The Orbital Debris Quarterly News

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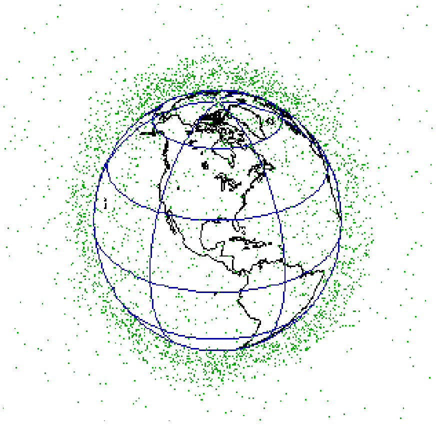

NEWS

Three Upper Stage Breakups in One Week Top February Debris Activity

Observations by the U.S. Space Surveillance Network (SSN) have confirmed a trio of upper stage breakups during the week of 15 February involving former Soviet, European, and Japanese vehicles, two of which had been in orbit for about a decade. February also witnessed two fragmentations associated with vehicles catastrophically decaying from highly elliptical orbits (see special article in this issue). During the quarter U.S. Naval Space Command personnel further discovered evidence for another breakup of a Proton Block DM ullage motor and six possible anomalous events, three of which occurred before the beginning of the year.

The first and most significant of the breakups took place on 15 February with the explosion of the Meteor 2-16 upper stage (1987-068B, Satellite Number 18313). The 10-year-old Tsyklon third stage brokeup into more than 80 fragments for which orbital elements were determined; sixty-three of these debris had been officially cataloged by early March. The 1360 kg upper stage was in an orbit of approximately 940 km by 960 km with an inclination of 82.6 degrees. The debris were thrown into orbits spanning an altitude regime of 300 km by 1200 km. Naval Space Command analysts calculated ejection velocities ranging from 15 m/s to more than 250 m/s. This was the second Tsyklon third stage to breakup violently. The first (1978-100D, Satellite Number 11087) was used on the Cosmos 1045 mission and also had lain dormant for a decade before breaking up.

A 9-year-old upper stage, this one an Ariane 4 third stage (1988-109C, Satellite Number 19689), apparently suffered a less dramatic breakup on 17 February. The 1200 kg stage had been launched on the second Ariane 4 mission on 11 December 1988, carrying the Skynet 4B and Astra 1A spacecraft. The orbit of the vehicle at the time of the breakup was 435 km by 35,875 km with an inclination of 7.3 degrees. The first indication of an event came when Millstone radar personnel, using data from the Eglin radar, linked four new objects with the Ariane vehicle. Specialists at Naval Space Command were then able to establish an approximate time of the event. Early indications were that the separation velocities were very low. Ariane 4 third stages on GTO missions were not passivated at end-of-mission until 1993, five years after the Skynet 4B and Astra 1A launch.

The third breakup of the week may be related to the malfunction of the COMETS H-II second stage (1998-011B, Satellite Number 25176) soon after launch on 21 February. The second burn of the stage ceased after only 47 seconds into a planned 3 min 12 sec maneuver, leaving the upper stage and payload in elliptical, low altitude

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Three Upper Stage Breakups in One Week Top February Debris Activity, Continued

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orbits instead of the desired GTO. Optical sensors in Hawaii tracked the COMETS spacecraft and H-II second stage during the evening of 21 February (22 February GMT) and detected and recorded approximately three dozen additional faint objects. By the following night only a few debris were observed near the 245 km by 1880 km, 30 degree inclination orbit of the second stage. Orbital parameters for only a single piece of debris had been determined by 26 February. The preliminary investigation into the H-II accident suggests an engine failure occurred which may have led to a rupture of a portion of the vehicle.

The last breakup of the quarter occurred on 14 March when the Proton Block DM ullage motor (aka SOZ unit; 1990-110H, Satellite Number 21013) brokeup into more than 110 pieces. This was the sixteenth breakup of this class and the fifth associated with a GLONASS mission. The orbit of the ullage motor at the time of the event was 520 km by 18,995 km with an inclination of 65.1 degrees. Within 10 days of the event element sets for only a half dozen new debris had been developed. The debris are likely to be long-lived and hard to track.

Three anomalous events were detected during the period: two involving old U.S. Transit spacecraft and one originating from a more recent Russian satellite. Transit 5B-2 (1963-043B, Satellite Number 704) apparently released a piece of debris about 9-10 January, and on 7 March Naval Space Command operators detected a new piece of debris from Transit 19 (1970-067A, Satellite Number 4507). These vehicles, both in polar orbits between 950 and 1200 km, were the ninth and tenth Transit-class spacecraft which have spawned debris unexpectedly. A single piece from the Eka 1 (aka Start 1) spacecraft (1993-014A, Satellite Number 22561) was first detected late on 4 March. In all cases, the separation velocities were very low.

Naval Space Command personnel also tied four new debris objects to possible pre-1998 anomalous events. A fragment (1976-067BA, Satellite Number 12543) from the breakup of Cosmos 839 in September 1977 apparently broke into two on 18 December 1997. A new object associated with a PAM-D upper stage (1997-035C, Satellite Number 24878) has also been found in a 344-minute, 39 degree elliptical transfer orbit. Such debris are frequently found after GPS missions and may represent unexpected mission-related debris. Finally, two debris were found in a decaying Proton geosynchronous transfer orbit. Their launch of origin is still under investigation. ❖

A New Category For Satellite Breakup

In March, 1995, an H-II second stage (1994-056B, Satellite Number 23231), which had successfully placed the ETS-VI spacecraft into GTO nine months earlier, was seen to breakup shortly before reentering from a rapidly decaying elliptical orbit. This event has been carried in official NASA records as a satellite breakup, although the cause had widely been attributed to the aerodynamic forces encountered by the stage as its perigee fell to 100 km. The debris generated was, consequently, very short-lived.

During a two-month period beginning in late December, 1997, three more similar incidents involving vehicles in catastrophic decay from highly elliptical orbits were observed by the U.S. Space Surveillance Network (SSN). The first subject was Cosmos 1172 (1980-028A, Satellite Number 11758), which decayed 26 December 1997 from a Molniya-type orbit. Shortly before its demise, the vehicle spawned at least one fragment which was officially cataloged (1980-028F, Satellite Number 25130) before its own decay on 24 December.

In February two other Soviet-era satellites met similar fates. Molniya 3-16 (1981-054A, Satellite Number 12512) decayed on 10 February, but five days earlier as many as 18 new objects were observed along its path by Naval Space Command's electronic fence. None of the debris were cataloged before reentry. About the same time, a 34-year-old Vostok upper stage (1964-006D, Satellite Number 751) was undergoing severe catastrophic decay, falling from an orbit of 110 km by 69,075 km on 6 February before reentering on 15 February. Within 48 hours before reentry the vehicle brokeup into at least 26 pieces.

All of the above incidents are assessed as aerodynamically-induced breakups and will be so noted in future NASA satellite breakup histories. Such breakups are probably unavoidable yet common for objects in decaying, highly elliptical orbits. Fortunately, the consequences are exceedingly minor and short-lived. Perhaps a benefit of these pre-reentry breakups is a reduction in the amount of material which might survive reentry and reach the surface of the Earth. ❖

Collision or Not?

In February press reports indicated that the third stage of a Minuteman 2 ballistic missile had apparently been struck by orbital debris (see, for example, Space News, 16-22 February 1998, pp. 3, 44). The vehicle was completing a short flight from Vandenberg AFB to the Kwajalein Atoll in the Pacific Ocean when it brokeup at an altitude of 450 km. At that time, the solid-propellant third stage had been shutdown and was nearing reentry. Airborne, sea-based, and ground-based sensors observed the unexpected breakup event. Although a collision with a piece of orbital debris large enough to fragment the stage was considered highly unlikely, the hypothesis was raised for serious investigation when one of the radars on Kwajalein appeared to have detected a small object in the vicinity of the vehicle immediately before the breakup. However, an extensive examination of the data cast doubt on the validity of the radar reading. Therefore, a collision-induced cause for the breakup is again assessed as a very low probability. ❖

NEWS, Continued

Beginning of Constellation Deployments

One of the important new contributors to the LEO environment will be commercial satellite constellations. Although these spacecraft networks will not represent any fundamentally new issues, failure to follow responsible procedures could exacerbate the orbital debris environment. By 31 March 1998 five constellations had begun deployments with 21 launches carrying 83 satellites (see table).

Spacecraft are deposited directly into their operational orbits in three of the five networks. Iridium satellites are initially placed in lower altitude parking orbits (between 500 and 650 km) for checkout before being raised to operational orbits of about 785 km. This technique allows spacecraft which malfunction very early to decay more quickly, as seen on two missions to date. Iridium satellites which are experiencing temporary difficulties can also be moved into slightly lower (~10 km) orbits below the operational vehicles.

Perhaps the most significant change observed with many constellation missions is related to the disposal of upper stages. Three different types of boosters are used to deploy Iridium satellites, and the upper stages normally perform propellant depletion maneuvers into much shorter-lived orbits (Delta II and Long March 2C) or directly into deorbit trajectories (Proton). On the first major Orbcomm launch with eight spacecraft, the Pegasus HAPS upper stage reduced its perigee by 400 km with a propellant depletion burn. After mission completion the Delta II second stage used by the inaugural Globalstar launch lowered its perigee by 1000 km! These actions not only reduce the likelihood of a subsequent propellant-induced explosion but also are significantly accelerating the removal of mass and cross-sectional area from LEO. ❖

CONSTELLATION	ALTITUDE (KM)	INCLINATION (DEG)	LAUNCH DATES	NO. OF S/C	LAUNCH VEHICLE
FAISAT	940-1020	82.9	24-Jan-95	1	COSMOS
			23-Sep-97	1	COSMOS
GLOBALSTAR	1420	52.0	14-Feb-98	4	DELTA II
GONETS	1410-1430	82.6	19-Feb-96	3	TSYKLON
			14-Feb-97	3	TSYKLON
IRIDIUM	780-790	86.4	05-May-97	5	DELTA II
			18-Jun-97	7	PROTON
			09-Jul-97	5*	DELTA II
			21-Aug-97	5	DELTA II
			14-Sep-97	7*	PROTON
			26-Sep-97	5	DELTA II
			09-Nov-97	5	DELTA II
			08-Dec-97	2	LONG MARCH 2C
			20-Dec-97	5	DELTA II
			18-Feb-98	5	DELTA II
			25-Mar-98	2	LONG MARCH 2C
			30-Mar-98	5	DELTA II
ORBCOMM	765-775	98.3	17-Jul-91	1	ARIANE 4
	735-745	70.0	03-Apr-95	2	PEGASUS
	815-825	45.0	23-Dec-97	8	PEGASUS XL
	780-875	108.0	10-Feb-98	2	TAURUS

* 1 Spacecraft failed in lower altitude parking orbit

NASA-DoD Orbital Debris Working Group is Formed

The first meeting of the NASA-DoD Orbital Debris Working Group was held in Colorado Springs during 13-14 January 1998. The working group was formed at the suggestion of the Office of Science and Technology Policy of the Executive Office of the President and assumed the remaining action items of the NASA-Air Force Space Command Partnership Council's Task Team on Orbital Debris. The co-chairmen of the new working group are Col. James Brechwald of Air Force Space Command and Nicholas Johnson of NASA.

The working group considered a large number of activities and selected and then prioritized 17 tasks. The focus of the joint work will be on the collection and interpretation of orbital debris space surveillance data for the purpose of better defining the current near-Earth environment. A special task group meeting was held at the NASA Johnson Space Center during 19-20 March to familiarize DoD personnel with the Haystack and HAX environment sampling efforts. The meeting also afforded the parties an opportunity to discuss plans and techniques for evaluating the threat of the 1998 Leonid Meteor Stream. ❖

News, Continued

1998 United Nations Meeting on Orbital Debris

The multi-year United Nations' examination of orbital debris issues reached a milestone 16-20 February with the discussion of mitigation measures during the annual meeting of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS STSC) in Vienna. This third year of formal presentations (1996 topic was measurements; 1997 topic was modeling) brought to a close the initial agenda objectives with a full draft report on the subject. The report will be reviewed during 1998 and adopted in its final form at the 1999 session.

During this year's meeting, presentations on orbital debris mitigation were made by France, Germany, Japan, the Russian Federation, the United Kingdom, the United States, the Inter-Agency Space Debris Coordination Committee (IADC), and the International Academy of Astronautics (IAA). A special working group was then assembled to prepare the third section of the draft report. Topics addressed included the minimization of mission-related debris, the passivation of upper stages and spacecraft at the end-of-mission, and the disposal of objects in low and high altitude orbits. The IADC was requested to assist the Subcommittee by assessing consequences of selected mitigation techniques on the future satellite population.

The 1999 session of the COPUOS STSC will also begin deliberations on what future actions, if any, the United Nations should undertake in this area. ❖

Project Reviews

Breakup Model Update

A comprehensive review and revision of the NASA standard breakup model has been in progress over the past several months. Since the last such review of the model, we have gone through another peak in solar cycle, so breakup fragments should show more evidence of atmospheric drag and provide better data for area-to mass ratio (A/M) analysis. We also have better catalog data on on-orbit fragments, and there have been additional ground tests. As a part of this project there were major efforts to develop analysis tools to derive A/M and breakup velocity distributions for the updated model. The former are described in this article, while the latter will be summarized in the next issue of the Orbital Debris Quarterly News.

One of the objectives of this task was to analyze the satellite catalog data to determine A/M values implied by their observed rate of energy loss resulting from atmospheric drag and to use this analysis to develop an A/M distribution function for the breakup model. To study this problem, two processors were developed to analyze high time resolution catalog data to determine A/M of breakup fragments. The breakups that were analyzed are shown in Table 1. One processor used a shooting method to establish a distribution in A/M from adjacent time-paired catalog data sets; a second used a non-linear least squares (χ^2) fitting method to the complete set of catalog data for a given object. The processors reflect a considerably different analysis approach, but provided consistent results. Plots of A/M vs. characteristic length for two of the breakups - the NOAA 3 rocket body and the P-78 spacecraft intercept test target - are presented in Figures 1 and 2. The characteristic length is derived from the radar cross-section (RCS) using the NASA Size Estimation Model from the Haystack radar data analysis project.

Both figures show a sharp cutoff in data below a size of 10 cm. The A/M values for the rocket body show higher value for A/M on the average than do the P-78 fragments, indicating that on the average the NOAA fragments will experience more atmospheric drag (at a given altitude) than will the P-78 fragments. If the orbiting fragments

(Continued on page 5)

Name	International Designator	Breakup Date	Breakup Orbit ha/hp [km]	Breakup Cause	Mass [kg][1] /# of Debris Cataloged[2]	Comment
SPOT 1 R/B	1986-019 C	11/13/86	835 / 805	Unknown	1520 / 489	ARIANE 1 Final Stage
NIMBUS 6 R/B	1975-052B	05/01/91	1103 / 1093	Propulsion	839 / 237	Delta 2nd Stage
NOAA 3 R/B	1973-086B	12/28/73	1510 / 1500	Propulsion	839 / 197	Delta 2nd Stage
NOAA 4 R/B	1974-089D	08/20/75	1460 / 1445	Propulsion	839 / 148	Delta 2nd Stage
NOAA 5 R/B	1976-077B	12/24/77	1520 / 1505	Propulsion	839 / 159	Delta 2nd Stage
LANDSAT 3 R/B	1978-026C	01/27/81	910 / 900	Propulsion	839 / 209	Delta 2nd Stage
NIMBUS 4 R/B	1970-025C	10/17/70	1085 / 1065	Unknown	600 / 372	AGENA D Stage
COSMOS 1045 R/B	1978-100D	05/09/88	1705 / 1685	Unknown	1360 / 44	SL-14 Final Stage
COSMOS 886	1976-126A	12/27/76	2295 / 595	Deliberate	1400 / 76	Test
COSMOS 970	1977-121A	12/21/77	1140 / 945	Deliberate	1400 / 70	Test
COSMOS 1275	1981-053A	07/24/81	1015 / 960	Electrical	900 / 305	Collision or Battery Malfunction
COSMOS 1375	1982-055A	10/21/85	1000 / 990	Electrical	650 / 58	Battery Malfunction
P-78 (SOLWIND)	1979-017A	09/13/85	545 / 515	Deliberate	850 / 285	Test

Table 1. Breakups Used for the A/M and Breakup Velocity Analysis

Project Reviews, Continued

Breakup Model Update, continued

(Continued from page 4)

are represented by standard shapes of spheres, plates, and cylinders/wires, from the location of fragments on these plots the large debris is better characterized by plates and cylinders (wires) than by spheres, particularly for the NOAA breakup.

The orbit data reveal different distributions for payloads and rocket bodies, as shown in Figures 3 and 4. The rocket body breakups are characterized by two well-defined triangular distributions that have relative importance based on the size of fragments being considered. As the size of the fragments decreases, the lower A/M triangular distribution becomes less important. The payload distributions show a single triangular distribution with an underlying rectangular floor. Because the differences between the distributions were similar at all sizes, fitting functions were derived for both payload and rocket body breakups. The new breakup model will use these two A/M distributions for the large fragmentation debris.

The SOCIT data were used to establish an A/M distribution for objects below catalog sizes using measured areas and masses for the fragments. A new shape analysis was performed on the data as a part of this analysis and led to lower values for average cross-sectional area. The characteristic length is a directly measured quantity for these fragments using the method adopted for measuring the irregular reference objects for RCS range measurements in the Haystack radar project. ❖

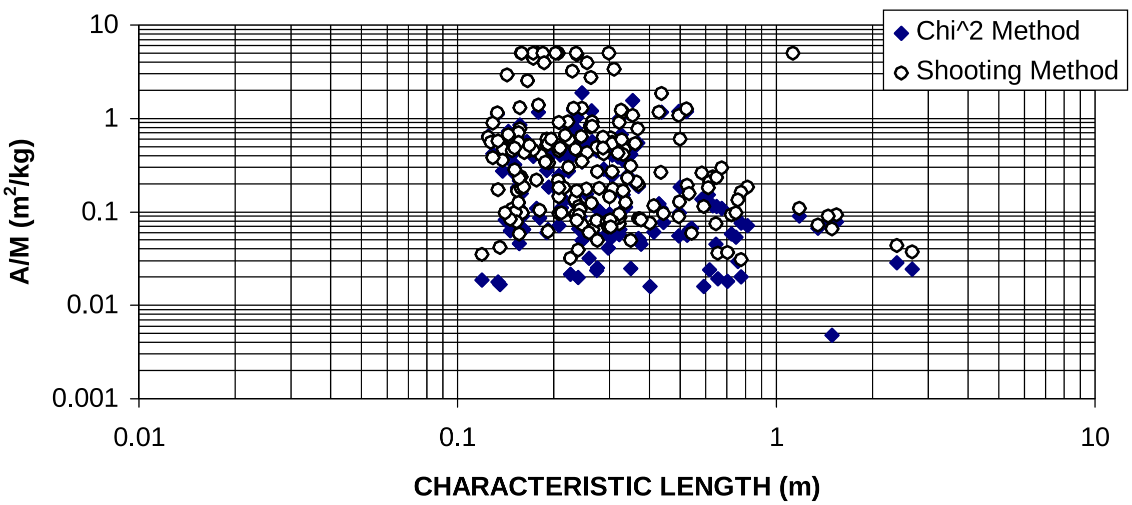


Figure 1. A/M for the NOAA 3 R/B Fragmentation.

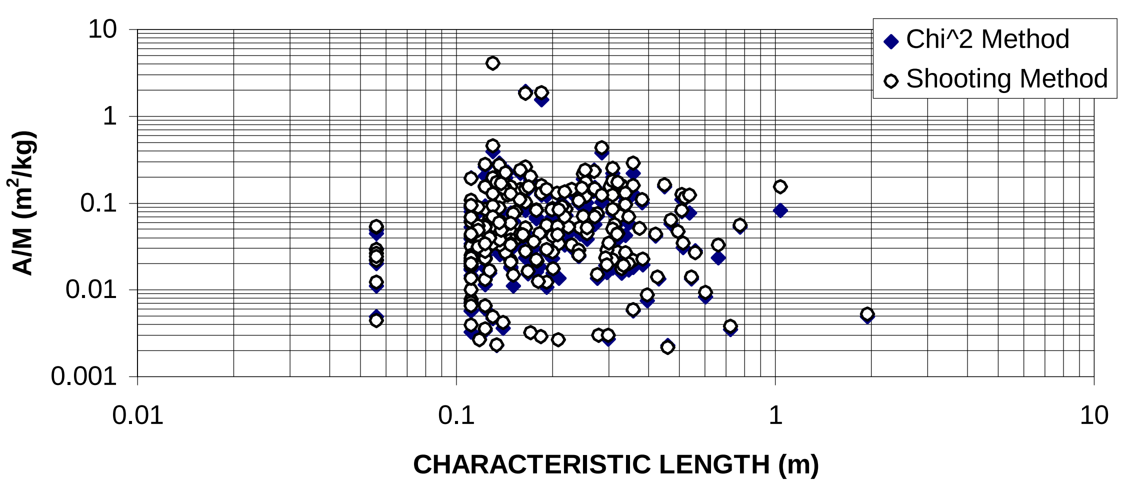


Figure 2. A/M for the P-78 / Solwind Fragmentation.

Project Reviews, Continued

Breakup Model Update, continued

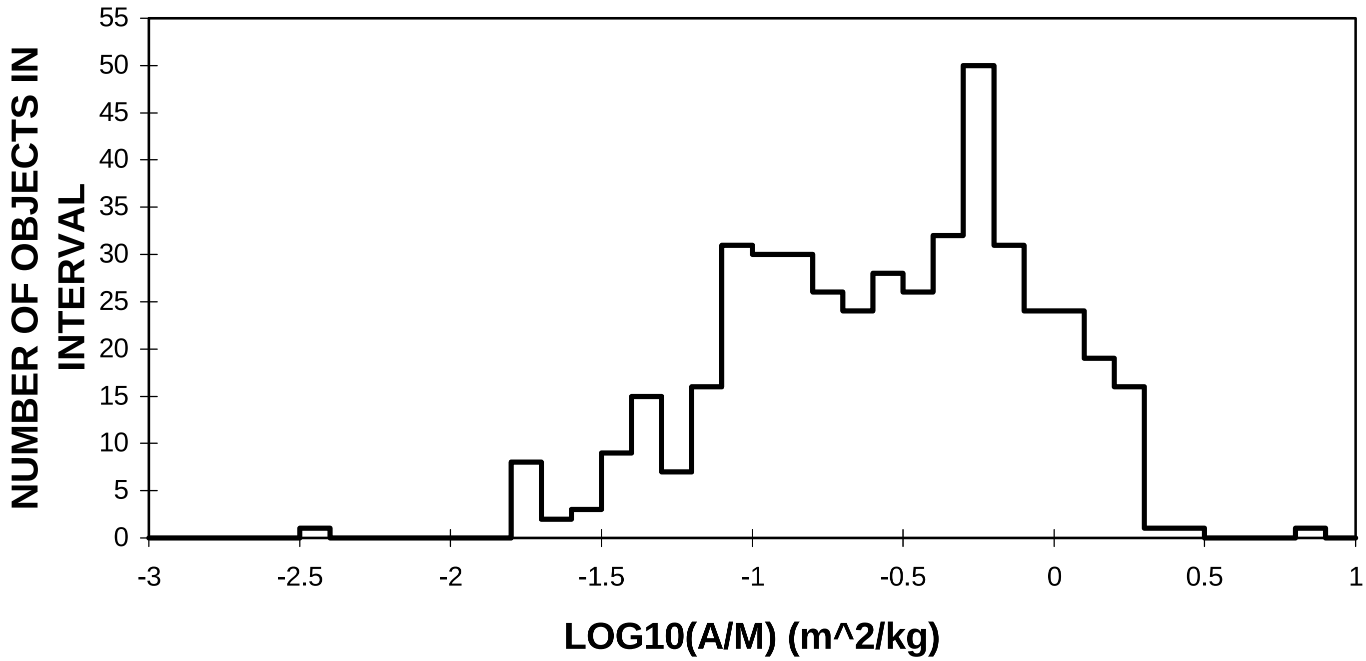


Figure 3. Distribution of Rocket Body Explosion Fragments (CHI2), Size Range = 10-15.8 cm, Number of Fragments in Distribution = 455.

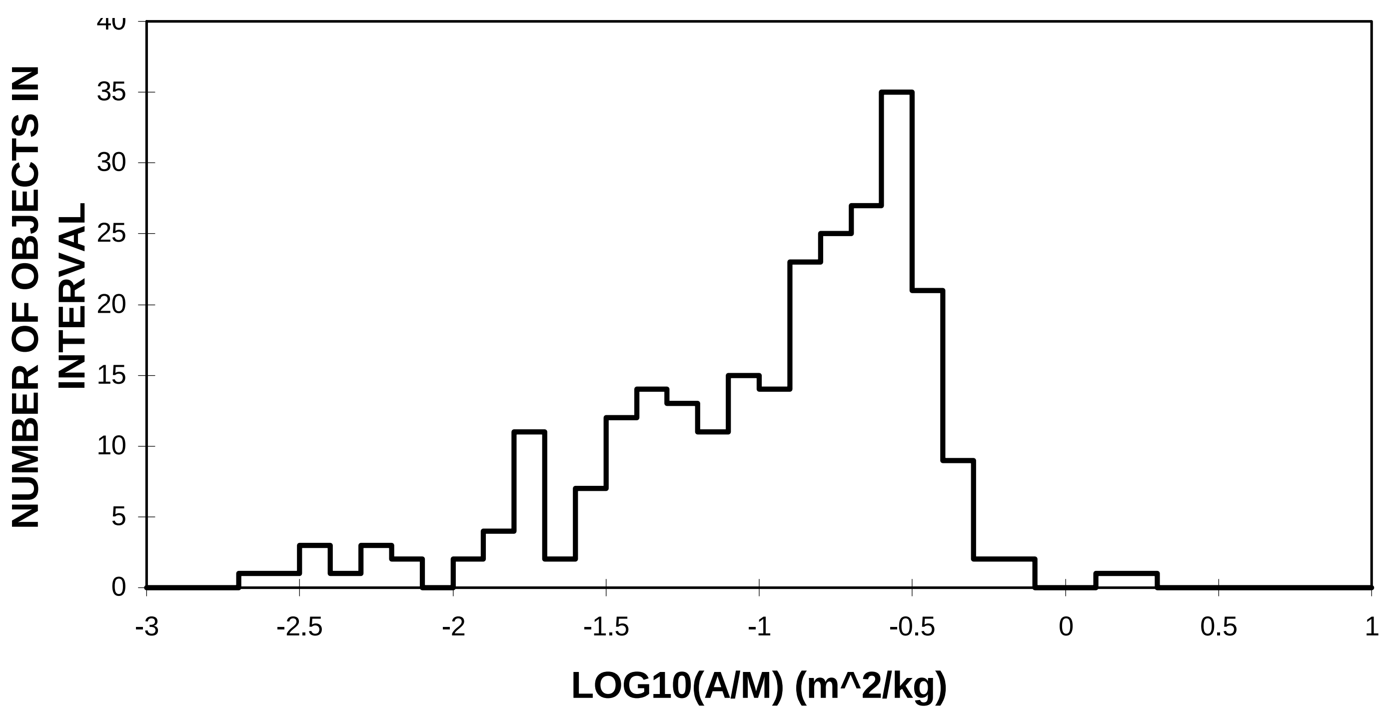
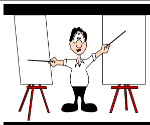


Figure 4. Distribution of Spacecraft Breakup Fragments (CHI2), Size Range = 10-15.8 cm, Number of Fragments in Distribution = 262.



Project Reviews, Continued

Final Report of the Haystack Data Review Panel

NASA began using the Haystack radar in 1990 to statistically sample the orbital debris (OD) environment to sizes smaller than 1 cm diameter. Haystack has been the primary source of the data on which current understanding and models of the environment are based. As such, NASA has striven to continually evaluate and improve the quality of the data and the inferences drawn from the data. Several peer review panels have been convened over the years to review the Haystack project. Starting in Dec. 1995, a panel headed by Dr. David K. Barton met to answer four specific questions dealing with the number and type of observations that have been made and the uncertainty limits which can be placed on the resulting size distributions. Their findings have now been published as NASA Technical Memorandum 4809. Other members of the panel included Dr. David Brillinger, Dr. A. H. El-Shaarawi, Patrick McDaniel, Dr. Kenneth H. Pollock, and Dr. Michael T. Tuley.

Their study has led to the following conclusions.

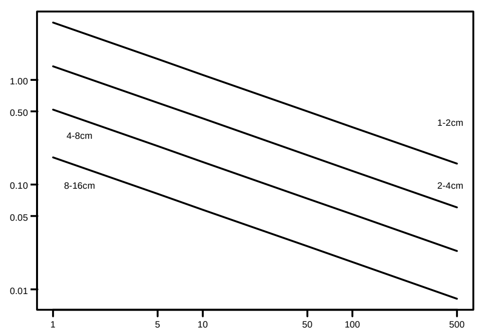
ISSUES

- *The number of observations relative to the estimated population of interest)*

The number of observations relative to the estimated population is a statistical question and the panel has taken a statistical approach to answering the question. An analytical procedure has been developed for calculating the number of observations required to estimate the target populations with prestated confidence bounds. The model takes into account known sources of error and assumes a family of distributions.

Conditioned on a number of assumptions which are discussed in Appendix A of the report, curves have been produced indicating the confidence interval for the population estimate as a function of the total number of observations available. Figure 1.1, based on a subset of the Haystack data collected in 1994 and representing 840 detections over a 97.22-hour observation period, shows the sort of behavior that might be expected as the number of observations increases. The curves in Fig. 1.1, parameterized as a function of debris particle size, show that confidence in the population estimate improves with increasing numbers of observations. These curves are illustrative of the type of results that can be obtained, but should not be taken as representing the actual values for the entire Haystack data set.

Standard Error of Detection Rate in Counts/Hour



Observation Time (hr)
(Includes Extra Poisson Variation Multiplier of 1.3)

Figure 1.1. Typical plots of standard error (s) for estimated number of detections per hour vs. total hours of observation for objects in different size intervals.

The details of the confidence interval curves will change as the population upon which they are based changes. However, a statistical procedure, explained in Appendix A, is available for NASA to produce curves based on other data sets.

- *The inherent ambiguity of the measured dBsm and the inferred physical size*

In the case of the conducting sphere, a given RCS in dBsm can be generated by as many as three different sphere diameters, producing ambiguity. The NASA size estimation model (SEM), although it follows the curve for average sphere RCS, was derived from many measurements at different aspect angles and frequencies on a sample set of 39 objects. The resulting translation of RCS to size is subject to uncertainty (not ambiguity), described by a distribution of size values about the mean, for a given RCS. Flux vs. size curves can be derived from Haystack data, along with estimates of their uncertainty, notwithstanding the variability of RCS with size, shape, and viewing angle. These distributions are taken into account in the development of the uncertainty bounds discussed under Issue #1.

- *The inherent aspect angle limitation in viewing each object and its relationship to the object's geometry*

A Haystack observation of an object is made at unknown aspects, representing samples from a possible 4π steradians of angle about the axis of the object. The conversion of measured RCS to size, via the SEM curve, is based on the average over all aspect angles and the distribution about this average caused by object shape and aspect angle variation. The use of this distribution in the derivation of confidence limits takes into account the fact that RCS values from only a limited number of aspect angles (typically one) are observed in a Haystack measurement.

- *Adequacy of the sample data set to characterize the debris populations potential geometry*

The sample data set derived from a high-velocity impact experiment produced a distribution of shapes that is quite similar to the distributions of shapes obtained from other high-velocity impact and explosion experiments. Without direct physical sampling of the objects on orbit, this is the most useful evidence that the measured data set is representative of objects on orbit. Therefore the measured data set can properly be assumed adequate to characterize the space debris population's potential geometry. ❖

Meeting Report

Government Industry Workshop

During 27-29 January 1998 representatives from the U.S. aerospace community, including launch vehicle and spacecraft manufacturers and owners as well as insurance and legal professionals, attended the U.S. Government Orbital Debris Workshop for Industry in Houston. The workshop originated from recommendations by the Office of Science and Technology Policy (OSTP) in the Executive Office of the President to hold workshops for industry focused on two orbital debris issues: national guidelines for mitigating orbital debris and orbital debris topics associated with commercial satellite constellations in low Earth orbit (LEO).

After a greeting by NASA Johnson Space Center Director George Abbey, Mr. Vic Villhard of OSTP reviewed the background for the workshop and set forth its objectives. Presentations were then made by representatives of NASA, DoD, the Department of Transportation's Federal Aviation Administration, and the Federal Communications Commission, describing their agency's interests and activities in orbital debris. Mr. Joseph Loftus, Jr., of NASA then summarized international orbital debris endeavors. Mr. Wayne Frazier of NASA Headquarters' Office of Safety and Mission Assurance followed with a background on the establishment of the NASA orbital debris safety standard (NSS 1740.14, August 1995).

The workshop attendees were then presented with a detailed explanation of the draft U.S. Government orbital debris mitigation standard practices which had been in development for over a year by an inter-agency working group. These draft standard practices are printed in their entirety on page 9 of this newsletter.

On the morning of the second day of the workshop emphasis shifted to the emerging commercial LEO satellite constellations. Characteristics of the systems proposed and being deployed were outlined. The issues of limiting the creation of mission-related debris, reducing the orbital lifetimes of mission-related debris and upper stages, and disposing of spacecraft at end-of-mission were addressed. Results from the NASA-Lockheed CONSTELL computer model were discussed for specific scenarios.

Three working groups were then formed for further deliberations on (1) normal operations and probability of impact, (2) end-of-mission passivation and disposal, and (3) collision avoidance. These working groups were led by Mr. Ruben Van Mitchell of FAA/DOT, Dr. Jeff Theall of NASA, and Lt. Col. Tony Andrews of DoD, respectively. Summaries of the working group observations were presented in a final workshop plenary session. The U.S. Government inter-agency working group on orbital debris is now reviewing the results of the workshop. ❖

Hypervelocity Shielding Workshop

Jeanne Lee Crews

The first Hypervelocity Shielding Workshop sponsored by NASA Johnson Space Center and The University Of Texas Institute for Advanced Technology was held 09-12 March 1998 in Galveston, Texas.

The workshop originated from a request by the JSC Director to address the recommendations from the National Research Council Report: Protecting the Space Station from Meteoroids and Orbital Debris. It was recommended that NASA hold a workshop to bring shielding experts from outside NASA to discuss advanced shielding concepts for possible implementation in future upgrades to existing International Space Station shielding and future shielding augmentation.

The workshop was hosted by NASA (Jeanne Lee Crews) and the Institute for Advanced Technology at the University of Texas at Austin (Dr. Harry Fair). After a greeting by Ms. Crews, Dr. Fair discussed the requirements for the workshop and established its objectives. Invited speakers opened the workshop: Mr. Donald Kessler, former NASA Senior Scientist for Orbital Debris Research and leading expert on the debris environment, presented a history of the orbital debris problem. Mr. Burton Cour-Palais, former NASA Senior Shielding Expert now with Southwest Research Institute, gave a history of the evolution of the requirement for NASA to shield manned spacecraft. Mr. Thomas Havel, U.S. Army Research Laboratory at Abereen Proving Ground, MD, discussed Armor Vehicle Technologies. Dr. William Isbell , General research Corp., summarized the U.S. DoD Investigations of Debris Generation and Spacecraft Shielding. Other submitted papers were presented by various shielding experts representing Universities, Industry, Gvernment, Japan, United Kingdom, and Russia.

At the end of each days presentations, seven working groups were formed and subjects ranging from launcher and diagnostic status and requirements to hydrocodes were addressed. The results of these working groups and the workshop proceedings will be made available in the near future.

The main points which emerged from the workshop were: 1) NASA is using state-of-the-art shielding for the ISS; however, for future shielding reqirements there are many new materials and potential concepts which require development. Thus, NASA should be funding research in the area of shielding materials and concepts. 2) There is a need to develop the capability to test in the area of concern: up to 15km/sec. Funding by NASA should support the development of launchers with this capability. 3) Hydrocodes need to be developed to support shielding designs and eventually decrease the need for expensive test programs. NASA should fund hydrocode development. ❖

Upcoming Meetings

The ***21st International Symposium in Space Technology & Science (ISTS),*** Japan, 24-31 May 1998. Web site: http://emu.crl.go.jp/ISTS/ISTSHome.html.

The ***32nd COSPAR Scientific Assembly,*** Nagoya Congress Center in Nagoya, Japan, 12-19 July 1998. Web site: http://cospar.isas.ac.jp/.

The ***49th International Astronautical Congress (IAF)***, Melborne, Australia, September 28 - October 2, 1998. Web site: http://www.iafastro.iplus.fr/.com.

The ***Inter-agency Space Debris Coordination Committee (IADC)*** meeting, Toulouse, France; 3-6 November 1998. ❖

Project Reviews, Continued

Draft US Government Orbital Debris Mitigation Standard Practices - January 1998

1. CONTROL OF DEBRIS RELEASED DURING NORMAL OPERATIONS

1-1. In all operational orbit regimes: Spacecraft and upper stages should be designed to eliminate or minimize debris released during normal operations. Each instance of planned release of debris larger than 5 mm in any dimension that remains on orbit for more than 25 years should be evaluated and justified on the basis of cost effectiveness and mission requirements.

2. MINIMIZING DEBRIS GENERATED BY ACCIDENTAL EXPLOSIONS

2-1. *Limiting the risk to other space systems from accidental explosions during mission operations:* In developing the design of a spacecraft or upper stage, each program, via failure mode and effects analyses or equivalent analyses, should demonstrate either that there is no credible failure mode for accidental explosion, or, if such credible failure modes exist, design or operational procedures will limit the probability of the occurrence of such failure modes.

2-2. *Limiting the risk to other space systems from accidental explosions after completion of mission operations:* All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload. Propellant depletion burns and compressed gas releases should be designed to minimize the probability of subsequent accidental collision and to minimize the impact of a subsequent accidental explosion.

3. SELECTION OF SAFE FLIGHT PROFILE AND OPERATIONAL CONFIGURATION

3-1. *Collision with large objects during orbital lifetime:* In developing the design and mission profile for a spacecraft or upper stage, a program will estimate and limit the probability of collision with known objects during orbital lifetime.

3-2. *Collision with small debris during mission operations:* Spacecraft design will consider and, consistent with cost effectiveness, limit the probability that collisions with debris smaller than 1 cm diameter will cause loss of control to prevent post-mission disposal.

3-3. *Tether systems* will be uniquely analyzed for both intact and severed conditions.

4. POSTMISSION DISPOSAL OF SPACE STRUCTURES

4-1. *Disposal for final mission orbits:* A spacecraft or upper stage may be disposed of by one of three methods:

a. Atmospheric reentry option: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit. If a space structure is to be disposed of by reentry into the Earth's atmosphere, either the total debris casualty area for components and structural fragments surviving reentry will not exceed 8 m^2, or it will be confined to a broad ocean or essentially unpopulated area.

b. Maneuvering to a storage orbit: At end of life the structure may be relocated to one of the following storage regimes:

I. Between LEO and MEO: Maneuver to an orbit with perigee altitude above 2000 km and apogee altitude below 19,700 km (500 km below semi-synchronous altitude).

II. Between MEO and GEO: Maneuver to an orbit with perigee altitude above 20,700 km and apogee altitude below 35,300 km (approximately 500 km above semi-synchronous altitude and 500 km below synchronous altitude).

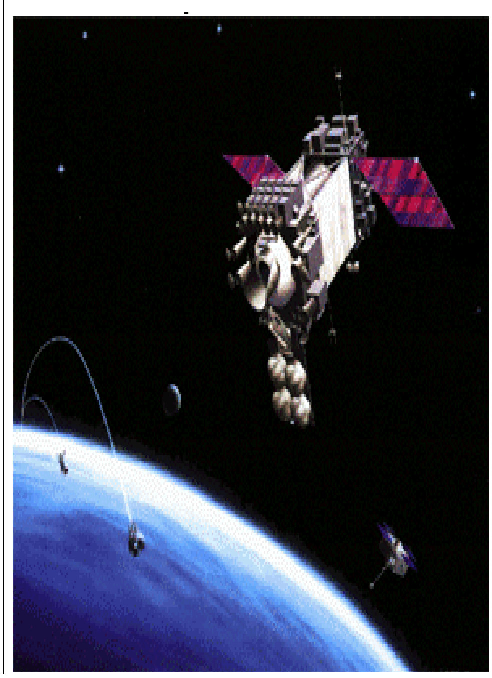
III. Above GEO: Maneuver to an orbit with perigee altitude above 36,100 km (approximately 300 km above synchronous altitude)

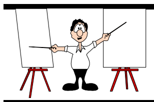
IV. Heliocentric, Earth-escape: Maneuver to remove the structure from Earth orbit, into a heliocentric orbit.

Because of fuel gauging uncertainties near the end of mission, a program should use a maneuver strategy that reduces the risk of leaving the structure near an operational orbit regime.

c. Direct retrieval: Retrieve the structure and remove it from orbit as soon as practical after completion of mission.

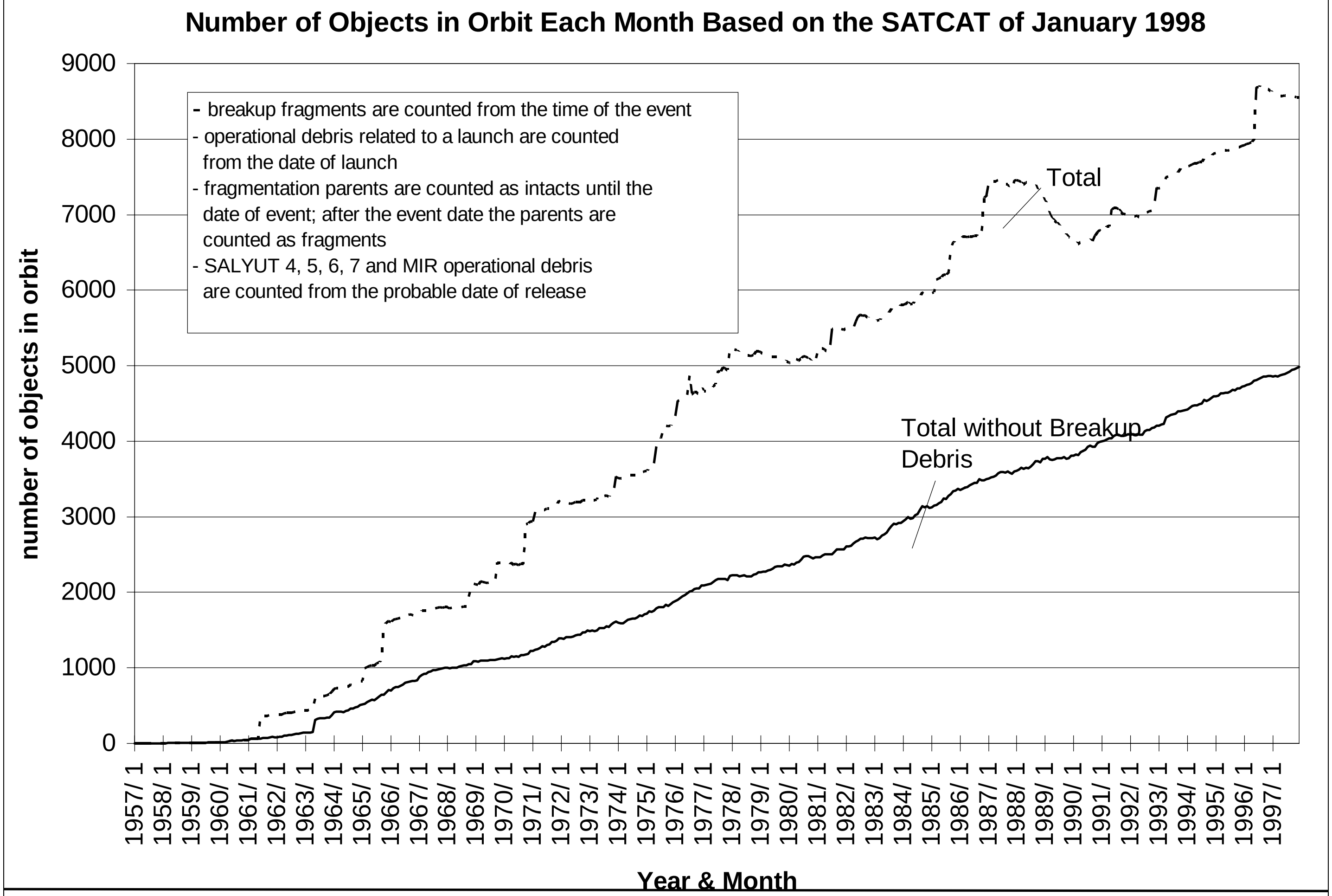
4-2. *Tether systems* will be uniquely analyzed for both intact and severed conditions when performing trade-offs between alternative disposal strategies. ❖





Project Reviews, Continued

Growth of the Number of Objects in Orbit



Anette Bade

Since 1957, the number of objects in orbit has been growing. The first breakup in June 1961 represents the first occurrence of a new source of Earth orbiting objects - orbital breakup debris. Since then numerous more breakups have occurred and contributed significantly to the orbiting population. The solid line in the frame shows the continuing growth of the number of objects in orbit without breakup debris until the end of 1997 on a monthly basis. The curve represents intact R/B and S/C, operational debris and debris from anomalous events like COBE. The dashed line represents the total number of all objects in orbit and shows the strong influence of the solar cycle on the debris part of the population.

Despite the wide range of launch rates during the past 35 years, the growth rate of Earth satellites excluding breakup debris has been relatively steady with little obvious influence from solar cycle effects. This growth rate may represent the future satellite population increase if satellite breakups can be eliminated. ❖

As you can see from this issue of the newsletter there is a great deal of activity in the orbital debris community. Within the Government there is more and more interaction, discussion, and coordination between agencies, as exemplified in the renewed and formalized NASA/DoD Orbital Debris Working Group. A real opportunity for extended Government / Industry interaction on orbital debris occurred in the U. S. Government Orbital Debris Workshop for Industry held in Houston in January as reported on page 10.

We have been fortunate to have Dr. Darren McKnight support the newsletter with guest articles having a non-Houston orbital debris perspective. Darren was the first the to identify the need for a focused newsletter for our community with his *Orbital Debris Monitor* and he has been a valuable contributor to our newsletter also. The January issue of the newsletter was Darren's last as a regular guest article contributor, but we are hoping he will be an occasional contributor in the future. Thanks very much for your contribution,

(Continued on page 11)

Next Issue

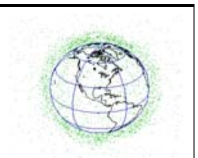
- Haystack Report
- Risk Assessment for Recent Breakups
- COSPAR Abstracts

ORBITAL BOX SCORE

(as of 31 March 1998, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	22	102	124
CIS	1329	2585	3914
ESA	23	204	227
INDIA	16	4	20
JAPAN	62	53	115
US	704	3206	3910
OTHER	310	24	334
TOTAL	2466	6178	8644

Check the desired box, complete form and mail to:
Cindi A. Karpiuk
NASA Johnson Space Center
SN3
Houston, Texas 77058



☐ **NEW SUBSCRIPTION**
☐ **ADDRESS CHANGE**

Name:	
Address:	
City:	
State:	
Zip Code:	
Country:	
Telephone:	
FAX No.:	
e-mail:	

INTERNATIONAL SPACE MISSIONS, January - March 1998

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1998-001A	LUNAR PROSPECTOR	USA	Lunar Orbit			1	0
1998-002A	SKYNET 4D	UK	35807	35765	4.19	2	3
1998-003A	STS 89	USA	382	359	51.64	0	0
1998-004A	SOYUZ TM 27	RUSSIA	385	379	92.19	1	0
1998-005A	USA 137	USA	No Elements Available			1	0
1998-006A	BRAZILSAT B3	BRAZIL	36037	35629	0.04	1	1
1998-006B	INMARSAT 3-F5	ESA	35826	35747	2.80		
1998-007A	GFO	USA	877	781	107.99	1	1
1998-007B	ORBCOMM FM3	USA	875	782	107.99		
1998-007C	ORBCOMM FM4	USA	874	781	107.99		
1998-008A	GLOBALSTAR U1	USA	Enroute to Operational Orbit			1	0
1998-008B	GLOBALSTAR U2	USA	Enroute to Operational Orbit				
1998-008C	GLOBALSTAR L1	USA	Enroute to Operational Orbit				
1998-008D	GLOBALSTAR L2	USA	Enroute to Operational Orbit				
1998-009A	COSMOS 2349	RUSSIA	279	213	70.37	1	0
1998-010A	IRIDIUM 50	USA	780	776	86.48	1	2
1998-010B	IRIDIUM 56	USA	780	775	86.50		
1998-010C	IRIDIUM 52	USA	Enroute to Operational Orbit				
1998-010D	IRIDIUM 53	USA	780	775	86.52		
1998-010E	IRIDIUM 54	USA	780	776	86.57		
1998-011A	COMETS	JAPAN	2492	398	30.05	1	1
1998-012A	SNOE	USA	580	535	97.70	0	2
1998-012B	BATSAT	USA	581	535	97.70		
1998-013A	HOTBIRD4	EUTELSAT	35810	35758	0.03	1	0
1998-014A	INTELSAT 806	INTELSAT	35792	35784	0.11	1	0
1998-015A	PROGRESS M-38	RUSSIA	230	189	51.70	1	0
1998-016A	UHF F/O F8	USA	Enroute to Operational Orbit			1	0
1998-017A	SPOT-4	FRANCE	811	791	98.80	1	0
1998-018A	IRIDIUM 51	USA	Enroute to Operational Orbit			2	4
1998-019B	IRIDIUM 61	USA	Enroute to Operational Orbit				
1998-019A	IRIDIUM 55	USA	Enroute to Operational Orbit			1	0
1998-019B	IRIDIUM 57	USA	Enroute to Operational Orbit				
1998-019C	IRIDIUM 58	USA	Enroute to Operational Orbit				
1998-019D	IRIDIUM 59	USA	Enroute to Operational Orbit				
1998-019E	IRIDIUM 60	USA	Enroute to Operational Orbit				

Editor's Note

(Continued from page 10)
Darren.

Because we will no longer have a regular contributor for the guest article, we will once again solicit guest articles from our readers. We are currently working on guidelines and review procedures for these articles so that if you spend your time preparing an article we will be able to use it. We have had several recent queries on articles and are deferring action on these queries until we have established and distributed these guidelines. Check the WVVW page with the newsletter for information prior to the next newsletter.

Finally, we are losing another member of the NASA orbital debris team with the retirement of Glen Cress. Glen headed the effort on acquisition and analysis of optical debris data from NASA's Liquid Mirror Telescope (LMT) and CCD Debris Telescope (CDT). This is an important effort in our group, and Gene Stansbery with the help of John Africano of Boeing will be leading these activities in the future. We wish Glen the best in his retirement and thank him for his contributions. ❖