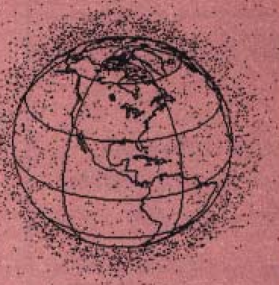
# Orbital Debris Quarterly News



*A publication of*

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**Johnson Space Center**
**Houston, Texas 77058**

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**June 1996** **Volume 1 Issue 1**


# Editor's Note

Welcome to the first issue of the Orbital Debris Quarterly News. The subject of orbital debris has matured rapidly in the past 5 years, as better data became available, debris environment models improved, and as a result of that effort, measures to control the generation of orbital debris became a serious subject. This newsletter will function primarily to keep the debris community apprised of the work that is going on as a part of the research effort at NASA Johnson Space Center (JSC). As you can see from this first issue, the effort is very diverse and yet we've been able to show you only a part of the overall effort.

The newsletter is designed to give you information on orbital debris projects, divided into the areas of modeling, measurements, risk assessment and protection, mitigation and management, abstracts of published or planned papers and reports that may be obtained upon request, and notices of meetings of interest to the orbital debris community. Although the primary focus of the newsletter will be JSC activities, we will also publish abstracts, notices of meetings, or project descriptions that you feel would be of interest to the debris community. Send this information in machine readable form to the Managing Editor, Ms. Cindi Karpiuk. The deadline for submitting information for inclusion in the next issue of the newsletter is June 30.

We are interested in updating and adding to our distribution list. If you have address corrections or want to add to the list, send the information to Ms. Karpiuk.

## Personnel Update

Nick Johnson joins the NASA Orbital Debris Research staff as Don Kessler retires. Nick brings extensive experience in working with the aerospace industry as well as a long history of concern with orbital debris, and he will be a valuable addition to the group.

# Project Reviews

## Status of the NASA Safety Standard on Orbital Debris (NSS 1740.14)

Robert C. Reynolds

The NASA Safety Standard 1740.14 - Guidelines and Assessment Procedures for Limiting Orbital Debris was approved within NASA in August, 1995. Release outside of NASA had been restricted pending release of the Office of Science and Technology Planning (OSTP) report. The safety standard has both guidelines and assessment procedures in five areas: (1) debris released during normal operations, (2) debris generated by accidental explosions and intentional breakups, (3) debris generated by on-orbit collisions, (4) postmission disposal of spacecraft, and (5) debris reentry after postmission disposal. The OSTP report has been published and the standard is now available for general release.

## Engineering Model

Jing Chang Zhang, Don Kessler

The orbital debris modeling team at NASA Johnson Space Center has developed the new engineering model ORDEM96. Unlike previous versions, the new engineering model is not simply a set of equations. Instead, the model describes the environment by the number of particles in orbit, then calculates the flux on a spacecraft or through the field of view of a ground sensor using a

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# News on Upcoming Meetings

## Orbital Debris Workshops

As a part of the process of implementing the NASA policy to limit the generation of orbital debris, JSC is planning to sponsor two industry/government workshops this calendar year. The first of these workshops will be primarily for upper level management and will address the rationale for the guidelines and what will be required of the engineering staff to perform debris assessments. The objective of this workshop will be to familiarize upper level management with the nature of the debris guidelines and help them identify the people within their organizations who should be involved in performing the debris assessments. The second workshop will be designed for the technical staff who perform the debris assessments and will focus on the analysis approach appropriate for each of the guidelines and concepts for introducing mitigation measures required to fall within the guidelines.

The dates for the workshops are unavailable pending the release of the OSTP report. NASA is requesting the Department of Defense co-sponsor the technical workshops.

## 31st COSPAR Scientific Assembly

The 31st Committee on Space Research (COSPAR) Scientific Assembly will be held in Birmingham, UK from July 14 - 21, 1996. There will be sessions on space debris (B0.7 - Space Debris) organized by Prof. Walter Flury of the European Space Operations Center (ESOC) and a session on hypervelocity impact processes (B0.8 - Hypervelocity Impacts in Space: Physics, Chemistry, and Mechanics) organized by Prof. J. A. M. McDonnell of the University of Kent at Canterbury.

## 47th International Astronautical Federation (IAF) Congress

The 47th IAF Congress will be held in Beijing, China on October 7 - 11, 1996. There will be three orbital debris sessions as a part of the 29th Safety and Rescue Symposium (IAA.6). There have also been space debris sessions in the space law colloquia at these meetings in the past. For more information contact: The IAF Secretariat, IAF, 3-5 Rue Mario-Nikis, 75015 Paris, France.

# Project Reviews

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computer program. The new model with the computer program is currently being reviewed.

The model approximates the environment with six different inclination bands, two eccentricity families (circular orbits or highly elliptical orbits), and six source components. Each inclination band has a unique distribution of semi-major axis for circular orbits, and a unique perigee distribution for highly elliptical orbits. In addition, each inclination band has unique size distributions, depending on the source of debris.

The new model is consistent with the U.S. Space Command catalogue for sizes larger than about 10 cm, considering the limitations of the sensors. For smaller sizes, the model is adjusted to be consistent with the flux measured by ground telescopes, the Haystack radar, and the Goldstone radar as well as the flux measured by the LDEF satellite and the Space Shuttle. In regions where no measurement data are available, results of other complex models such as EVOLVE were taken into account.

The computer program utilizes the orbital collision theory of Kessler to relate the distributions of orbital elements to flux on a spacecraft or through a ground sensor. The program is a DOS application, requires little memory, little hard disk and little CPU time; typical run times are less than one second. The program is provided with a menu system whose use is simple and intuitive.

## An Update on the EVOLVE Program

Robert Reynolds, Mark Matney

When there was only USSPACECOMMAND catalog data to serve as a check point for debris environment modeling, it was clear that larger than 10 cm size intact objects and fragmentation debris were the only significant sources of objects in orbit. However, when data started coming back from the Haystack radar, it became clear that at 1 cm debris sizes there had to be non-fragmentation sources of debris. After extensive analysis of this data it appeared that two likely non-fragmentation sources of debris were: (1) sodium-potassium (NaK) liquid droplets associated with ejected reactor cores from Soviet RORSAT satellites, and (2) by-products of solid rocket motor (SRM) burns - thermal liner material, slag, and material from erosion of the exhaust cone.

EVOLVE and its input data for historical traffic have been modified to account for non-fragmentation sources, the first two being the sources described above. The model for SRM uses test data from ground-based SRM firings and model data from SRM design projects and includes not only the number of particles released but also the time of release within the burn and the ejection velocity of the debris relative to the motor. The model for NaK particle production is taken more directly from the Haystack radar data and knowledge of the number of such reactors that have had ejected cores. Inclusion of these sources in EVOLVE has significantly improved the comparison of EVOLVE results with the data. Although work is continuing to improve the models, the conclusion at this time is that these sources can account for the observations and that the nature of these sources is reasonably well understood.

## Debris Environment Modeling

### Using Tethers for Power Augmentation for Space Station

Anette Bade, Bob Reynolds, Don Kessler

The orbital debris modeling group at the NASA Johnson Space Center (JSC) was asked by Marshall Space Flight Center (MSFC) to perform meteoroid and orbital debris assessments for the International Space Station

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Alpha (ISSA) Tether Power Augmentation Study. During the project, JSC performed studies of three different single strand aluminum tether configurations. The length and diameter of the tethers were: (1) 20 km in length, 1 mm diameter, (2) 5 km in length, 5 mm in diameter, and (3) 29.5 km in length and 5 mm diameter. This last configuration was established as the baseline by MSFC. To avoid risk to the STS during rendezvous, the baseline tether was also deployed above the ISSA.

When tethers are used in space, orbital debris is a very important issue. Tethers have a very large collision cross-sectional area for large objects in orbit, so the risk of collision between an operating spacecraft and a tether is much larger than for a normal space system of comparable mass and cross-sectional area. Tethers of normal design are susceptible to being severed by impact with relatively small (on the order of 1/3 to 1/4 the diameter of the tether) M/OD, so the probability that the tether will be cut during mission operations may be high. The resulting tether fragment places other operating S/C at risk and, if deployed upwards, also the ISSA.

In this study a variety of cases were investigated for the frequency in which a tether might be severed by M/OD impact, on the types of orbits assumed by a tether after the severing occurs, and of the level of risk and duration of risk to space systems by tether fragments associated with the ISSA tether. These risk factors depend on the direction of deployment (upward or downward), the tether length, diameter, and mass, and on the area and mass of the end mass (e.g. a plasma contactor for a conducting tether).

## Breakup Modeling Update

Bob Reynolds, Anette Bade, Peter Eichler

The breakup model contained in EVOLVE is currently being reviewed and updated as an interim step to a more comprehensive breakup model revision that is being planned for later this year. Important points in the interim model are:

1. There are two classes of explosions modeled in EVOLVE - high intensity explosions and low intensity explosions. Several types of explosions involve only a fraction of the total vehicle mass going into the fragmentation cloud. This amount of mass is derived from engineering data and analysis of the number of cataloged fragments;

2. There are two size-dependent velocity distributions in EVOLVE - one distribution for explosions and another for collisions. The collision velocity is assumed to be 10 km/sec, which affects both the velocity distribution and the amount of material going into the ejecta cloud;

3. The maximum amount of material that can be put into the ejecta cloud in a collision has been reduced to account for off-center collisions. Various assumptions on momentum transfer in this ejecta cloud and the associated explosion-like fragmentation cloud in catastrophic collisions will be tested with the new model. The new breakup models will be documented in a report on EVOLVE source terms.

## Historical Data Base of Launched Objects 1957-1995

Peter Eichler

The population of objects smaller than 10 cm, which has been generated mainly as a result of more than 100 breakup events in low Earth orbit, has to be modeled by environment evolution models such as NASA's EVOLVE, calibrated by comparison to statistical measurements such as the Haystack radar and LDEF impact crater distributions. While the direct collision risk to spacecraft in orbit is currently dominated by explosion fragments below 10 cm diameter, reliable data on the masses of large objects such as payloads and rocket bodies, is of special interest as this determines the amount of fragments generated in case the object is suffering a breakup event. This is especially the case for long term environment projections and environment stability/critical density analysis, where collisions among objects in earth orbit are playing a dominant role, and reliable assessment of the sizes and masses of the larger object population is essential.

As input data for EVOLVE environment projections, a file is used containing the necessary information on all historical launches between 1957 and 1995. The file contains the required information on all launched payloads, rocket bodies and operational debris: international designator, object number, common name, country of origin, orbital parameters, object type, launcher type, mass, physical dimensions, etc. Within the last 12 months, a major effort was undertaken at NASA/JSC to improve and validate EVOLVE environment projection results. One of the major tasks was to verify, correct and update the data file containing the information on the historical launches used as input for EVOLVE.

Of the 19,097 intact objects contained in the EVOLVE historical launch data set, 3,494 were still in orbit as of January 1, 1995. Combined with more than 10,000 fragments generated by on-orbit breakups, EVOLVE is estimating a total population of nearly 14,000 objects above 10 cm in orbit. By January 1, 1995, from the total of approximately 26,600 tons launched, approximately 2,400 tons are still in orbit, 1,860 of them in low earth orbits below 2000 km altitude.

## Orbital Debris Collector (ODC) on Mir

Glen Cress

As part of the Mir Environment Effects Payload (MEEP), JSC has developed an experiment to capture small size (10µm to 1mm) hypervelocity particles in the Mir environment and return them to earth to determine compositional and texture make-up. The experiment results will complement those obtained from LDEF, will greatly increase the yield of analyzable particle residues, and will provide for man-made vs. natural particles with improved accuracy. The experiment consists of two sets of $SiO_2$ aerogel capture medium (with density of 0.02g/cc) with almost four square feet of surface area each and oriented in opposite directions. The ODC was launched on STS-76, deployed on the Mir Via EVA crewmen and will be returned to Earth on STS-86 after being exposed for about 18 months.

## Orbital Debris Radar Calibration Spheres (ODERACS)

Glen Cress

The processing and analysis of the Haystack

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radar data from ODERACS 1 and ODERACS 2 are nearing completion. A final report is being prepared and will be published this summer. ODERACS 1 deployed six metal calibration spheres from STS-60 in February 1994. ODERACS 2 deployed three metal calibration spheres and three small wire dipoles from STS-63 in February 1995. The primary objectives of the experiments were to verify the calibration accuracy of the Haystack radar and to validate the JSC Orbital Debris Analysis System(ODAS).

The Haystack radar collected multiple measurements from the ODERACS spheres and dipoles. The data were recorded from tracking and fly-through passes. The tracking data from the ODERACS spheres verified the calibration accuracy of the Haystack radar for primary polarization returns, and has provided confidence that the average radar cross-section measurements for small debris are valid.

The tracking data from the ODERACS dipoles confirmed that the primary polarization balanced. The ODERACS fly-through data was used to improve the accuracy of the ODAS for processing orbital debris data and to confirm that the physical sizes and orbital parameters calculated from the Haystack radar measurements are correct.

## Update on Shield Testing at the JSC Hypervelocity Impact Test Facility

Justin Kerr, Jeanne Crews, Eric Christiansen

The NASA JSC Hypervelocity Impact Test Facility (HIT-F) provides hypervelocity impact test and analysis support to the Shuttle and International Space Station (ISS) programs as well as other space flight initiatives. The JSC HIT-F employs three two-stage light gas guns to impact target materials. The light gas guns can repeatably accelerate spheres to velocities exceeding 8 km/s. Personnel recently completed a test report entitled, Hypervelocity Impact Tests on Shuttle Material Targets (JSC-27315).

Hypervelocity impact tests were completed for McDonnell Douglas (MDA) to evaluate the penetration resistance of ISS avionics wire harnesses. MDA wanted to test both unpowered and powered wire harnesses. To satisfy this requirement the HIT-F reconfigured the 17 caliber test range and constructed ISS electronics (RPCMs and DDCU) to support powered wire harness testing. Phase I testing was unpowered and evaluated the performance of the baseline shielding configuration (50% overlay of 1 layer beta cloth) and a protected configuration (50% overlay of 1 layer beta cloth and 1 layer Nextel AF62). Phase II was conducted with powered harnesses and included a third shielding option. Phase III or Sure Kill testing was conducted under powered conditions to determine the impactor size required to short the circuit. Testing showed that the baseline harness fails (wire conductor exposed) when impacted by an aluminum projectile 0.3-0.4 mm in diameter at a velocity of 7 km/s while the protected option fails at a projectile diameter of 1 mm. A follow on series of wire harness tests was conducted to evaluate the Rocketdyne wire harness shielding strategy. Results of this testing are documented in general reports. The first report titled Hypervelocity Impact Test for McDonnell Douglas International Space Station Avionics Wire Harness Phase I was published as a JSC report in October, 1995. Other reports will be published in the coming months.

Current testing at the HIT-F includes MDA Pressurized Mating Adapter (PMA) Phase II M/OD shield testing, CSA/University of Toronto SSRMS boom segment testing, Boeing Phase II ISS M/OD shield certification testing, JPL Cassini MLI M/OD shield testing, and a study of impact effects of pressure vessels.

## Space Station and Orbiter Penetration Risk Assessment

Eric Christiansen, Jim Hyde

The BUMPER code is used to calculate meteoroid and orbital debris (M/OD) penetration probabilities for the International Space Station (ISS), Shuttle Orbiter and other spacecraft such as Hubble Space Telescope, Iridium, Mir, and LDEF. Mission altitude and attitude timelines and a detailed finite element model (FEM) description of the spacecraft are used in the assessments. BUMPER calculations of Shuttle M/OD risks include determining probability of "critical" penetrations, chance of radiator leaks resulting in mission abort, and damage resulting in repairs such as window replacements. Shuttle mission support begins approximately 11 months prior to launch with initial M/OD assessments made in support of the Cargo Integration Review (CIR) followed by periodic updates as mission profiles are adjusted and optimized to reduce M/OD risks. Significant decreases in probability of "critical" penetrations and mission abort due to radiator tube leaks were obtained by adjusting flight attitudes and payload bay door position for several missions including STS-73 and STS-75. A major effort is currently underway to update the Orbiter FEM with improved failure criteria definition and penetration equations. Every FEM element is assigned a material configuration with its particular penetration equation (the current Orbiter FEM model employed by the JSC Hypervelocity Impact Test Facility for these calculations has ~12,600 elements averaging ~2 square feet each). A large number of different penetration equations are needed to describe damage and threshold failure for the different Orbiter materials and systems. These penetration equations have been developed from hypervelocity impact tests at the JSC Hypervelocity Impact Test Facility (HIT-F).

## Orbiter Impact Damage Assessment

Eric Christiansen, Ron Bernhard, Justin Kerr

Post-flight meteoroid and Orbital Debris (M/OD) damage to the Orbiter is identified, analyzed and compared to damage predictions made using the NASA M/OD probability analysis code, BUMPER. These assessments provide an important tool for monitoring changes in the meteoroid and orbital debris environments, and to calibrate the BUMPER damage prediction code. During STS-73 a relatively large (17 mm x 15 mm x 6 mm deep) crater was found on the exterior of OV-102's port payload bay (PLB) door which is covered by a Nomex felt material (flexible reusable surface insulation or FRSI). The outside of the left PLB door was exposed to M/OD impacts in the ram direction for a majority of the 16 day STS-73 mission because the left door was kept nearly closed (~120° closed) to protect the radiator tubes and Spacelab/EDO pallet from M/OD impacts. Analysis of samples recovered from the impact crater indicated this damage was caused by an orbital debris impact. Several pieces of the impactor were removed from the crater; the largest of which measured 1.5 mm x 1 mm x 1 mm and was determined by scanning electron microscope/energy dispersive X-ray analysis (SEM/EDXA) to be a piece of Lead-Tin solder attached to a piece of fiber-board from an electrical circuit board. Other macro-particles (up to 1mm in one dimension) and many microscopic particles of the circuit board were also found

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in the crater. From the crater geometry and results of hypervelocity impact tests on FRSI at the JSC HIT-F, it was determined that the crater was caused by an oblique impact of ~2 mm diameter orbital debris particle impacting at ~4-5 km/sec. This damage and 31 other impacts found and analyzed on OV-102 after STS-73 are described in JSC Report No. 27323 ("STS-73 meteoroid/orbital debris impact damage assessment report"). Orbital debris damage occurring to the Orbiters during STS-73 and other missions during 1995 was generally higher for low altitude missions in 1995 (by factor of ~3-4X) than previous years. Orbital debris fluxes may continue to worsen through 1998 until the solar activity begins to increase which will increase atmospheric drag and hopefully reduce the flux of orbital debris encountered during Shuttle missions.

## Release of Debris Assessment Software (DAS) Version X.09

Robert Reynolds

A beta test version of the Debris Assessment Software is available for user test. The software runs in a DOS-PC environment; it will run under MS Windows, and is being adapted to run under Windows 95. The software was designed to assist in performing assessments as described in NASA Safety Standard 1740.14, and is structured to correspond to the sections of that document. The program functions interactively and produces both tabular and plot output. More information can be obtained from the User's Manual which accompanies the software.

# Abstracts of Papers

## A Comparison of Haystack Radar Measurements with EVOLVE Debris Environment Predictions

Robert Reynolds and Mark Matney

Haystack radar data are an important new source of information on the orbital debris environment. Orbital debris environment models have, for many years, predicted the environment for debris sizes ranging from 1 mm to 10 cm. However, until the Haystack data acquisition began there was no systematic source of data for this size range and model results could not be directly substantiated.

This paper will compare the Haystack data with debris environment predictions made by the EVOLVE program. The data are verifying some model predictions, while indicating areas where existing models need to be improved. The data have established the importance of breakups as a primary source of debris to sizes below 1 cm but also indicated the presence of other debris sources. Data taken by Haystack in the zenith staring mode have established limits on the breakup velocity distribution for explosions; these data also provide information on debris to sizes of roughly 4 mm. Data taken by Haystack at low elevation angle give information on the inclination and, less dramatically, the eccentricity distribution; these data indicate that sources other than breakups must also be contributing to the environment. The evidence of debris streams in the Haystack data can be accounted for by breakups; however, other sources could also contribute.

*Presented at the*
*46th International Astronautical Congress,*
*Oslo, Norway*
*October, 1995*
*Paper No.: IAA-95-IAA.6.3.08*

## A Fast Propagator To Model Orbital Debris Environment Evolution In The Geosynchronous Region

Karl Siebold, Albert Jackson IV, Robert Reynolds

This paper describes the effects of perturbations on the orbital evolution of objects in the geostationary region relevant to debris modeling. An analytic orbital propagator will be presented, which is fast enough to be useful for debris modeling and accurate enough to model all important effects caused by perturbations which affect the geosynchronous region. The geostationary ring is also affected by highly eccentric objects in geosynchronous transfer orbits. This fact will be considered in the propagator. The perturbations included in this propagator are the Lunar and Solar gravitational perturbations, the largest terms in the Earth's gravity harmonics, zonal J2 and tesseral J22. To test the accuracy and speed of the analytic propagator two high fidelity numerical integrators were implemented for verification. Rigorous orbit test cases were chosen for validation. The results of these test cases are presented.

*Presented at the 46th International*
*Astronautical Congress*
*Oslo, Norway*
*October, 1995*
*Paper No.: IAA-95-IAA.6.4.05*

## Synergistic Use Of Debris Environment Models For Flexible, Long Term Projections

Peter Eichler and Robert Reynolds

Long term debris environment projections are of great importance for assessing the necessity and effectiveness of debris mitigation measures. Two types of models have been developed to predict these environments. Environment evolution models like the EVOLVE code are using detailed mission model data to input spacecraft, upper stages, and operational debris into specific orbits at specific times; debris from fragmentations are placed in orbits defined by the state vector of the fragmenting object(s) and the breakup model. The second type, typified by the CHAIN program, uses a particle-in-box model that bins the environment in size and altitude rather than following the orbit evolution of individual debris fragments. A

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# Abstracts of Papers

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three-step approach using both the EVOLVE and CHAIN model in a synergistic way was used to increase the reliability of long-term environment projections. EVOLVE historical projections 1957-1995 could be validated by comparison to measurements. The comparison of 100 year projection runs of EVOLVE and CHAIN for different traffic scenarios showed a good agreement. In this paper, for the first time, CHAIN projections up to 10,000 years, based on validated boundary conditions derived by EVOLVE are presented, indicating clearly the need of early implementation of effective mitigation measures to prevent exponential population growth by collisional cascading effects.

*Presented at the*
*46th International Astronautical Congress,*
*Oslo, Norway*
*October, 1995*
*Paper No.: IAA-95-IAA.6.4.07*

## A Parametric Approach To Evaluating Cost Effectiveness Of Debris Mitigation Measures

Robert Reynolds, Joel Greenberg

There has been increasing concern for the consequences of a growing orbital debris environment on future space operations, and efforts have begun to limit this growth by adopting new design and operations procedures for developing programs. However, any attempts to require the use of debris mitigation measures must consider both the cost of implementing the measures and the effectiveness in reducing the risk to other space users.

A parametric model to characterize spacecraft failure rates in terms of vulnerable area and for various policies on debris mitigation has been developed and integrated within the TECHSAT / SMALLSAT satellite design and life cycle costing model. These models have been utilized to assess the effect of the orbital debris environment on mission life cycle costs. This paper's focus is on developing a methodology for assessing cost-effectiveness of debris mitigation measures. This paper discusses the cost consequences of changing satellite design attributes to respond to debris environment growth and describes how the SMALLSAT and TECHSAT design tools can be used to assess mission life cycle cost impacts from having to operate in the orbital debris environment. It also discusses concerns from having to employ debris mitigation measures to control costs to future programs.

*Presented at the*
*46th International Astronautical Congress,*
*Oslo, Norway*
*October, 1995*
*Paper No.: IAA-95-IAA.6.6.02*

## Micrometeoroid And Orbital Debris Impact Study

Anette Bade, Robert Reynolds, Don Kessler

The orbital debris modeling group at the NASA Johnson Space Center (JSC) was asked by Marshall Space Flight Center (MSFC) to perform meteoroid and orbital debris assessments for the International Space Station Alpha (ISSA) Tether Power Augmentation Study. During the project JSC supported weekly telephone conferences and performed various studies as requested by Les Johnson, the MSFC study leader. This report assimilates and summarizes the results of that effort.

There were three objectives to the JSC M/OD study effort. These were:

1. to estimate expected times required for M/OD impact to sever the tether while it is being used to generate power;
2. to assess the risk the tether represents to other space systems in the same altitude regime as the Space Station; and
3. to assess the risk to Space Station itself from recontact with tether fragments after the tether is cut. The tether might be cut intentionally, to reduce the risk to STS during rendezvous for example, accidentally, or by impact with M/OD.

*Report in support of the Space Station Tether Power Augmentation Study*

## Verification & Validation of the EVOLVE &CHAIN Environment Evolution Models

Robert Reynolds, Peter Eichler, Mark Matney

An important component of the orbital debris environment modeling program at NASA Johnson Space Center is the verification and validation of models used in the debris environment evolution codes. The EVOLVE program was designed to make use of historical launch data and be independent of measurements of the orbital debris environment, so that comparisons of EVOLVE "predictions" of the current environment could be compared with measurements to validate the breakup and orbit evolution models used by EVOLVE. Similarly, EVOLVE and CHAIN, which use radically different methods for calculating debris environment evolution and for calculating collision rates for future environments, can be compared to validate their debris environment projections.

In this paper verification and validation of the environment models will be discussed in three areas. These are:

1. comparison of EVOLVE calculations with data contained in the United States Space Command catalog. This comparison will include comparisons of the environments in general as well as data from breakups;
2. comparison of EVOLVE calculations with Haystack radar data, providing validation of model results to sub-centimeter debris sizes; and
3. comparison of EVOLVE and CHAIN results for debris environment projections for a scenario where future space activity is a continuation of historical trends.

To illustrate the effectiveness of the CHAIN model for studying very long term (100's of years) environment evolution, the EVOLVE/CHAIN comparison cases will be projected by CHAIN into the phase where collisional cascading is dominating debris environment evolution.

*Presented at the 1st International Workshop on Space Debris*
*Moscow, Russia*
*October, 1995*

## Observations Of RORSAT Debris Using The Haystack Radar

Mark Matney , Don Kessler

Debris measurements by the Haystack radar

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since 1990 have revealed a large family of objects in circular orbits with altitudes between 850 and 1000 km and inclinations near 65 degrees. The polarization characteristics of the objects are consistent with small metallic spheres; the majority of which are less than 2 cm in diameter. The flux rates observed indicate that there are some 70,000 such objects in the size range visible to the Haystack radar. The observations to date are totally consistent with the theory that the objects are droplets of the liquid metal Sodium-Potassium coolant used aboard old Soviet RORSAT nuclear reactors that were boosted into these orbits for long-term storage. Currently, no other theory is totally consistent with all the observations. Because some of the cores of the RORSAT reactors were deliberately ejected, it is possible that the majority of the droplets come from the coolant that was in the primary loops of these reactors when they were jettisoned. Such droplets pose a long-term collision problem for satellites in the popular 850 to 1000 km altitude range. Separate studies in 1989 by the Goldstone radar point to a similar swarm of millimeter-sized debris from another RORSAT reactor, Cosmos 1900, at lower altitudes. In addition, chemical analysis of LDEF craters has revealed the presence of micron-sized droplets of Sodium-Potassium in LEO from the RORSATs.

*Presented at the*
*1st International Workshop on Space Debris*
*Moscow, Russia*
*October*

## Revised Abstract: Geosynchronous Orbit Propagation by Symplectic Map

Albert Jackson, IV

A report is given about an orbit propagation method based on a recent development in the numerical integration of differential equations. A method called symplectic mapping. The method has been applied to the propagation of spacecraft and particles in geosynchronous orbit and a high eccentricity orbit. The results of this method have been compared to a very accurate numerical integrator and the comparison presented here. The method is interesting because of improved speed while holding to comparable accuracy as compared to more conventional numerical integrators.

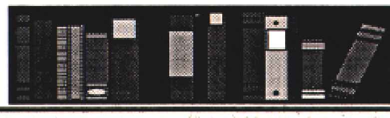
*Presented at the*
*AAS/AIAA Space Flight Mechanics Meeting*
*Austin, Texas*
*February 11-15, 1996*

## A New and Detailed Evaluation of the Number and Masses of Objects in Earth Orbit

Peter Eichler and Phillip Anz-Meador

The risk of collision with orbital debris is of rising concern for spacecraft design and operations. The basis for collision risk analysis is the assessment of the number of objects as a function of mass/size, altitude and inclination. Within the scope of a major update of the historical launch data set at NASA/JSC, several weaknesses (completeness of the data, obsolete masses etc.) could be identified and corrected. In this paper, detailed analysis is presented on the characteristics of the launched objects as well as the orbiting population of 1.1.1995, as their number and masses broken down in country of origin, launcher type used, and orbit type (LEO, MEO, GTO, MOLNIYA, GEO).

*Presented at the*
*AAS/AIAA Space Flight Mechanics Meeting*
*Austin, Texas*
*February 11-15, 1996*



# NEWS

## Russian Views On The "Rorsat" Question

Andrew Potter

Several Russians have expressed skepticism at the conclusion that the unusual objects detected by the Haystack radar in the 900 - 1000 km region are drops of the sodium-potassium alloy used in their nuclear reactors. At the Space Debris Workshop on 09-11 October 1995 in Moscow, S. A. Meshcheryakov presented an analysis of the effects of radiant heating of sodium-potassium alloy by sunlight in vacuum. He concluded that sunlight would quickly evaporate the alloy, so that the particles seen by Haystack radar could not be this material. A preliminary analysis by NASA scientists came to a different conclusion — that the particles would evaporate slowly. Dr. Nazarenko of the Russian Academy of Science has suggested that environment models can be made to fit the data without assuming any special source at that altitude range. The NASA EVOLVE model cannot fit the data without assuming a special source. Evidently, further work is needed to resolve this question.

## Indirect Evidence for Collisions and Explosions.

We rely on the U.S. Space Command to detect breakups. Most commonly, the NAVSPASUR radar fence detects a cloud of objects crossing the fence at about the time that a cataloged object is expected to cross. Breakups detected in this way are guaranteed to be major events, where in most cases, the original object has completely disintegrated. However, we expect smaller events to be more common. For example, models predict that one collision of a 0.5 cm object with large spacecraft in the 900-1100 km altitude region should occur each year. A collision of this kind probably would not lead to complete breakup of the satellite, but would generate clouds of small debris and would make some change to the dynamics of the orbit. Recently, Russian, U.S. and European scientists have pointed out that release of energy by a satellite for whatever reason will abruptly change the orbital elements or the spin rate of the satellite. These changes can be used to identify possible collisions or explosions. An example of this kind of breakup was the Kosmos 1484 breakup that occurred on October 18, 1993. This "breakup" generated a large cloud of small debris, but curiously enough, the satellite appeared completely intact, as seen from radar imaging observations done by the German radar FGAN. However, there was a discontinuous change in the orbital elements of the satellite at about the time of the "breakup". The only source of energy aboard the satellite was a pair of small tanks containing compressed ammonia gas. The tanks were heavily insulated by layers of aluminized mylar. The presumption is that one of the tanks exploded due to overpressure, and generated a cloud of fragments of the aluminized mylar insulation. In this case, the debris generated was detected. However, had it not been seen, the abrupt change in orbital elements would have indicated that an explosive event had taken place on the satellite. Smaller explosions or collisions in low earth orbit might not generate large enough debris to be seen by ground-based radars. Events that occur near the geosynchronous arc or in geotransfer orbits may be too far away to permit radar detection of the debris, even if the fragments are large.

Lydija Rykhlova, M. Smirnov, A. Mikisha, and S. Barabanov of the Institute for Astronomy, Moscow have applied this concept to identify likely breakups in GEO and GTO orbits. They looked for abrupt changes in the orbital semi-major axis in the upper stages that have been used to carry satellites to GEO. Of 52 such stages analyzed, they found 12 that showed significant discontinuous orbit changes. It can be presumed that some explosive event has taken place to cause these changes.

*(Continued from page 7)*

M.J Lewis and R. Sridharan of the Lincoln Laboratory of the Massachusetts Institute for Technology have also looked for anomalies in orbital elements for GEO-related objects. They found 8 suspected breakups, 6 of which were Titan transtages and 2 were payloads. One Titan Transtage (SSC 3432) is definitely a breakup, since the event was observed by ground telescopes.

Bart De Pontieu of the Max Planck Institute at Garching near Munich has applied this concept to satellites in low earth orbit. He used data for the photometric periods of artificial satellites collected by a dedicated group of amateurs, the Belgian Working Group for Satellites, a part of the Belgian Astronomical Society. This group has collected more than 35,000 measurements of more than 1,200 satellites over the last thirty years. De Pontieu found evidence of energetic events for several satellites, as evidenced by abrupt changes in their photometric period. The continued application of this concept to LEO objects may give observational evidence to support theories that predict increasing numbers of collisions of small objects with large satellites.

L. Rykhlova, et al. Presented at the IADC Meeting at ESOC, Darmstadt, 27 February to 1 March, 1996

M.J. Lewis and R. Sridharan. Presented at the 1996 Space Surveillance Workshop, MIT Lincoln Laboratories, April 1-5, 1996

Bart De Pontier, private communication, May, 1996

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