The Orbital Debris Quarterly News

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NEWS

Marshall Researchers Developing Patch Kit to Mitigate ISS Impact Damage

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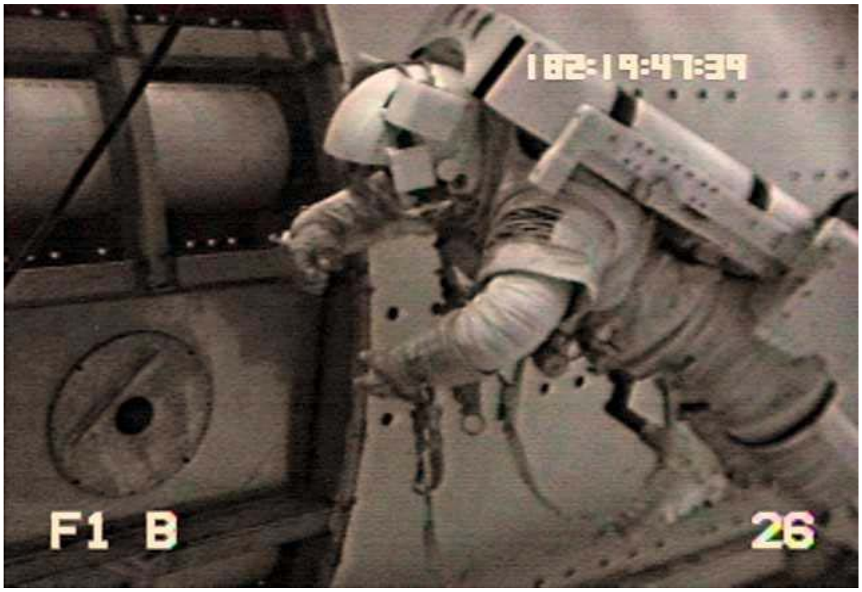
KERMIt, a Kit for External Repair of Module Impacts, is now being developed at the Marshall Space Flight Center in Huntsville, Ala. Its purpose: to seal punctures in the International Space Station caused by collisions with meteoroids or space debris. The kit will enable crewmembers to seal punctures from outside damaged modules that have lost atmospheric pressure. Delivery of the kit for operational use is scheduled for next year.

This article -- which expands on material appearing in the July 1999 issue of "Orbital Debris Quarterly" -- discusses the rationale for an externally applied patch, requirements influencing patch design, patching procedure and developmental status.



Astronaut installing toggle bolt in simulated puncture sample plate on Laboratory Module in Neutral Buoyancy Laboratory. A patch was later placed over the toggle bolt and adhesive injection simulated to evaluate crew interfaces and EVA operations.

External Repair Rationale

The decision was made to develop a kit for external patching for several reasons: time constraints, accessibility, work envelope, collateral damage and EVA suit compatibility.

A primary risk factor in repairing punctured modules is the time constraint involved. Even given the relatively large volume of air within the Space Station upon assembly completion, analyses have shown that a 1-inch-diameter hole can cause pressure to drop to unacceptable levels in just one hour. In that timeframe, the crew must conclude a module has been punctured, determine its location, remove obstructions restricting access, obtain a repair kit and seal the leak. This action would be a challenge even if the crew was not injured and no significant subsystem damage had occurred.

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And in the months before completion of ISS assembly, when the total pressurized volume of the station is much less, depressurization is even more rapid. The same is true -- whatever the timeframe -- for punctures over 1 inch in diameter. With such tight time constraints, it may be wiser for the crew to isolate the damage, retreat to a safe area, stabilize subsystems and allow the damaged module to depressurize.

A second factor is accessibility. Though some ISS modules house standardized racks, which fold down for access to interior pressure module walls, about 30 percent of the interior walls remain inaccessible. Some wall surfaces are blocked behind utility runs in standoffs. In the end cones of certain modules, there are no fold-down racks, so access is even more limited. Others lack the standard racks entirely. In these modules, subsystem and scientific equipment is attached directly to secondary structures, and is not designed to be removed in orbit. In these modules, up to 90 percent of the wall surface is inaccessible.

A third reason to patch externally is to exploit the larger work envelope generally available outside the damaged module. If you fold down a standard rack to get to a hole, the cavity vacated by the rack is only 37 inches wide, 75 inches tall and 40 inches deep. This work envelope can be particularly tight and confining in a pressure-loss situation, when repairs must be made wearing a space suit. Outside the station, however, work envelopes on module surfaces are less restricted, providing good lateral, vertical and depth clearances for repairs.

Despite protective measures designed to protect both structure and crew, there is an inevitable risk of collateral damage received during an impact. A puncture can generate particulate debris within the affected module; this can be hazardous to the crew, whether module repairs are to be done in “shirtsleeves” or a protective space suit. Collateral damage also can cause subsystems to behave erratically or in degraded modes, forcing the crew to stabilize vehicle systems as a first priority. Assessment of collateral damage may require significant time, thereby increasing the likelihood of module depressurization.

A final reason for external repair is that neither the EMU nor the Orlan space suits are designed to operate effectively in depressurized modules. Though Russians in the Orlan suit entered the damaged Spektr module aboard Mir in August 1997, they planned to repair the module externally. Another complication with using an EVA suit inside a depressurized module is the need to depressurize an adjacent module to enter the one that is damaged.

Patching Requirements

There are several requirements for an ideal external patch kit such as KERMIt. These requirements primarily address size, function and compatibility.

Meteoroids and other space debris vary in size, shape, and composition, and the same is true of the holes these objects can produce. Patch size and performance requirements are derived from a study of previous on-orbit impacts and ground-based meteoroid/debris impact simulations.

Thus, patches must be capable of sealing holes up to 4 inches in diameter, and cracks with a maximum length of 8 inches. Damage beyond such limits is highly improbable; it is also significantly more difficult to repair damage exceeded those limits.

An ideal external patch also must be able to seal a hole for a minimum of six months, permitting the crew plenty of time to analyze damage and make more permanent repairs as needed.

Finally, the patch must be compatible with a permanent patch, if the crew determines such a procedure is necessary to restore structural strength to original levels.

Patch Kit Design

Marshall researchers intend the KERMIt Patch Kit to meet these specific requirements. The kit consists of three components: patches, tools and adhesive. The patch design (as illustrated in the July 1999 “Orbital Debris Quarterly) is a clear lexan disk with a toroidal seal on one side, a toggle bolt through the center and fittings for injecting adhesive. Several hand tools are provided for surface preparation, hole measurement and marking, and adhesive injection. The adhesive is a white, two-part epoxy glue, packaged in cartridges that snap into the injector like a double-barreled caulking gun.

Repair Operations

The patching operation begins with a crew EVA to locate and examine the leak site on the exterior of the depressurized module. Any damaged debris shields and thermal insulation obstructing the hole must be removed. Surface preparation tools are then used to clean

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A few of many simulated puncture sample plates, with patches installed, produced for ground testing. These were injected with adhesive in normal gravity and tested for seal effectiveness at one atmosphere. Patch thickness and diameter vary, depending on hole size and module wall irregularities.

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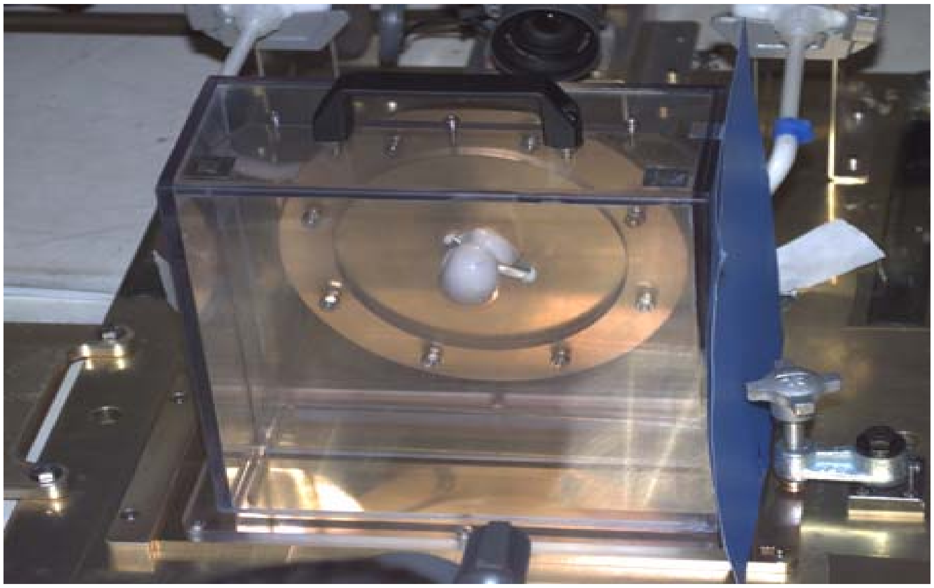
surrounding exposed areas. A special tool is used to determine the size and shape of the hole and to mark reference points. Upon completion of the EVA, the crew uses data on the hole to select properly sized patch components tailored to the size of the damage.

A second EVA is undertaken to deliver the patch, adhesive injector and cartridges to the work site. The toggle bolt is inserted through the hole. A Zipnut on the toggle bolt is tightened, compressing the toroidal seal against the damaged module wall. Next, the adhesive is injected into fittings on the clear disc, filling the cavity formed by the disc, ring and punctured wall. When the cavity is filled, the injector is removed. The adhesive cures, forming a cast plug that seals the hole. Curing takes two to seven days. Afterward, the module may be repressurized in stages to verify proper function of the seal.

Development Activities

Development and testing of the KERMIt Patch Kit is underway at the Marshall Center. Extensive leak tests have been done to assure the patch can hold a one-atmosphere pressure differential. In September 1998, KC-135 tests were conducted comparing adhesive flow in reduced gravity with one gravity flow.

The kit underwent a Preliminary Design Review in February 1999, and in June, Marshall conducted tests in the Neutral Buoyancy Laboratory to examine the adequacy of crew interfaces. A six-month life test of the patch is expected to be conducted in coming months. The operational patch kit is slated to be delivered in September 2000. ❖



Simulated puncture sample plates with patches preinstalled, used to test adhesive flow during injection in reduced gravity aboard the KC-135, adhesive is white globule in center of clear plastic enclosure. Videos and still photos were taken.

Orbital Debris Workshop held at UNISPACE III

The International Academy of Astronautics organized a workshop on orbital debris in conjunction with the United Nations-sponsored UNISPACE III conference. Held on 28 July in Vienna, the objective of the workshop was to inform UNISPACE III participants of the (1) the current understanding of the orbital debris environment, (2) mitigation measures now in use, and (3) the activities of the professional societies, the Inter-Agency Space Debris Coordination Committee, and the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space.

Presentations were made by N. Johnson of NASA (on behalf of J. Loftus), W. Flury of ESA, S. Toda of Japan's National Aerospace Laboratory, F. Alby of CNES, and L. Perek of the Czech Republic. These formal presentations were followed by a round-table discussion on future directions of orbital debris research and by an open discussion period among the workshop attendees.

Three recommendations were approved during the workshop:

1. The United Nations should continue its work on space debris,
2. Debris minimization measures should be applied uniformly and consistently by the entire international space-faring community, and
3. Studies should be continued on future possible solutions to reduce the population of on-orbit debris. ❖

Final Report on Orbital Debris Collector Published

Results from the 18-month exposure of NASA Johnson Space Center's Orbital Debris Collector (ODC) on the Mir space station were published in August. Authored by the NASA-Lockheed Martin team of Fred Horz, Glen Cress, Mike Zolensky, Tom See, Ron Bernhard, and Jack Warren, the 146-page report (Optical Analysis of Impact Features in Aerogel from the Orbital Debris Collection Experiment on the Mir Station, NASA TM-1999-209372) documents the postflight inspections, optical studies, and detailed compositional analyses. During its 18-month exposure on the Mir space station, the ODC was impacted by a large number of small orbital debris particles. See a description of the preliminary analysis in "Mir Orbital Debris Collector Data Analyzed," *The Orbital Debris Quarterly News,* April 1999, page 1. ❖

NEWS

U.S. Government Begins Orbital Debris Meetings with Industry

In January 1998 the U.S. Government (especially NASA, the Department of Defense, the Federal Aviation Administration, and the Federal Communications Commission) held a workshop for industry to review the current assessment of the orbital debris environment and to present a set of draft orbital debris mitigation standard practices (see *The Orbital Debris Quarterly News*, April 1998, pp. 8-9). Following-up on this successful meeting, the U. S. Government interagency working group on orbital debris, led by the White House Office of Science and Technology Policy, decided to solicit additional direct input from leading aerospace corporations.

This effort began in earnest in September 1999, when NASA and DoD officials, on behalf of the interagency working group, visited senior personnel at TRW and Boeing. The objectives of the meeting included

(1) an explanation of U.S. Government policy and strategy on orbital debris,
(2) a review of U.S. Government orbital debris mitigation guidelines, and
(3) the solicitation of feedback from industry on a variety of orbital debris issues.

Meetings with other leading aerospace companies are planned for later this year. Comments received from industry will then be reviewed by the interagency working group as it further develops national orbital debris mitigation strategies. ❖

Small Debris Observations by the COBRA DANE Radar

Under the sponsorship of the NASA JSC Orbital Debris Program Office, in August and September the COBRA DANE (AN/FPS-108) radar conducted special observations to detect and, if possible, to track small debris not currently in the official U.S. Space Command Satellite Catalog. The L-band (~25 cm wavelength) phased-array radar, located at the western end of the Aleutian Island chain (52.7 N, 174.1 E), became operational in 1977 and for many years was one of the most capable sensors of the U.S. Space Surveillance Network (SSN). However, in 1994 the facility terminated its role as a collateral sensor for the SSN.

In an effort to explore methods of improving the overall sensitivity of the SSN, NASA and the Department of Defense collaborated in the exercise which paid special attention to the region below 600 km altitude, where the Space Shuttle and International Space Station operate. Using a "debris fence" and operating at full-power, COBRA DANE attempted to track uncorrelated targets (UCTs) and to obtain both metric and radar cross-sectional data. The Air Force Space Command's Space Warfare Center analyzed the data and developed preliminary orbital elements. The site tried to reacquire the objects in order that the calculation of orbital parameters could be refined. In turn, these data were forwarded to other SSN sensors, in particular the FPS-85 at Eglin AFB, Florida, to determine if these sites could also detect and track the objects.

To date this effort has resulted in the creation of element sets for over 560 objects, of which more than 500 were being tracked on a regular basis. Nearly one-fourth of these objects transit human space flight regimes. Four cataloged satellites which had previously been lost were found during the exercise. Data analysis is continuing. ❖

UN Releases Report on Orbital Debris

The *Technical Report on Space Debris*, prepared and adopted by the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (see *The Orbital Debris Quarterly News*, April 1999, p. 7), has recently been published. The 50-page report (A/AC.105/720, Sales No. E.99.1.17) is the product of a multi-year effort in the STSC, since the issue first appeared on the Subcommittee agenda in February 1994.

The report summarizes the discussions within the STSC on the topics of measurements of orbital debris (1996), modeling of the orbital debris environment and risk assessments (1997), and orbital debris mitigation measures (1998). The consolidated report was formally adopted by the STSC at its February 1999 meeting in Vienna and was released at the UNISPACE III conference in July.

Orbital debris will remain on the agenda of the STSC. The topic for the next meeting in February 2000 is the geosynchronous environment. Specific issues to be addressed include the status of operational spacecraft and debris in GEO, disposal of spacecraft at the end of mission, and guidelines for the abandonment of upper stages and mission-related debris in near-GEO and geosynchronous transfer orbits. ❖

Visit the New NASA Johnson Space Center Orbital Debris Website

http://www.orbitaldebris.jsc.nasa.gov

Project Reviews

Post-Flight Examination of the STS-88 Orbiter

J. Kerr

During December 1998, the Space Shuttle Endeavour spent nearly 12 days in a low altitude (390 km), high inclination (51.6 degree) orbit for the first assembly sequence of the International Space Station. In September 1999 a report sponsored by the NASA Orbital Debris Program Office summarized the orbital debris and micrometeoroid damage discovered during post-flight inspections (STS-88 Meteoroid/ Orbital Debris Impact Damage Analysis, JSC-28641, Justin Kerr and Ronald Bernhard).

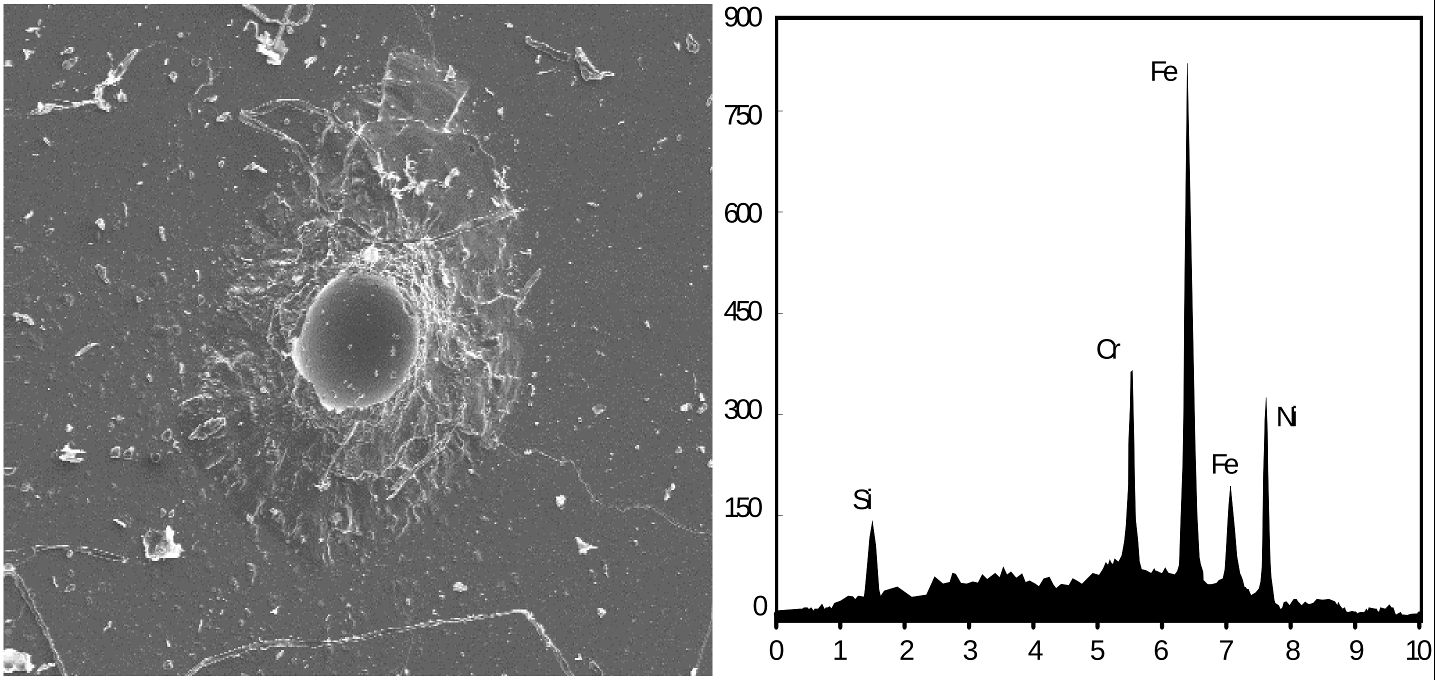
The primary orbiter surface areas examined included the crew compartment windows (3.6 m^2), the reinforced carbon-carbon (RCC) leading edge of the wings (41 m^2), the flexible reusable surface insulation (FRSI) on the exterior of the payload bay doors (40 m^2), and radiator panels (117 m^2). In all, 50 impact sites were examined by tape pull, dental mold, or wooden probe extraction techniques. Damage regions ranged from 0.07 mm to 6.0 mm in equivalent diameter.

A total of 40 window impacts were identified with the help of a new optical micrometer and fiber optic light source. Four windows required replacement following this mission — 3 windows due to craters which exceeded their replacement criteria and 1 due to cumulative damage over a number of missions. The largest window impactor was due to a paint flake estimated to have been 0.03 mm in diameter and 0.04 mm in thickness. Scanning electron microscopy with energy dispersive X-ray spectrometers permitted the characterization of 17 of the impactors: 7 orbital debris and 10 meteoroid. Of the orbital debris impactors, 43% were aluminum, 43% were stainless steel, and 14% were paint.

Examination of the radiators led to the discovery of four impact features with a minimum 1.0 mm damage diameter. Two of four sites yielded sufficient residue to determine the nature of the impactor. One of the impactors was orbital debris (0.3 mm diameter paint flake) and one impactor was a 0.3 mm diameter meteorite. These two impactors created face sheet perforations.

Inspections of the FRSI found five new impact sites greater than 1 mm in extent: one meteoroid (1.2 mm in diameter) and two orbital debris (1.0 and 1.5 mm diameter aluminum). In addition, one new impact site was located on the RCC surfaces. The damage was caused by a 0.4 mm diameter aluminum orbital debris impactor.

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



SEM image and EDX spectra of window impact from the dental mold sample taken from impact overhead window 8, sample #1. This stainless steel debris (estimated diameter = 0.04 mm) impact led to replacement of the window.

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Project Reviews

GEO Spacecraft Disposals in 1997-1998

A recently published study of GEO spacecraft which were retired during 1997-1998 has found that fewer than one-fourth were maneuvered into orbits meeting the widely accepted recommendation for a perigee of at least 300 km above GEO. The assessment, conducted by the NASA JSC Orbital Debris Program Office, appeared in the August issue of *Space Policy*. One of the objectives of the study was to ascertain the degree of compliance with voluntary GEO disposal measures promoted by the International Telecommunications Union (ITU) and the Inter-Agency Space Debris Coordination Committee (IADC).

At the start of 1999, more than 270 GEO spacecraft, nearly half of all GEO spacecraft launched since 1963, were still operational (Figure 1). Contrary to popular belief, nearly a quarter of the operational spacecraft were in orbits with inclinations greater than 2 degrees and as much as 15 degrees. The value of the GEO regime continues to increase, as evidenced by the deployment of 64 new spacecraft during the two-year study period, as the missions of only 38 spacecraft were terminated.

Orbital histories of each of the retiring spacecraft were examined to determine whether disposal maneuvers were performed, and, if so, the nature of those maneuvers. Surprisingly, nearly one-third (12) of the spacecraft were simply abandoned in GEO. Only one of these,

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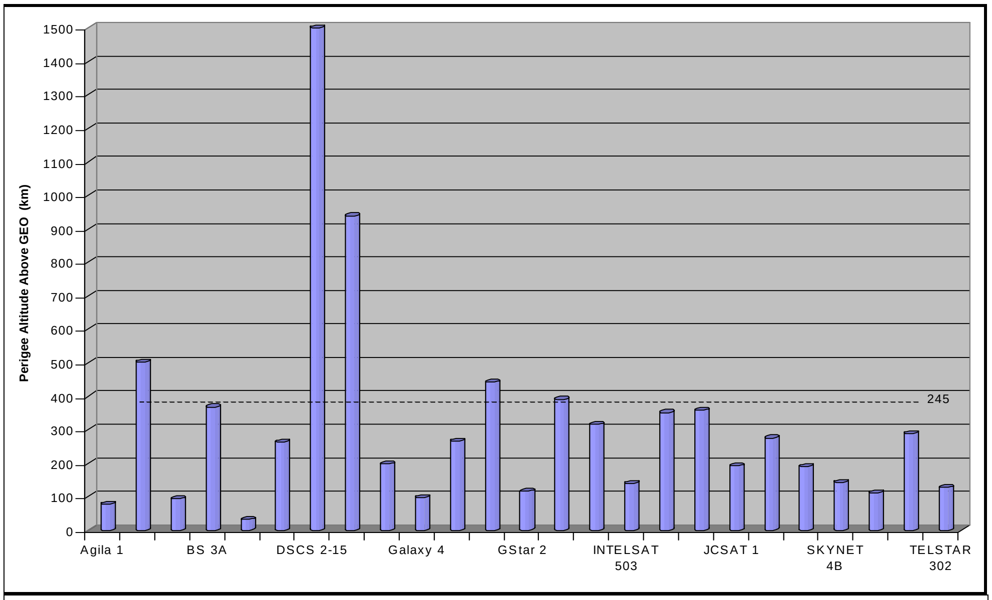
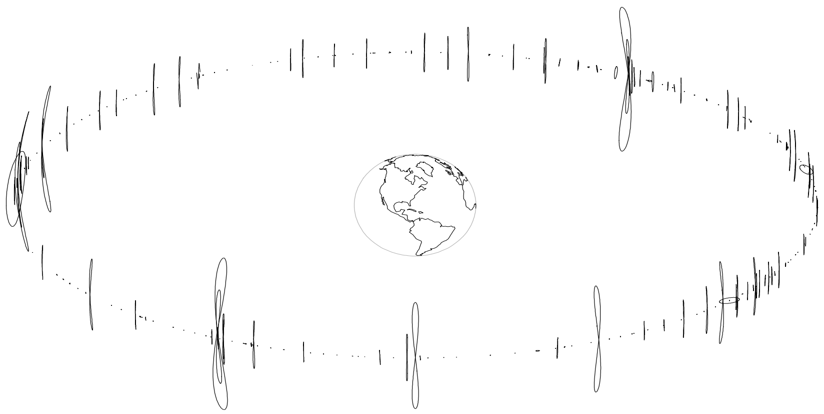
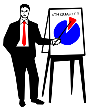


Twenty-five spacecraft were maneuvered into a wide range of disposal orbits during 1997-1998.



Positions of 255 active geosynchronous spacecraft on 1 January 1999.



Project Reviews

GEO Spacecraft Disposals in 1997-1998, Continued

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Telstar 401, is known to have suffered a sudden, catastrophic failure, preventing postmission maneuvers. The other 11 spacecraft were of Russian or Chinese origin.

Of the 25 spacecraft maneuvered into orbits above GEO (Figure 2), only nine reached the ITU-recommended perigee of GEO + 300 km. The perigees of four others were raised above the minimum GEO + 245 km altitude recommended by the IADC (the specific IADC recommended altitude may be as much as GEO + 435 km depending upon the characteristics of the spacecraft).

Another spacecraft, INSAT 2D, suffered a crippling short circuit and had to be decommissioned in an orbit with apogee near GEO and perigee 2500 km below GEO. The fates of upper stages and apogee kick motors near GEO as well as upper stages and mission-related debris in geosynchronous transfer orbits were also examined.

The principal finding of the study was that compliance with international recommendations for GEO spacecraft disposal fell far short of expectations. More uniform adherence to these proposed standard practices is needed to protect the GEO environment. ❖

Upcoming Meetings

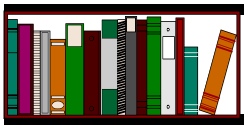
10-13 January 2000: ***38th AIAA Aerospace Sciences Meeting and Exhibit***, Reno, Nevada, USA. The 38th AIAA Aerospace Sciences Meeting and Exhibit will again place emphasis on fundamental science issues. Participation by the basic research community is especially encouraged. The meeting will feature both invited and contributed presentations that address the future scientific and technical challenges facing the aerospace community.

11-13 April 2000: *Space Control Conference 2000*, Lexington, Massachusetts, USA. The conference is the 18th annual meeting hosted by MIT Lincoln Laboratory on space control issues, surveillance technology (including orbital debris), and monitoring and identification. For further information contact Susan Andrews at scc@ll.mit.edu

12 April 2000: *Orbital Debris Mitigation and Risk Assessments for Spacecraft and Launch Vehicles*, NASA Johnson Space Center, Houston, Texas. This meeting for NASA program managers and supporting aerospace industries will be held to familiarize personnel with the requirements of NASA Policy Directive 8710.3 and NASA Safety Standard 1740.14. Emphasis will be placed on what systems must be evaluated, when and how orbital debris assessments should be submitted, and how to determine compliance with the specific guidelines of NSS 1740.14.

12-14 June 2000: *Space and Air Survivability Workshop 2000*, Colorado Springs, Colorado, USA. The purpose of this workshop, which is jointly sponsored by the AIAA and the DoD Joint Technical Coordinating Group on Aerospace Survivability, is to (1) summarize environment hazards and directed threats to commercial and military spacecraft performance (including orbital debris), (2) discuss spacecraft survivability analysis methods, tools, and test techniques, and (3) explore how aircraft survivability methodologies and enhancement techniques might be applied to improve spacecraft survivability. For further information contact Mr. Joel Williamsen, jowillia@du.edu

16-23 July 2000: *33rd Scientific Assembly of COSPAR*, Warsaw, Poland. Four sessions on orbital debris are being jointly organized by Commission B and the Panel on Potentially Environmentally Detrimental Activities in Space to include such topics as techniques to measure orbital debris, methods of orbital debris modeling, hypervelocity impact phenomenology, and debris mitigation practices. For further information contact Prof. Walter Flury, wflury@esoc.esa.de ❖



Abstracts From Papers

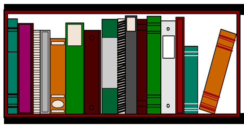
Optical Observations of the Orbital Debris Environment at NASA 1999 AMOS Technical Conference

J. Africano, J. Lambert, E. Stansbery

To gain a better understanding of the LEO and MEO (low and middle earth orbit) optical orbital debris environments, especially in the important, but difficult to track one to ten centimeter size range, NASA Johnson Space Center (JSC) has built a zenith-staring Liquid Mirror Telescope (LMT) near Cloudcroft, NM. The mirror of the LMT consists of a three-meter diameter parabolic dish containing several gallons of mercury that is spun at a rate of ten revolutions per minute. A disadvantage of the LMT is its inability to point in any direction other than the zenith. However, this is not a major limitation for statistical sampling of the LEO and MEO orbital debris population.

While the LMT is used for the characterization of the LEO and MEO orbital debris environments, its inability to point off zenith limits its utility for the GEO environment where objects are concentrated over the equator. To gain a better understanding of the GEO debris environment, NASA JSC has built a CCD Debris Telescope (CDT). The CDT is a 12.5-inch aperture Schmidt portable telescope with automated pointing capability. The CDT is presently co-located with the LMT. The CDT can see down to 17.1 magnitude in a 30 second exposure with a 1.5 degree field of view. This corresponds to a ten percent reflective, 0.8-meter diameter object at geosynchronous altitude.

Both telescopes are used every clear night. We present results from 3 years of observations from the LMT and preliminary results from the CDT. ❖



Abstracts From Papers

Recent Measurements of the Orbital Debris Environment at NASA/JSC

1999 AMOS Technical Conference

E. Stansbery, T. Settecerri, J. Africano

Space debris presents many challenges to current space operations. Although, the probability of collision between an operational spacecraft and a piece of space debris is quite small, the potential losses can be quite high. Prior to 1990, characterization of the orbital debris environment was divided into two categories. Objects larger than 10 cm are monitored by the United States Space Surveillance Network (SSN) and documented in the U.S. Space Command (USSPACECOM) catalog. Knowledge of debris smaller than 0.1 cm has come from the analyses of returned surfaces. The lack of information about the debris environment in the size range from 0.1 to 10 cm led to a joint NASA-DOD effort for orbital debris measurements using the Haystack radar and the unbuilt Haystack Auxiliary (HAX) radars. The data from these radars have been critical to the design of shielding for the International Space Station and have been extensively used in the creation of recent models describing the orbital debris environment.

Recent debris campaigns have been conducted to verify and validate through comparative measurements, the results and conclusions drawn from the Haystack/HAX measurements. The Haystack/HAX measurements and results will be described as well as the results of the recent measurement campaigns. ❖

Characterization of the Pegasus-Haps Breakup

50th International Astronautical Congress

T. Settecerri, P. Anz-Meador, N. Johnson

On June 4, 1996, the upper stage of a Pegasus launch vehicle broke up in orbit at 625-km altitude. International Designator 1994-029B, US Space Command (USSPACECOM) catalog number 23106, was a Hydrazine Auxiliary Propulsion System (HAPS) that had been in orbit since May 1994. On this launch, the payload failed to achieve its intended orbit due to premature shutdown of the main propulsion system and some residual probably remained in the HAPS stage. The dry mass of the system was only 97 kg; yet by August 1996 USSPACECOM Space Surveillance Network (SSN) had detected, identified, and tracked over 700 object related to this breakup. Approximately half remain in orbit. The unusual nature of this event is further reflected in the post-event behavior of many of the debris. Preliminary analysis of the decay rates for individual objects indicated a bimodal distribution in area to mass ratio. The lower lobe of this distribution appears to be typical of a fragmentation event, as compared to other fragmentation debris. However, the distribution's upper lobe appears to indicate the presence of large numbers of relatively "light" debris, *i.e.* those debris whose orbits are significantly modified by atmospheric perturbations (and radiation pressure) over a short period of time. This general implication for long-term orbital evolution is borne out by subsequent observations of the behavior of this debris cloud. Indeed, since the event the debris cloud has steadily decayed such that the environment is nearly back to the pre-event level.

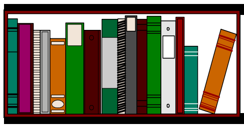
The focus of this paper examines the HAPS cataloged objects (> 10 cm) along with smaller objects detected by the Haystack and Haystack Auxiliary (HAX) radars during NASA's normal debris measurement campaigns. The radar signature from Haystack and HAX indicates that the shapes of the debris objects are dipole-like. This confirms speculation that the graphite epoxy over-wrapped tank unraveled or delaminated due to the propellant explosion. The objective is to characterize this anomalous breakup so as to explain how a relatively small dry mass created over 10,000 pieces greater than 1 mm in diameter. The characteristic shape, catalog lifetimes and size distribution of a representative number of debris pieces are analyzed to estimate the area to mass ratio. Several methods were developed to determine the area/mass ratio and initial velocity of numerous breakups. Different breakups types and vehicles classes were examines which led to new size distribution models which were later incorporated into the EVOLVE environment model. Debris velocities relative to the initial HAPS velocity vector (Δv) are examined to describe the energetics of the fragmentation event and the directional distribution in a co-moving reference frame. ❖

Modeling of Space Debris Reentry Survivability and Comparison of Analytical Methods

50th International Astronautical Congress

W. Rochelle, B. Kirk, B. Ting, L. Smith, R. Smith, E. Reid, N. Johnson, C. Madden

Prediction of reentry survivability of objects during orbital decay is necessary because of adoption of guidelines to reduce orbital lifetimes of non-operational spacecraft and upper stages. The purpose of this paper is to present results from the NASA Object Reentry Survival Analysis Tool (ORSAT) for several reentry bodies and benchmark/parametric analyses of hollow spheres. The ORSAT methodology is summarized describing operation of six general models of the code: trajectory, atmosphere, aerodynamics, aeroheating, thermal, and debris area/ground impact risk. Spinning and non-spinning spheres are evaluated, as well as cylinders, boxes, and flat plates for various tumbling modes. The demise altitude is predicted when the object integrated heat load becomes greater than the material heat of ablation. Results are presented to assess effects of drag coefficient, ballistic coefficient, atmosphere model, wall thickness, diameter, flight path angle, and material on object demise or survival. Results are also presented to determine demise or survival of various spacecraft, including the Delta second stage rocket fragments, Sandia barium fuel rod, and Japanese Advanced Earth Observing Satellite (ADEOS) components. Close agreement of ORSAT predictions is shown with Sandia fuel rod flight measurements and Delta second stage reconstructed trajectory predictions from Aerospace Corporation. ❖



Abstracts From Papers

The Current State of Orbital Debris Mitigation Standards in the United States
50th International Astronautical Congress

J. Loftus, N. Johnson

Minimizing orbital debris generation has been United States national policy since February 1988, capping years of measurements and research by NASA and the Department of Defense. Today, orbital debris mitigation policies and standards in the U.S. have evolved and expanded to virtually all U.S. government space endeavors and a growing number of commercial programs as well. The current National Space Policy, signed by President Clinton in September 1996, not only directs the principal U.S. government agencies conducting space missions to minimize or reduce the accumulation of orbital debris but also recognizes the necessity of such practices by the international community.

NASA Policy Directive 8710.3 (May 1997) has replaced NASA Management Instruction 1700.8 (April 1993), and detailed orbital debris mitigation guidelines (NASA Safety Standard 1740.14, August 1995) are under revision. In the Department of Defense, orbital debris minimization and mitigation guidance are being formulated within the framework of U.S. Space Command Directives and Instructions. Separate instructions have also been issued by the component commands, e.g., U.S. Air Force Space Command. In 1997 both the Federal Aviation Administration, which licenses commercial space launches, and the National Oceanic and Atmospheric Administration, which licenses remote sensing spacecraft, issued notices of proposed rule making which included explicit passages addressing orbital debris mitigation. The Federal Communications Commission is also taking a more direct examination of orbital debris issues during its licensing of communications spacecraft.

Since 1996, under the direction of the White House Office of Science and Technology Policy, a U.S. Government interagency working group on orbital debris has been developing recommended orbital debris mitigation standard practices for both government and industry. The first U.S. Government and industry workshop on orbital debris mitigation was held in January 1998. All of the above efforts support the U.S. Government promotion of responsible international debris mitigation measures, especially in the Inter-Agency Space Debris Coordination Committee and the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful Uses of Outer Space.

The special issue of the disposition of geosynchronous spacecraft is also addressed. Both the International Telecommunications Union and the Inter-Agency Space Debris Coordination Committee have made recommendations for the removal of spacecraft from the geostationary arc at the end of mission. Most operators, however, have yet to accommodate their end-of-mission maneuvers to meet these criteria. NASA has been endeavoring to meet the recommendations but has encountered issues and difficulties which may also be experienced by other operators. ❖

The Use of the Satellite Breakup Risk Assessment Model (SBRAM) to Characterize Collision Risk to Manned Spacecraft
50th International Astronautical Congress

M. Matney, J. Theall

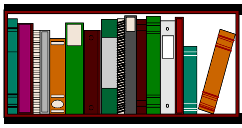
NASA uses environment models such as ORDEM96 to characterize the long-term orbital debris collision hazard for spacecraft in LEO. Occasionally, however, there are breakups of satellites or rocket bodies that create enhanced collision hazard for a period of time. This enhanced collision hazard can pose increased risks to space operations - especially those involving manned missions where the tolerance for risk is very low. NASA has developed SBRAM to simulate the enhanced debris environment in the days and weeks that follow such a breakup. This simulation provides the kind of risk probabilities that can be used by mission planners to consider if changes are warranted for the mission.

Announcements of breakups come to NASA from US Space Command as soon as they are identified. The pre-breakup orbit and time of breakup are used to determine the initial conditions of the explosion. SBRAM uses the latest explosion models developed at NASA to simulate a debris cloud for the breakup. The model uses a Monte Carlo technique to create a random debris cloud from the probability distributions in the breakup model. Each piece of debris randomly created in the cloud is propagated in a deterministic manner to include the effects of drag and other orbital perturbations. The detailed geometry of each simulated close approach to the target spacecraft is noted and logged and the collision probability is computed using an estimated probability density in down-range and cross-range positions of both the target spacecraft and debris object. The collision probability is computed from the overlap of these probability densities for each close-approach geometry and summed over all computed conjunctions. Cloud propagation runs over the desired time interval are then repeated until the scale of the collision risk can be estimated to a desired precision.

This paper presents an overview of the SBRAM model and a number of examples, both real and hypothetical, to demonstrate its use. In addition, a number of different examples are shown how the data can be used by decision makers on issues such as spacecraft orientation and timing of EVAs. ❖

Visit the New NASA Johnson Space
Center Orbital Debris Website

http://www.orbitaldebris.jsc.nasa.gov



Abstracts From Papers

Automated Detection of Orbital Debris in Digital Video Data from a Telescope
50th International Astronautical Congress

T. Hebert, J. Africano, G. Stansbery

To measure, monitor, and predict the orbital debris environment , the Orbital Debris Program Office of the NASA Johnson Space Center collects and analyzes video tapes recorded through a 3-meter zenith-staring telescope in New Mexico. Video data is digitally recorded in the hours both preceding dawn and following twilight. In these tapes, orbital debris above the earth's shadow appear as illuminated objects against a background of stars. Trained observers review the video tapes and record the apparent inclination, brightness, and velocity of illuminated objects seen in the tapes. This tedious review process leads to inter- and intra- observer variances. Methods and results from a PC-based system that automates the detection and measurement of orbital debris and meteors in these videotapes are presented. This automated detection and measurement system combines general-purpose off-the-shelf hardware with special-purpose software to: (a) enable a one-step transfer of 3 hours of compressed video onto the PC hard drives; (b) provide fully automated processing of the video data to detect and measure orbital debris and satellites to a maximum height of 64,000 km (assuming circular orbit) as well as meteors; (3) offer a user-friendly interface facilitating the rapid review of detected events, and (4) offer push-button report-generation wherein orbital debris measurements as wel as user validations, and conclusions are automatically written out in a standardized report format. Results using the automated system were compared to those from two trained observers in reviewing 40 hours of video. The known orbital heights and inclinations of satellites in the USAF Space Command Catalog that passed through the telescope field of view provide a ground truth by which error performance in automated versus manual measurement of orbital height and inclination is shown. These data demonstrate that the computer automated system outperforms the combined results from two trained observers, achieving up a ten percent improvement in the detection rate of orbital debris per tape and a five-fold improvement in the detection rate of meteors. ❖

Man-Made Debris In and From Lunar Orbit
50th International Astronautical Congress

N. Johnson

During 1966-1976, as part of the first phase of lunar exploration, 29 manned and robotic missions placed more than 40 objects into lunar orbit. Whereas several vehicles later successfully landed on the Moon and/or returned to Earth, others were either abandoned in orbit or intentionally sent to their destruction on the lunar surface. The former now constitute a small population of lunar orbital debris; the latter, including four Lunar Orbiters and four Lunar Module ascent stages, have contributed to nearly 50 lunar sites of man's refuse. Other lunar satellites are known or suspected of having fallen from orbit. Unlike Earth satellite orbital decays and deorbits, lunar satellites impact the lunar surface unscathed by atmospheric burning or melting. Fragmentations of lunar satellites, which would produce clouds of numerous orbital debris, have not yet been detected.

The return to lunar orbit in the 1990's by the Hagoromo, Hiten, Clementine, and Lunar Prospector spacecraft and plans for increased lunar exploration early in the 21st century, raise questions of how best to minimize and to dispose of lunar orbital debris. Some of the lessons learned from more than 40 years of Earth orbit exploitation can be applied to the lunar orbital environment. For the near-term, perhaps the most important of these is postmission passivation. Unique solutions, e.g., lunar equatorial dumps, may also prove attractive. However, as with Earth satellites, debris mitigation measures are most effectively adopted early in the concept and design phase, and prevention is less costly than remediation. ❖

CONSTELL: NASA's Satellite Constellation Model
50th International Astronautical Congress

P. Krisko, R. Reynolds, J. Opiela, J. Theall

The CONSTELL program represents an initial effort by the orbital debris modeling group at NASA/JSC to address the particular issues and problems raised by the presence of LEO satellite constellations. It was designed to help NASA better understand the potential orbital debris consequences of having satellite constellations operating in the future in LEO. However, it could also be used by constellation planners to evaluate architecture or design alternatives that might lessen debris consequences for their constellation or lessen the debris effects on other users of space.

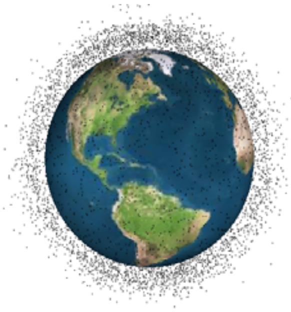
CONSTELL is designed to perform debris environment projections rapidly so it can support parametric assessments involving either the constellations themselves or the background environment which represents non-constellation users of the space. The projections need to be calculated quickly because a number of projections are often required to adequately span the parameter space of interest. To this end CONSTELL uses the outputs of other NASA debris environment models as inputs, thus doing away with the need for time consuming upfront calculations. Specifically, CONSTELL uses EVOLVE or ORDEM96 debris spatial density results as its background environment, debris cloud snapshot templates to simulate debris cloud propagation, and time dependent orbit profiles of the intact non-functional constellation spacecraft and upper stages.

In this paper the environmental consequences of the deployment of particular LEO satellite constellations using the CONSTELL model will be evaluated. Constellations that will undergo a parametric assessment will reflect realistic parameter values. Among other results the increase in loss rate of non-constellation spacecraft, the number of collisions involving constellation elements, and the replacement rate of constellation satellites as a result of debris impact will be presented. ❖

INTERNATIONAL SPACE MISSIONS

July - September 1999

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1999-036A	MOLNIYA 3-50	RUSSIA	488	39869	62.9	2	1
1999-037A	GLOBALSTAR M035	USA	1412	1415	52	1	0
1999-037B	GLOBALSTAR M032	USA	1412	1415	52		
1999-037C	GLOBALSTAR M051	USA	1412	1415	52		
1999-037D	GLOBALSTAR M030	USA	1412	1415	52		
1999-038A	PROGRESS M-42	RUSSIA	346	351	51.7	1	0
1999-039A	OKEAN -O	RUSSIA/ UKRAINE	660	664	98	1	4
1999-040A	STS-93	USA	260	280	28.5	0	0
1999-040B	CHANDRA	USA	10358	138498	28.5	2	0
1999-041A	GLOBALSTAR M026	USA	1413	1415	52	1	0
1999-041B	GLOBALSTAR M028	USA	1412	1415	52		
1999-041C	GLOBALSTAR M043	USA	1412	1415	52		
1999-041D	GLOBALSTAR M048	USA	1412	1415	52		
1999-042A	TELKOM-1	INDO	35780	35793	0	1	0
1999-043A	GLOBALSTAR M024	USA	1411	1417	52	1	0
1999-043B	GLOBALSTAR M027	USA	1412	1415	52		
1999-043C	GLOBALSTAR M053	USA	1412	1415	52		
1999-043D	GLOBALSTAR M054	USA	1412	1415	52		
1999-044A	COSMOS 2365	RUSSIA	184	330	67.1	1	1
1999-045A	COSMOS 2366	RUSSIA	963	1008	82.9	1	0
1999-046A	KOREASAT 3	KOREA	35781	35792	0	1	0
1999-047A	YAMAL 101	RUSSIA	35660	35763	0	2	2
1999-047B	YAMAL 102	RUSSIA	35205	36346	0.1		
1999-048A	FOTON-12	RUSSIA	215	365	62.8	1	4
1999-049A	GLOBALSTAR M033	USA	EN ROUTE TO OP. ORBIT			2	0
1999-049B	GLOBALSTAR M050	USA	EN ROUTE TO OP. ORBIT				
1999-049C	GLOBALSTAR M055	USA	EN ROUTE TO OP. ORBIT				
1999-049D	GLOBALSTAR M058	USA	EN ROUTE TO OP. ORBIT				
1999-050A	ECHOSTAR 5	USA	35774	35799	0.2	1	0
1999-051A	IKONOS 2	USA	678	682	98.2	1	0
1999-052A	TELSTAR 7	USA	35775	35797	0.1	1	0
1999-053A	LMI 1	RUSSIA	35779	35794	0.1	2	1
1999-054A	RESURS F-1M	RUSSIA	181	222	82.3	1	0



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ORBITAL BOX SCORE

(as of 29 September 1999, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	26	101	127
CIS	1339	2575	3914
ESA	23	228	251
INDIA	19	5	24
JAPAN	65	50	115
US	874	2994	3868
OTHER	280	27	307
TOTAL	2626	5980	8606

Orbital Debris and the Internet

Orbital Debris Information

NASA Johnson Space Center:
http://www.orbitaldebris.jsc.nasa.gov

NASA White Sands Test Facility:
http://www.wstf.nasa.gov/hypervl/debris.htm

NASA Marshall Space Flight Center:
http://see.msfc.nasa.gov/see/mod/srl.html

NASA Langley Research Center:
http://setas-www.larc.nasa.gov/index.html

University of Colorado:
http://www-ccar.colorado.edu/research/debris/html/ccar_debris.html

European Space Agency:
http://www.esoc.esa.de/external/mso/debris.html

Italy: http://apollo.cnuce.cnr.it/debris.html

United Nations: http://www.un.or.at/OOSA/spdeb

Orbital Debris Documents

National Research Council, “Orbital Debris – A Technical Assessment”:
http://www.nas.edu/cets/aseb/debris1.html

National Research Council, “Protecting the Space Station from Meteoroids and Orbital Debris”:
http://www.nas.edu/cets/aseb/statdeb1.html

National Research Council, “Protecting the Space Shuttle from Meteoroids and Orbital Debris”:
http://www.nas.edu/cets/aseb/shutdeb1.html