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Project Reviews

International Space Station Debris Risk Assessment Process

Dana M. Lear, Eric L. Christiansen

The 8th International Space Station Integrated Meteoroid & Orbital Debris Threat Assessment (ITA) is currently underway, with release planned for early 1999. Analysts at the NASA/Johnson Space Center's Hypervelocity Impact Technology Facility (HIT-F) have been producing ITAs since the early 1990s in support of the International Space Station effort. Frequent ISS assembly plan changes have facilitated the need to repeat the assessments every 9 to 12 months. Although the assessments typically require 6 months to produce, each is the result of many years of testing and research. The overall assessment process is complex but can be simplified into four general areas of concentration: (1) Finite Element Model definition, (2) M/OD environment model definition, (3) ballistic limit equation definition, and (4) overall probability analysis.

Since the first ISS M/OD assessments, Finite Element Models (FEMs) have been used to define the physical shape of ISS surfaces. The smallest analysis feature on the FEM is the *element*, conceptually a small, flat panel, which is used to define all of the outermost ISS surfaces. The current ISS FEM consists of approximately 90,000 of these elements (Figure 1). Each element has an associated Property Identification Number, or PID, and a Ballistic Limit Equation, or BLE. Groups of elements are used to make up module surface features; these in turn are used to make up ISS modules. The modules are then assembled further into a complete ISS FEM. This FEM information is used by the analysis computer program, BUMPER-II, to perform the fundamental M/OD risk calculations.

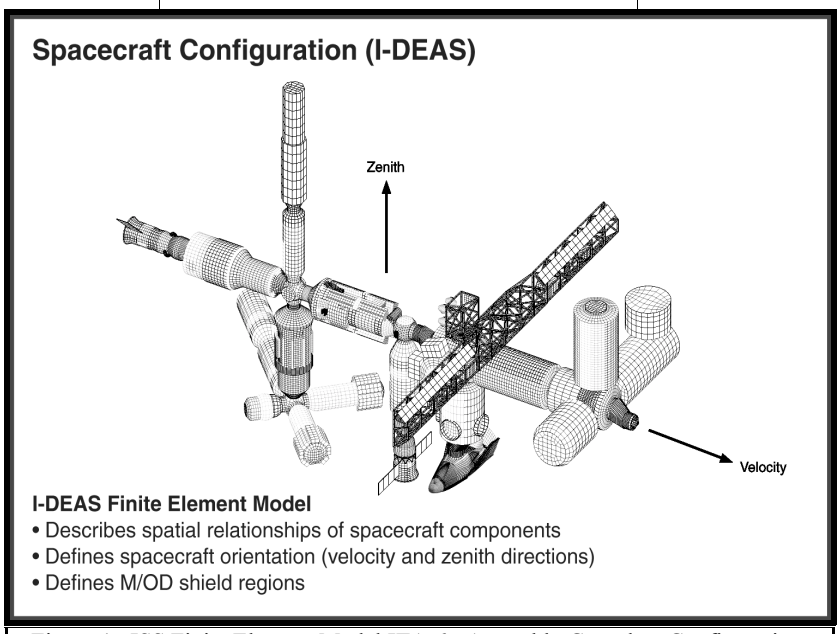

Figure 1. ISS Finite Element Model ITA-6: Assembly Complete Configuration. Approximately 90,000 elements total. Large PV arrays and orbiter not included.

The meteoroid and orbital debris environments implemented in BUMPER-II are described in NASA documents SSP 30425 and TM 104825. Each of these documents contains

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information about M/OD particle concentrations, sizes, orbits, and altitudes. Figure 2 illustrates the M/OD threat directions assessed in BUMPER-II.

The FEM and M/OD environment provide sufficient information for BUMPER-II to determine how many M/OD particles of a particular diameter will impact the FEM over a specific period of time including the effects of shadowing. An M/OD analysis of this type is called a Probability of Non-Impact analysis, or PNI. But what if we want to know how many of these impacting particles will penetrate the surface? To take this extra analysis step with BUMPER-II, it is necessary to describe the threshold size of an impacting particle that just penetrates each particular surface of the FEM, and requires use of the BLE.

The BLEs have been derived from analysis based on thousands of hypervelocity impact tests. A BLE defines the maximum, or *critical*, particle diameter that a particular surface can withstand as a function of velocity, impact angle, and particle diameter (Figure 3). The element property identification numbers, or PIDs mentioned earlier, are used to link a particular BLE to a region of the FEM. A penetration occurs above a particular BLE curve for a given impact angle and impact velocity. BUMPER-II uses the discrete velocity and angle distributions with the BLEs for each PID to assess the Probability of Non-Penetration, or PNP (Figure 4). ∨

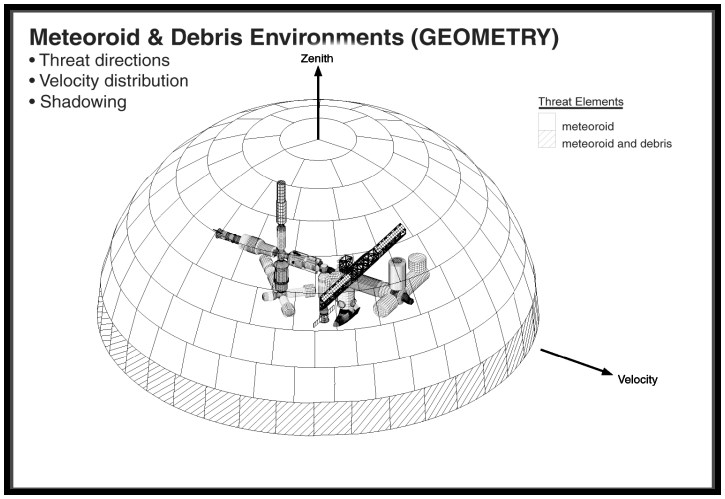


Figure 2. M/OD Threat Directions
Meteoroid - 149 threat directions. Debris - 90 threat directions.
(Each threat direction for **EACH** element assessed.)

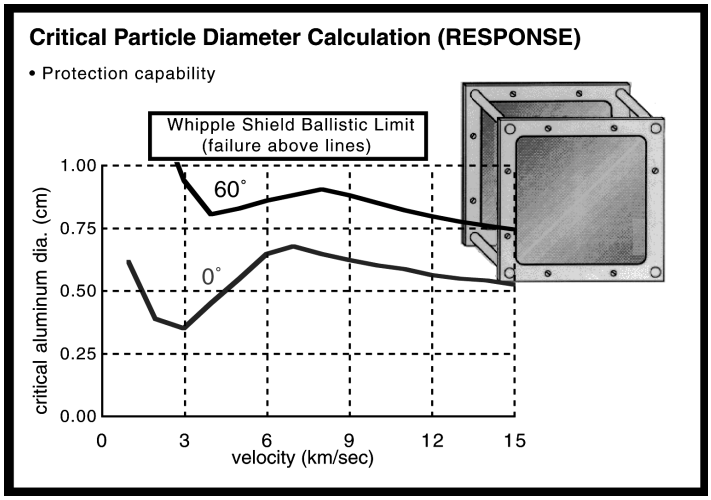
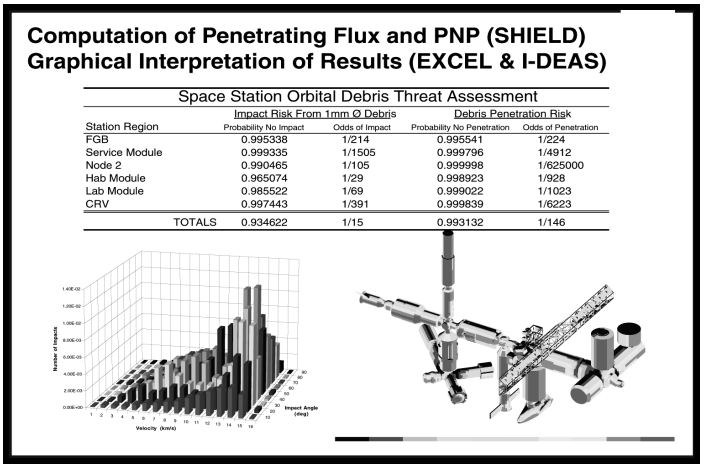


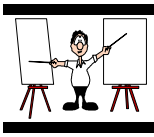
Figure 3. Typical PID Ballistic Limit Equation Curves
Impact angles of 0° and 60° (**for illustration only**)



Space Station Orbital Debris Threat Assessment

Station Region	Impact Risk From 1mm Ø Debris: Probability No Impact	Impact Risk From 1mm Ø Debris: Odds of Impact	Debris Penetration Risk: Probability No Penetration	Debris Penetration Risk: Odds of Penetration
FGB	0.995338	1/214	0.995541	1/224
Service Module	0.999335	1/1505	0.999796	1/4912
Node 2	0.990465	1/105	0.999998	1/625000
Hab Module	0.965074	1/29	0.998923	1/928
Lab Module	0.985522	1/69	0.999022	1/1023
CRV	0.997443	1/391	0.999839	1/6223
TOTALS	0.934622	1/15	0.993132	1/146

Figure 4. Examples of BUMPER PNI & PNP Results. Upper Table provides the PNI and PNP for each element of the FEM. Graphic in lower left-hand corner describes the assessed orbital debris penetration risk on a particular surface PID as a function of impact angle and velocity. Graphic in lower right-hand corner provides a color-coded illustration of predicted high (red) versus low (blue) impact zones on the FEM.
(**for illustration only**)



Project Reviews

Update from NASA's Orbital Debris Observatory

John L. Africano and John V. Lambert

Liquid Mirror Telescope

1998 Summer Shutdown:

Each year the LMT is closed for maintenance during the summer months because of poor weather. As part of the general housekeeping this year, the dome and prime focus areas were thoroughly cleaned, and all electrical connections were checked and reseated. The mirror support system was re-aligned so that there is less than a one arc-second error between the main bearing rotational axis and the gravity vector. A new optics package, an aspherical doublet corrector, was also installed replacing the rear single element of the old corrector. This new corrector removes field distortion, provides better image quality over a larger field-of-view, and covers a broader spectral range. Preliminary results confirm improved image quality from the new corrector which should permit the LMT to detect fainter objects. Regular operations resumed on October 12, 1998 and, by mid-November, fifty hours of debris observations had been obtained.

Automated Debris Detection System:

We have developed a prototype hardware/ software system to automate the debris detection process. The hardware portion of the system is composed entirely of off-the-shelf components: a dual-processor Pentium-II PC with 54 Gbytes of disk space, an IEEE-1394 SCSI-PCI card, and a Sony DHR-1000 digital video tape player. The software consists of special-purpose digital video C-code and IDL processing routines developed by Lockheed-Martin at JSC. The program controls the digital video tape player; decodes the compressed video images; automatically detects and measures the positions and brightnesses of moving objects; and compiles a report on all detected debris. The human operator can review and verify the video record for each detection event. The debris detection software is now in the final stages of development and testing.

We have tested the automated debris detection system using about thirty-two hours of digital video data, some 3.6 million images, previously processed by human screeners. The automated processing is somewhat slower (sixteen times real time) than the manual processing, but well worth it. Comparisons between the results of the automated system and the human screeners indicate that, while the automated detection system may occasionally miss a debris event located very close to the edge of the field-of-view, it almost always finds one or two additional events per tape not found by either screener. Once operational, the automated debris detection system will allow us to keep up with the large volume of data being collected each clear night by the LMT.

Observational Results:

We have completed manual processing of the first forty-seven video tapes, about seventy-five hours of data, collected by the LMT. In these observations, we detected 62 correlated objects and 231 uncorrelated targets (UCTs). Assuming an albedo of 0.1 for the debris objects we are detecting objects down to about 2 to 3 cm in diameter. About 30 of these uncorrelated objects may be associated with the RORSAT sodium potassium (NaK) droplets. Assuming a 0.8 albedo for these objects leads to detections as small as 1.5 cm.

The LMT and the Haystack radar detection rates as a function of object size are compared in Figure 1. The observed Haystack detection rate was increased by a factor of 5.2 to account for the difference between the LMT (0.24 degrees) and Haystack (0.05 degrees) beam sizes. While there are still several additional observational biases to be considered in processing the LMT data, the optical results are very consistent with the radar results. The main difference occurs in the 5 to 20 cm size regime. At this time we are exploring possible explanations for these differences.

The total number of detectable objects in orbit was estimated from the LMT observations using a variation of the technique developed by

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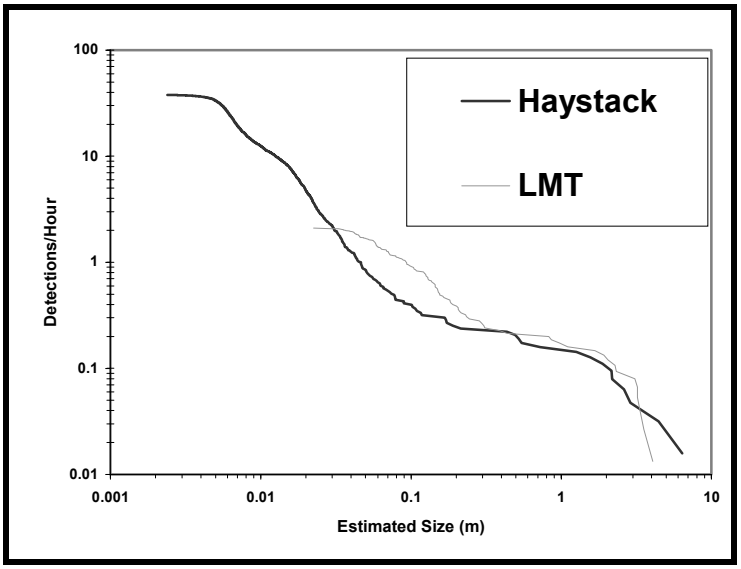


Figure 1. Comparison of Optical and Radar Size Distributions.

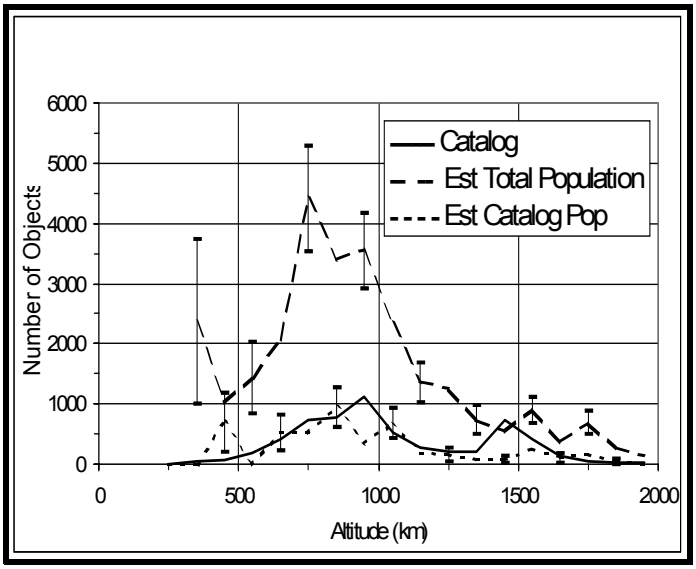
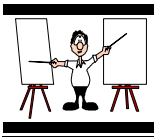


Figure 2. LMT Optical Population Estimates.



Project Reviews

Update from NASA's Orbital Debris Observatory, Continued

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Seniw (1992). This approach assumes that the arrival rate of orbiting objects into the LMT field-of-view obeys Poisson statistics and that the objects are randomly distributed in circular orbits. A basic limitation in deriving the orbital population directly from observations is that objects in orbits with inclinations less than the site latitude or greater than the supplement of the site latitude cannot be observed and are excluded from the estimated population.

Based on the 293 detections in the initial seventy-five hours of LMT observations, the detectable orbital population with inclinations between 33 and 147 degrees under one thousand kilometers altitude is estimated to be 22,000 ± 7,000. For comparison, the number of cataloged objects in this orbital region at the end of 1997 was 3,341. An empirical validation of the analysis technique was performed by attempting to recover the cataloged orbital population from the sixty-two correlated LMT detections. Based on these detections of cataloged objects, the detectable cataloged population was estimated to be 3,000 ± 700. The altitude distributions of the cataloged and the derived orbital populations are indicated in Figure 2. LMT observations are currently being routinely conducted during every suitable twilight period. Analysis of the much larger database now available is underway and will provide more refined orbital population estimates.

The determination of the orbital population from optical observations is subject to several biases. A correction has been applied for the intrusion of the Earth's shadow into the LMT detection volume which results in a variation in the effective observing time with altitude. A correction has also been applied to remove meteor detections using the Earth's shadow at higher solar depressions; the population estimates for the lower altitudes may be contaminated by a few meteor detections observed at low solar depressions. No correction has been applied for the decreasing size sensitivity of the LMT with altitude in the above estimate. Examination of the cataloged and derived altitude distributions in Figure 2 suggests a possible undersampling of objects in sun-synchronous orbits which can not be observed by the LMT. Work is continuing to remove these biases.

References: W.P. Seniw, ed. "Space Population – Final Report". Project Report STK-192. MIT Lincoln Laboratory. Lexington, MA. 11 March 1992.

CCD Debris Telescope (CDT)

One of the limitations of the LMT is that it cannot observe debris in geosynchronous orbits, due to the fact that it is located at 33 degrees North latitude and is restricted to zenith staring with a relatively small (0.3 degree) field-of-view. The CCD Debris Telescope (CDT), an automated 32-cm aperture, portable Schmidt telescope presently co-located with the LMT, is employed for observations of the geosynchronous Earth orbit (GEO) debris environment. The CDT is equipped with a CCD camera capable of detecting seventeenth magnitude (~0.8-meter) objects at 36,000 km. The CDT is currently conducting nightly systematic searches of the near-GEO environment as part of an international measurement campaign under the auspices of the Inter-Agency Space Debris Coordination Committee (IADC). Testing for this campaign took place in late 1997 and data collection began in January 1998. About 300 hours of observations totaling more than 30,000 frames had been collected on forty-three nights through mid-1998.

Figure 3 presents a typical CCD exposure. The telescope is moved to a particular azimuth and elevation. The telescope is allowed to settle with the drives turned off, then a 20 second exposure is taken. Since the telescope is not tracking, the stars leave trails, geostationary objects are star-like, and geosychronous objects leave short trails.

Automated data reduction software is used to process each frame to find moving objects and report the positions, magnitudes and times of each detection. At present, the CDT data are FTPed to Maui for reduction using software developed by the Maui branch of the Air Force Research Laboratory (AFRL) for their Raven small telescope program. Processing these data over the internet takes from five to twenty minutes per frame depending on network activity. Arrangements are being made between NASA and AFRL to transfer this software to JSC. Processing will then only take sixty to ninety seconds per frame! To date, we have reduced over seven thousand CDT frames. The initial results indicate that fifty-three percent of the frames contained at least one moving object; twenty-nine percent of the frames had

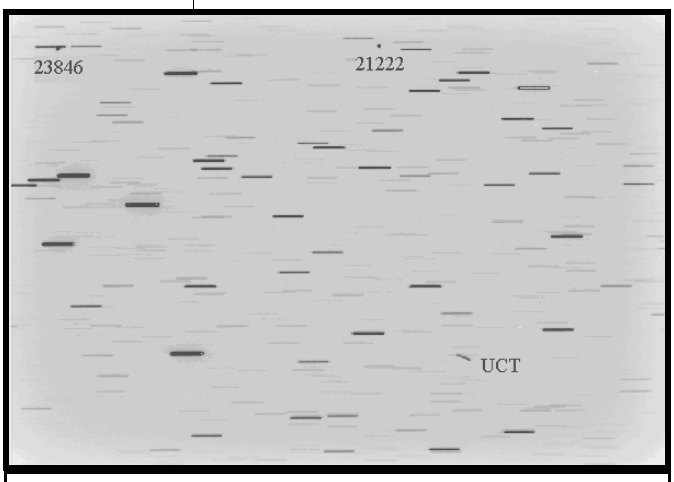

Figure 3. Typical CDT Image.

Post-Flight Inspection STS-89

During January 1998, the Space Shuttle Endeavour spent nearly 16 days in a low altitude (280-390 km), high inclination (51.6 deg) orbit for the eighth Shuttle/MIR Phase I mission. In November 1998 a report sponsored by the NASA Orbital Debris Program Office summarized the orbital debris and micrometeoroid damage discovered during post-flight inspections (STS-89 Meteoroid/ Orbital Debris Impact Damage Analysis, JSC-28499, Justin Kerr, Ronald Bernhard, and Nicole Petersen).

The primary orbiter surface areas examined included the crew compartment windows (3.4 m^2), the reinforced carbon-carbon (RCC) leading edge of the wings (41 m^2), the flexible reusable surface insulation (FRSI) on the exterior of the payload bay doors (70 m^2), and the radiator panels installed on the inside of the

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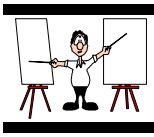

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Post-Flight Inspection STS-89, Continued

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payload bay doors (117 m^2). In all, 122 impact sites were examined by tape pull, dental mold, or wooden probe extraction techniques. Damage regions ranged from 0.250 mm to 4.5 mm in equivalent diameter.

A total of 115 window impacts were identified with the help of an optical micrometer and fiber optic light source. A total of 4 windows were replaced due to hypervelocity impact damage created by 2 meteoroids and 2 particles of orbital debris. The largest window impactor was a meteoroid estimated to have been 0.20 mm in diameter. Laboratory analysis permitted characterization of 43 of the impactors: 23 orbital debris and 20 meteoroids. Of the orbital debris impactors, 70% were aluminum, 13% were stainless steel, and 17% were paint.

Examinations of the radiators led to the discovery of one impact feature with a minimum 1.0 mm radiator tape damage diameter. The impactor created a 0.9 mm diameter hole in the radiator facesheet. It is estimated that the particle was a 0.7 mm diameter meteoroid.

Inspections of the FRSI found five impact sites greater than 1.0 mm in extent: two orbital debris, one meteoroid, and two impactors of unknown origin. All three identified particles were estimated to have been 0.4 - 0.5 mm in diameter. One impact site was also found on an RCC panel, caused by an unknown impactor.

Post-flight inspections of Space Shuttle orbiters continue to produce valuable data on the natural and artificial particulate environment in low Earth orbit. A new, more comprehensive assessment of these mission data has been recently initiated at JSC with preliminary results anticipated in 1999. v

1998 Ends with Eighth Satellite Breakup

The fragmentation of another Proton fourth stage propulsion unit in late November brought the satellite breakup total for the year to eight. Noteworthy is the fact that seven of these events involved vehicles launched prior to 1991, when orbital debris mitigation measures were less widely followed. The remaining breakup during 1998 was a minor event which occurred during orbital insertion – a rare operational breakup. Fortunately, two of the eight breakups were of no long-term environmental consequence, belonging to the newly recognized category of aerodynamic breakups of vehicles in catastrophically-decaying, highly-elliptical orbits (Orbital Debris Quarterly News, Volume 3, Issue 2).

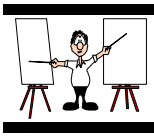
The breakup of an ullage motor unit (1985-037G, U.S. Satellite Number 15714) from the Cosmos 1650-1652 GLONASS mission was discovered by personnel of U.S. Naval Space Command on 29 November 1998. At the time, the approximately 55-kg object's orbit was 320 km by 18,620 km with an inclination of 52 degrees. As many as 60 debris were detected by the Navy's electronic fence and the FPS-85 phased-array radar at Eglin AFB, Florida. This was the 18th known breakup of a Proton fourth stage ullage motor and the third such event of 1998.

Coming a little more than a week after the launch of Zarya, the first element of the International Space Station (ISS), and less than a week before the launch of STS-88 with the Unity module, the breakup dictated a rapid assessment of the potential risks posed by the debris. The nature of the debris orbits ensured that the debris spent very little time each day below 400 km. More importantly, the planar intersections of the ISS and the majority of the debris cloud did not occur at such low altitudes. Due to solar-lunar perturbations, the perigee of the parent satellite's orbit varies from about 290 km to 420 km with a frequency of less than four years. Consequently, debris from this breakup will regularly penetrate the ISS altitude.

Analysts at the Naval Space Operations Center also discovered evidence of a piece separation from a 7-year-old Soviet oceanographic satellite, Okean-3 (1991-039A, U.S. Satellite Number 21397). The new object, first detected on 12 October by the PAVE PAWS West phased-array radar, was visible to six of the Space Surveillance Network (SSN) radars and was quickly cataloged as U.S. Satellite Number 25505. Both objects are in nearly identical orbits of about 620 km by 655 km with an inclination of 82.5 degrees. This is the first instance of an anomalous event associated with this class of Ukrainian-designed spacecraft.

Indications of a possible fragmentation of Cosmos 41 or its Molniya launch vehicle upper stage appeared with the December 1998 cataloging of six debris (U.S. Satellite Numbers 25552-25557) officially linked with the 1964-049 mission. However, several questions remain to be answered. Cosmos 41 was the first spacecraft inserted into a Molniya-class orbit: a highly elliptical (initially about 400 km by 40,000 km), semi-synchronous orbit inclined about 63 degrees to the equator. Although the spacecraft was a mission failure (antennas did not deploy), no fragmentation was detected. In 1982 a fragment (U.S. Satellite Number 13091), which had been tracked by the SSN since late 1969, was cataloged as part of the Cosmos 41 mission. The six new debris have track histories dating back as far as 1972 with most (4) being first discovered during 1992-1993. At this time, the source of the debris – either the spacecraft or the upper stage – is still unclear, as is the nature of the fragmentation, i.e., breakup or anomalous event. v

Visit the NASA Johnson Space Center Orbital Debris Website
http://sn-callisto.jsc.nasa.gov.



Project Reviews

EVOLVE 4.0 Preliminary Results

Paula Krisko

EVOLVE 4.0 is the latest version of the NASA in-house orbital debris environment model. Its major implementations include the NASA Standard Breakup Model revision (*Orbital Debris Quarterly News* Volume 3, Issues 2 and 4), an option for environmental analysis of GEO, and non-fragmentation debris source models, *i.e.*, solid rocket motor (SRM) and RORSAT sodium potassium particles. Sensitivity studies of the EVOLVE 4.0 results pertaining to orbital debris mitigation measures, the traffic and breakup models within EVOLVE 4.0, and the GEO debris environment are slated for this fiscal year. Testing is in progress as to the requirements for statistically significant results of these various planned studies.

EVOLVE 4.0 first defines a baseline in future launch traffic then allows explosions and collisions to occur based on predefined probability distributions. An actual event is triggered by a random number selection. This Monte Carlo process is continued throughout the projection time period. Clearly, no one Monte Carlo projection will adequately predict the future state. But several such projections, each based on a unique random number seed, will give an estimate of the bounds of possible future states. Additionally, the mean of those iterations will give a picture of the expected behavior of the environment over time. It is still a matter of debate within the orbital debris community as to how many Monte Carlo projections are necessary to give a statistically significant representation of the future state, and also, as to the actual significance of the mean of the Monte Carlo projections. Our current studies with EVOLVE 4.0 are geared to address these issues.

As an example of these studies, Figure 1 displays the EVOLVE 4.0 projections of the 100 year cumulative spatial density of objects greater than 10 cm in size for 100 separate Monte Carlo iterations. These data are confined to the altitude bin of 900 km to 950 km. The projected environmental growth of each iteration in this region is dependent on the number and dates of explosions and collisions, both of which accelerate the growth, and on the predicted solar cycle, which decelerates it (or reverses it in some cases). The mean of all 100 iterations and the standard deviation of the mean are plotted in Figure 2. The standard deviation of the mean clearly increases with time. This is understandable given that all iterations must begin with the same initial conditions, the January 1, 1998 historical environment, and are permitted to diverge from that time within the constraints of the explosion and collision event probability distributions.

Until now, the mean of 10 Monte Carlo iterations has been considered sufficient to describe the behavior of the debris environment for any one size/altitude bin. But a plot of the change in the mean value at 2098AD with an increasing number of Monte Carlo iterations (Figure 3) indicates that, in this case at least, the mean begins to stabilize at about 40 Monte Carlo iterations. That is, as far as the standard deviation of the mean is concerned, 10 Monte Carlo iterations may not be enough to model this size/altitude bin, but 100 may be unnecessary. The region of diminishing returns appears to be entered for Monte Carlo iterations greater than 40 in number.

The question of the validity of using the mean, itself, as a representation of the most likely future state of the environment was also addressed. Histograms of the frequency of occurrence of projected cumulative debris spatial densities from the distributions for the years 2032AD, 2065AD, and 2098AD were examined. All appeared relatively normal, bolstering the assumption that the mean value of 100 Monte Carlo iterations is a legitimate predictor of the future state in this size/altitude bin.

Of course, the analysis of one size/altitude bin does not predict the behavior over the entire space. An expansion of the above study is

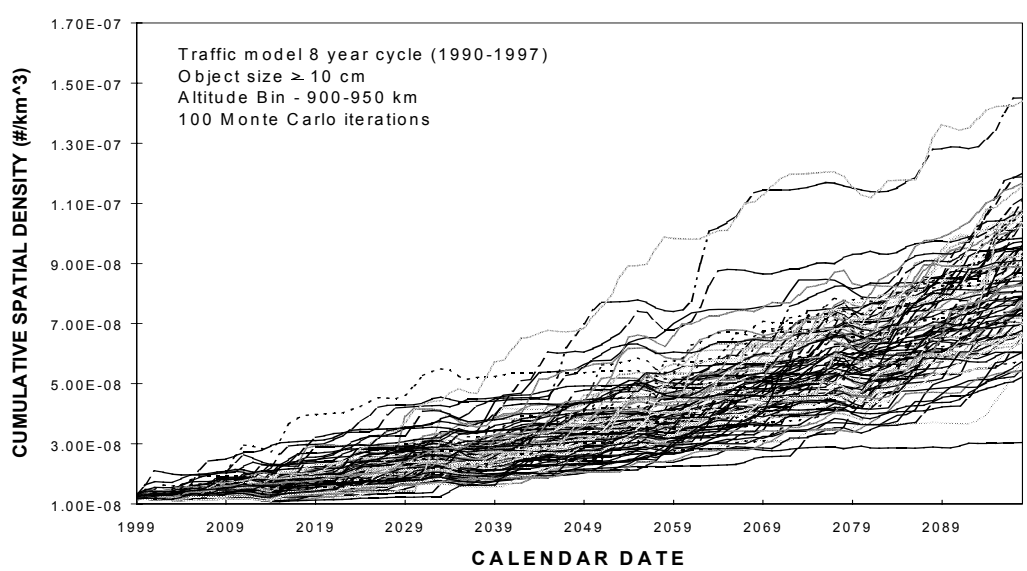
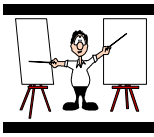


Figure 1. EVOLVE 4.0 test run with 100 Monte Carlo iterations



Project Reviews, Continued

EVOLVE 4.0 Preliminary Results, Continued

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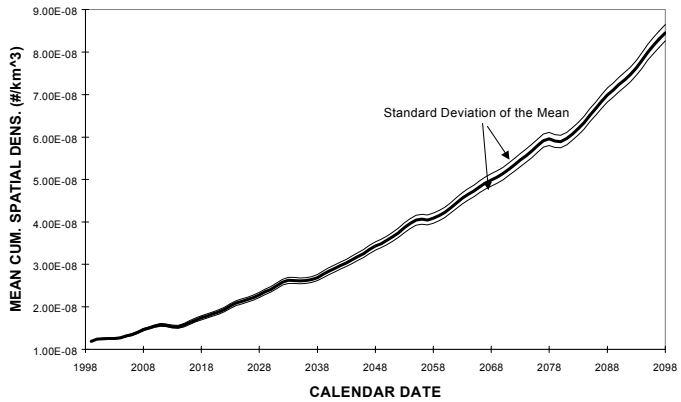


Figure 2. Mean of 100 Monte Carlo iterations and Standard Deviation of the Mean.

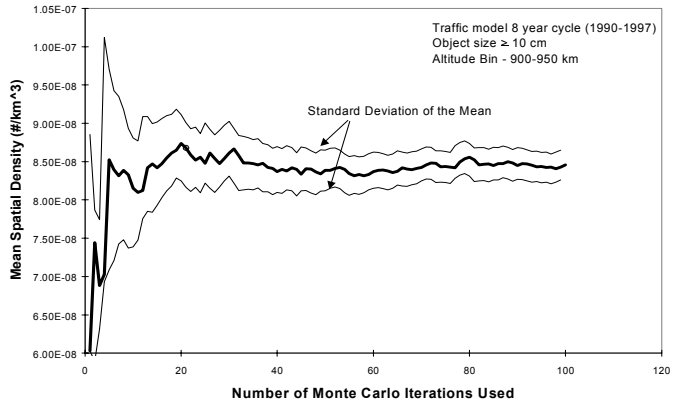


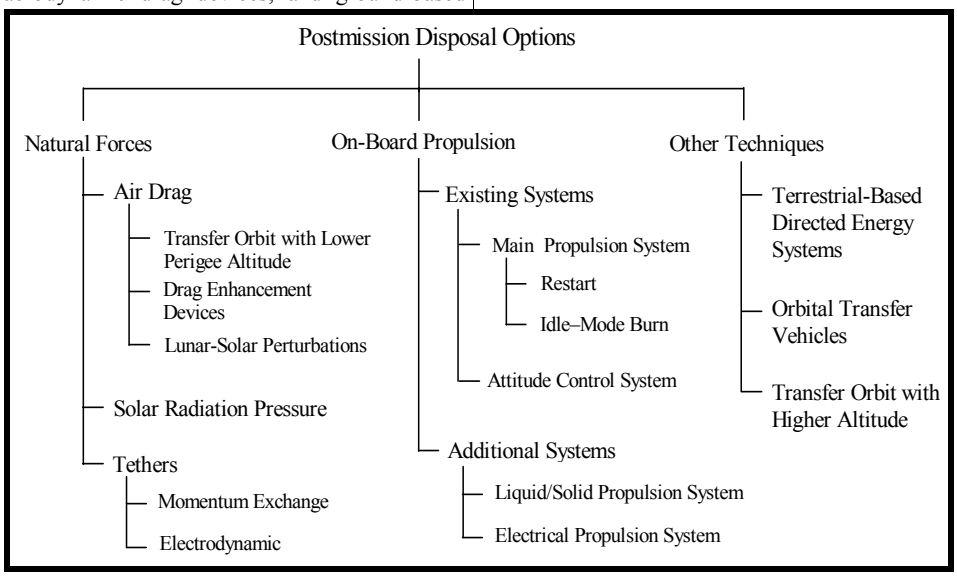
Figure 3. Change in mean cumulative spatial density in 2098AD as the number of Monte Carlo iteratons increases.

Postmission Disposal of Upper Stages (JSC-27862)

NASA Policy Directive 8710.3 (successor to NASA Management Instruction 1700.8) describes NASA's policy to limit the generation of orbital debris. The only specific requirement in this policy statement is to perform orbital debris assessments during the development of NASA programs. In August, 1995 NASA's Office of Safety and Mission Assurance (Code Q) released NASA Safety Standard (NSS) 1740.14, +*Guidelines and Assessment Procedures for Limiting Orbital Debris*, which defines the assessment topics and criteria and provides specific direction for preparing the required debris assessment reports. The reports are to be completed by the time of the Preliminary Design Review (PDR) and 45 days prior to the Critical Design Review (CDR).

Guideline 6 of NSS 1740.14 covers the topic of spacecraft and upper stage disposal at end of mission. *Postmission Disposal of Upper Stages* (JSC-27862) was prepared to assist NASA program managers in evaluating the various options available to meet this guideline for upper stages. The main body of this new report provides a high-level review of the postmission disposal options, followed by a more in-depth review in the Appendix. The disposal options are divided into three broad groups: natural forces, on-board propulsion, and other techniques (Figure). These options are discussed in terms of the potential impact on weight, power consumption, design complexity, technology readiness, required duration of attitude control system operation, and other users of space.

Some options are available for immediate consideration in operational or near-term programs, e.g., main engine restart or idle-mode burn, employment of solid rocket motors, and taking advantage of lunar-solar gravitational perturbations. On the other hand, some options may require further development and qualification before use, e.g., tethers, aerodynamic drag devices, and ground-based lasers. Not all options require additional hardware, but most do. The set of options that might be considered depends upon the particular characteristics and requirements of each program. It is important for spacecraft designers to begin consideration of postmission disposal early in the program development cycle. ∨



NEWS

Disposal of GEO Spacecraft: Challenging Case Histories

The aerospace community has long recognized the benefits of removing spacecraft from the geosynchronous regime to higher altitude disposal orbits upon mission completion to avoid accidental collisions. Also important is the passivation of the spacecraft to reduce chances of a later, spontaneous debris-producing event. The first such transfers were conducted in 1977 by INTELSAT. A postmission disposal policy was adopted in the 1990's by the International Telecommunications Union under ITU-R S 1003, Environmental Protection of the Geostationary Satellite Orbit. In 1997 the Inter-Agency Space Debris Coordination Committee (IADC) developed a precise formulation of the minimum disposal altitude above GEO based upon spacecraft characteristics.

NASA Safety Standard 1740.14, effective since 1 August 1995, also recommends transferring spacecraft to disposal orbits above GEO, followed by spacecraft passivation (Guidelines 6-2 and 4-2, respectively). Although spacecraft already in operation prior to August 1995 are not formerly subject to NSS 1740.14, their program managers are encouraged to comply with the standard's guidelines, if possible. In recent years evaluations of three NASA spacecraft nearing their end of mission have illustrated some of the challenges that can arise.

The International Ultraviolet Explorer (1978-012A) was launched in January 1978 and was inserted into an inclined, elliptical geosynchronous orbit, originally 30,300 km by 41,300 km with an inclination of 34.4 degrees. Unlike geostationary spacecraft, IUE could not be placed into a disposal orbit completely above GEO. An orbit modification was desired, but the state of the attitude control system (only one operational gyro) led to a decision to passivate the spacecraft (expel residual hydrazine and discharge batteries) in place. The IUE spacecraft was successfully retired on 30 September 1996.

For the past few years the first Tracking and Data Relay Satellite (TDRS-1, 1983-026B), launched in April 1983 on a 10-year mission, has been supporting science missions in Antarctica from an inclined (currently 10 degrees) geoysynchronous orbit. Disposal plans are now being considered, even though a mission termination date has not yet been set. The spacecraft is atypical of other GEO spacecraft nearing disposal with its current propellant reserve of over 160 kg of hydrazine. Unfortunately, due to age and difficulties encountered during the original orbit insertion, TDRS-1's propulsion and attitude control systems are severely handicapped. Complete expulsion of all residual propellant, by either burning or venting, may not be possible. Both TDRS-1 and IUE raise issues about the ability of small thrusters to deplete residual propellants due to the large number or duration of firings which might be required. In the case of TDRS-1, the propulsion system may also fail when a low system pressure is reached, again leaving residual propellant.

NASA's Advanced Communications Technology Satellite (ACTS, 1993-058B), in operation for a little more than five years, is now slated for retirement in September 2000. Plans for disposal were first drafted in early 1998 when the reserve propellant budget indicated sufficient quantities for transfer to a disposal orbit. However, a station-keeping maneuver performed in July 1998 revealed significantly less propellant reserves than previously calculated by a simple book-keeping method. Consequently, plans are now being re-examined with the intent of determining how best to dispose of ACTS.

Spacecraft nearing end of mission often rely on degraded subsystems (attitude control, thermal control, propulsion, etc.) which are necessary for disposal operations. In addition, more accurate techniques for measuring the amount of propellant on-board are needed. Designers and operators should consider non-nominal conditions early in the program development and, if possible, include multiple means of accomplishing postmission disposal transfer and passivation. In the event that conditions prevent meeting all disposal objectives, engineering and management judgment is required to define how best to meet the intent of the guidelines. ∨

Debris from STS-88 EVAs

During the successful December assembly of the International Space Station Zarya and Unity modules by the crew of STS-88, three EVAs were required to connect cables, install and deploy antennas, and various other chores. During these EVAs at least five objects were released, either intentionally or accidentally. However, like virtually all debris generated during human space flights, the orbital lifetimes are estimated to be very short, a few months or less. In fact, one of the debris had already decayed by 14 December.

Two of the new orbital debris were actually designed to be released soon after the launch of the Zarya module on 20 November. Two wire antennas on the module, which failed to deploy automatically, were wrapped around spools which are meant to be thrown off during deployment. Both antennas were successfully released during STS-88 EVAs.

During the first EVA two other objects were accidentally lost: a slidewire carrier (3.9 kg) and a foot platform Worksite Interface (WIF) with attached tether (< 2 kg). Fortunately, the slidewire carrier had already served its purpose, and the WIF was one of six such devices, of which only four were needed for the STS-88 mission. On the second EVA an insulation blanket also inadvertently drifted away.

EVAs have long been a source of short-lived orbital debris, including the discarded airlock of Voskhod 2, Ed White's thermal glove during Gemini 4, a screwdriver from STS-51 I, and literally hundreds of debris which originated during EVAs from the Salyut and Mir space stations. Mir alone has generated over 300 debris objects during its 13-year flight, the majority appearing after EVAs. However, only one of all these debris was still in orbit at the end of the year. ∨

Upcoming Meetings

7-10 February 1999: ***9th AAS/AIAA Spaceflight Mechanics Conference*** **(Space Debris session)**, Beaver Run Resort, Breckenridge, Colorado. Website: http://www.astronautical.org

22-26 February 1999: ***Meeting of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space***, United Nations, Vienna, Austria.

13-15 April 1999: ***Space Control Conference***, The Conference is the 17th in a series host by Lincoln Laboratories. Major areas: Space Control Issues, Surveillance technology, Monitoring and Identification.

4-8 October 1999: ***50th International Astronautical Congress***, Amsterdam, The Netherlands. Technical program includes 29

(Continued on page 11)

Abstracts From Papers

Observations of Manmade and other NEO's using the NASA/JSC Liquid Mirror Telescope Presented at the 30th Annual Meeting of the Division for Planetary Sciences, 11-16 October 1998

J. Africano, J. Lambert, E. Stansbery, A. Potter, and M. Mulrooney

The NASA Johnson Space Center is conducting observations with a three-meter aperture liquid mirror telescope (LMT) from a site near Cloudcroft, NM. The zenith-staring telescope, utilizing a rotating pool of mercury as its primary mirror, is used primarily for the detection and monitoring of manmade debris in Earth orbit. The LMT with its prime focus CCD camera is capable of detecting objects down to two centimeters in low Earth orbit. Data collected during the quick transits of objects through the field-of-view provide surprisingly accurate estimates of size and orbital parameters which are used to generate debris populations and orbital distributions. Intrusion of the Earth's shadow into the LMT's orbital coverage volume restricts the debris monitoring activities to a few hours at morning and evening twilight. During the remainder of the night, the LMT serves as an astronomical survey instrument providing deep, ~23 Mv, cataloging of stellar and non-stellar objects including near-Earth asteroids and comets in a half-degree band at thirty-three degrees north declination. The predicted detection limit for NEOs moving at 5 deg/day is 23.2 Mv, dropping to 21.9 Mv for NEOs moving at 50 deg/day. The annual sky coverage for NEO surveys would be about 7000 square degrees, and the estimated rate of discovery would be about 300 new NEO detections per

Meeting Report

16th Meeting of the IADC

The Inter-Agency Space Debris Coordination Committee (IADC) held its 16th meeting 3-6 November 1998 in Toulouse, France. With CNES, the French space agency, serving as host, more than 90 specialists gathered to share research on a wide range of technical and policy issues aimed at better understanding and curbing the growth of the orbital debris environment.

The IADC is an inter-governmental organization established to lay and to expand a technical foundation for addressing the orbital debris environment and related issues. Established in 1993 following six years of bilateral discussions led by NASA, the IADC membership currently consists of the world's leading space agencies: ASI (Italy); BNSC (UK); CNES (France); CNSA (China); DLR (Germany); ESA (European Space Agency); ISRO (India); NASDA, ISAS, and NAL (Japan); RSA (Russia), and NASA (including DoD).

The activities of the IADC are governed by Terms of Reference with an underpinning scope to "(a) review all ongoing cooperative space debris research activities between member organizations; (b) recommend new opportunities for cooperation; (c) serve as the primary means for exchanging information and plans concerning orbital debris research activities; and (d) identify and evaluate options for debris mitigation."

Organizationally, the IADC is guided in these endeavors by a Steering Group and four Working Groups. The latter are focused on orbital debris (1) measurements, (2) environment and data base, (3) protection, and (4) mitigation. Each working group is normally composed of 2-3 specialists from each IADC member. In addition, international consortia sponsoring major satellite programs or relevant specialized agencies of the United Nations may be invited to participate in IADC meetings when specific issues of interest are discussed.

Recent accomplishments of the IADC include:

- establishment of a common electronic data base of resident space objects and of laboratory analyses of returned spacecraft surfaces;
- establishment of a communications network and data base to facilitate the timely exchange of information on the imminent reentry of a space object which might pose a special hazard to people or property;
- development of a technically-based guideline for the minimum reboost altitude for GEO spacecraft at end-of-mission;
- coordination of international LEO and GEO orbital debris observations;
- technical assistance to the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful Uses of Outer Space;
- initiating the compilation of lists of orbital

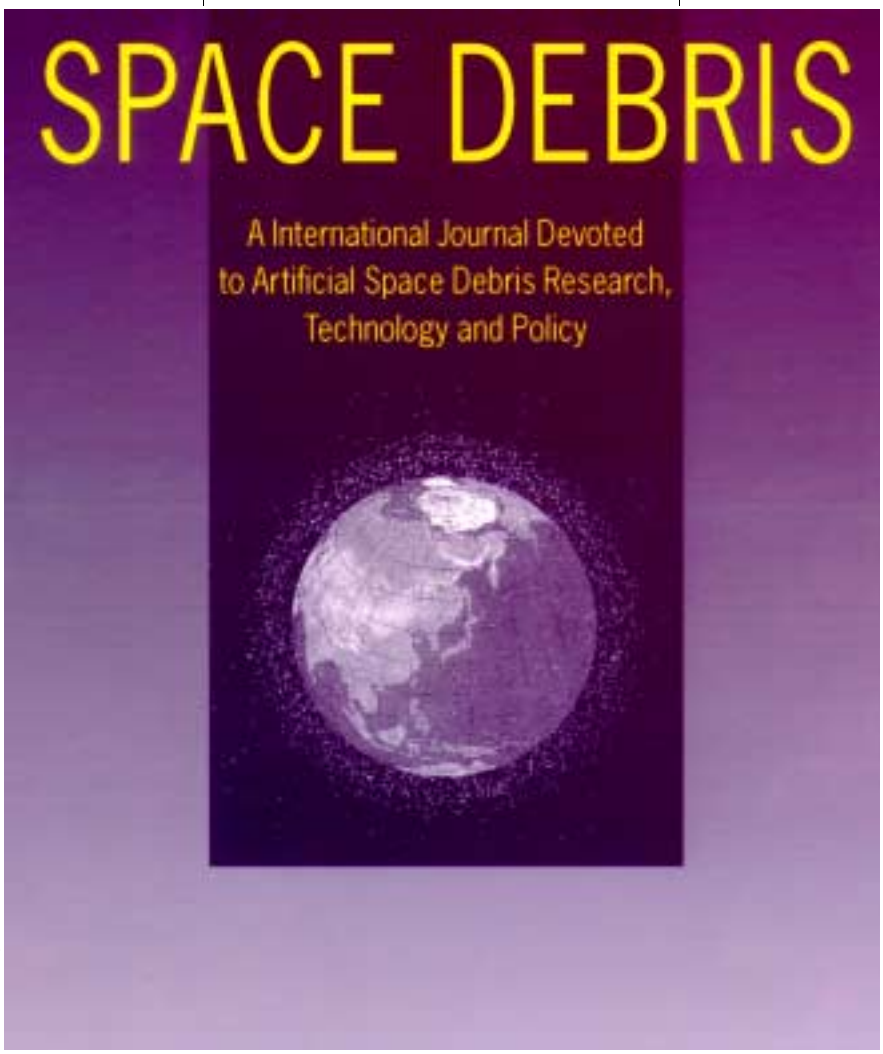
New Publication Announcement

Space Debris

... to provide an exchange of authoritative space-debris information among scientists, engineers, and policy-makers...

An International Journal devoted to Artificial Space Debris Research, Technology, and Policy

Editors: Walter Flury, ESAIESOC, Germany
Donald J. Kessler, Orbital Debris and Meteoroid Consultant, USA



Space Debris is an international journal on man-made space debris research, technology and policy concerned with enviromental issues resulting from the accumulation of non-functioning spacecraft and fragments of spacecraft in Earth orbit. The journal will publish peer-reviewed papers on a wide range of related subjects. These subjects will include the results of experiments which contribute to understanding the current and future space environment; descriptions of models which use natural laws and existing data to predict the environment; test results and analyses describing the hazard to spacecraft and how to decrease that hazard; hypervelocity velocity impacts and shielding; atmospheric entry and hazard on the ground; and analyses of policy recommendations and the cost-effectiveness of policy implementation. While an understanding of the natural meteoroid environment is necessary to an understanding of the space-debris environment, papers should include meteoroid analysis only to the extent that it contributes to the understanding of space debris.

The goal of this journal is to provide an exchange of authoritative space-debris information among scientists, engineers, and policy-makers. This will ensure that scientists performing theoretical analyses have access to the latest measurements; that engineers designing spacecraft have access to the latest environment models and shielding designs; and that policy-makers have access to the most cost-effective techniques of controlling the future space-debris environment. All papers will be held to the highest standards and will be refereed by senior professionals within the space debris community, as well as professionals within closely related communities such as asteroid, comet, planetary, and meteoroid studies, as well as those involved with spacecraft design -and operations, remote sensing, cost management, and policy development.

The new journal, ***Space Debris***, will commence publication in 1999. The journal aims to provide a forum for the exchange of authoritative space-debris information among scientists, engineers, and policy makers. If you want to participate in this exchange, they encourage you to submit your articles to ***Space Debris*** now.

For publication in Space Debris no page charges are levied and 50 offprints of your article are supplied free of charge.

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INTERNATIONAL SPACE MISSIONS

October - December 1998

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1998-055A	STEX	USA	742	760	85.0	1	0
1998-056A	EUTELSAT-W2	EUTELSAT	35723	35750	0.0	1	1
1998-056B	SIRIUS 3	SWEDEN	35775	35796	0.0		
1998-057B	HOTBIRD 5	EUTELSAT	35768	35805	0.0	1	0
1998-058A	UFO 9	USA	34812	36762	6.0	1	0
1998-059A	MAQSAT/ARIANE 5 R/	ESA	997	35504	7.1	0	0
1998-060A	SCD 2	BRAZIL	743	769	25.0	1	1
1998-061A	DS 1	USA	Heliocentric Orbit			1	0
1998-061B	SEDSAT 1	USA	547	769	31.4		
1998-062A	PROGRESS M-40	RUSSIA	350	361	51.7	1	0
1998-062C	SPUTNIK 41	RUSSIA	343	355	51.7		
1998-063A	AFRISTAR	USA	35767	35805	0.0	1	1
1998-063B	GE 5	USA	35786	35795	0.0		
1998-064A	STS 95	USA	536	557	28.5	0	0
1998-064B	PAN SAT	USA	542	569	28.4		
1998-064C	SPARTAN 201	USA	550	560	28.4		
1998-065A	PAS 8	USA	35787	35789	0.3	2	1
1998-066A	IRIDIUM 2	USA	Enroute to Operational Orbit			1	0
1998-066B	IRIDIUM 86	USA	Enroute to Operational Orbit				
1998-066C	IRIDIUM 85	USA	Enroute to Operational Orbit				
1998-066D	IRIDIUM 84	USA	Enroute to Operational Orbit				
1998-066E	IRIDIUM 83	USA	781	775	86.4		
1998-067A	ISS	USA	390	402	51.6	1	1
1998-068A	BONUM 1	RUSSIA	35784	34787	0.1	2	0
1998-069A	STS 88	USA	390	402	51.6	0	2
1998-069B	SAC A	ARGENTINA	380	397	51.6		
1998-069C	MIGHTY SAT 1	USA	380	394	51.6		
1998-069F	ISS (UNITY)	ISS	390	402	51.6		
1998-070A	SAT MEX 5	MEXICO	35770	35805	0.1	1	0
1998-071A	SWAS	USA	638	651	69.9	1	1
1998-072A	NADEZHDA 5	RUSSIA	977	1013	83.0	1	0
1998-072B	ASTRID 2	SWEDEN	978	1013	83.0		
1998-073A	Mars Climate Orbiter	USA	Heliocentric Orbit			1	0
1998-074A	IRIDIUM 11A	USA	Enroute to Operational Orbit			2	4
1998-074B	IRIDIUM 20A	USA	Enroute to Operational Orbit				
1998-075A	PAS 6B	USA	35766	35795	0.1	1	0
1998-076A	COSMOS 2361	RUSSIA	969	1013	82.9	1	0
1998-077A	COSMOS 2362	RUSSIA	19126	19129	64.8	2	7
1998-077B	COSMOS 2363	RUSSIA	19119	19133	64.8		
1998-077C	COSMOS 2364	RUSSIA	19123	19128	64.8		

Upcoming Meetings

(Continued from page 9)

Symposia and 111 sessions which address the latest technological, economic, legal, management, political, and environmental issues of astrodynamics and space.

11-13 October 1999: ***17th Inter Agency Space Debris Coordination Committee Meeting***, Darmstadt, Germany.

6-9 November 2000: ***Hypervelocity Impact Symposium***, Galveston, Texas, USA. **First call for abstracts April 1999.** HVIS is a biennial event that is dedicated to enabling and promoting an understanding of the basic physics of high velocity impact and related technical areas. This international event provides a forum for researchers to share and exchange a wealth of knowledge through oral and poster presentations, and commercial exhibits. The HVIS 2000 is the seventh symposium in a series that will be co-hosted by **NASA Johnson Space Center** and the **Institute for Advanced Technology**. All papers presented at the Symposium will be published in a refereed volume of the *International Journal of Impact Engineering.* For more information visit the website at www.iat.utexas.edu/ conferences/hvis2000.html. v

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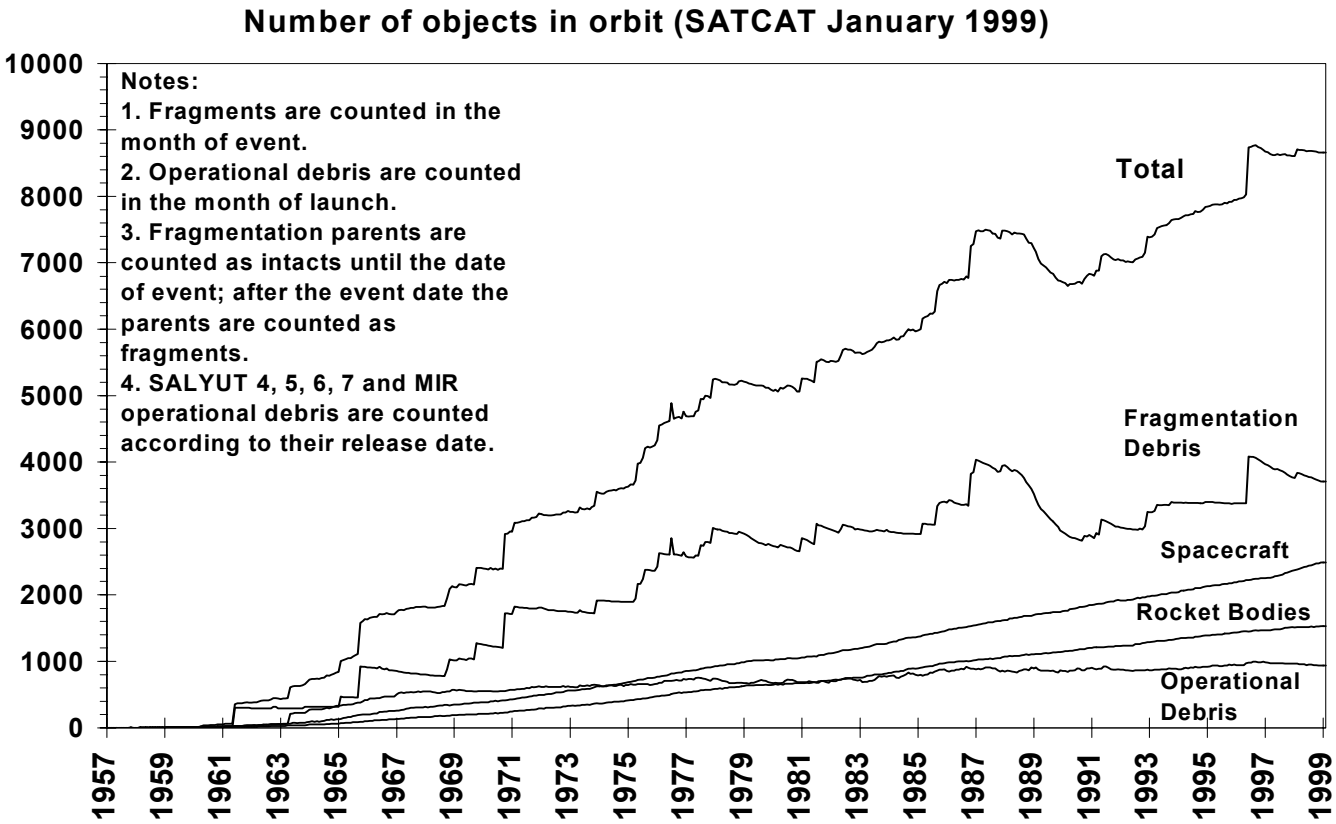
ORBITAL BOX SCORE

(as of 31 December 1998, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	24	101	125
CIS	1340	2579	3919
ESA	24	213	237
INDIA	17	4	21
JAPAN	65	49	114
US	828	3139	3967
OTHER	266	25	291
TOTAL	2564	6110	8674



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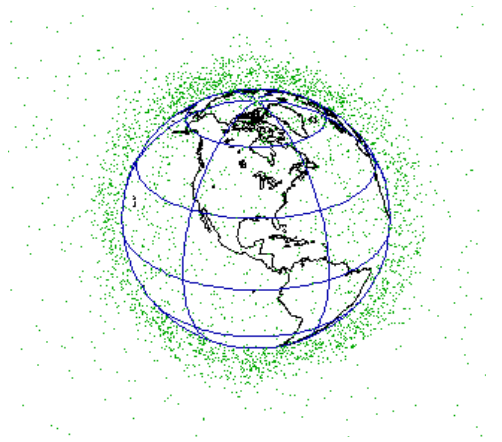

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