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Inside...

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First Satellite Breakups of 2006

The first significant breakup of a satellite in Earth orbit in nearly a year occurred on 4 May 2006 when a 20-year-old Soviet rocket body fragmented without warning. This was the fifth time since 1988 that a launch vehicle orbital stage of this type experienced a spontaneous explosion after spending many years in a dormant state. A little more than a month later, a Russian Proton fourth stage ullage motor broke-up, the 34th on-orbit fragmentation of this component type since 1984.

A Tsyklon third stage (International Designator 1985-108B, U.S. Satellite Number 16263) had been used to insert Cosmos 1703 into an orbit of 635 km by 665 km with an inclination of 82.5°. At the time of the May breakup, the orbit of the rocket body had decayed slightly to about 610 km by 640 km, and the vehicle was flying over northern Scandinavia.

More than 50 debris were large enough (> 5 cm) to be tracked by the U.S. Space Surveillance Network (SSN). Of these, 49 had been officially cataloged by mid-June. The accompanying figure indicates the orbits of 44 debris, including the main remnant of the orbital stage, about one week after the event.

Although the lowest perigees were greater than 500 km, some of the debris exhibited significant decay rates, indicating that their area-to-mass ratios were noticeably higher than typical debris. Nine debris had already reentered by mid-June, and a total of two dozen or more debris are expected to reenter by mid-August. Consequently, the overall effect of the breakup on the near-Earth environment should be minor.

The cause of the breakup of the previous four stages of this type has been linked to the presence of residual propellants (NASA JSC Technical

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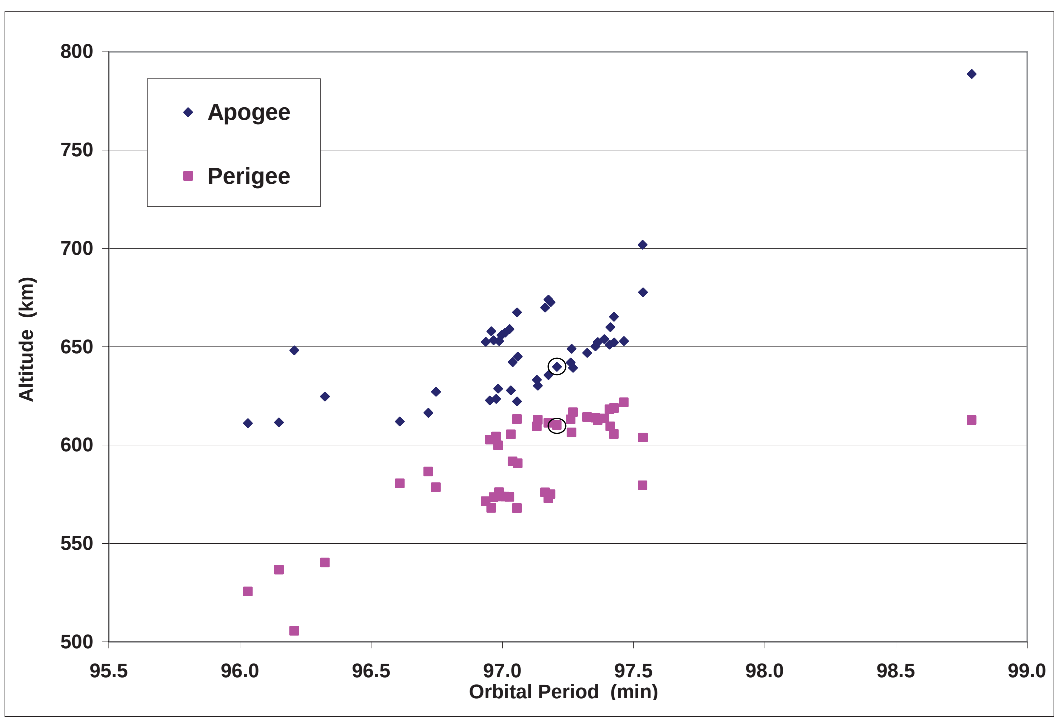

Debris cloud (44 pieces) of the Tsyklon third stage six days after it broke-up on 4 May 2006. The main remnant of the stage is highlighted with circles.

Satellite Breakups

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Publication 62530, *History of On-Orbit Satellite Fragmentations, 13th edition*). The Tsyklon third stages, with a dry mass of about 1360 kg, used hypergolic propellants, namely nitrogen tetroxide and unsymmetrical dimethylhydrazine. A mixture or over-pressurization of these propellants could lead to a tank rupture.

On 10 June, a 17-year-old ullage motor from a Russian Proton launch vehicle broke-up in an elliptical orbit of 655 km by 18,410 km with an inclination of 65.1°. This is the 34th identified breakup of a motor of this type, which also employs hypergolic propellants. More than 70 debris were detected after the event, but due to the nature of the eccentric orbit the official cataloging process will take time. This ullage motor was flown before Russian officials were aware of the breakup potential of the component and could implement mitigation measures.

A much less severe debris-generating event apparently occurred on 14 February 2006, when a single fragment separated from the fifth oldest man-made object in Earth orbit, the Vanguard 3 spacecraft (International Designator 1959-007A, U.S. Satellite Number 20). Unlike Vanguards 1 and 2, which are also still in orbit about the Earth, Vanguard 3 remains attached to the small third stage of its launch vehicle. The combined mass of the spacecraft and stage is only 45 kg. The new piece of debris was cataloged in April 2006 (International Designator 1959-007B, U.S. Satellite Number 29005) in an orbit very similar to that of Vanguard 3, *i.e.*, approximately 500 km by 3300 km with an inclination of 33.4°. The principal candidate causes for the release are (1) deterioration of the surface materials of Vanguard 3 or its orbital stage and (2) impact of the assembly by a very small meteoroid or orbital debris. ♦

ISS Large Area Debris Collector (LAD-C) Update

The Preliminary Design Review (PDR) for LAD-C was held in Houston, Texas on 31 May 2006. The U.S. Department of Defense Space Test Program (DoD STP) organized and hosted the PDR. Participants included LAD-C team members from the U.S. Naval Research Laboratory (NRL), STP, and the NASA Orbital Debris Program Office, as well as engineers supporting International Space Station (ISS) and Extra Vehicular Activity (EVA) Offices.

A total of 10 presentations were given during the PDR. They covered project, science, and instrument overview, mechanical design, material control, electronic design, software flow and data acquisition, thermal control, test plans, and EVA issues. At the conclusion of this successful PDR, issues and action items were summarized, and assigned to various members for follow-up in regular biweekly teleconferences.

LAD-C will benefit orbital debris, cosmic dust, and satellite safety communities. Major contributing organizational members of LAD-C and their responsibilities are: NRL (lead, management, acoustics, engineering), NASA Orbital Debris Program Office (science planning and operations), JAXA/ISAS and Chiba University (aerogel, calibration), ESA Space Debris Office (system software, calibration), UC Berkeley (calibration), University of Kent at Canterbury (calibration). The DoD STP office is in charge of flight preparations, including system integration and safety. The responsibility of post-flight analysis and modeling will be shared by all team members. The current schedule for LAD-C is: Safety Review on 16 August 2006, Critical Design Review (CDR) in November 2006, and system delivery in September 2007. The deployment is tentatively scheduled for 2008, with retrieval in 2009. ♦

PROJECT REVIEWS

STS-114 Micrometeoroid/Orbital Debris (MMOD) Post-Flight Assessment

J. HYDE, R. BERNHARD, & E. CHRISTIANSEN

NASA Johnson Space Center (JSC) personnel assisted Kennedy Space Center (KSC) inspection teams in the identification of 41 micrometeoroid/orbital debris (MMOD) impact sites on the OV-103 vehicle (Discovery) during STS-114 post-flight inspections. There were 14 MMOD impacts reported on the crew module windows (Figure 1). The largest impact feature, a 6.6 mm x 5.8 mm crater on window #4, was caused by a particle with an estimated diameter of 0.22 mm (Figure 2). This impact was among the largest ever recorded on a crew module window. The window was removed and replaced. Scanning Electron Microscope/Energy Dispersive X-ray (SEM/EDX) analysis of dental mold samples from the impact site to determine particle origin was inconclusive, possibly due to contamination picked up on

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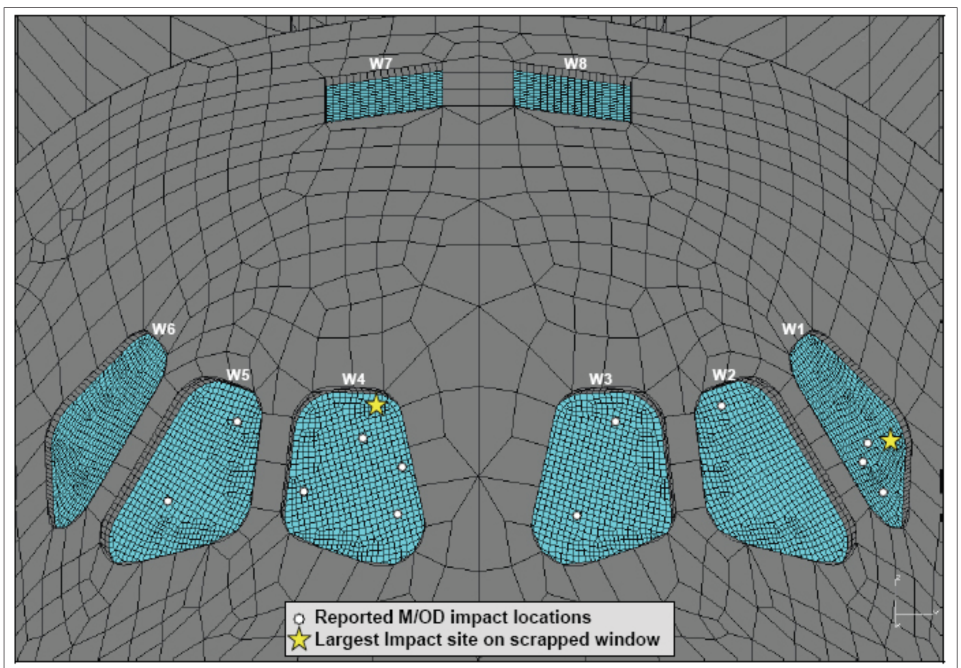

Figure 1. STS-114 crew module window impact map.

STS-114

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the ferry flight from Edwards Air Force Base to KSC.

The radiators on the inside of the payload bay doors sustained 19 impacts (Figure 3) with one of the impacts causing a face sheet perforation. The 0.61 mm diameter hole was produced by a particle with an estimated diameter of 0.4 mm, which approaches the 0.5-mm critical particle diameter of the wing leading edge reinforced carbon-carbon (RCC) panel high-temperature regions (Zone 3, Figure 4) that was established during Return to Flight testing of the RCC panels.

An inspection of the payload bay door exterior insulation (FRSI) revealed a 5.8 mm x 4.5 mm defect that was caused by an MMOD particle with unknown composition, as the sample obtained was contaminated.

Figure 5 provides a summary of the exterior surface survey that was conducted following the STS-114 mission. Two windows were removed and replaced due to hypervelocity impact. Nineteen impacts were recorded on the payload bay door radiators, with one face sheet penetration. Three impact sites were identified on the FRSI. There were four hypervelocity impact sites detected on the wing leading edge RCC panels. One impact was detected on the top cover of the TPS sample box (TSB) payload that was mounted on a carrier in the aft portion of the payload bay. ♦

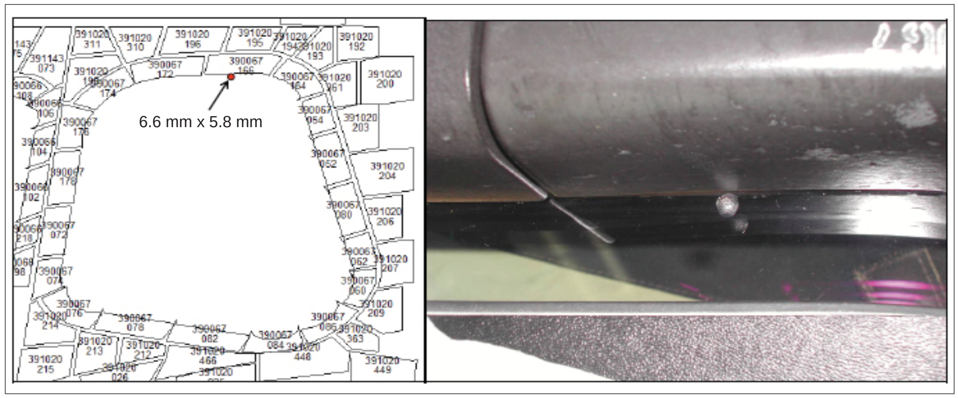


Figure 2. Hypervelocity impact on window #4.

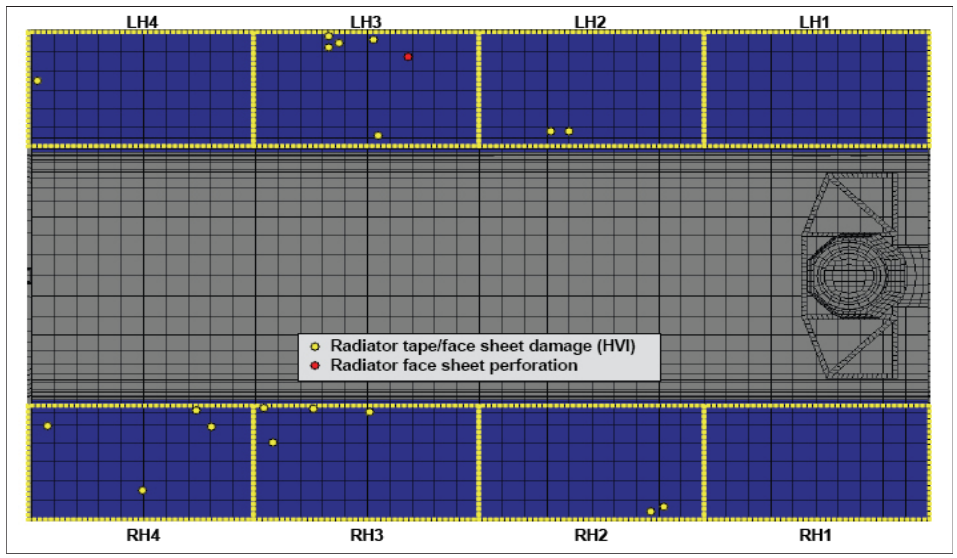
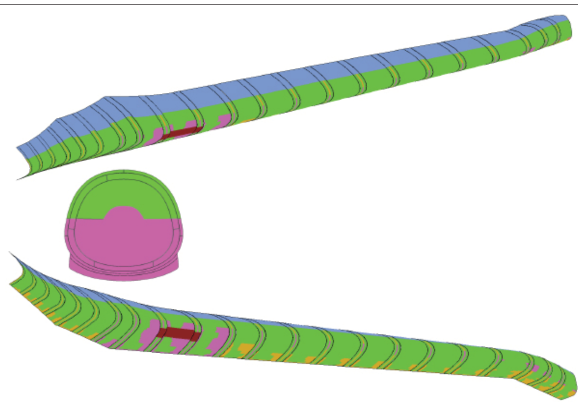


Figure 3. STS-114 payload bay door radiator impact map.



MMOD Failure Criteria for RCC WLE, NC, chin panel

Zone		Critical Deb Diam 7 km/s & 0° (cm)	Nose Cap Area (m²)	Wing LE Area (m²)
1	2.5 cm diameter hole allowed	0.489		12.07
2	< 2.5 cm diameter hole allowed	0.110 → 0.484	0.99	19.09
3	Coating Damage (Test 6)	0.081		2.53
4	Coating Damage (Test 5)	0.058	1.94	1.66
5	Coating Damage (Test 4)	0.047		0.34
	TOTAL		2.93	35.69

Figure 4. RCC failure criteria and critical particle size.

Region	Debris	Meteoroid	Unknown	TOTAL	Max. Diameter (mm) Crater	Max. Diameter (mm) Projectile
Windows	0	1	13	14	6.6	0.2
Radiators	2	2	15	19	3.2	0.5
FRSI	1	0	2	3	5.8	1.3
RCC	0	0	4	4	1.8	0.2
TSB cover	1	0	0	1	0.5	0.1
	4	3	34	41		

Figure 5. STS-114 impact damage summary.

New Satellite Impact Experiments

T. HANADA, Y. TSURUDA, & J.-C. LIOU

To investigate the outcome of low- and hyper-velocity impacts on satellites, two new impact experiments were conducted recently by Kyushu University, with collaboration from the Kyushu Institute of Technology and the NASA Orbital Debris Program Office. The targets for the two impact tests were identical micro satellites, 15 cm x 15 cm x 15 cm in size with a communication antenna on the top (see Figure 1). The main structure of each micro satellite was composed of five layers (top, bottom, and three internal layers parallel to the top and bottom layers) and four side panels. Unlike the target prepared for the previous test[1] (a cylindrical-shaped micro satellite without side panels), this new structure made the targets more realistic. The layers and panels were made of Carbon Fiber-Reinforced Plastics (CFRP), assembled by angle bars made of an aluminum alloy. The thickness of the five layers was 2 mm while that of the four side panels was 1 mm. The interior of each micro satellite was equipped with fully functional wireless radios, lithium-ion batteries, communication circuit, electric power supply circuit, command and data handling circuit, and solar cells on one of the side panels. The total mass of each micro satellite was approximately 800 g.

Figure 1. The target microsatellite before the impact experiment.

Two different solid spheres, made of an aluminum alloy, were prepared as projectiles. One was 3 cm in diameter and 40 g in mass whereas the other one was 1.4 cm in diameter and 4 g in mass. The projectiles were launched from a two-stage light gas gun at Kyushu Institute of Technology. The first experiment was performed at a low-velocity of 1.5 km/s using the 40-g aluminum alloy solid sphere. The second experiment was performed at a hypervelocity of 4.4 km/s using the 4-g aluminum alloy sphere. The impact kinetic energy to target mass ratios for the two experiments were approximately the same (55 J/g), and placed the outcome as catastrophic according to the NASA Standard Breakup Model[2] which defines a threshold of 40 J/g or higher for catastrophic collisions.

Both target satellites were completely fragmented after the impact (see Figure 2), consistent with the NASA criterion. The projectile of the low-velocity impact experiment was partially damaged but the projectile of the hypervelocity impact experiment was completely fragmented beyond recognition. Figure 3 shows the 500 largest fragments from each experiment. The CFRP panel and layer pieces are easily recognizable among the fragments. The overall characteristics of the two fragment sets are similar, although some differences exist. For example, many line-shaped fragments were generated by the hypervelocity impact (see the lower right corner of the display in Figure 3) whereas only a few line-shaped fragments were generated by the low-velocity impact. Such a difference may lead to differences in fragment size distribution and area-to-mass ratio distribution.

To date, approximately 1500 fragments from each experiment have been collected for detailed analysis. Each piece has been weighed, measured, and analyzed based on the analytic method used in the NASA Standard Breakup Model. These fragments account for about 95% of the target mass for both experiments. Investigations of the fragment size distribution, area-to-mass ratio distribution, size-to-area conversion, and delta-velocity distribution are underway at the Kyushu University. Details of the two tests and preliminary results will be presented at the 2006 COSPAR Scientific Assembly to be held in Beijing, China in July 2006. The final analysis results will be presented at the 57th International Astronautical Congress to be held in Valencia, Spain in October 2006.

1. Hanada, T., *A New Low-Velocity Satellite Impact Experiment*, Orbital Debris Quarterly News, 9-3, p. 6, 2005.

2. Johnson, N. L., P. H. Krisko, J.-C. Liou, and P. D. Anz-Meador, *NASA's New Breakup Model of EVOLVE 4.0*, Adv. Space Res., 28, No.9, p. 1377-1384, 2001. ♦

Figure 2. Fragmentation of the micro satellite right after the low-velocity impact. Pieces were mixed with white catch foams from the interior of the test chamber.

(a) Low-velocity impact experiment (b) Hypervelocity impact experiment

Figure 3. Comparison of fragments from low- and hyper-velocity impact experiments.

Detection of Small GEO Debris with MODEST Data Using an Automatic Detection Algorithm

T. YANAGISAWA, P. SEITZER, & E. BARKER

To better define the debris environment in the geosynchronous (GEO) region, it is necessary to extend optical observations to small objects that are below the coverage limit of the satellite catalog. This objective can be achieved with observations using bigger telescopes and/or innovated image processing techniques to uncover faint objects which cannot be recognized from a single image. An automatic processing algorithm for detections of unresolved GEO objects on charge coupled device (CCD) frames has been developed recently[1]. This article summarizes a recent study to apply this new technique to the NASA Michigan Orbital DEbris Survey Telescope (MODEST) data.

The new algorithm uses many CCD frames to detect faint GEO objects that are invisible on a single CCD image. As shown in Figure 1, sub-images are cropped from numerous CCD images to fit the movement of a GEO object. A median image of all the sub-images is then created. In this process, photons from the GEO object are located on the same pixels of sub-images, and streaks of field stars are removed by taking the median because they are in different places on the sub-images. This median process also improves the signal-to-noise ratio enabling one to detect unresolved GEO objects. Using the average is slightly more powerful than the median in respect of the detection of faint objects which are not unresolved from the background noise levels.. However, the median has the advantage of eliminating extremely large noise spikes , such as cosmic rays and hot pixels that remain in an average image. In the median image, the algorithm finds candidates of GEO objects using a threshold value and a parameter concerned with the candidate's shape. In order to detect invisible GEO objects, a wide range of shift values of GEO objects must be investigated.

The algorithm has been applied to the MODEST data. The observation sequence for MODEST is a 5 second exposure every 37.9 seconds as the telescope tracks a position of constant right ascension and declination on the sky. The CCD camera attached to the telescope uses time-delay integration (TDI) mode during the exposure to match the motion of GEO objects. Therefore, GEO objects appear as point sources and field stars appear as streaks. As the time interval of each frame is 37.9 seconds, typical GEO objects appear on eight serial frames as the objects traverse the 1.3° field-of-view of the telescope. Eight frames are available to improve a signal-to-noise ratio for the detection of unresolved GEO objects. Although a median may be able to remove streaks of stars, active removal of those streaks before calculating median is preferable because only eight frames are available for the analysis. In order to do this, a median frame made of eight serial frames is subtracted from each of the serial frames as shown in Figure 2. By the characteristic of median, GEO objects are removed in the median frame and only streaks of stars remain. Subtracting this median frame from each frame removes streaks of stars. Although some influences remain near the streaks of bright stars, these influences are effectively eliminated by patching the mask pattern image made of the median image. After applying these processes to all the frames, the analysis of MODEST data was carried out using the algorithm. The detection threshold value needs to be determined carefully. If the analysis goal is to detect very faint GEO objects, the threshold value must be low, which allows for the possible detection of many false candidates and be a time-consuming analysis. For this analysis, 3.5 times of the sky background noise was used for the threshold value. All of the processes are constructed with Perl scripts and IRAF (Image Reduction and Analysis Facility) software[2].

About 200 MODEST images taken on 9 July 2005 were analyzed. Three PCs that contain two Intel Xeon 2.4 GHz CPUs and 4 GB DDR-SDRAM were used for the analysis. It took approximately 2.5 days on the three PCs to analyze the data set. As a result, 10 GEO objects were detected. Seven of them had been already detected by the current detection algorithm of MODEST, while three of the detections were new ones. Magnitudes of these three objects on V band are 19.3, 19.9 and 20.1, respectively. Figure 3 shows parts of the eight serial frames around one of these objects and the median image. Although the object is hard to see in the eight individual frames, it is clearly recognized in the median image. Using eight frames and this algorithm, the detection limit is increased by one magnitude fainter than previous method.

The disadvantage of the algorithm is the amount of time needed for analysis. A typical night of MODEST observation records approximately 1000 frames of data. This means 75 PCs are required to analyze one night's data within 24 hours. However, the cost of these PCs is less expensive than the building and maintaining of a new telescope when the same results can be achieved. In addition, the processing speed of PCs is increasing very rapidly and a new system may solve the computing

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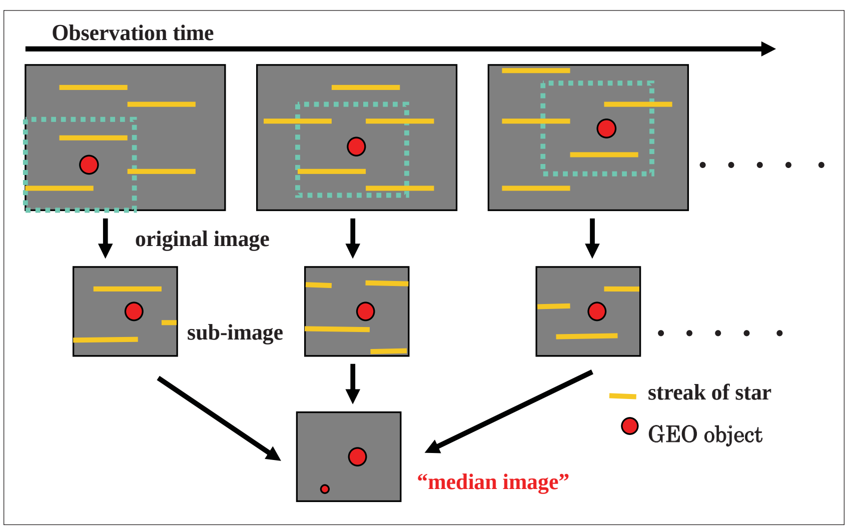

Figure 1. Process of the algorithm.

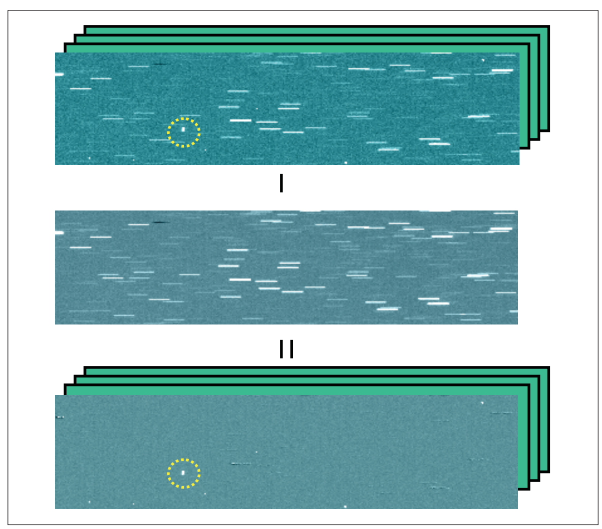

Figure 2. Process to remove streaks of stars

Detection Algorithm

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time problem in a few years.

The algorithm is available for various purposes other than detections of small GEO objects. Small stellar objects such as asteroids, comets, and Kuiper Belt objects are good targets. As a matter of fact, nearly one hundred previously unknown main-belt asteroids have been detected at the observational facility of the Japan Aerospace Exploration Agency (JAXA) using this algorithm. Detection of these objects allows researchers to better define the asteroidal population. Another potential application for this algorithm is the detection of faint near-Earth objects (NEOs). Current detection threshold is about 1 km for the JAXA facility. It is based on a simple observation technique that finds moving objects by comparing a few CCD frames. Although high performance computers are required, this new algorithm, when combined with existing telescopes, should be able to detect NEOs down to about a few hundred meters in size. The algorithm may also be used to discriminate dark or small objects released from satellites or airplanes.

For the future optical observation of GEO objects, a system that consists of many small telescopes and high speed machines with the algorithm will work effectively and cheaply. Small telescopes have an advantage of short focal lengths allowing for a large field-of-view. The disadvantage of small aperture is compensated by using the algorithm described. By deploying many small telescopes, a wide region of the sky is constantly observed. Although a large telescope is able to get many photons, it is not appropriate for a wide field survey because of its narrow field-of-view. In addition, it costs a significant amount of money to build and maintain a large telescope. The budget for building a telescope is proportional to third power of its diameter. On the other hand, the detection ability is proportional to its diameter. The system of many small telescopes and the algorithm should be able to produce better results at a lower cost.

The algorithm for detections of unresolved GEO objects were shown to work well for small subset of MODEST data tested. Further testing will be conducted on additional MODEST datasets in the near future.

1. Yanagisawa, T., et al., *Automatic Detection Algorithm for Small Moving Objects*, Publ. Astron. Soc. Japan, 57, p. 399-408, 2005

2. http://iraf.noao.edu/ ♦

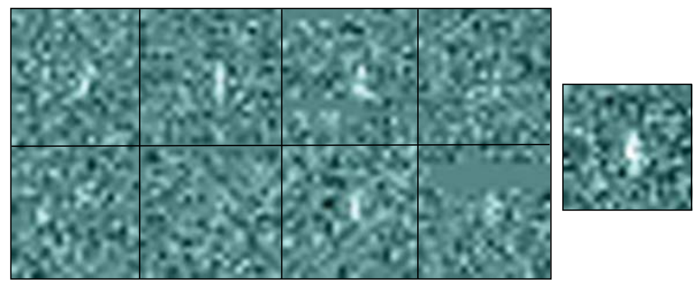

Figure 3. Detected GEO object. The left figure shows parts of eight serial frames around one of these objects and the right one shows the median image of the eight frames.

ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

36th COSPAR Scientific Assembly
16-23 July 2006, Beijing, China

The New Jettison Policy for the International Space Station

N. JOHNSON

During more than seven years of operations by the International Space Station (ISS), approximately three dozen pieces of debris were released and subsequently cataloged by the U.S. Space Surveillance Network (SSN). The individual mass of these objects ranged from less than 1 kg to 70 kg. Although some of these debris were separated from the ISS accidentally, some were intentionally cast-off, especially the larger items. In addition, small operational satellites are candidates for launch from the ISS, such as the TNS-0 satellite deployed from ISS in March 2005. Recently an official ISS Jettison Policy was developed to ensure that decisions to deliberately release objects in the future were based upon a complete evaluation of the benefits and risks to the ISS, other resident space objects, and people on the Earth. The policy identifies four categories of items which might be considered for release: (1) items that pose a safety issue for return on-board a visiting vehicle, (2) items that negatively impact ISS utilization, return, or on-orbit stowage manifests, (3) items that represent an EVA timeline savings, and (4) items that are designed for jettison. Some of the principal issues to be addressed during this evaluation process are the potential for the object to recontact the ISS within the first two days after jettison, the potential of the object to breakup prior to reentry, the ability of the SSN to track the object, and the risk to people on Earth from components which might survive reentry. This paper summarizes the history of objects released from ISS, examines the specifics of the ISS jettison policy, and addresses the overall impact of ISS debris on the space environment. ♦

LAD-C - A Large Area Debris Collector on the ISS

J.-C. LIOU, F. GIOVANE, R. CORSARO, & E. STANSBERY

LAD-C is a 10 m^2 aerogel and acoustic sensor system under development by the U.S. Naval Research Laboratory (NRL) with main collaboration from the NASA Orbital Debris Program Office at Johnson Space Center. LAD-C is tentatively scheduled to be deployed by the U.S. Department of Defense Space Test Program (STP) on the International Space Station (ISS) in 2008. The system will be retrieved, after one to two years of data and sample collection, for post-flight analysis. In addition to micrometeoroid and orbital debris sample return, the acoustic sensors will record impact times, locations, signal strengths, and acoustic waveforms of the largest collected samples.

LAD-C attempts to utilize the ISS as a scientific platform to characterize the near-Earth micrometeoroid and orbital debris environment in the size regime where few data exist. The addition of acoustic sensors will enable potential source identification of some of the collected residuals. This dynamical link can be combined with laboratory analysis of the collected samples to further our understanding of orbital debris and the sources of micrometeoroids - asteroids and comets. ♦

Comparison of Fragments Created by Low- and Hyper-velocity Impacts

T. HANADA, Y. AKAHOSHI, & J.-C. LIOU

This paper summarizes two new satellite impact tests conducted at the Kyushu University in early 2006. The objective of the tests was to investigate the outcome of low- and hyper-velocity impacts on two identical target satellites. The first experiment was performed at a low velocity of 1.5 km/s using a 40-g aluminum alloy sphere. The second experiment was performed at a hyper-velocity of 4.4 km/s using a 4-g aluminum alloy sphere. The target satellites were 15 cm x 15 cm x 15 cm in size and 800 g in mass. The ratios of impact energy to target mass for the two tests were approximately the same. The target satellites were completely fragmented in both tests, although there were some differences in the characteristics of the fragments. The projectile of the low-velocity impact experiment was partially fragmented while the projectile of the hypervelocity impact experiment was completely fragmented beyond recognition. Approximately 1000 fragments from each experiment were collected. They are being measured and analyzed based on the analytic method used in the NASA Standard Breakup Model (2001 revision). Preliminary analysis results will be presented in this paper. ♦

Instability of the Present LEO Satellite Populations

J.-C. LIOU & N. JOHNSON

Several studies conducted during 1991-2001 demonstrated, with some assumed launch rates, the future unintended growth potential of the Earth satellite population, resulting from random, accidental collisions among resident space objects. In some low Earth orbit (LEO) altitude regimes where the number density of satellites is above a critical spatial density, the production rate of new breakup debris due to collisions would exceed the loss of objects due to orbital decay.

A new study has been conducted in the Orbital Debris Program Office at the NASA Lyndon B. Johnson Space Center, using higher fidelity models to evaluate the current debris environment. The study assumed no upper stages or spacecraft were launched after December 2005. A total of 150 Monte Carlo runs were carried out and analyzed. Each Monte Carlo run simulated the current debris environment and projected it 200 years into the future. The results indicate that the LEO debris environment has reached a point such that even if no further space launches were conducted, the Earth satellite population would remain relatively constant for only the next 50 years. Beyond that, the debris population would begin to increase noticeably, due to the production of collisional debris. Detailed analysis shows that this growth is driven by collision activities between 900 and 1000 km altitude - the region which has the highest concentration of debris currently.

In reality, the satellite population growth in LEO will undoubtedly be worse since spacecraft and their orbital stages will continue to be launched into space. Postmission disposal of vehicles (*e.g.*, limiting postmission orbital lifetimes to less than 25 years) will help, but will be insufficient to constrain the Earth satellite population. To preserve the near-Earth environment for future space activities, it might be necessary to remove existing large and massive objects from regions where high collision activities are expected. ♦

Comparing the Long-term Evolution of the Space Debris Environment with DELTA, LEGEND and SDM

C. MARTIN, J.-C. LIOU & A. ROSSI

The long-term evolution of the space debris population is studied worldwide using large and complex computer models.

Three such codes have been developed and upgraded over the last several years by different groups worldwide: DELTA 2.0 developed for ESA by QinetiQ in the UK, LEGEND developed at NASA JSC in the USA, and SDM 3.0 developed for ESA, at ISTI/CNR in Italy.

Several studies of the space debris environment have already been performed with these models. The results of this research agree, in general terms, on the trends apparent in the long-term evolution of the debris population under different simulation scenarios. Nonetheless, it is usually difficult to compare in detail the results generated by the different models, due to the variety of assumptions and initial conditions adopted.

Within Working Group 2 of the Inter-Agency Space Debris Co-ordination Committee (IADC) an effort was initiated several years ago to compare the results of the evolution models available within the participating member organisations. To achieve this a common set of input data and a common simulation scenario was identified and agreed. The current development status of the models is presently particularly favourable for a comparison, as DELTA, LEGEND and SDM have each implemented a common fragmentation model. This should help reduce the discrepancies in the evolution results and could help in identifying the sources of residual differences observed.

This paper will firstly present a brief overview of the three different environment models. Then the common simulation scenario will be outlined and the results of the comparison between DELTA, LEGEND and SDM will be presented and discussed. Overall, the comparison reveals a very good agreement between the model predictions, with the observed differences considered principally due to the collision prediction algorithms and orbit propagation techniques. ♦

A Study of the Material Density Distribution of Space Debris

J. OPIELA

Material density is an important, yet often overlooked, property of orbital debris particles. Many models simply use a typical density to represent all breakup fragments. While adequate for modeling average characteristics in some applications, a single value material density may not be sufficient for reliable impact damage assessments. In an attempt to improve the next generation NASA Orbital Debris Engineering Model, a study on the material density distribution of the breakup fragments has been conducted and summarized in this paper.

The material density distribution of the on-orbit breakup debris population may be estimated by combining three sources of data: available pre-launch information on satellite materials, ground-based satellite breakup experiments, and chemical compositions of residuals collected from returned surfaces. Analysis of these data provides a basis to compile a simple mass density distribution as a function of particle size. For example, about 75% of on-orbit breakup debris fragments come from upper stages, which are simpler and more standardized than payloads in construction and composition. Available material information from manufacturers can be used to develop a reasonable distribution function for this component. For spacecraft breakup debris, it has been found that the range of material densities may be simplified into three representative values: high (*e.g.* steel), medium (*e.g.* aluminum), and low (*e.g.* plastic). Although the three data sources mentioned above are not comprehensive, and some interpretation and extrapolation are needed, the resulting density distribution still represents a step forward in providing more reliable damage assessments for future debris models. ♦

Flux Comparisons from the Goldstone Radar, Haystack Radar, and HAX Radar Prior, During, and After the Last Solar Maximum

C. STOKELY, R. GOLDSTEIN, & E. STANSBERY

The continual monitoring of the low Earth orbit (LEO) environment using highly sensitive radars is essential for an accurate characterization of the dynamic debris environment. This environment is continually changing or evolving since there are new debris sources, previously unrecognized debris sources, and debris loss mechanisms that are dependent on the dynamic space environment. Such radar data are used to supplement, update, and validate existing orbital debris models.

NASA has been utilizing radar observations of the debris environment for over a decade from three complementary radars: the NASA JPL Goldstone radar, the MIT Lincoln Laboratory (MIT/LL) Long Range Imaging Radar (known as the Haystack radar), and the MIT/LL Haystack Auxiliary radar (HAX). All of these systems are high power radars that operate in a fixed staring mode to statistically sample orbital debris in the LEO environment. Each of these radars is ideally suited to measure debris within a specific size region. The Goldstone radar generally observes objects with sizes from 2 mm to 1 cm. The Haystack radar generally measures from 5 mm to several meters. The HAX radar generally measures from 2 cm to several meters. These overlapping size regions allow a continuous measurement of cumulative debris flux versus diameter from 2 mm to several meters for a given altitude window. This paper will discuss the analysis of Haystack, HAX, and Goldstone data from 1998 through 2005. These years correspond to periods before, during, and after the peak of the last solar cycle. Additionally, the flux as a function of altitude for debris sizes greater than 5 mm will be described using Haystack and Goldstone radar data before, during, and after the last solar cycle. These analysis results include error bars that represent statistical sampling errors, and are detailed in this paper. ♦

SOCIT4 Collisional-Breakup Test Data Analysis: With Shape and Materials

P. KRISKO, M. HORSTMAN, & M. FUDGE

In this paper we revisit the SOCIT4 data set, which was compiled from the last of a series of four hypervelocity impact tests conducted under a U.S. Department of Defense (DoD) program in 1991 through 1992. This test targeted a flight-ready, U.S. Transit navigation satellite, yielding collision fragments in the size regime of sub-millimeter through tens of centimeters. We explore, in detail, the fragment material, shape, and pickup position relationships. The intent of our study is not only to gain an understanding of the collisional-breakup process of this particular payload, but also to determine how these data may apply to other breakups.

What emerges is a clear distinction in fragment area-to-mass between primarily metal (heavy) and primarily non-metal (light) fragments. Metal fragments, which are dominated by aluminum, follow the characteristic curve of increasing area-to-mass with decreasing size: objects move from the character of large irregular shards to that of small solid spheroids. Non-metal fragments, dominated by phenolic/plastic, also move towards solid spheroids as their sizes decrease. But unlike the metals, their area-to-mass curve plateaus in the midsize region (~1 cm), coinciding with a peak in plate-like, non-metal fragments. The internal structure of the Transit payload, with its phenolic surface skin and packed arrays of plastic circuit-boards, certainly governs this behavior.

In the small fragment regime (~1 mm) phenolic/plastic ellipsoidal 'nuggets' display a melted and reformed character and dominate the population. They outnumber aluminum 'nuggets' by over four to one. This is of particular interest since Space Shuttle returned surfaces (windows, radiator panels) show little evidence of impacts by plastics at all. In fact, the main identifiable sources of debris hits in the sub-millimeter range appear to be aluminum and then steel. ♦

Identification of a Debris Cloud from the Nuclear Powered SNAPSHOT Satellite with Haystack Radar Measurements

C. STOKELY & E. STANSBERY

Data from the MIT Lincoln Laboratory (MIT/LL) Long Range Imaging Radar (known as the Haystack radar) have been used in the past to examine families of objects from individual satellite breakups or families of orbiting objects that can be isolated in altitude and inclination. This is possible because for some time after a breakup, the debris cloud of particles can remain grouped together in similar orbit planes. This cloud will be visible to the radar, in fixed staring mode, for a short time twice each day, as the orbit plane moves through the field-of-view. There should be a unique three-dimensional pattern in observation time, range, and range rate which can identify the cloud. Eventually, through slightly differing precession rates of the right ascension of ascending node of the debris cloud, the observation time becomes distributed so that event identification becomes much more difficult.

Analyses of the patterns in observation time, range, and range rate have identified good debris candidates released from the polar orbiting SNAPSHOT satellite (International Designator 1965-027A). For orbits near 90° inclination, there is essentially no precession of the orbit plane. The SNAPSHOT satellite is a well known nuclear-powered satellite launched in 1965 to a near circular 1300 km orbit with an inclination of 90.3°. This satellite began releasing debris in 1979 with new pieces being discovered and cataloged over the years. Fifty-one objects are still being tracked by the U.S. Space Surveillance Network. An analysis of the Haystack data has identified at least 60 pieces of debris separate from the 51 known tracked debris pieces, where all but 2 of the 60 pieces have a size less than 10 cm. The altitude and inclination (derived from range-rate with a circular orbit assumption) are consistent with the SNAPSHOT satellite and its tracked debris cloud. ♦

MEETING REPORT

Non-Imaging Space Object Identification Workshop
27-28 April 2006, Maui, Hawaii, USA

This meeting focused on the new directions researchers are taking to determine physical properties too far away or too small to image. Several papers discussed using photometric signatures to determine classes of objects (Payne and Gregory), which is a very promising area of research. John Lambert discussed using optical glints to determine orientation, configuration, and dynamics. Ed Barker delivered a paper on the light curve analysis being done at NASA Johnson Space Center. The advances in the use of spectral signatures to determine the surface properties was also discussed including demixing of spectral signatures (Luu and Hamada) and laboratory measurements of future satellite missions (Abercromby). All of the above topics can be applied to space debris research since the objects are usually quite small and can be quite far away from the observer. ♦

INTERNATIONAL SPACE MISSIONS
April - June 2006

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2006-009A	SOYUZ-TMA 8	RUSSIA	334	349	51.6	1	0
2006-010A	JCSAT 9	JAPAN	35785	35788	0.0	1	0
2006-011A	FORMOSAT 3A	TAIWAN	496	538	72.0	1	0
2006-011B	FORMOSAT 3B	TAIWAN	499	546	72.0		
2006-011C	FORMOSAT 3C	TAIWAN	717	749	72.0		
2006-011D	FORMOSAT 3D	TAIWAN	496	538	72.0		
2006-011E	FORMOSAT 3E	TAIWAN	496	538	72.0		
2006-011F	FORMOSAT 3F	TAIWAN	498	577	72.0		
2006-012A	ASTRA 1KR	LUXEMBOURG	35776	35801	0.0	1	0
2006-013A	PROGRESS-M 56	RUSSIA	334	349	51.6	1	0
2006-014A	EROS-B	ISRAEL	504	514	97.3	1	0
2006-015A	YAOGAN 1	CHINA	627	630	97.8	1	0
2006-016A	CLOUDSAT	USA	702	703	98.2	1	1
2006-016B	CALIPSO	USA	702	703	98.2		
2006-017A	COSMOS 2420	RUSSIA	183	342	67.1	1	1
2006-018A	GOES-13	USA	35782	35789	0.5	1	0
2006-019A	KOMPASS-2	RUSSIA	402	491	78.9	1	3
2006-020A	SATMEX 6	MEXICO	35778	35796	0.0	1	1
2006-020B	THAICOM 5	THAILAND	EN ROUTE TO GEO				
2006-021A	RESURS DK-1	RUSSIA	356	585	69.9	1	0
2006-022A	KAZSAT 1	KAZAKHSTAN	35762	35787	0.0	2	5
2006-023A	GALAXY 16	USA	35771	35801	0.1	1	0
2006-024A	USA 187	USA	NO ELEMS. AVAILABLE			2	0
2006-024B	USA 188	USA	NO ELEMS. AVAILABLE				
2006-024C	USA 189	USA	NO ELEMS. AVAILABLE				
2006-025A	PROGRESS-M 57	RUSSIA	334	349	51.6	1	0
2006-026A	COSMOS 2421	RUSSIA	405	417	65.1	1	0
2006-027A	USA 184	USA	NO ELEMS. AVAILABLE			1	0

ORBITAL BOX SCORE
(as of 04 JUL 2006, as cataloged by US SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	52	319	371
CIS	1360	2791	4151
ESA	36	36	72
FRANCE	43	307	350
INDIA	31	109	140
JAPAN	94	61	155
US	1026	3032	4058
OTHER	358	25	383
TOTAL	3000	6680	9680

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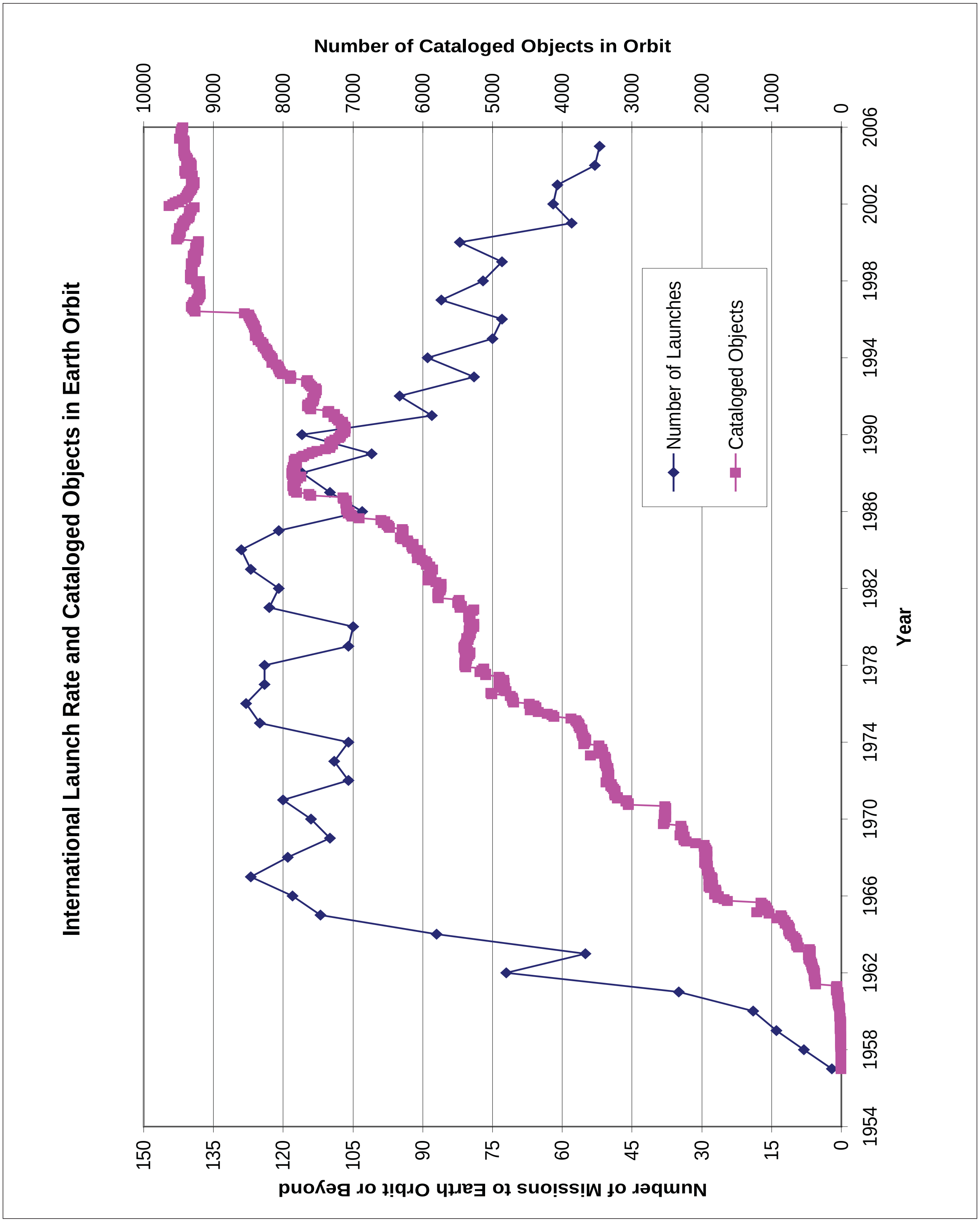
UPCOMING MEETINGS

10-14 September 2006: The 7th Air Force Maui Optical and Supercomputing (AMOS) Technical Conference, Wailea, Maui, Hawaii, USA.

The 2006 AMOS Conference will cover various topics in space surveillance, imaging processing, optics, and computer simulations. One orbital debris session is planned for the conference. Additional information on the conference is available at http://www.maui.afmc.af.mil/conferences.html.

2-6 October 2006: The 57th International Astronautical Congress, Valencia, Spain.

A Space Debris Symposium is planned for the congress. The four scheduled sessions will address the complete spectrum of technical issues of space debris, including measurements and space surveillance, modeling, risk assessment, reentry, hypervelocity impacts, protection, mitigation, and standards. Additional information on the Congress is available at http://www.iac2006.org.



International Launch Rate and Cataloged Objects in Earth Orbit by Year: The annual number of world-wide space launches and the monthly number of objects in Earth orbit as cataloged by the U.S. Space Surveillance Network are shown.

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