National Aeronautics and Space Administration

Orbital Debris Quarterly News

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Inside...

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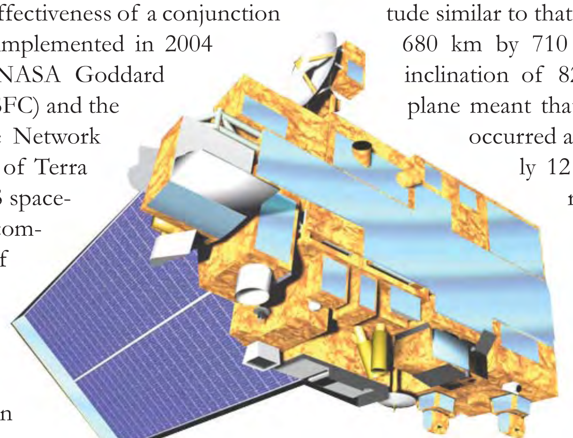
Collision Avoidance Maneuver Performed by NASA's Terra Spacecraft

The Terra spacecraft, often referred to as the flagship of NASA's Earth Observing System (EOS), successfully performed a small collision avoidance maneuver on 21 October 2005 to ensure safe passage by a piece of orbital debris two days later. This action demonstrated the effectiveness of a conjunction assessment procedure implemented in 2004 by personnel of the NASA Goddard Space Flight Center (GSFC) and the U.S. Space Surveillance Network (SSN). The trajectories of Terra and its companion EOS spacecraft are frequently compared with the orbits of thousands of objects tracked by the SSN to determine if an accidental collision is possible. More than 2600 objects are known to pass through the altitude regime of Terra multiple times (sometimes more than two dozen) each day.



Terra (International Designator 1999-068A, U.S. Satellite Number 25994) was launched on 18 December 1999 on a nominal 6-year mission to monitor the complex nature of the Earth's atmosphere and surface. The nearly five-metric-ton spacecraft circles the Earth at an altitude of 705 km with an orbital inclination of 98.2°. When a conjunction assessment on 17 October predicted a piece of debris from a Scout G-1 upper stage (International Designator 1983-063C, U.S. Satellite Number 14222) would come within 500 m of Terra on 23 October, GSFC and SSN personnel undertook a more detailed assessment of the coming conjunction.

The Scout debris was in an orbit with an altitude similar to that of Terra (approximately 680 km by 710 km), but its posigrade inclination of 82.4° and different orbit plane meant that a collision would have occurred at a high velocity of nearly 12 km/s. By 21 October refined analysis of the future close approach indicated that the miss distance was only approximately 50 m with an uncertainty that yielded a probability of collision on the order of 1 in 100. Consequently, a decision was made for Terra to execute a collision avoidance maneuver.

Terra normally maneuvers a few times each year to maintain its precision orbit, and the collision avoidance maneuver was designed to serve this same function to prevent the waste of precious propellant. A very small maneuver was performed nearly two days before the anticipated encounter, ensuring that the Scout debris would pass Terra at a distance of more than 4 km. A post-encounter assessment confirmed that this goal was achieved without disruption to the important Terra mission. ♦

ERBS and UARS Spacecraft Complete Postmission Disposal Activities

During October-December 2005, two of NASA's venerable scientific spacecraft were decommissioned following the completion of postmission disposal operations. The Earth Radiation Budget Experiment (ERBS) and the Upper Atmosphere Research Satellite (UARS) returned valuable environmental data for 21 and 14 years, respectively, before their missions were terminated (*Orbital Debris Quarterly News*,

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ERBS and UARS

continued from page 1

9-4, p. 1).

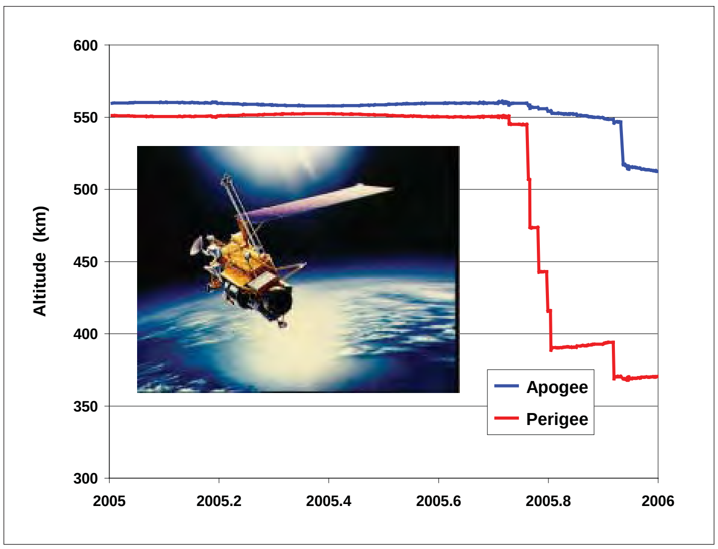
ERBS (International Designator 1984-108B, U.S. Satellite Number 15354) had already been placed in a lower altitude orbit in 2002, in anticipation of its future disposal. This proved to be a fortuitous decision because by 2005 the degradation of ERBS support systems prevented the execution of normal maneuvers which would further lower the orbit. However, a series of maneuvers in September and October was able to consume the remaining 80 kg of propellant. These maneuvers left the mean altitude of ERBS essentially unchanged, while reducing its eccentricity.

Passivation of ERBS was completed, and the spacecraft was officially decommissioned on 14 October. From its current orbit, ERBS is expected to reenter the atmosphere within 17 years, well in compliance with the NASA and U.S. Government recommendation of not more than 25 years after end of mission.

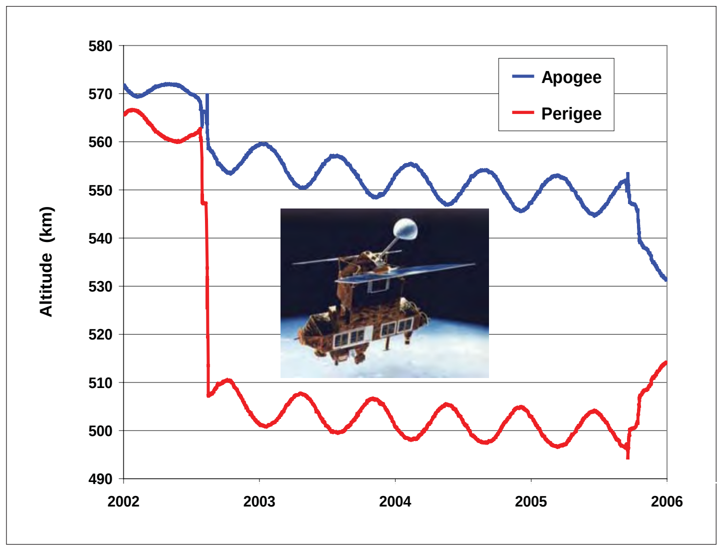
UARS (International Designator 1991-063B, U.S. Satellite Number 21701) was still operating in an orbit near 550 km when it began a series of eight maneuvers to hasten its fall back to Earth and to passivate the spacecraft as an explosion preventive measure. The first six maneuvers, conducted between 4 October and 1 December, were designed to lower perigee to an altitude just above the orbit of the International Space Station (ISS), near 350 km altitude. Since the amount of propellant remaining after these six maneuvers was still uncertain, further near-term, post-maneuver conjunction assessments with ISS would have been difficult. Therefore, the remaining two maneuvers lowered apogee, avoiding any possible imminent collision threat with ISS.

The final UARS maneuver was performed on 8 December and was followed by vehicle passivation. When UARS eventually decays through the orbital regime of ISS, routine tracking by the U.S. Space Surveillance Network will help ensure that any potential collision risk is eliminated, if necessary via a collision avoidance maneuver by ISS. However, such a situation is highly unlikely. Hundreds of cataloged objects pass through the ISS altitude region many times a day, but the frequency of ISS collision avoidance maneuvers is less than one per year.

UARS is now expected to reenter the atmosphere in about 5 years, at least 20 years earlier than if no maneuvers had been performed. ♦



By performing a series of disposal maneuvers, UARS reduced its remaining orbital lifetime by more than 20 years.



ERBS operated near 600 km for nearly 18 years before its orbit was lowered to accelerate its decay after end of mission.

Large Area Debris Collector (LAD-C) Update

The official kickoff meeting for the Large Area Debris Collector (LAD-C) was hosted by the U.S. Department of Defense (DoD) Space Test Program (STP) in Houston, Texas on 27 October 2005. LAD-C is a 10 m^2 aerogel and acoustic sensor system designed to characterize and collect sub-millimeter micrometeoroids and orbital debris on the International Space Station (ISS). The project is led by the U.S. Naval Research Laboratory (NRL) in Washington D.C. with primary collaboration by the NASA Orbital Debris Program Office at Johnson Space Center, and possible contribution by the European Space Agency and several other organizations. The STP Office is responsible for the manifesting, integration, and deployment of LAD-C on ISS, and the retrieval of the system after one to two years.

The kickoff meeting included presentations by STP managers and engineers on project organizations, roles and responsibilities; on ISS and Shuttle payload, integration, and safety requirements; and on extravehicular activity issues. According to STP's payload schedule, LAD-C deployment is tentatively set for mid-2007 with an exposure time of at least one year before retrieval and return to Earth. The LAD-C Principal Investigator and Co-Investigators presented overviews on LAD-C mission objectives and requirements; on the acoustic and electronic components of the system (see *Orbital Debris Quarterly News*, 8-2, p. 3); and on the primary science objectives, and the benefits of the science return for orbital debris, cosmic dust, and safety communities. Additional issues regarding the mechanical design, power requirements, system location and orientation, and potential ISS environment contamination were also discussed at the meeting. Follow-up biweekly teleconferences will be arranged to continue the technical information exchange among all team members. ♦

Revision of Space Shuttle Wing Leading Edge Reinforced Carbon-Carbon Failure Criteria Based on Hypervelocity Impact and Arc-Jet Testing

E. CHRISTIANSEN, J. HYDE, D. LEAR, T. PRIOR, & F. LYONS

As part of the Shuttle Return-to-Flight (RTF) effort, the NASA Johnson Space Center's Hypervelocity Impact Technology Facility (JSC/HITF) performed hypervelocity impact (HVI) testing and analysis of Shuttle wing leading-edge (WLE) reinforced carbon-carbon (RCC) test samples to update WLE threshold failure criteria. After the hypervelocity impact tests, the samples were exposed to typical reentry heating conditions at the NASA JSC Arc-Jet (AJ) Facility to determine the extent of heating-induced damage growth. It was found from the HVI/AJ testing that non-penetrating pits would lead to burn-through in some areas of the WLE where burn-through can lead to loss-of-vehicle (LOV) during reentry. Figure 1 shows the resulting damage caused by a 0.8 mm diameter aluminum hypervelocity impactor and subsequent damage growth due to AJ testing.

For STS-107 and previous missions, WLE failure threshold consisted of 1 in. diameter allowable hole sizes in RCC on the upper surface and ¼ in. hole size on the lower surface. The results of the recent RCC/AJ testing indicated that the WLE failure criteria for LOV should be reduced for MMOD assessments on STS-114 and future missions. Figures 2 and 3 show the WLE and nose failure criteria maps before and after the recent changes for STS-114. The reduction in allowable damage results in increased calculated MMOD risks for future missions, if all other things remain constant.

The Shuttle and International Space Station (ISS) Programs decided to decrease MMOD impact risks to STS-114 and subsequent flights by reversing the orientation of the ISS during the ISS docking phase of the Shuttle mission. The change in orientation – essentially flying the ISS "backwards" – provided incidental shielding to the Shuttle as well as directing MMOD sensitive areas of the WLE and nose cap away from the

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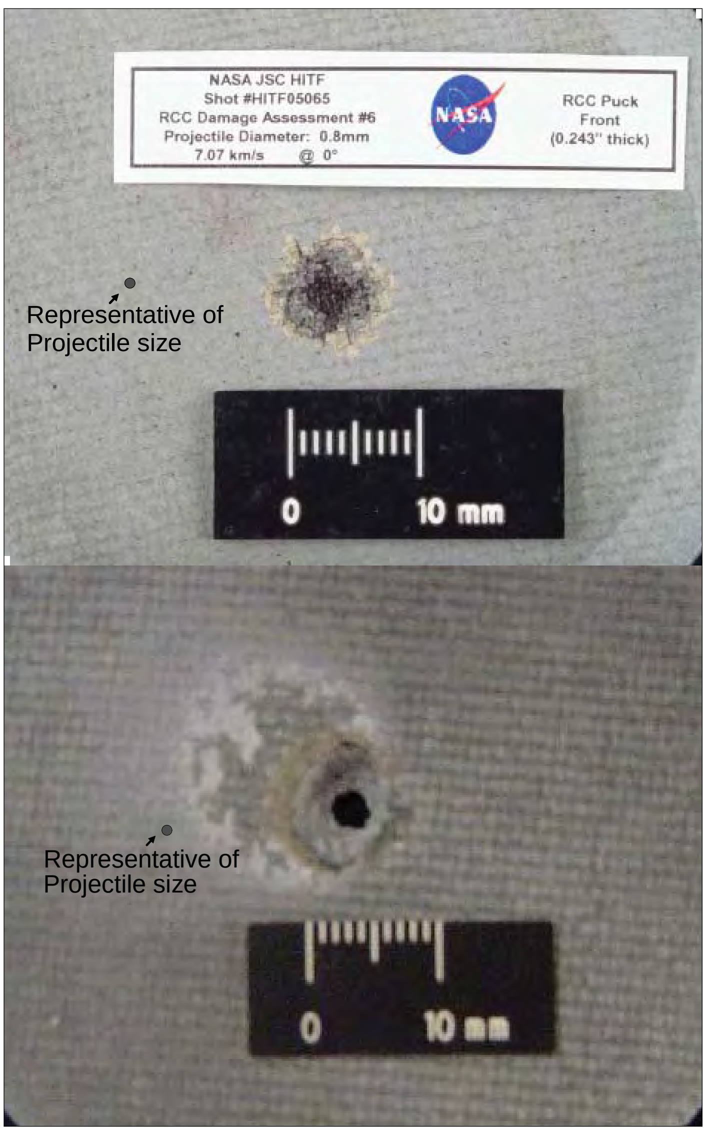


Figure 1. Results of 0.8 mm aluminum HVI/AJ testing of RCC.

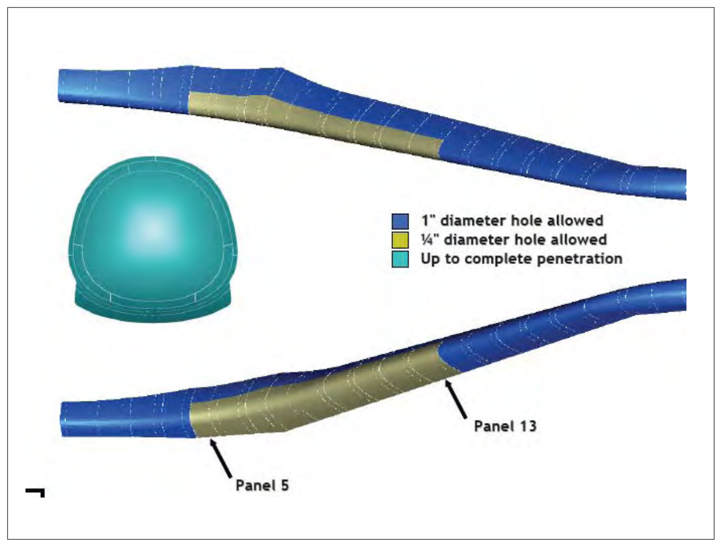


Figure 2. Pre-STS-107 Failure Criteria Map

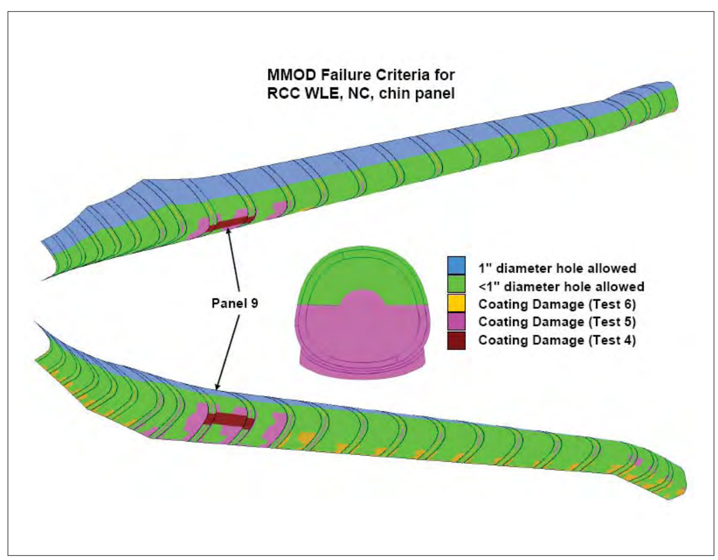


Figure 3. Post-STS-107 Failure Criteria Map

Object Reentry Survivability Analysis Tool (ORSAT) – Version 6.0

W. ROCHELLE, J. DOBARCO-OTERO, R. SMITH, R. DELAUNE, & K. BLEDSOE

The Object Reentry Survival Analysis Tool (ORSAT) has been used for the last decade by NASA to determine when and if an object demises during reentry by using integrated trajectory, atmospheric, aerodynamic, aerothermodynamic, and thermal/ablation models. The analysis performed using ORSAT is used to determine whether a satellite is compliant with NASA Safety Standard 1740.14, which states that the risk to humans on the ground due to an uncontrolled reentry should be less than 1 in 10,000. During the past two years, engineers supporting the NASA Orbital Debris Program Office have been upgrading and improving the code with higher fidelity algorithms. The latest version of the code, version 6.0, was written in a modular manner that will ease implementation of future upgrades.

The trajectory model in previous versions of ORSAT has been replaced with a new model that has the ability to take into consideration forces such as winds and lift. The spherical Earth model in the previous version of ORSAT has also been replaced with an oblate Earth model, in which the gravitational force is a function of both altitude and latitude.

In order to accommodate the new sharp conical shape that has been added to this version, new drag coefficients were required to properly model the drag force on this type of object. The drag coefficients are a function of Mach number and cone half-angle.

The 1999 NASA Marshall Space Flight Center Global Reference Atmosphere Model (GRAM-99) has also been incorporated into the code. This atmosphere model has the ability to predict wind velocities, which will improve the predicted debris footprint of a controlled entry. The user also has the option to enter a user-defined atmosphere for a given day. This option is useful if an engineer is investigating a reentry which will occur at a known date and place.

Heating rate distributions and two-dimensional (2-D) thermal math models were developed and added for spheres and cylinders that are able to predict when the shells of these shapes are breached in reentry. Figure 1 shows the 2-D temperature distributions of a 0.25-m radius non-spinning spherical aluminum shell in a typical case. An additional heating rate term, the gas cap radiation, was added to improve the predicted heating rate received by objects returning from the Moon or deep space, such as the Genesis and Stardust capsules.

Several other upgrades have also been added to the code. Due to the presence of non-metallic ablators in thermal protection systems, such as the insulation of the Space Shuttle External Tank, a model that predicts the recession rate of these ablators was also added. The ability to model structural failure of solar arrays from the main body due to aerodynamic forces was also incorporated into ORSAT 6.0. In addition, ORSAT 6.0 has the capacity to model tanks bursting during reentry. Plotting scripts were added to the code to allow the user to process and review results faster. ♦

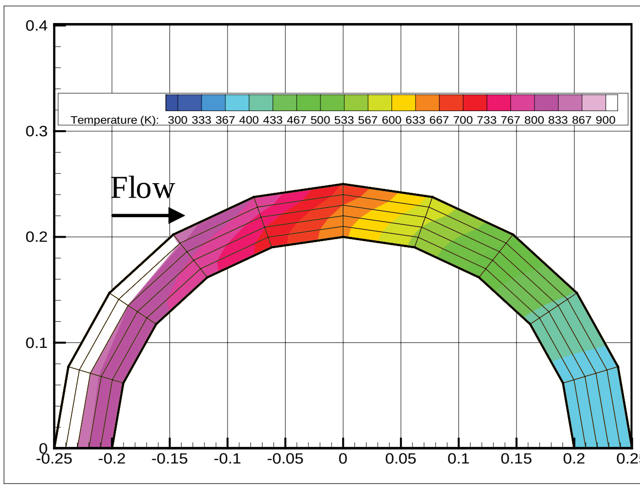


Figure 1. Circumferential and radial temperature distribution of a spherical shell.

Space Shuttle Wing Leading Edge

continued from page 3

majority of the MMOD particle flux. Figure 4 shows the Shuttle-ISS docked orientation change with respect to the ISS velocity direction. In all ISS missions prior to STS-114, the belly of the vehicle faced into the ram "velocity" direction of ISS motion and highest MMOD impact flux. The change for STS-114 orients the bottom of the Shuttle in the wake direction of ISS reducing MMOD impacts to the most vulnerable surfaces of the vehicle and improving crew safety and mission success.

Figure 5 shows a detail of the WLE RCC area of the orbiter that is represented by a detailed finite element mesh containing over 50,000 elements. Each color change represents a different region of the mesh area. This mesh area has 592 distinct regions, where hypervelocity impact damage resistance is defined to reflect failure criteria and physical differences such as location, thickness, and material. The Nose Cap/Chin Panel area of the orbiter was also revised and is now composed of nearly 5000 elements. These newly revised mesh areas represent a significant increase in analytical resolution, allowing property definition and risk calculations for specific regions of individual WLE components such as panels and seals. ♦

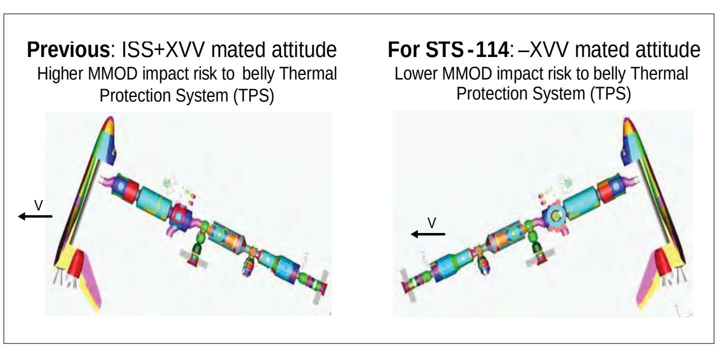


Figure 4. Shuttle-ISS docking and flight orientations before STS-114 and for STS-114.

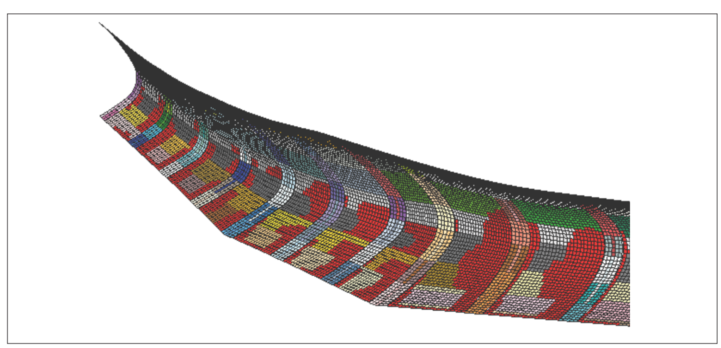


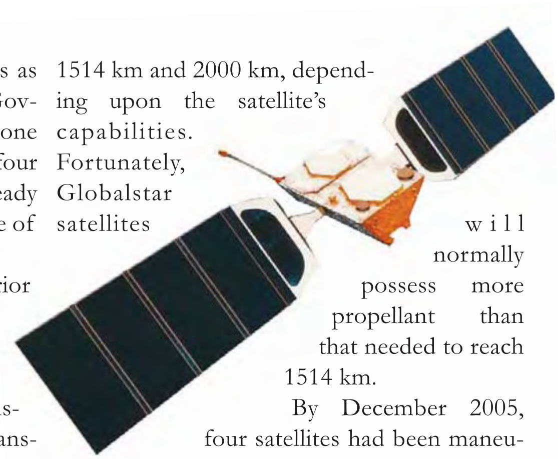
Figure 5. Revised WLE RCC Finite Element Mesh

Disposal of Globalstar Satellites

Deployment of the commercial Globalstar communications satellites began in February 1998, and the constellation of 48 vehicles was completed less than two years later. Unlike the satellites of the Iridium and Orbcomm systems, which were also initially deployed in the second half of the 1990s and circle the Earth near 800 km, the operational altitude of the Globalstar network is near 1414 km. From this higher altitude, the disposal of a satellite after mission completion can pose significant challenges.

With original design lifetimes of 7.5 years, one would expect that some Globalstar satellites might be nearing the end of their useful lives. In fact, such is the case. In October 2005, Globalstar LLC declared to the Federal Communications Commission its intention of transferring the satellites to disposal orbits as high as 2000 km, in accordance with U.S. Government recommendations. Moreover, one satellite, which was in the first group of four Globalstar satellites to reach orbit, has already been placed in a disposal orbit at an altitude of nearly 1900 km.

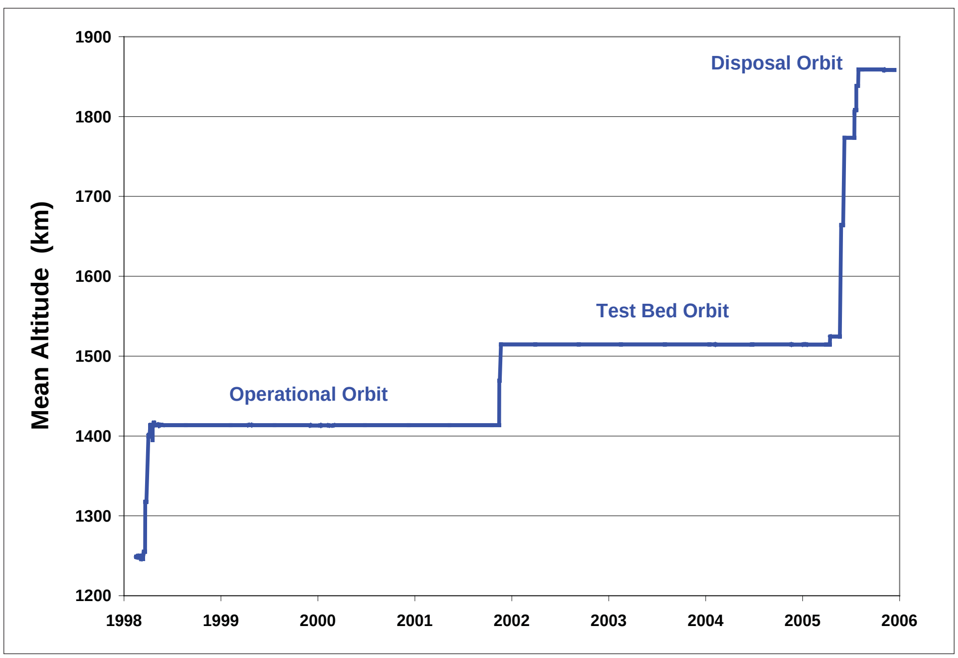
Globalstar satellites were designed prior to the development of the U.S. Government Orbital Debris Mitigation Standard Practices, which recommend that at the end of mission LEO satellites be left in disposal orbits of less than 25 years or be transferred to long-lived orbits above 2000 km. In response to this recommendation, Globalstar has increased the designed disposal orbit from 1514 km (100 km above the Globalstar constellation) to a range of altitudes between 1514 km and 2000 km, depending upon the satellite's capabilities. Fortunately, Globalstar satellites will normally possess more propellant than that needed to reach 1514 km.



By December 2005, four satellites had been maneuvered to orbits of approximately 1515 km, where system tests will be conducted before transferring the satellites to their final disposal orbits. Two of these satellites are expected to reach 2000 km after testing is completed. The third satellite should reach nearly 1940 km, with the fourth satellite climbing to approximately 1760 km. A fifth satellite now in an operational orbit is scheduled to be placed in the temporary test-bed orbit before moving into a final disposal orbit of 1760 km.

All of these disposal orbits are in regions of lesser spatial density (see page 8) and would result in a reduced threat of collision between retired Globalstar satellites and other large space objects. These maneuvers also make the best use of excess propellant which should be expended to passivate the satellite, as also recommended by the U.S. Government Orbital Debris Mitigation Standard Practices to prevent a future explosion.

Not all Globalstar satellites can be maneuvered to higher altitude disposal orbits. To date, two satellites have experienced catastrophic failures and are stranded in orbits near the Globalstar constellation. ♦



Orbital History of Globalstar M002 (U.S. Satellite Number 25164)

Disposal of GPS Spacecraft

After more than 12 years as a member of the U.S. Global Positioning System (GPS), a Navstar spacecraft (USA 90, International Designator 1993-017A, U.S. Satellite Number 22581) was retired in December 2005 and placed into a higher altitude disposal orbit. By placing the vehicle into a nearly circular orbit (eccentricity approximately 0.0002) more than 1000 km above the GPS constellation, Air Force spacecraft operators ensured that the now derelict satellite would not venture near the GPS operational altitude for hundreds of years. Studies have shown that older Navstar spacecraft left in disposal orbits with eccentricities of only 0.001 or more can be susceptible to perturbations which can cause the perigee to decrease by thousands of kilometers over the span of many decades. By transferring Navstar spacecraft to stable, long-lived orbits, the risk of future satellite collisions and the creation of new orbital debris are reduced. ♦

Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov

ABSTRACT FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

Texas Section of the American Physical Society (TSAPS) 2005 Fall Meeting
20-22 October 2005, Houston, Texas, USA

Orbital Debris Photometric Study

H. RODRIGUEZ

In an effort to better understand differences between optical and radar size estimates of orbital debris, a photometric study of debris pieces from an exploded mock satellite has been initiated. This study will take brightness measurements of debris of various shapes and sizes at varying phase angles and orientations. The NASA Orbital Debris Program Office at Johnson Space Center (JSC) has an array of debris pieces from a mock satellite that was exploded in the European Space Operations Centre's ESOC2 test. A Xenon lamp will be used to simulate solar illumination and a CCD camera will record a digital image in filters defining specific bandpasses in the visible spectrum. The illumination of the debris will be varied by observing at different phase angles and orientations through the programming of a robotic arm. The ultimate goal in the optical measurements group at JSC is to create an optical Size Estimation Model (SEM) that will correlate with the current radar SEM. The radar SEM uses laboratory-produced debris pieces observed at different orientations to convert radar cross section to characteristic length. The optical cross section (OCS) of a target is a product of albedo and physical cross section, where albedo is defined as the fractional flux reflected from a surface. The albedo of an object is necessary to convert the brightness into a size. By examining the brightness variations as functions of surface material, shape, and orientation, a better determination of albedo or size may be obtained. ♦

MEETING REPORT

The 56th International Astronautical Congress
17-21 October 2005, Fukuoka, Japan

The 56th International Astronautics Congress (IAC) was held in Fukuoka, Japan from 17 – 21 October 2005. The conference covered a wide range of topics including three days of orbital debris papers. Including those papers from the NASA Orbital Debris Program Office given at the conference (see abstracts in *Orbital Debris Quarterly News,* 9-4, p. 6-7), several papers were considered highlights for the section.

Beginning with optical observation, the paper given by Rudiger Jehn (ESA/ESOC), *Estimating the Number of Debris in the Geostationary Ring*, discussed the methods used to determine a statistical sample of the data when it is not uniformly distributed in longitude or latitude. Also, a paper discussing brightness measurements and how shape might be affecting those measurements was given by Hirohisa Kurosaki (JAXA), *Observation of Rotational Motion of LEO debris by Optical Telescope.*

Two papers of note from the modeling section were from Carmen Pardini (ISTA-CNR) and Shin-ichiro Nishida (JAXA/ISTA). Pardini's paper, *Are de-orbiting missions possible using electrodynamic tethers? Review from the Space Debris perspective*, discussed the vulnerability of debris impacts on tethers and found that two-line tethers have a better chance of survival except at high inclinations where the electrodynamic mechanism of orbital decay becomes inefficient. The paper by Nishida, *Development Status of Active Space Debris Removal System,* discussed an expendable package which would be attached to the debris where the tether would gather electrons and a field emitter array cathode would emit them. It would then lower the debris piece without the need for fuel. ♦

UPCOMING MEETINGS

4-11 June 2006: The 25th International Space Technology and Science (ISTS) Conference, Kanazawa, Japan.

The conference will include technical sessions on space debris and a panel discussion session on international space law of space debris. Additional information on the Conference is available at http://www.ists.or.jp.

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

Three Space Debris Sessions are planned for the Assembly. They will address the following issues (1) advanced ground-based radar and optical, and space-based *in-situ* measurements, (2) population and environment modeling, (3) debris mitigation measures, (4) reentry tracking and survival analysis, and (5) hypervelocity impact testing and shielding design. The meeting will also discuss new developments toward national and international standards and guidelines. More information for the conference can be found at http://meetings.copernicus.org/cospar2006/.

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 SPACE MISSIONS
October-December 2005

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2005-039A	SOYUZ-TMA 7	RUSSIA	341	356	51.7	1	0
2005-040A	SZ-6	CHINA	331	338	42.4	1	2
2005-040E	SZ-6 MODULE	CHINA	344	350	42.4		
2005-041A	GALAXY 15	USA	35776	35798	0.1	1	1
2005-041B	SYRACUSE 3A	FRANCE	35770	35801	0.0		
2005-042A	USA 186	USA	NO ELEMS. AVAILABLE			1	0
2005-043A	BEIJING 1 (TSINGHUA)	CHINA	683	704	98.2	0	1
2005-043B	TOPSAT	UK	683	706	98.2		
2005-043C	UWE-1	GERMANY	683	708	98.2		
2005-043D	SINAH 1	IRAN	682	704	98.2		
2005-043E	SSETI-EXPRESS	ESA	683	707	98.2		
2005-043F	CUBESAT XI-V	JAPAN	683	708	98.2		
2005-043G	MOZ.5/SAFIR/ RUBIN 5/SL-8	GERMANY	685	712	98.2		
2005-044A	INMARSAT 4-F2	INMARSAT	EN ROUTE TO GEO			1	0
2005-045A	VENUS EXPRESS	ESA	HELIOCENTRIC			0	0
2005-046A	TELKOM 2	INDONESIA	35781	35793	0.0	1	1
2005-046B	SPACEWAY 2	USA	EN ROUTE TO GEO				
2005-047A	PROGRESS-M 55	RUSSIA	341	356	51.7	1	0
2005-048A	GONETS D1M 1	RUSSIA	1438	1447	82.5	1	0
2005-048B	COSMOS 2416	RUSSIA	1439	1448	82.5		
2005-049A	INSAT 4A	INDIA	EN ROUTE TO GEO			1	1
2005-049B	MSG 2	EUMETSAT	EN ROUTE TO GEO				
2005-050A	COSMOS 2417	RUSSIA	19121	19124	64.9	2	2
2005-050B	COSMOS 2418	RUSSIA	19114	19129	64.9		
2005-050C	COSMOS 2419	RUSSIA	19119	19125	64.9		
2005-051A	GIOVE-A	ESA	23228	23282	56.1	1	0
2005-052A	AMC-23	USA	35776	35793	0.1	1	1

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

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	51	310	361
CIS	1359	2680	4039
ESA	36	33	69
FRANCE	43	300	343
INDIA	31	111	142
JAPAN	89	55	144
US	1015	2949	3964
OTHER	346	20	366
TOTAL	2970	6458	9428

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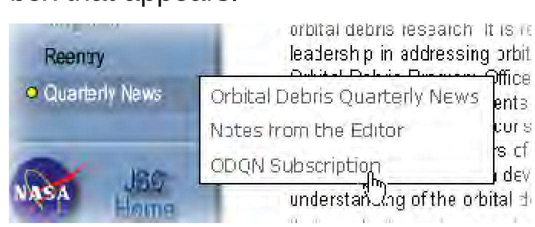

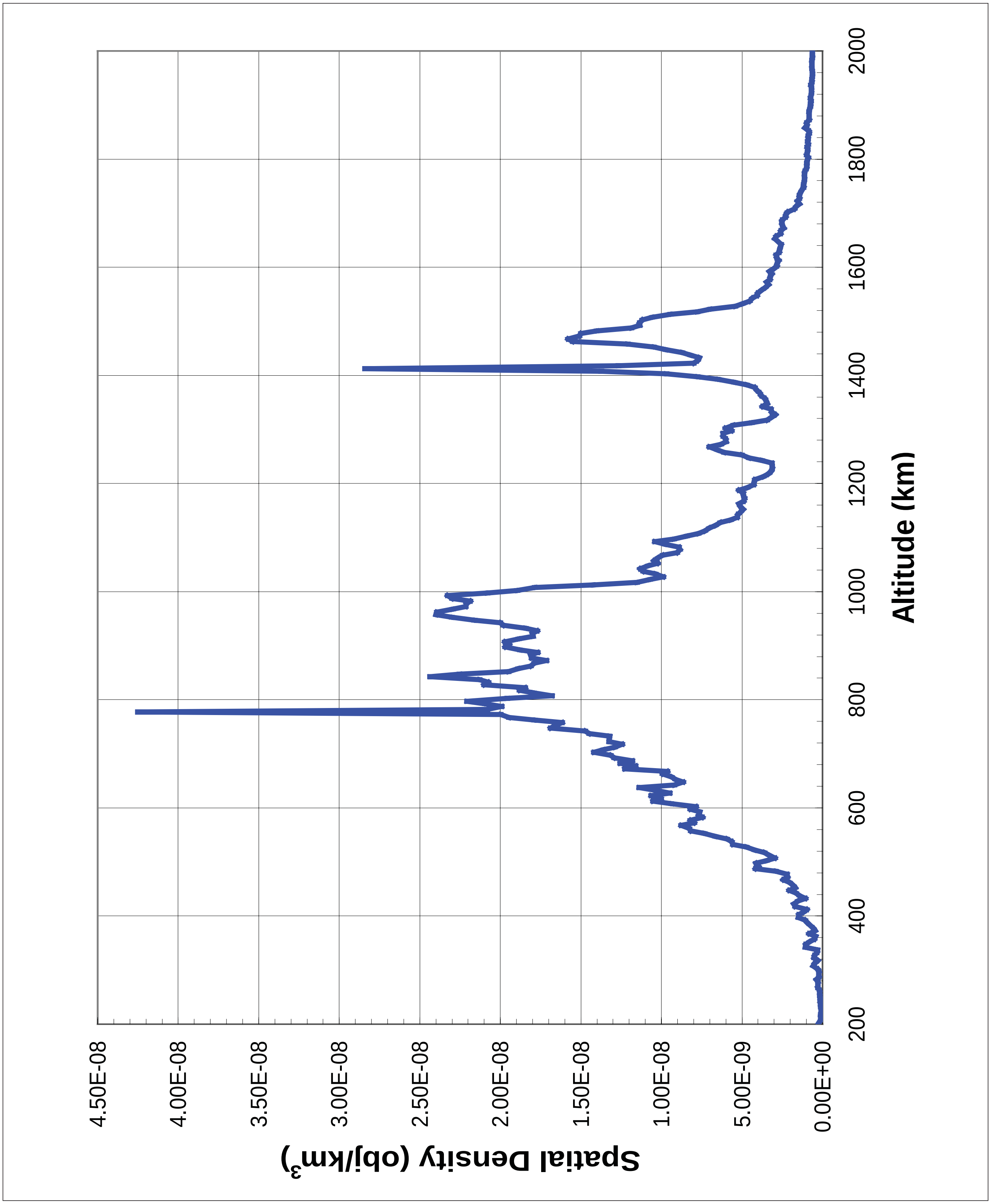

Spatial density distribution of objects in the low Earth orbit region as of 1 January 2006. These are objects, both cataloged and uncataloged, tracked by the U.S. Space Surveillance Network. The peak at 780 km is due to the Iridium constellation satellites while the peak at 1414 km is due to the Globalstar constellation satellites.

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