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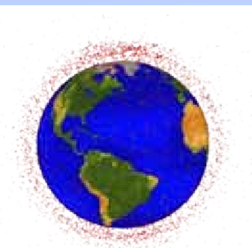

A publication of
the NASA Orbital
Debris Program Office

Reentry of NASA Satellite

Following a highly successful atmospheric monitoring mission lasting 14 years and an additional 6 years in a gradually decaying disposal orbit, NASA's Upper Atmosphere Research Satellite (UARS) finally fell back to Earth early on 24 September, GMT. The 5.7-metric-ton spacecraft (International Designator 1991-063B, U.S. Satellite Number 21701) entered the dense portion of the atmosphere at 0400 GMT over the middle of the Pacific Ocean at 14.1°S, 170.2°W.

An assessment of the survivability potential for UARS had been conducted during 2001-2002 [1]. Only 12 of 150 evaluated components were found likely to reach the surface of the Earth. Since some of these components were used up to four times on UARS, the total number of surviving debris was expected to be 26 and distributed along a path 800 km long, beginning about 500 km downrange of the atmospheric interface noted above. All surviving debris is assessed as having fallen harmlessly into the Pacific Ocean.

Reference

1. A summary of this assessment was presented at the *34th COSPAR Scientific Assembly*: Rochelle, W.C., Marichalar, J.J., and Johnson, N.L. Analysis of Reentry Survivability of UARS Spacecraft, PEDAS1-B1.4-0029-02 (2002). ♦

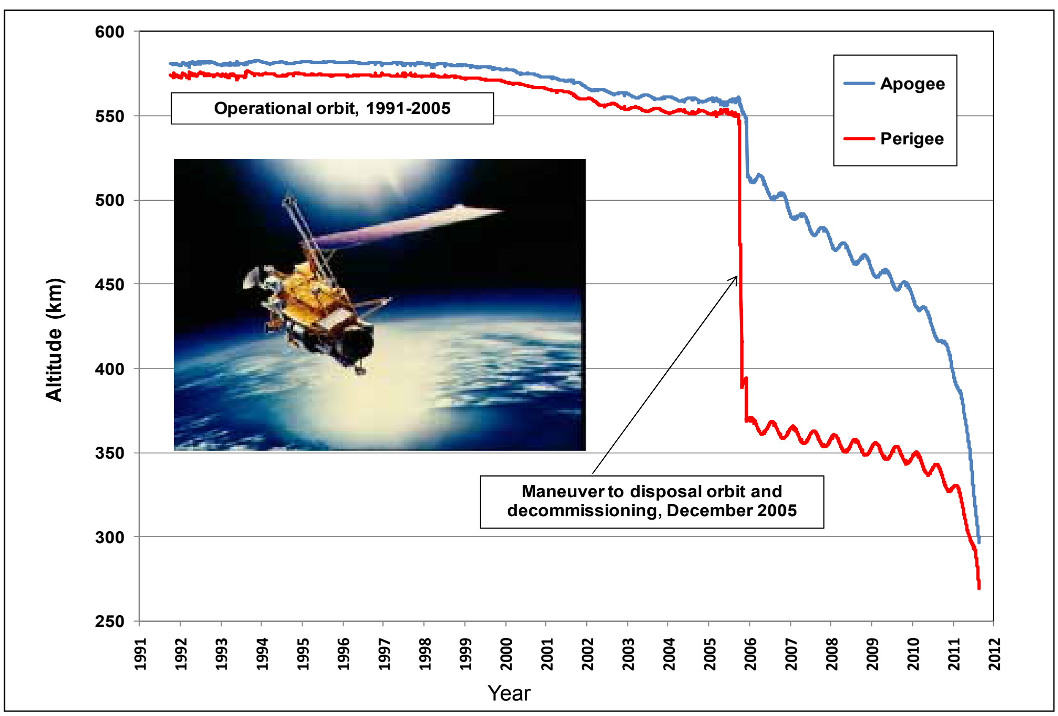

Figure 1. Orbital history of UARS.

ERS-2 Maneuvered Into Shorter-lived Disposal Orbit

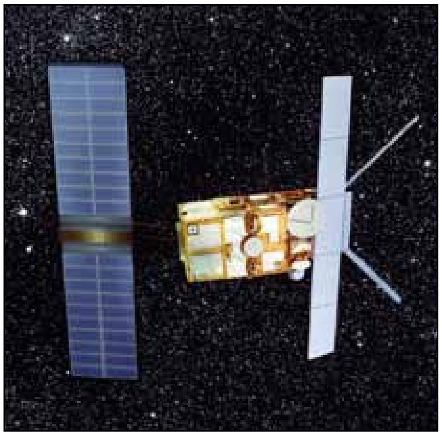

Figure 1. Illustration of ERS-2 in orbit.

The European Space Agency's (ESA) oldest dedicated Earth observation satellite completed its highly successful mission of providing surveillance of the world's oceans, land, ice, and atmosphere in July 2011 after more than 16 years in space. Known as ERS-2 (the second European Remote Sensing satellite), the spacecraft (International Designator 1995-021A, U.S. Satellite Number 23560) operated in a sun-synchronous orbit with a mean altitude near 785 km.

In accordance with ESA and international guidelines, over a period of 2 months, ERS-2 was maneuvered more than 60 times into an orbit with a mean altitude of approximately 570 km. From this orbit, the 2.1-metric-ton spacecraft is expected to fall back to Earth in about 15 years, well within the recommendation of a maximum postmission orbital lifetime of 25 years. Following the depletion of all ERS-2 propellants, the vehicle's other systems were also passivated to eliminate the potential for a future explosion and the inadvertent creation of additional orbital debris. ♦

AIAA Position Paper on Space Debris: 30 Years On

The American Institute of Aeronautics and Astronautics (AIAA) was the first body to publish a comprehensive technical and policy assessment of orbital debris issues. The 30th anniversary of that milestone paper was marked in July 2011 with many of its findings and recommendations remaining as valid today as three decades ago.

Following a presentation by NASA's Donald Kessler on "Sources of Orbital Debris and the Projected Environment for Future Spacecraft" at the May 1980 AIAA International Meeting and Technology Display [1], the AIAA Technical Committee on Space Systems undertook a formal review of the many topics associated with orbital debris. The resulting concise, 7-page treatise was formally released one year later [2]. At the time, the U.S. Space Surveillance Network was routinely tracking about 5,000 objects in orbit around the Earth; today that number has grown to over 22,000 (Figure 1).

Not surprisingly, the majority of the position paper was focused on the definition of the orbital debris environment and the potential hazards it posed to operational spacecraft, both manned and robotic. At the time very little was known about the population of debris smaller than 10 cm, the nominal sensitivity limit of the U.S. Space Surveillance Network, but much could be inferred from the more than 60 satellite explosions identified by that date and studies of debris generation in terrestrial laboratories. Already, the calculated probabilities of damaging impacts on spacecraft by man-made debris far outweighed those from natural debris (i.e., meteoroids) of the same size.

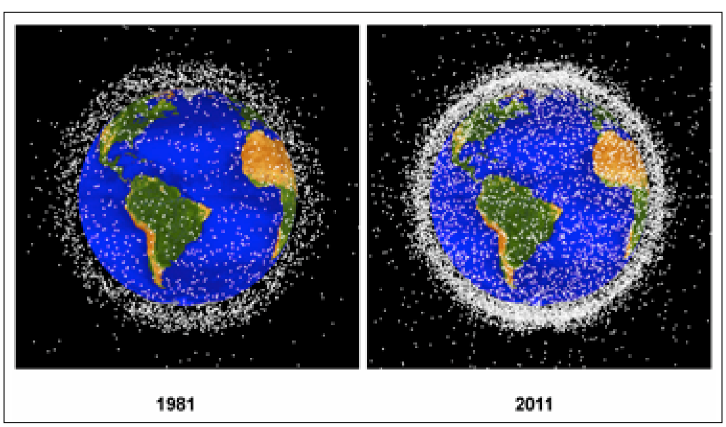

Figure 1. Despite the efforts of many space-faring nations and organizations to curtail the growth of the satellite population, which is nearly all orbital debris, near-Earth space is becoming increasingly congested.

Another section of the position paper provided a short summary of what was then being done and by whom. With the establishment in 1979 of a funded research activity at the Lyndon B. Johnson Space Center, NASA led a small group of U.S. government experts and support personnel with studies designed to characterize more completely the orbital debris environment and to predict more accurately the threat of hazardous collisions. The paper noted that operational procedures were being modified to reduce the probability of collision with debris and that, with sound planning decisions, the problem of space debris was to some degree controllable.

The AIAA Position Paper on Space Debris then listed five fundamental policy and procedural questions which needed to be addressed:

> "Should a policy be adopted that requires all spacecraft to be boosted out of geostationary orbit at the end of useful life?
>
> "Should a policy be adopted to regulate which objects may be left in long-life orbits?
>
> "If the on-orbit debris hazard becomes significant, will the use of collision avoidance systems relieve the problem?
>
> "If the on-orbit debris hazard becomes significant, will the employment of impact protection (bumpers) relieve the problem? and
>
> "What are the implications of anti-satellite operations?"

All of these questions are still pertinent today, and most have been answered with

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AIAA Paper

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national and international orbital debris mitigation guidelines.

The AIAA summarized its position with several points, including (1) the collision hazard posed by space debris was real but not severe, (2) space debris issues should be faced by all space users and coordinated action should be taken immediately, and (3) satellite shields and collision avoidance were useful, but constraining the generation of further debris was of greater importance. The paper also underscored the need for an international dialog to be initiated on the space debris issue with the goal of forming responsible groups to coordinate research and to recommend policy, and concluded with a call for corrective action "now to forestall the development of a serious problem in the future."

Although the magnitude of the orbital debris population has grown considerably since 1981, the framers of the original AIAA position paper on space debris should be satisfied that much has been done internationally, both by national governments and commercial entities, to curtail the generation of long-lived orbital debris. The on-going activities of the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations attest to the seriousness that the topic of space debris is now given.

References

1. Kessler, D.J. Sources of Orbital Debris and the Projected Environment for Future Spacecraft, *AIAA International Meeting and Technology Display,* AIAA-80-0855 (1980).

2. Anom., Space Debris, A Position Paper, *American Institute of Aeronautics and Astronautics* (1981). ♦

DoD-NASA Orbital Debris Removal Workshop

The Space Policy Office of the Under Secretary of Defense (Policy) organized and hosted a DoD-NASA Orbital Debris Removal Workshop at the Pentagon on 29 August 2011. The objectives of the event were to coordinate DoD and NASA activities in support of the 2010 National Space Policy direction on orbital debris removal, to identify potential debris removal technology options across DoD and NASA, and to foster a collaborative environment between NASA and DoD for orbital debris technology synergies.

Major General Jay Santee (USAF, Principal Director, Office of the Secretary of Defense – Space Policy) and Mr. John F. Hall, Jr. (Director, Export Control & Interagency Liaison Division, NASA/HQ) provided opening remarks at the beginning of the meeting. A total of 10 presentations were given by NASA and DoD personnel and 1 private company during the day-long workshop. The presentations focused on various technical approaches for active debris removal (ADR) and the challenges ahead. An open discussion on technical and policy issues also took place before the end of the meeting. This debris removal workshop was a follow-on to the NASA/DoD Meeting on ADR organized by the NASA Orbital Debris Program Office on 2 March 2011 (ODQN, April 2011, p. 2). Both events represent a trend for NASA and DoD to initiate collaborative efforts and pave the way for further joint activities in the future. ♦

HIMS at NASA's 2011 Desert Research and Technologies Studies

The Habitat particle Impact Monitoring System (HIMS) again participated in NASA's Desert Research and Technologies Studies (D-RATS) this year. The 2011 D-RATS activities took place at the Black Point Lava Flow, north of Flagstaff, AZ. While last year's activities focused on concept validation and impact data collection (see "Habitat Particle Impact Monitoring System," ODQN, October 2010, p. 4), this year's objective was the demonstration of a complete end-to-end system, including a HIMS stand-alone unit and a separate unit integrated with the Habitat Demonstration Unit (HDU) infrastructure. Figure 1 shows the HDU configured with the Deep Space Habitat (DSH) main module, the Dust-mitigation Module, the Hygiene Module, and the X-Hab Loft. The piezoelectric, polyvinylidene fluoride

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Figure 1. The HDU in its 2011 configuration. The main DSH module is an upgraded version of the 2010 Pressurized Excursion Module. The arrow indicates the center of the rectangular pattern defined by the HIMS sensors.

HIMS

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vibration sensors are unchanged from their 2010 configuration. Sets of four sensors are located at the corners of a rectangular pattern beneath the window in DSH Segment D. One set is attached to the inside of the DSH fiberglass shell, one set to the outside of the shell, and one set to the outside of the foam insulation that covers the outside of the shell. The DSH has been rotated 180° relative to its 2010 configuration, so Segment D is now on the front of the HDU, facing the side of the entrance ramp.

Figure 2. The HDU Crew Display iPad, showing the HIMS alert screen. Impact locations are highlighted on the images while numerical results appear in a scrolling table.

Figure 3. The air gun supported in its tripod-mounted cradle. The red-edged box in the forward part of the cradle is the ballistic chronometer.

Using the extensive impact and background noise data gathered last year, the HIMS team implemented a multilateration algorithm in the software. This technique locates the source of the impact based on differences in signal arrival times at the different sensor locations. Using the test signals recorded during the 2010 D-RATS, the HIMS software demonstrated a location accuracy of about 8 cm. Impact severity is a function of the total energy contained in the signal. An absolute measure of severity (e.g., degree of penetration) can be defined for the specific surface/material. The HDU avionics team integrated the HIMS software with the HDU Caution/Warning system, sending impact alerts to the Crew Display (a tablet computer; see Figure 2). The stand-alone HIMS unit also ran in parallel on the separate HIMS portable computer during the tests. MMOD impacts were again simulated using a 10-pump pneumatic rifle firing steel BBs. The gun was supported by a tripod-mounted cradle (Figure 3), which also held the ballistic chronometer. This device (using the projectile's time of flight between two photocells) allowed measurement of the speed of each individual test shot.

Check-out tests performed on HDU Practice Day 2 showed a poor response of both the integrated and stand-alone systems. Analysis of the results indicated the HIMS software performed as expected but was limited by low signal preamplifier gain and network communication bottle-necks. Swapping the preamp for a higher-gain model considerably improved system performance. Crewed tests on HDU Test Day 2 yielded excellent performance of the stand-alone system. The integrated system still suffered from extreme network lag due to much higher than expected data transfer requirements that plagued other HDU systems, as well.

With the successful demonstration of the HIMS, and many lessons learned from the HDU activities during D-RATS, this project will move forward in testing and developing a system to detect and characterize debris impacts on crewed space vehicles and multilayer inflatable structures. ♦

PROJECT REVIEW

Proper Implementation of the 1998 NASA Breakup Model

P. KRISKO

The NASA Breakup Model for on-orbit explosions and collisions was significantly updated in 1998 and is still in use by the NASA Orbital Debris Program Office today. The major details of the model were published in Johnson et al., 2001 [1]. They include a description of the use of fragment characteristic length (size) as the independent variable (in lieu of fragment mass), linking the model to the observable quantity of size of an orbiting object. An area-to-mass distribution is applied to small fragments based on a NASA empirical dataset. Explosion and collision fragment observations from both on-orbit and ground-test events are used to derive fragment characteristic length and delta-velocity distributions.

Over the intervening years five international space agencies have successfully implemented the 1998 NASA Breakup Model. Several other agencies and groups, both inside and outside the United States, are investigating its use. The NASA Orbital Debris Program Office has assisted a number of these groups in the implementation process, and in a few cases found a common initial misunderstanding as to the mass conservation standard applied in the model. What follows is clarification of that process for both on-orbit explosions and collisions with reference to the descriptions in Johnson et al., 2001.

Past confusions of mass conservation appear to lie in the treatment of the fragment characteristic length (Lc) distributions. These are derived from ground-test and on-orbit fragmentation events. The NASA Breakup Model deposits fragment of Lc from 1 mm to over 1 m. For explosions the number of fragments of size Lc or larger, in meters, is governed by the following power law,

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NASA BU Model

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$$N(L_c)\ [-] = S * 6 * (L_c[m]/1[m])^{-1.6} \quad (1)$$

with S as an empirically derived unitless factor between 0.1 and 1 that is dependent on explosive body type. For collisions the relationship is,

$$N(L_c)\ [-] = 0.1 * (M[kg]/1[kg])^{0.75} * (L_c[m]/1[m])^{-1.71} \quad (2)$$

with the mass in kg, M, derived empirically for catastrophic collisions, as the sum of total mass of both colliding objects, the more massive target, M_t, and the less massive projectile, M_p,

$$M\ [kg] = M_t\ [kg] + M_p\ [kg] \quad (3)$$

For non-catastrophic collisions only a portion of the mass is involved in the collision. Most cases include a large target that is cratered by a much smaller projectile that is completely fragmented. With the relative impact velocity, v_{imp}, in km/s the empirical relationship is,

$$M\ [kg] = M_p[kg] * (v_{imp}\ [km/s]/1[km/s])^2 \quad (4)$$

These power laws extend from 1 mm to over 1 m. In all fragmentation cases the mass must, of course, be conserved. This is achieved by relying on observations of fragmentation dynamics. For example, in the derivation of Equation 1, seven on-orbit explosions from 600-1000 kg upper stages were studied. Figure 1, taken from Johnson et al., 2001, displays their initial fragment clouds with respect to Equation 1. In the region above 1 m the data shows the deposit of several large pieces that do not necessarily follow the power law distribution. These would realistically be larger, more massive components farther from the explosion center (e.g., remnants of equipment shelves, pressurant tanks, nozzle bells, etc.). In fact these fragments account for the bulk of fragment mass. Based on this understanding, the correct implementation of the 1998 NASA Breakup Model includes the distribution of fragments from 1 mm to 1 m following the power law distribution in Equation 1, with an additional two to eight large fragments after 1 m, keeping mass conserved as showed by example in Figure 2.

Likewise, large collision fragments are modeled based on the requirements for mass conservation and on observations of large fragments in catastrophic collisions, and the cratering of large targets by destroyed small projectiles in non-catastrophic collisions. As illustrated in Figure 3, catastrophic collision fragments are deposited from 1 mm upward along that collisional characteristic length distribution until the bin before 1 m. The total mass, $M = M_t + M_p$, is achieved through deposit of several large fragments on that last bin. Non-catastrophic collision fragments are deposited from 1 mm upward until the total mass, $M = M_p * v_{imp}^2$, is achieved. The final fragment is deposited in a single massive fragment reminiscent of a cratered target mass.

Reference

1. Johnson, N.L., Krisko, P.H., Liou, J.-C., et al. NASA'S new breakup model of EVOLVE 4.0, *Adv. Space Res.*, **28**(9), 1377-1384 (2001). ♦

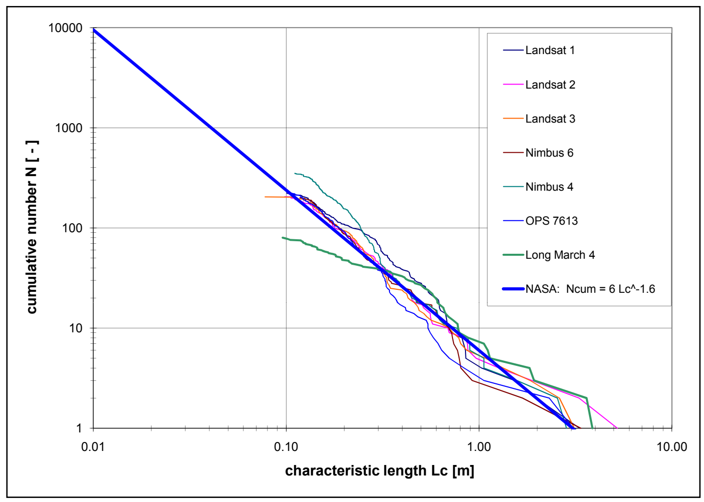

Figure 1. Observed characteristic length distributions of cataloged fragments from seven upper stage breakups used in the 1998 NASA Breakup Model (reprinted from Johnson et al., 2001).

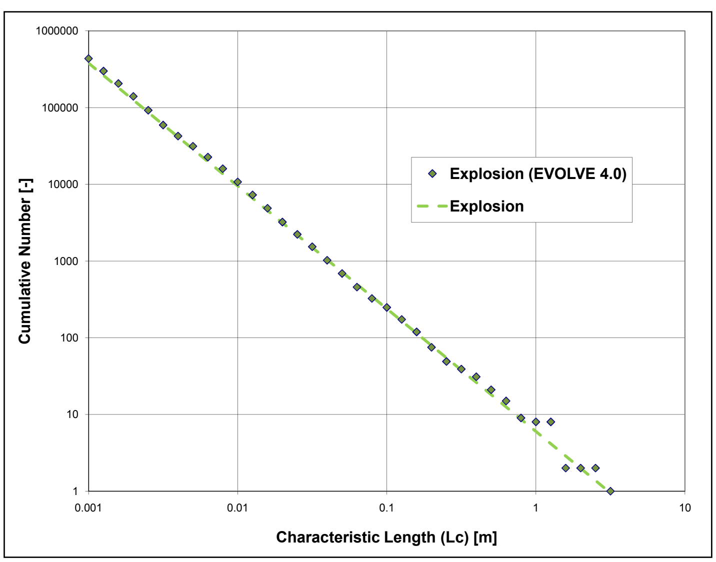

Figure 2. Explosion fragment distribution (1000 kg upper stage), as modeled by the 1998 NASA Breakup Model, compared to the full power law distribution.

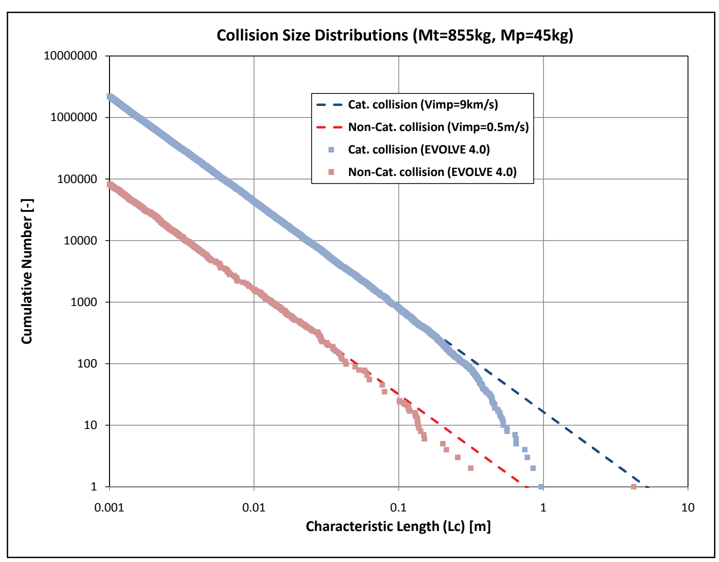

Figure 3. Collision fragment distributions (Mt = 855 kg, Mp = 45 kg) for sample catastrophic and non-catastrophic collisions, as modeled by the 1998 NASA Breakup Model, compared to the full power law distributions.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

12th Annual Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)
13-16 September 2011, Maui, HI

Toward Realistic Dynamics of Rotating Orbital Debris, and Implications for Light Curve Interpretation

G. OJAKANGAS AND N. HILL

Optical observations of rotating space debris near GEO contain important information on size, shape, composition, and rotational states, but these aspects are difficult to extract due to data limitations and the high number of degrees of freedom in the modeling process. For tri-axial rigid debris objects created by satellite fragmentations, the most likely initial rotation state has a large component of initial angular velocity directed along the intermediate axis of inertia, leading to large angular reorientations of the body on the timescale of the rotation period. This lends some support to the simplest possible interpretation of light curves -- that they represent sets of random orientations of the objects of study. However, effects of internal friction and solar radiation are likely to cause significant modification of rotation states within a time as short as a few orbital periods. In order to examine the rotational dynamics of debris objects under the influences of these effects, a set of seven first-order coupled equations of motion were assembled in state form: three are Euler equations describing the rates of change of the components of angular velocity in the body frame, and four describe the rates of change of the components of the unit quaternion. Quaternions are a four-dimensional extension of complex numbers that form a seamless, singularity-free representation of body orientation on S3. The Euler equations contain explicit terms describing torque from solar radiation in terms of spherical harmonics, and terms representing effects of a prescribed rate of internal friction. Numerical integrations of these equations of motion are being performed, and results will be presented. Initial tests show that internal friction without solar radiation torque leads to rotation about the maximum principal axis of inertia, as required, and solar radiation torque is expected to lead to spin-up of objects. Because the axis of maximum rotational inertia tends to be roughly coincident with the normal to the largest projected cross-sectional area, internal friction is expected to lead to reduced variation of light curve amplitudes at a given phase angle, but a large dependence of the same on phase angle. At a given phase angle, databases are generated which contain reflected intensities for comprehensive sets of equally-likely orientations, represented as unit quaternions. When projected onto three dimensions (S2) and color-coded by intensity, the set is depicted as points within a solid, semi-transparent unit sphere, within which all possible reflected intensities for an object at a given phase angle may be inspected simultaneously. Rotational sequences are represented by trajectories through the sphere. Databases are generated for each of a set of phase angles separately, forming a comprehensive dataset of reflected intensities spanning all object orientations and solar phase angles. Symmetries in the problem suggest that preferred rotation states are likely, defined relative to the object-sun direction in inertial space and relative to the maximum principal axis of inertia in the body coordinate system. Such rotation states may greatly simplify the problem of light curve interpretation by reducing the number of degrees of freedom in the problem. ♦

A Search for Optically Faint GEO Debris

P. SEITZER, S. LEDERER, E. BARKER, H.COWARDIN, K. ABERCROMBY, J. SILHA

Existing optical surveys for debris at geosynchronous orbit (GEO) have been conducted with meter class telescopes, which have detection limits in the range of 18th-19th magnitude. We report on a new search for optically faint debris at GEO using the 6.5-m Magellan 1 telescope 'Walter Baade' at Las Campanas Observatory in Chile. Our goal is to go as faint as possible and characterize the brightness distribution of debris fainter than R = 20th magnitude, corresponding to a size smaller than 10 cm assuming an albedo of 0.175. We wish to compare the inferred size distribution for GEO debris with that for LEO debris.

We describe results obtained during 9.4 hours of observing time during 25-27 March 2011. We used the IMACS f/2 instrument, which has a mosaic of 8 CCDs, and a field of view of 30 arc-minutes in diameter. This is the widest field of view of any instrument on either Magellan telescope. All observations were obtained through a Sloan r' filter. The limiting magnitude for 5 second exposures is estimated to be fainter than 22.

With this small field of view and the limited observing time, our objective was to search for optically faint objects from 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 (SSN # 25001 and 33519) with the 6.5-m telescope, followed by a survey for objects on similar orbits but with a spread in mean anomaly.

To detect bright objects over a wider field of view (1.6x1.6 degrees), we observed the same field centers at the same time through a similar filter with 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 describe our experiences using Magellan, a telescope never used previously for orbital debris research, and our initial results. ♦

The 62nd International Astronautical Congress (IAC) 3-7 October 2011, Cape Town, South Africa

A New Look at the Geo and Near-Geo Regimes: Operations, Disposals, and Debris

N. JOHNSON

Since 1963 more than 900 spacecraft and more than 200 launch vehicle upper stages have been inserted into the vicinity of the geosynchronous regime. Equally important, more than 300 spacecraft have been maneuvered into disposal orbits at mission termination to alleviate unnecessary congestion in the finite GEO region. However, the number of GEO satellites continues to grow, and evidence exists of a substantial small debris population. In addition, the operational modes of an increasing number of GEO spacecraft differ from those of their predecessors of several decades ago, including more frequent utilization of inclined and eccentric geosynchronous orbits. Consequently, the nature of the GEO regime and its immediate surroundings is evolving from well-known classical characteristics. This paper takes a fresh look at the GEO satellite population and the near-and far-term environmental implications of the region, including the effects of national and international debris mitigation measures. ♦

Space Debris: A 50-year Retrospective and a Look Forward

N. JOHNSON

The year 2011 marks the 50th anniversary of the first known explosion of a man-made satellite in orbit about the Earth. After more than 200 additional fragmentations and countless other debris-generating events, today the planet is surrounded by more than 22,000, rapidly moving, large debris and millions of smaller, but still hazardous, orbital particles. Terrestrial and in-situ sensors have identified debris in low and high altitude orbits ranging from tens of microns to tens of meters in size, none of which existed prior to the space age. The first accidental, high-speed collision between two spacecraft in 2009 underscored the worsening condition of near-Earth space, while simultaneously foreshadowing a much less benign future unless all space-faring organizations redouble their efforts for the mitigation and potentially the removal of space debris. The creation of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 and the adoption by the United Nations of Space Debris Mitigation Guidelines in 2007 have been important milestones in the international recognition of and response to the challenge of the long-term sustainability of activities in outer space. ♦

Demonstration of a Particle Impact Monitoring System for Crewed Space Exploration Modules

J. N. OPIELA, J.-C. LIOU, R. CORSARO, F. GIOVANE

When micrometeorite or debris impacts occur on a space habitat, crew members need to be quickly informed of the likely extent of damage and be directed to the impact location for possible repairs. The goal of the Habitat Particle Impact Monitoring System (HIMS) is to develop a fully automated, end-to-end particle impact detection system for crewed space exploration modules, both in space and on the surfaces of Solar System bodies. The HIMS uses multiple thin film piezo-polymer vibration sensors to detect impacts on a surface, and computer processing of the acoustical signals to characterize the impacts. Development and demonstration of the HIMS is proceeding in concert with NASA's Habitat Demonstration Unit (HDU) Project. The HDU Project is designed to develop and test various technologies, configurations, and operational concepts for exploration habitats.

This paper describes the HIMS development, initial testing, and HDU integration efforts. Initial tests of the system on the HDU were conducted at NASA's 2010 Desert Research and Technologies Studies (Desert-RATS). Four sensor locations were assigned near the corners of a rectangular pattern. To study the influence of wall thickness, three sets of four sensors were installed at different layer depths: on the interior of the PEM wall, on the exterior of the same wall, and on the exterior of a layer of foam insulation applied to the exterior wall. Once the system was activated, particle impacts were periodically applied by firing a pneumatic pellet gun at the exterior wall section. Impact signals from the sensors were recognized by a data acquisition system when they occurred, and recorded on a computer for later analysis. Preliminary analysis of the results found that the HIMS system located the point of impact to within 8 cm, provided a measure of the impact energy/damage produced, and was insensitive to other acoustic events. Based on this success, a fully automated version of this system will be completed and demonstrated as part of a crew "Caution/Warning" system at the 2011 Desert-RATS, along with a crew response procedure. ♦

Simultaneous Multi-filter Optical Photometry of GEO Debris

P. SEITZER, H. COWARDIN, E. BARKER, K. ABERCROMBY, T. KELECY

Information on the physical characteristics of unresolved pieces of debris comes from an object's brightness, and how it changes with time and wavelength. True colors of tumbling, irregularly shaped objects can be accurately determined only if the intensity at all wavelengths is measured at the same time. In this paper we report on simultaneous photometric observations of objects at geosynchronous orbit (GEO) using two telescopes at Cerro Tololo Inter-American Observatory (CTIO). The CTIO/SMARTS 0.9-m observes in a Johnson B filter, while the 0.6-m MODEST (Michigan Orbital DEbris Survey Telescope) observes in a Cousins R filter.

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Optical Photometry of GEO Debris
continued from page 7

The two CCD cameras are electronically synchronized so that the exposure start time and duration are the same for both telescopes. Thus we obtain the brightness as a function of time in two passbands simultaneously, and can determine the true color of the object at any time. We will report here on such calibrated measurements made on a sample of GEO objects and what is the distribution of the observed B-R colors.

In addition, using this data set, we will show what colors would be observed if the observations in different filters were obtained sequentially, as would be the case for conventional imaging observations with a single detector on a single telescope.

Finally, we will compare our calibrated colors of GEO debris with colors determined in the laboratory of selected materials actually used in spacecraft construction. ♦

The 5th International Association for the Advancement of Space Safety (IAASS) Conference 17-19 October 2011, Versailles-Paris, France

Evaluating and Addressing Potential Hazards of Fuel Tanks Surviving Atmospheric Reentry

R. KELLEY, N. JOHNSON

In order to ensure reentering spacecraft do not pose an undue risk to the Earth's population, it is important to design satellites and rocket bodies with end-of-life considerations in mind. In addition to the possible consequences of deorbiting a vehicle, consideration must be given to the possible risks associated with a vehicle failing to become operational or reach its intended orbit. Based on recovered space debris and numerous reentry survivability analyses, fuel tanks are of particular concern in both of these considerations. Most spacecraft utilize some type of fuel tank as part of their propulsion systems. These fuel tanks are most often constructed using stainless steel or titanium and are filled with potentially hazardous substances such as hydrazine and nitrogen tetroxide. For a vehicle which has reached its scheduled end-of-mission, the contents of the tanks are typically depleted. In this scenario, the likely survival of a stainless steel or titanium tank during reentry poses a risk to people and property due to the high melting point and large heat-of-ablation of these materials. If a large portion of the fuel is not depleted prior to reentry, there is the added risk of a hazardous substance being released when the tank impacts the ground. This paper presents a discussion of proactive methods which have been utilized by NASA satellite projects to address the risks associated with fuel tanks reentering the atmosphere. In particular, it will address the design of a demiseable fuel tank, as well as the evaluation of fuel tank designs which are selected to burst during reentry. ♦

Empirical Tests of the Predicted Footprint for Uncontrolled Satellite Reentry Hazards

M. MATNEY

A number of statistical tools have been developed over the years for assessing the risk of reentering objects to human populations. These tools make use of the characteristics (e.g., mass, material, shape, size) of debris that are predicted by aerothermal models to survive reentry. The statistical tools use this information to compute the probability that one or more of the surviving debris might hit a person on the ground and cause one or more casualties.

The statistical portion of the analysis relies on a number of assumptions about how the debris footprint and the human population are distributed in latitude and longitude, and how to use that information to arrive at realistic risk numbers. Because this information is used in making policy and engineering decisions, it is important that these assumptions be tested using empirical data.

This study uses the latest database of known uncontrolled reentry locations measured by the United States Department of Defense.

The predicted ground footprint distributions of these objects are based on the theory that their orbits behave basically like simple Kepler orbits. However, there are a number of factors in the final stages of reentry - including the effects of gravitational harmonics, the effects of the Earth's equatorial bulge on the atmosphere, and the rotation of the Earth and atmosphere - that could cause them to diverge from simple Kepler orbit behavior and possibly change the probability of reentering over a given location. In this paper, the measured latitude and longitude distributions of these objects are directly compared with the predicted distributions, providing a fundamental empirical test of the model assumptions. ♦

Renewable Energy and the Environment: OSA Optics and Photonics Congress 2-3 November 2011, Austin, TX

Observations of Human-made Debris in Earth Orbit

H. COWARDIN

Pollution is generally considered to be contaminants of Earth's surface, hydrosphere and atmosphere, but there is another problem overhead, everyday: space debris. This paper discusses observational methods used to characterize the growing debris population. ♦

ABSTRACTS FROM THE NASA HYPERVELOCITY IMPACT TECHNOLOGY GROUP

The 62nd International Astronautical Congress (IAC), 3-7 October 2011, Cape Town, South Africa

Shuttle Hypervelocity Impact Database

J. HYDE, E. CHRISTIANSEN, D. LEAR

NASA has inspected the Shuttle for micrometeoroid and orbital debris (MMOD) impacts since the early 1990s, resulting in a Shuttle MMOD impact database with over 2800 entries. The data is currently divided into tables for crew module windows, payload bay door radiators and thermal protection system regions, with window impacts compromising just over half the records. In general, the database provides dimensions of hypervelocity impact damage, a "component level" location (i.e., window number or radiator panel number) and the orbiter mission when the impact occurred. Additional detail on the type of particle that produced the damage site is provided when sampling data and definitive analysis results are available.

The paper will provide details and insights on the contents of the database including examples of descriptive statistics using the impact data. A discussion of post flight impact damage inspection and sampling techniques that were employed during the different observation campaigns will be presented.

Future work to be discussed will be possible enhancements to the database structure and availability of the data for other researchers. A related database of ISS returned surfaces that are under development will also be introduced. ♦

MEETING REPORT

The 12th Annual Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), 13-16 September 2011, Maui, HI, USA

The 12th Annual AMOS Conference was held from 13 – 16 September 2011. Organized in part by the Air Force Research Laboratory and the Maui Economic Development Board, the AMOS conference is an important forum for Space Situational Awareness (SSA) topics, including many that relate directly or indirectly to orbital debris.

Focusing on how non-resolved object characterization, optical systems, orbital debris, and space-based assets all play an important role in SSA; possible collaboration efforts between projects were emphasized.

Colonel L. K. Lewis and General W. L. Shelton gave the keynote addresses. The conference sessions began with SSA topics, followed by Non-Resolved Object Characterization. In this second session, papers included "Use of Light Curve Inversion for Non-Resolved Optical Detection of Satellites" (L. Scott) and "Cylindrical RSO Signatures, Spin Axis Orientation and Rotation Period Determination" (P. Somers). G. Ojakangas presented a model on "Toward Realistic Dynamics of Rotating Orbital Debris and Implications for Lightcurve Interpretation" using quaternions and D. Hall discussed "AMOS Galaxy 15 Satellite Observations and Analysis – the GEO zombie satellite."

On the following day, the session continued with "Fingerprinting of Non-resolved Three-axis Stabilized Space Objects Using a Two-Facet Analytical Model" (A. Chaudhary) and "Understanding Satellite Characterization Knowledge Gained from Radiometric Data" (A. Harms). M. Hejduk's paper on "Specular and Diffuse Components in Spherical Satellite Photometric Modeling" showed possibilities for different phase functions that provide a better fit to orbital debris than the current Lambertian assumption for optical measurements. Major D. Bedard presented a poster and paper on "Measurement of the Photometric and Spectral BRDF of Small Canadian Satellites in a Controlled Environment," as well as investigations into space weathering.

The session on orbital debris was chaired by E. Stansbery and included papers on "Pan-STARRS Status & GEO Observation Results" (M. Bolden); "A Search for Optically Faint GEO Debris" (P. Seitzer); "Effective Search Strategies for Break-up Fragments in GEO" (T. Hanada); "A New Orbital Analyst Tool for Associating Un-Cataloged Analyst Debris with Their Sources" (B. Bowman); and "Commercially-Hosted Payloads for Debris Monitoring" (Lt Col J. Shell).

Panel discussions were held on Space Debris Observation Status and Needs and on Future Directions for Collaborative SSA.

The AMOS conference was attended by over 630 participants and representation from 9 countries. ♦

UPCOMING MEETING

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

The theme for the space debris sessions for the 39th COSPAR is "Steps toward Environment Control." Topics to be included during the sessions are advances in ground- and space-based surveillance and tracking, in-situ measurement techniques, debris and meteoroid environment models, debris flux and collision risk for space missions, on-orbit collision avoidance, re-entry risk assessments, debris mitigation and debris environment remediation techniques and their effectiveness with regard to long-term environment stability, national and international debris mitigation standards and guidelines, hypervelocity impact technologies, and on-orbit shielding concepts. Additional information of the event can be found at http://www.cospar-assembly.org/.

SATELLITE BOX SCORE
(as of 05 October 2011, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	109	3515	3624
CIS	1412	4661	6073
ESA	39	44	83
FRANCE	49	437	486
INDIA	45	130	175
JAPAN	116	71	187
USA	1154	3709	4863
ALL OTHERS	504	113	617
TOTAL	3428	12680	16108

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INTERNATIONAL SPACE MISSIONS
1 July 2011– 30 September 2011

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2011-030A	SJ-11-03	CHINA	691	703	98.2	1	4
2011-031A	STS 135	USA	371	385	51.6	0	0
2011-031B	PSSC-2	USA	345	352	51.6		
2011-032A	TIANLIAN 1-02	CHINA	35772	35802	0.9	1	0
2011-033A	GLOBALSTAR M083	GLOBALSTAR	918	934	52.0	1	0
2011-033B	GLOBALSTAR M088	GLOBALSTAR	1413	1415	52.0		
2011-033C	GLOBALSTAR M091	GLOBALSTAR	1413	1414	52.0		
2011-033D	GLOBALSTAR M085	GLOBALSTAR	915	932	52.0		
2011-033E	GLOBALSTAR M081	GLOBALSTAR	1102	1179	52.0		
2011-033F	GLOBALSTAR M089	GLOBALSTAR	915	933	52.0		
2011-034A	GSAT 12	INDIA	35761	35813	0.0	1	0
2011-035A	SES 3	LUXEMBOURG	35775	35798	0.0	1	1
2011-035B	KAZSAT 2	KAZAKHSTAN	35784	35789	0.1		
2011-036A	NAVSTAR 66 (USA 232)	USA	20179	20185	55.0	1	0
2011-037A	SPEKTR R	RUSSIA	15164	325078	69.1	1	5
2011-038A	BEIDOU IGSO 4	CHINA	35704	35871	55.2	1	0
2011-039A	SJ-11-02	CHINA	687	706	98.1	1	4
2011-040A	JUNO	USA	HELIOCENTRIC			0	0
2011-041A	ASTRA 1N	LUXEMBOURG	35722	35729	0.0	1	1
2011-041B	BSAT-3C	JAPAN	35785	35789	0.0		
2011-042A	PAKSAT 1R	PAKISTAN	35778	35792	0.1	1	0
2011-043A	HAIYANG 2A	CHINA	965	968	99.4	1	0
2011-044A	EDUSAT	ITALY	641	697	98.3	1	2
2011-044B	NIGERIASAT 2	NIGERIA	692	729	98.3		
2011-044C	NIGERIASAT X	NIGERIA	657	698	98.3		
2011-044D	RASAT	TURKEY	667	699	98.3		
2011-044E	APRIZESAT 5	USA	611	697	98.3		
2011-044F	APRIZESAT 6	USA	628	697	98.3		
2011-044G	SICH 2	UKRAINE	684	704	98.3		
2011-044H	BPA-2/SL-24	RUSSIA	691	1296	98.2		
2011-045A	EXPRESS AM-4	RUSSIA	683	20331	51.1	1	1
2011-046A	GRAIL A	USA	LUNAR ORBIT			0	0
2011-046B	GRAIL B	USA	LUNAR ORBIT				
2011-047A	CHINASAT 1A	CHINA	35782	35791	0.6	1	0
2011-048A	COSMOS 2473	RUSSIA	35738	35780	0.1	1	1
2011-049A	SES 2	LUXEMBOURG	35779	35794	0.1	1	1
2011-049B	ARABSAT 5C	ARABSAT	35808	35919	0.1		
2011-050A	IGS 6A	JAPAN	588	591	97.7	1	2
2011-051A	ATLANTIC BIRD 7	EUTELSAT	35783	35789	0.0	1	0
2011-052A	TACSAT 4	USA	749	12001	63.6	1	0
2011-053A	TIANGONG 1	CHINA	335	348	42.8	1	4
2011-054A	QUETZSAT 1	MEXICO	35722	35798	0.1	1	1