National Aeronautics and Space Administration

Orbital Debris
Quarterly News

Volume 14, Issue 2
April 2010

Inside...

A publication of the NASA Orbital Debris Program Office

Orbital Debris Success Story – A Decade in the Making

During the STS-128 post-flight inspection of the Space Shuttle Discovery (August-September 2009), 14 micrometeoroid and orbital debris (MMOD) impacts on the crew cabin windows, up to 16 impacts on the wing leading edge and nose cap, and 21 impacts on the payload bay cooling radiators were found. Of these, one is perhaps the most important because it highlights a success story over 10 years in the making (see Figure 1).

Although not the largest, the impact crater was strategically located directly over one of the cooling tubes bonded to the back side of the radiator face sheet. The impact crater is important because, if not for decisions to "harden" the Space Shuttle fleet to the increasing orbital debris environment in the 1990s, the impact would have breached the Freon cooling loop and, by flight rule, forced the Shuttle to land at the next primary landing site (PLS) within 24 hours, resulting, potentially, in loss-of-mission.

The Space Shuttle was designed in the 1970s, before the risk from human-made orbital debris was widely recognized. The Shuttle was originally designed with requirements for protection against only the micrometeoroid environment. Almost immediately, damage from orbital debris started showing up. The first significant impact was a 0.2-mm paint chip that damaged a window during the 1983 STS-7 mission and required the window to be replaced prior to re-flight.

In the early 1990s, NASA applied the BUMPER code to predict the risk of damage to different surfaces of the spacecraft given its orbit, orientation, and the MMOD environment. Analysis showed that the Shuttle risk was highly dependent on its flight attitude or orientation. The highest vulnerability to loss-of-mission was penetration of the cooling loop bonded to the inside surface of the radiator facesheet (see Figure 2a).

During this time, the on-orbit heat rejection system in the Shuttle vehicle consisted of two Freon coolant loops routed through the radiator panels attached to the payload bay doors and accumulator tanks. There was no provision for isolating a leak in the system. Puncture of a tube by MMOD would totally deplete the coolant in one of the two loops, necessitating that approximately half of the heat sources (such as avionics in the crew cabin) be switched off. Flight rules under this situation required

continued on page 2

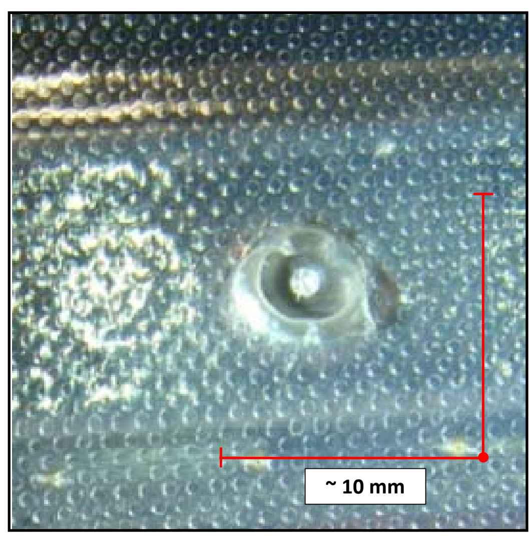

Figure 1. Impact crater on the radiator located on the interior of the Shuttle payload bay doors. The impact was on an aluminum "doubler" directly over the tube carrying Freon coolant used to cool electronic equipment and avionics in the Shuttle.

Success Story

continued from page 1

a next PLS abort, i.e., that the Shuttle mission be aborted immediately and preparations made to land at the next available primary landing site. Because coolant is lost quickly from the pumped flow system in the event of a leak, some of the avionics would be turned off during reentry and landing, decreasing the ability to recover from some other anomaly that could occur during this critical mission phase (due to loss of redundancy in the avionics systems).

The BUMPER predictions were put to the test during the first flight of the U.S. Microgravity Laboratory (USML-1) during STS-50 in 1992. One of the experiments required that the Shuttle fly nose up, payload bay into the velocity vector for 10 days of the 14-day mission. After much discussion with Shuttle managers and impact tests on various spacecraft components that were contained in the payload bay of the Orbiter, it was decided to fly the mission as planned. Fortunately, no MMOD impact breached the Freon cooling loop. However, post-flight inspection of the radiators showed that the number of impact features closely matched the pre-flight BUMPER predictions and were much higher than typical for Shuttle missions flown with the payload bay facing Earth.[1]

continued on page 3

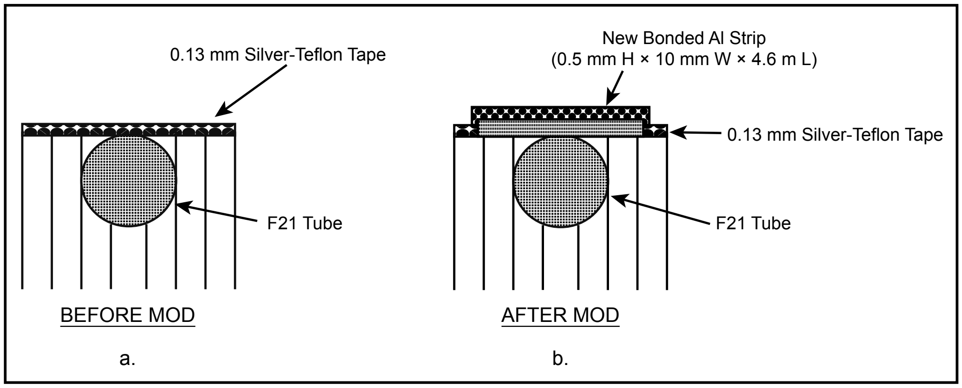

Figure 2. The Shuttle radiators are curved panels on the inside of the payload bay doors that are exposed to space when the doors are open. The panels are a honeycomb structure sandwiched between a facesheet and a backsheet with a total thickness of either 12.7 or 22.9 mm. Aluminum tubes are bonded to the backside of the 0.28-mm thick facesheet at intervals. This figure shows a cross section of the honeycomb radiator showing the configuration before and after the addition of the 0.5-mm aluminum "doubler" modification (MOD).

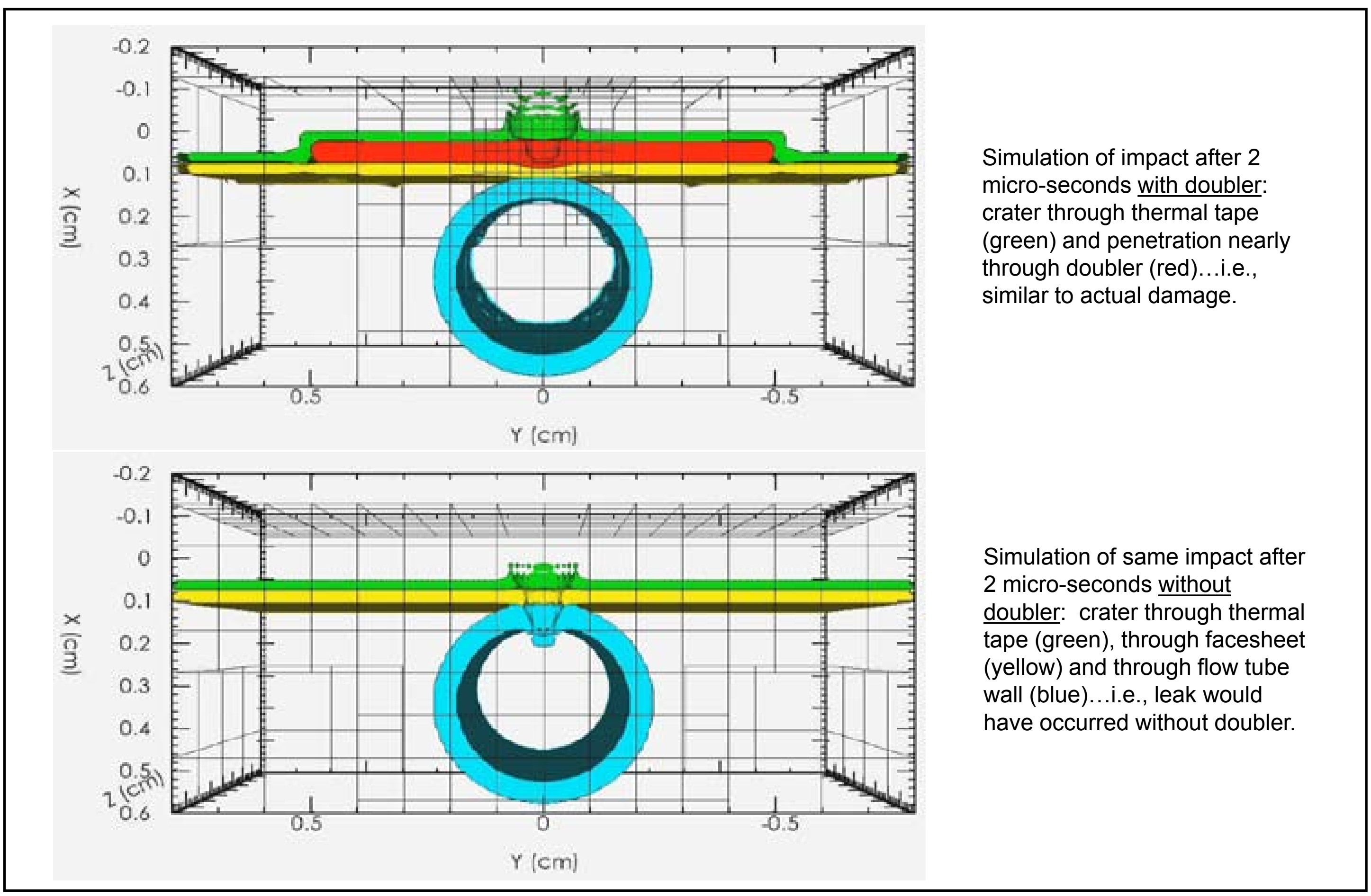

Figure 3. Hydrocode simulation of the impact with and without the aluminum "doubler." Without the doubler, the Freon cooling loop would have been breached.

Success Story

continued from page 2

After STS-50, new flight rules were implemented that required the Shuttle to fly with the payload bay to the Earth and the tail toward the velocity vector "unless payload or orbiter requirements dictate otherwise."[2] This procedure worked well while the Shuttle flew independently. Flights to the Russian space station Mir and later to the International Space Station (ISS), once again exposed the cooling loops to higher risk of MMOD impact for long periods while docked.

In 1997, modifications were approved by the Space Shuttle Program to "harden" the Orbiters from the increasing orbital debris environment. Three of these modifications involved the Freon cooling system, two of which would prove critical for STS-128. First, an extra layer of 0.5-mm thick aluminum (aluminum doubler) was bonded to the radiator facesheet directly over the cooling tubes (see Figure 2b). Automatic isolation valves were added to each coolant loop that could isolate a leak in a radiator panel from the rest of the Freon system (accumulator and pumps) so that sufficient Freon remained to activate the cooling system for all electronics during reentry, when heat is rejected to the flash evaporator system. If sufficient coolant is saved, the need for a next PLS abort is alleviated. The modifications were incorporated into the Shuttle fleet during routine maintenance between 1998 and 1999. These modifications, made 11 years prior to the STS-128 mission, saved the mission from early termination.

During the STS-128 mission, an orbital debris particle impacted the aluminum doubler directly above the Freon tube. Simulations show that had the doubler not been in place, the Freon tube would have been breached (Figure 3.). Without the second modification isolating the leak to the radiator panels, all of the Freon (which is under pressure) would have leaked from the system, requiring the Shuttle to land within 24 hours and with reduced avionics.

This success story is a tribute to the entire NASA Orbital Debris and Space Shuttle management teams. The Orbital Debris Program Office created the debris environment flux models that were based on solid science and measurement data. The Hypervelocity Impact Technology Facility (HITF) team applied the BUMPER code, which demonstrated the vulnerability of the Freon cooling system and its impact to overall mission risk. Then, the Space Shuttle Program Management made critical decisions in tight economic conditions to enhance the safety to the Orbiters from the MMOD threat. A decade later, their hard work and tough decisions paid off.

1. Christiansen, E. L., Bernhard, R. P., Hyde, J. L., et al. "Assessment of High Velocity Impacts on Exposed Space Shuttle Surfaces." *Proceedings of the First European Conference on Space Debris,* ESA-SD-01, 447-452, (1993).

2. Portree, D. S. F. and Loftus, J. P. Jr. Orbital Debris and Near-Earth Environmental Management: A Chronology, *NASA Reference Publication 1320*, (1993). ♦

Old and New Satellite Breakups Identified

The U.S. Space Surveillance Network (SSN) officially confirmed in January the breakup of a Russian spacecraft slightly more than a decade ago and detected the fragmentation of a Chinese spacecraft during February. Fortunately, neither event produced significant numbers of large debris.

Meteor 2-8 (1982-025A, U.S. Satellite Number 13113) was the first of a series of Soviet meteorological spacecraft to employ the Tsyklon (SL-14) launch vehicle and an operational orbit of approximately 950 km at an inclination of 82.5 degrees. The spacecraft, which apparently ceased functioning in the mid-1980s, experienced a minor perturbation in its orbit in May 1999. In January 2010, the SSN cataloged 40 debris (U.S. Satellite Numbers 36318-36357) associated with Meteor 2-8 and traced back to the date of the orbit change.

At the time of the breakup, the spacecraft was in a nearly circular orbit with a mean altitude of 948 km. Whereas the orbit of Meteor 2-8 has declined only a few kilometers since 1999, the debris from the spacecraft, which possess higher drag characteristics, are now found in lower orbits, currently reaching from an altitude

continued on page 4

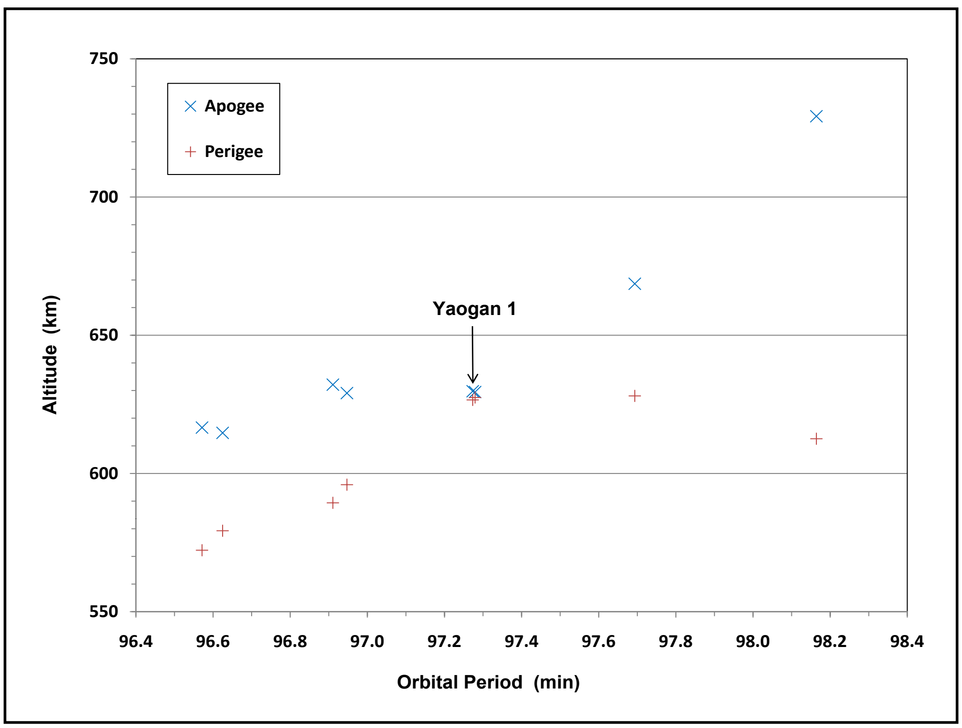

Figure 1. The Yaogan 1 spacecraft ejected seven debris with moderate velocities on 4 February 2010. (Date as of 1 March 2010)

Satellite Breakups

continued from page 3

of 835 km to 945 km. The debris are all quite small with the largest exhibiting a radar cross-section of about 0.02 m^2, roughly equivalent to 15 cm in diameter.

Two other spacecraft in the Meteor 2 series have been linked to anomalous fragmentation events, including Meteor 2-17, for which 30 debris have been cataloged to date. Meteors 2-5, 2-6, and 2-7 have also released cataloged debris ranging from 8 to 19 in number. All of the Meteor 2 events have occurred many years after launch and are possibly due to a degradation of the vehicle itself.

The most recent satellite fragmentation involved China's Yaogan 1 spacecraft (2006-015A, U.S. Satellite Number 29092) in early February 2010. The spacecraft had been operating in an orbit near 630 km with an inclination of 97.9 degrees. The spacecraft, which had not maneuvered since mid-2007, exhibited a minor orbit perturbation on 4 February.

Soon thereafter, the SSN detected seven new debris associated with Yaogan 1 (Figure 1). Preliminary data indicate that two of the new pieces are large: on the order of 2 meters each. The cause of the fragmentation is under investigation. ♦

Update on Three Major Debris Clouds

The first quarter of 2010 marked the third anniversary of the intentional destruction of the Chinese Fengyun-1C spacecraft and the first anniversary of the accidental collision of the U.S. Iridium 33 and Russian Cosmos 2251 spacecraft. The cataloged debris from these three hypervelocity fragmentations now represents an increase in the low Earth orbit (LEO) satellite population of more than 60% (Figure 1).

The total number of debris cataloged by the U.S. Space Surveillance Network (SSN) from Fengyun-1C has continued to grow and had reached 2841 by the end of March 2010, of which less than 85 had reentered. Moreover, more than 500 additional debris were being tracked by the SSN and were awaiting formal cataloging.

Meanwhile, the known large debris from the Iridium-Cosmos collision also has increased. The number of cataloged debris from Iridium 33 and Cosmos 2251 now stands at 1228 and 512, respectively, for a total of 1740. About 400 additional debris have also been identified for future cataloging.

Therefore, the combined cataloged population from these two events, less those debris which have already reentered, is more than 4400. These debris are concentrated in the heart of LEO but spread across the entire region (Figure 2). However, the total number of large debris known to still be in orbit is approximately 5500. For debris as small as 1 cm the total number from these three fragmentations alone is more than 250,000. ♦

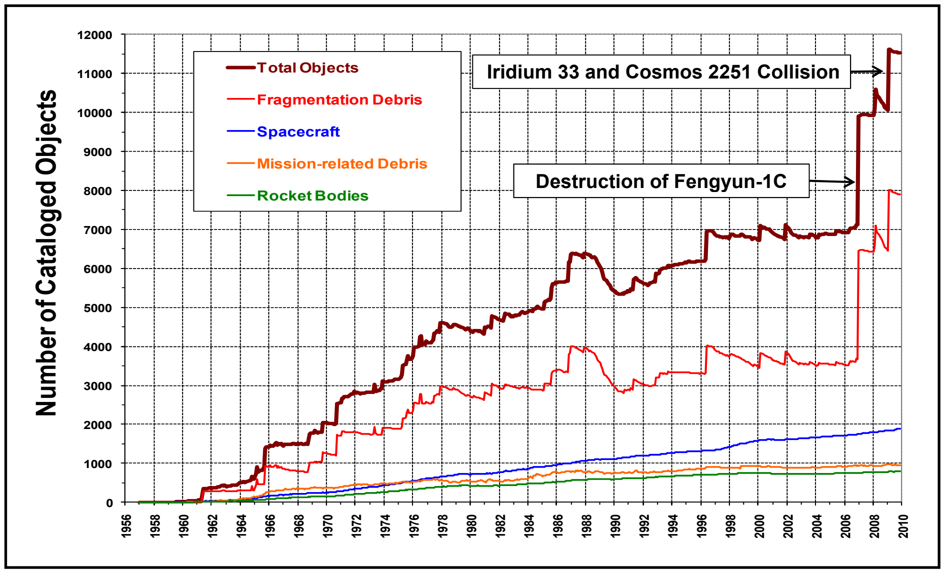

Figure 1. Growth of the cataloged LEO space object population (objects with orbital periods less than 127 minutes).

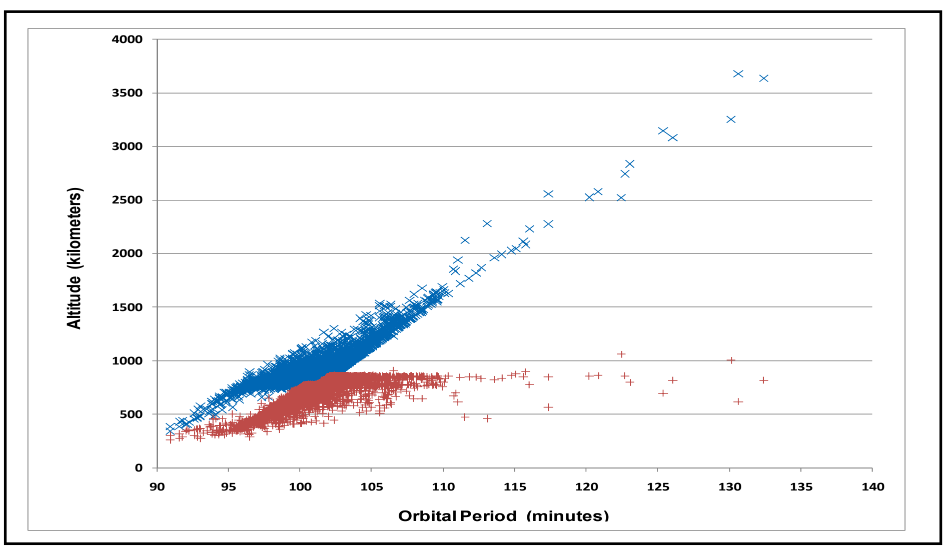

Figure 2. Distribution of cataloged debris from Fengyun-1C, Iridium 33, and Cosmos 2251, as of January 2010.

MMOD Inspection of the HST Bay 5 Multi-Layer Insulation Panel

In addition to the micrometeoroid and orbital debris (MMOD) impact inspection of the Hubble Space Telescope (HST) Wide Field Planetary Camera 2 (WFPC2) radiator (ODQN, July 2009, pp. 2-3 and January 2010, pp. 3-4), the HST Program Office also provided the HST Bay 5 Multi-layer Insulation (MLI) panel to the NASA Orbital Debris Program Office for a 5-week MMOD inspection in February and March. This MLI panel was deployed in 1990 and retrieved during the last HST servicing mission in 2009. As shown in Figure 1, it was located near one of the two solar arrays. The dimensions of the panel are 1.1 m × 1.5 m, with two large cut-out areas approximately 26 cm × 41 cm. The MLI consists of 17 layers of materials, and the outermost layer is a 127-µm thick, fluorinated ethylene-propylene Teflon with a vapor-deposited Al coating on the backside.

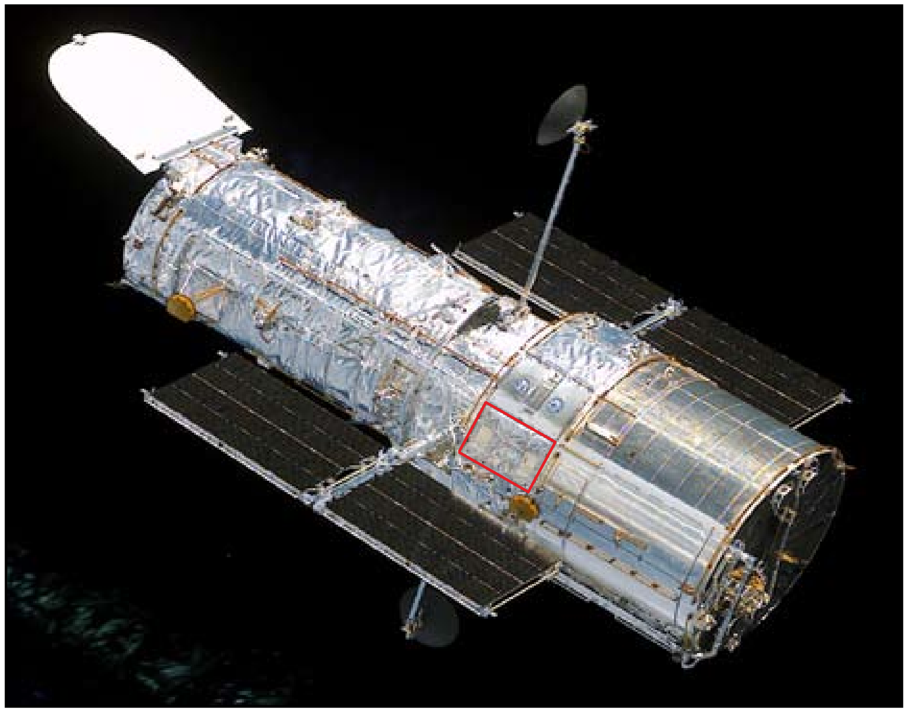

Figure 1. An image of the Hubble Space Telescope. The Bay 5 MLI is outlined by red lines. (edited NASA Photo/S109E5700)

The MMOD inspection of the Bay 5 MLI was conducted in the Space Exposed Hardware Lab at the NASA Johnson Space Center. Just like the inspection of the WFPC2 radiator, a laser projector was used to project coordinate grids on the panel and a Keyence digital microscope was used to take images of the impact features. Due to the reflective nature of the MLI surface and the existence of many creases and cracks, the inspection was rather difficult and time consuming. The available surface was divided into three different zones for inspection. Zone 1 includes detailed photographic documentation of impact features down to 100 µm in diameter, Zone 2 includes photographic documentation of impact features down to 400 µm in diameter, and Zone 3 includes simple visual inspection of impact features down to 400 µm in diameter. The areas of the three zones are approximately 1500 cm^2, 7600 cm^2, and 5000 cm^2, respectively. The numbers of MMOD impact features identified in the three zones are 536, 215, and 138, respectively. Two sample MMOD impact features on the MLI are shown in Figure 2. Numerous small non-impact features, such as surface contamination, were also observed during the process.

The ultimate goal of the MMOD inspection of the HST radiator and MLI is to

continued on page 6

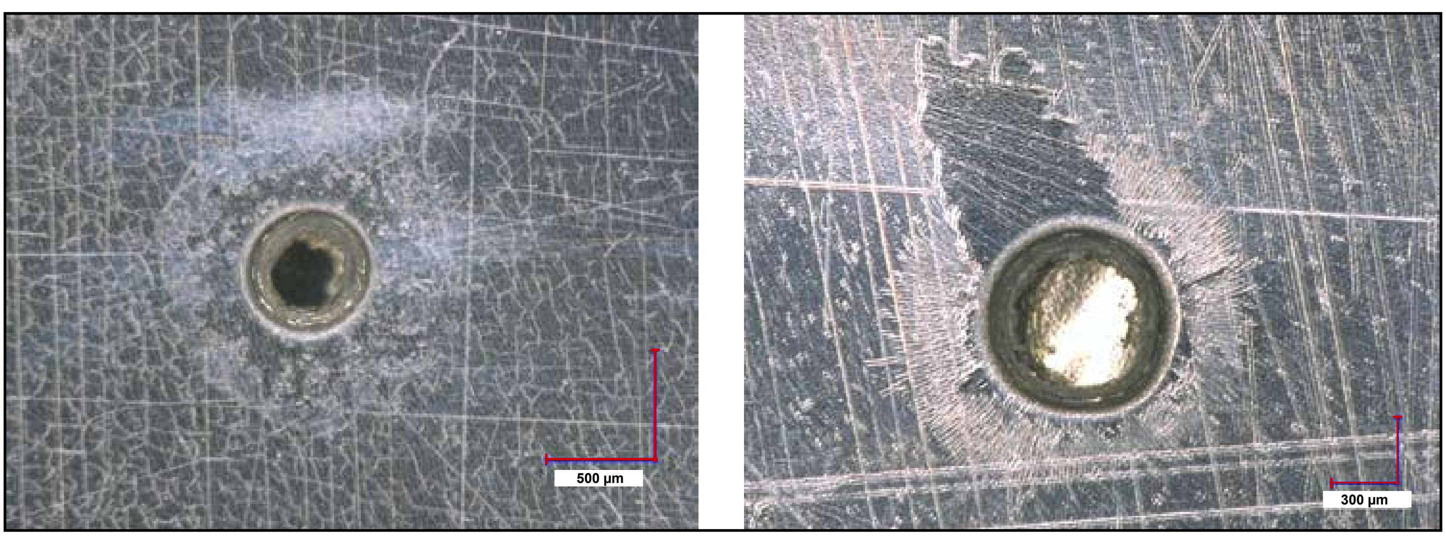

Figure 2. Two sample MMOD impact features on the HST Bay 5 MLI.

MMOD Inspection

continued from page 5

use the data to better define the 100 µm and larger MMOD populations in the environment. When a 100-µm diameter MMOD particle impacted the WFPC2 radiator (4-mm thick aluminum coated with YB-71 thermal paint), it deposited its entire kinetic energy onto the surface and caused damage approximately 300 µm or larger in diameter. On the other hand, a 100-µm diameter MMOD particle could easily perforate a thin film, such as the top layer of the Bay 5 MLI, and leave behind a hole just slightly larger than its diameter. Based on the radiator and the Bay 5 Zone 1 inspection data, it appears that the impact density (number of impacts per unit area) of the ≥100 µm holes on the MLI is approximately one order of magnitude higher than that of the ≥300 µm craters on the radiator. On-going hypervelocity impact tests and hydrocode simulations will eventually provide a better impact feature-to-particle size conversion. Several factors could potentially contribute to the different MMOD impacts between the Bay 5 MLI and the WFPC2 radiator: different space exposure time (MLI's 19.2 years versus radiator's 15.6 years), different exposure orientation in space (the two were approximately 90° apart), and secondary ejecta contamination (MLI was below a solar array while the radiator was 90° away from both solar arrays). Detailed modeling of the latter two effects will be performed to understand the differences between the two sets of data. ♦

PROJECT REVIEWS

Small Debris Observations from the Iridium 33/Cosmos 2251 Collision

M. MATNEY

The accidental collision of the active Iridium 33 satellite (1997-051C, U.S. Satellite Number 24946) and the nonfunctional Cosmos 2251 satellite (1993-036A, U.S. Satellite Number 22675) on 10 February 2009 was a "wake-up call" to the international community that random collisions between satellites represent the single largest contributor to the future orbital debris environment. So far, more that 1700 debris objects have been catalogued from the collision, and more than 2100 are actively being tracked.

The Iridium 33 satellite, part of the U.S.-launched Iridium satellite commercial communication constellation, was in a 776 x 779 km, 86.4º inclination orbit. The Cosmos 2251 satellite, launched by Russia, was in a 776 x 800 km, 74.04º inclination orbit. Consistent with model and empirical data, two debris clouds were created with orbit inclinations roughly centered at the inclinations of each parent body.

While the U.S. Space Surveillance Network (SSN) was able to rapidly assess the large debris population (debris larger than about 10 cm in size), there was much concern about smaller debris that might still pose a risk for spacecraft. NASA was especially concerned about risks to the planned STS-125 Hubble Space Telescope (HST) servicing mission scheduled for the spring of 2009. Since the Space Shuttle HST-servicing missions fly at a higher altitude than the normal International Space Station missions fly, this collision represented a potential added risk to the flight.

NASA was able to use its radar resources to obtain small debris data on the clouds to characterize the changes in the centimeter environment. The Haystack radar has been NASA's primary source of data for centimeter-sized debris since 1990. It can observe debris with sizes down to 1 cm throughout its range window. Its very high sensitivity is a trade-off with its very narrow 0.058° half-power beam-width. Haystack is able to make accurate measurements of an object's radar cross section, range, and Doppler range-rate along the radar boresight. However, measurement of velocity perpendicular to the beam is not as accurate, especially for low signal-to-noise detections. Therefore, debris orbits are best determined statistically using a staring mode. The Goldstone radar is able to supplement the Haystack data by detecting debris down to about 2-3 mm in low-Earth orbit. It also is limited to observing in a statistical staring mode.

Delta-velocity imparted by the energetic breakup means that each debris particle has a somewhat different period, inclination, and other orbit parameters than its siblings. This causes each debris orbit to evolve slightly differently than the others. There are two important time scales associated with this differential orbit evolution. The first is the time it takes for the debris to thoroughly randomize in mean anomaly due to differential orbital periods. This typically takes only a few days. After this randomization occurs, each orbit cloud forms a "ring" or torus around the Earth. Any statistical sample of a segment of this ring would represent an unbiased sample of the entire population. The second time scale is the time it takes for the ring to spread in ascending node due to perturbations by the Earth's oblateness. Depending on the inclinations of the debris in the ring, this process can take months to years. For the 2009 collision, the Cosmos 2251 cloud has mostly spread around the Earth after 1 year, while the Iridium 33 cloud, in an inclination much closer to 90º with a much slower precession rate, is still in a recognizable ring after 1 year.

The ideal time to observe one of these clouds with a staring radar like Haystack is after the debris have randomized in mean anomaly so that a short arc of the ring can be sampled, but before the ring has thoroughly wrapped around the Earth. By taking advantage of this behavior, observations can be made while the debris rings are still concentrated in spatial extent and can still be distinguished from the background debris populations.

For this analysis, we use the NASA Standard Breakup Model to simulate the breakup clouds. This model uses a Monte Carlo method to predict the population of debris as a function of size, as well as the distribution in delta-velocity. The actual state vectors of the

continued on page 7

Small Debris Observations

continued from page 6

parent bodies at the time of collision are used to generate a Monte Carlo cloud, with each sample particle then propagated to the time of the radar observations. This information is used to predict the probability of detection for each computer-created debris object, given the times and pointing directions of the actual radar observations. The predicted cloud shows distinct patterns in time, range, and Doppler range rate. Actual detected cloud particles can be compared to this pattern to see if they fall within it. In addition, the radars observe other debris objects unrelated to the collision clouds. By noting the time, range, and range-rate of these objects, most of these "interlopers" can be removed from the database so that we are left with a set of detections that can be assigned with a high degree of confidence to each cloud.

The data used for these analyses was limited to standard radar staring mode where the Earth's motion brought the debris rings through the field of view of the radar beam. This method has been determined to give the best statistical samples of the cloud. Note that a similar procedure was described in "Haystack radar observations of debris from the Fengyun-1C antisatellite test" (ODQN, July 2008, pp. 7-8).

For the Haystack radar, observations began 20 March 2009, several weeks after the initial breakup, and continued for several weeks. Because of observation time window limitations (Haystack is shared with other users), some days had better coverage of one cloud than another did. Figure 1 shows a typical observation set with Haystack observations of the Cosmos 2251 debris cloud. As can be seen, a subset of Haystack detections correlate with the predicted debris cloud in time and range-rate. A similar process (not shown) is used to correlate the objects with the debris cloud in range. For the Goldstone radar, a special observation run was made on 26 February 2009. Unfortunately, due to limited time available, only the Cosmos 2251 cloud was observed, but the presence of the 3 mm debris from the Cosmos cloud is clearly visible in Figure 2.

By correlating the data from multiple observation days and comparing them to the predicted size distribution, it is possible to construct approximate size distributions for

continued on page 8

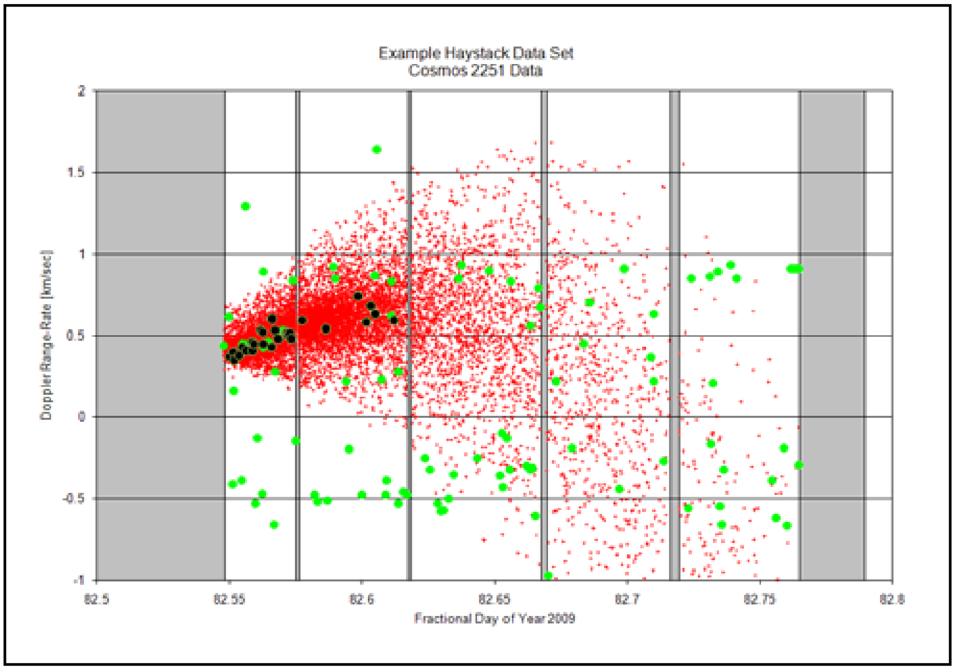

Figure 1. This is a sample of Haystack data taken on day 82 of year 2009, at a time when the Cosmos 2251 cloud was passing through the beam. Time is on the x-axis, the grey gaps represent periods when the radar was not taking data, and the y-axis represents the Doppler range-rate measurements. The green dots represent objects detected that are not believed to be part of the collision cloud, and the black dots represent those that have been assigned to the collision cloud. The cloud of red dots are predicted values for the model cloud.

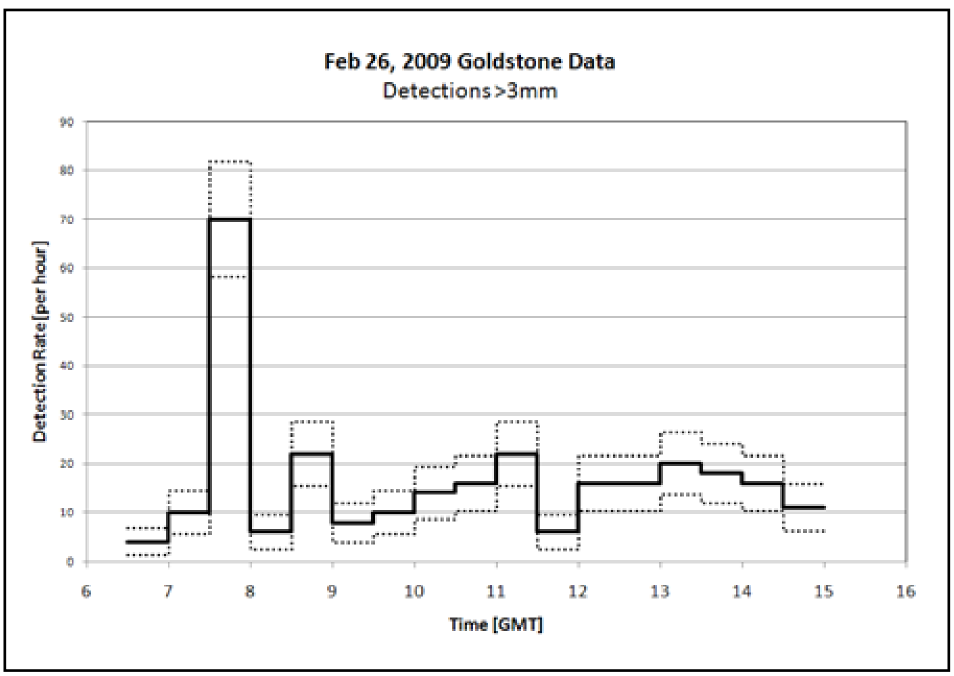

Figure 2. This chart shows the detection rate in the Goldstone radar data from 26 February 2009. The Cosmos 2251 cloud shows up as a noticeable spike in the detection rate between 07:30 and 08:00. Dotted lines are one sigma error bars in the detection rate.

Small Debris Observations

continued from page 7

each debris cloud. Figure 3 shows the composite Cosmos 2251 cloud, including radar data from the SSN. For comparative purposes, a model of the initial cumulative number distribution is plotted. The collision function is predicated upon both parent body masses. Satellite masses were 900 kg in Figure 3 and 556 kg in Figure 4.[1] While the catalogued population slope is steeper than the model slope, Haystack and Goldstone measurements indicate that the millimeter and centimeter populations follow the model slope closely. Figure 4 shows the estimated size distribution of Iridium 33 debris from the Haystack and SSN data. Even though there are interesting variations in the size distribution, the overall populations are similar to those predicted by the models.

Differences in magnitude may be attributable to initial state (model) versus evolved cloud (radar data), un-modeled functional dependencies for a target and projectile of comparable mass, fractional masses being directly involved in the accidental collision's phenomenology, and other unidentified factors.

Using this analysis of the measured debris clouds, NASA was able to adjust the orbital debris risk calculations for the STS-125 and other missions to accurately reflect the enhancements to the debris population. Because these debris clouds will persist for decades, these analyses will be reflected in the ORDEM2010 model populations and other future debris models.

1. Johnson, N. L., et al. "NASA's New Breakup Model of EVOLVE 4.0." *Adv. Space Res.* **28**, No. 9, 1377-1384, (2001). ♦

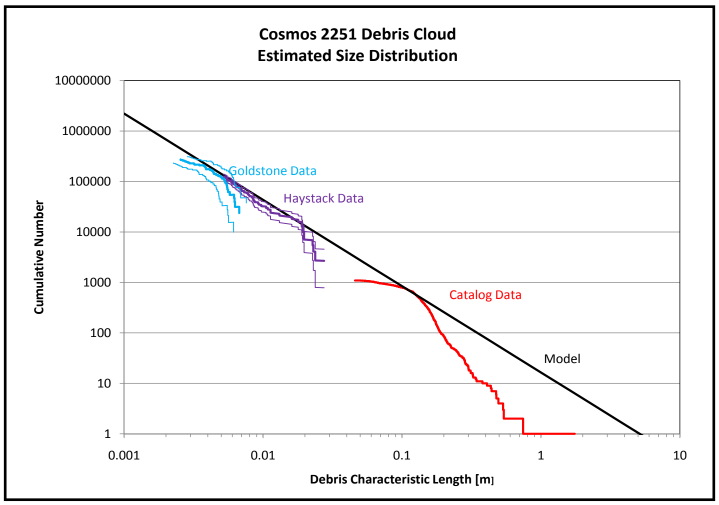

Figure 3. This is a composite size distribution of the Cosmos 2251 debris cloud based on Goldstone, Haystack, and SSN data compared to the model size distribution. The Goldstone and Haystack populations also show a +/- one sigma uncertainty on the inferred population.

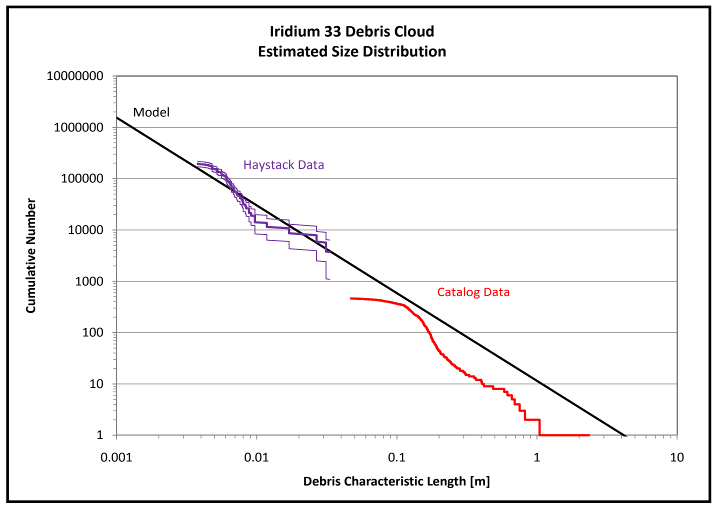

Figure 4. This is a composite size distribution of the Iridium 33 debris cloud based on Haystack and SSN data compared to the model size distribution. The Haystack population also shows a +/- one sigma uncertainty on the inferred population.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

33rd Annual American Astronautical Society, Rocky Mountain Section, Guidance and Control Conference 6-10 February 2010, Breckinridge, Colorado

Orbital Debris: The Growing Threat to Space Operations

N. L. JOHNSON

For nearly 50 years, the amount of man-made debris in Earth orbit steadily grew, accounting for about 95% of all cataloged space objects over the past few decades. The Chinese anti-satellite test in January 2007 and the accidental collision of two spacecraft in February 2009 created more than 4000 new-cataloged debris, representing an increase of 40% of the official U.S. Satellite Catalog. The frequency of collision avoidance maneuvers for both human space flight and robotic operations is increasing along with the orbital debris population. However, the principal threat to space operations is driven by the smaller and much more numerous uncataloged

continued on page 9

Orbital Debris: The Growing Threat

continued from page 8

debris. Although the U.S. and the international aerospace communities have made significant progress in recognizing the hazards of orbital debris and in reducing or eliminating the potential for the creation of new debris, the future environment is expected to worsen without additional corrective measures. ♦

Sustainable Use of Space through Orbital Debris Control

H. KLINKRAD AND N. L. JOHNSON

The paper describes the current orbital debris environment, outline its main sources, and identify internationally accepted debris mitigation measures to reduce orbital debris growth by controlling these sources. However, analyses of the long-term effects of mitigation measures on the debris environment indicate that even extreme measures, such as an immediate halt of all launch activities, will not lead to a stable debris population. Some orbit altitudes, particularly in the LEO regime, already have critical mass concentrations that will trigger collisional cascading within a few decades, unless debris environment remediation measures are introduced. Physical principles and operational procedures for active mass removal are described, and their effectiveness on the long-term sustainability of space activities are demonstrated. ♦

The Kessler Syndrome: Implications to Future Space Operations

D. J. KESSLER, N. L. JOHNSON, J.-C. LIOU, AND M. MATNEY

The term "Kessler Syndrome" is an orbital debris term that has become popular outside the professional orbital debris community without ever having a strict definition. The intended definition grew out of a 1978 Journal of Geophysical Research paper predicting that fragments from random collisions between catalogued objects in low Earth orbit would become an important source of small debris beginning in about the year 2000, and that afterwards, "…the debris flux will increase exponentially with time, even though a zero net input may be maintained." The purpose of this paper is to clarify the intended definition of the term, to put the implications into perspective after 30 years of research by the international scientific community, and to discuss what this research may mean to future space operations. The conclusion is reached that while popular use of the term may have exaggerated and distorted the conclusions of the 1978 paper, the result of all research to date confirms that we are now entering a time when the orbital debris environment will increasingly be controlled by random collisions. Without adequate collision avoidance capabilities, control of the future environment requires that we fully implement current mitigation guidelines by not leaving future payloads and rocket bodies in orbit after their useful life. In addition, we will likely be required to return some objects already in orbit. ♦

An Overview of NASA's Orbital Debris Environment Model

M. MATNEY

Using updated measurement data, analysis tools, and modeling techniques, the NASA Orbital Debris Program Office has created a new Orbital Debris Environment Model. This model extends the coverage of orbital debris flux throughout the Earth orbit environment, and includes information on the mass density of the debris as well as the uncertainties in the model environment. This paper gives an overview of this model and its implications for spacecraft risk analysis. ♦

Current and Near-Term Future Measurements of the Orbital Debris Environment at NASA

E. STANSBERY, J.-C. LIOU, M. MULROONEY, AND M. HORSTMAN

The NASA Orbital Debris Program Office places great emphasis on obtaining and understanding direct measurements of the orbital debris environment. The Orbital Debris Program Office's environmental models are all based on these measurements. Because OD measurements must cover a very wide range of sizes and altitudes, one technique realistically cannot be used for all measurements. In general, radar measurements have been used for lower altitudes and optical measurements for higher altitude orbits. For very small debris, in situ measurements such as returned spacecraft surfaces are utilized. In addition to receiving information from large debris (>5-10 cm diameter) from the U.S. Space Surveillance Network, NASA conducts statistical measurements of the debris population for smaller sizes. NASA collects data from the Haystack and Goldstone radars for debris in low Earth orbit as small as 2-4 mm diameter and from the Michigan Orbital DEbris Survey Telescope for debris near geosynchronous orbit altitude for sizes as small as 30-60 cm diameter. NASA is also currently examining the radiator panel of the Hubble Space Telescope Wide Field Planetary Camera 2, which was exposed to space for 16 years and was recently returned to Earth during the STS-125 Space Shuttle mission. This paper will give an overview of these on-going measurement programs at NASA as well as discuss progress and plans for new instruments and techniques in the near future. ♦

11th Hypervelocity Impact Symposium
11-15 April 2010, Freiburg, Germany

Acoustic Response of Aluminum and Duroid Plates to Hypervelocity Impacts

M. J. BURCHELL, S. STANDEN, M. J. COLE, R. D. CORSARO, F. GIOVANE, J.-C. LIOU, V. PISACANE, AND E. STANSBERY

The growing need for real-time impact sensors for deployment on both space vehicles and space habitats (in orbit or on the surface of atmosphereless bodies such as the Moon) has stimulated sensor development programs. The sensors should be low mass, low power, easily read out electronically, cover large areas and be sensitive to impacts which can cause damage up to and including penetration. We propose that piezo-strain acoustic sensors can play an important role in this work. Accordingly, we report on a series of hypervelocity impact tests of acoustic sensors mounted on thin plates (aluminum and Duroid plates). The acoustic sensors gave strong signals for impacts of submillimeter-to-millimeter-scale projectiles. We investigated dependencies on impactor speed and size and angle of incidence, and tested the difference between cratering and penetrating impacts. ♦

Microsatellite Impact Fragmentation

T. HANADA, J. MURAKAMI, Y. TSURUDA, AND J.-C. LIOU

This paper summarizes recent microsatellite impact tests conducted in collaboration with the NASA Orbital Debris Program Office. The motivation for the impact tests is twofold. First, as new satellite materials continue to be developed, there is a need for impact tests on satellites made of modern materials to better characterize the outcome of future on-orbit satellite fragmentation. Second, it is necessary to extend tests to different velocity regimes to cover potential low-velocity collisions in the geosynchronous region. To date, seven impact tests have been carried out. All microsatellites were totally fragmented and generated more than 1000 fragments each. Fragments down to about 2 mm in size were collected, measured, and analyzed. The main summary of this paper includes size, mass, area-to-mass ratio, and shape distributions of fragments generated from each test and how they vary with size, material type, and impact parameters. ♦

MEETING REPORTS

13th Meeting of the NASA/DoD Orbital Debris Working Group
25 January 2010, Colorado Springs, Colorado

The Air Force Space Command hosted the 13th annual meeting of the NASA/DoD Orbital Debris Working Group Meeting in Colorado Springs on 25 January 2010. Six presentations were given by the DoD personnel during the morning session. They included (1) a review of the U.S. National, DoD, and Air Force orbital debris policies and guidelines, (2) orbital debris management of the Air Force missions, (3) ongoing efforts for National Space Situational Awareness, (4) a review of the SL-12 breakups, (5) satellite breakup parameter determination, and (6) risk management for launch collision avoidance.

Gene Stansbery and J.-C. Liou from the NASA Orbital Debris Program Office provided six briefings during the afternoon session. They included a summary of the NASA-DARPA Orbital Debris Removal Conference, the status of the new orbital debris engineering model ORDEM2010, the development status of the Meter Class Autonomous Telescope, a progress report on the DRAGONS in-situ measurement project, the preliminary result of the micrometeoroid and orbital debris impact inspection of the HST Wide Field Planetary Camera 2 radiator, and NASA's assessments of the risks to NASA spacecraft from on-orbit fragmentation. Meeting participants also discussed action items from the previous meetings and identified several new action items in the late afternoon. ♦

13th Annual FAA Commercial Space Transportation Conference
10-11 February 2010, Arlington, Virginia

Despite a heavy blizzard, the 13th Commercial Space Transportation Conference, sponsored by the Federal Aviation Administration and the American Institute of Aeronautics and Astronautics, was held in Washington, D.C. on 10 – 11 February 2010. The conference had 11 different sessions. One of the sessions, the Space Traffic Management discussion panel, directly addressed hazards to orbital debris. This session was moderated by the Deputy Associate Administrator for Commercial Space Transportation, James Van Laak. Four presentations were made prior to accepting questions from the audience. Panelists were Gene Stansbery, from NASA's Orbital Debris Program Office; William Ailor, from the Aerospace Corporation; Carl Walz, from Orbital Sciences Corporation; and Lt Col Guin Leeder, from the U.S. Strategic Command. Due to the weather, two of the panelists participated by telecon.

During the NASA presentation, it was pointed out that the President's National Space Policy directly addresses commercial space operations and the goal to minimize the creation of orbital debris. The policy also tasks the Secretary of Transportation and the Chairman of the Federal Communications Commission to continue addressing orbital debris issues through licensing procedures.

After summarizing the current state of

continued on page 11

FAA Commercial Space Transportation Conference

continued from page 10

knowledge and future projections of the orbital debris environment, it was concluded that there are limited strategies for space traffic management. Operators should perform launch collision avoidance to ensure that initial operations do not lead to a potential collision; once on orbit, perform Collision Avoidance against the tracked population (recognizing that this is a small percentage of the risk); and follow the U.S. Orbital Debris Mitigation Standard Practices, including spacecraft disposal, to prevent adding to the long term debris population. ♦

33rd Annual American Astronautical Society, Rocky Mountain Section, Guidance and Control Conference 6-10 February 2010, Breckinridge, Colorado

The ODPO participated in the 33rd Annual Guidance and Control Conference organized by the Rocky Mountain Section of the American Astronautical Society. Held in beautiful Breckenridge, Colorado, the Orbital Debris session was held the morning of 6 February. It was very well attended, and proved to be a good overview of both the NASA Orbital Debris program and the state of orbital debris studies worldwide. Many of the attendees were experts in areas other than orbital debris. Consequently, their attendance reflects the broad interest in the subject.

Nick Johnson, from NASA Johnson Space Center (JSC), presented the initial overview, "Orbital Debris: the Growing Threat to Space Operations," showing the overall growth in the orbital debris environment and how the recent Fengyun-1C anti-satellite test and the Iridium 33/Cosmos 2251 collision have made marked changes in the debris population in low-Earth orbit.

Tim Payne of Air Force Space Command presented an overview of "The Space Surveillance Network (SSN) and Orbital Debris" in which he summarized the tracking and collision avoidance capabilities of the SSN.

Two talks presented overviews of activities by the NASA ODPO. Gene Stansbery presented the "Current and Near-Term Future Measurements of the Orbital Debris Environment at NASA," summarizing NASA's ongoing measurement activities. Mark Matney presented an update on the ORDEM model status with "An Overview of NASA's Orbital Debris Environment Model."

Richard Gavin from NASA JSC presented "NASA's Orbital Debris Conjunction Assessment and Collision Avoidance Strategy," summarizing the history of how collision avoidance strategies have been used for NASA's crewed vehicles.

Don Kessler, the "father" of orbital debris studies, made a rare public appearance to present a very thorough overview of the history and technical aspects of the famous "Kessler Syndrome" with "The Kessler Syndrome: Implications to Future Space Operations."

Heiner Klinkrad, from the European Space Agency, finished the session by bringing an international perspective on the issues of passive and active orbital debris removal techniques with "Sustainable Use of Space through Orbital Debris Control." ♦

UPCOMING MEETINGS

19-21 May 2010: The 4th IAASS Conference, Huntsville, Alabama

The theme of the fourth conference of the International Association for the Advancement of Space Safety will be "Making Safety Matter." The IAASS conference will address several issues associated with orbital debris, including space traffic management, safety risk management, probabilistic risk assessment, regulations and standards for safety, and spacecraft reentry safety. The IAASS, legally established 16 April 2004 in the Netherlands, is a non-profit organization dedicated to furthering international cooperation and scientific advancement in the field of space systems safety. The IAASS membership is open to anyone having a professional interest in space safety. Additional information is available at <http://www.congrex.nl/10a06/>.

18 - 25 July 2010: The 38th COSPAR Scientific Assembly, Bremen, Germany

The four debris sessions planned during the Assembly will offer 32 technical oral presentations. They will cover topics in ground-based and in-situ measurement techniques, debris and meteoroid environment modeling, collision risks for space missions, on-orbit collision avoidance, reentry risk assessments, debris mitigation measures and their effectiveness for long-term environment stability, national and international debris mitigation standards and guidelines, hypervelocity impact testing, and shielding designs. A joint session with the Space Weather Panel, "Space Situational Awareness and its Relationship with Science," is also planned with 19 technical oral presentations. Additional information for the Assembly is available at <http://www.cospar-assembly.org>.

27 September - 1 October 2010: The 61st International Astronautical Congress (IAC), Prague, Czech Republic

The theme for the 2010 IAC is "Space for Human Benefit and Exploration." A Space Debris Symposium with 50 technical oral presentations is planned during the Congress. It will include five sessions on (1) measurements, (2) modeling and risk analysis, (3) hypervelocity impacts and protection, (4) mitigations, standards, and legal issues, and (5) space surveillance and space situation awareness. Additional information for the Congress is available at <http://www.iac2010.cz>.

SATELLITE BOX SCORE

(as of 07 April 2010, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	85	3207	3292
CIS	1400	4370	5770
ESA	38	44	82
FRANCE	48	421	469
INDIA	39	131	170
JAPAN	112	77	189
USA	1127	3694	4821
OTHER	463	114	577
TOTAL	3312	12058	15370

INTERNATIONAL SPACE MISSIONS

01 January – 31 March 2010

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2010-001A	BEIDOU G1	CHINA	35775	35800	1.7	1	0
2010-002A	RADUGA 1M-2	RUSSIA	35777	35797	0.0	1	1
2010-003A	PROGRESS-M 04M	RUSSIA	342	353	51.6	1	0
2010-004A	STS-130	USA	342	353	51.6	0	0
2010-005A	SDO	USA	35779	35791	28.1	1	0
2010-006A	INTELSAT 16	INTELSAT	35776	35795	0.1	1	1
2010-007A	COSMOS 2459	RUSSIA	19044	19216	64.8	2	6
2010-007B	COSMOS 2461	RUSSIA	19121	19139	64.8		
2010-007C	COSMOS 2460	RUSSIA	19125	19134	64.8		
2010-008A	GOES-15	USA	35785	35790	0.4	1	0
2010-009A	YAOGAN 9A	CHINA	1081	1100	63.4	1	2
2010-009B	YAOGAN 9B	CHINA	1081	1101	63.4		
2010-009C	YAOGAN 9C	CHINA	1081	1101	63.4		
2010-010A	ECHOSTAR 14	USA	35783	35789	0.0	1	1

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

Technical Editor
J.-C. Liou

Managing Editor
Debi Shoots

Correspondence concerning the ODQN can be sent to:

Debi Shoots
NASA Johnson Space Center
Orbital Debris Program Office
Mail Code JE104
Houston, TX 77058

debra.d.shoots@nasa.gov

DAS 2.0 NOTICE

Attention DAS 2.0 Users: an updated solar flux table is available for use with DAS 2.0. Please go to the Orbital Debris Website (http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html) to download the updated table and subscribe for email alerts of future updates.

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058

www.nasa.gov