, 19-21 March 2000, Darmstadt, Germany

A Mathematical Model for Combining Data from a Telescope with the Information About the Orbital Debris Environment that is Contained in Two Line Element Set Files

T. Hebert, E. Stansbery

This paper presents an optimal framework for combining information contained in two line element (TLE) files with sensor measurement data to estimate the orbital debris environment. This method can be applied to radar as well as optical data. Results from applying this method to data from the NASA liquid mirror telescope demonstrate an improvement in accuracy and a marked reduction in uncertainty in estimates of the orbital debris environment. ❖

International Space Station as an Observation Platform for Hypersonic Re-Entry of Its Visiting Vehicles

J. Bacon

The International Space Station (ISS) will receive an armada of visiting supply vehicles during its life in orbit. Over 500 tons of material will be destroyed in targeted re-entries of these vehicles. Because all such re-entries lie in the same orbital plane of the station, and because the visiting vehicles typically deorbit within a few hours of departure, the ISS will usually be within sight of the re-entry process, at a range of only 300-600 kilometers. This vantage point offers an unprecedented opportunity for systematically measuring hypersonic destructive processes. This paper examines the integrated operational constraints of the ISS, its supply vehicles, and candidate sensors which can be employed in the scientific observation of the re-entry process. It is asserted the ISS program has the potential to reduce the worldwide risks from future deorbiting spacecraft, through systematic experimental characterization of the factors which affect the rupture, debris survival, and footprint size of its visiting vehicle fleet. ❖

INTERNATIONAL SPACE MISSIONS

January - March 2001

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2001-001A	SHEN ZHOU 2	CHINA	330	345	42.6	1	1
2001-002A	TURKSAT-2A	TURKEY	35772	35801	0.1	1	0
2001-003A	PROGRESS-M1 5	RUSSIA	259	276	51.6	1	0
2001-004A	NAVSTAR 50	USA	20144	20220	55.0	2	0
2001-005A	SICRAL 1	ITALY	35773	35798	0.1	1	1
2001-005B	SKYNET 4F	UK	35778	35795	3.9		
2001-006A	STS 98	USA	370	386	51.6	0	0
2001-006B	ISS (DESTINY)	USA	380	390	51.6		
2001-007A	ODIN	SWEDEN	611	621	97.8	1	7
2001-008A	PROGRESS-M 44	RUSSIA	380	391	51.6	1	0
2001-009A	USA 157	USA	ELEMENTS UNAVAILABLE			1	0
2001-010A	STS 102	USA	362	379	51.6	0	1
2001-011A	EUROBIRD	EUTELSAT	35826	35909	0.1	1	1
2001-011B	B-SAT 2A	JAPAN	35752	35832	0.0		
2001-012A	XM-2	USA	EN ROUTE TO OP. ORBIT			1	0

Upcoming Meetings

1-5 October 2001: *52nd International Astronautical Congress*, Toulouse, France. The theme for the congress is "Meeting the Needs of the New Millennium". The objective is to promote further exchanges between all the participants concerning scientific research, space activity applications and perspectives to meet the needs of society for the new millennium. Technical programs include three debris sessions: "Measurements and Modeling of Space Debris and Meteoroids," "Breakups, Risk Analysis and Protection," and "Mitigation Measures and Standards." Thirty papers will be presented in the three sessions. More information can be found at www.iaf2001.org.

ORBITAL BOX SCORE

(as of 28 March 2001, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	33	338	371
CIS	1328	2555	3883
ESA	29	243	272
INDIA	20	5	25
JAPAN	67	45	112
US	936	2858	3794
OTHER	310	26	336
TOTAL	2723	6070	8793

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