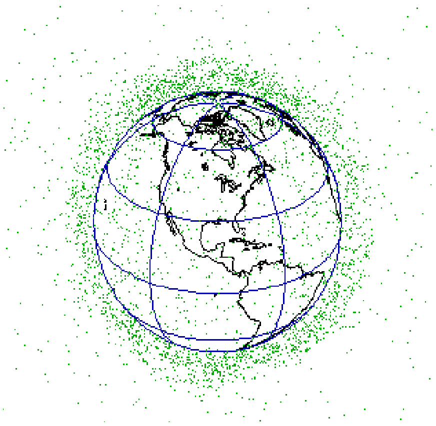
The Orbital Debris Quarterly News



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NEWS

Satellite Fragmentations in 1996

Nicholas Johnson

The year 1996 witnessed four significant satellite fragmentations, including the first recorded natural collision between two cataloged objects and the worst official satellite breakup in terms of cataloged debris. In addition, a number of anomalous events occurred with most related to classes of satellites known for such behavior.

On 19 February, the Russian Proton Block DM being used to carry the Raduga 33 spacecraft apparently brokeup into at least 200 objects near its first GTO apogee. Although no debris were cataloged, six to nine debris have routinely been in track by the US Space Surveillance Network during most of the year.

The breakup of the STEP II Pegasus/HAPS upper stage on 3 June created more than 700 trackable debris in LEO centered on the fragmentation altitude of 625 km (Orbital Debris Quarterly Newsletter, Vol. 1, Issue 2). By mid-December more than 650 debris were still in orbit (of which 534 were officially cataloged) and more than 75 cataloged debris had already decayed. Special observations of the debris cloud by the Haystack and Goldstone radars have provided insight into the smaller debris regime of 3-5 mm in diameter. Preliminary analyses suggest that the number of such small debris from this one event equals the previous background population of this size near 600 km. Hence, the risk to spacecraft like the Hubble Space Telescope from objects with approximately 3 mm or greater diameter has doubled.

The collision of the French CERISE spacecraft and a fragment from the SPOT 1 Ariane 1 upper stage on 24 July produced only one new piece of debris, but this event has highlighted the growing hazard of satellite collisions in LEO (Orbital Debris Quarterly Newsletter, Vol. 1, Issue 2). This event will be the subject of several papers in early 1997, e.g., at the AAS Guidance and Control Conference 06 February in Breckenridge, Colorado, USA and at the Second European Conference on Space Debris 17-19 March in Darmstadt, Germany.

Finally, on about 1 December 1996, a Proton Block DM auxiliary motor unit (SOZ) brokeup in a semi-synchronous transfer orbit (GLONASS-type), producing at least 100 detectable debris. This marks the 14th object of this type to breakup in LEO (3), SSTO (4), or GTO (7). The source of the

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ORBITAL BOX SCORE
(as of 01 JAN 1997, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies and Debris	Total
CHINA	16	96	112
CIS	1315	2521	3836
ESA	19	174	193
INDIA	14	3	17
JAPAN	54	55	109
US	657	3333	3990
OTHER	227	23	250
TOTAL	2302	6205	8507

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Satellite Fragmentations in 1996

latest event was an auxiliary motor used to support the Cosmos 1883-1885 mission of 1987 (Sat. No. 18374, International Designator 1987-079G). Although the probable cause of these breakups was identified by a joint Russian-American investigation in 1992, older units already in orbit before corrective actions were implemented are still subject to future breakups.

In 1996, four anomalous events which all involved the separation of a single new piece of debris were linked to a Soviet Vostok upper stage (Sat. No. 19046 on 30 July) in a sun-synchronous orbit and to three Transit-class spacecraft (Sat. Nos. 1952, 1864 and 2965) in polar orbits. Intriguingly, the three Transit spacecraft released their debris within a period of only eight days: 27 Nov - 5 Dec. Also during the year, a dozen debris were cataloged with the international designator 1966-077, purportedly originating from an old Agena D upper stage, Sat. No. 2403. However, some of these debris may be associated with other 1960-era missions. Prior to 1996, Sat. No. 2403 was linked with anomalous events in 1991, 1992 (2) and 1995.

INTERNATIONAL SPACE MISSIONS, OCTOBER - DECEMBER 1996

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1996-59A	FSW 2-3	China	171	342	63.0	1	1
1996-60A	MOLNIYA 3-48	Russia	610	39768	62.8	2	1
1996-61A	SAC-B/HETE*	US, Argentina	488	556	38.0	0*	0
1996-62A	MARS GLOBAL EXPLORER	US	Heliocentric Orbit			1	1
1996-63A	ARABSAT 2B	Arabsat Corp.	35742	35829	0.1	1	1
1996-63B	MEASAT 2	Malaysia	35777	35794	0.1		
1996-64A	MARS-96	Russia	85	1500	51.6?	1	0
1996-65A	STS-80	US	347	358	28.5	0	0
1996-65B	ORFEUS-SPAS	Germany	347	358	28.5		
1996-65C	WAKE SHIELD	US	347	358	28.5		
1996-66A	PROGRESS M-33	Russia	371	390	51.5	1	0
1996-67A	HOT BIRD 2	Eutelsat	35774	35797	0.1	1	0
1996-68A	MARS PATHFINDER	US	Heliocentric Orbit			1	0
1996-69A	KOSMOS 2335	Russia	403	417	65.4	1	0
1996-70A	INMARSAT 3-3	Inmarsat	35699	35878	2.7	1	0
1996-71A	KOSMOS 2336	Russia	979	1012	82.9	1	0
1996-72A	USA-129	US	No Elements Available			1	0
1996-73A	BION 11	Russia	219	377	62.8	1	5

*SAC-B AND HETE DID NOT SEPARATE FROM LAUNCH VEHICLE UPPER STAGE

Leonid Meteors

Mark Matney

While the Orbital Debris group at JSC is usually interested in man-made debris issues, there has been considerable interest lately with the upcoming apparition of the Leonids meteor storm. The Leonids is normally a minor meteor shower observable in November each year, but at certain times in history it has produced some spectacular displays. At such times, the observed meteor rates have jumped by several orders of magnitude over a period of a few hours. These displays have been associated with the return of its parent comet Tempel-Tuttle to the inner Solar System on its 33 year orbital period. The last time the Leonids "stormed" was in 1966, so meteor scientists and satellite operators are expecting renewed activity around the return of comet Tempel-Tuttle in 1998. While exact predictions are difficult, it is expected that the Leonids should have major displays in November of 1998 and/or 1999, with the highest rates probably in 1999. If the Leonids storm is as strong as some scientists have speculated, on-orbit satellites may be exposed to "years" worth of meteoroid flux exposure in just a few hours at the peak of the storm. Unfortunately, our data on the effects of a storm on operational satellites is incomplete, because the last storm in 1966 was at the dawn of the Space Age.

The meteoroids in the Leonids stream are very fast, with velocities around 70 km/sec, compared to typical velocities of 20 km/sec for sporadic meteoroids and 10 km/sec for orbital debris. Because of the geometry of comet Tempel-Tuttle's orbit, the Leonid meteoroids arrive from the "ram" direction (approximately) of the Earth's motion through space. The storm is expected to only last a few hours as the Earth passes through the densest part of the comet's dust trail, and it is hoped that the peak times can be predicted to within a few hours.

Several programs are underway to make measurements of the timing of the peak and mass distribution of the Leonids stream. It is hoped that this information, in conjunction with numerical models, can be used to improve the predicted time and magnitude of the peak of the storm. It is also of interest to measure the flux of

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Upcoming Meetings

Second European Conference on Space Debris, March 17-19, Darmstadt, Germany. Sessions on Modeling, Measurements, Hypervelocity Impact Testing, Protection, and Mitigation. For further information contact: Prof. Walter Flury at the European Space Operations Center, Darmstadt, Germany (e-mail: wflury@esoc.esa.de)

14th Inter-Agency Space Debris Coordination Committee Meeting will be held March 20-21 in Darmstadt, Germany.

15th Space Control Conference, March 25-27, Lexington, MA. This conference is traditionally concerned with the Space Surveillance Network. At this conference there will be reports on the Haystack/HAX project and reports on debris observations and debris characterization. The conference is sponsored by MIT Lincoln Laboratories. For further information contact the conference co-chairman, Dr. Lee Spence. (e-mail: spence@ll.mit.edu).

SPIE - Optical Science, Engineering and Instrumentation SD97 Symposium, 27 July - 01 August 1997, San Diego California, U.S.A. This year's theme promotes a comprehensive understanding of the debris environment with an eye toward evaluating the limitations of our knowledge, and to continue to explore the practical implications of operating in an environment with debris. For further information visit the SPIE Web Site at http://www.spie.org/web/meetings/calls/submissions.html or phone 360/676-3290; FAX 360/647-1445; e-mail: sd97@spie.org.

International Astronautical Congress (IAF), 06-10 October 1997, Turin, Italy. The conference theme "Developing Business for Space" will be explored through a series of symposia. Topics to include space technology, inner and outer space missions, economic, legal, management, political and environmental aspects of the world's programs for peaceful utilization of space. For further information, please contact the IAF Secretariat, International Astronautical Federation, 3-5 Rue Mario-Nikis, 75015 Paris - France

Meeting Report

Space Debris & IAA, IAF & COSPAR

Walter Flury

Professional societies have an important role to bring the space debris issue to the attention of a wider audience and to further the understanding of the various aspects of space debris.

The Committee on Space Research (COSPAR) holds its Scientific Assembly every second year. COSPAR is an interdisciplinary scientific organization concerned on an international scale with the process of all types of scientific research carried out with space vehicles, rockets, and balloons. Space debris at COSPAR is dealt with in the Scientific Commission B which is concerned with Space Studies of the Earth-Moon System, Planets and Small Bodies of the Solar System. More specifically, it is Sub-Commission B1 on Space Related Studies of Small Bodies in the Solar System, which covers the topic "Space Debris". Space debris sessions have been regularly held at COSPAR since 1982.

At the annual Congress of the International Astronautical Federation (IAF), several sessions on space debris usually take place. The IAF Congress comprises symposia organization by IAF Committees or by its sister organization IAA, the International Academy of Astronautics. At IAF, space debris sessions are organized by the IAA Committee on Safety, Rescue and Quality, by the IAA Committee on Space Plans and Policies, and by the IAF Symposium on Materials and Structures.

A plenary session on space debris was held at the IAF Congress in Oslo, 1995. In plenary sessions current topics of a general and wider interest are addressed. Plenary sessions are not in competition with other sessions running in parallel. They are of an inter-disciplinary nature and are usually well attended. In 1993, the IAA complied a position paper on orbital debris. It has been widely distributed including to the nations within the UN Committee on the Peaceful Uses of Outer Space.

The 48th Congress of the International Astronautical Federation will be held on October 6-10, in Torino, Italy. There have traditionally been three orbital debris sessions in the Safety and Rescue Symposium sponsored by the International Academy of Astronautics, plus a joint session sponsored with one of the IAF technical committees.

At the IAF in Beijing, the session was jointly sponsored with the launch vehicle committee; at Turin the joint session will be with the Space Systems Committee of the IAF. Abstracts for this meeting are due March 1, 1997.

Cour-Palais Receives Distinguished Scientist Award

Burton G. Cour-Palais, a retired NASA research scientist, was awarded the Distinguished Scientist Award from the International Hypervelocity Impact Society during their meeting in Darmstadt, Germany in October 1996. Cour-Palais, the first NASA scientist to receive this honor, was recognized for his work on shielding concepts to protect space-exposed hardware from meteoroid and orbital debris impacts. He supported the Gemini Program through the Space Station Program during his twenty-nine year career.

This award is given to scientists who have made a significant and lasting contribution to the field of hypervelocity impact science, the study of the effect of collisions at extremely high speeds, and is judged on its importance, scope, the service it yields and how it is currently used.

The Hypervelocity Impact Society awards grants for studies throughout the world. Its objectives are to foster the development and exchange of technical information in the discipline of impact phenomena by promoting technical excellence, encouraging peer reviewed publications and holding meetings on a regular basis.

Guest Article

The Need For Wake Debris Modeling

Darren S. McKnight

I. Introduction

The term “debris wake” was coined in the early 1990's to describe the small debris released from the exterior surfaces of large orbiting objects due to environmental effects such as thermal flexing, atomic oxygen erosion, small particulate impacts, etc. While at the time, the existence of debris wakes was merely theoretical, there were many observations and data points that clearly indicated that such continuously-generated debris clouds must be present to explain several interesting phenomenon. As early as 1982 manifestations of debris wakes were observed emanating from the Space Shuttle (Ref. 1). Two case studies in the 1990s heightened the awareness of so-called debris wakes: (1) the data from the Interplanetary Dust Experiment (IDE) on the Long Duration Exposure Facility (LDEF) showed numerous periodic encounters with highly-dense clouds of very small debris and (2) the close encounter of the STS-48 with a Soviet/Russian rocket body with such a geometry that the rocket body's debris wake created a highly directional impact flux on the Orbiter. Debris wakes are generally considered to consist of sub-centimeter sized flakes of paint/insulation and impact ejecta/spallation but may include larger debris depending on the construction of the parent satellite in question. The critical characteristic of a debris wake is that it is fairly continuously created, though observations have shown that significant pulses of debris are created as objects pass through the terminator. As a result of the continuous nature of the debris wakes and the many small impact features chronicled from returned spaceborne samples it is hypothesized that for the debris environment below 1 mm debris wakes are more significant to impact flux modeling than breakup debris and should be explicitly included in environment models.

This article will examine the methods and assumptions applied to the trackable and cm-sized debris components of the manmade particulate population and use these as a baseline to examine the importance of debris wake modeling. A conceptual approach to modeling debris wakes is provided.

II. Modeling of the Centimeter and Larger Debris Environment

The trackable debris environment population (roughly 10cm in diameter or greater) is continuously monitored by the space surveillance systems of the United States and the Former Soviet Union. The trackable satellite population is neither sampled nor estimated but measured directly. The sources for almost all of these objects are very well known and the time between observations of these objects is relatively small (hours to days) in comparison to their orbital decay rates (days to decades).

The major source of cm-sized object measurement is the Haystack campaign which has been conducted for over six years. (Ref. 2) Over 3000 hours of observations have been made by the Haystack complex since 1990 with over 9000 detections (i.e. nondestructive samplings) equating to an estimated population of 1-10cm debris on the order of 10 times greater than the trackable population across a wide band of low Earth orbit. Using engineering insight it may be surmised that this equates to detecting about 6000 - 8000 actual objects of an estimated 50,000 - 70,000 population of 1-10cm objects: around 0.1 - a smaller ratio than the unity value for the trackable environment. In addition, these smaller objects have characteristically larger ballistic coefficients (i.e. BC = $C_D A/m$) which result in faster orbital decay rates. The ability of using these data to model past, current, and future 1-10cm debris populations is suspect due to the fact that all the sources of such debris are not known and that they will decay in a couple of months to a couple of years.

III. Sub-Centimeter Sized Debris Environment Modeling

The purpose of the previous discussion of trackable and 1-10cm debris was to introduce the issue of data sampling applicability in determining population characteristics in context for the need for debris wake modeling.

In every way discussed thus far the sub-cm debris modeling efforts are made more difficult: less data taken less often for a more dynamic population fueled by largely unknown sources. While it is often implied that the millions of sub-cm debris created during breakup events are the source of the many micron-sized pits discovered on returned spaceborne samples, it can be shown that this is not the case. Table 1 provides lifetime calculations for several sized fragments for various applicable orbits.

Orbit	1micron	10micron	100micron	1mm
200/200	(< 1day)	(< 1day)	(< 1day)	(< 1day)
	[< 1day]	[< 1day]	[< 1day]	[< 1day]
200/1000	(< 1day)	(< 1day)	(< 1day)	(1day)
	[< 1day]	[< 1day]	[< 1day]	[2 days]
600/600	(< 1day)	(< 1day)	(3 days)	(20 days)
	[< 1day]	[4 days]	[1.5 mths]	[1 yr]
600/1400	(< 1day)	(5 days)	(2 mths)	(1 yr)
	[9 days]	[3 mths]	[2 yrs]	[3.5 yrs]

Table 1. Orbital lifetimes for fragments in various orbits considering only atmospheric drag. The terms in parentheses denote the lifetime for a solar max (1980) and the bracketed value is for solar min (1986). The "200/200" orbit is a 200km circular orbit

This table covers the relevant altitudes since nearly all *in situ* measurements have been from objects retrieved from 600km or below. From this table it can be seen that very small fragments have greatly decreased orbital lifetimes resulting in many more particles being needed to produce a given measured flux value. The flux values will come from returned samples or onboard impact detectors. The table below provides a summary of some of the more noteworthy data records for small manmade debris impact analyses focusing on the 100 micron

Guest Article, Continued

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The Need For Wake Debris Modeling, Continued

population. 100 micron was selected since it is an intermediate size in the debris wake continuum, and this size has been reliably measured by most returned sample efforts. There are few micrometeoroid impacts from this size object, and it is still large enough to pose a hazard to the Orbiter (window durability).

From Table 2 it can be seen that there is a wide range of estimates of the population of 100 micron particles at these altitudes which is to be expected due to the variety of altitudes, time frames, and means of data collection plus the fact that there is no reason to believe that the 100 micron population is a consistent quantity. Again, the ratio of number of impacts (destructive sampling of the population) used to derive population characteristics to the estimated population can be determined (last column in Table 2). It is drastically different than for the larger classes of debris: 0.0000002, on average.

For the 400-500km region the 100 micron flux determined by LDEF results in a requirement for a billion particles to be present to provide this constant background. This number population equates to a mass of about 400 grams which would have to be refreshed at least daily. An alternate hypothesis to the average background scenario is that the majority of the impact features come during a short period of time when the satellite encounters very dense debris wakes or otherwise-formed debris clouds. Such clouds would have to have a continuous source to remain viable as a contributor to the environment for any period of time. Indeed, the results from a short time period of the IDE experiment on LDEF point toward a very large percentage of the small impacts occurring during a small period of time. The concept of sub-cm debris being generated as discrete debris streams from larger objects rather than a uniform background level is the crux of the debris wake modeling.

The rapid decay of this small debris coupled with the infrequent measurements relative to the orbital decay of such debris is drastically different than the trackable debris assessment. The smaller debris require more constant tending than the trackable population even though the actual measurement frequency is reversed - years between measurements for sub-cm debris even though they have the orbital lifetimes on the order of days, at best. All the data taken by LDEF, Solar Max, Mir, etc. were outdated (i.e. the debris population estimated would have decayed) before the samples even reached the analysts on the ground. If the analysts were using this data to support the development of a predictive model that considered known input parameters and sources by which to compare the measured data to hypotheses and validation exercises, then the data would have long-term utility. However, without that context each sampling of sub-cm particulate data is merely a single data point with little, if any, importance relative to other samplings. All this discussion supports the need to develop a closed form, time-dependent model of sub-cm debris to include breakup debris, solid rocket motor effluents, and debris wakes. While the characteristics of breakup debris and solid rocket motor effluents have been studied in reasonable depth little has been done to model debris wakes.

Program	Years in Orbit	Average Altitude (km)	(Sample) Number of Impacts	Time Exposed (yr)	Area Exposed (m^2)	Flux ($\#/m^2/yr$)	Population Estimate	Sample/ Population
LDEF	84-90	350-500	855	5.7	150	1	1E9	9E-7
Solar Max	80-84	575	20	4	204	2	2E8	1E-8
Mir	86	375	5	1.6	0.2	0.9	9E8	6E-8
EuReCa	92-93	502	1080	0.9	40	30	3E10	4E-8
Hubble Solar Panels	90-93	614	750	3.6	21	10	1E10	8E-8

Table 2. There have been many examples of returned spaceborne samples providing a snapshot of the 100 micron manmade particulate environment as shown. The population estimate is the calculated number of fragments needed in a 50 km altitude bin centered on the sample altitude to create the given flux (Ref. 4).

IV. Solution to Sub cm-sized Debris Environment Modeling

Reference 5 was the first analytic conceptualization of a model for the debris wake phenomenon. As developed in this paper, debris wake models may be composed of release mechanisms such as atomic oxygen erosion, thermal flexing, and particulate impacts. The rate of production of debris via these three mechanisms is a function of material exposed, orbit, area exposed, attitude, year, and age. The state of the material exposed and its propensity to be released is a complex function of its orientation with respect to UV radiation, impacting particulates, original composition and/or bonding of material, and operational state of the parent satellite. There are several potential types of surfaces to be considered: paint, thermal insulation, bare metal, electrical wiring, etc.

Each resident space object (i.e. cataloged satellite) might have a series of release algorithms for each type of material which are a function of particle size. In this way, each resident space object (RSO) would have a release function (actually the sum of the individual material release algorithms) assigned to it that could be applied to the satellite catalog to represent a steady state sub-cm environment model that will in turn be modulated by atmospheric drag. However, while the environment could be determined as a function of altitude alone, the inherent nature of a debris wake would necessitate 3-D phasing information to truly utilize the functionality of newly developed debris wake models. This combination will not only provide precise impact rates for specific encounter geometries but also provide these as a function of material type.

These models can only be developed via a combination of hypothesis testing and validation exercises using returned spaceborne samples coupled with laboratory test data. A thorough review of the current database in both of these areas may provide some useful data, but most likely much new data will have to be acquired to allow the development of the debris wake models as envisioned. Current activities are underway to initiate the efforts required to substantially start this development process.

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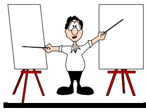


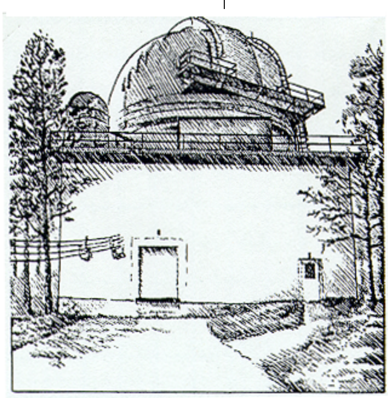
Project Reviews

Liquid Mirror Telescope

Glenn Cress, Andrew Potter

October 1996 marked the beginning of the operational phase for the Liquid Mirror Telescope (LMT), which was developed at NASA-JSC and moved to Cloudcroft, New Mexico for the purpose of measuring the population of small orbital debris. At the end of November, approximately 30 hours of video data had been recorded for future processing and analysis.

The LMT consists of a 3-meter diameter parabolic dish that holds several gallons of liquid mercury. The dish is spun up to a rate of 10 revolutions per minute. Centrifugal force and surface tension cause the mercury to spread out in a thin layer over the dish creating a reflective surface that is as good as any polished glass mirror. To provide the required stability, the mirror is mounted on a precision air-bearing. By "staring" straight-up, the telescope can observe the orbital debris that passes overhead through its 0.5 degree field-of-view. The LMT is "housed" inside a large 74-feet high observatory which was originally built by the US Air Force for satellite surveillance. This observatory, located just outside of Cloudcroft, N. M., provides excellent viewing conditions. The elevation above sea level is 9,061 feet. The skies are among the darkest in the USA, and the atmosphere contains relatively little water vapor, dust, smoke, or aerosols that affect the transmission of light through the air.



The Liquid Mirror Telescope Facility located in Cloudcroft, New Mexico

By comparing optical measurements from the LMT with radar measurements from the Haystack radar, we will be able to verify the radar data by an independent technique, and get a more complete picture of the 1 to 10 cm size debris environment, since radar and optical techniques do not see exactly the same debris population. (Some objects have high optical reflectivity, but low radar reflectivity, and vice versa). Cloudcroft is located at 32.9 degrees north latitude, which means that debris having orbital inclinations less that 32.9 degrees cannot be seen. However, the major fraction of debris in low earth orbit has inclinations larger than this value. A long-term goal for the LMT is to move it to an equatorial site, where measurements of debris at all inclinations could be made.

The original LMT detector is a Ford 2048 x 2048 15 micron pixel CCD that would be capable of very good performance for geosynchronous debris, if the LMT were located near the equator. This is because debris near geosynchronous altitudes move slowly across the field of view. However, its performance for fast-moving debris in low earth orbit has not been satisfactory because of its slow readout rate. We have improved the detection capability for fast-moving debris by installing an intensified CCD video camera that is on loan from Dr. Paul Hickson, University of British Columbia. This camera can detect low earth orbit debris as small as 5 cm, which is useful, but far from matching the capability of the Haystack radar. We are now in the process of procuring a new CCD camera that should be capable of detecting 1 cm size debris in low earth orbit. This new camera, which will be delivered in several months, will operate at speeds up to 200 frames per second and with extremely low read noise. Maximum signal to noise ratio is achieved by making the exposure equal to the pixel crossing time of a debris object. The output images can be stacked to form a cube, with two spatial dimensions, and one temporal dimension. The computational problem reduces to locating the trajectory of the debris image through this time-space cube. The disadvantage of this new detector is its smaller field-of-view (0.12 degrees), which makes it inefficient for detecting debris larger than about 3 cm in size. For this reason, we will probably use both the new CCD camera and the intensified CCD camera (which has a full 0.3 x 0.4 degree field-of-view) for alternate periods of time. Eventually, it should be possible to butt several of the high-speed CCDs together to cover the entire field of view.

Flight Readiness Reviews (FRRs)

Mark Matney, Al Jackson, Jing Chang Zhang

One of the tasks of the Orbital Debris Program is to support regular Flight Readiness Reviews (FRRs) for the Shuttle program to inform them of the expected orbital debris and meteoroid environment for each mission.

In June, the Pegasus HAPS breakup raised concerns for the Shuttle mission planners because of the large number of debris pieces that were being tracked from this breakup by the Space Surveillance Network. For the STS-79 FRR, a preliminary analysis of the breakup cloud based on model calculations was performed to estimate any increased risk to the Shuttle. It was determined that because of the low altitude (390 km) of the August mission, the risk would be well within operational guidelines.

Because of the unusually large number of debris from the Pegasus breakup, a series of special radar observations were performed to quantify the number of small debris in the cloud. The results of these measurements were incorporated into the FRR for STS-80. This mission was at a low altitude (350 km), and, despite the long duration of the flight, the computed addition of the HAPS debris flux did not place the Shuttle outside of normal safe operating parameters.

The original timeline for the STS-80 mission bracketed the Leonids shower. Even though the expected Leonid meteor storm is still several years away, it was predicted that the flux of Leonid meteoroids would be higher than usual. The expected flux from the Leonids was computed based on a reasonable estimate of the 1996 peak and it was shown that it did not adversely impact the allowable mission hazard, including a scheduled EVA. In the actual event, the mission was delayed past the expected peak from the Leonids.

Of special interest is the orbital debris hazard for STS-82. This is the next

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Project Reviews, Continued

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Flight Readiness Reviews (FRRs), Continued

Hubble repair mission and is scheduled for February, 1997.

Because of the high altitude of this mission (nearly 600 km), it is expected to encounter the highest flux of HAPS debris, approximately doubling the flux such a mission would be expected to experience from the normal debris background. The Shuttle program is in the process of incorporating the results into their flight plan.

EVOLVE Review and Breakup Modeling Update

Anette Bade

One part of this review was the detailed comparison of catalog data on 16 specific breakups with predictions from the current breakup models. Based on the analysis of the number distribution and the time history of the trackable debris, it appears that for the low intensity explosions of upper stages the ballistic coefficient of the trackable objects should be increased. At the same time the number of generated trackable objects should be increased. For this specific breakup class too few trackable objects were generated and they did not decay fast enough. These coherences became obvious due to the fact that since the last review in 1989 we have had another peak in the solar cycle. So now there was more interaction with the atmosphere since then.

Another important result is that a similar conclusion is reached when studying the complete debris population. The number of the trackable fragments in orbit each year is strongly influenced by the solar cycle, according to the SATCAT. The EVOLVE results do not show this influence to the same extent. The agreement between the SATCAT and EVOLVE for the rocket bodies and the payloads is quite good and may become even better when the new propagator for Molniya type orbits is integrated in EVOLVE. The mission related objects show some differences, which are mainly due to poor data.

The publication of the NASA technical report, containing the complete set of findings, is expected to be published early in 1997.

Official Release of the Engineering Model 1996

Jing-Chang Zhang and Nicholas Johnson

After incorporating the comments received from international orbital debris experts during the review process, ORDEM96 (Orbital Debris Engineering Model 1996) is ready for official release. The documentation has been published as NASA Technical Memorandum 104825.

Compared to the Beta test version, ORDEM96 Version 1.0 contains some changes. The most significant change is the correction of an error in the order of the angular distribution when calculating the flux crossing the FOV of a ground sensor. Other changes are rather cosmetic; for example, the program now runs on a computer without a co-processor and allows the user to choose the name of the output file or to input 0° and 180° inclination. There are no changes in the functional forms which describe the orbital element distributions of debris particles.

The document and the software were distributed to the international orbital debris community in December, 1996. ORDEM96 will also be available on the internet in the near future.

Leonids Meteor Shower

Walter Marker and Tom Settecerri

NASA/JSC is embarking on a joint program with the University of Western Ontario (UWO) in London, Ontario, Canada to assess the impact of high velocity meteors to spacecraft and space suits. The most notable meteors are Leonids associated with the 55P/Tempel-Tuttle comet. This comet, which returns to perihelion every 33 years, has been associated with spectacular events in the past. UWO is developing the capability to model meteor showers/storms in terms of flux and size distributions. NASA/JSC will conduct VHF radar measurement of the Leonids showers in 1996-1998 to support the modeling efforts. The overall goal is to predict the Leonid storm intensity in 1999/2000 after the parent comet is projected to return to perihelion.

Background: The visual meteor background (sporadic meteors where the brightness is greater than +6.6 magnitude) nominal zenith hourly rate (ZHR) is about 6 per hour. During the yearly Leonid meteor shower this rate increases to over 100 per hour depending on the observer's location. However, in 1999 or 2000 the rate could increase to over 100,000/hr. In addition, the high velocity of the Leonids (72 km/sec) combined with high flux could have a severe impact on spacecraft.

Radar Measurements: NASA/JSC operates a 300 kW VHF radar during the predicted meteor shower in 1996 to provide data to support UWO's modeling efforts. The VHF radar is capable of observing the ionization trail of meteors entering the Earth's atmosphere. Depending on their velocity, meteors ionize over a narrow range of altitudes. Radar observations of meteor ionization trails fall into two categories: overdense and underdense. The nomenclature is derived from the number of electrons generated per unit length. Overdense meteors reflect a high percentage of the radar energy and tend to persist greater than 0.25 seconds. Overdense echoes, because of their persistence, are important to high altitude wind profiling radars. The observed velocity (Doppler) is dominated by the slow movement of the meteor trails due to high altitude winds. Underdense meteors, which tend to reflect a low percentage of a radar's transmitted energy, persist for less than 0.1 sec. In addition, underdense meteor trails have very fast rise and fall times that require a special orientation for radar observations. The best orientation is to direct the radiation perpendicular to the meteors' apparent radiant. For the sporadic meteors the overdense meteors have a visual brightness of about +5.0 and higher; while those below +5.0 are usually underdense meteors. However, for the Leonids this demarcation is about +6.0. The NASA/JSC radar has the capability of observing ionization trails that have a limiting optical brightness of +12.0. This corresponds to meteors as small as 48 μm in diameter and equates to a mass of about 0.05 μgram. NASA/JSC hopes to characterize the 1996 Leonid shower in

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terms of flux and size per unit time. The flux is important to predict the storm intensity in 1999/2000. The potential to observe small size meteors could help refine the models by determining the lower size limit of particles that remain in the parent comet's orbit.

HAX Radar

Gene Stansbery, Tom Settecerri

NASA/JSC has begun augmenting its Haystack X-band radar measurements of the orbital debris environment with the Haystack Auxiliary (HAX) Ku-band Radar. The two radars are located in Tyngsboro, Massachusetts adjacent to each other. The HAX radar became operational in late 1993 and started providing NASA/JSC with debris data in 1994 while Haystack has been providing debris data since 1990. Because the two radars share much of the same real time processing and control systems, they cannot be operated at the same time. For debris observations, both radars are operated in similar beam park modes with their antennas pointing at specific azimuth and elevation angles and detecting whatever flies through their beams. Because HAX is less sensitive than Haystack, we had always planned to only collect HAX data pointed at the zenith. However, we discovered at Haystack that range rate (or Doppler) information can provide very good estimates of inclination for non-zenith pointing angles. Therefore, in FY96, we stared collecting data at 80-degrees elevation angle pointing east.

The orbital debris data is recorded at the Haystack facility and sent to JSC on 8mm magnetic tapes. In the debris mode the return signal strength from each pulse is recorded from four separate channels: the principal polarization sum , orthogonal polarization sum , the traverse difference and the elevation difference. The Orbital Debris Analysis System (ODAS) at JSC processed the data from the four channels to determine: range Doppler, Radar Cross Section (RCS), and path through the beam. The average RCS is converted to size using the NASA size estimation model, and the path through the beam is used to determine the orbital elements of the detected object. Each detection is compared with predicted beam crossings of satellites in the USSPACECOM catalog . In the past, Haystack measurements of inclination and size have compared very well with USSPACECOM values for correlated targets.

The table below shows a comparison for some of the Haystack and HAX radar's parameters. The figure below shows the cumulative detection rate verses the signal-to-noise ratio (SNR) for FY94 HAX data processed to date. The dashed line in this figure shows the theoretical false alarm rate due to noise alone (adapted from a computer program by Blake). The solid line shows the detection rate due to real targets plus noise. The point where the slope of the solid line turns up and the solid line approaches the dashed line is the practical SNR limit for the radar using the current detection scheme. The plot shows that we detect just over one object per hour before the detection rate is dominated by noise. We have chosen the detection threshold to give a false alarm rate of one false alarm every 10 hours, or about 10% of the detection rate from real targets.

A measurement comparison between the Haystack and HAX radars will be presented at the Second European Conference on Space Debris, in March 1997, in Darmstadt, Germany and at the MIT/LL Space Surveillance Workshop also in March '97.

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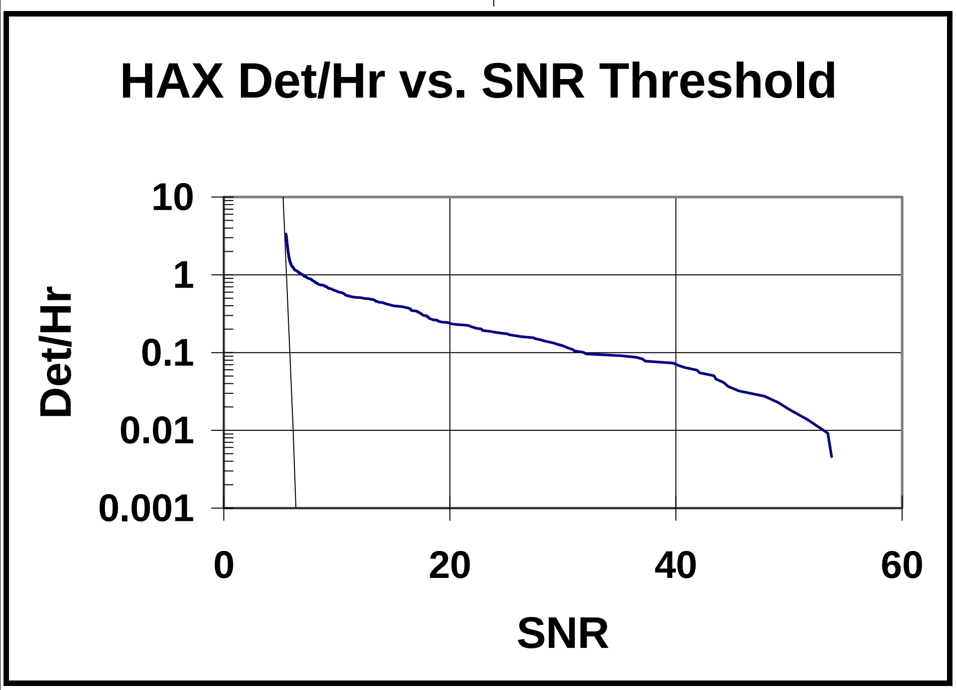

PARAMETER	Haystack	HAX
Peak Power (kW)	400	60
Pulse Width (msec)	1.024/2.009/4.998	2.009
Pulse Repetition Frequency	40	95
Antenna gain (dB)	67.2	64.0
Single pulse SNR on a 0 dBsm target at 1000km (1.024 msec pulse)	58 dB	43.0
Antenna Beam Width (FWHM-deg)	0.058	0.1
Number of Non-coherent pulses integrated for a detection	12	12

NEWS, Continued

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Leonid Meteors

"invisible" meteoroids - those with visual magnitudes too dim to be seen by ground observers but still large enough to damage spacecraft. In a joint program with the University of Western Ontario, NASA is using its VHF Transportable Radar to make measurements of the Leonids activity in November of each year. In addition, NASA astronomers at Cloudcroft Observatory are using NASA's CCD Debris Telescope to observe the column of dust along the parent comet's orbit to determine the spatial density, if possible. NASA's Liquid Metal Mirror Telescope will make observations of the shower to measure the rates of very dim meteors. In addition, the International Meteor Organization (IMO), a loosely knit, world-wide organization of meteor observers, will be collating its data to arrive at a global picture of how the Leonids behave each year.

NASA is also interested in computational modeling to determine the danger to spacecraft using the BUMPER code. These include the risk to the partially completed International Space Station as it will appear in 1999, the Space Shuttle, and a GEO TDRS satellite. It is hoped that an accurate picture of the risks to operational spacecraft will be available well in advance of the storm.

Abstracts from Papers

Engineering Model of the Debris Environment

Jing Zhang, Donald Kessler, Mark Matney, Peter Eichler, Robert Reynolds, Nicholas Johnson, Phillip Anz-Meador, and Eugene Stansbery

NASA's 1996 orbital debris engineering model was developed at NASA Johnson Space Center early this year and was reviewed by more than 20 international orbital debris experts from ESA, Russia, Japan, China, NASA and other US organizations. This model is a computer-based, semi-empirical model which combines direct measurements of the environment with the output and theory of more complex orbital debris models. It approximates the environment with 6 inclination bands. Each band has a unique distribution of semi-major axes for nearly circular orbits and a unique perigee distribution for highly elliptical orbits. In addition, each inclination band has a unique size distribution which depends on the source of debris.

Applying collision probability equations, the computer program ORDEM96 has been written to relate the distributions of orbital elements to flux on a spacecraft or through the field of view of a ground sensor. The program outputs the cross-sectional flux, including its velocity distribution and the relation between velocity and azimuth angle of an impact. The flux on an oriented surface, like the 14 surfaces of LDEF, is not directly provided. However, the velocity distribution and the relation between velocity and angle are sufficient for further processing in order to obtain the oriented surface flux. In this paper, we provide a technique for such a processing and calculate oriented surface fluxes for the orbits of the Space Station and the Space Shuttle.

Presented at the 47th International Astronautical Congress, 7-11 October 1996, Beijing, China, paper no.: IAA-96-IAA.6.3.04

Editor's Note

This past quarter has been relatively quiet in the orbital debris area, although there was a breakup of a Proton auxiliary power unit (SOZ) in semi-synchronous transfer orbit on December 1. Work continues on the Liquid Metal Mirror Telescope, currently located at the observatory at Cloudcroft, New Mexico. The reprocessing of the Haystack data is nearing completion, and in this issue we have the first reports from the Haystack Auxiliary (HAX) radar.

We also welcome submission of an article by Darren McKnight on debris wakes from spacecraft. Darren will be a regular contributor to the newsletter, reporting on debris topics of interest away from the Houston area. We will also be including two features from the Orbital Debris Monitor that were of interest to Darren's subscribers - the Quarterly Launch Report and the Box Score for the beginning of each quarter. We welcome Darren as a part of the newsletter crew and are sure that his articles will be of

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Guest Article, Continued

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The Need For Wake Debris Modeling

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3. McKnight, D.S., "LEO Orbital Debris Characterization: Issues and Concerns", Presented to the National Research Council's Committee on Space Debris Workshop, November 1993.

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5. Maclay, T.D., and McKnight, D.S., "The Contributions of Debris Wakes from Resident Space Objects to the Orbital Debris Environment," 45th Congress of the International Astronautical Federation, Jerusalem, Israel, Oct. 9-14, 1994, IAA-94-IAA.6.4.692.

Guest Article Submission Requirements

To submit an article to be considered for publication, please send it in machine readable format on diskette to

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Editor's Note, Continued

considerable interest to our readers.

Most of the group here is preparing for the Second European Space Debris Conference and the Interagency Space Debris Coordination Committee meeting that occur March 17-21 in Darmstadt, Germany. There was a large and diverse turnout for the First European Space Debris Conference, and we are anticipating that this conference should be very productive. We will have reports of both meetings in the next issue.

Next Issue

Report on the 2nd European Conference on Space Debris

Report on the Interagency Space Debris Coordination Committee meeting

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