

Orbital Debris Quarterly News

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Inside...

Eighteen-Year-Old Solid Rocket Motor Casing Found

NASA's OD Chief Scientist Receives Awards 3

Publication of the Handbook for Limiting Orbital Debris

A New MMOD Sensor ... **Resistive Grid Detector_4**

Stabilizing the Future LEO Debris Environment 5 Abstracts from the NASA OD Program Office Meeting. Space Missions and Orbital Box Score

A publication of The NASA Orbital Debris Program Office

ISS Maneuvers to Avoid Russian **Fragmentation Debris**

way (Figure 1).

fragmentations during March-June, creating approximately 500 large debris and an unknown

On 27 August the International Space Station number of smaller debris (ODQN, Vol. 12, (ISS) conducted its first collision avoidance Issues 2 and 3). By mid-September a total of 480 maneuver in five years to evade a piece of debris fragmentation debris had been officially cataloged from the Russian spacecraft Cosmos 2421. Europe's by the U.S. Space Surveillance Network, of which Automated Transfer Vehicle, the Jules Verne, burned about half were still in orbit. Since Cosmos 2421 two of its main engines for slightly more than was approximately 60 km above ISS at the time of 5 minutes to push the large complex out of harm's the fragmentations, all debris either were initially in orbits routinely transiting the ISS orbital regime or Cosmos 2421 had experienced three major were in higher orbits which would later pass through the orbit of ISS.

continued on page 2



S124E009973

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

33246, International Designator 2006-026RU) forthcoming logistics missions, a retrograde Number 33258, International Designator 2006that 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

maneuver of 1 meter per second was selected to 026SG) did fragment into three pieces on lower slightly the mean altitude of ISS, the first 6 August. Such disintegrations of breakup such maneuver in 8 years. To accomplish this debris have occasionally been observed before. 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 about two hours before the nominal time detected during the third quarter of 2008, another

The fragment (U.S. Satellite Number of closest approach by the debris. Due to of the debris from Cosmos 2421 (U.S. Satellite 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 motor casing to a Delta 2 launch vehicle used a nearly two-decades-old secret in July when a on 12 June 1990 to deliver the Indian INSATlaunch vehicle rocket motor casing was found 1D geosynchronous spacecraft from the Cape during a routine muster of cattle on a three- Canaveral Air Force Station, Florida. This solid million-acre pastoral property. First spotted by rocket motor served as the launch vehicle's Mr. Arthur Taylor while flying a Cessna aircraft third stage (U.S. Satellite Number 20645, in the muster operation, the casing appeared International Designator 1990-051C), which in relatively good condition (Figure 1) and did carried the payload from a low altitude parking not seem to be very old. Mr. Michael White orbit into a geosynchronous transfer orbit of forwarded numerous photos of the object to 135 km by 39,750 km with an inclination of the NASA Orbital Debris Program Office, 27.2 degrees. Reentry of the stage occurred a including one with a clear serial number next to few months later. the nozzle attachment point.

Space Center personnel were able to trace the Argentina during the past several years.

The object joins similar solid rocket motor Using the serial number, NASA Kennedy casings found in Saudi Arabia, Thailand, and



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 characterized Scientist for Orbital Debris, received two high level awards for his outstanding work in support post-kinetic of the successful engagement of the USA-193 spacecraft in February of this year (see "Satellite and through analytical Breakups During First Quarter of 2008," ODQN, Vol. 12, Issue 2). In a special ceremony on 30 July, General Kevin Chilton, Commander he enabled senior leaders of the U.S. Strategic Command, and Rear to make critical satellite Admiral Douglas McClain, Director of Global Operations for USSTRATCOM, presented decisions." Nick with the Joint Meritorious Civilian Service Award from the Chairman of the Joint Chiefs Nick also received the of Staff.

USA-193 was a classified military satellite Service Medal, NASA's which contained a tank with \sim 450 kg of toxic hydrazine fuel in a frozen state. The citation NASA Administrator. for the award stated that Nick "properly

the risk associated to natural and intercept reentry of the satellite; expertise and superb communication ability, mitigation reentry

Earlier, on 19 June, NASA Distinguished highest award from the ٠



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

Publication of the Handbook for Limiting Orbital Debris

Limiting for Handbook 8719.14) was completed and supporting material to assist in implementing (radar, optical, and in situ) and current signed by NASA's Chief Safety Officer the NPR and NASA-STD. Mr. Bryan O'Connor on 30 July 2008. The engineering processes, procedures, practices, methodology behind the NASA Orbital Debris Handbook is intended to provide the scientific and methods in the two documents are explained Program's studies, both past and present. background to NASA's Orbital Debris Program, further within. as defined in NPR 8715.6A "Procedural Requirements for Limiting Orbital Debris" and background of the orbital debris environment then discussed. Finally, reentry survivability NASA-STD 8719.14, "Process for Limiting as it exists now, then follows with discussion background and modeling technique is Orbital Debris". The Handbook serves as of research and results for how the future

The first edition of the Handbook a companion to these two documents, and environment is expected to evolve. Background

Orbital Debris (NASA- provides each NASA program and project with in the measurement techniques and research The uniform modeling approaches follows, providing more Hypervelocity impact research, as well as NASA-Handbook 8719.14 begins with a mitigation history and current status, are

Orbital Debris Handbook

continued from page 3

the physical and mathematical phenomenon orbital debris. that occurs when an object reenters the Earth's references are included at the end of each atmosphere.

Nearly 100 figures and over a dozen tables detailed research, should the need exist. are included to assist the reader with a visual

presented, so that the reader better understands understanding of all issues associated with Additional and detailed chapter so that the reader may do more

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 μ m 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 is greater than 50 μ m, one or more of the



An illustration of the Resistive Grid Figure 1. Sensor

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.

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

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 sensor¹) 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

Sensors

continued from page 4

needed since the measurements can be 100 x 100 array of 1 mm-square multiplexed.

The mass of an RGS system of the DRAGONS type with 1 m² 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 on existing and proven technology. Based on larger than 10 cm x 10 cm, would contain a robust and currently-available technology, the Quarterly News, Vol 8, Issue 3, 3-4, 2004.

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 largeparticle-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 RGS is a suitable candidate for deployment on 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



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

future spacecraft and on the lunar surface.

¹Corsaro, R., et al., PINDROP - An acoustic particle impact detector, Orbital Debris

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 Unfortunately, the ongoing space society. 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

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 from the previous one in the following areas: breakup events, such as Fengyun-1C (FY-1C) and Briz-M, may continue to occur. Even with a the initial environment for future projection, 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 would be needed to stabilize the future LEO 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

mutual collisions among existing objects, even 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 (1) the tracked FY-1C fragments were added to (2) a more realistic scenario, where the disposal commonly-adopted postmission (PMD) mitigation measures were implemented for future launches, was selected as the benchmark, and (3) the focus was on what 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

Active Debris Removal

continued from page 5

compared with the baseline scenario. A total of 100 Monte Carlo simulations were carried However, this population growth could be out for each scenario, and the averages were reduced by half with a removal rate of two calculated for comparison. The main result of the study is shown in Figure 1. The top curve is The bottom curve indicates that the future the projection for the 10 cm and larger objects LEO environment could be stabilized with a in LEO. Even with a good implementation of removal rate of five objects per year. The trend

200-year future environment projections were the PMD mitigation measures, the population also suggests that if more objects are removed, will still increase by about 75% in 200 years. objects per year, starting from the year 2020.



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.

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.

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-

correlated (CT) and uncorrelated (UCT) targets. Approximately five minutes of data is collected for an object, which requires an assumed circular objects found were 30 cm and 10 cm for a CT orbit (ACO) to obtain the orbital elements. and UCT, respectively. There are two known Biases are determined by assuming the TLE is GEO break-ups from the Titan 3C-4 transtage truth and comparing the ACO orbital parameter break up and the Ekran 2 breakup. UCTs are to it. When assessing all objects, the mean biases American Observatory (CTIO). A total of are 82°, 0.15°, and 0.04 for RAAN, inclination, known to be. All of the data from the five years 151 nights of data have been collected and mean motion, respectively. However, of MODEST data will be discussed herein. ◆

and compiled into optical observations of 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 found in the area where the parent bodies are

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 scan a single fragment, measure its size and into the shapes and sizes of debris produced shape properties, and import the fragment

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

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 and the methods used to discern hypervelocity 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 detection system (WLEIDS) and its role in (LOCV) risk. MMOD impacts on the Payload Bay Door be presented. Finally, an analysis of alternative radiators, wing leading edge reinforced carboncarbon (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

impact damage. Impact damage contingency plans and on-orbit repair techniques will also be discussed. The wing leading edge impact An overview of significant the reduction of on-orbit risk reduction will 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- GEO spacecraft and launch vehicle orbital of-mission plans, and disposal of vehicles in stages is to ensure that the vehicles do not 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

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 submicron 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 vet 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 high percentage of aluminum debris in shuttle 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 an explicit extension of the NASA Standard impact event of the Satellite Orbital Debris Characterization Impact Test (SOCIT) series conducted in 1991-1992. Results of this test, labeled SOCIT4, vielded 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

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 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

could be developed to reduce the future Different annual removal rates and different debris population growth. The present paper ADR target selection criteria were tested, and summarizes a comprehensive study based on more realistic simulation scenarios, including fragments generated from the 2007 Fengyun-1C event, mitigation measures, and other target indicate that (1) an effective removal strategy can 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

that a simple ADR target selection criterion as the baseline environment for comparison. the resulting 200-year future environment projections were compared with the baseline scenario. Results of this parametric study 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.

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 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 onorbit collisions) have been used to predict the extent and characteristics of such hypervelocity collision debris clouds, but until now there have

In the days and weeks following the ASAT 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 NASA uses can give an accurate statistical 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. ٠

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 data2-4 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

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.

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> 4. K. S. Jarvis, T. L. Thumm, E. S. Barker, K. Abercromby, and M. K. Mulrooney. "Liquid Low Earth Orbit Orbital Debris Environment March 1999 - September 2000." ISC-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 The collisional breakup models future. 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. and from Haystack, for debris larger than 1 cm, collision at 220 km altitude. 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,

Measurements from the U.S. Space Surveillance in September 1986, the Delta 180 payload was Network (SSN), for debris larger than 10 cm, struck by its Delta II rocket body in a planned Although no show that the number of fragments created Haystack data was available in 1985-6 and very from Fengyun significantly exceeds model 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.

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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 longterm 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

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

scales, which complicate the short-term orbit 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 Matney1 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 0.175² after revisions were made to the basis set of supplied brightness data (NASA-Liquid Mirror Telescope photometry data³⁻⁵). 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) highprecision 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, fullcatalogue 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, Abercromby, T. L. Parr-Thumm, J. L. Africano, 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.

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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. 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.

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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 Michigan Orbital DEbris Survey Telescope) 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

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 15th 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 predictions assuming a circular orbit are done on the basis of angular rate are not at GEO. Debris Program Office, Johnson Space Center, for where the object will be for the next hour, A second objective is to obtain magnitudes and Houston, Texas, USA.

colors in standard astronomical filters (BVRI) for comparison with reflectance spectra of likely spacecraft materials.

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

MEETING REPORTS

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

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

The 37th COSPAR Scientific Assembly was rocket motor slag population, impact of papers submitted to the journal "Advances in meeting was also held during the Scientific expires. ♦ Assembly. Luciano Anselmo introduced the

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Surveillance Technologies Conference was held 16-19 September 2008 in Wailea, Maui, oral presentations beginning with Dr. David Hawaii. Orbital debris issues were highlighted Finkleman's discussion of several issues including on the analysis of orbits for the same high areain 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, covariance information. Thomas Schildknecht

Program Office. The session contained five systematic conjunctions between resident space to-mass population. The final paper of the objects. Tim Floher also discussed conjunction analysis for two ESA missions, ERS-2 and Envisat, using two-line element sets which lack

The 9th Advanced Maui Optical and Space Program Manager for NASA's Orbital Debris reported on color photometry and light curves for the high area-to-mass population near the GEO orbit regime and Thomas Kelecy reported session comparing data from on-orbit collision was given by Gene Stansbery. ♦

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

Space Debris Symposium included five sessions: presented during the symposium. Measurements and Space Surveillance, Modeling included optical LEO to GEO observations, and Risk Analysis, Hypervelocity Impacts and radar measurements,

Congress (IAC) was held in Glasgow, Scotland Measurement Projects and Modeling Aspects. hypervelocity impact test results, mitigation from 29 September - 3 October 2008. The A total of 41 papers and discussions were policies and compliance examples, and active debris environment

The 59th International Astronautical Protection, Mitigation and Standards, and modeling, satellite fragment characterizations, Topics 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	

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

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center 2101 NASA Parkway Houston, TX 77058

www.nasa.gov

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		
				I			
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	NIMIO 4	CANADA	35785	35788	0.1	1	1
2008 045 4	GALAXV 19	LISA	35778	35706	0.1	1	0
2000-045/1	UNLINA IV	05/4	55776	55770	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		
2000 0100	00511052111	ROBBIT	19139	19201	01.0		
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