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Inside...

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NASA Sends Centaur Stage to Watery Grave

On 30 August NASA's twin Radiation Belt Storm Probes (RBSPs) were successfully inserted into highly elliptical Earth orbits by an Atlas V launch vehicle. The Centaur upper stage released the two spacecraft into orbits of about 600 km by 30,000 km with inclinations of 10 deg. These orbits will permit the spacecraft to examine the complex Van Allen radiation belts under varying solar conditions.

At the end of their missions, which are expected to last at least 2 years, the 600-kg (dry mass) RBSP spacecraft will use their on-board propulsion systems to lower their perigees to permit a natural reentry within less than 1 year. NASA, U.S., and international orbital debris mitigation guidelines recommend that any vehicle within or regularly passing through the low Earth orbit (LEO) region be limited to an orbital lifetime of no more than 25 years after mission termination. This guideline reduces the chances that the satellite will accidentally collide with another resident space object and create new orbital debris.

The above guideline also applies to launch vehicle stages. The RBSP Centaur stage could also have maneuvered into a lower orbit to accelerate its fall back to Earth within the desired 25-year period. However, the Centaur stage has a dry mass of approximately 2.2 metric tons with a diameter of 3.1 m and a length of 12.7 m (see figure). An uncontrolled reentry into the atmosphere would produce surviving debris that could pose a risk to people and property on Earth. To meet the twin objectives of quickly removing the stage from orbit and avoiding hazards from surviving debris, a decision was made to execute a controlled reentry of the stage over a broad ocean area.

About an hour and a half after lift-off from Cape Canaveral, Florida, the RBSP spacecraft were released 12 minutes apart while flying over the Pacific Ocean south of Hawaii. After a short maneuver to avoid accidentally colliding with the spacecraft, the Centaur readied itself for its third and final major burn. The stage successfully executed its de-obit maneuver about 10 minutes after the release of the second RBSP spacecraft. All

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Atlas 5 Centaur Stage.

Centaur Stage

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surviving debris fell in a constrained region of the Atlantic Ocean just south of the equator between South America and Africa.

Although this was NASA's first controlled reentry of a launch vehicle for many years, orbital stage reentries have recently become more common. In fact, the Centaur reentry was the seventh de-orbit of a launch vehicle orbital stage during 2012. Moreover, these reentries involved launch vehicles from China, Europe, Japan, the Russian Federation, and the U.S., underscoring the recognition by the international community of the need to reduce reentry risks whenever possible.

On 17 September the Fregat upper stage used to insert ESA's MetOp B spacecraft into a sun-synchronous orbit at an altitude of 820 km executed the eighth controlled rocket body reentry for the year, matching the number of such reentries during 2011. At least one more launch vehicle orbital stage de-orbit is expected by the end of 2012, a feat that would set a new annual record for controlled rocket body reentries. In contrast, the totals for 2009 and 2010 were only one and three, respectively.

♦

New Russian Launch Failure Raises Breakup Concern

The failure of a Russian launch vehicle upper stage on 6 August has led to concerns that the partially-loaded rocket body might explode as two similar stages have done in recent years. Like its sisters, the new Proton Briz-M stage was left stranded in an elliptical orbit with a perigee in low Earth orbit (LEO), where debris from a future explosion could pose a threat to numerous operational spacecraft there. This latest accident also left two fully-fueled spacecraft in orbits like that of their carrier.

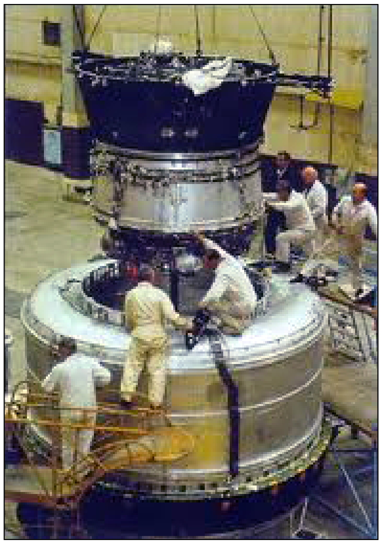

Figure 1. Briz-M central tank and main engine being inserted into the APT.

The launch malfunction occurred when the Briz-M upper stage (International Designator 2012-044C, U.S. Satellite Number 38746), carrying the Telkom 3 and Express MD2 spacecraft, shut-down shortly after the start of the third of its planned four maneuvers. At the time, the stage was in an orbit of 265 km by 5015 km with an inclination of 49.9 deg. Both spacecraft were later autonomously released from the stage.

The Briz-M stage has a diameter of 4.0 m and a length of 2.65 m and is comprised of two major parts: (1) a core section with a central propellant tank carrying a propellant mass of 5.2 metric tons and the main propulsion system and (2) an auxiliary propellant tank (APT) with an initial propellant mass of 14.6 metric tons and shaped like a donut to encompass the core section (Figure 1). During a normal mission, the APT is separated after the first few burns, and the core section completes the payload delivery task. In the 6 August accident, the APT had not yet been separated, leaving more than 5 metric tons of propellant in the integrated 2.6 metric ton (dry mass) stage.

Concern about a future explosion of the Briz-M stage is based upon the breakups of two Briz-M stages (one in 2007 and one in 2010) that had suffered very similar flight malfunctions (Table 1). In these two earlier cases, the failures also occurred prior to separation of the APT. The breakups, however, did not take place until 12 and 31 months, respectively, after the failures (ODQN April 2007, p. 3 and January 2011, pp. 2-3). Although only about 100 large debris from each of these Briz-M stages have been cataloged to date (Figure 2), a much larger number of hazardous debris are believed to stretch from 300 to nearly 29,000 km.

Another Briz-M stage suffered an on-orbit malfunction in August 2011. In that case, the failure took place after the APT was released. This stage contains less than 5 metric tons of propellant and has not yet exploded, although the potential for a severe breakup is believed to still exist. The orbital lifetimes of the 2011 and the 2012 Briz-M stages are estimated to be at least several decades.

At the end of a nominal mission, any residual propellants and pressurants in the central tank are vented into space, according to international orbital debris mitigation guidelines. This passivation process, however, is not guaranteed to function in at least some failure scenarios, as evidenced by the two aforementioned Briz-M breakups.

In addition to the stages themselves, the

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Table 1. Summary of Recent Briz-M Failures

Date of Failure	International Designator	Initial Perigee Altitude	Initial Apogee Altitude	Initial Inclination	Residual Propellants	Breakup (time after failure)
28 February 2006	2006-006B	495 km	14,705 km	51.5 deg	~11 metric tons	12 months
14 March 2008	2008-011B	645 km	26,565 km	48.9 deg	> 5 metric tons	31 months
17 August 2011	2011-045B	1000 km	20,315 km	51.3 deg	< 5 metric tons	Not applicable
6 August 2012	2012-044C	265 km	5015 km	49.9 deg	> 5 metric tons	Not applicable

Russian Launch Failure

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disposition of the spacecraft must be addressed. The 2006 and 2011 missions each carried a single, large spacecraft of European manufacture: Arabsat 4A and Express AM4, respectively. After consideration of various disposal options, both spacecraft were sent on controlled, destructive reentries over the Pacific Ocean. This decision eliminated the risk of a future collision by either of the spacecraft with another resident space object, as well as the risk of a debris-producing explosion.

In the case of the 2008 failure, the AMC 14 spacecraft, manufactured in the U.S., had sufficient propellant reserves to gradually raise itself and eventually to enter a useful geosynchronous orbit, although one with an inclination of 13 deg. No decision has yet been made regarding the fates of Telkom 3 and Express MD2.

Finally, another variant of the Briz-M, the Rokot Briz-KM has also encountered two failures since 2005. In the first instance, a malfunction prevented the stage and its payload, the European Cryosat, from even entering an Earth orbit. The second mishap occurred in February 2011 and stranded a Russian geodetic satellite, GEO-IK 2, in an elliptical orbit when a second burn of the stage was not executed. This stage, too, is believed to contain a significant amount of residual propellants, which might someday trigger an explosion. ♦

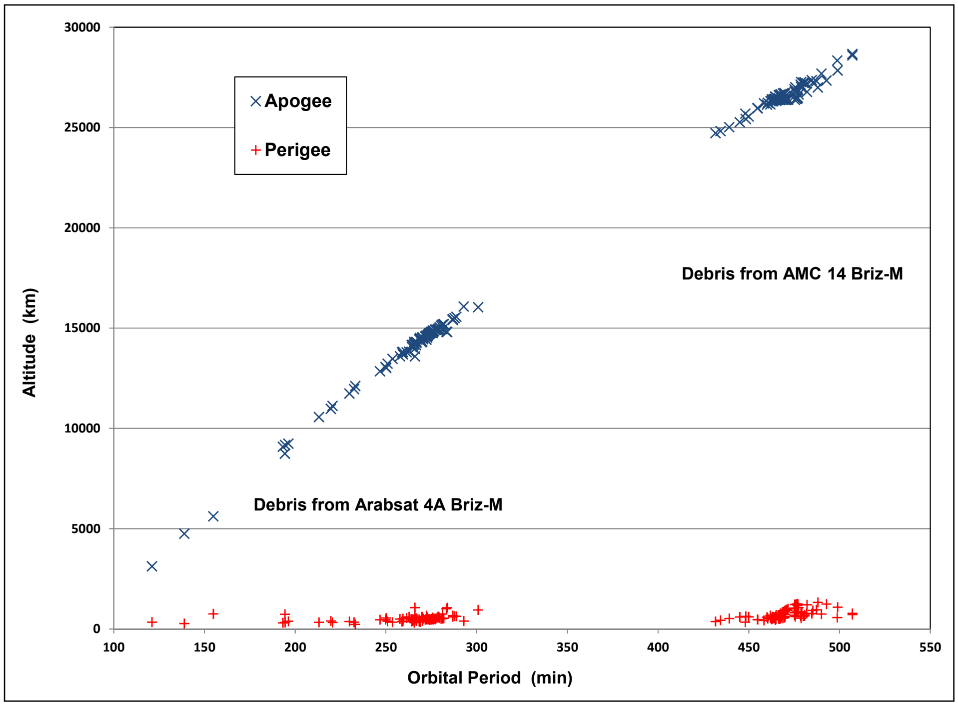

Figure 2. Distribution of debris from 2007 and 2010 Briz-M stage breakups.

PROJECT REVIEW

Origin of the Inter-Agency Space Debris Coordination Committee

N. JOHNSON

The Inter-Agency Space Debris Coordination Committee (IADC) is recognized as the pre-eminent international technical organization for all issues associated with orbital debris. This august body is now comprised of 12 member agencies, representing 11 nations and the regional European Space Agency (ESA). October 2012, marks the 25th anniversary of the first ESA/NASA orbital debris coordination meeting, which would evolve into the IADC, and the 20th anniversary of the proposal to establish a formal, multi-national group of orbital debris experts.

Good things often arise from unfortunate events, and the IADC is a case in point. On 26 November 1986, an Ariane 1 second stage spontaneously exploded in low Earth orbit, creating the largest orbital debris cloud to that date. A total of 492 large debris was eventually cataloged from the fragmentation, although fortunately only 32 still remain in orbit today. This significant space event led NASA's Orbital Debris Program Office to host an international conference on the breakup of launch vehicle upper stages the following May and led ESA to establish a Space Debris Working Group.

Following the successful conference, NASA and ESA decided to hold a bilateral orbital debris coordination meeting in Rolleboise, France, in October 1987, "to discuss the various aspects of space debris, exchange opinions, present study results and agree on contact points for policy, management, and technical experts." Due to the considerable number and breadth of topics of mutual interest, a decision was made to hold a second meeting the following year, which in turn led to additional meetings at roughly annual intervals.

In early 1989, a U.S. government interagency *Report on Orbital Debris* recommended that the "U.S. should inform other space-faring nations about the conclusions of this report and seek to evaluate the level of understanding and concern of other nations and relevant international organizations about orbital debris issues.

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IADC

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Photograph of the attendees of the 30th meeting of the IADC at McGill University in Montreal, Quebec, Canada, during May, 2012.

Where appropriate, the U.S. should enter into discussions with other nations to coordinate debris minimization policies and practices." Consequently, NASA orbital debris experts visited both the Soviet Union and Japan by the end of 1989 and established separate orbital debris working groups with the two nations.

Thus, in 1990 NASA was supporting three distinct, but very similar, bilateral orbital debris coordination meetings. This inefficient situation began to take a toll on NASA orbital debris experts in terms of time, travel, and expense. Hence, a consolidation of these efforts was the logical next step. At the 6th meeting of the ESA/NASA orbital debris coordination committee in April 1991, Japan was invited as an active participant. Beginning with the next gathering in February 1992, the forum was officially renamed the ESA/Japan/NASA orbital debris coordination committee, but the original ESA/NASA numbering system was retained, making this the 7th official meeting. A few days after this meeting, which took place in the Netherlands, NASA orbital debris specialists extended their journey to Moscow to meet with their Russian counterparts for the next meeting of the US/USSR orbital debris coordination committee.

By the time of the 8th meeting of the ESA/Japan/NASA committee, which was held at the NASA Johnson Space Center in Houston, Texas, during 20-21 October 1992, the need for a more formal and possibly more inclusive organization was apparent. A strawman Terms of Reference for the new committee was circulated for review and later comment. The scope of the proposed committee's activities was to "(1) review all ongoing cooperative debris research activities between member organizations, (2) identify, evaluate, and approve new opportunities for cooperation, and (3) serve as the primary means for exchanging information and plans concerning orbital debris research activities."

The 9th meeting of the committee, hosted by ESA at the European Space Operations Center (ESOC) at Darmstadt, Germany, in April 1993, was the first to include all four of the founding members of the IADC, although a new name for the committee had yet to be chosen. At this meeting, the concept of establishing a steering group and four working groups (measurements, environment & database, testing & shielding, and mitigation) was adopted. Each future meeting would be divided into opening and closing plenary sessions with concurrent splinter meetings of the steering group and the four working groups in between.

The name of the Inter-Agency Space Debris Coordination Committee was officially adopted in Moscow during October 1993. Here the first formal Terms of Reference of the IADC was signed by the heads of the four delegations: K. Debatin for ESA, S. Toda for Japan, G. Levin for NASA, and A. Krasnov for the Russian Space Agency (RKA). Although much expanded, the current IADC Terms of Reference retains many elements of the original framework document.

The IADC grew rapidly with the addition of the space agencies of China (CNSA) in 1995; France (CNES), India (ISRO), and the United Kingdom (then BNSC, now UKSA) in 1996; Germany (then DARA, now DLR) in 1997; Italy (ASI) in 1998; the Ukraine (then NSAU, now SSAU) in 2000; and Canada (CSA) in 2010. The 12-member committee now holds its annual 4-day meeting each spring with more than 100 orbital debris specialists attending. The Steering Group, comprised primarily of the heads of each member agency delegation, also meets for one day on the sidelines of the International Astronautical Congress each fall.

The many achievements of the IADC include the first international set of space debris mitigation guidelines, the establishment of a data exchange network for the uncontrolled reentry of satellites posing elevated risks to people and property on Earth, organized observation campaigns of untracked debris in both low and high altitude orbits, and a manual on the design and effectiveness of shielding to protect spacecraft from space debris. Although not a part of the United Nations, since 1997 the IADC normally provides a special technical presentation before the annual meeting of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPUOS). The IADC space debris mitigation guidelines were used as the foundation for the development of the UN COPUOS space debris mitigation guidelines.

Additional information on the IADC and its activities can be found at www.iadc-online.org. ♦

An Update on the Effectiveness of Postmission Disposal in LEO

J.-C. LIOU

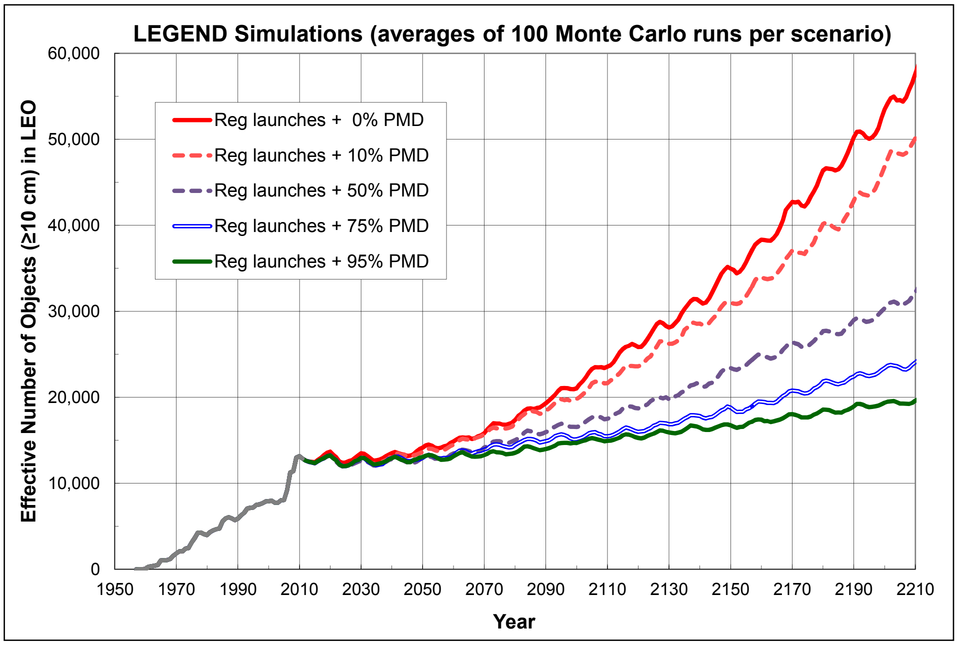

Figure 1. Effective numbers for the 10 cm and larger objects in LEO. The effective number is defined as the fractional time, per orbital period, an object spends below 2000 km altitude.

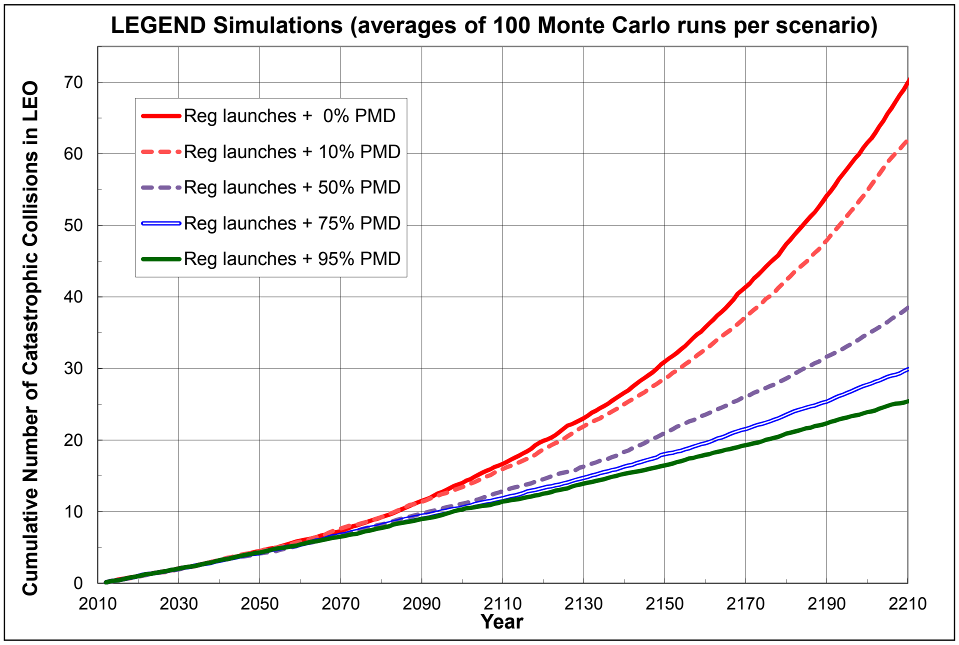

Figure 2. Cumulative numbers of catastrophic collisions predicted by the 5-projection scenario. Each curve represents the average of 100 MC runs.

The commonly-adopted orbital debris mitigation measures were developed to reduce the growth of the future debris population. A major component in debris mitigation is postmission disposal (PMD). The key PMD element for LEO satellites is the 25-year rule. It is intended to limit the long-term presence of rocket bodies (R/Bs) and spacecraft (S/C), as well as mission-related debris, in the environment. The effectiveness of PMD has been demonstrated and documented since the development of mitigation measures began in the 1990s [1-3]. This article provides a simple update, based on the current environment, using the NASA LEGEND model.

The study focused on the ≥10 cm population in LEO. The historical simulation covered 1957 through 2011 and followed the recorded launches and known breakup events. The future projection was carried out for 200 years with an 8-year launch traffic, 2004 - 2011, repeated during the projection period. An 8-year mission lifetime was assumed for future S/C. No stationkeeping and no collision avoidance maneuvers were implemented and only objects 10 cm and larger were included in collision consideration. Additionally, no explosions were allowed for R/Bs and S/C launched after 2011. The 25-year PMD rule success rates were set at 0%, 10%, 50%, 75%, and 95%, respectively, for the five study scenarios.

Figure 1 shows the effective numbers of objects in LEO, including both historical and the five future projections. Each projection curve is the average of 100 Monte Carlo (MC) LEGEND runs. As expected, the 0% PMD projection follows a rapid and non-linear increase in the next 200 years. With a 50% compliance of the 25-year rule, the population growth was reduced approximately by half. However, even with a 95% compliance of the 25-year rule, the LEO debris population will still increase by an average of more than 50% in 200 years.

The projected collision activities are shown in Figure 2 and summarized in Table 1. A catastrophic collision occurs when the ratio of impact energy to target mass exceeds 40 J/g. The outcome of a catastrophic collision is the total fragmentation of the target, whereas a non-catastrophic collision only results in damage to the target and generates a small amount of debris. Even with a 95% compliance of the 25-year rule, on average, 26 catastrophic and 19 non-catastrophic collisions are expected in the next 200 years.

Predicting the future debris environment is very difficult. The results are always sensitive to key assumptions adopted by the model, including the future launches and solar activity. Nevertheless, one can make reasonable

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Effectiveness of Postmission Disposal

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Table 1. Projected collision activities for the next 200 years in LEO. All collisions are for 10 cm and larger objects. The numbers are averages of 100 MC runs.

	0% PMD	10% PMD	50% PMD	75% PMD	95% PMD
Catastrophic Collisions	71	63	39	30	26
Non-catastrophic Collisions	76	65	37	24	19
Total Collisions	147	128	76	54	45

assumptions, define nominal scenarios, and then draw conclusions from the average results for effective environment management. This updated study again illustrates the effectiveness of orbital debris mitigation. It is the first and the most cost-effective defense against future population growth.

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Detection of Optically Faint GEO Debris

P. SEITZER, S. LEDERER, E. BARKER,
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J. SILHA, AND A. BURKHARDT

To date there have been extensive optical surveys for debris at geosynchronous orbit (GEO) conducted with meter class telescopes, such as those conducted with MODEST (the Michigan Orbital DEbris Survey Telescope, a 0.6-m telescope located at Cerro Tololo in Chile), and the European Space Agency's (ESA) 1.0-m SDT (Space Debris Telescope) located in the Canary Islands.

These surveys have detection limits in the range of 18th-19th magnitude, which corresponds to sizes larger than 10 cm assuming an albedo of 0.175. All these surveys reveal a substantial population of objects fainter than R = 15th magnitude which are not in the public U.S. Satellite Catalog.

To optically detect objects fainter than 20th magnitude (and presumably smaller than 10 cm) requires a larger telescope and excellent imaging conditions. Here we report on observations obtained with a 6.5-m telescope: the Magellan telescope 'Walter Baade' at Las Campanas Observatory in Chile. Our goal is to go as faint as possible from the ground and study the brightness distribution of GEO debris, which are fainter than R = 20th magnitude. Does the distribution continue to increase as one reaches fainter limiting magnitudes? How does it compare with the distribution of debris at low Earth orbit (LEO)?

We describe preliminary results obtained during 6 hours of observing time during 25-27 March 2011. We used the Inamori Magellan Areal Camera and Spectrograph (IMACS) instrument in f/2 imaging mode, which had a mosaic of eight CCDs, and a field of view of 0.5 degrees in diameter. This is the widest field of view of any instrument on either Magellan telescope. The image scale is 0.4 arc-seconds/pixel. The limiting magnitude for our 5-second exposures though a Sloan r' filter is measured to be fainter than R = 21. The system saturates at R = 15th in 5 seconds in the typical sub-arc-second image quality of the Magellan telescopes. We tried to observe as close as possible to the edge of Earth shadow at GEO for two reasons: 1) this minimized the solar phase angle and maximized the apparent brightness, and 2) objects below GEO were in Earth shadow and thus not visible. This is important because all we can measure from this data are positions and angular rates, and we do not (yet) have the capability of doing real-time orbits.

In the 6 hours of photometric observing time we detected 19 individual objects, as determined by manual review of all the images, but only 12 of them had rates consistent with GEO objects. In order for us to consider an object as real it had to appear in at least three images. We are looking for objects with hour angle (HA) rates within ± 2 arc-seconds/second, and declination (DEC) rates within ± 5 arc-seconds/second. These rates correspond to motions expected for GEO objects in circular orbits with inclinations ranging from 0 to 16 degrees.

The detections group into three types: streaks, streaks of non-uniform brightness, and resolved and partially resolved flashes. Examples are presented in Figures 1 through 3. Each sub-image is 51.6 x 51.6 arc-seconds in size. Horizontal lines are stars (in Figure 3, the star tracks are slightly tilted to the upper right).

Approximately one third of the detections show a series of three or more flashes during each 5-second exposure. One interpretation is that we are detecting tumbling objects. Objects that are non-uniform streaks are tumbling at a rate close to our 5-second exposure time; objects with flashes are tumbling faster. Approximately 25% of the detected objects show glints.

None of the faint objects detected are in the public U.S. Satellite Catalog.

The rate of detection of objects with GEO rates is approximately 10 per hour per square degree.

We can compare this with the detection rate of GEO debris on MODEST during observing campaigns in previous years. The CCD camera in this telescope had a field-of-view of 1.3 x 1.3 degrees, a somewhat broader filter close to the same central wavelength of the Magellan Sloan r' filter, the same 5-second exposure time as Magellan, and a different survey technique. The average detection rate of objects with angular rates consistent with those at GEO in the magnitude range 15-18th R magnitude was approximately 1 object/square degree/hour. This is about one tenth of the rate observed with Magellan.

The Magellan and MODEST results are consistent with a rising population of GEO objects as one reaches fainter limiting magnitudes. The statistics are unfortunately small at the faint end due to the Magellan

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DETECTION OF GEO DEBRIS

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results, but more GEO objects were detected in 6 hours of observing with Magellan in a smaller field-of-view than with MODEST in an 8 hour night with a camera covering an eight times larger area of sky. ♦

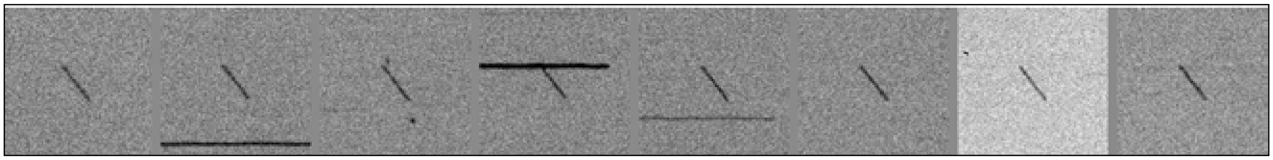

Figure 1. An object detected as a uniform short streak. The primary motion is north to south.

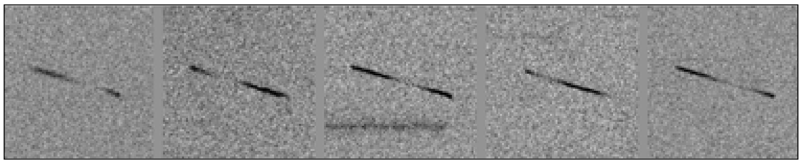

Figure 2. An object detected as a non-uniform streak.

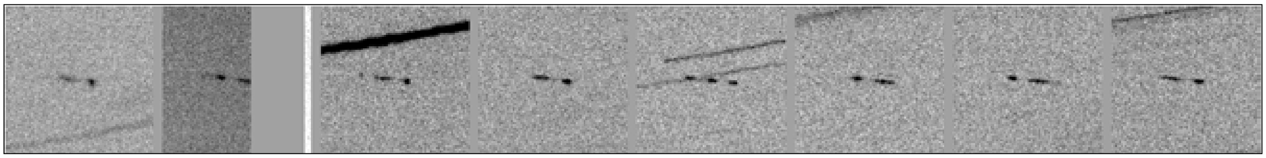

Figure 3. An object detected as a series of unequal brightness flashes. The primary motion is east to west.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

The 13th Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference
11-14 September 2012, Maui, Hawaii

Optical Signature Analysis of Tumbling Rocket Bodies via Laboratory Measurements

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J.-C. LIOU

The NASA Orbital Debris Program Office (ODPO) has acquired telescopic lightcurve data on massive intact objects, specifically spent rocket bodies (R/Bs), to ascertain tumble rates in support of the Active Debris Removal (ADR) studies to help remediate the LEO environment. Tumble rates are needed to plan and develop proximity and docking operations for potential future ADR operations.

To better characterize and model optical data acquired from ground-based telescopes, the ODPO's Optical Measurements Center (OMC) at NASA/JSC emulates illumination conditions in space using equipment and techniques that parallel telescopic observations and source-target-sensor orientations. The OMC employs a 75-W Xenon arc lamp as a solar simulator, an SBIG CCD camera with standard Johnson/Bessel filters, and a robotic arm to simulate an object's position and rotation. The OMC does not attempt to replicate the rotation rates, but focuses on ascertaining how an object is rotating as seen from multiple phase angles. The two targets studied are scaled (1:48) SL-8 Cosmos 3M second stages. The first target is painted in the standard Russian government "gray" scheme and the second target is white/orange as used for commercial missions.

This paper summarizes results of the two scaled rocket bodies, each observed in three independent rotation states: (a) spin-stabilized rotation (about the long axis), (b) end-over-end rotation, and (c) a 10 degree wobble about the center of mass. The first two cases represent simple spin about either primary axis. The third – what we call "wobble" – represents maximum principal axis rotation, with an inertia tensor that is offset from the symmetry axes. By comparing the resultant phase and orientation-dependent laboratory signatures with actual lightcurves derived from telescopic observations of orbiting R/Bs, we intend to assess the intrinsic R/B rotation states. In the simplest case, simulated R/B behavior coincides with principal axis spin states, while more complex R/B motions can be constructed by combinations of OMC-derived optical signature that together form a rudimentary basis set. The signatures will be presented for specific phase angles for each rocket body and shown in conjunction with acquired optical data from multiple telescope sources.

The results of the data show possible correlations between the laboratory data and telescopic data for the rotations states mentioned above (b) and (c), but with limited data the results were not definitive to differentiate between color schemes and rotations. The only rotation that did not correlate with the observed telescopic data was the spin-stabilized rotation. ♦

Satellite Material Type and Phase Function Determination in Support of Orbital Debris Size Estimation

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E.G. STANSBERY

In performing debris surveys of deep-space orbital regions, the considerable volume of the area to be surveyed and the increased orbital altitude suggest optical telescopes as the most efficient survey instruments; but to proceed this way, methodologies for debris object size estimation using only optical tracking and photometric information are needed. Basic photometry theory indicates that size estimation should be possible if satellite albedo and shape are known. One method for estimating albedo is to try to determine the object's material type photometrically, as one can determine the albedos of common satellite materials in the laboratory. Examination of laboratory filter photometry (using Johnson BVRI filters) on a set of satellite material samples indicates that most material types can be separated at the 1-sigma level via B-R versus R-I color differences with a relatively small amount of required resampling, and objects that remain ambiguous can be resolved by B-R versus B-V color differences and solar radiation pressure differences. To estimate shape, a technique advanced by Hall et al., based on phase-brightness density curves and not requiring any *a priori* knowledge of attitude, has been modified slightly to try to make it more resistant to the specular characteristics of different materials and to reduce the number of samples necessary to make robust shape determinations. Working from a gallery of idealized debris shapes, the modified technique identifies most shapes within this gallery correctly, also with a relatively small amount of resampling. These results are, of course, based on relatively small laboratory investigations and simulated data, and expanded laboratory experimentation and further investigation with *in situ* survey measurements will be required in order to assess their actual efficacy under survey conditions; but these techniques show sufficient promise to justify this next level of analysis. ♦

Characterizing Orbital Debris and Spacecraft through a Multi-Analytical Approach

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H. COWARDIN, K. ABERCROMBY,
E. BARKER, AND A. BURKHARDT

Defining the risks present to both crewed and robotic spacecraft is part of NASA's mission, and is critical to keep these resources out of harm's way. Characterizing orbital debris is an essential part of this mission. We present a proof-of-concept study that employs multiple techniques to demonstrate the efficacy of each approach.

The targets of this study are IDCSPs (Initial Defense Communications Satellite Program). Thirty-five of these satellites were launched by the US in the mid-1960s and were the first US communications satellites near the GEO regime. They were emplaced in slightly sub-synchronous orbits. These targets were chosen for this proof-of-concept study for the simplicity of their observable exterior surfaces. The satellites are 26-sided polygons (86 cm in diameter), initially spin-stabilized and covered on all sides in solar panels.

Data presented here include: (a) visible broadband photometry (Johnson B and Cousins R bands) taken with the University of Michigan's 0.6-m aperture Curtis-Schmidt telescope MODEST (for Michigan Orbital DEbris Survey Telescope) in Chile in November 2011, (b) laboratory broadband photometry (Johnson BV Cousins RI) of solar cells, obtained using the Optical Measurements Center (OMC) at NASA/JSC (see Cowardin et al., AMOS 2012 paper for more details), (c) visible-band spectra taken using the Magellan 6.5 m Baade Telescope at Las Campanas Observatory in Chile in March 2012 (see also Seitzer et al., AMOS 2012 paper), and (d) visible-band laboratory spectra of solar cells using a Field Spectrometer.

Color-color plots using broadband photometry (e.g., B-R vs. R-I) demonstrate that different material types fall into distinct areas on the plots (Cowardin, AMOS 2010). Spectra will be binned in wavelength to compare with photometry results and plotted on the same graph for comparison. This allows us to compare lab data with telescopic data, and photometric results with spectroscopic results. In addition, the spectral response of solar cells in the visible wavelength regime varies from relatively flat (modern 'black' solar cells with uniform albedo as a function of wavelength) to older solar cells whose reflectivity is sharply peaked in the blue (similar to the IDCSP solar cells). With a target like IDCSPs, the material type is known *a priori*. Therefore, this study will also be used to determine whether laboratory spectra of pre-launch (pristine) solar cells differ from the telescopic spectra of IDCSPs that have been exposed to the harsh environment of space for ~45 years to investigate whether space weathering effects are evident. ♦

Probable Rotation States of Rocket Bodies in Low Earth Orbit

G. OJAKANGAS AND H. COWARDIN

In order for Active Debris Removal to be accomplished, it is critically important to understand the probable rotation states of orbiting, spent rocket bodies (RBs). However, rotational dynamics is non-intuitive and misconceptions are common. Determinations of rotation and precession rates have been published that are inconsistent with the theory presented here. In a state of free precession, the total angular momentum of the object is constant, while kinetic energy decreases due to internal friction, approaching rotation about the axis of maximum inertia. For solid internal friction, the timescale is hundreds to thousands of years for quality factors of ~100 and assuming metallic rigidities, but for friction in partially-filled liquid fuel tanks, we predict that the preferred rotational state is approached rapidly, within days to months. However, history has shown that theoretical predictions of the timescale have been notoriously inaccurate. In free precession, the 3-1-3 Euler angle rates φ (precession rate of long axis about fixed angular momentum with cone angle θ) and ψ (roll rate around long axis) have comparable magnitudes until very close to $\theta=\pi/2$, so that otherwise the true "rotation period" is not simply twice the primary light curve period. Furthermore $\dot{\theta}$, nonzero due to friction, becomes asymptotically smaller as

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$\theta=\pi/2$ is approached, so that θ can linger within several degrees of flat spin for a relatively long time. Such a condition is likely common, and cannot be distinguished from the "wobble" of a cylinder with a skewed inertia tensor unless the RB has non-axisymmetric reflectivity characteristics. For an RB of known dimensions, a given value of θ fixes the relative values of φ and ψ. In forced precession, the angular momentum precesses about a symmetry axis defined by the relevant torque. However, in LEO, only gravity gradient and magnetic induction torques are dominant, and these cannot cause precession periods shorter than a week or more likely, months. Thus forced precession is probably not observable over observation campaigns spanning a few days or less. Spin-orbit resonances are likely for low rotation rates approaching the mean motion, possibly causing large deviations between the symmetry axis and the geocentric direction. An expression for the magnetic induction torque on an arbitrarily rotating cylinder, hitherto not available in the literature, is presented here. Numerical integrations of the equations of motion for a cylindrical RB in LEO with arbitrary initial conditions and subject to magnetic and gravity gradient torques as well as prescribed internal dissipation are in progress. ♦

Visible Light Spectroscopy of GEO Debris

P. SEITZER, S. LEDERER,
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E. BARKER, AND K. ABERCROMBY

Our goal is to understand the physical characteristics of debris at geosynchronous orbit (GEO). Our approach is to compare the observed reflectance as a function of wavelength with laboratory measurements of typical spacecraft surfaces to understand what the materials are likely to be. Because debris could be irregular in shape and tumbling at an unknown rate, rapid simultaneous measurements over a range of wavelengths are required. Acquiring spectra of optically faint objects with short exposure times to minimize these effects requires a large telescope.

We describe optical spectroscopy obtained with two imaging spectrographs on the 6.5-m Magellan telescopes at Las Campanas Observatory in Chile. Our first observing run was 12-14 March 2012 with the IMACS imaging spectrograph on the 'Walter Baade' telescope, which was followed by a run on 1-2 May 2012 on the 'Landon Clay' telescope. Both telescopes have spectrographs with an imaging mode for acquisition. After acquisition and centering of a GEO object, a slit and grism are moved into the beam for spectroscopy. We used low resolution grisms blazed near 600 nm for wavelength coverage in the 400-800 nm region. Typical exposure times for spectra were 15-30 seconds.

Spectra were obtained for objects in the GEO regime listed as debris in the US Space Command public catalog, and one high area to mass ratio GEO object. In addition, spectra were obtained of IDCSP (Initial Defense Communications Satellite Program) satellites with known properties at launch just below the GEO regime. All spectra were calibrated using white dwarf flux standards and solar analog stars.

We will describe our experiences using Magellan, a telescope never used previously for orbital debris spectroscopy, and our initial results. ♦

The 63rd International Astronautical Congress (IAC)
1-5 October 2012, Naples, Italy

The Effects of Solar Maximum on the Earth's Satellite Population and Space Situational Awareness

N.L. JOHNSON

The rapidly approaching maximum of Solar Cycle 24 will have wide-ranging effects not only on the number and distribution of resident space objects, but also on vital aspects of space situational awareness, including conjunction assessment processes. The best known consequence of high solar activity is an increase in the density of the thermosphere, which, in turn, increases drag on the vast majority of objects in low Earth orbit. The most prominent evidence of this is seen in a dramatic increase in space object reentries. Due to the massive amounts of new debris created by the fragmentations of Fengyun 1C, Cosmos 2251, and Iridium 33 during the recent period of solar minimum, this effect will again be pronounced.

However, space surveillance systems are also affected, both directly and indirectly, historically leading to an increase in the number of lost satellites and a decrease in the routine accuracy of the calculation of their orbits. Thus, at a time when more objects are drifting through regions containing exceptionally high-valued assets, such as the International Space Station and remote sensing satellites, their position uncertainties increase. In other words, as the possibility of damaging and catastrophic collisions increases, our ability to protect space systems is degraded. Potential countermeasures include adjustments to space surveillance techniques and the resetting of collision avoidance maneuver thresholds. ♦

Using the Design for Demise Philosophy to Reduce Casualty Risk Due to Reentering Spacecraft

R. KELLEY

Recently the reentry of a number of vehicles has garnered public attention due to the risk of human casualty from fragments surviving reentry. A number of NASA programs have actively sought to minimize the number of components likely to survive reentry at the end of their spacecraft's life in order to meet and/or exceed NASA safety standards for controlled and uncontrolled reentering vehicles. This philosophy, referred to as "Design for Demise" or D4D, has steadily been adopted, to at least some degree, by numerous programs. The result is that many programs are requesting evaluations of components at the early stages of vehicle design, as they strive to find ways to reduce the number of surviving components while ensuring that they meet the performance requirements of their mission.

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Using the design for demise philosophy

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This paper will discuss some of the methods that have been employed to ensure that the consequences of the vehicle's end-of-life are considered at the beginning of the design process. In addition this paper will discuss the technical challenges overcome, as well as some of the more creative solutions which have been utilized to reduce casualty risk. ♦

Searching for Optically Faint GEO Debris

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K. ABERCROMBY, E. BARKER,
A. BURKHARDT, H. COWARDIN,
P. KRISKO, AND J. SILHA

We report on results from a search for optically faint debris (defined as R > 20th magnitude, or smaller than 10 cm assuming an albedo of 0.175) at geosynchronous orbit (GEO) using the 6.5-m Magellan telescope 'Walter Baade' at Las Campanas Observatory in Chile. Our goal is to characterize the brightness distribution of debris to the faintest limiting magnitude possible.

Our data was obtained during 6 hours of observing time during the photometric nights of 26 and 27 March 2011 with the IMACS f/2 instrument, which has a field of view (fov) of 0.5 degrees in diameter. All observations were obtained through a Sloan r' filter, and calibrated by observations of Landolt standard stars.

Our primary objective was to search for optically faint objects from one of the few known fragmentations at GEO: the Titan 3C Transtage (1968-081) fragmentation in 1992. Eight debris pieces and the parent rocket body are in the Space Surveillance Network public catalog. We successfully tracked two cataloged pieces of Titan debris with the 6.5-m telescope, followed by a survey for unknown objects on similar orbits but with different mean anomalies.

To establish the bright end of the debris population, calibrated observations were acquired on the same field centers, telescope rates, and time period with a similar filter on the 0.6-m MODEST (Michigan Orbital DEbris Survey Telescope), located 100 km to the south of Magellan at Cerro Tololo Inter-American Observatory, Chile.

We will show the calibrated brightness distributions from both telescopes, and compare the observed brightness distributions with that predicted for various population models of debris of different sizes. ♦

Design and Fabrication of DebriSat – A Representative LEO Satellite for Improvements to Standard Satellite Breakup Models

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M. VOELKER, AND T. HUYNH

This paper discusses the design and fabrication of DebriSat, a 50 kg satellite developed to be representative of a modern low Earth orbit (LEO) satellite in terms of its components, materials used, and fabrication procedures. DebriSat will be the target of a future hypervelocity impact experiment to examine the physical characteristics of debris generated after an on-orbit collision of a modern LEO satellite. One of the major ground-based satellite impact experiments used by DoD and NASA in their development of satellite breakup models was SOCIT, conducted in 1992. The target used for SOCIT was a Navy transit satellite (40 cm, 35 kg) fabricated in the 1960s. Modern satellites are very different in materials and construction techniques than those built 40 years ago. Therefore, there is a need to conduct a similar experiment using a modern target satellite to improve the fidelity of satellite breakup models. To ensure that DebriSat is truly representative of typical LEO missions, a comprehensive study of historical LEO satellite designs and missions within the past 15 years for satellites ranging from 1 kg to 5000 kg was conducted. This study identified modern trends in hardware, material, and construction practices utilized in recent LEO missions. Although DebriSat is an engineering model, specific attention is placed on the quality, type, and quantity of the materials used in its fabrication to ensure the integrity of the outcome. With the exception of software, all other aspects of the satellite's design, fabrication, and assembly integration and testing will be as rigorous as that of an actual flight vehicle. For example, to simulate survivability of launch loads, DebriSat will be subjected to a vibration test. As well, the satellite will undergo thermal vacuum tests to verify that the components and overall systems meet typical environmental standards. Proper assembly integration techniques will involve precise torqueing of fasteners, thread locking, and the use of appropriate bonding compounds. Finally, the implementation of process documentation and verification procedures is discussed to provide a comprehensive overview of the design and fabrication of this representative LEO satellite. ♦

MEETING REPORTS

The 39th COSPAR Scientific Assembly
14-22 July 2012, Mysore, India

The 2012 COSPAR was held at the state-of-the-art Infosys training facility in the historical city of Mysore, India. The program for the Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) included four space debris sessions – Debris Measurements, Debris Environment Modeling, Debris Orbital Dynamics, Debris Mitigation and Remediation. A total of 26 oral presentations and 2 posters were given by researchers during the 3-day PEDAS sessions. Highlights included optical observations of the GEO debris, orbital evolution of debris in MEO and GEO, and concepts for debris

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COSPAR Scientific Assembly

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removal. A business meeting was held at the conclusion of the PEDAS sessions to review the plan for the next COSPAR in 2014 and other PEDAS-related items. Dr. Seishiro Kibe of JAXA was elected to become the PEDAS Deputy Organizer, replacing NASA's Nicholas Johnson, in 2013.

In addition to the PEDAS activities, a special session on Cross-Disciplinary Challenges in Space Situational Awareness (SSA) was organized by the Panel on Space Weather (PSW). It included two solicited talks on advancing SSA through international coordination and a review on the Earth's small micrometeoroid and orbital debris environment. Several associated events also took place during COSPAR, including a Panel Review on SSA, Space Weather, and Space Debris Research to promote Indo-US collaboration in these areas. ♦

The 13th Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference
11-14 September 2012, Maui, Hawaii

The Advanced Maui Optical and Space Surveillance Technologies Conference was held 11-14 September. The keynote speaker for the event was the commander of Air Force Space Command, General William Shelton. Much of his talk concerned the need and proposed method for modernizing the data processing and control system at the Joint Space Operations Center, or JSpOC. New sensors such as the Space Fence and the Space Surveillance Telescope will overwhelm the current system. Also, information from non-traditional sensors has no direct path for supplying data to the current system.

Nine papers were presented during the Orbital Debris session; Thomas Schildknecht was the session chair. The first session speaker, Pat Seitzer, described spectra of debris and other near geosynchronous objects collected with one of the 6.5-m Magellan telescopes. Several papers covered orbital characteristics of the high area-to-mass ratio (HAMR) objects, which pass through the geostationary ring. Matt Hejduk and Greg Ojakangas presented NASA's Orbital Debris Program Office (ODPO) sponsored papers. Hejduk presented preliminary work aimed at developing an optical size estimation model and Ojakangas presented theoretical work on tumbling rocket bodies.

Lawrence Livermore National Laboratory presented results of a "brute force" model of the future debris environment. Their results showed a decrease in the population during the current solar cycle and increasing thereafter. This is in disagreement with LEGEND and other models' results, which show a stable environment for the next 30-50 years before collisions outpace atmospheric reentry and the debris population continues to grow.

Creon Levit from NASA Ames ended the session with a study proposing laser "nudging" of debris to avoid potential collisions.

In addition, there were orbital debris-relevant talks during other sessions of the conference, particularly in the Non-Resolved Optical Characterization session. Two poster papers from NASA ODPO were also presented. One concerned measurements and laboratory simulations of tumbling rocket bodies and the second paper looked at characterizing debris and satellites through a multi-analytical approach.

Additional sidebar meetings discussed present and future collaborations. ♦

UPCOMING MEETINGS

21-23 May 2013: The 6th IAASS Conference, Montreal, Canada

The main theme of the 6th International Association for the Advancement of Space Safety (IAASS) is "Safety is not an option." The objective of the 2013 conference is to reflect and exchange information on a number of topics in space safety and sustainability of national and international interest. Among the topics to be included in the event are "Space debris and space debris removal" and "Spacecraft re-entry safety." Abstract submission deadline is 14 December 2012. More information on the conference is available at: <http://iaassconference2013.spacesafetyfoundation.org>.

22-25 April 2013: 6th European Conference on Space Debris, Darmstadt, Germany

This major international conference will cover all disciplines in space debris research, including radar, optical, and in-situ measurements; space surveillance and catalogs; debris environment modeling; on-orbit and reentry risk assessments; orbit prediction and determination; debris mitigation and remediation; hypervelocity impacts and shielding; standardization and policies. In addition, the conference will include a special theme on the topic of active debris removal, in support of orbital debris environment remediation to ensure a long-term sustainability of near-earth space activities. Abstract submission deadline is 7 December 2012. Additional information about the conference is available at: <http://www.congrexprojects.com/13a09>.

SATELLITE BOX SCORE

(as of 3 October 2012, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	131	3595	3726
CIS	1421	4774	6195
ESA	41	45	86
FRANCE	55	437	492
INDIA	48	127	175
JAPAN	121	78	199
USA	1123	3823	4946
OTHER	597	114	711
TOTAL	3537	12993	16530

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

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INTERNATIONAL SPACE MISSIONS

1 July 2012 – 30 September 2012

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2012-035A	ECHOSTAR 17	USA	35779	35794	0.0	1	1
2012-035B	METEOSAT 10 (MSG 3)	EUMETSAT	35783	35787	1.6		
2012-036A	SES 5	LUXEMBOURG	35779	35793	0.1	1	1
2012-037A	SOYUZ-TMA 5M	RUSSIA	403	428	51.6	1	0
2012-038A	HTV-3	JAPAN	399	421	51.6	0	0
2012-039A	KANOPUS-V 1	RUSSIA	500	507	97.5	2	0
2012-039B	BKA 2	BELARUS	505	507	97.5		
2012-039C	ExactView-1	CANADA	805	822	98.9		
2012-039D	TET-1	GERMANY	504	506	97.5		
2012-039E	MKA-FKI 1	RUSSIA	804	822	98.9		
2012-040A	TIANLIAN 1-03	CHINA	35770	35802	1.9	1	0
2012-041A	COSMOS 2481	RUSSIA	1482	1511	82.5	1	0
2012-041B	GONETS M 03	RUSSIA	1479	1509	82.5		
2012-041C	YUBELEINY 2	RUSSIA	1482	1510	82.5		
2012-041D	GONETS M 04	RUSSIA	1480	1510	82.5		
2012-042A	PROGRESS-M 16M	RUSSIA	403	428	51.6	1	0
2012-043A	INTELSAT 20	INTELSAT	35778	35795	0.0	1	1
2012-043B	HYLAS 2	UK	35776	35797	0.0		
2012-044A	TELKOM 3	INDONESIA	264	4905	49.9	1	1
2012-044B	EXPRESS MD2	RUSSIA	264	4977	49.9		
2012-045A	INTELSAT 21	INTELSAT	35784	35790	0.1	1	0
2012-046A	RBSP A	USA	596	30513	9.9	1	0
2012-046B	RBSP B	USA	607	30661	9.9		
2012-047A	SPOT 6	FRANCE	697	699	98.2	1	0
2012-047B	PROITERES	JAPAN	640	657	98.3		
2012-048A	USA 238	USA	NO ELEMS. AVAILABLE			1	1
2012-048B	SMDC ONE 1.2	USA	NO ELEMS. AVAILABLE				
2012-048C	AENEAS	USA	NO ELEMS. AVAILABLE				
2012-048D	CSSWE	USA	NO ELEMS. AVAILABLE				
2012-048E	CXBN	USA	NO ELEMS. AVAILABLE				
2012-048F	CP5	USA	NO ELEMS. AVAILABLE				
2012-048G	CINEMA	USA	NO ELEMS. AVAILABLE				
2012-048H	RE	USA	NO ELEMS. AVAILABLE				
2012-048J	SMDC ONE 1.1	USA	NO ELEMS. AVAILABLE				
2012-048K	AEROCUBE 4.5A	USA	NO ELEMS. AVAILABLE				
2012-048L	AEROCUBE 4.5B	USA	NO ELEMS. AVAILABLE				
2012-048M	AEROCUBE 4	USA	NO ELEMS. AVAILABLE				
2012-049A	METOP-B	EUMETSAT	819	822	98.7	1	0
2012-050A	BEIDOU M5	CHINA	21462	21592	55.0	1	1
2012-050B	BEIDOU M6	CHINA	21477	21574	55.1		
2012-051A	ASTRA 2F	LUXEMBOURG	23968	35813	0.6	1	1
2012-051B	GSAT 10	INDIA	16399	35762	1.4		
2012-052A	VRSS-1	VENEZUELA	621	654	98.0	0	0