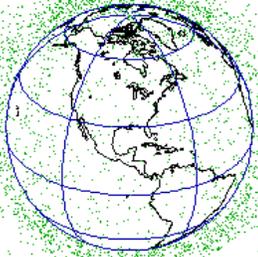


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NEWS

NEWS

Naval Space Operations Center Finds New Evidence of Debris Separations from Three Spacecraft

N. Johnson

During July and August personnel of the Naval Space Operations Center, which serves as the alternate Space Control Center for the US Space Surveillance Network, detected five new debris from three spacecraft, each more than 15 years old. The causes of these "anomalous events", which involve very low separation velocities, remain a mystery, although material degradation or small particle impacts are probable agents.

At least six polar-orbiting Transit satellites have generated debris more than 20 years after launch. Sometime between 20 and 23 July, a single object was released from Transit 17 (1967-92A, Satellite Number 2965), marking at least the fourth such event for this spacecraft since 1981. The last previous debris release was in December 1996 (see Orbital Debris Quarterly News, January 1997). The five debris previously cataloged with this source all exhibited high area-to-mass ratios and have decayed from orbit.

Another newly discovered debris has been

traced to Transit 10 (1965-109A, Satellite Number 1864) which was also involved in a late 1996 release. The debris was found in early August, but orbital analysis could not determine when it had been created. The two debris pieces remain in orbits very similar to that of the parent.

In late August the NOAA 7 spacecraft (1981-59A, Satellite Number 12553) spawned at least three new debris, one of which was cataloged as Satellite Number 24935. The debris appear to have been released, perhaps at the same time, during 23-24 August. The spacecraft had previously released two debris on 26 July 1993, three years after spacecraft deactivation, but both decayed the following year.

The mechanism behind the generation of anomalous event debris large enough to be tracked by ground-based sensors remains poorly understood. Some space objects, e.g., U.S. Transit spacecraft and Soviet Vostok upper stages, seem predisposed to such incidents and, therefore, are probably related

to the design or materials selection of the vehicles. Transit spacecraft are likely to exhibit multiple events, whereas the Vostok upper stages appear limited to a single event. However, only a small percentage of vehicles in these families are involved in anomalous events.

A newly cataloged debris (Satellite Number 24893) from the Kosmos 1939 Vostok upper stage (Satellite Number 19046) had actually been tracked by the SSN for nearly five years, and a sister debris remains in track but not yet cataloged. Normally, the total number of debris released by a satellite does not exceed six, although in two cases, Snapshot (1965-27A) and COBE (1989-89A), the debris counts were 50 or more. To date, the number of orbital debris produced during anomalous events accounts for only 2% of the total cataloged satellite population, but this figure could increase as the large resident space object population increases and ages.



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Intentional LEO Spacecraft Breakup in September

N. Johnson

On 16 September the Russian Military Space Forces destroyed a reconnaissance spacecraft in low Earth orbit, producing a cloud of short-lived debris. Kosmos 2343, launched on 15 May 1997, was the sixth in a new generation of military spacecraft which debuted in 1989. Unlike other reconnaissance spacecraft which occasionally have been destroyed when malfunctions prevented planned reentry operations (14 such incidents during 1964-1993), this new class of vehicles appear to employ self-destruction as a standard end-of-life operating procedure. Previous missions of this type include Kosmos 2031, Kosmos 2101, Kosmos 2163, Kosmos 2225, and Kosmos 2262.

Kosmos 2343 had just completed a four-month mission when it broke up at 2208 GMT while passing 230 km over the Kamchatka peninsula. Three of the five previous vehicles (Kosmos 2101, 2163, and 2225) were destroyed at virtually the same location. During the next 48 hours the U.S. Space Surveillance Network (SSN) was able to characterize the orbits of 32 debris, three with apogees near 900 km indicating ejection velocities on the order of 200 m/s.

Although half of the debris (those ejected in a retrograde direction) reenter very quickly, historically as many as 180 debris have been detected by the SSN. Consequently, upon being notified of the Kosmos 2343 breakup

event, the NASA Johnson Space Center Space Science Branch initiated an immediate threat assessment of the debris cloud with respect to the Mir space station. Assuming a complete fragmentation of the estimated 6500 kg dry mass of Kosmos 2343, a debris cloud of 1 mm and larger particles was simulated and propagated for a week. Even though some tracked debris possibly came within 20 km of Mir, 70% of the threat had passed after the first 24 hours. No tracked debris triggered a collision warning, i.e., predicted penetration into a 4 km by 10 km by 4 km box centered around Mir. An assessment was also made to determine if any unacceptable risk might be posed to the forthcoming Space Shuttle mission, STS-86 on 25 September, to Mir, but no significant hazard was found.

Detection of Very Small Debris With Haystack

G. Stansbery

NASA/JSC has been using the Haystack radar under a Memorandum of Agreement (MOA) with the U.S. Air Force to statistically characterize the orbital debris population in low earth orbit (LEO) for debris sizes between about 0.6 - 30 cm diameter since 1990. Several

recent impacts on the Space Shuttle have suggested that the population of smaller debris (0.1-0.2 cm diameter) has recently increased. At its current sensitivity, Haystack has detected no such increase. It is possible to "tweak" the pulselength, pulse repetition frequency (PRF), and the number of pulses integrated over a limited range window at Space Shuttle altitudes

to improve the sensitivity of Haystack. NASA has contracted with MIT Lincoln Laboratory to perform a study to select the optimum radar parameters with the goal of detecting 0.25 cm diameter debris at Space Shuttle altitudes and 0.5 cm diameter debris at 1000 km altitude. Further, they will implement and test the chosen parameters to ensure data validity.



Meeting Report

IAA Subcommittee on Space Debris

The International Academy of Astronautics (IAA) Subcommittee on Space Debris met in Turin in conjunction with the International Astronautical Federation (IAF) Congress. The meeting was chaired by Professor Walter Flury and was attended by 20 members.

The primary topic of discussion at the meeting was a draft of a debris mitigation paper that is being prepared by the subcommittee for the Scientific and Technical Subcommittee of the UN Committee on Peaceful Uses of Outer Space (UNCOPUOS). An abstract of this paper appears below.

The 1999 IAF meeting, to be held in Amsterdam, was also discussed. It was proposed that

one of the debris sessions at this Congress be devoted to satellite constellations, perhaps in a joint session with one of the spacecraft committees. The Aerospace Corporation also presented an overview of its recently established Center for Orbital and Reentry Debris Studies.

Abstract for the Space Debris Mitigation Paper:

The International Academy of Astronautics (IAA) is glad to be given the opportunity to address the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful uses of Outer Space on the important matter of space debris. Our allocution will focus on this year's topic—space debris mitigation. IAA has been aware of the space debris

problem for many years and issued the IAA Position Paper on Orbital Debris in 1993. Being concerned about this problem which causes a growing threat for the future of space flight, the IAA initiated a study to be performed under the supervision of its Committee on Safety, Rescue, and Quality. The objectives were to elaborate on the need and urgency for mitigation actions and to identify implementation methods. Since the issue is so complex, it may not be possible to come to a final solution in due time. Therefore, some preliminary guidelines, codes of conduct, or principles addressing the minimization or avoidance of space debris could be proposed as an interim solution.



Project Reviews

Orbital Debris as Detected on Exposed Spacecraft

R.P. Bernhard, E.L. Christiansen

Several projects of major importance to understanding of the particulate population in LEO were derived from Space Transportation System (STS) flights in 1984. Mission STS-41C retrieved about 3 square meters of Solar Maximum Satellite hardware after being exposed 4.15 years in LEO, and deployed the 130 meter² Long Duration Exposure Facility (LDEF) satellite. In November 1984 STS-51A retrieved the PALAPA-B2 satellite after 9 months in space. Data from over 1600 impacts on Solar Max reinforced the significant presence of orbital debris in LEO and its detrimental effects with respect to the engineering and design of satellites. Re-examination of many of these impacts have been completed recently and help us to understand the origin of many orbital debris particles. Results from the inspection of approximately 1 square meter of the PALAPA-B2 satellite surface after being exposed for 0.75 years produced over 50 holes in the thermal blanket material and eight impacts into the solar cell material, several of which penetrated the 700µm thick structure. Also detected was the penetration of Mylar thermal blanket by human waste products (urine and sweat based droplets), which supported like findings on the thermal blankets of Solar Max.

In 1990 LDEF was retrieved from space and pre-deintegration inspection was conducted on 130 square meters of exposed experiments from February through April of that year. Over 35,000 impacts greater than 0.5mm were documented as a result. Unlike the previous satellite surfaces inspected, LDEF surfaces were designed as collection devices for qualitative and quantitative analytical analysis. Findings from studies illustrated the abundance of orbital debris and that a significant percentage of the impacts occurring on the rear (non velocity vector) side are caused by orbital debris (mostly Aluminum) as well. Further examination reveals that the aluminum type impacts may be sub-classified into metallic aluminum or Al₂O₃ in composition. Also detected on LDEF were craters containing only Sodium/Potassium, the origin of which can be related to the metallic Na/K used as coolant in nuclear reactors on some satellites. From this data, fluxes of orbital debris with respect to velocity vectors on non-spinning satellites were established and orbital dynamics for particles

in LEO resulting in such collisions could be derived.

With the advent of Space Shuttle flights in the 1980's a number of Orbiter structures have received impact craters large enough to warrant repair. STS-7, flown in June of 1983, sustained significant damage to the right middle window from a Earth-orbiting spacecraft paint particle. To date several thousand impacts have been documented during post flight inspection of the Shuttle Orbiter, over 200 impacts on the windows have been inspected optically, resulting in the removal of over 50 windows. The largest crater 1.2cm in diameter was caused by man-made orbital debris. Other Orbiter surfaces have also been severely damaged by hypervelocity impact of orbital debris resulting in repair or replacement of spacecraft components. The two largest impacts analyzed were 1.7cm on the outside payload bay door, and 4.8cm in a Reinforced Carbon Carbon (RCC) panel on the wing leading edge. Analysis showed that the impactor origins were both man-made debris.

Space Shuttle Orbiters

Post flight inspection of the Shuttle Orbiters reveal numerous impact damage sites to the exposed surfaces after every mission. Thermal protection tile, windows, and cargo bay door radiator panels are areas in which damage is easily recognized, and they also represent regions in which damage can cause serious implications to Orbiter safety. Over the last several years hundreds of impacts have been documented and repaired. The following paragraphs are examples of significant impacts caused by orbital debris during recent shuttle missions.

STS-72 (Endeavour) was flown at an altitude of 250 nm (288 statute miles) and an inclination of 28.45 degrees for 8 days, 22 hours. During the last day of the mission the rudder speed brake was opened to approximately 10 degrees while the Orbiter was tail forward in attitude. During this time the interior surface of the brake encountered a hypervelocity particle. The large impact damage (3.4 mm in diameter and 11 mm deep) produced in Inconel Thermal Spring Seal was examined, several particles of metallic Aluminum were detected in the region

between the Inconel Thermal Spring and the Foam RTV Seal material (figure 1). Traces of Aluminum were also detected on tape pull samples taken from the penetration in the Inconel thermal spring. Calculations show that the colliding orbital debris particle was approximately 1.0mm in diameter.

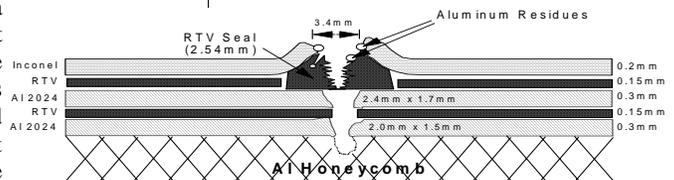


Figure 1. Diagram illustrating a cross-sectional view of the impact damage into the thermal seal on the vertical brake.

STS-73 (Columbia) was launched the morning of October 20, 1995; during this extended duration Orbiter (EDO) mission of 15 days and 22 hours, the Orbiter and International Microgravity Laboratory (IML) were exposed to the low Earth orbit environment at 150 nautical miles altitude and 39 degrees inclination. The principal attitude (approximately 13 days of the mission) of the craft was port wing forward, and nose toward space. There was a 17 degree roll bias that put the belly of the Orbiter slightly into the velocity direction. The port side cargo bay door was in a partially open position for 12 days (figure 2), with the Reusable Flexible Surface Insulation (FRSI) on the exterior of the door exposed in the ram direction, and subject to the greatest number of impacts. The starboard side door was in the full open position which makes it less likely to be impacted on the exterior surface due to

(Continued on page 4)



Figure 2. STS-73 mission photograph (with Earth in the background) illustrating the partially open position of the port side cargo bay door. With the door in this position the cargo bay is more protected from hypervelocity impacts.



Project Reviews, Continued

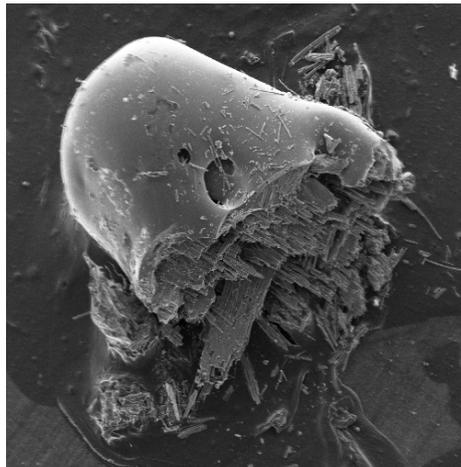
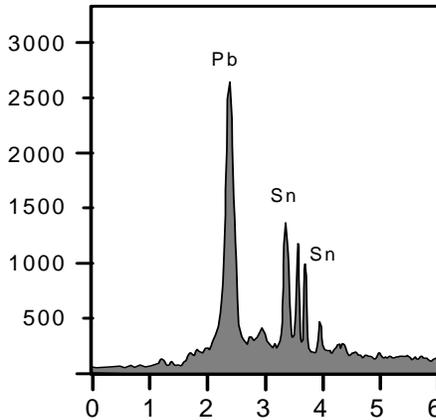
Orbital Debris as Detected on Exposed Spacecraft, cont.

(Continued from page 3)

shadowing from the Orbiter wing and fuselage, and in the trailing side position during most of the mission.

The most predominate hypervelocity impact occurred near the aft of door number 4 approximately 56 inches from the door hinge line. During the visual inspection of the Orbiter the damage site was sampled by the Tape Pull Method, resulting in the detection of Silver, Lead, and Tin, components of electrical solder. The FRSI damage was cored and transported to JSC for further examination. Materials detected within the 17mm by 11mm hole were orbital debris in nature, consisting of remnants of electrical circuit board type components. Lead solder adhered to layered fibrous material in particles up to 1.2mm in length (figure 3 and 4) have been removed from the impact and examined via SEM/EDXA to help verify by morphology and chemistry the origin of the impacting projectile. Several other payload bay door FRSI impacts were classified as being orbital debris in origin (aluminum).

STS-75 (Columbia) was launched February of 1996 and was a 14 day mission. The primary objective of STS-75 is to carry the Tethered Satellite System Reflight (TSS-1R) into orbit and to deploy it spaceward on a conducting tether. The Tether Satellite System will circle the Earth at an altitude of 296 kilometers which will place the tether system within the rarefied electrically charged layer of the atmosphere known as the ionosphere. On Flight Day 4 (2/25/95), deploy operations began at 2:45pm CST. At approximately 7:30pm CST, after TSS-1R had deployed 19.7km of tether and had almost reached full deployment, the tether broke. Post flight inspection determined that the tether was not severed by hypervelocity impact. But the TSS pallet structure was damaged by a significant hypervelocity impact to the left forward titanium trunnion pin structure. The approximately 1.0mm crater is located on the inside edge of the trunnion pin structure. A spray pattern of secondary ejecta is also detected covering a region of the trunnion device. Figure 5 is a close up view of the impact damage site, illustrating the hypervelocity impact crater, and the secondary ejecta spray pattern produced by the hypervelocity impact (the zone on the titanium rib structure backside where the Chemglaze paint was spalled off



Figures 3 and 4. SEM image and EDX spectra of the projectile recovered from the STS-73 FRSI impact damage.

(6mm in diameter), is on the opposite side from the crater.

SEM/EDX analysis of samples taken from the impact crater and the secondary ejecta spray pattern revealed significant amounts of melt-like aluminum residues. The droplet of aluminum extracted from the ejecta spray pattern is primarily aluminum (Al), with traces of titanium (Ti) present. Calculations estimate a 0.75mm orbital debris was needed to cause the detected damage.

STS-76 (Atlantis) Meteoroid and Orbital Debris (M&OD) damage to Orbiter OV-104 was identified, analyzed, and will be compared to damage predictions made using the standard NASA M&OD analysis codes (BUMPER).

Hypervelocity impact damage size ranged from 0.02 mm to 2.05 mm and projectile residues were detected in 3 impact samples (whole sample, dental mold impressions, or epoxy molds).

The Orbiter's crew module window number 6/Right Side position had an impact 2.05 mm in diameter and 0.18 mm deep. Analysis of the projectile residues detected on the epoxy impression made of this impact determined the origin to be man-made spacecraft paint, having traces of Ti, Al, S and Cl present. Window #3 (left forward) had eleven small impacts detected, ranging from 0.02 mm to 0.06 mm in diameter. Several of these samples were examined by SEM/EDXA; impact #3 contained Al₂O₃ (orbital debris). Window #5 (right middle) had one impact recorded which was 0.145 mm in diameter.

STS-79 (Atlantis) This was the fourth rendezvous and docking with Mir and the first to carry a double Spacehab module. Window inspections detected 13 impact pits and 6 windows were replaced: 4 due to impacts during STS-79, 1 due to previous impact damage (STS-74 & 76) that grew, and 1 replacement due to haze. Window 4 had six new impacts, 2 of which contained residues of metallic aluminum. Windows 6, 7 and 8 were also replaced due to hypervelocity impacts, each containing residues of orbital debris type. The impact on window 7 was 2.3 mm in diameter, and the impact to window 8 was 4.3 mm.

STS-79 had 18 impacts observed and recorded on the exposed radiator panels.

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Figure 5. Optical photograph illustrating the hypervelocity impact crater damage site on the TSS trunnion structure.



Guest Article

Legal and Insurance Communities Perspective on Orbital Debris

D. McKnight

There are truly only four “communities” when it comes to orbital debris. The operational community consists of satellite and launch vehicle manufacturers; companies and space agencies that launch and operate spacecraft; and the military. It is this community that all the others support; though there are times when this distinction is blurred in the eyes of many in the following communities. The research community is closely tied to space operations, often some organizations have both responsibilities. Research is both a benefactor and a contributor to the operational space community. On the one hand, without systems going into space there would be little opportunity for the most advanced and useful experiments and developments. However, the majority of these advances are directly being fueled by needs of the operational community; often even linked organizationally. The insurance community is responsible for stabilizing much of the operational community by providing a means for risks to be taken. The companies that represent these interests have evolved largely out of their aviation business bringing many of the historical practices that have served them well in that arena. The interest of the insurance industry for space activity is usually very shortlived with the majority of interest in the launch and initial deployment of a satellite, even though the trend is toward longer and longer timeframes of coverage after system startup. The legal community deals from the longterm perspective: forming policy, law, and regulation that will have very long lasting effects on all the other communities. For example, the Outer Space Treaty of 1967, the Liability Convention of 1972, and the Registration Convention of 1976 provide the basis for almost all substantive discussion about orbital debris and law.

Over the years, I have tried to maintain a constant and meaningful relationship with colleagues of mine from the legal and insurance communities. I would best describe myself as a member of the research community. I suspect that researchers are best suited to provide the vital linkage between the remaining three communities due

to the absence of conflicts of interest and the needs of each of the other communities. The legal and insurance communities have been very active in publishing articles and papers about orbital debris even though they have often been maligned for not knowing as much as “real experts” in orbital debris. However, I would like to write briefly about what the legal and insurance communities really need from the research community (and to a lesser extent the operational community) to allow them to provide their valuable service to their clients.

It is important to note at the outset that most people in the operational, legal, and insurance communities really only care about the bottomline: “is debris going to affect the way that I do my job?” To date, the legal and insurance professions, while being active to maintain a currency in the area, have not had their workload adversely affected - less than 5% of their time on the job over the last year has gone toward orbital debris issues. While we, in the research community, spend a significant amount of time speaking about measurements, experiments, and analyses that may impact a special part of our understanding of orbital debris the legal/insurance worker really only cares about two things (1) what is the predicted hazard to operational spacecraft from large orbital debris and (2) have we lost any operational and/or insured satellites to orbital debris (even to include significant operational degradation). It might be a surprise to the research community that the legal/insurance communities have only a fleeting interest in the how and why orbital debris is growing. They are much more concerned about definitive analyses related to satellite failures due to orbital debris. The most important issue - have we lost satellites due to orbital debris impacts - is apparently receiving the least attention. I have personally done some research in correlating satellite anomalies of unknown cause to debris-relevant parameters so I know firsthand just how difficult this type of detective work is to do. However, the quest for definitive answers, on not only if a satellite has been damaged by debris but also what parts of the satellite are most susceptible to debris impacts, is severely curtailed by the desire of the operational community to control information about their systems.

While this is understandable from economic, security, and political perspectives, is short-sighted and will eventually result in more cost to operational users because of future satellite failures that may have been preventable if all the data on impact events had been made available. Some in the insurance community believe that operators use political arguments to justify lack of action rather than acknowledging research findings and proactively making engineering decisions accordingly.

Interestingly, the recent collision between a piece of debris from an Ariane rocket body and the French satellite Cerise has provided the impetus for enlightening discussions. What if the operational satellite had been American or Russian? Who would be responsible for the damage? The Americans and Russians have means to track large objects so they might have been expected to avoid this debris or accept responsibility for all losses. Alternately, since the venting of rocket bodies has started to become commonplace, almost an accepted practice, would the breakup of an unvented rocket body now be seen as negligent - some would argue vehemently for this ruling. It is also intriguing to notice that Cerise, the victim of the first known collision between two trackable objects, is still functioning. This is almost an unfortunate situation since it provides yet another family of encounters that must be considered when analyzing the future debris population relative to legal/insurance issues.

The advent of the family of LEO satellite constellations is posing a new and challenging task for the debris community in general. The information flow between researchers and operators to and from legal and insurance professionals must be refined. The rapid distribution of relevant information has been highlighted as the most important service the research/operations communities can provide. New spatial density values for the regions where these constellations will operate, planned mitigation activities by the operators (Motorola has done this very well to date), and determination of the type of event that would lead to catastrophic consequences are just three items of special interest to the legal/insurance community. Similarly, the lack of

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Guest Article, Continued

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data for debris in geosynchronous orbit is also of great concern. While this lack of data is not likely to change in the near future it is crucial that priorities are identified. A related issue that must be addressed for the legal/insurance folks is the need for some venue to get up-to-date and relevant information. The technical conferences have become largely an opportunity to mull over "the same old stuff." This makes it very difficult for the legal/insurance communities to stay abreast of critical information since it is very tedious to sort through the tens of papers at each conference to find the very few papers with new information and insights.

As with any complex, multinational issue there is a tendency to talk issues through thoroughly, maybe even too thoroughly, before any action or even call for action is initiated. While there has been some national space policy directives issued by several countries and NASA has issued a comprehensive debris mitigation approach, there have been few international binding rules put into place. This undoubtedly will change when debris becomes so severe as to produce several high profile satellite collisions or even if analyses simply predict a significant collision within a few years time frame. Individuals in the legal/insurance communities are concerned that continued inaction will result in a situation where they will not only be involved but be involved extensively in arbitration and/or policy reviews.

At that time, the legal/insurance personnel will have a lot to say about space operations and the future profitability of space exploitation but they really would prefer to never be in that position. For the most part, the legal/insurance people that I interface with on a regular basis do not understand why more is not being done to curtail the growth of orbital debris by governments and operational users to minimize the chance that they will ever have to be involved in a substantial way. There have been some positive moves to control the growth of debris but these are not always communicated well to the community at large for a variety of reasons. A recent positive move by the Federal Aviation Administration (FAA) [formerly Department of Transportation, Office of Commercial Space Transportation (DOT/OCST)] was to submit for formal rulemaking the following guidelines for commercial space license applications: "An applicant's launch proposal shall ensure that for all vehicle stages or components that reach earth orbit - (1) There is no unplanned physical contact between the vehicle or its components and the payload after payload separation; and (2) Debris generation will not result from the conversion of energy sources into energy that fragments the vehicle and its components. Energy sources include chemical (fuel), pressure (e.g., pneumatic), and kinetic (e.g., gyroscopes) energy." While this wording is no more stringent than

several other policies issued over the years the proposal that it become part of the commercial launch license submittal process is significant.

In summary, the legal/insurance communities are dedicated to keeping informed about orbital debris but would like to see international fora where this issue is discussed to be used to discuss new, relevant items for them. With current workloads, it is difficult for them to filter through the plethora of debris publications each year to determine if something new (like a technique, policy, or event) and relevant has taken place.

[Information used for this article comes from years of formal and informal interactions with many lawyers and insurance personnel. In preparation for this article I also talked to several experienced individuals in the legal and insurance professions who have consistently sought out the most up-to-date information on orbital debris and have truly tried to lead their colleagues into a new level of understanding about this complex phenomena. I hope that I have captured your thoughts and concerns accurately.]



Upcoming Meetings

The 15th Inter-agency Space Debris Coordination Committee (IADC) meeting is scheduled to be held in Houston, TX, 09-12 December 1997.

US Government Orbital Debris Workshop for Industry is scheduled to be held in Houston, TX, 27-29 January 1998. The objectives of the workshop are to brief industry on draft US Orbital Debris Standard Practices and orbital debris issues related to LEO satellite constellations.

Hypervelocity Shielding Workshop, Galveston, Texas, 08-11 March 1998, hosted by NASA Johnson Space Center (J.L. Crews) and the Institute for Advanced Technology (IAT) (H.D. Fair). The purpose of this meeting is to produce a document containing state-of-the-art hypervelocity shielding and design concepts. Topics as they pertain to usable shielding concepts and design to include experimental results, numerical simulations, ballistic limit

equations, velocity, scaling, velocity effects, impactor size, shape and density effects, assessment and overview.

Abstracts may be submitted for consideration no later than 01 January 1998 and should focus on application, limitations, state-of-the-art concepts and unanswered questions.

Inquiries/submissions on the above meetings should be mailed to:

C. Karpiuk, NASA Johnson Space Center, SN3, Houston, Texas 77058 or electronically to ckarpiuk@ems.jsc.nasa.gov

The 32nd COSPAR Scientific Assembly will be held at the Nagoya Congress Center in Nagoya, Japan, from 12-19 July 1998.

SPIE's 43rd Annual Meeting will be held at the San Diego Convention Center and Marriot Hotel & Marina in San Diego, California from 19-24 July 1998.



Guest Article Submission Requirements

To submit an article to be considered for publication, please send it in machine readable format on diskette to

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



Abstracts from Papers

The Reentry of Large Orbital Debris

N. Johnson

The natural reentry of a large space object occasionally commands international attention, as in the orbital decays of the Skylab and Salyut 7 space stations, the nuclear-powered Kosmos 954 and Kosmos 1402 spacecraft, and the FSW 1-5 recoverable capsule. However, on average a piece of large orbital debris (radar cross-section $> 1 \text{ m}^2$) falls back to Earth once a week. These objects are normally inactive spacecraft, expended launch vehicle upper stages, and hardware associated with spacecraft deployments or operations. The time and geographic location of entry into the dense upper atmosphere is projected or recorded by U.S. national technical means. An examination of 328 such reentries which occurred during the 1992-1996 period was conducted, in part, to determine if impact zones were randomly distributed about the Earth as has been assumed, despite the planet's asymmetrical atmosphere and gravitational field. For objects in orbit for more than 30 days, reentry locations were found to be essentially uniform in terms of latitude and longitude. However, for recently launched objects (orbital lifetime less than 30 days), the reentries demonstrated a greater probability for Northern Hemisphere impacts. No significant differences were discovered among the three categories of objects: spacecraft, upper stages, and debris. The individual and aggregate masses of the subject reentries were also evaluated, and the issues of debris survivability and ground dispersal were addressed. Unfortunately, the capability to predict accurately the time and location of natural reentries does not yet exist.

The Passivation of Orbital Upper Stages, A Lesson Not Yet Learned

N. Johnson

In the early days of the space age, liquid-propellant orbital upper stages were normally abandoned in place after completing their assigned tasks, often with significant amounts of stored energy remaining on board in the form of residual propellants, compressed gases, electrical

energy accumulators, and an assortment of pyrotechnic devices. Although the violent breakup of such upper stages occurred repeatedly, rapidly becoming the most significant source of long-term orbital debris, not until 1981 did the phenomenon receive the attention it deserved. The insights gained during the investigation of seven major Delta second stage breakups, which generated a total of more than 1300 cataloged debris fragments, pointed toward the presence of residual propellants, often in conjunction with specific environmental conditions, as the probable source of the breakup energy. Consequently, beginning in 1981, the Delta launch vehicle program office instituted a policy of propellant depletion burns to be performed shortly after payload deployment. During the 1980's NASA worked closely with the operators of the Ariane and Long March launch vehicles after these vehicles experienced similar difficulties. Once again, end-of-life passivation measures adopted for the upper stages led to a cessation of breakup events. Regrettably, passivation of orbital upper stages has not yet been universally accepted, and the breakups of Titan, Kosmos, Proton, Zenit, Rokot, and Pegasus upper stages during the 1990's may have been prevented. Launch vehicle designers and operators should place a renewed emphasis on upper stage passivation.

Options for Postmission Disposal of Upper Stages

P. Eichler, R. Reynolds, A. Bade, J. Zhang, K. Siebold, A. Jackson, N. Johnson, J. Loftus, R. McNamara

The two most important and effective procedures for limiting growth of the orbital debris environment have been identified to be: (1) prevent the accidental explosion of upper stages left in orbit and (2) mitigate the accumulation of mass in orbit to prevent collisions among large, massive objects in orbit. The fragments generated by such collisions would be a source of risk to operating spacecraft. To mitigate the accumulation of mass in Low Earth Orbit (LEO), NASA Safety Standard 1740.14: Guidelines and Assessment Procedures for Limiting Orbital Debris, August 1995, addresses the issues of postmission disposal of spacecraft and upper stages left in LEO and highly elliptical orbits. According to the guidelines, these systems in general should be

left in an orbit in which, using conservative projections for solar activity, atmospheric drag and gravitational perturbations will limit the lifetime to no longer than 25 years after completion of mission.

Consequently, JSC undertook a series of studies to investigate the most efficient and cost-effective options for reducing orbit lifetime. One of the studies was focused on postmission disposal options for upper stages. An upper stage left at Sun-synchronous orbit altitude, for example, may have an orbit lifetime of centuries, and an upper stage left in Geosynchronous Transfer Orbit with an perigee altitude above 400 km may have an orbit lifetime of several thousand years. In this paper the basic capabilities of various options for cost-effective postmission disposal of upper stages are examined, covering LEO orbits (e.g., Sun-synchronous orbits) as well as high elliptical orbits (e.g., Geostationary Transfer Orbits). Options include the use of natural forces for lifetime reductions (e.g., using mission orbits with lower perigee altitudes, air drag enhancement devices, and lunar-solar perturbations) and adding propulsive capabilities (e.g., restart or idle mode run of main engine, Solid Rocket Motors, Electric Propulsion Systems, use of attitude control thrusters). The advantages and drawbacks of the various options are discussed, giving program managers hints for the choice of the option best suited for specific mission types, e.g., depending on initial orbit, existing propulsion systems, existing electrical power level, electrical power and attitude control lifetime, and acceptable maneuver time and mass penalties.

(Continued on page 8)





Abstracts from Papers

Recent Results from Space Shuttle Meteoroid / Orbital Debris Pre-flight Risk and Post-Flight Damage Assessments

G. Levin, E. Christiansen, J. Loftus,
R. Bernhard

NASAs Bumper code is utilized to perform pre-flight meteoroid/orbital debris risk assessments prior to each Shuttle mission. The pre-flight risk assessments are used to determine the relative risk of each proposed mission. When the assessment indicates that the mission profile results in risks outside the accepted limits, changes to the mission profile are analyzed until such time as an acceptable risk is achieved. Pre-flight risk assessments are also used to test our knowledge of the orbital debris environment.

At the conclusion of each Shuttle mission selected areas on the Orbiter are carefully inspected for meteoroid/orbital debris damage. Areas that are of particular importance are the Orbiters radiator panels, the windows, and the reinforced carbon-carbon on the leading edge of the wings and on the nose cap. Contents of impact damage craters are analyzed using a scanning electron microscope to determine the nature and origin of the impactor.

A review of the preflight predictions and the post flight damage assessments is presented for a series of Space Shuttle missions. In addition data is presented on meteoroid/orbital debris damage to the Hubble Space Telescope as observed during the 1994 and 1997 Hubble repair missions.

Visible Effects of Space Debris on the Shuttle Program

T. Jensen, E. Christiansen

An overview of an adverse space debris environment which directly effects operational risk of the Space Shuttle Vehicle is presented with methods of managing this rapidly changing risk. This paper will highlight the issue of space debris as it affects the operation of the world's only man-rated reusable spacecraft, the Orbiter. The Shuttle Program and its contractors have evaluated empirical evidence of the space debris threat,

identified failure/acceptability criteria used for Shuttle mission planning, and pursued operational solutions. Additionally, design enhancements which reduce the potential of an unacceptable debris strike are being studied for early implementation as recommended by the System Safety Advisory Panel.

Steps in managing the space debris risk involve: understanding the current debris environment, definition of potential subsystem failure criteria, and implementation of suitable operational and/or design changes to minimize the potential threat. With the reusable Orbiter spacecraft, the Space Shuttle Program provides empirical evidence of the changing space debris environment. The most clear and unequivocal indicators are best characterized by a growing number of Orbiter window strikes, and several large particle hits ≥ 0.5 mm. Recognizing this vehicle threat, the Shuttle Program recently tasked its Orbiter contractor to identify and rank specific high exposure Orbiter subsystems. Results of this study have lead to appreciable changes on the failure criteria associated with the driving subsystem risk. NASA's Flight Systems Safety and Mission Assurance (FSS&MA) Office has adopted preliminary limits of acceptability based upon a likelihood of Catastrophic and Early Mission Termination risk. Operationally, the Orbiter attitude timeline is optimized to reduce critical subsystem exposure. However, NASA is actively pursuing shielding and/or redundancy management controls to minimize the overall vehicle risk.

The long-term effectiveness of Shuttle Program space debris controls will be judged by the merits of accurate preflight environment characterization, adherence to program acceptability criteria, operational workarounds, and timely implementation of proposed design enhancements. Leveraging this empirical data offers invaluable lessons-learned on the programmatic effects of space debris applicable to any future reusable spacecraft.

The World State of Orbital Debris Measurements and Modeling

N. Johnson

For more than 20 years orbital debris research

around the world has been striving to obtain a sharper, more comprehensive picture of the near-Earth artificial satellite environment. Whereas significant progress has been achieved through better organized and funded programs with the assistance of advancing technologies in both space surveillance sensors and computational capabilities, the potential of measurements and modeling of orbital debris has yet to be realized. Greater emphasis on a systems-level approach to the characterization and projection of the orbital debris environment would prove beneficial. Ongoing space surveillance activities, primarily from terrestrial-based facilities, are narrowing the uncertainties of the orbital debris population for objects greater than 2 mm in LEO and offer a better understanding of the GEO regime down to 10 cm diameter objects. In situ data collected in LEO is limited to a narrow range of altitudes and should be employed with great care. Orbital debris modeling efforts should place high priority on improving model fidelity, on clearly and completely delineating assumptions and simplifications, and on more thorough sensitivity studies. Most importantly, however, greater communications and cooperation between the measurements and modeling communities are essential for the efficient advancement of the field. The advent of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 has facilitated this exchange of data and modeling techniques. A joint goal of these communities should be the identification of new sources of orbital debris.

(presented at the Thermal and Fluids

Spacecraft Orbital Debris Reentry: Aerothermal Analysis

Analysis Workshop, NASA Johnson Space Center, Houston TX)

G. Rochelle, R. Kinsey, E. Reid, R. Reynolds, N. Johnson

In the past 40 years, thousands of objects have been placed in Earth orbit and are being tracked. Space hardware reentry survivability must be evaluated to assess risks to human life and property on the ground. The objective of this paper is to present results of a study to determine altitude of demise (burn-up) or

(Continued on page 12)



Project Reviews, Continued

Orbital Debris as Detected on Exposed Spacecraft, cont.

(Continued from page 4)

Only the largest damages were recorded—generally, damage > ~1.0 mm will be recorded but damage < 1.0 mm may not be depending on the inspector's judgment. Several smaller impacts were observed by inspectors but not recorded. Two of the damage sites were penetrations through the radiator face sheet material. The largest was 4.75 mm diameter tape damage (0.95 mm face sheet damage) and had residues of stainless steel present. The second hole was 2.75 mm in diameter (0.75 mm face sheet hole) and had a significant amount of spacecraft paint residues detected.

Hypervelocity damage greater than 3.5 mm in diameter in the FRSI material on exterior of payload bay (PLB) doors in forward exposed area was photographed and sampled. The hole was approximately 3.0 mm deep and contained large amounts of metallic aluminum.

STS-80 (Columbia) Six windows had a total of 31 impacts with 2 (7 & 8) window replacements (the largest impact being 1.14 mm in diameter/copper residue). Six of the impacts contained detectable amount of meteoritic residues while 13 impact samples analyzed by SEM/EDXA contained orbital debris type residues: aluminum (either metallic or aluminum oxide); 3 with stainless steel type alloys (Ni, Cr, Fe); and others with electrical component type (silver, copper) and residues of spacecraft paint (consisting of mostly Zn and/or Ti). A total of 8 impacts were recorded on radiators; the largest 5.54 mm and another 3.15 mm, originated from a stainless steel projectile.

STS-81 (Atlantis) The surfaces of OV-104 were inspected and three significant impacts to the windows (5 & 6) were found. Window 6 was replaced with 2 impacts (1.2 mm and 1.0 mm in diameter). Sample procedures were discontinued on the windows pending and investigation into the sampling techniques so no SEM was conducted. The radiators had nine hypervelocity impacts, of which two were face sheet penetrations, 1.5 mm face sheet hole caused by stainless steel type alloy (ni, Cr, Fe), and 1.0 mm with meteoritic residues present. One face sheet crater impact sample (0.5 mm in diameter) analyzed by SEM/EDXA contained orbital debris type residues containing primarily Na and K.

STS - 8 2

(Discovery) The STS-82 mission was the second in a series of planned servicing missions to the orbiting Hubble Space Telescope (HST). HST was placed in orbital (Altitude: 360 statute miles/ Inclination: 28.45) on April 24, 1990 by the Space Shuttle Discovery on STS-31. The first servicing mission

was done by Space Shuttle Endeavor on STS-61. Window inspections after the mission revealed 23 impacts, but no samples for SEM were taken. The radiator panels had 5 impacts: one contained residues of spacecraft paint, but none were complete face sheet penetrations. The largest FRST damage was 2.85 mm in diameter and was caused by orbital debris (aluminum).

STS-83 (Columbia) Post flight inspection of OV-102 (Columbia) was conducted resulting in 60 window pits documented, but no replacements were needed. The cargo bay door radiator panels sustained two face sheet penetrations (0.4 mm and 0.57 mm) and three craters into the face sheet.

The outside of the cargo bay door (FRSI material) had a large (3.2 mm diameter and 3.0 mm deep) hypervelocity damage site and large amounts of spacecraft paint type residues were found associated with the impact. The leading edge of the right hand wing also had a large (3.25 mm in diameter) orbital debris impact on its RCC surface. Residues detected within this sample were aluminum in nature.

STS-84 (Atlantis) This flight had a total of 19 window impact pits and 1 window replacement. Window number 1 was replaced due to the impact seen in figure 6, this photograph was taken by the crew on orbit. Mold impressions from these impacts were available for SEM analysis resulting in the identification of 2 orbital debris hits and 3 damages caused by meteoroids.



Figure 6. Optical photograph illustrating the hypervelocity impact crater damage site on window #1, taken on orbit.

The radiators experienced six new hypervelocity impacts, three of which were face sheet penetrations, the largest was 4.0 mm x 3.9 mm (tape damage)/1.1 mm face sheet damage, and had stainless steel (Fe, Cr, Ni) residues detected by SEM/EDXA.

CONCLUSIONS

Orbital debris damage to the Orbiter has been detected on low altitude missions during 1995-1997. Assessments of Orbiter damage will continue to provide data for monitoring the debris environment and to improve and validate the orbital debris model and the BUMPER M/OD damage prediction code. A more comprehensive summary of Orbiter impacts can be found in "STS-50 (6/92) through STS-85 (8/97): Orbiter Meteoroid/Orbital Debris Impacts" JSC Report No. 28033.





Project Reviews, Continued

Measurements of the Orbital Debris Environment: Comparison of the Haystack and HAX Radars

Tom Settecerri, Gene Stansbery

The Long Range Imaging Radar (LRIR), also known as Haystack, has been observing the orbital debris environment since 1990. Starting in March 1994, the Haystack Auxiliary (HAX) radar began collecting orbital debris data similar to Haystack. In fiscal year 1994, HAX collected 371 hours while staring at zenith (90° elevation). The HAX data complements the Haystack data very well and has expanded Johnson Space Center Space Science Branch's ability to characterize the orbital debris environment compared to LRIR alone. HAX has several system differences. HAX transmits less power and hence has less sensitivity, has a wider field-of-view (beam width), and transmits at a different frequency.

The HAX antenna beam width is nearly twice that of LRIR which collects more data on cataloged objects than LRIR. Haystack

observes many cataloged satellites, but because of its narrow beam width and higher sensitivity most of these detections are observed in the sidelobes –these data are not usable. Another difference is HAX's higher transmitter frequency. HAX transmits at 16.7 GHz (wavelength = 1.8 cm); whereas, LRIR transmits at 10.0 GHz (wavelength = 3.0 cm). This difference provides an additional measurement to further validate the NASA size estimation model. The estimated size calculated from the HAX data agrees very well with measurements made by the U.S. Space Command Eglin radar. The most important HAX benefit is debris observation time. LRIR and HAX share a common orbital debris data recording system such that only one system can collect radar data at any time. Then, during most of the winter months while LRIR is conducting radio astronomy research, HAX can be collecting debris data. This provides JSC with twice the observation time than with

Haystack alone. The results shown in this report confirm NASA's expectations that the additional HAX operating time supplements the LRIR data where there are low counting statistics and that the radars' collective datasets are very complementary.

The Haystack/HAX measurements have provided orbital debris researchers with two important tools for characterizing the environment. Haystack provides the ability to detect small debris objects from previously unknown sources and to extend the size distribution from the catalog limit (~10 cm) down to 0.5 cm. HAX data supplement the LRIR observations by providing additional measurements at a different wavelength, better statistics on large debris objects, and more data at low altitudes where NASA manned vehicles orbit.

JSC Analysis of Preliminary LMT Data

R. Reynolds, M. Matney, K. Dietz, B. Nowakowski

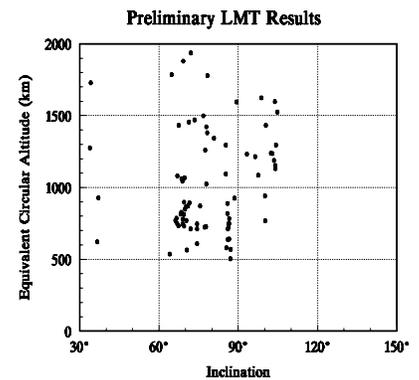
NASA's Liquid Mirror Telescope, located in Cloudcroft, New Mexico, has been making observations on the LEO environment since 1996. Because the current data mode is to store the optical images on videotape, a tedious screening method is required to transform the observations into useful data. Initial screening is performed for NASA by Prairie View A&M University. Because of the difficulties inherent in this type of screening, a special study was undertaken this summer to assess the accuracy of the screening methods and to identify ways to improve the techniques used.

So far, 27 tapes have been screened (representing about 50 hours of data), and the data analyzed in some detail. The rescreening of one tape revealed that out of total 13 potential debris objects, a total of 4 were missed during the initial screening. As a result of this study, new screening procedures have been adopted to obtain more accurate detection rates in order to assess spatial densities.

Unlike the Haystack radar which can measure an object's altitude very precisely but has some uncertainty in the inclination measurement, the

LMT can only approximate the altitude but can potentially measure the inclination to higher precision. For orbiting objects, an approximate altitude is computed by measuring the rate at which the object passes through the field of view and computing the altitude of a satellite in a circular orbit that would move at that same rate. The shadow height of the Earth can be checked for the given observation time to determine if the object was illuminated. Several observations of what appeared to be LEO objects were rejected because they were at altitudes well below the shadow height. These objects were probably slow meteors detected by the LMT. The inclinations of the detected objects are computed using the direction of the object's path through the telescope's field of view.

Results of the data analyzed so far are shown in the following figure. The data is shown only up to 2000 km altitude. A number of objects were detected at higher altitudes as well. Groupings of objects are clearly shown in the data. One group below about 1000 km altitude and around 70° inclination appears to be the family of small debris seen by Haystack thought to come from old Russian RORSAT reactors, but that debris was seen by the Haystack in 65° inclination orbits. There is



another debris family at similar altitudes around 87° inclination. It is possible that this data family is debris from the Pegasus HAPS breakup of June, 1996. If so, then the debris should have inclinations closer to 82°. A preliminary comparison of the derived inclinations of catalogued objects observed by LMT to their known values showed similar discrepancies. We believe that there are problems with the direction measurements used to compute inclinations, but we have not yet identified the specific problem that is causing the errors.

(Continued on page 11)



Project Reviews, Continued

New Hardware Bandpass Filter for HAX

G. Stansbery

In 1994, the Haystack Auxiliary (HAX) became operational. When originally designed, it was anticipated that the HAX would collect debris data only pointed vertically. However, it was discovered with Haystack that orbital inclination could be accurately estimated from range rate. This led to modifying the staring angles used to collect Haystack debris data. The optimum staring angle for Haystack was determined to be 75 deg. elevation and 90 deg. azimuth. An additional hardware bandpass filter is needed to allow HAX to collect debris data at the same staring angle. NASA has contracted with MIT Lincoln Laboratory to design, build, and test hardware and software to allow the Haystack Auxiliary (HAX) radar to collect data at a staring angle of 75 deg. elevation and 90 deg. azimuth. This will include a bandpass filter to allow HAX to detect debris with range rates of +/- 2.5 km/sec.

JSC Analysis of Preliminary LMT Data, cont.

(Continued from page 10)

Once the tapes are rescreened to find any objects missed in the initial screenings, we hope to compute flux values to compare with Haystack data. In addition, new observations are now being made on the LMT using a digital camera. The newer detector system is much more sensitive and the data is taken and stored directly in digital mode, simplifying brightness measurements and computation of the object's path and speed. Even though the LMT is best suited to observe the GEO environment, it is hoped that LEO observations can augment and verify the measurements of the centimeter population made by the Haystack and HAX radars.

INTERNATIONAL SPACE MISSIONS, APRIL - JUNE 1997

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1997-32A	STS-94	USA	304	308	28.5	0	0
1997-33A	PROGRESS m-35	Russia	386	392	51.7	1	0
1997-34A	IRIDIUM 15	USA	774	780	86.4	1	4
1997-34B	IRIDIUM 17	USA	775	780	86.4		
1997-34C	IRIDIUM 18	USA	774	779	86.4		
1997-34D	IRIDIUM 20	USA	772	782	86.4		
1997-35E	IRIDIUM 21	USA	629	643	86.4		
1997-35A	USA 132	USA	20124	20247	54.9	2	0
1997-36A	SUPERBIRD C	Japan	35770	35799	0.0	1	0
1997-37A	SEASTAR	USA	707	709	98.2	1	0
1997-38A	SOYUZ TM-26	Russia	386	392	51.6	1	1
1997-39A	STS-85	USA	290	301	57.0	0	0
1997-039B	CRISTA-SPAS 2	USA	291	301	57.0		
1997-040A	PAS 6	USA	35774	35799	0.1	1	0
1997-41A	KOSMOS 2345	Russia	35027	36548	1.2	2	3
1997-42A	AGILA 2	Philippines	35777	35791	0.3	1	0
1997-43A	IRIDIUM 26	USA	776	779	86.4	1	3
1997-43B	IRIDIUM 25	USA	775	780	86.4		
1997-43C	IRIDIUM 24	USA	774	781	86.4		
1997-43D	IRIDIUM 23	USA	775	780	86.4		
1997-43E	IRIDIUM 22	USA	775	780	86.4		
1997-44A	LEWIS	USA	307	331	97.6	1	0
1997-45A	ACE	USA	Beyond Earth Orbit				0
1997-46A	PAS 5	USA	35778	35803	0.1	2	1
1997-47A	FORTE	USA	799	833	70.0	1	0
1997-48A	IRIDIUM DUMMY	China	623	632	86.3	1	3
1997-48B	IRIDIUM DUMMY	China	623	633	86.3		
1997-49A	HOT BIRD 3	EUTELSAT	35775	35798	0.5	1	1
1997-49B	METEOSAT 7	EUMETSAT	35779	35795	1.8		
1997-50A	GE3	USA	35744	35824	0.1	1	0
1997-51A	IRIDIUM 29	USA	777	778	86.4	1	0
1997-51B	IRIDIUM 32	USA	776	780	86.4		
1997-51C	IRIDIUM 33	USA	776	779	86.4		
1997-51D	IRIDIUM 27	USA	554	558	86.4		
1997-51E	IRIDIUM 28	USA	776	779	86.4		
1997-51F	IRIDIUM 30	USA	776	778	86.4		
1997-51G	IRIDIUM 31	USA	777	778	86.4		
1997-52A	KOSMOS 2346	Russia	939	996	82.9	1	0
1997-52B	FAISAT 2V	USA	939	996	82.9		
1997-53A	INTELSAT 803	INTELSAT	35754	35819	0.1	1	0
1997-54A	MOLNIYA 1-90	Russia	447	39909	62.8	2	1
1997-55A	STS-86	USA	383	391	51.7	0	0
1997-56A	IRIDIUM 19	USA	Enroute to Op. Orbit				
1997-56B	IRIDIUM 37	USA					
1997-56C	IRIDIUM 36	USA					
1997-56D	IRIDIUM 35	USA					
1997-56E	IRIDIUM 34	USA					
1997-57A	IRS 1D	India	697	831	98.6	1	0

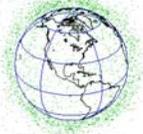


Editor's Notes

The last three months have proved to be an interesting time in the orbital debris community. The papers presented at the International Astronautical Federation Congress in Turin, Italy, were of high quality, covered a wide variety of topics, and presented a number of new ideas. In addition there were several ancillary meetings on orbital debris with the Interagency Space Debris Coordination Committee having meetings of its Steering Group and the Working Group of Environments and Databases and International Academy of Astronautics having a meeting of the Subcommittee on Space Debris.

On another note, we are interested in reducing the costs for providing this newsletter to the orbital debris community by having more people access the newsletter via the Internet. Over the next year we will be asking people to let us know if the electronic version of the newsletter serves their purposes and, if so, whether we can move them from the current mailing list to an electronic mailing list to notify them when a new version of the newsletter is available. The address for the home page where the newsletter resides is http://sn-callisto.jsc.nasa.gov/newsletter/news_index.html.

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Next Issue

- ◆ Hydrocode Article
- ◆ IAF Side Meeting Notes - Photos and Graphs

ORBITAL BOX SCORE

(as of 8 October 1997, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies and Debris	Total
CHINA	21	99	120
CIS	1323	2522	3845
ESA	20	194	214
INDIA	16	4	20
JAPAN	58	54	112
US	671	3267	3938
OTHER	270	26	296
TOTAL	2379	6166	8545



Abstracts from Papers, continued

Spacecraft Orbital Debris Reentry: Aerothermal Analysis, continued

(Continued from page 8)

fragments of a spent Delta second stage undergoing orbital decay-stainless steel cylindrical propellant tank and titanium Surminal Analysis Tool (ORSAT) and Miniature ORSAT (MORSAT) were used to determine trajectories, aerodynamics, reentry predictions of the Japanese Advanced Earth Observing Satellite (ADEOS) aluminum and nickel box-type components and the Russian COSMOS 954 satellite beryllium cylinders were made with MORSAT. These objects were also shown to survive reentry.

The methodology of the two codes is presented, along with results of a parametric study of reentering objects modeled as spheres and cylinders. Parameters varied included mass, diameter wall thickness, ballistic coefficient, length, type of material, and mode of tumbling/spinning. Two