The Orbital Debris Quarterly News

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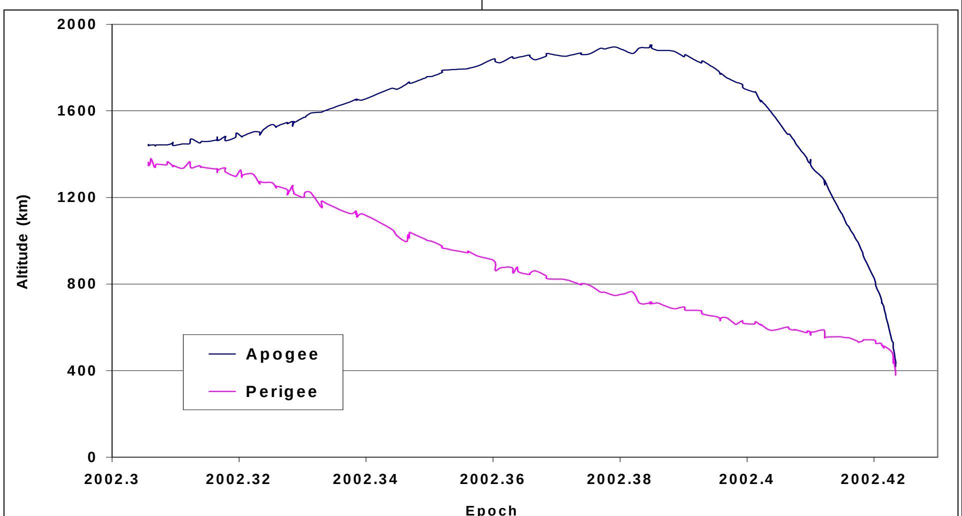
NEWS

A New Collision in Space?

A 30-year-old spacecraft was apparently struck in April by a small piece of orbital debris or a meteoroid. The event, which occurred at an altitude of approximately 1370 km, was sufficient to alter the orbit of the spacecraft and to produce a new piece of debris which was large enough to be tracked by several sensors in the U.S. Space Surveillance Network (SSN). Radar returns suggest the fragment diameter was between 20 and 50 centimeters.

Analysts of Air Force Space Command's 1st Space Control Squadron in Cheyenne Mountain near Colorado Springs, Colorado, noticed a new object in the vicinity of Cosmos 539 (1972-102A, U.S. Satellite Number 6319) and calculated that the fragment was ejected from the spacecraft on 21 April at a relative velocity of 19 m/s. The newly created debris was cataloged as U.S. Satellite Number 27423 on 6 May.

The magnitude of the ejection velocity was far greater than is customary for what are known as anomalous events, i.e., infrequent piece separations from older spacecraft and upper stages of launch vehicles. The causes of these debris-producing events are thought to be related to the degradation of satellite surface materials under the harsh temperature and radiation environment of outer space and to sub-millimeter particle impacts.



Orbital history of the fragment released from Cosmos 539 (April-June 2002).

Also immediately obvious was the high susceptibility of the fragment to solar radiation pressure, demonstrated by rapid and dramatic changes in its orbit. From an initial orbit of about 1365 km by 1445 km with an inclination of 74 degrees, the fragment's perigee began to decrease while its apogee increased. Within four weeks the orbit had been perturbed into one of 750 km by 1895 km. At this point, atmospheric drag became the dominant factor, causing the object to reenter the atmosphere a little more than two weeks later on 3 June (see figure). Thus, the fragment existed for only 43 days, despite originating in an orbit from which decay normally requires thousands of years.

Of equal interest was the behavior of the parent satellite, Cosmos 539. At the time of the event the spacecraft was in an orbit of approximately 1340 km by 1380 km. Satellite tracking data indicated that a small but permanent change in the orbit of Cosmos 539 coincided with the creation of the piece of debris. Such an orbital perturbation would be a natural result of a collision with a small object.

The orbital period of the spacecraft was reduced by nearly a second. Taking into account the mass of the spacecraft, this change in orbit could have been caused by a collision with a meteoroid or orbital debris only a few centimeters in diameter. Orbital debris are typically more dense than meteoroids, but their collision velocities are lower. The probability

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A New Collision in Space?, Continued

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of collision with any object of this size, which is below the detection threshold of the SSN, is low; however, at this altitude the flux of centimeter-size orbital debris is approximately 10 times that of meteoroids.

This event is reminiscent of an anomaly experienced by the NOAA 7 spacecraft. In August 1997, more than seven years after being decommissioned, the NOAA 7 spacecraft (1981-059A, U.S. Satellite Number 12553) also demonstrated an abrupt 1 second change in its orbital period, accompanied by the release of three debris. Although two of the new debris were released with low relative velocities, one of the fragments was thrown into a noticeably higher orbit.

Although it remains possible that on-board energy releases from the two long-dead spacecraft could have caused these events, the circumstantial evidence points toward collisions with unseen objects. ❖

Publication of the FY99 CDT Report

K. S. Jarvis

The report (JSC-29712) "CCD Debris Telescope Observations of the Geosynchronous Orbital Debris Environment, Observing Year 1999" has been published. NASA has been using the Charged Coupled Device (CCD) Debris Telescope (CDT), a transportable 32-cm Schmidt telescope located near Cloudcroft, NM, to help characterize the debris environment in Geosynchronous Earth Orbit (GEO). The CDT is equipped with a SITe 512 X 512 CCD camera. The pixels are 24 microns square (12.5 arcseconds) resulting in a 1.7 by 1.7 degree field-of-view. The CDT system is capable of detecting 17th magnitude objects in a 20 second integration which corresponds to a ~0.6-meter diameter, 0.20 albedo object at 36,000 km altitude. The telescope pointing and CCD operation are computer controlled to automatically collect data for an entire night. The CDT has collected more than 1500 hrs of data since November 1997. This report describes the collection and analysis of 81 nights (~530 hours) of data collected in 1999. It is available upon request. ❖

Second Identified Satellite Breakup of 2002

The second satellite breakup of 2002 has been belatedly identified. Tracking data from the U.S. Space Surveillance Network now indicates that an Ariane 4 upper stage (1992-041C, U.S. Satellite Number 22032) generated at least nine pieces of debris in February. At the time of the event the upper stage was in an orbit of approximately 250 km by 26,550 km with an inclination of 7.0 degrees. Due to low perigees, all debris are in steadily decaying orbits and will not present a long-term hazard to other resident space objects.

This marks the sixth known fragmentation of an Ariane 4 third stage. Interestingly, the last three vehicles involved in such events (1988-109C, 1991-075C, and 1992-041C) had been in orbit 9-10 years at the time of their respective breakups. All flights were conducted prior to the implementation of passivation measures for Ariane geosynchronous transfer missions in September 1993. No Ariane launch vehicle launched since that time is known to have experienced an on-orbit fragmentation.

During the second quarter of 2002, three minor debris-producing occurrences also took place. In May, SSN analysts detected an anomalous event involving a 16-year-old Soviet rocket body. The Vostok (also known as SL-3) upper stage (1985-090B, U.S. Satellite Number 16111) was in an orbit of 510 km by 565 km with an inclination of 97.7 degrees when a piece separated on 5 May. Through June the decay rate of the new debris was lower than that of the rocket body, which is atypical for debris of this type. Six other Vostok upper stages, aged 8-26 years, have been associated with similar anomalous events since 1987. These releases of debris are probably linked to the design of the vehicle.

A two-year-old Chinese Long March 4B upper stage (2000-050B, U.S. Satellite Number 26482) was the source of at least two new debris in mid June. The event occurred after the stage had fallen to 30 km below the International Space Station. This was only the fifth Long March 4B upper stage to be placed in low Earth orbit, and two of the previous four stages have suffered severe breakups after being abandoned, producing hundreds of new debris large enough to be tracked.

Finally, yet another anomalous event occurred during the second quarter of 2002, this time involving a 30-year-old spacecraft. See "A New Collision in Space?" in this issue for a complete description of this unusual incident. ❖

Project Reviews

Tools for Rule-of-Thumb Calculations for Orbital Debris

D. J. Kessler

Bob Naumann, who was responsible for some of the best meteoroid measurements and analysis during the 1960's, once said, "If you cannot get an approximate answer to a problem using the back of an envelope, then you don't know what you are doing". My desk at NASA may have looked like I collected empty envelopes, but I actually used them frequently for this purpose. Unfortunately, envelopes eventually get lost, along with the documentation of the solutions to those problems.

I have become a strong believer in the idea that one should know the approximate answer to a problem before tackling it with detailed computer calculations. However, to do this requires insight and some tools. In the past, I have published ways of integrating over various distributions in order to obtain a "properly weighted" average for that distribution. In this article, I will describe one of the tools that I have used to understand the relative importance

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Project Reviews

Tools for Rule-of-Thumb Calculations for Orbital Debris, Cont'd

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of various sources of orbital debris.

The cumulative number N of orbital debris or meteoroid particles of mass m or diameter s and greater can be approximated over some mass or diameter interval as

$$N = A\, m^{-\alpha} = B\, s^{-\beta}$$

where A, B, α, and β are constants. If mass density is independent of size, then $\beta = 3\alpha$. By taking the differential of these expressions, multiplying by the mass or area of a particle, then integrating to determine the total mass within that interval, one determines the following: If α is greater than 1, most of the total mass of the distribution is in the smaller sizes; if α is less than 1, most of the total mass is in larger sizes. If β is greater than 2, most of the total area of the distribution is in the smaller sizes; if β is less than 2 most of the total area is in larger sizes. This means that if the value of either α or β is decreasing with size, then the point on that distribution where a line proportional to m^{-1} or s^{-2} is tangent represents the region of maximum contribution to either mass or area, respectively. Let's apply this to the meteoroid flux and orbital debris flux.

Meteoroid Flux

The meteoroid flux given by Zook, et. al. (Icarus, 18, 953-964, 1970) includes detailed calculations of area and mass contributions from the meteoroid flux. Therefore, the Zook paper provides a good test of this simple technique. Figure 1 (All fluxes and areas used throughout this article are cross-sectional.) contains the cumulative meteoroid flux as given by Zook. Also shown is a line of "constant mass", represented by flux proportional to s^{-3}, and a line of "constant area" represented by flux proportional to s^{-2}. Each line was drawn tangent to the meteoroid curve. This chart tells us that most of the meteoroid mass is located at about 200 µm, where the lines are tangent to the meteoroid curve. Using the average mass density used in the Zook paper, this corresponds to a mass of 7.4 x 10^{-6} gm, very close to the value of 6.3 x 10^{-6} gm given in the paper. Similarly, most of the meteoroid area is located near a meteoroid size of 60 µm, or 2 x 10^{-7} gm, again very close to the value given by Zook. This 60 µm size was an important finding in 1970, because it was generally believed that much smaller meteoroids were responsible for the light scattering that produces the zodiacal light.

The total mass flux can now be approximated by the product of the flux at 200 µm times the mass of a 200-µm meteoroid. However, this calculation will consistently produce a smaller mass flux by several factors. This is because the calculation assumes there is no contribution from sizes smaller or larger than the major contributing size. For example, this simple calculation gives a mass flux of about 3.7 x 10^{-5} gm/m^2-yr. This corresponds to the Zook value of 1.2 x 10^{-4} gm/m^2-yr. Therefore, in this case, the actual value is about a factor of 3.2 larger than the value determined by the simple calculation. The simple calculation for the total area flux gives 2.8 x 10^{-3} cm^2/m^2-yr, where the Zook value is 1.3 x 10^{-2} cm^2/m^2-yr, or about a factor of 4.6 larger than the value determined by the simple calculation. A rule of thumb is that this simple calculation obtains values that are too low by about a factor of 4; exactly how low depends on how quickly the flux curve departs from its tangent constant mass or area line.

Orbital Debris Flux

The orbital debris flux given by the ORDEM96 model was used to illustrate these simple calculations, although the ORDEM2000 model could be used just as effectively as long as the flux vs. size plot includes sizes larger than 1 meter. Figure 2 contains the cumulative orbital debris flux at 900 km, also with a line of constant mass and a line of constant area. Again, each line was drawn tangent to the debris curve. However, this time the lines are tangent at much larger sizes. Most of the orbital debris mass is concentrated in about 2.5 m debris, while most of the area is in about 2 m debris. No other sizes are capable of significantly contributing to the total mass. However, this is not completely true of the area, where about 10% of the total area at 900 km

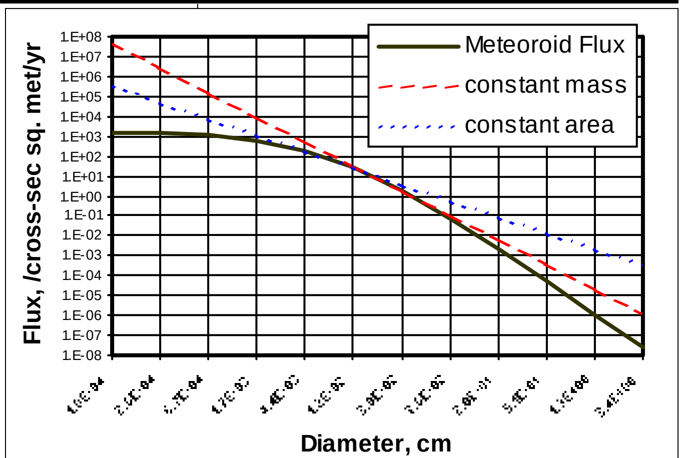

Figure 1. Meteoroid flux from Zook, et. al.

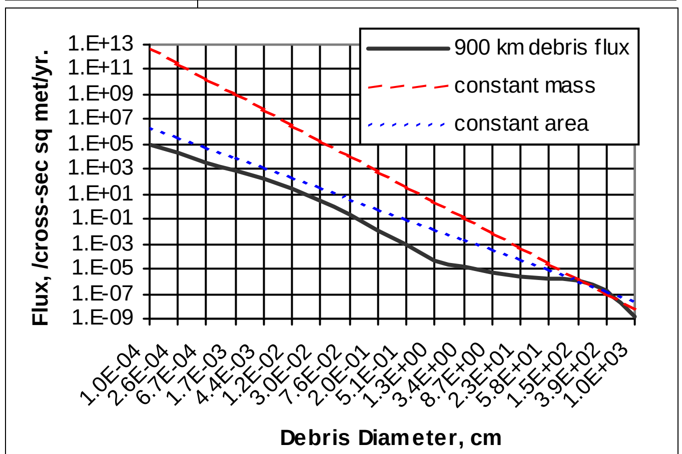

Figure 2. Orbital Debris Flux from ORDEM96: 900 km, 51.6 deg inclination in yr 2000

currently results from smaller debris over a broad range of sizes centered around 200 µm. The importance of this will be discussed later.

Knowing from the catalogue size distribution that about 25% and 20% of the nearly 9000 catalogued objects are larger than about 2 m and 2.5 m, respectively, and that the mass of a 2.5 m object is about 400 kg, and putting in the rule-of-thumb factor of 4 gives a total mass in orbit of about 3 x 10^6 kg, and a total cross-sectional area of about 3 x 10^4 m^2.

By combining this total area with flux levels for catalogued objects above 2 x10^{-6} /m^2-yr for much of LEO, one quickly determines that one should expect a collision rate between catalogued objects of about 0.06/yr, or once every 17 years. (The exact formulation includes a "½" factor and another factor of 2 or

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Tools for Rule-of-Thumb Calculations for Orbital Debris, Cont'd

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3 resulting from the collision cross-section area being several factors higher between nearly equally sized objects.) In addition, each collision is likely to catastrophically break up 2 satellites, producing about 800 kg of fragments for an average fragment production rate that exceeds 30 kg/yr.

A point of caution: The curve fit in ORDEM96 approximates the catalogue population and is not as accurate as the actual size distribution from the catalogue. The shape of the catalogue size distribution places both the area and mass concentrations at slightly larger values than in ORDEM96. Because these larger sizes also represent a smaller fraction of the population, the total mass and area are about the same as predicted from ORDEM96; however, since an average collision would involve larger satellites, the catalogue would predict a larger fragment production rate.

The fragment production rate of meteoroids impacting spacecraft surfaces can also be quickly approximated: Given the previous meteoroid total mass flux, the previous spacecraft total surface area, and the fact that a hypervelocity impact into an aluminum surface at 20 km/sec will eject about 400 times its impact mass, gives a meteoroid-induced spacecraft fragment production rate of about 1.4 kg/yr…lower than the fragmentation rate due to collisions between catalogued objects. However, some fragile spacecraft surfaces, such as glass or paint, will produce more fragment mass per collision, possibly contributing much more mass to the production rate of fragments.

Given the two fragment production rates of collisions between spacecraft and collisions between meteoroids and spacecraft, one might be tempted to conclude that meteoroid impacts with spacecraft surfaces are not an important debris source. However, the collision fragment size distribution varies as $m^{-0.8}$, meaning that most of the mass of this distribution is in the larger sizes—sizes slightly larger than the impacting object. Consequently, only about 1% of the mass of the more than 30 kg/yr produced by collisions involving meter-size objects will be smaller than 200 μm, whereas all of the 1.4 kg/yr produced by meteoroid impacts will be in this smaller size range. Consequently, meteoroid impacts might be an important source of debris around 200 μm and smaller, depending on the relative importance of other sources.

By comparing the size distributions of meteoroids and orbital debris for sizes smaller than about 1 mm, one can see that these smaller orbital debris sizes will generally produce a fragment rate that is about equal to or less than (depending on altitude) that caused by meteoroids. Therefore, one can conclude that collisions of this smaller debris at 10 km/sec with spacecraft surfaces will add to the 1.4 kg/yr of fragments caused by meteoroids, increasing the rate to perhaps 2 kg/yr.

In addition, the concentration of mass in the meteoroid environment near 200 μm and the quick reduction in the flux for smaller sizes are ideal conditions for the meteoroid environment to produce a significant "secondary" flux of ejecta sizes smaller than 200 μm from any near-by large surfaces. Such a flux was expected and observed on the lunar surface and has been observed on recovered spacecraft surfaces such as Solar-Max and LDEF. It should be expected to be more severe near any large structure such as the space station. For large structures in LEO, the more significant secondary environment will likely result from the concentration mass of large debris, possibly causing a significant secondary flux of ejecta larger than 1 cm. By comparing the lines of constant mass in Figures 1 and 2, the orbital debris mass flux is shown to be five orders of magnitude greater than the meteoroid mass flux. Therefore, as the space station increases in size, so will the secondary flux…possibly to levels greater than the primary flux; however, detailed predictions of the level of the secondary flux have never been performed.

And what about the minor orbital debris area concentration near 200 μm? Because it is not associated with a mass concentration, it cannot represent a significant source of debris. This size will be hit by smaller sizes more frequently than any other size, except the larger debris. Is this important? I'll leave the answer to this question to others…perhaps the only significances is that it represents the size that will most likely contribute to a "night glow" if the orbital debris environment continues to grow. ❖

Optical Observations of GEO Debris

P. Seitzer
Dept of Astronomy, University of Michigan

During the period January through March 2002 the University of Michigan's 0.61/0.91 m Schmidt telescope MODEST (Michigan Orbital DEbris Survey Telescope) was used to survey the geosynchronous regime in support of a worldwide observing campaign for the IADC. Observation was scheduled for a total of 42 nights (all dark or grey lunar phase), and data was obtained every single night. Only 3 nights had significant cloud cover.

The telescope and CCD camera survey a strip of sky 100 degrees long by 1.3 degrees high each night. A 5 second long exposure is obtained every 37.9 seconds. The limiting magnitude is fainter than 18th magnitude through a broad R filter. GEO objects are detected up to 8

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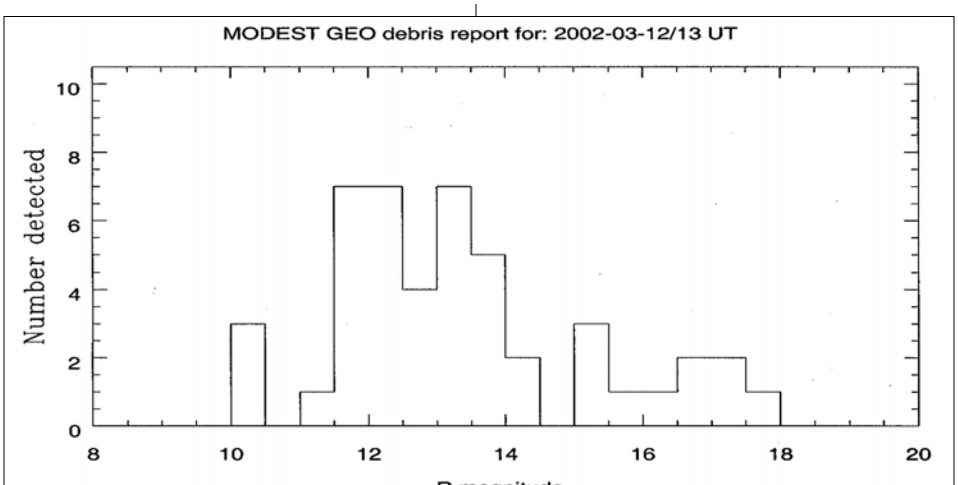

Figure 1. Histogram of magnitudes of GEO objects for the night of March 12 to 13, 2002.

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Optical Observations of GEO Debris, Cont'd

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times as they drift across the system's field of view. The data is reduced online, and the next afternoon a nightly report is sent back to the Orbital Debris Program Office in Houston. Further details on the project can be found in Orbital Debris Quarterly News, July 2001.

As an example of these observations, Figure 1 shows the histogram of detections for the night of March 12 to 13, 2002, when the system was observing a geocentric orbital latitude of +4.8 degrees. A total of 46 objects were detected with angular rates corresponding to those expected for uncontrolled objects at GEO. The brightest objects are intact spacecraft which have ceased stationkeeping. The faintest object detected this night was almost 18th magnitude. The lack of detected objects fainter than this is due to the system sensitivity, and should not be used to infer the lack of a faint debris population at GEO. Considerable effort is underway to tune up the system sensitivity to reach fainter objects.

Figure 2 shows the angular motions of objects detected that night. The error bar for motion is smaller than the size of the symbols. The limits for detection are currently set at -5 to +5 arc-seconds/second in declination, and -2 to +2 arc-seconds/second in hour angle. On this particular night, the 'dance' of uncontrolled objects was predicted to be moving south, which is clearly seen in this figure.

GEO debris observations with MODEST are expected to resume later this year.

This project is supported through a grant from NASA's Orbital Debris Program Office to the University of Michigan. ❖

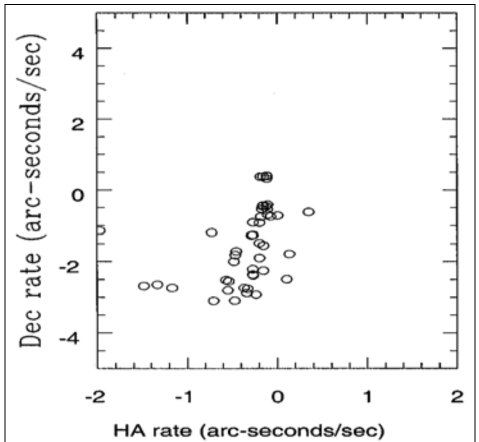


Figure 2. Distribution of angular motions for GEO objects for the night of March 12 to 13, 2002.

Satellite Breakups Remain a Problem After 40 Years

For more than 40 years the single largest component of the known Earth satellite population has been debris generated from the breakups of spacecraft and launch vehicle orbital stages. The first recorded breakup was a launch vehicle stage named Ablestar, which exploded a little more than an hour after deploying the Transit 4A satellite in June 1961. This event created nearly 300 fragments since identified by the US Space Surveillance System (SSN), of which two-thirds are still in orbit. Prior to the event, the entire Earth satellite population consisted of just over 50 objects.

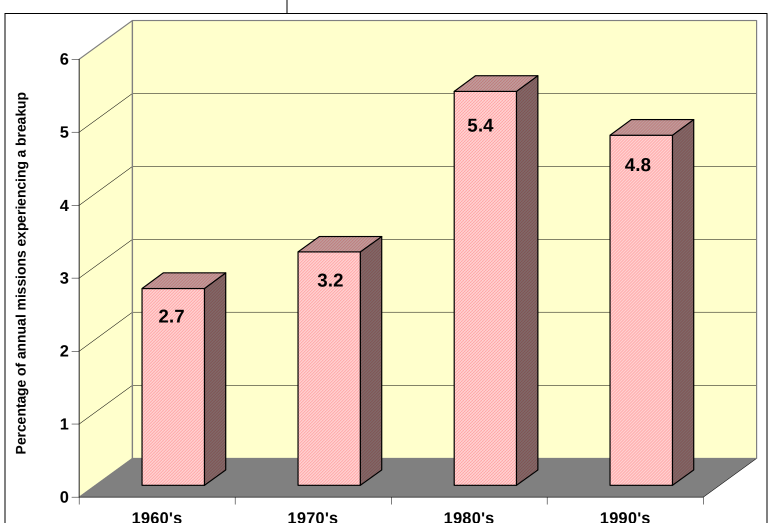
Officially, breakup debris today constitute approximately 38% of all cataloged satellites larger than 10 cm. In addition, the vast majority of approximately 1,000 objects currently being tracked by the SSN but not yet cataloged are almost certainly the remnants of 176 known satellite breakups. Studies of the Earth satellite population suggest that more than 95% of objects as small as 1 cm in diameter, which number at least 100,000, originated in satellite breakups. A collision with a 1 cm object is potentially catastrophic for all operational spacecraft.

Since 1981 the U.S. has strongly recommended the passivation of satellites, particularly launch vehicle orbital stages, at the end of their missions. The purpose of this process is to eliminate all sources of stored energy which might cause a satellite to explode, *e.g.*, residual propellants or pressurized fluids. No satellite which has been successfully passivated has later experienced a fragmentation. Today, all major space agencies in the world recommend passivation as part of disposal or decommissioning operations.

However, a recent assessment of the orbital debris population indicates that the prevention of satellite breakups remains a significant challenge. During the past four decades, more than 4% of all space missions have been linked to satellite breakups. The figure below illustrates the percentage by decade of launch; aerodynamic breakups which occur during or immediately prior to atmospheric reentry are not included. Perhaps surprisingly, the breakup rates for the 1980's and 1990's are actually higher than in the previous two decades. In part, this can be explained by the explosion of satellites many years after their launch, but a closer look reveals that this is a minor influence.

To date, 41 satellites launched during the 1990's have been the source of breakups. This represents 25% of all known breakups, despite the fact that the annual launch rate during the decade was only 85, down from 116 in both the 1970's and 1980's. In addition, of all the breakup debris still in orbit in 2001, almost exactly 25% was from the breakups of vehicles launched during the 1990's. Three of the largest debris clouds in orbit in 2001 were from launch vehicle explosions (Russian, Chinese, and American) which occurred following successful missions in the 1990's.

In February 2003 the United Nations will begin consideration of specific orbital debris mitigation guidelines. It is clear that the passivation of spacecraft and launch vehicles must remain a high priority. ❖



Nearly 5% of all space missions in the 1990's were involved in satellite breakups, which in turn contribute to the orbital debris population.

INTERNATIONAL SPACE MISSIONS

March—June 2002

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2002-015A	JCSAT 8	JAPAN	35769	35805	0.0	1	1
2002-015B	ASTRA 3A	LUXEMBOURG	35765	35806	0.0		
2002-016A	INTELSAT 903	ITSO	35780	35777	0.0	1	0
2002-017A	COSMOS 2388	RUSSIA	481	39868	63.1	2	1
2002-018A	STS 110	USA	309	402	51.6	0	0
2002-019A	NSS 7	NETHERLANDS	35785	35790	0.0	1	0
2002-020A	SOYUZ TM-34	RUSSIA	388	398	51.6	1	0
2002-021A	SPOT 5	FRANCE	825	826	98.8	1	0
2002-022A	AQUA	USA	699	706	98.2	1	0
2002-023A	DIRECTV 5	USA	35773	35800	0.0	2	1
2002-024A	HAIYANG 1	CHINA	793	794	98.8	1	1
2002-024B	FENGYUN 1D	CHINA	850	874	98.8		
2002-025A	OFEQ 5	ISRAEL	370	759	143.5	1	0
2002-026A	COSMOS 2389	RUSSIA	950	1017	83.0	1	0
2002-027A	INTELSAT 905	ITSO	35774	35800	0.1	1	0
2002-028A	STS 111	USA	349	387	51.6	0	0
2002-029A	EXPRESS 4A	RUSSIA	35776	35792	0.2	2	3
2002-030A	GALAXY 3C	USA	EN ROUTE TO OP. ORBIT			1	0
2002-031A	IRIDIUM 97	USA	658	670	86.6	1	0
2002-031B	IRIDIUM 98	USA	658	667	86.6		
2002-032A	NOAA 17	USA	807	823	98.8	0	0
2002-033A	PROGRESS-M 46	RUSSIA	387	398	51.6	1	0

ORBITAL BOX SCORE

(as of 3 July 2002, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	34	298	332
CIS	1334	2504	3838
ESA	32	280	312
INDIA	22	161	183
JAPAN	72	46	118
US	967	2771	3738
OTHER	323	27	350
TOTAL	2784	6087	8871

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Meeting Report

2002 Space Control Conference
23 – 25 April 2002 MIT Lincoln Laboratory, Lexington, Massachusetts

The 20th Space Control Conference was held at MIT Lincoln Laboratory in Lexington, Massachusetts, 23-25 April. The conference is coordinated with the Air Force Research Laboratory. The conference addressed Space Control Issues, Space Surveillance Technology, and Monitoring and Identification of Objects in Space. There were sessions on the Air Force Space Surveillance Network, Ground Observations from Space, the Space Surveillance Assessment (SSA) Sensors, SSA Metric Analysis, Debris and the Space Environment, and SSA Characterization. The Debris and Space Environment session had talks on NASA JSC measurements of the orbital debris environment, the optical emission characteristics of space debris, radiometric sizing of debris objects, and LINEAR- the database of the Minor Planet Center. ❖

Upcoming Meetings

15-21 September 2002: AMOS 2002 Technical Conference, Wailea, Maui, Hawaii. This annual conference features papers on the topics of optical equipment, space surveillance, and computing technology from all types of programs: academia, industry, government, and military. There are topics related to astronomy, atmospherics, new instruments, space object identification, and adaptive optics, as well as space debris. Additional information can be found at http://ulua.mhpcc.af.mil/AMOS2002/index.html

10-19 October 2002: The World Space Congress 2002, Houston Texas. This is the second joint congress of COSPAR, IAF, IAA, and IISL. Several debris-related sessions, including measurements, modeling, hypervelocity impact tests, and mitigation measures and policies, have been planned. Additional information for the congress is available at www.aiaa.org/WSC2002/index.cfm.