National Aeronautics and Space Administration

# Orbital Debris Quarterly News

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## Inside...



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## ISS Maneuvers to Avoid Russian Fragmentation Debris

On 27 August the International Space Station (ISS) conducted its first collision avoidance maneuver in five years to evade a piece of debris from the Russian spacecraft Cosmos 2421. Europe's Automated Transfer Vehicle, the Jules Verne, burned two of its main engines for slightly more than 5 minutes to push the large complex out of harm's way (Figure 1).

Cosmos 2421 had experienced three major fragmentations during March-June, creating approximately 500 large debris and an unknown number of smaller debris (ODQN, Vol. 12, Issues 2 and 3). By mid-September a total of 480 fragmentation debris had been officially cataloged by the U.S. Space Surveillance Network, of which about half were still in orbit. Since Cosmos 2421 was approximately 60 km above ISS at the time of the fragmentations, all debris either were initially in orbits routinely transiting the ISS orbital regime or were in higher orbits which would later pass through the orbit of ISS.

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*Figure 1. The Jules Verne Automated Transfer Vehicle (top) performed the maneuver to avoid a potential collision with debris from Cosmos 2421.*

# ISS Maneuvers

*continued from page 1*

The fragment (U.S. Satellite Number 33246, International Designator 2006-026RU) that caused ISS's collision avoidance maneuver was in the latter category. In fact, it was not until the beginning of August that the perigee of the debris had reached the apogee of ISS (Figure 2).

For several months numerous debris from Cosmos 2421 passed close to ISS, and multiple times collision avoidance maneuvers were prepared, only to be cancelled later when the calculated probability of collision fell below the Red Threshold of 0.0001, *i.e.*, 1 in 10,000. For the conjunction of 27 August the miss distance was predicted to be as large as 1.6 km, but the probability of collision was 1 in 72, dictating the execution of the prepared maneuver plan.

The burn of the ATV's engines began about two hours before the nominal time of closest approach by the debris. Due to forthcoming logistics missions, a retrograde maneuver of 1 meter per second was selected to lower slightly the mean altitude of ISS, the first such maneuver in 8 years. To accomplish this feat, ISS was rotated 180 degrees to align the engines of the ATV with the direction of travel about the Earth.

A total of eight collision avoidance maneuvers have now been conducted during the ISS program. The first seven maneuvers all occurred early in the program in the period from October 1999 to May 2003.[1] One of the reasons for the long hiatus in collision avoidance maneuvers is the improvemet in the accuracy of space surveillance tracking and the conjunction assessment process.

Although no new satellite breakups were detected during the third quarter of 2008, another of the debris from Cosmos 2421 (U.S. Satellite Number 33258, International Designator 2006-026SG) did fragment into three pieces on 6 August. Such disintegrations of breakup debris have occasionally been observed before. The cause is likely to be the fragile nature of the debris or an impact by a small particle.

1. Johnson, N.L., "Current Characteristics and Trends of the Tracked Satellite Population in the Human Space Flight Regime, Paper IAC-06-B6.1.03, presented at the 57th International Astronautical Congress, Valencia, Space, September-October 2006. ♦

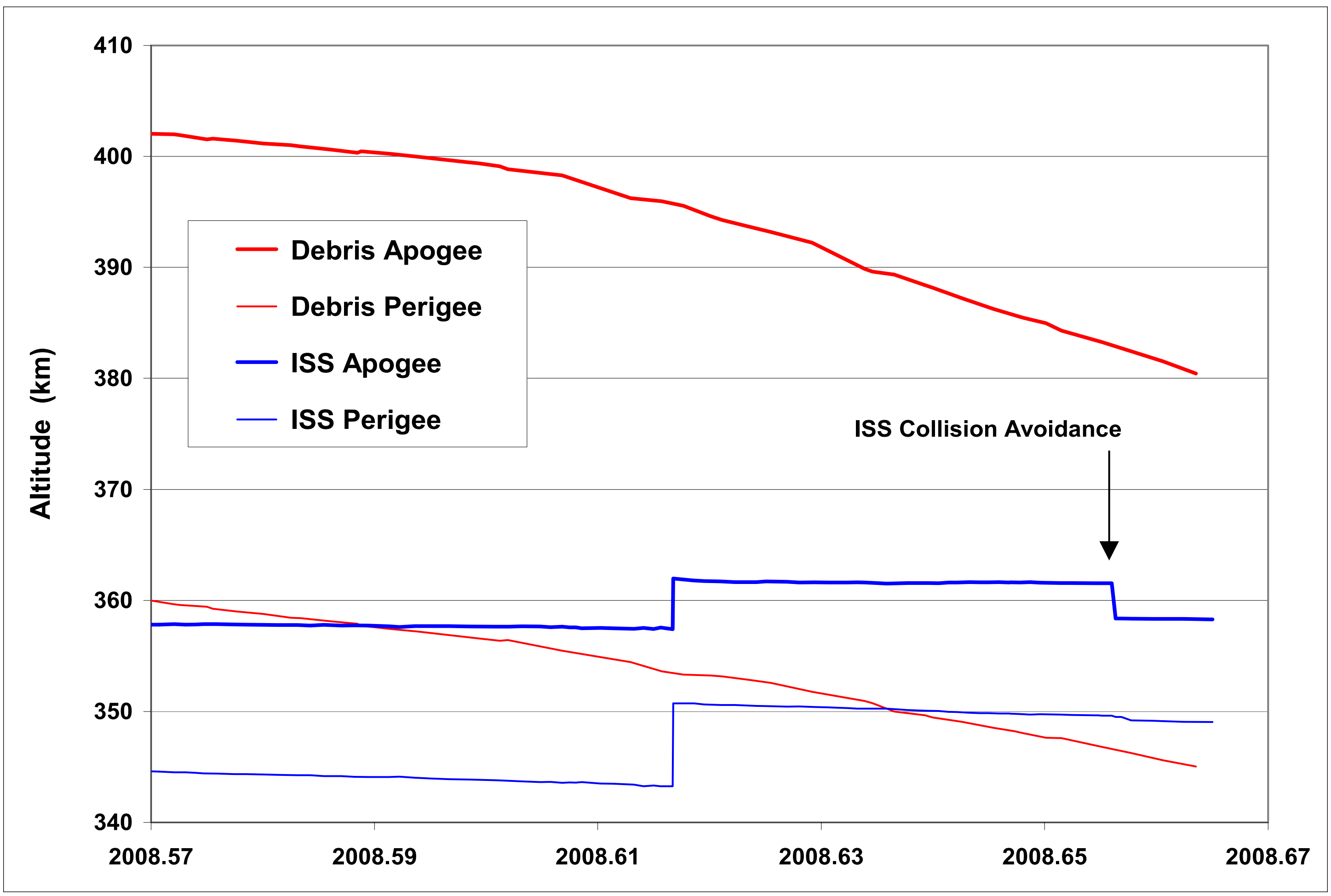


*Figure 2. The fragment from Cosmos 2421 which caused the ISS collision avoidance maneuver did not intersect the orbit of ISS until the beginning of August.*

# Eighteen-Year-Old Solid Rocket Motor Casing Found in Australia

The Australian outback finally revealed a nearly two-decades-old secret in July when a launch vehicle rocket motor casing was found during a routine muster of cattle on a three-million-acre pastoral property. First spotted by Mr. Arthur Taylor while flying a Cessna aircraft in the muster operation, the casing appeared in relatively good condition (Figure 1) and did not seem to be very old. Mr. Michael White forwarded numerous photos of the object to the NASA Orbital Debris Program Office, including one with a clear serial number next to the nozzle attachment point.

Using the serial number, NASA Kennedy Space Center personnel were able to trace the motor casing to a Delta 2 launch vehicle used on 12 June 1990 to deliver the Indian INSAT-1D geosynchronous spacecraft from the Cape Canaveral Air Force Station, Florida. This solid rocket motor served as the launch vehicle's third stage (U.S. Satellite Number 20645, International Designator 1990-051C), which carried the payload from a low altitude parking orbit into a geosynchronous transfer orbit of 135 km by 39,750 km with an inclination of 27.2 degrees. Reentry of the stage occurred a few months later.

The object joins similar solid rocket motor casings found in Saudi Arabia, Thailand, and Argentina during the past several years. ♦

*Figure 1. A solid rocket motor casing from a commercial U.S. Delta 2 launch vehicle was found in Australia, nearly 18 years after it reentered.*

# NASA's Orbital Debris Chief Scientist Receives Awards

Nicholas (Nick) Johnson, NASA's Chief Scientist for Orbital Debris, received two high level awards for his outstanding work in support of the successful engagement of the USA-193 spacecraft in February of this year (see "Satellite Breakups During First Quarter of 2008," ODQN, Vol. 12, Issue 2). In a special ceremony on 30 July, General Kevin Chilton, Commander of the U.S. Strategic Command, and Rear Admiral Douglas McClain, Director of Global Operations for USSTRATCOM, presented Nick with the Joint Meritorious Civilian Service Award from the Chairman of the Joint Chiefs of Staff.

USA-193 was a classified military satellite which contained a tank with ~450 kg of toxic hydrazine fuel in a frozen state. The citation for the award stated that Nick "properly characterized the risk associated to natural and post-kinetic intercept reentry of the satellite; and through analytical expertise and superb communication ability, he enabled senior leaders to make critical satellite reentry mitigation decisions."

Earlier, on 19 June, Nick also received the NASA Distinguished Service Medal, NASA's highest award from the NASA Administrator. ♦


*Figure 1. General Kevin Chilton presented Nicholas Johnson with the Joint Meritorious Civilian Service Award.*

# Publication of the Handbook for Limiting Orbital Debris

The first edition of the Handbook for Limiting Orbital Debris (NASA-Handbook 8719.14) was completed and signed by NASA's Chief Safety Officer Mr. Bryan O'Connor on 30 July 2008. The Handbook is intended to provide the scientific background to NASA's Orbital Debris Program, as defined in NPR 8715.6A "Procedural Requirements for Limiting Orbital Debris" and NASA-STD 8719.14, "Process for Limiting Orbital Debris". The Handbook serves as a companion to these two documents, and provides each NASA program and project with supporting material to assist in implementing the NPR and NASA-STD. The uniform engineering processes, procedures, practices, and methods in the two documents are explained further within.

NASA-Handbook 8719.14 begins with a background of the orbital debris environment as it exists now, then follows with discussion of research and results for how the future environment is expected to evolve. Background in the measurement techniques and research (radar, optical, and in situ) and current modeling approaches follows, providing more methodology behind the NASA Orbital Debris Program's studies, both past and present. Hypervelocity impact research, as well as mitigation history and current status, are then discussed. Finally, reentry survivability background and modeling technique is

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# Orbital Debris Handbook

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presented, so that the reader better understands the physical and mathematical phenomenon that occurs when an object reenters the Earth's atmosphere.

Nearly 100 figures and over a dozen tables are included to assist the reader with a visual understanding of all issues associated with orbital debris. Additional and detailed references are included at the end of each chapter so that the reader may do more detailed research, should the need exist.

The Handbook is available in Adobe PDF format at the NASA Headquarters web site (http://www.hq.nasa.gov/office/codeq/doctree/NHBK871914.pdf). The Handbook will be revised at regular intervals as needed. ♦

# PROJECT REVIEWS

## A New Sensor for Micrometeoroid and Orbital Debris In Situ Measurements: the Resistive Grid Detector

F. GIOVANE

Several sensor systems are being designed to monitor large (>50 μm) hypervelocity particles in space. Because of the low spatial density of these large particles, the candidate sensor systems must have a large detection area, while the constraints of a space environment deployment require that these systems be low in mass, robust, and if possible, low in power and telemetry requirements. Here a simple system, the Resistive Grid Sensor (RGS), is described. In future articles some of the other systems presently under development will be explored.

The Resistive Grid Sensor is a passive micrometeoroid and orbital debris (MMOD) impact flux measuring device. It was originally designed as a very robust system requiring few resources (*i.e.*, mass, power, telemetry), whose purpose was to complement other sensor systems and validate their performance. Its development emphasized the detection of large (>50 μm) particles that might pose a hazard to space assets. However, a direct variant of the device can also detect particles that are submicron in diameter. The RGS system concept was proposed by F. Giovane and F. Kub at the Naval Research Laboratory in 1997.

The RGS relies on a simple principle for its functionality. Thin resistive lines, lying in parallel, are printed by a lithographic process onto a suitable space-qualified substrate. In a configuration for the detection of large hypervelocity MMOD particles, approximately 1000 resistive lines 75 μm in width and 15 cm long, separated by a 75 μm gap, are printed on a circuit board having a resistive coating. Each of these 1000 resistive lines is connected at each end to a bus, as seen in Figure 1, to create a single resistor composed of the individual resistive line. The lines are connected in parallel and have a total sensitive area measuring 15 cm x 15 cm. Several prototype boards have been fabricated by the Applied Physics Laboratory at Johns Hopkins University using standard microelectronics technology. These units are being tested for the U.S. Naval Academy's Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS) project (Professor V. Pisacane is the Principal Investigator). This project is also supported by the NASA Orbital Debris Program Office. The intention is to fly an RGS on a DoD spacecraft in the 800-to-1000 km altitude range to monitor the MMOD fluxes in the region.

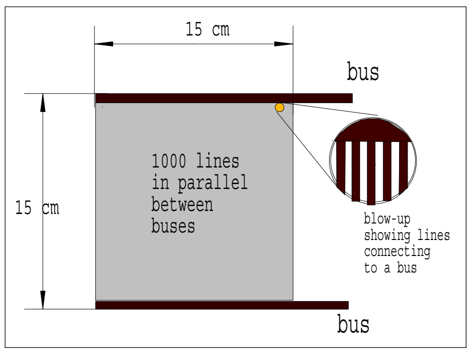


*Figure 1. An illustration of the Resistive Grid Sensor.*

The RGS relies for its functionality on the physical action of a hypervelocity particle impacting a surface. In the size regime for which the sensor is developed, two basic interactions can occur, depending on the thickness of the substrate on which the RGS is mounted and the characteristic of the impacting particle. Either the particle will penetrate or will cavitate the substrate, thereby destroying an area of approximately 3 to 10 times its diameter. For the DRAGONS experiment, if the particle is greater than 50 μm, one or more of the resistive grid lines will be destroyed as a result of the hypervelocity impact. By measuring the resistance increase of the sensor (*i.e.*, between the bus lines) the number of destroyed resistive lines can be determined, and a measurement of the impacting particle's size can be estimated.

Resistance measurements either can be made at intervals or when other instruments (such as the PINDROP acoustic sensor[1]) indicate an impact. The resistance is then compared with previous measurements, which have been corrected for temperature, to determine the number of lines destroyed by the impact. Generally, for the DRAGONS project, particles smaller than 10 μm will erode the grid lines, but not destroy an entire line. In this case, the change in the resistance of the RGS will be very small and will not be mistaken for a line break, even if many small particles impact the sensor between resistance measurements. Particles between 10 and 50 μm may, with statistical predictability, take out a single line. While 50 μm and greater hypervelocity particles of any significant density will almost always sever one or more lines.

Because each RGS is only 15 cm x 15 cm, several RGSs are tiled (typically on the same backing substrate) to form a larger sensor area. As with other in situ instruments, the sensor's area requirement depends on the mission duration and the anticipated particle flux of the largest particles of interest. The electronics to measure resistance of an RGS consist of a voltage reference and a 12-bit analog-to-digital (A/D) converter. A microprocessor is used to control the measurement and record the data for download. Only one voltage reference and A/D converter for the entire RGS array is

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# Sensors

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needed since the measurements can be multiplexed.

The mass of an RGS system of the DRAGONS type with 1 $m^2$ total area would be about 1.1 kg (using the current configuration of a 0.5 mm G10 epoglass board with carbon fiber honeycomb support). Electronics, housing, and wire would add another 0.7 kg. Power requirements of the system during measurements would be 32 mW for about 1 sec. If resistance measurements were made once an hour, then the total electrical energy requirement (without heaters) would be essentially just the quiescent consumption of the microprocessor. Further, down-link data rate requirements can also be very low, as only changes in the resistance of the individual resistive grid boards need be reported.

The RGS concept can also be applied to the detection of very small hypervelocity particles. It is fully within the state of technology to lithograph micron-width resistive lines onto a silicon wafer. Such a wafer, measuring a bit larger than 10 cm x 10 cm, would contain a 100 x 100 array of 1 mm-square resistive grids, each made with 1000 resistive lines of 0.5 μm width. The interconnections, multiplexing, and detection electronics would all be built into the wafer. Such an RGS would be sufficiently sensitive to detect hypervelocity particles down to about 0.1 μm.

To date, the RGS has not been flown. Examples of the large-particle-detecting DRAGONS RGS have been built and subjected to hypervelocity impact testing using the two-stage light gas gun facility (led by M. Burchell) at the University of Kent in the United Kingdom. Figure 2 shows the effect of a 100 μm glass particle impacting at 5 km/s on an RGS mounted on a fiber-epoxy substrate. A large RGS array, covering over one square meter in area, could be easily built based on existing and proven technology. Based on robust and currently-available technology, the RGS is a suitable candidate for deployment on future spacecraft and on the lunar surface.

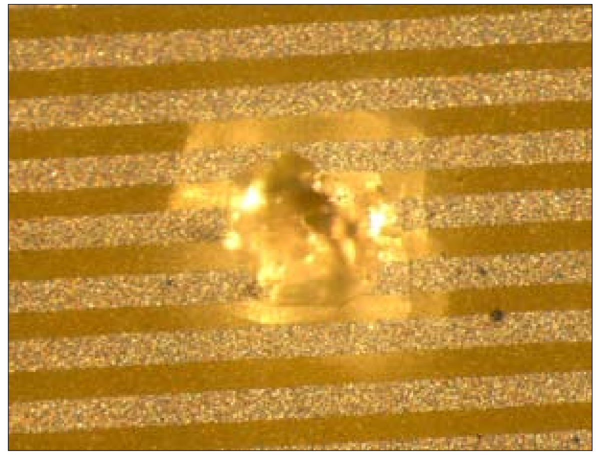

*Figure 2. Damage caused by a 100 μm glass particle, with an impact speed of 5 km/s, on a prototype RGS board.*

[1]Corsaro, R., et al., PINDROP – An acoustic particle impact detector, Orbital Debris Quarterly News, Vol 8, Issue 3, 3-4, 2004. ♦

# Stabilizing the Future LEO Debris Environment with Active Debris Removal

J.-C. LIOU, N.L. JOHNSON, AND N.M. HILL

Fifty years after the launch of Sputnik 1, satellites have become an integral part of human society. Unfortunately, the ongoing space activities leave behind an undesirable byproduct – orbital debris. As of 1 June 2008, more than 17,000 objects were tracked by the U.S. Space Surveillance Network (SSN). The majority of them, approximately 13,000, have their orbital elements maintained in the U.S. Satellite Catalog. Other than the 800 or so active payloads, this population is dominated by breakup fragments, spent upper stages, and retired payloads.

The growth of the orbital debris population has been a concern to the international space community for decades. Many policies and procedures are established to address the issue. A good example is the adoption of space debris mitigation guidelines by the United Nations in 2007. However, recent numerical studies have shown that the debris environment in low Earth orbit (LEO, defined as the region up to 2000 km altitude) has reached a point where the debris population will continue to increase, due to mutual collisions among existing objects, even if all future launches are suspended.[1,2] In reality, the population increase will be worse than the "no future launches" prediction because satellites will continue to be launched and major breakup events, such as Fengyun-1C (FY-1C) and Briz-M, may continue to occur. Even with a full implementation of the commonly-adopted mitigation measures, the LEO population growth cannot be stopped. To better preserve the near Earth environment for future space generations, additional remediation measures, such as active debris removal (ADR), must be considered.

The ADR modeling study was initiated by the NASA Orbital Debris Program Office in late 2006. The first effort was focused on the object selection criteria. A non-mitigation (sometimes referred to as the business-as-usual) scenario was used as the baseline for comparison. The main conclusion of the study was that the product of the mass and collision probability of each object was an excellent removal selection criterion.[3] Numerical simulations based on this criterion showed most objects in the critical inclination and altitude regimes were identified and removed, and the LEO debris population growth, using the non-mitigation scenario as a benchmark, was significantly reduced. The present study differs from the previous one in the following areas: (1) the tracked FY-1C fragments were added to the initial environment for future projection, (2) a more realistic scenario, where the commonly-adopted postmission disposal (PMD) mitigation measures were implemented for future launches, was selected as the benchmark, and (3) the focus was on what would be needed to stabilize the future LEO debris environment.

The simulations were based on the NASA long-term orbital debris projection model, LEGEND. A scenario where, at the end of mission lifetimes, spacecraft and upper stages were moved to 25-year decay orbits (assuming a 90% success rate), was adopted as the baseline environment for comparison. Two annual removal rates and different ADR target selection criteria were tested, and the resulting

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# Active Debris Removal

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200-year future environment projections were compared with the baseline scenario. A total of 100 Monte Carlo simulations were carried out for each scenario, and the averages were calculated for comparison. The main result of the study is shown in Figure 1. The top curve is the projection for the 10 cm and larger objects in LEO. Even with a good implementation of the PMD mitigation measures, the population will still increase by about 75% in 200 years. However, this population growth could be reduced by half with a removal rate of two objects per year, starting from the year 2020. The bottom curve indicates that the future LEO environment could be stabilized with a removal rate of five objects per year. The trend also suggests that if more objects are removed, then the future LEO debris population could actually be lower than what is in the current environment.

As the international space community continues to work together to limit the generation of orbital debris, a more aggressive approach, active debris removal, must be seriously considered to remediate the environment. Based on the study results, ADR is an effective means to stabilize, or even reduce, the future LEO debris population. A combination of mitigation measures and active debris removal appears to be the only way to preserve the near-Earth environment. However, there are still many challenges ahead. Detailed cost analyses must be performed. Then, new ADR policies or guidelines will have to be developed in conjunction with the development of viable removal techniques. Finally, the source of funding needs to be identified, and the legal and liability issues must be addressed as well.

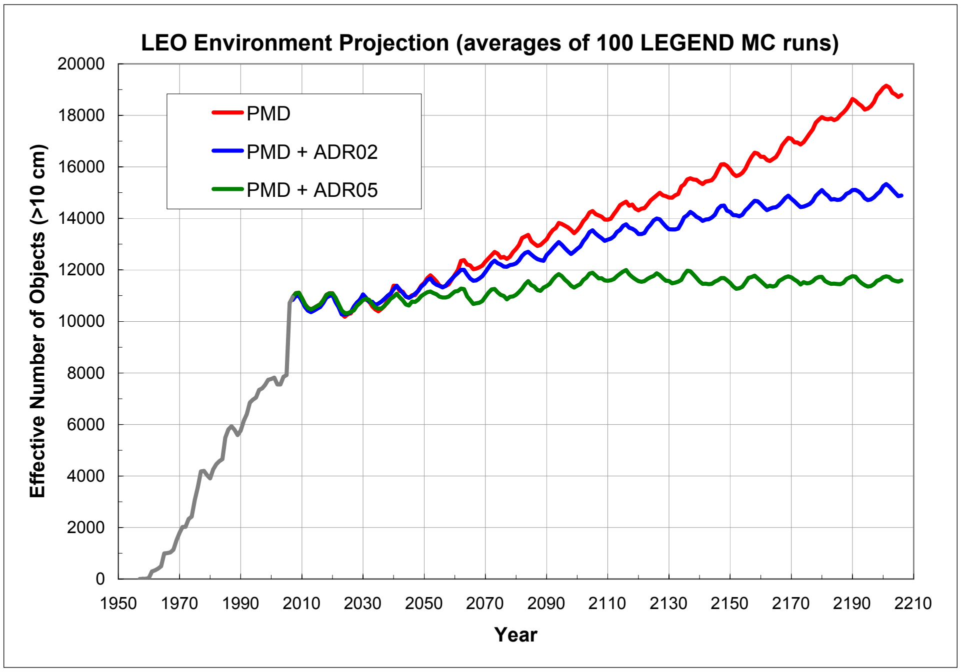


*Figure 1. Comparison of three different scenarios. From top to bottom: postmission disposal (PMD) only, PMD and ADR of two objects per year, and PMD and ADR of five objects per year, respectively.*


1. Liou, J.-C. and Johnson, N.L. Risks in space from orbiting debris, *Science,* 311, 340-341, 2006.

2. Liou, J.-C. and Johnson, N.L. Instability of the present LEO satellite populations, *Adv. Space Res.*, 41, 1046-1053, 2008.

3. Liou, J.-C. and Johnson, N.L. A sensitivity study of the effectiveness of active debris removal in LEO, *Acta Astronautica*, 2008 (10.1016/j.actaastro.2008.07.009, in press). ♦


# ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

## 59th International Astronautical Congress (IAC)
## 29 September - 3 October 2008, Glasgow, Scotland

### A Summary of Five Years of Michigan Orbital Debris Survey Telescope (MODEST) Data

K.J. ABERCROMY, P. SEITZER,
E. BARKER, H.M. RODRIGUEZ, AND
M. MATNEY

The acquisition of survey mode data of human-made objects in the geosynchronous orbit commenced in January 2002 using the Michigan Orbital Debris Survey Telescope (MODEST), located at Cerro Tololo Inter-American Observatory (CTIO). A total of 151 nights of data have been collected and compiled into optical observations of correlated (CT) and uncorrelated (UCT) targets. Approximately five minutes of data is collected for an object, which requires an assumed circular orbit (ACO) to obtain the orbital elements. Biases are determined by assuming the TLE is truth and comparing the ACO orbital parameter to it. When assessing all objects, the mean biases are 82°, 0.15°, and 0.04 for RAAN, inclination, and mean motion, respectively. However, RAAN is ill-defined when the inclination is close to 0° so the mean bias for RAAN becomes 2° when excluding those objects. The smallest objects found were 30 cm and 10 cm for a CT and UCT, respectively. There are two known GEO break-ups from the Titan 3C-4 transtage break up and the Ekran 2 breakup. UCTs are found in the area where the parent bodies are known to be. All of the data from the five years of MODEST data will be discussed herein. ♦

## Measurement Techniques for Hypervelocity Impact Test Fragments

N.M. HILL

The ability to classify the size and shape of individual orbital debris fragments provides a better understanding of the orbital debris environment as a whole. The characterization of breakup fragmentation debris has gradually evolved from a simplistic, spherical assumption towards that of describing debris in terms of size, material, and shape parameters. One of the goals of the NASA Orbital Debris Program Office is to develop high-accuracy techniques to measure these parameters and apply them to orbital debris observations.

Measurement of the physical characteristics of debris resulting from ground-based, hypervelocity impact testing provides insight into the shapes and sizes of debris produced from potential impacts in orbit. Current techniques for measuring these ground-test fragments require determination of dimensions based upon visual judgment. This leads to reduced accuracy and provides little or no repeatability for the measurements. With the common goal of mitigating these error sources, allaying any misunderstandings, and moving forward in fragment shape determination, the NASA Orbital Debris Program Office recently began using a computerized measurement system. The goal of using these new techniques is to improve knowledge of the relation between commonly used dimensions and overall shape. The immediate objective is to scan a single fragment, measure its size and shape properties, and import the fragment into a program that renders a 3D model that adequately demonstrates how the object could appear in orbit. This information would then be used to aid optical methods in orbital debris shape determination.

This paper provides a description of the measurement techniques used in this initiative and shows results of this work. The tradeoffs of the computerized methods are discussed, as well as the means of repeatability in the measurements of these fragments. This paper serves as a general description of methods for the measurement and shape analysis of orbital debris. ♦

## Space Shuttle MMOD Threat Mitigation Techniques

J.L. HYDE, E.L. CHRISTIANSEN,
D M. LEAR, AND J.H. KERR

Prior to each shuttle mission, threat assessments are performed to determine the risk of critical penetration, payload bay door radiator tube leak and crew module window replacement from Micrometeoroid and Orbital Debris (MMOD). Mission parameters, such as vehicle attitude, exposure time and altitude are used as inputs for the analysis. Ballistic limit equations, based on hypervelocity impact testing of shuttle materials, are used to estimate the critical particle diameters of the outer surfaces of the vehicle. The assessments are performed using the BUMPER computer code at the NASA/JSC Hypervelocity Impact Technology Facility (HITF). The most critical involves the calculation of Loss of Crew and Vehicle (LOCV) risk. An overview of significant MMOD impacts on the Payload Bay Door radiators, wing leading edge reinforced carbon-carbon (RCC) panels and crew module windows will be presented, along with a discussion of the techniques NASA has implemented to reduce the risk from MMOD impacts. This paper will describe on-orbit inspection of the RCC regions and the methods used to discern hypervelocity impact damage. Impact damage contingency plans and on-orbit repair techniques will also be discussed. The wing leading edge impact detection system (WLEIDS) and its role in the reduction of on-orbit risk reduction will be presented. Finally, an analysis of alternative shuttle flight attitudes on MMOD risk will be demonstrated. ♦

## The New NASA Orbital Debris Mitigation Procedural Requirements and Standards

N.L. JOHNSON AND E. STANSBERY

NASA has issued major updates to its principal orbital debris mitigation policy directive and standards. The new NASA Procedural Requirements for Limiting Orbital Debris (NPR 8715.6A) with its supporting NASA Standard 8719.14, both refine earlier orbital debris mitigation documents and in some areas expand their applicability. Organizational and individual responsibilities, along with general directives, are set forth in NPR 8715.6A. New requirements include routine conjunction assessments for all maneuverable NASA spacecraft in LEO and GEO, prompt notifications of intended or unintended debris generation, preparation and maintenance of formal end-of-mission plans, and disposal of vehicles in operation around the Moon and Mars and at the Earth-Sun Lagrangian points. NASA Standard 8719.14 replaces the 1995 NASA Safety Standard 1740.14 with no major new requirements but with several refinements and additions, some of which had already been adopted. Compliance with human casualty risk limitations from reentering debris will be calculated explicitly and not be expressed in terms of average debris casualty area. Moreover, the minimum kinetic energy threshold for potentially injurious reentering debris is set at 15 Joules. The overarching requirement for the disposal of GEO spacecraft and launch vehicle orbital stages is to ensure that the vehicles do not come within GEO + 200 km for at least 100 km after end of mission, rather than setting specific requirements for the disposal orbit. Spacecraft operating in or routinely transiting LEO must remain in the region for no more than 25 years after end of mission or 30 years after launch, whichever occurs sooner. A comprehensive new NASA handbook on orbital debris has also been prepared to provide background on the orbital debris environment and the related NASA mitigation requirements and standards. ♦

## Material Density Distribution of Small Debris in Earth Orbit

P.H. KRISKO, Y-L. XU, J.N. OPIELA, AND M.J. MATNEY

Over 200 spacecraft and rocket body breakups in Earth orbit have populated that regime with debris fragments in the sub-micron through meter size range. Though the largest debris fragments can cause significant collisional damage to active spacecraft, these are few and trackable by radar. Fragments on the order of a millimeter to a centimeter in size are as yet untrackable. But this smaller debris can result in damage to critical spacecraft systems. Ongoing research at the NASA Orbital Debris Program Office on the sources of these small fragments has focused on the material components of spacecraft and rocket bodies and on breakup event morphology. This has led to fragment material density estimates and also the beginnings of shape categorizations.

Until recently the NASA Standard Breakup Model has not considered specific material density distinctions of small debris fragments (*i.e.*, those smaller than 10 cm in characteristic length or size). The basis of small debris in that model is the fourth hypervelocity impact event of the Satellite Orbital Debris Characterization Impact Test (SOCIT) series conducted in 1991-1992. Results of this test, labeled SOCIT4, yielded size and area-to-mass distributions of fragments smaller than 10 cm in the NASA model. Recent re-analysis of that dataset highlighted the material-specific characteristics of metals and non-metals (Krisko et al., 2008). Concurrent analysis of Space Shuttle in-situ impact data showed a high percentage of aluminum debris in shuttle orbit regions (Opiela, 2006). Both analyses led to the definition of three main on-orbit debris material density categories – low density (< 2 g/cc), medium density (2 to 6 g/cc), and high density (> 6 g/cc).

This report considers the above studies in an explicit extension of the NASA Standard Breakup Model where separate material densities for debris are generated and these debris fragments are propagated in Earth orbit. The result is preliminary, but displays a process by which the near-Earth environment is parameterized by debris density percentages within altitude bands of that environment. This model version is used in the upgraded NASA Orbital Debris Engineering Model (ORDEM2008). ♦

## Controlling the Growth of Future LEO Debris Populations with Active Debris Removal

J.-C. LIOU, N. L. JOHNSON, AND N.M. HILL

Active debris removal (ADR) was suggested as a potential means to remediate the low Earth orbit (LEO) debris environment as early as the 1980s. The reasons ADR has not become practical are due to its technical difficulties and the high cost associated with the approach. However, as the LEO debris populations continue to increase, ADR may be the only option to preserve the near-Earth environment for future generations. An initial study was completed in 2007 to demonstrate that a simple ADR target selection criterion could be developed to reduce the future debris population growth. The present paper summarizes a comprehensive study based on more realistic simulation scenarios, including fragments generated from the 2007 Fengyun-1C event, mitigation measures, and other target selection options.

The simulations were based on the NASA long-term orbital debris projection model, LEGEND. A scenario, where at the end of mission lifetimes, spacecraft and upper stages were moved to 25-year decay orbits, was adopted as the baseline environment for comparison. Different annual removal rates and different ADR target selection criteria were tested, and the resulting 200-year future environment projections were compared with the baseline scenario. Results of this parametric study indicate that (1) an effective removal strategy can be developed based on the mass and collision probability of each object as the selection criterion, and (2) the LEO environment can be stabilized in the next 200 years with an ADR removal rate of five objects per year. ♦

## Measurements of the Small Particle Debris Cloud from the 11 January 2007 Chinese Anti-Satellite Test

M. MATNEY, E. STANSBERY, J.-C. LIOU, C. STOKELY, M. HORSTMAN, AND D. WHITLOCK

On January 11, 2007, the Chinese military conducted a test of an anti-satellite (ASAT) system, destroying their own Fengyun-1C spacecraft with an interceptor missile. The resulting hypervelocity collision created an unprecedented number of tracked debris – more than 2500 objects. These objects represent only those large enough for the U.S. Space Surveillance Network (SSN) to track – typically objects larger than about 5-10 cm in diameter. There are expected to be even more debris objects at sizes too small to be seen and tracked by the SSN. Because of the altitude of the target satellite (865 x 845 km orbit), many of the debris are expected to have long orbital lifetimes and contribute to the orbital debris environment for decades to come.

In the days and weeks following the ASAT test, NASA was able to use Lincoln Laboratory's Haystack radar on several occasions to observe portions of the ASAT debris cloud. Haystack has the capability of detecting objects down to less than one centimeter in diameter, and a large number of centimeter-sized particles corresponding to the ASAT cloud were clearly seen in the data. While Haystack cannot track these objects, the statistical sampling procedures NASA uses can give an accurate statistical picture of the characteristics of the debris from a breakup event.

For years computer models based on data from ground hypervelocity collision tests (e.g., the SOCIT test) and orbital collision experiments (e.g., the P-78 and Delta-180 on-orbit collisions) have been used to predict the extent and characteristics of such hypervelocity collision debris clouds, but until now there have not been good ways to verify these models in the centimeter size regime. It is believed that unplanned collisions of objects in space similar to ASAT tests will drive the long-term future evolution of the debris environment in near-Earth space. Therefore, the Chinese ASAT test provides an excellent opportunity to test the models used to predict the future debris environment.

For this study, Haystack detection events are compared to model predictions to test the model assumptions, including debris size distribution, velocity distribution, and assumptions about momentum transfer between the target and interceptor. In this paper we will present the results of these and other measurements on the size and extent of collisional breakup debris clouds. ♦

## A New Bond Albedo for Performing Orbital Debris Brightness to Size Transformations

M. K. MULROONEY, M. J. MATNEY, AND E. S. BARKER

In 2007 we developed a technique for estimating the intrinsic size distribution of orbital fragmentation debris objects via optical measurements.[1] We recommended an albedo value of 0.13 be applied globally to optical brightness measurements of fragmentation debris in order to recover object size. The basis set of NASA-LMT optical data[2-4] has since been revised by application of a Lambertian phase function rather than a mixed specular/ Lambertian correction. Using the prior derived formalism and the re-processed optical observations coupled with published RCS values, we have derived a new albedo distribution for fragmentation debris and a consequent revised transformational albedo value of 0.175. Herein we present the empirical and mathematical arguments for our approach and by example apply it to a comprehensive set of photometric data acquired via NASA's Liquid Mirror Telescopes during the 1998-2001 observing seasons.

1. M. Mulrooney and M. Matney, "Derivation and Application of a Global Albedo Yielding an Optical Brightness to Physical Size Transformation Free of Systematic Errors." 2007 AMOS Technical Conference, Kihei, HI. September 2007.

2. A. E. Potter and M. K. Mulrooney. "Liquid Metal Mirror for Optical Measurements of Orbital Debris." *Advances in Space Research,* Vol. 19, pp. 213-219, 1997.

3. K. S. Jarvis, E. S. Barker, T. L. Thumm, J. L. Africano, M. J. Matney, E. G. Stansbery, K. Abercromby, and M. K. Mulrooney. "Liquid Mirror Telescope (LMT) Observations of the Low Earth Orbit Orbital Debris Environment March 1997 – September 2001." Houston, TX, 2007.

4. K. S. Jarvis, T. L. Thumm, E. S. Barker, J. L. Africano, M. J. Matney, E. G. Stansbery, K. Abercromby, and M. K. Mulrooney. "Liquid Mirror Telescope (LMT) Observations of the Low Earth Orbit Orbital Debris Environment March 1999 – September 2000." *JSC-29713,* Houston, TX, 2006. ♦

## A Comparison of Three Catastrophic On-Orbit Collisions

G. STANSBERY, M. MATNEY, J.-C. LIOU, AND D. WHITLOCK

Orbital debris environment models, such as NASA's LEGEND model, show that accidental collisions between satellites will begin to be the dominant cause for future debris population growth within the foreseeable future. The collisional breakup models employed are obviously a critical component of the environment models. The Chinese Anti-Satellite (ASAT) test which destroyed the Fengyun-1C weather satellite provided a rare, but not unique, chance to compare the breakup models against an actual on-orbit collision. Measurements from the U.S. Space Surveillance Network (SSN), for debris larger than 10 cm, and from Haystack, for debris larger than 1 cm, show that the number of fragments created from Fengyun significantly exceeds model predictions using the NASA Standard Collision Breakup Model. However, it may not be appropriate to alter the model to match this one, individual case. Two other on-orbit collisions have occurred in the past which have produced significant numbers of debris fragments. In September 1985, the U.S. conducted an ASAT test against the Solwind P-78 spacecraft at an altitude of approximately 525 km. A year later, in September 1986, the Delta 180 payload was struck by its Delta II rocket body in a planned collision at 220 km altitude. Although no Haystack data was available in 1985-6 and very few debris pieces were cataloged from Delta 180 due to its low altitude, measurements were collected in dedicated tests by SSN phased-array radars in the days after each test. This paper will examine the available radar data from each test and compare and contrast the results with model predictions and with the results from the more recent Fengyun ASAT test. ♦

## 2008 Advanced Maui Optical and Space (AMOS) Surveillance Technologies Conference
## 16- 19 September 2008, Wailea, Maui, Hawaii, USA

## Prediction and Tracking Analysis of a Class of High Area-to-Mass Ratio Debris Objects in Geosynchronous Orbit

T. KELECY, E. BARKER, P. SEITZER, T. PAYNE, AND R. THURSTON

A subset of the population of deep space objects is thought to be high area-to-mass ratio (A/m) debris having origins from sources within the geosynchronous orbit (GEO) belt. The typical A/m values for these have been observed to range anywhere from ones to tens of $m^2/kg$, and hence, are susceptible to significant solar radiation pressure effects which result in long-term migration of eccentricity (0.1 - 0.6) and inclination over time. However, the nature of the debris orientation-dependent dynamics also results in time-varying solar radiation forces about an average value over shorter time scales, which complicate the short-term orbit determination (OD) processing and prediction. In November of 2007, several of these objects were acquired and tracked from the 0.9-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile using prediction products derived from the orbit determination of optical angles tracking data. The estimated states computed using the Orbit Determination Tool Kit (ODTK) included dynamic estimation of the area-to-mass ratio, the variations of A/m relative to an average value. The work presented in this paper assesses the OD prediction and tracking performance using the ODTK-derived predictive products that were utilized during the survey, the CTIO tracking data that was collected, and the post-fit orbit products resulting from additional data collected after the observations. The OD and A/m estimation performance for a selected object tracked is presented, and the derived prediction performance is also analyzed by comparison with the CTIO 0.9 m telescope acquisition metrics. The post-fit prediction assessments of tens of kilometers positional accuracy over 24-48 hour prediction spans is consistent with the arc-minute level tracking offsets that were observed. ♦

## An Investigation of Global Albedo Values

M. K. MULROONEY, M. J. MATNEY,
M. D. HEJDUK, AND E. S. BARKER

Mulrooney and Matney[1] developed a technique for estimating the intrinsic size distribution of orbital fragmentation debris, and among the conclusions of their study was the recommendation of a global albedo value of 0.13 for these debris objects. In 2008 this value was revised upward to 0.175[2] after revisions were made to the basis set of supplied brightness data (NASA-Liquid Mirror Telescope photometry data[3-5]). These revisions primarily involved uniform application of Lambertian phase function correction as opposed to the specular/Lambertian mixture in the original dataset. While these two studies demonstrated the soundness of their approach, uncertainties in the optical and radar data used for the calculations led the studies to produce only a provisional, rather than definitive, global albedo value for fragmentation debris. Calculations using alternate photometric and RCS (Radar Cross Section) data is required to support the use of their albedo in a truly global context. As a first step in this vetting process we perform an albedo consistency check by utilizing RCS values from an alternate source – the United States Air Force Space Command Studies and Analysis Division (AFSPC/A9A) high-precision RCS catalogue. As with prior work, these values will be passed through NASA's Size Estimation Model which primarily provides a diameter correction (downward) for objects in the Rayleigh scattering regime. Analysis using other photometric sources, such as the GEODSS visual magnitude data repository, will be performed in future.

In addition to fragmentation debris, there is utility in exploring the albedo distribution of non-fragmentation objects – including intact rocket bodies, payloads, and mission-related objects. Queries about space object size are often tendered against object types other than merely fragmentation debris; frequently, full-catalogue size profiling is desired, which includes payloads and rocket bodies. When published size information about these objects is available, these actual measurements can be used for such profiling; but since they are often unavailable, it would be helpful to have an expansion of the Mulrooney and Matney technique available for this class of objects. As a first step in this process, we will determine the character of the albedo distribution for non-fragmentation targets based on LMT photometry and available data from the A9 high-precision RCS catalogue. Since the size distribution for this object class does not follow a simple power-law, a suitable subset will be extracted whose behavior is approximated by a weak power-law and a bias corrected albedo will be derived.

1. M. Mulrooney and M. Matney, "Derivation and Application of a Global Albedo Yielding an Optical Brightness to Physical Size Transformation Free of Systematic Errors." *Proceedings of 2007 AMOS Technical Conference*, Kihei, HI, pp. 719-728, 2007.

2. M. Mulrooney, M. Matney, and E. Barker, "A New Bond Albedo for Performing Orbital Debris Brightness to Size Transformations." 2008 International Astronautical Congress, Glasgow, Scotland, October 2008 (in preparation).

3. A. E. Potter and M. K. Mulrooney. "Liquid Metal Mirror for Optical Measurements of Orbital Debris." *Advances in Space Research,* Vol. 19, pp. 213-219, 1997.

4. E. S. Barker, K. S. Jarvis, K. J. Abercromby, T. L. Parr-Thumm, J. L. Africano, and E. G. Stansbery "The LEO Environment as Determined by the LMT between 1998 and 2002." Proceedings of the 2005 AMOS Technical Conference, Wailea, Maui, HI, pp. 206-215, 2005.

5. K. S. Jarvis, T. L. Thumm, E. S. Barker, J. L. Africano, M. J. Matney, E. G. Stansbery, K. Abercromby, and M. K. Mulrooney. "Liquid Mirror Telescope (LMT) Observations of the Low Earth Orbit Orbital Debris Environment March 1999 – September 2000." *JSC-29713,* Houston, TX, 2006. ♦

## Optical Studies of Orbital Debris at GEO Using Two Telescopes

P. SEITZER, K.J. ABERCROMBY,
H.M. RODRIGUEZ, AND E. BARKER

We present a status report on optical observations of debris at geosynchronous orbit (GEO) using two telescopes simultaneously at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. This program commenced in March 2007.

The University of Michigan's 0.6/0.9-m Schmidt telescope **MODEST** (for **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope) was used in survey mode to find objects that potentially could be at GEO. Because GEO objects only appear in this telescope's field of view for an average of 5 minutes, a full six-parameter orbit can not be determined. Interrupting the survey for follow-up observations leads to incompleteness in the survey results. Instead, as objects are detected on **MODEST,** initial predictions assuming a circular orbit are done for where the object will be for the next hour, and the objects are reacquired as quickly as possible on the CTIO 0.9-m telescope. This second telescope then follows-up during the first night and, if possible, over several more nights to obtain the maximum time arc possible, and the best six parameter orbit.

Our goal is to obtain an initial orbit for *all* detected objects fainter than R = 15$^{th}$ in order to estimate the orbital distribution of objects selected on the basis of two observational criteria: magnitude and angular rate. Objects fainter than 15$^{th}$ are largely uncataloged and have a completely different angular rate distribution than brighter cataloged objects. Combining the information obtained for both faint and bright objects yields a more complete picture of the debris environment rather than just concentrating on the faint debris. One objective is to estimate what fraction of objects selected on the basis of angular rate are not at GEO. A second objective is to obtain magnitudes and colors in standard astronomical filters (BVRI) for comparison with reflectance spectra of likely spacecraft materials.

This paper reports on results from 35 nights of observations in March 2007, November 2007, and March 2008:

- A significant fraction of objects fainter than R = 15$^{th}$ have eccentric orbits (e > 0.1)
- Virtually all objects selected on the basis of angular rate are in the GEO and GTO regimes.
- Calibrated magnitudes and colors in BVRI were obtained for many objects fainter than R = 15$^{th}$ magnitude.

This work is supported by NASA's Orbital Debris Program Office, Johnson Space Center, Houston, Texas, USA. ♦

# MEETING REPORTS

## 37th COSPAR Scientific Assembly
## 13 - 20 July 2008, Montréal, Canada

The 37th COSPAR Scientific Assembly was held 13-20 July 2008 in Montreal, Canada. Four debris sessions were held during the Scientific Assembly. Of the papers, a total of 6 invited, 20 contributed, and 5 poster papers were presented. The highlights included presentations on recent GEO optical observations and high area-to-mass ratio debris modeling, solid rocket motor slag population, impact of the Fengyun-1C breakup, general LEO environment modeling, and one special review on the Canadian activities in space debris mitigation technologies. A PEDAS business meeting was also held during the Scientific Assembly. Luciano Anselmo introduced the new and improved review process for debris papers submitted to the journal "Advances in Space Research," and Nicholas Johnson was nominated and appointed to be the Vice Chair of PEDAS in 2010, after the tenure of the current Vice Chair, Professor Richard Crowther, expires. ♦

## 2008 Advanced Maui Optical and Space (AMOS) Surveillance Technologies Conference
## 16- 19 September 2008, Wailea, Maui, Hawaii, USA

The 9th Advanced Maui Optical and Space Surveillance Technologies Conference was held 16-19 September 2008 in Wailea, Maui, Hawaii. Orbital debris issues were highlighted in many technical sessions as well as in the keynote address given by Lieutenant General William Shelton, Commander, Joint Functional Component Command for Space. The Orbital Debris Session was chaired by Gene Stansbery, Program Manager for NASA's Orbital Debris Program Office. The session contained five oral presentations beginning with Dr. David Finkleman's discussion of several issues including systematic conjunctions between resident space objects. Tim Floher also discussed conjunction analysis for two ESA missions, ERS-2 and Envisat, using two-line element sets which lack covariance information. Thomas Schildknecht reported on color photometry and light curves for the high area-to-mass population near the GEO orbit regime and Thomas Kelecy reported on the analysis of orbits for the same high area-to-mass population. The final paper of the session comparing data from on-orbit collision was given by Gene Stansbery. ♦

## The 59th International Astronautical Congress
## 29 September - 3 October 2008, Glasgow, Scotland

The 59th International Astronautical Congress (IAC) was held in Glasgow, Scotland from 29 September – 3 October 2008. The Space Debris Symposium included five sessions: Measurements and Space Surveillance, Modeling and Risk Analysis, Hypervelocity Impacts and Protection, Mitigation and Standards, and Measurement Projects and Modeling Aspects. A total of 41 papers and discussions were presented during the symposium. Topics included optical LEO to GEO observations, radar measurements, debris environment modeling, satellite fragment characterizations, hypervelocity impact test results, mitigation policies and compliance examples, and active debris removal strategies and techniques. ♦

# UPCOMING MEETING

**30 March - 2 April 2009: The 5th European Conference on Space Debris, ESA/ESOC, Darmstadt, Germany**

The Fifth European Conference on Space Debris, through two parallel sessions, will provide a forum for presenting and discussing results and for defining future directions of research. The theme of the conference is space surveillance, with a focus on space surveillance techniques, space object catalogs, and system studies for a European space surveillance system. The conference program will also highlight all classical disciplines of space debris research. This will include radar, optical and in-situ measurements; debris environment modeling; on-orbit and re-entry risk assessments; orbit prediction and determination; debris mitigation principles; hypervelocity impacts and shielding; and standardization and policies. Abstracts should be submitted by 14 December 2008 and the deadline for papers is 29 March 2009. Additional information about the conference is available at <http://www.congrex.nl/09a03/>.

## SATELLITE BOX SCORE

(as of 01 October 2008, as cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

| Country/ Organization | Payloads | Rocket Bodies & Debris | Total |
|---|---|---|---|
| CHINA | 70 | 2704 | 2774 |
| CIS | 1375 | 3153 | 4528 |
| ESA | 38 | 36 | 74 |
| FRANCE | 46 | 330 | 376 |
| INDIA | 36 | 108 | 144 |
| JAPAN | 105 | 70 | 175 |
| US | 1096 | 3163 | 4259 |
| OTHER | 424 | 97 | 521 |
| TOTAL | 3190 | 9661 | 12851 |


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## INTERNATIONAL SPACE MISSIONS
## 01 July – 30 September 2008

| International Designator | Payloads | Country/ Organization | Perigee Altitude (KM) | Apogee Altitude (KM) | Inclination (DEG) | Earth Orbital Rocket Bodies | Other Cataloged Debris |
|---|---|---|---|---|---|---|---|
| 2008-034A | PROTOSTAR 1 | BERMUDA | 35783 | 35792 | 0.0 | 1 | 1 |
| 2008-034B | BADR 6 | ARAB SAT. COMM. ORG | 35771 | 35800 | 0.0 | | |
| 2008-035A | ECHOSTAR 11 | USA | 35779 | 35794 | 0.0 | 1 | 0 |
| 2008-036A | SAR LUPE 5 | GERMANY | 474 | 501 | 98.2 | 1 | 0 |
| 2008-037A | COSMOS 2441 | RUSSIA | 711 | 735 | 98.3 | 1 | 0 |
| 2008-038A | SUPERBIRD 7 | JAPAN | 35771 | 35805 | 0.1 | 1 | 1 |
| 2008-038B | AMC-21 | USA | 35777 | 35795 | 0.1 | | |
| 2008-039A | INMARSAT 4-F3 | INMARSAT | EN ROUTE TO GEO | | | 1 | 1 |
| 2008-040A | RAPIDEYE 2 | GERMANY | 606 | 632 | 98.0 | 1 | 2 |
| 2008-040B | RAPIDEYE 5 | GERMANY | 623 | 649 | 98.0 | | |
| 2008-040C | RAPIDEYE 1 | GERMANY | 598 | 635 | 98.0 | | |
| 2008-040D | RAPIDEYE 3 | GERMANY | 620 | 639 | 98.0 | | |
| 2008-040E | RAPIDEYE 4 | GERMANY | 623 | 648 | 98.0 | | |
| 2008-041A | HJ-1 A | CHINA | 627 | 663 | 98.0 | 1 | 22 |
| 2008-041B | HJ-1 B | CHINA | 626 | 672 | 98.0 | | |
| 2008-042A | GEOEYE 1 | USA | 670 | 687 | 98.1 | 1 | 0 |
| 2008-043A | PROGRESS-M 65 | RUSSIA | 350 | 356 | 51.6 | 1 | 0 |
| 2008-044A | NIMIQ 4 | CANADA | 35785 | 35788 | 0.1 | 1 | 1 |
| 2008-045A | GALAXY 19 | USA | 35778 | 35796 | 0.1 | 1 | 0 |
| 2008-046A | COSMOS 2442 | RUSSIA | 19089 | 19144 | 64.8 | 2 | 3 |
| 2008-046B | COSMOS 2443 | RUSSIA | 19152 | 19334 | 64.8 | | |
| 2008-046C | COSMOS 2444 | RUSSIA | 19139 | 19284 | 64.8 | | |
| 2008-047A | SZ-7 | CHINA | 329 | 336 | 42.4 | 1 | 4 |
| 2008-047G | BX-1 | CHINA | 327 | 337 | 42.4 | | |
| 2008-047H | SZ-7 MODULE | CHINA | 329 | 336 | 42.4 | | |
| 2008-048A | DEMOSAT/FALCON 1 | USA | 622 | 643 | 9.4 | 1 | 0 |


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