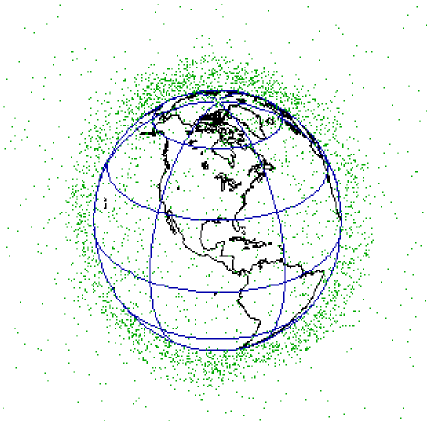
The Orbital Debris Quarterly News



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NEWS

The Search for a Previously Unknown Source of Orbital Debris: The Possibility of a Coolant Leak in Radar Ocean Reconnaissance Satellites (JSC-27737)

Don Kessler

Early models of the orbital debris environment predicted that upper-stage and payload explosions or collisions between objects might produce a significant population in the size range of 1 mm to 10 cm. However, measurements of objects in this size range, begun in 1989, revealed populations with distribution characteristics different from those predicted by either explosions or collisions. The measured spatial and temporal characteristics required that these new populations consist of a large number of small-debris objects injected into orbit with very low velocities relative to one another. In addition, the measured radar polarization of the debris concentration between 850 km and 1000 km was different from that measured at other altitudes, suggesting that this population in near-circular orbits was much more spherical in shape than debris at other altitudes.

Additional measurements and analysis were conducted to try to identify the sources of the new debris. Times of increased flux at 600 km altitudes were found to be associated with overhead passing of COSMOS 1900, a Radar Ocean Reconnaissance Satellite (RORSAT) orbiting around 720 km -- providing a clue about, but not explaining, the higher-altitude debris. Specially-configured measurements using the Haystack radar determined the orbital inclination of the debris source between 850 km and 1000 km to be between 63 and 67 degrees, matching that of the remaining orbiting RORSATs. The RORSAT design was examined to determine a possible cause of this debris and was found to contain a significant amount of coolant consisting of the liquid-metal alloy Sodium-Potassium (NaK). The leakage of this coolant from COSMOS 1900 and a number of other RORSATs, producing a large number of orbiting liquid metal spheres, was consistent with all observations.

Additional experiments were conducted to test the theory of coolant leakage. The Long Duration Exposure Facility (LDEF) was reexamined, resulting in the discovery of hypervelocity impact craters containing NaK. The Haystack and Millstone Hill radars were used with telescopes to acquire and track a sample of small objects in the RORSAT orbits, resulting in detailed radar and optical measurements of nine objects. All nine objects were concluded to be metal spheres with the same mass density as NaK.

While the measurements to date cannot prove conclusively that the RORSATs have leaked NaK into Earth orbit, no other explanation is consistent with all observations. The issue has been discussed with Russia and there is ongoing effort to reach consensus.

Inside...

NEWS, Continued

Newly Recognized 1996 Breakup

Nicholas Johnson

In early 1997, US Space Command began cataloging debris from the apparent April-May, 1996, breakup of an Ariane 4 upper stage. The Ariane 4 H10 rocket body (Sat. No. 21057, International Designator 1991-003C) was left in GTO on 15 January 1991 after successfully releasing the Italsat 1 and Eutelsat 2 F2 spacecraft. Since deliberate passivation of Ariane GTO stages was not implemented until 1993, the vehicle was not purged of its residual propellants or pressurants. Breakup debris from Sat. No. 21057 was first recognized by Naval Space Command analysts in early May 1996, from observations acquired by the Millstone and Eglin radars of the US Space Surveillance Network. The orbit of Sat. No. 21057 on 28 April 1996 was approximately 235 km by 30,930 km with an inclination of 6.7 degrees.

Within two months, element sets for as many as 20 debris had been developed. Official cataloging of the debris began in February 1997, and by the end of March five debris had been assigned permanent satellite numbers: 24722, 24723, 24724, 24741, and 24750. A sixth fragment was also being tracked at that time as an 8X, XXX object. Of the seven objects now being tracked by the SSN (the parent plus six debris), five have exhibited very little orbital decay since the event. These debris possess orbital periods of 542-547 minutes, compared to orbital periods of 404-405 minutes for the parent and one debris.

To date, five other Ariane rocket bodies have been positively linked to on-orbit fragmentations: two Ariane 1 (1979-104 and 1986-019), one Ariane 3 (1987-078), and two Ariane 4 (1991-015 and 1992-021). Sat. No. 21057 represents the longest time from launch to breakup of any of these other events. The longest interval was previously 3 years in contrast to the 5 year interval for Sat. No. 21057. In addition, two other Ariane upper stages from the 1985-056 and 1986-026 missions may have experienced similar breakups based on SSN observations. However, since passivation measures were begun in 1993 for GTO missions, no subsequent Ariane upper stage is known to have broken-up.

In a related matter at the 14th meeting of the Interagency Space Debris Coordination Committee (IADC) in March 1997, a uniform list of historical satellite breakups was adopted. To the compilation of breakups noted in the 10th edition of "History of On-Orbit Satellite

(Continued on page 5)

INTERNATIONAL SPACE MISSIONS, JANUARY - MARCH 1997

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1997-01A	STS-81	USA	381	392	51.6	0	0
1997-02A	GE2	USA	35779	35795	0.0	1	1
1997-02B	NAHUEL 1A	Argentina	35771	35802	0.0		
1997-03A	SOYUZ-TM 25	Russia	378	394	51.6	1	0
1997-04A	STS-82	USA	590	599	28.5	0	0
1997-05A	MUSES B/HARUKA	Japan	576	21399	31.3	1	0
1997-06A	KOSMOS 2337	Russia	1412	1430	82.6	1	0
1997-06B	KOSMOS 2338	Russia	1412	1424	82.6		
1997-06C	KOSMOS 2339	Russia	1412	1416	82.6		
1997-06D	GONETS-D1 4	Russia	1403	1413	82.6		
1997-06E	GONETS-D1 5	Russia	1410	1414	82.6		
1997-06F	GONETS-D1 6	Russia	1412	1416	82.6		
1997-07A	JCSAT 4	Japan	35786	35788	0.0	1	0
1997-08A	USA 130	USA	No Elements Available			3	0
1997-09A	INTELSAT 801	Intelsat	35761	35807	0.0	1	0
1997-10A	ZEYA	Russia	467	479	97.3	1	2
1997-11A	TEMPO 2	USA	35753	35819	0.6	1	0

ORBITAL BOX SCORE

(as of 26 MAR 1997, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies and Debris	Total
CHINA	16	96	112
CIS	1318	2507	3825
ESA	19	183	202
INDIA	14	3	17
JAPAN	56	56	112
US	658	3301	3959
OTHER	229	23	252
TOTAL	2310	6109	8479

NEWS, Continued

'Large' Solid Rocket Motor Particle Impact on Shuttle Window

by Albert Jackson and Ronnie Bernhard

An extensive investigation of the Long Duration Exposure Facility trailing edge found approximately 1000 impacts of which 86% were attributed to micron sized solid rocket motor products. Such particles are expected to be produced during normal thrusting operation of a solid rocket motor. Larger particles in the 100 micron to 1000 micron size range are indeed produced during normal burn but some of these particles are shattered into micron sized particles during passage through the nozzle by strong sheer forces. Many larger particles may be released after motor burnout.

Figures 1 and 2 show an impact crater found on Shuttle window #6 from STS-50 and the chemical analysis of the residue. The crater is roughly one millimeter in size. The impactor is estimated to be 100 to 150 microns in size. The chemistry of this object, as determined from its residue, is aluminum oxide. This would be the first documented instance of an aluminum oxide particle of this size as a known impactor. This particle was originally classified as being metallic aluminum but further energy disperse X-ray analysis in the windowless mode showed it to be aluminum oxide. Solid rocket motor burns could possibly produce pure aluminum also. Therefore of interest are impacts on STS-48 and a 2 mm window crater on STS-71. Both were classified as aluminum but need to be further examined for aluminum oxide.

We have in hand important evidence for particles larger than the .1 to 10 micron sized solid rocket motor flux. Work is under way to identify and model the production of particles the size of 100 microns to 1 cm from spacebased solid rocket motor burns.

(1) Hörz, F., Bernhard, R. P., and See, T., Projectile Composition and Modal Frequencies on the Chemistry of Micrometeroids, LDEF Experiment, *Proc. of the 2nd LDEF Post-Retrieval Symposium, NASA CP-3194*,
551-573, 1992.

(2) Christiansen, E. and Bernhard, R., Scanning Electron Microscope Analysis of Hypervelocity Impacts on Space Shuttle Windows, JSC Technical Report #27147

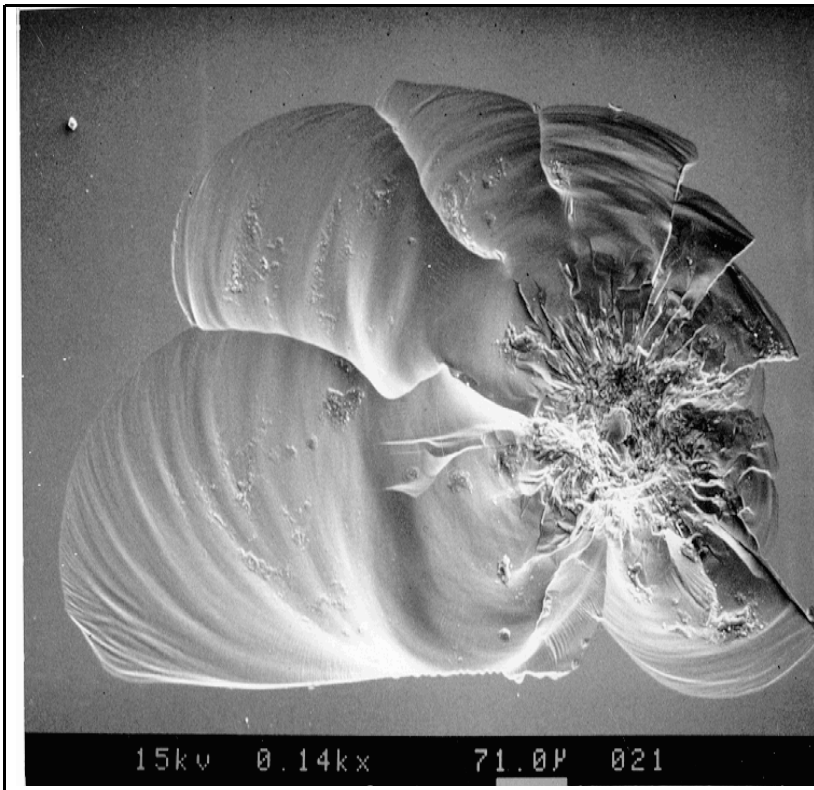


Figure 1 Scanning electron microscope image of hypervelocity impact on shuttle window #6 for mission STS-50.

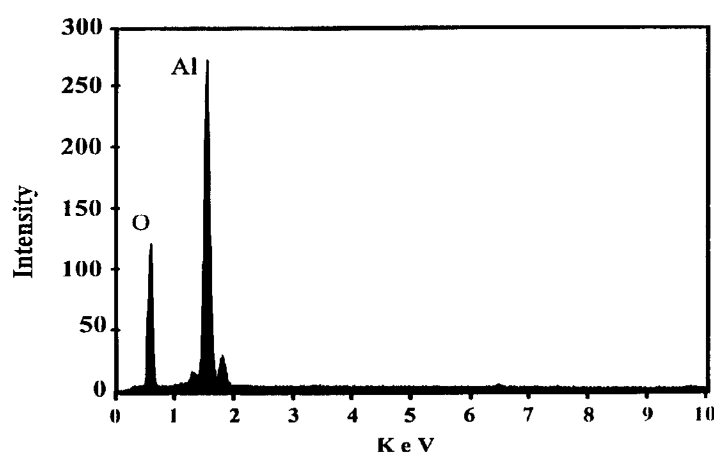


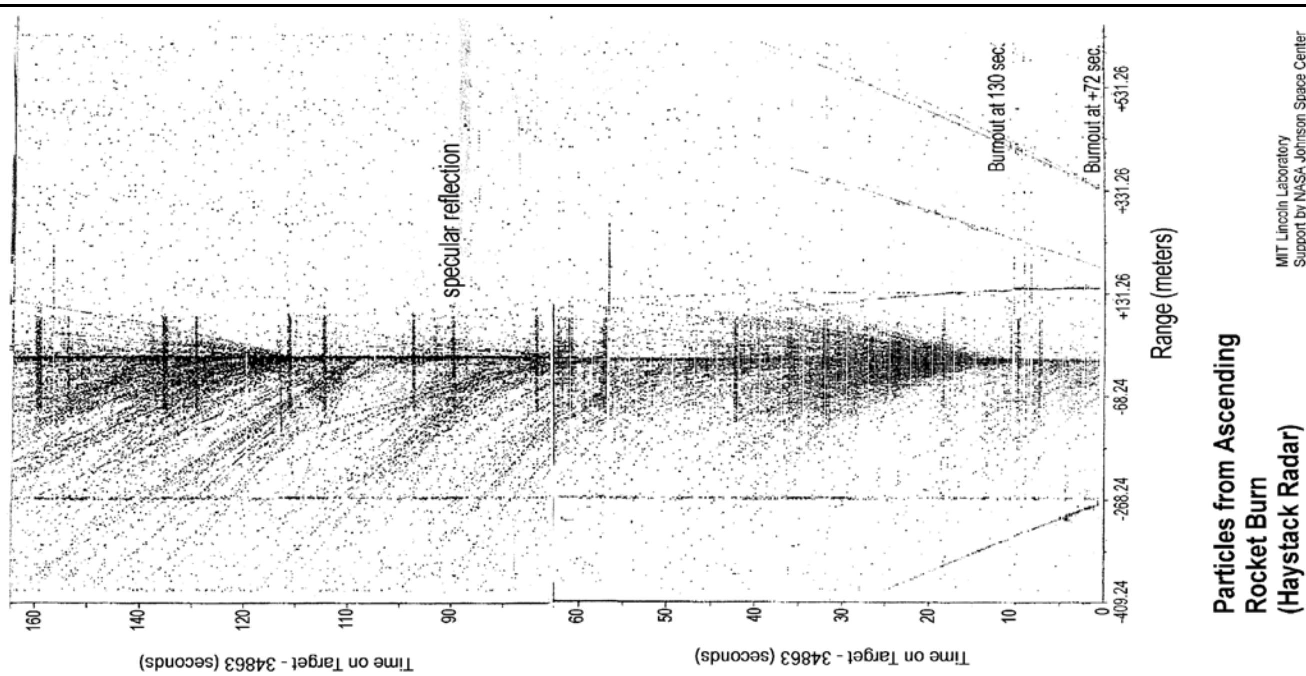
Figure 2. Energy disperse X-Ray analysis of residue found in impact on STS-50. The elements in the spectrum are aluminum and oxygen implying the residue is aluminum oxide.

NEWS, Continued

Rocket Body Components Survive Reentry

Two large fragments of a Delta second stage (1996-24B, Sat. No. 23852), which reentered the Earth's atmosphere on 22 January 1997, have been recovered from Texas fields and transferred to JSC for study. The large object, the main propellant tank made of stainless steel with a mass of more than 250 kg, landed near Georgetown, Texas (30° 37’ N, 97° 40’ W), while the smaller, 30 kg titanium sphere used for helium pressurant was found further downrange near Seguin, Texas (29° 35’ N, 97° 58’ W). An additional, very small and light-weight fragment may have landed near Tulsa, Oklahoma.

After delivering its MSX payload to a 902 x 911 km, sun-synchronous orbit, the rocket body was commanded to perform a propellant-depletion burn which moved the vehicle into a 207 by 860 km orbit. This maneuver reduced the orbital lifetime of the stage from several hundred years to only nine months. Whereas the propellant tank exhibited no apparent region of concentrated reentry heating, distinct differences in the two hemispheres of the titanium sphere indicate the object may have been stabilized through much of the reentry process. Efforts are underway at JSC to improve computer simulations which predict what type of spacecraft and rocket body components are likely to survive natural orbital decay.



Portion of a radar track of an ascending SRM vehicle showing release of particulates after completion of the burn. The track after burnout extended over 313 seconds. The particle size range sensed was approximately 0.5 to 3 centimeters. The measurements were performed by MIT Lincoln Laboratory with the Haystack Radar.

Upcoming Meetings

Seventh International Space Conference of Pacific-Basin Societies (7th ISCOPS), Nagasaki, Japan, 15-18 July 1997. Session C8 suggested as Space Debris and Environment. For further information contact: Prof. Kuninori T. Uesugi, ISAS, Telephone 81-427-51-3911 ext. 2328, FAX 81-427-59-4241; email: tono@ISASMAC1.newslan.isas.ac.jp

SPIE - Optical Science, Engineering and Instrumentation SD97 Symposium, 27 July - 01 August 1997, San Diego California, U.S.A. This year's theme promotes a comprehensive understanding of the debris environment with an eye toward evaluating the limitations of our knowledge, and to continue to explore the practical implications of operating in an environment with debris. For further information visit the SPIE Web Site at http://www.spie.org/web/meetings/calls/submissions.html or phone 360/676-3290; FAX 360/647-1445; e-mail: sd97@spie.org.

International Astronautical Congress (IAF), 06-10 October 1997, Turin, Italy. The conference theme "Developing Business for Space" will be explored through a series of symposia. Topics to include space technology, inner and outer space missions, economic, legal, management, political and environmental aspects of the world's programs for peaceful utilization of space. For further information, please contact the IAF Secretariat, International Astronautical Federation, 3-5 Rue Mario-Nikis, 75015 Paris - France

Meeting Report

14th Meeting of the IADC

The 14th working meeting of the Inter-Agency Space Debris Coordination Meeting was held at the European Space Operations Center in Darmstadt, Germany, during 20-21 March. One of the first actions of the IADC Steering Group was the acceptance of Germany as the newest member of the organization, joining China, ESA, France, India, Japan, Russia, United Kingdom, and United States. The two-day meeting witnessed productive sessions of the four working groups and tentative agreements in three major areas.

First, preliminary consensus was reached on the architecture of a risk object reentry notification system designed to provide all IADC members with the most accurate reentry predictions for large objects and satellites containing potentially hazardous materials. The US Space Surveillance Network and the Russian Space Surveillance System will provide their routine tracking data to an IADC risk object database available to all IADC members on a bulletin board system maintained by ESA. Other IADC members are encouraged to share their own tracking data and their reentry predictions. Once approved by the respective IADC member governments, the risk object reentry notification system may be implemented quickly.

The foundation of an IADC Common Database is also taking shape. Again available on an ESA-run bulletin board for easy access by IADC members, the database will initially contain the following information: (1) solar and geomagnetic activity and forecasts, (2) data on launch sites and launch vehicles, (3) geometric and radar cross-section descriptions of spacecraft and rocket bodies, (4) spacecraft name, initial orbit, and mission, (5) a table of historic satellite fragmentations, and (6) satellite orbital parameters and status, as provided in the current NASA Satellite Situation Report.

Finally, plans were prepared to begin an international GEO orbital debris search in the Fall of 1997. The NASA CCD Debris Telescope and the ESA 1-m Zeiss telescope will start observations in October with the goal of characterizing the population of uncontrolled small objects, possibly breakup debris, near the GEO regime. As schedules permit, the Japanese NAO and CRL telescopes, the Swiss Zimmerwald telescope, and Russian and Chinese facilities will also conduct GEO orbital debris surveys. Particular attention will be paid to estimating the mean motion, inclination, and right ascension of the ascending node of the objects detected.

The next meeting of the IADC will take place in December 1997 in the USA.

(Continued from page 2)

Fragmentations" (prepared by Teledyne Brown Engineering for NASA Johnson Space Center, July 1996), the recent breakups of the STEP II rocket body (1994-09), the CERISE spacecraft (1995-033), and the Cosmos 1883-1885 auxiliary motor (1987-79) were added as was the breakup of the Cosmos 1714 rocket body which brokeup in late December 1985 on the day of launch. This last breakup of a Zenit upper stage was identified in 1995 ("History of Soviet/Russian Satellite Fragmentations - A Joint US-Russian Investigation", prepared by Kaman Sciences Corporation for NASA Johnson Space Center, October, 1995).

Guest Article

An International Review of Debris Source Modeling

Darren McKnight

Orbital debris has been defined as "any manmade Earth-orbiting object which is nonfunctional with no reasonable expectation of assuming or resuming its intended function or any other function for which it is or can be expected to be authorized, including fragments and parts thereof." (Ref. 1) As is implied by this definition, large intact rocket bodies and payloads are considered debris once they no longer perform their intended mission. The modeling of the deposition of these large objects is handled by launch traffic models and often reinforced with constant observations. In the last issue of this newsletter, the other extreme of debris sources was covered: debris wakes.

There is, however, a significant number of sources between these two extremes. Objects are released during normal operations such as lens covers, refuse, etc. Even smaller debris such as solid rocket motor effluents are produced in large quantities during normal operations; this is an especially important debris source in geosynchronous transfer orbits. Sometimes debris is released in small quantities due to anomalous problems such as Na-K leaks from nuclear reactors. But by far the most prolific source of lethal-sized debris is satellite fragmentations. Satellites have broken up in orbit over 130 times in the last 40 years - almost all of these being explosions of some type.

With fragmentation debris accounting for nearly fifty percent of all the trackable debris currently in orbit, and probably a much higher percentage of the critical 1-10 cm debris, the modeling techniques for this source are critically important to determination of current and future hazard from debris. There are basically two key truths in the international fora of breakup modeling: 1) all modeling begins with data and there is not enough data, and 2) almost all breakup models evolved out of the same initial formulations.

MORE DATA IS NEEDED

Both explosion and collisional fragmentation models have a shortage of data for comprehensive validation. Explosion models generated in the 1970's built upon the debris from an Atlas tank fragmentation that occurred in support of a penetration aids program. From this data acquisition opportunity, a fairly complex model was instantiated based upon the Mott fragmentation theory. (Ref. 2) In the 1980's, several attempts were made to reduce fragmentation data from on-orbit explosions to help support the development and/or validation of existing models. However, it is very difficult to convert measured radar cross-section (RCS) to fragment mass reliably so this data is very suspect for detailed model adjustments. In the early 1990's, the European Space Operations Centre (ESOC) sponsored a major explosion modeling effort that revolved around a significant experimental program. (Ref. 3)

Collisional fragmentation models had their genesis in the 1970's with theoretical extrapolations of impacts into semi-infinite targets. (Ref. 4) In the 1980's, data from US Department of Defense programs for antisatellite and spacebased defensive systems yielded a vast amount of data that supported development of collisional breakup models. In the 1990's, the Satellite Orbital Debris Characterization Impact Test (SOCIT) Series was conducted which fragmented a series of real space hardware via hypervelocity impact. (Ref. 5) As a result of these data acquisition efforts, key aspects of hypervelocity impact breakup models have evolved into fairly robust applications.

MOST MODELING HAS SAME ROOTS

Breakup models nominally consist of mass and velocity distributions plus some conversion algorithm between size and mass. However, over time the importance of the ballistic coefficient for fragments has resulted in distributions being generated for this parameter. Normally these parameters are determined as a function of mass but some models provide them as a function of size. In general, there have not been wholesale changes to breakup models used 20 years ago. There have really been two major changes: 1) changing of fixed constants in equations to scenario-dependent variables and 2) more analytic considerations infused into the models.

The explosion model originally hypothesized by Bess in his landmark paper in 1975 and recasted in 1985 by Su and Kessler (Ref. 6), has held up very well over the years. Debris environment modelers around the world use the original algorithms in varying degrees. The Japanese, the Italians (CNUCE) and the British at the Defence Evaluation and Research Agency (DERA) all use the same basic relationship derived from the Atlas tank explosion years before. However, the work performed by ESOC in the early 1990's has provided the impetus for new advances in explosion modeling that should be examined carefully due to the meticulous experimental plan executed by ESOC. While ESOC branched out from the original NASA formulation by acquiring more data and reducing it appropriately, two separate US Department of Defense entities developed new algorithms based upon analytical processes. The concept of two different types of explosions - high-intensity and low-intensity - has remained intact from the early formulation and has even been refined in recent years by analysts outside of the US. Russian explosion models are uniquely not based upon the same tenets and data as used by everyone else. However, while this fresh outlook has the potential for being useful for the orbital debris community, their algorithms are not sufficiently mature operationally to provide an alternative for consideration. The main work in this area known to the author is by Kiselev at Moscow State University.

Collisional fragmentation models have been applied and developed internationally much like explosion models. The power law was proposed in the 1970's by NASA and accepted almost universally. (Ref. 6) However, as more data became available in the 1980's, the fixed constants of the mass distribution algorithm were replaced by variables that were determined from the specific scenario being considered. (Ref. 7) While the mass distribution was enhanced over the years, so has the "complete fragmentation threshold" - the condition that

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Project Reviews

LEO Constellation Studies

R. Reynolds and A. Bade

One of the new areas for orbital debris analysis is the consideration of LEO satellite constellations in performing orbital debris environment projections. To better understand this problem, a new project has been started to: (1) characterize the effects of the orbital debris environment on LEO constellations and (2) understand the effects of the orbital debris environment component induced by the constellation on the constellation itself as well as on other users of space. To this end, a new model (CONSTELL) has been developed to perform either assessments for specific constellation architectures or to perform parametric studies to better understand the sensitivity of constellations with regard to various design and operational factors.

CONSTELL will be used to analyze the problem of multiple constellations operating simultaneously in LEO. The objectives of the work are: (1) to quantify the impact risk imposed on constellations by the constellation itself and by other users of space; (2) to evaluate different design options and operational procedures that might be considered to limit the risk of damage and failure of constellation spacecraft caused by debris impact; (3) to develop predictive risk parameters based on background orbital debris and constellation architecture characteristics that might be used to estimate debris effects on constellations and other users of space; and (4) to understand the sensitivity of the predictions to uncertainties in assumptions (such as the sensitivity of the spacecraft design to debris impact) and contributing models (such as the collisional breakup model).

The CONSTELL model contains a reasonably detailed simulation for the constellation architecture. Some of the architecture parameters that can be considered in this model are presented in the following table:

	COMMENTS
MAJOR PARAMETERS	
Constellation Altitude	Keep altitude as low as possible. Higher altitude generally leads to higher background debris fluxes, leads to longer lifetimes for debris generated by constellation.
Number of Operational Spacecraft	More operational s/c leads to greater feedback of constellation debris with the constellation
Size (Mass) of Spacecraft and Upper Stages	Increased collision cross-section leads to greater collisional interaction, more mass leads to more debris generated in catastrophic breakup
Size of Debris Causing Loss of Operational Spacecraft	Determines the importance of debris impact relative to design failures
Spacecraft Operational Lifetime	Controls the amount of constellation support traffic, number of inactive spacecraft in the environment
Technology Replacement Cycle Time	Controls the amount of constellation support traffic, number of inactive spacecraft in the environment
Constellation Lifetime	More or less important depending on the constellation altitude
Disposal Orbit Perigee Altitude	For both upper stages and inactive spacecraft; controls the amount of time inactive spacecraft and upper stages remains in the environment; can lead to localized increase in spatial densities that affect other programs
SECONDARY PARAMETERS	
Mission Orbit Inclination	Higher inclinations yield higher average relative velocities on impact, more spatial density enhancement at peak latitudes
Spacecraft Disposal Option	Re-Orbit or abandon; will become more important the higher the constellation altitude
Probability of Accidental Explosion of Upper Stage	Secondary because probability will always be small
(Planned) Probability of Spacecraft Design Failure	Loss of function or loss of control; contributes to number of inactive spacecraft in environment
Number of Spacecraft Delivered per Upper Stage	Controls the number of spent upper stages in the environment; may be different for constellation deployment and spacecraft replacement

Abstracts from Papers

NASA/JSC ORBITAL DEBRIS MODELS

Nicholas Johnson, Eric Christiansen, Robert Reynolds, Mark Matney, Jing-Chang Zhang and Al Jackson

NASA Johnson Space Center's orbital debris program develops and maintains an extensive assortment of computer models and simulations along with the requisite input databases. The major models and simulations can be categorized as environment definition and risk assessment. The EVOLVE and ORDEM96 (Orbital Debris Engineering Model 1996) computer programs determine the past, present and future near-Earth orbital particulate environment while the BUMPER and DAS (Debris Assessment Software) computer programs provide a means for evaluating the risks of specific space missions. The recently completed ORDEM96 engineering model has been officially released to the international orbital debris community. The BUMPER model, which has been adopted by the US Space Shuttle program and the International Space Station program, has also been improved and now incorporates the ORDEM96 environment prediction. DAS also assists the space program manager in making debris mitigation decisions in accordance with NASA Safety Standard 1740.14. To support tese principal models and to conduct specialized analyses, NASA/JSC employs a host of auxiliary models, including explosion and collision satellite breakup models, orbit propagation and decay models, space traffic models, solid rocket motor effluent models, hypervelocity impact ballistic limit models and models to relate debris measurements to debris environment model parameters. Special emphasis is now being placed on increasing the fidelity of GEO environment models, future traffic models, highly elliptical orbit propagation models and solid rocket motor effluent models.

SPACE DEBRIS MITIGATION

Joseph Loftus, Jr.

The continual accumulation of mass and cross-section on orbit increases the potential for future collisions among derelict objects and potentially with active satellites. There has been one confirmed collision between a piece of debris and an active satellite. There are a number of cases that are suspect to collisions between inactive objects.

There are a significant number of LEO constellations planned for deployment over the next 15 years and the effect will be to significantly increase spatial density in low Earth orbit. Of 961 communications spacecraft proposed for the period 1997 to 2005, 672 are low earth orbit constellations. Both design and operations practices will be required to manage these activities efficiently.

The cost of mitigation measures is strongly a function of the timeliness of the planning for dealing with the issue. Most of the constellations are planning on active control measures for both the spacecraft and the launch vehicle upper stage.

During the next decade, it will be necessary to decommission many of the spacecraft deployed in GSO in the early 1980's. Many of these systems have experienced significant degradation which limits the effectiveness of disposal options. None of these spacecraft were designed with end of mission disposition requirements. It is clear that there will need to be consideration given to the end of life disposition in future designs.

DEBRIS ENVIRONMENT INTERACTIONS WITH LEO CONSTELLATIONS

Karl Siebold, Robert Reynolds, Anette Bade and Nicholas Johnson

Several low Earth orbit (LEO) constellations for world-wide telecommunication services are being planned for deployment in LEO in the near future. Because of their size and complexity, these constellations have the potential for contributing to the orbital debris environment at a significant level. In this paper, we present the results of a parametric assessment of the impact of LEO constellations on the orbital debris environment. The increase in loss rate of non-constellation spacecraft is considered in this analysis as well as the increase in loss rate or replacement rate for constellation satellites as a result of debris impact. Primary parameters in the analysis are the number, size, altitude and inclination of the constellation. Parameters are also defined for the vulnerable area for loss of spacecraft and disposition of constellation spacecraft at the end of life. In this paper we also present preliminary results for debris environment effects when there is more than one LEO constellation.

MODELING METEOROID/ ORBITAL DEBRIS IMPACTS FOR THE RUSSIAN SPACE STATION MIR

Eric Christiansen and James Hyde

The Russian Mir orbital station represents a significant source of information concerning the effects of the meteoroid/orbital debris (M/OD) environment due to its large area (now ~1000 m^2 excluding solar arrays) and long exposure duration (up to 10 years for some components). Of particular interest is the comparison of predicted levels of damage using the M/OD probability analysis code BUMPER to actual damage sustained during flight. This paper provides BUMPER predictions of pressure shell "leaks" and solar array impacts which are compared to Mir flight experience. This exercise serves a useful purpose in calibrating BUMPER results which are used in M/OD risk assessments for the International Space Station (ISS) and the Space Shuttle.

Progressively more detailed M/OD assessments have been performed at the NASA Johnson Space Center (JSC) Hypervelocity Impact Test Facility (HIT-F) since 1991 using the BUMPER code. The M/OD calculations have been refined through improved modeling of Mir structural shielding dimensions and material properties, and the results of hypervelocity impact (HVI) testing at the HIT-F and in Russia. Ballistic limit equations to predict threshold perforation of the Mir pressure shell or critical components are required for the ~50 shield types on Mir.

MODELING FLUXES RESULTING FROM NEW OR MOLNIYA-CLASS OBJECTS

Jing-Chang Zhang, Karl Siebold and Nicholas Johnson

Molniya-type orbits are highly elliptical with

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Abstracts from Papers

(Continued from page 8)
an inclination around 63° and perigee typically in the southern hemisphere. Satellites occupying these orbits are either Russian Molniya communications spacecraft with argument of perigee initially at 280° or 288° or Russian Kosmos spacecraft with argument of perigee initially at 316° or 318°. The inclinations of these orbits are chosen to maintain a fairly stable argument of perigee.

To calculate the fluxes on a spacecraft caused by orbital debris, it is common practice to assume that the argument of perigee (ω) and the right ascension of ascending node (Ω) are randomly distributed. For Molniya orbits, however, this assumption is not valid as the argument of perigee is stable rather than random. This is one of the major reasons why Molniya-type orbits have been excluded from modeling in ORDEM96 (the NASA 1996 engineering model).

When a new breakup occurs, the debris produced by the breakup increases the collision risk in some region over a period of time. Since the orbits of those debris are concentrated in the neighborhood of the parent orbit, the assumption of random argument of perigee and random right ascension of ascending node does not apply, either. Therefore, there is a need to address such a risk specifically.

In this paper, an approach is provided which calculates the collision probability without making the assumption of random Ω and ω. This approach is used to calculate the fluxes resulting from objects in Molniya-type orbits. A parametric study is conducted on fluxes caused by a Molniya-type object whereby the orbital altitude and inclination of the target object is varied. Such results are important for future update of ORDEM96 to include Molniya-type orbits.

This approach can also be used to handle a new breakup. As an example, the fluxes from the recent Pegasus breakup debris for a Space Shuttle mission are calculated and compared with the background flux. Finally, errors that might be made if assuming random Ω and ω are addressed.

A COMPARISON OF HAYSTACK AND HAX MEASUREMENTS OF THE ORBITAL DEBRIS ENVIRONMENT

Eugene Stansbery and Thomas Settecerri

The NASA Johnson Space Center Space Science Branch has been analyzing orbital debris data collected by the Haystack radar, operating at 10 GHz, since 1990. The major objective of these measurements has been to characterize the debris environment for the International Space Station and the U.S. Space Shuttle. The environment has been characterized by number, size, altitude, and inclination. The Haystack Auxiliary (HAX) radar, operating at 16 GHz, began collecting orbital debris data in 1995. The HAX radar is less sensitive than Haystack but is available more often. HAX utilizes similar data collection procedures, the same real-time data collection system and the same analysis software as Haystack. Therefore, results from the two radars should be consistent with each other after accounting for the known differences in sensitivity and wavelength. This paper discusses the data collection and analysis of the two data sets and the reasons for any differences between the two results.

RADAR MEASUREMENTS OF THE PEGASUS DEBRIS CLOUD

Eugene Stansbery, R. Goldstein, Thomas Settecerri and Mark Matney

On June 3, 1996, a 97 kg Pegasus rocket body broke into over 700 debris pieces tracked by the Space Surveillance Network (SSN). This is an unusually high number of debris pieces for such a small object. The Haystack radar observed this debris cloud in August and again in October 1996. The cloud was also observed by the Goldstone radar in October 1996. These two radars provide an estimate of the number of pieces associated with this breakup for debris sizes as small as 4 mm diameter.

CHARACTERIZATION OF THE BREAKUP OF THE PEGASUS ROCKET BODY 1994-029B

Nicholas Johnson, Eugene Stansbery, Mark Matney, Tom Settecerri and R. M. Goldstein

The breakup of a Pegasus Hydrazine Auxiliary Propulsion System (HAPS) [Satellite Number 23106, International Designator 1994-029B] on 3 June 1996 is now officially recognized as the worst satellite breakup on record in terms of cataloged debris. The number of debris produced by the relatively small vehicle (<100 kg) and debris decay characteristics have posed serious debris modeling difficulties. One noteworthy aspect of the Pegasus HAPS, which was not passivated at the end of mission, was its use of graphite-epoxy overwrap of aluminum liners for the propellant and pressurant tanks. The low altitude of the breakup and the large range of ejection velocities have also presented special concerns for other spacecraft in low Earth orbit, in particular the US Space Shuttle and the Hubble Space Telescope. In addition to orbital data collected by the US Space Surveillance Network, special observations of the debris cloud have been conducted by the Haystack and Goldstone radars. These observations have shown tha the overabundance of debris is not only limited to the trackable population but also extends to debris diameters well below 1 cm. Attempts to detect the debris with optical sensors have been less successful. This paper presents NASA Johnson Space Center's analysis of the Pegasus HAPS fragmentation event and how these debris contribute to the current and future near-Earth space environment.

AN OVERVIEW OF REVISED NASA SAFETY STANDARD 1740.14

Robert Reynolds, P. Eichler and Nicholas Johnson

The NASA Policy to limit the generation of orbital debris on NASA missions was stated in NASA Management Instruction 1700.8. This policy was implemented in the form of a NASA Safety Standard (NSS 1740.14) in

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August of 1995. Since the publication of this standard, all NASA programs have begun to perform orbital debris assessments as a part of their design development activity. Debris assessment reports are provided to the NASA Associate Administrator supporting their program for review and approval and to the NASA Office of Safety and Mission Assurance (Code Q) for review and concurrence. Established programs and programs far enough into their development so that the costs for redesign to meet the guidelines would be excessive and which were, therefore, grandfathered from having to meet the guidelines have been asked to review their operations procedures to determine if there are low-cost measures that should be taken to reduce their potential generation of orbital debris.

The experience gained in evaluating program responses and responding to program queries has led to release of an update to NSS 1740.14. While there have been some revisions to the guidelines, the intent of the guidelines remains the same. In particular, there has been no revision of the 25-year rule for low Earth orbit postmission disposal or in the guideline for disposal orbits for geosynchronous missions. Tethers, which were treated within the guidelines in the first version of the standard, are now treated in a separate section. Finally, the process of providing the assessment of the upper stage for a payload program is clarified.

REPORT ON THE NASA/ SCHMIDT GEO SURVEY PROGRAM

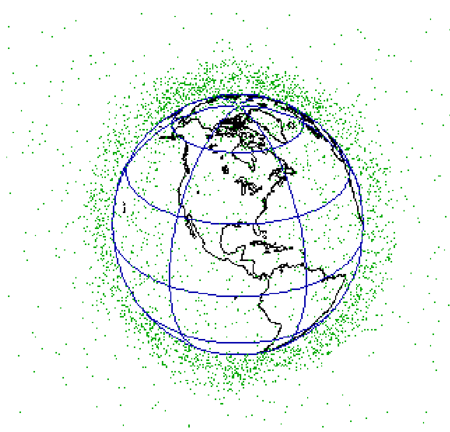
David Talent, Thomas Settecerri, Andrew Potter and Karl Henize

During the interval from December 1992 through April 1994, five observing runs were conducted on Mt. Haleakala, Maui, HI by observers from NASA Johnson Space Center for the purpose of obtaining data on the orbital debris population in and near geosynchronous orbit. The instrument used during the investigation was the NASA 32-cm diameter, f/1.3 Schmidt Telescope with a Thompson 7882 (384 x 576) CCD; the imaging field of view was 1.8 X 1.2 degrees. Limiting performance, under typical location conditions, was characterized by the detection of stars of magnitude 17.1 during standard star field exposures of 30 seconds duration. A total of 42 nights (252 hours) of image data were obtained. The telescope and camera, under computer control, obtained images of field positions on the sky at small solar phase angles ahead of, or behind, the antisolar point on the sky. To facilitate the search for previously uncatalogued debris pieces, two images, separated by 51 seconds in time, were obtained of each field. Over 3000 images were obtained during the program. Many of the objects detected were easily correlated with known objects. In total, about 330 uncorrelated target (UCT) observations were culled from the background of known objects. Correcting for redundant observations, the UCT list was reduced to about 140 unique objects. This suggests that 20% to 30% of the GEO population detectable with the NASA/Schmidt is currently not part of the tracked population. Sizes indicated by simple interpretation of the observed magnitudes indicate that most of these objects have characteristic dimensions between 0.5 to 1.0 m. Additionally, orbits derived under circular orbit assumptions suggest that some of the UCTs may have a common origin. Possible breakups, some previously unknown, will be discussed.

THE HISTORICAL CONTRIBUTION OF SOLID ROCKET MOTORS TO THE ONE CENTIMETER DEBRIS POPULATION

Albert Jackson, Peter Eichler, Robert Reynolds, Andrew Potter and Nicholas Johnson

We have an ongoing activity to advance our understanding of SRM contributions to the debris environment and enhance our modeling of such contributions to orbital debris. It is known that the SRM particle deposition must manifest itself in the small particle population of .1 to 10 microns size, but we present arguments that there should be a larger particle SRM constituent in the 1 mm to 1 cm size range. The motivation for this arises from radar observations of the particle environment show a population in the 1 cm and down range that needs a source, and aluminum and aluminum oxide particle impacts on the Shuttle in the size range of 100 to 150 microns composed of aluminum and aluminum oxide. We present a radar track of an ascending SRM that shows the ejection of many small particles for a considerable time after burn out. The various lines of indirect evidence about inflight SRM particle ejection are summarized. Some modeling of ejection, orbit evolution and spatial densities due to SRM particle is presented.



Guest Article, Continued

must exist for an object to be totally fragmented. Analysts at ESOC and DRA use relationships developed in the US in their entirety. The Italians at CNUCE use the nominal relationships summarized in Ref. 6 with some slight modifications to the fragmentation threshold. The Japanese community is more concerned with geosynchronous satellites and, as such, do not need to consider such high impact velocities - 500 m/s in GEO vice 10 km/s in LEO. A recent paper reviewed how they have modified the basic power law for use in GEO. (Ref. 8) No significant original work in the area of collision-induced fragmentation of on-orbit assets has been discovered in the Russian literature. The velocity distribution for collisional breakups is very, very data-limited yet everyone internationally basically uses the same model or an analytically-equivalent relationship.

USE OF DEBRIS SOURCE MODELS

This short examination of breakup models has shown that there is a fairly consistent application of models internationally. However, as these are applied to determine the state of the debris environment now and in the future by different countries with different objectives in mind, the results diverge significantly. In the next issue of this newsletter, an international review of environment modeling techniques will be provided which are partially based upon the breakup models just examined.

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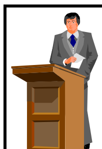

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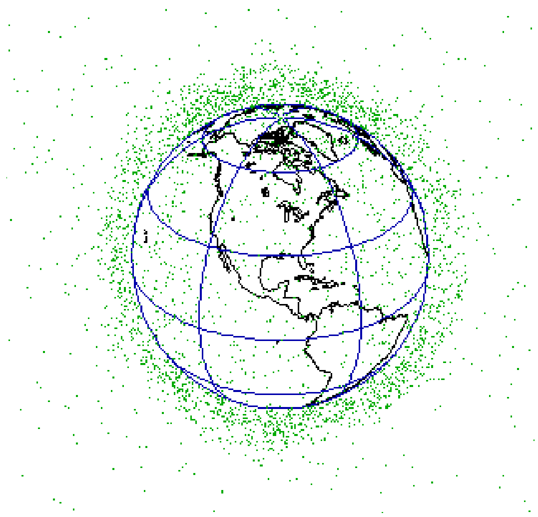
If possible please send a hard copy of the paper to the mailing address above to assure that the electronic version was received unchanged.

Editor's Note

This past quarter has been very interesting for the orbital debris community. The survival of at least two tanks from the MSX upper stage reentry highlighted the need to understand survival of components of reentering space systems when orbit decay and atmospheric reentry is being used as a means of controlling growth of the orbital debris environment. This subject is being addressed by the IADC.

The second European Conference on Space Debris, held in Darmstadt Germany, March 17-19, was a great success. Professor Walter Flury, the conference organizer, is planning to publish all papers from the conference as an ESA technical report. We will announce publication of this report when it occurs.

Plans for the upcoming US Government/Industry workshop on orbital debris continue to develop. The workshop could occcur as early as August but maybe later. The meeting date should be set by the time the next issue of the newsletter comes out. The workshop will also be announced electronically on the Orbital Debris home page.



Next Issue

Haystack Data Processing Update

News on Government Industry/ Orbital Debris Workshop

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