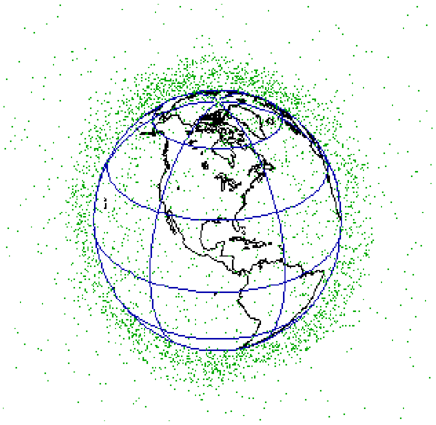
The Orbital Debris Quarterly News



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NEWS

Shuttle Modifications for Station Support

Joe Loftus

The space shuttle orbiter was designed for a meteoroid environment when its requirements were established in the early 1970's. The first orbital debris models were not developed until the mid-1980's and the early models were analytic in nature. Only with the development of ORDEM96 is there a semi-empirical model.

In the past the shuttle has been protected from the most adverse effects of the orbital debris environment by controlling the attitude orientation on the vehicle to minimize the exposure to damage that could cause early mission termination or critical damage that could induce hazard to safe entry. In the Mir missions and more particularly in the International Space Station assembly missions it is not feasible to always use such tactics, so modifications are to be made to make the shuttle more robust so that the risk level for these missions is no more than it has been for earlier missions.

Until August 1995 there had not been a detailed evaluation of the orbiter to establish criteria for orbital debris damage. A task group was formed to do the analysis, test and establish criteria for orbital debris damage. Because the orbiter was designed to fail-operational, fail-operational, fail-safe criteria there is a great deal of system redundancy, and the systems are physically separated.

There are three areas of concern: impact on critical structural components such as the windows and the crew compartment pressure vessel, the carbon-carbon leading edge, and the landing gear wheel well; impact on sensitive elements that could cause loss of capability and require early mission termination, e. g., the fluid loop of the radiators, one of the hydraulic lines in the trailing edge of the wing; and finally those impact events which induce turnaround work and program costs such as window hits which require replacement of the window because the stress concentration around the crater makes it unsuitable for the subsequent flight ascent loads.

To address the structural elements it was necessary to assess the criteria that were used to define critical impacts. This required testing to establish the ballistic response characteristics of the materials used in the various components of the shuttle. Because of the entry environment the carbon-carbon leading edge was the most critical. The concern is that the penetration of the carbon would allow the entry of hot gas during entry and destroy the structural integrity of the wing. Tests were conducted to define the ballistic response curve of the carbon and the effect of ejecta or spall from the first surface on the second surface. Samples with penetrations were then tested in the arc-jet heating facility to determine the erosion of the hole under conditions of entry heating. Finally, computational fluid dynamics techniques were used to determine the effect of the flow through the hole on the interior structure of the wing. At the conclusion of the

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Inside...

NEWS

INTERNATIONAL SPACE MISSIONS

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1997-058A	PROGRESS M-36	Russia	382	391	51.7	1	0
1997-058C	SPUTNIK JR.	Russia	385	389	51.7		
1997-058D	INSPEKTOR	Russia	378	388	51.7		
1997-059A	ECHOSTAR 3	USA	35712	35860	0.0	1	0
1997-060A	PHOTON 8	Russia	218	375	62.8	1	2
1997-061A	CASINI/HUYGENS	USA	Heliocentric Orbit			0	0
1997-062A	APSTAR 2R	China	35774	35798	0.1	1	0
1997-063A	STEP M4	USA	434	501	45.0	1	0
1997-064A	USA-133	USA	No Elements Available			1	0
1997-065A	DSCS IIIB 5	USA	No Elements Available			2	0
1997-066A	Maqsat H	ESA	533	26635	7.8	1	1
1997-066B	Masquat B (with RB)	ESA	533	26569	7.8	1	0
1997-066C	YES	ESA	540	26626	7.8	1	0
1997-067A	USA 134	USA	19911	20450	54.9	2	0
1997-068A	USA 136	USA	No Elements Available			1	0
1997-069A	IRIDIUM 43	USA	774	780	86.4	1	0
1997-069B	IRIDIUM 41	USA	772	782	86.4		
1997-069C	IRIDIUM 40	USA	768	770	86.4		
1997-069D	IRIDIUM 39	USA	773	780	86.4		
1997-069E	IRIDIUM 38	USA	768	771	86.4		
1997-070A	Coupon 1	Russia	35760	35812	0.0	2	3
1997-071A	SIRIUS 2	Sweden	35763	35803	0.1	1	1
1997-071B	INDOSTAR 1	Indonesia	Enroute to Op. Orbit				
1997-072A	RESURS-F21	Russia	208	245	82.3	1	4
1997-073A	STS-87	USA	281	286	28.5	0	0
1997-073B	SPARTAN 204-04	USA	280	285	28.5		
1997-074A	TRMM	USA	367	385	35.0	1	1
1997-074B	ETS 7	Japan	376	539	35.0		
1997-075A	JCSAT 5	Japan	35783	35791	0.1	1	1
1997-075B	EQUATOR-S	Germany	491	67203	3.9		
1997-076A	ASTRA 1G	Luxembourg	35466	36107	0.0	2	1
1997-077A	IRIDIUM 42	USA	767	770	86.4	1	5
1997-077B	IRIDIUM 44	USA	776	779	86.4		
1997-078A	GALAXY 8	USA	35779	35797	0.0	1	0
1997-079A	KOSMOS 2347	Russia	404	417	65.0	1	0

(table continued on page 4)

GAO Report Released on US Space Surveillance

Nicholas Johnson

In December 1997 the U.S. General Accounting Office (GAO) issued a report on the space surveillance needs of NASA and the U.S. Department of Defense (DOD). Entitled “Space Surveillance, DOD and NASA Need Consolidated Requirements and a Coordinated Plan” (GAO/NSIAD-98-42), the report summarizes the GAO’s evaluation of “(1) how well DOD’s space surveillance capabilities support DOD’s and NASA’s current and future surveillance requirements and (2) the extent to which potential surveillance capabilities and technologies are coordinated to provide opportunities for improvements”.

The 40-page report makes only two recommendations:

“The GAO recommends that the Secretary of Defense and the Administrator of NASA, in consultation with the Director of Central Intelligence, establish a consolidated set of governmentwide space surveillance requirements for evaluating current capabilities and future architectures to support NASA’s, DOD’s, and other federal agencies’ space

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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	22	101	123
CIS	1325	2519	3844
ESA	23	201	224
INDIA	16	4	20
JAPAN	61	55	116
US	684	3220	3904
OTHER	288	25	313
TOTAL	2419	6125	8544

NEWS

New NRC Report on Orbital Debris

Nicholas Johnson

The U.S. National Research Council, acting on behalf of the National Academy of Sciences and at the request of NASA, has recently released the third in a series of studies on the hazards of the orbital debris environment. The new report, "Protecting the Space Shuttle from Meteoroids and Orbital Debris" (December 1997), follows earlier studies on the general orbital debris issue ("Orbital Debris, A Technical Assessment", 1995) and International Space Station-related issues ("Protecting the Space Station from Meteoroids and Orbital Debris", 1997).

This latest report examines five major areas: risk to the Orbiter and crew, risk management strategy, tools for risk assessment, collision avoidance, and risk mitigation. In all, 10 recommendations are made, many of which represent activities already underway at NASA. The NRC committee, comprised of experts in Space Shuttle systems, the orbital debris environment and effects, and vehicle survivability, found "that the threat to the shuttle from meteoroids and orbital debris is real, although the magnitude of the threat and the resulting hazard are not clear". The committee also concluded that "NASA has developed a world-class center of expertise on the meteoroid and orbital debris hazard". NASA's ORDEM96 and BUMPER models received high praise, although modifications to improve model fidelity were recommended. The committee also noted recent decisions to improve the Orbiter itself to increase reliability and safety (see "Shuttle Modifications for Station Support" elsewhere in this issue).

The NASA Space Shuttle program office is now reviewing the report and evaluating its findings and recommendations.

Shuttle Modifications, *continued*

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process a new damage criterion was defined that indicated that the shuttle was significantly more robust than the earlier criteria had acknowledged. The critical area of the wing is the mid point of the wing leading edge where the nose shock and the wing shock intersect. The thermal insulation on the wing spar, which was initially designed for the radiant heat from the reinforced carbon-carbon leading edge, is to be modified to accept the heat loads of reentry plasma through a penetration of the RCC.

Modifications to the cooling system to make it more robust consist of "armoring" the fluid loop lines in the radiator by bonding over them a 0.020" strip 0.40" wide. To further protect cooling capability, an isolation valve was added at the accumulator. The valve allows the crew to isolate a penetrated radiator and preserve the coolant flow through the flash evaporator, so that while cooling is reduced it is not lost to a level that requires early termination of the mission.

While the shuttle cannot be made as robust as the station shielded elements, these modifications reduce its risk estimates to values comparable to the station for the limited periods it is at the station. Further modifications are being evaluated.

Recent Satellite Fragmentation Investigations

Nicholas Johnson

During the final quarter of 1997 three satellite breakups, two new and one historical, were the focus of investigations by NASA and the U.S. Space Surveillance Network (SSN).

Early on 27 November a 10-year-old Soviet spacecraft, Kosmos 1869 (Satellite Number 18214), broke into at least 20 fragments from its orbit of 604 km by 634 km with an inclination of 82.5 degrees. The event dictated immediate attention for two reasons: the Space Shuttle Columbia (STS-87) was in orbit at the time and the debris exhibited unusually high decay rates, indicative of large area-to-mass ratios. In fact, the decay rates were so large that within four days after the breakup, all but one debris had apparently reentered the atmosphere. Due to the large decay rates, determination of the initial ejection velocities was very difficult. However, it is likely that all fragments were released at very low velocities. Analysis is still continuing, but the 1900 kg spacecraft appears to have remained essentially intact.

The Christmas Eve launch of the Asiasat 3 spacecraft by a Russian Proton booster experienced an apparent explosion of the DM3 fourth stage (Satellite Number 25129) at the start of the apogee kick burn on Christmas morning. The malfunction bears a strong resemblance to the breakup of the Raduga 33 Proton fourth stage on 19 February 1996. In that case, approximately 200 debris were found in the geosynchronous transfer orbit. Early observations by the SSN found less than 10 objects which might be associated with the Asiasat 3 upper stage breakup. The investigation into the event is continuing.

Finally, analysts at Naval Space Command in Dahlgren, Virginia, have identified as many as nine debris associated with the breakup of Kosmos 1285 (Satellite Number 12627) on 21 November 1981. However, most or all of these objects may have originated from Satellite Number 12933, one of the two officially cataloged debris from the original breakup. Kosmos 1285 was a member of the Oko family of spacecraft placed into highly elliptical orbits. From 1977 (starting with Kosmos 862) until 1984 a total of 16 spacecraft are believed to have been fragmented by an explosive charge placed on the spacecraft. After 1984 the explosive was no longer carried, and breakups ceased.

NEWS

DoD Policy on Disposal of Satellites

Robert Reynolds

United States Space Command (USSPACECOM) has published a policy directive for the disposal of DoD spacecraft, “Satellite Disposal Procedures,” UPDIO-39, 3 November 1997. The directive does not address upper stages used to place those spacecraft in their mission orbits. The directive includes procedures to prepare for disposal of satellites approaching end of life as well as acceptable disposal procedures. The first priority for disposal is given to safing the satellite. The second priority is transferring the satellite to a disposal orbit as follows:

(1) LEO programs (Defense Meteorological Satellite Program (DMSP)): The goal is for future DMSP satellites to have the capability of transferring to a disposal orbit with a lifetime no longer than 25 years.

(2) MEO (Global Positioning System (GPS)): Boost GPS spacecraft to an orbit at least 500 km above semisynchronous (12-hour) orbit and 500 km below GEO in an orbit as near circular as possible.

(3) GEO (FLTSATCOM, UFO, DSCS, DSP, Milstar): Boost to an orbit at least 300 km above GEO in an orbit as near circular as possible.

New Passivation Measures Implemented on Pegasus Upper Stage

Nicholas Johnson

Following the June 1996 breakup of the STEP-2 Pegasus Hydrazine Auxiliary Propulsion System (HAPS) upper stage, Orbital Sciences Corporation (OSC) has implemented new design and operational features which should eliminate a recurrence of what officially became the worst satellite fragmentation on record. Over 700 debris at least 10 cm in diameter have been tracked by the U.S. Space Surveillance Network (SSN) and as many as 300,000 debris larger than 4 mm in diameter have been inferred from detections made by the Haystack and Goldstone radars. Eighteen months after the event, 678 debris had been officially cataloged with approximately 63% still in orbit as well as up to three dozen additional debris being tracked but not yet cataloged.

An investigation by OSC led the firm to conclude that the residual high pressure helium in the STEP-2 HAPS was the most likely cause of the breakup. Failure of a regulator between the helium tank and the hydrazine propellant tank may have permitted a repressurization of the propellant tank, which, along with environmental factors, could have caused the tank to burst. OSC’s first action was to remove the helium tank and to employ a lower-pressure, blow-down propulsion system. In addition, with the HAPS mission of 23 December 1997 (the first use of HAPS since the 1994 STEP-2 mission) post-flight elimination of residual helium, hydrazine, and nitrogen was also introduced. This had the further beneficial effect of lowering the altitude of the HAPS stage from approximately 825 km circular to an orbit of 410 km by 827 km, significantly reducing the expected orbital lifetime of the HAPS vehicle. It is noteworthy that these changes, both hardware and procedural, did not noticeably degrade the performance of the HAPS upper stage. Furthermore, OSC actions not only removed the most likely source of the earlier accident but also eliminated other forms of stored energy which could have led to future breakups.

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International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
1997-080A	KOSMOS 2348	Russia	181	353	67.1	1	0
1997-081A	PROGRESS M-37	Russia	388	399	51.7	1	0
1997-082A	IRIDIUM 45	USA	En Route to Op. Orbit			1	0
1997-082B	IRIDIUM 46	USA	En Route to Op. Orbit				
1997-082C	IRIDIUM 47	USA	En Route to Op. Orbit				
1997-082D	IRIDIUM 48	USA	En Route to Op. Orbit				
1997-082E	IRIDIUM 49	USA	En Route to Op. Orbit				
1997-083A	INTELSAT 804	INTELSAT	En Route to Op. Orbit			1	0
1997-084A	ORBCOMM FM 5	USA	822	829	45.0	2	0
1997-084B	ORBCOMM FM 6	USA	821	832	45.0		
1997-084C	ORBCOMM FM 7	USA	826	834	45.0		
1997-084D	ORBCOMM FM 8	USA	825	833	45.0		
1997-084E	ORBCOMM FM 9	USA	821	831	45.0		
1997-084F	ORBCOMM FM 10	USA	827	838	45.0		
1997-084G	ORBCOMM FM 11	USA	825	836	45.0		
1997-084H	ORBCOMM FM 12	USA	829	837	45.0		
1997-085A	Early Bird 1	USA	479	488	97.2	1	1
1997-086A	AISASAT 3	China	369	35990	51.0	2	1

Upcoming Meetings

Hypervelocity Shielding Workshop (HSW), March 8-11, 1998 in Galveston, TX. For more information e-mail ckarpiuk@ems.jsc.nasa.gov.
The 32nd COSPAR Scientific Assembly will be held at the Nagoya Congress Center in Nagoya, Japan, from 12-19 July 1998. Abstracts were due January 9.
U.S. Government Orbital Workshop for Industry, 27-29 January 1998.
21st International Symposium in Space Technology & Science (ISTS) will be held in Sonic City in Omuja, Saitama Prefecture, Japan May 24-31, 1998. More information may be found on the Internet at emu.crl.go.jp/ISTS/ISTSHome.html.
United Nations' Committee on Peaceful Uses of Outer Space Scientific & Technical Subcommittee, 16-20 February 1998, Vienna.
The ***49th International Astronautical Congress (IAF)*** will be held in Melbourne, Australia, September 28 - October 2, 1998. The theme for the congress is "Pacific Rim: A Rapidly Expanding Space Market". There will be two sessions on orbital debris. Abstracts are due March 1. The sessions are being organized by Prof. Walter Flury. For more information see the Web page at http://www.iafastro.iplus.fr/.

Meeting Reports

15th Meeting of the IADC

Nicholas Johnson

Over 90 orbital debris specialists from 12 countries met in Houston 9-12 December 1997 for the 15th meeting of the Inter-Agency Space Debris Coordination Committee (IADC). The organization, now comprised of nine members (BNSC, CNES, CNSA, DLR, ESA, ISRO, Japan, NASA, and RKA), is the preeminent international forum for exchanging technical information on orbital debris research and for coordinating joint studies. The meeting included two plenary sessions, but most of the time was spent in breakouts into the four Working Groups (Measurements, Environment and Data Base, Protection, and Mitigation) and the Steering Group. Four new action items were adopted in the areas of LEO constellation modeling, reentry survivability, preparation of a hypervelocity impact protection manual, and hypervelocity impact test facility calibration. In addition, on-going cooperation in LEO and GEO debris observation campaigns, a compilation of orbital debris sources, and the exchange of information on risk objects nearing reentry will be continued.

One especially noteworthy achievement of the meeting was the development of a technical consensus on the minimum disposal altitude for geosynchronous spacecraft. This recommendation will be presented to IADC national representatives to the International

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The 48th International Astronautical Federation Congress

Robert Reynolds

The 48th International Astronautical Federation (IAF) Congress was held in Turin, Italy, October 4-10, 1997 and had as its theme "Developing Business from Space". There were three sessions devoted to orbital debris as a part of the 30th Safety, Rescue, and Quality Symposium (IAA.6) organized by Ms. Gloria Heath. In addition, there were a number of sessions on space-based communications, risk mitigation, economics, space law, and space commercialization that had papers of interest to the orbital debris community.

The three orbital debris sessions were focused on measurements and modeling (IAA.6.3), risk analysis and implementation of mitigation measures (IAA.6.4), and finally a joint session with the Space Systems Symposium on mitigation measures in space system design (IAA.6.5). There were 25 papers presented in these three sessions; they are listed by title with the presenting author at the end of this article. The sessions were well attended and, particularly in the joint session, there were many people in the audience from outside the debris community.

As an adjunct to the Congress there were splinter meetings of the IAA Subcommittee on Space Debris, chaired by Professor Walter Flury, and meetings of both the Interagency Space Debris Coordination Committee (IADC) Steering Group and Working Group 2. The IAA subcommittee meeting was reported in the last issue of this newsletter.

Session IAA.6.3

1. The World State of Orbital Debris Measurements and Modeling. (N. Johnson)
2. Mid-Size Space Debris Measurements with the TIRA System. (L. Leushacke)
3. The Search for a Previously Unknown Source of Orbital Debris: The Possibility of a Coolant Leak in Radar Ocean Reconnaissance Satellites. (D. Kessler)
4. On the Possibility of Using Comsats to Detect Small GEO Orbital Debris. (J. Greenberg)
5. Optical Measurements of Space Debris in GSO. (T. Schildknecht)
6. Optical Observations of Ariane Upper Stages. (P. Maley)
7. *In-Situ* Debris Observation Activities In Japan. (S. Kibe)
8. I*n-Situ* Measurement of Meteoroids and

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Guest Article

Increasing Your Orbital Debris IQ

Darren McKnight

Is the orbital debris community really informed about the relative importance of orbital debris vis a vis other space hazards and are the subtle and unique characteristics of orbital debris understood? A survey was distributed at the International Astronautical Federation Congress in Italy in October 1997 in an attempt to gauge an answer to this question. It should be mentioned that the survey was crafted by an engineer (myself) and not a statistician. It was distributed at sessions focused on orbital debris and no follow up was performed to encourage completion of the survey. As a result, the compilation of the survey answers cannot be considered stastically significant but I do believe that the results serve as a useful barometer of the engaged community's level of understanding.

SURVEY RESULTS: The respondents to the survey represented five countries and had an average experience level of 20 years in the aerospace industry. Eighty percent of the respondents listed environmental modeling, remote measurements, or risk/hazard calculations as an area in which they work while there were no legal or insurance experts represented.

The survey was broken up into two parts: perspective and actions.

In the perspective section, the respondents were asked to characterize the hazard from orbital debris in low Earth orbit (LEO) and geosynchronous orbit (GEO) according to the following definitions: low - negligible effect on satellite operations, medium - actual reduction in capability of some satellites due to the debris environment, high - functional degradation to satellites from debris impact is nearly a certainty during a satellite's proposed mission lifetime. The table below shows the results for the perceived hazard in LEO and GEO - values in the table represent the percent of respondents for each category.

There was no disagreement between the respondents that the hazard in LEO is higher than in GEO, while there was some disagreement as to the level of hazard in LEO. 65% of the respondents also identified rocket bodies as "the type of hardware [that] has contributed the most to the orbital debris environment," while the remaining respondents identified payloads. It should be noted that by number rocket bodies have contributed the most to the debris environment but payloads account for the majority of the mass in orbit which may be the driving factor for debris production in the future.

	LOW	MED	HIGH
LEO	33	55	15
GEO	89	11	0

Similarly, the survey asked the respondents how many satellites had suffered anomalies from debris impacts in the past. 70% percent of the respondents thought that 1-5 satellites have suffered operationally from debris impacts while the remainder of the respondents selected 5-10 satellites; no respondents thought that no satellites have suffered anomalies due to debris impacts. Interestingly, when asked to estimate how many satellites would be "severely damaged in the next ten years if there are no changes to current space operations," the distribution was almost identical: 70% for 1-5 satellites, 20% for 5-10 satellites, and only 10% for 10-20 satellites.

The survey asked respondents to prioritize listed factors as to their "impact... on the average annual orbital debris population growth rate." They are listed below from most important to least important:

- satellite breakup rate (by number)
- launch rate (by number)
- altitude of breakup events
- type of breakup event
- annual mass launched to orbit
- amount of antisatellite testing
- solar activity

An issue dear to my heart due to some research conducted in the late 80's and early 90's is the cataloged population growth rate. 75% of the respondents answered that the population had grown at a linear rate while 25% thought it had grown at an exponential rate. Clearly there is a correct answer to this question - linear growth rate. There have been short periods of time when the cataloged growth rate has been exponential but on average over the last 30 years the population has definitely grown at a linear rate.

As a transition into the "actions" section two questions were asked related to international rules of the road. 35% of the people surveyed thought that "spacefaring countries of the world are doing enough to control orbital debris" while 65% did not. On an optimistic note, 65% of the respondents felt that "currently envisioned mitigation actions [will] be effective in curtailing the growth of orbital debris over the next 25 years" while 35% did not.

The two best debris mitigation techniques selected were design alternatives and operational changes. All respondents felt that debris mitigation techniques have been effective. The criteria for selecting mitigation techniques are (in order of priority, highest priority first): cost, effectiveness, engineering practicality, and previous use. Survey results show that the most pressing issue related to future debris mitigation is the design and operations of the numerous LEO constellations being deployed and/or envisioned at this time. Similarly, the most important single mitigation technique, according to the survey respondents, is the passivation of rocket bodies after their operational use. The second most effective technique is end-of-life maneuvers to minimize orbital lifetime of derelict objects.

Looking toward the future, the respondents selected the areas that countries should invest in to stem the growth of orbital debris. They are listed below with the highest priority first:

- operational solutions (i. e., procedural changes)
- measurements of the environment (remote and *in situ*)
- engineering solutions (i. e., hardware design)
- basic research
- legal issues

LOOKING AHEAD: While the results of this survey show that many key issues related to orbital debris are well known, there is some disturbing lack of consensus on some areas that are related to both a lack of knowledge (i. e., more research is needed) and a lack of knowledge dissemination which could be corrected easily. The very newsletter that you are currently reading provides a valuable tool for educating the debris community. While

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Orbital IQ, *continued*

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this publication admittedly has a more focused objective than its predecessor (my old Orbital Debris Monitor) it covers NASA's and IADC's research and operational support activities which accounts for a large portion of the community's efforts. The format and structure of the IADC's proceedings also provides a useful summary of advances in orbital debris that would serve as a fine synopsis of the state of the debris community's progress. The IADC organization provides a tighter scrutiny than IAF or COSPAR congresses which must, by their charter, encourage a wider range of inputs and reviews. I encourage NASA to put the IADC proceedings, or even better a summary of the proceedings, on the Internet on a regular basis. This could be done on the NASA web page or on a separate debris-focused web site. Hopefully, this web site will evolve into a tool that will help to provide a mechanism to increase and maintain the community's knowledge base. As knowledge is gained in the critical area of orbital debris it must be disseminated to eliminate duplication of effort and to insure the timely application of this new knowledge.

Astronautical Federation Congress, *continued*

(Continued from page 5)

Space Debris in GEO. (G. Drolshagen)

9. From Measurement Results to Space Debris Environment Models. (R. Jehn)

Session IAA.6.4

1. Recent Results from the Space Shuttle: Meteoroid/Orbital Debris Pre-Flight Risk and Post-Flight Damage Assessments. (G. Levin)
2. Visible Effects of Space Debris on the Shuttle Program. (T. Jensen)
3. Cerise Microsatellite Recovery from First Ever Detected Collision. (M. Sweeting)
4. Collision Risk with Fragments from On-Orbit Breakups. (R. Jehn)
5. Monitoring of In-Orbit Collision Risk. (F. Alby)
6. The Long-Term Impact of Constellations on the Debris Environment After the Implementation of Debris Mitigation Measures. (R. Walker)
7. Effects of the RORSAT NaK Drops on the Long Term Evolution of the Space Debris Population. (A. Rossi)
8. The Reentry of Large Orbital Debris. (N. Johnson)
9. Interception of a Bolide? (F. Dubois)

Session IAA.6.5

1. Space Debris Mitigation and Space Systems Design. (D. Rex)
2. Options for Pomission Disposal of Upper Stages. (R. Reynolds)
3. Orbital Debris Risk Assessments and Collision Avoidance Procedures for the Space Shuttle. (J. Loftus)
4. Protecting the Space Station from Meteoroids and Orbital Debris . (G. Gleghorn)
5. Telecommunications Satellite Constellations and the LEO Debris Population. (W. Mendell)
6. Reorbit Operations of Geostationary Satellites in NASDA. (S. Mori)
7. Elimination of the Orbital Debris Threat: Using a Ground Laser to Deorbit the Debris Objects. (I. Bekey)
8. Economic Implications of Orbital Debris Mitigation (LEO Missions). (J. Greenberg)

GAO Report, *continued*

(Continued from page 2)

programs and surveillance information needs."

"The GAO recommends that the Secretary of Defense and the Administrator of NASA, in consultation with the Director of Central Intelligence, develop a coordinated governmentwide space surveillance plan that (1) sets forth and evaluates all feasible alternative capabilities to support human space flight and emerging national security requirements and (2) ensures that any planned funding for space surveillance upgrades is directed toward satisfying consolidated governmentwide requirements."

In June 1997 the Commander in Chief of US Space Command began the process of soliciting space surveillance requirements from US Government agencies, including NASA. These requirements are being evaluated and consolidated. The NASA Administrator submitted a space surveillance requirements matrix for human space flight as well as robotic missions on 27 August 1997. This matrix calls for improving the sensitivity of the US Space Surveillance Network (SSN) to 5 cm as soon as possible and to 1 cm in the mid term. Other requirements addressed improving the capabilities of the SSN to track space objects in elliptical, high altitude orbits, to determine the positional accuracy of space objects, and to detect and report satellite fragmentations.

A free copy of the report may be obtained by writing to U.S. General Accounting Office, P.O. Box 37050, Washington, DC 20013.

IADC, *cont.*

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Telecommunications Union. A request for membership in IADC by the Italian Space Agency, ASI, was favorably received and will be acted upon at the next Steering Group meeting 15 July 1998 in Nagoya, Japan. The minutes of the 15th meeting will be published shortly. The 16th meeting of the IADC is scheduled for November 1998 in Toulouse, France.

Next Issue

- **Report on the Government / Industry Workshop**
- **Report on the Breakup Model Update Project**
- **Hypervelocity Impact Research at JSC**

Project Reviews

1997 Leonids Observations at JSC

Walter Marker

Both radar and low-light level TV (LLTV) observations of the 1997 Leonids Meteor shower were made from NASA Johnson Space Center (JSC). Optical observations were also attempted at Cloudcroft, New Mexico, but were prohibited by clouds. Meanwhile, the joint Canadian/US Meteor observations from Edwards Air Force base also obtained simultaneous radar and LLTV Leonid observations. Many hours of LLTV observations were obtained at JSC. Surprisingly, the atmospheric conditions at JSC were fairly good. Some clouds were present each night, but after the clouds moved out the atmospheric clarity was very good for Houston. The LLTV was oriented to observe the same volume of space as the radars in an attempt to obtain simultaneous radar and LLTV observations of the same meteors. However, the pointing accuracy of the radars was much better than that of the LLTV. Analysis is underway to verify that both systems observed the same meteors.

Radar observations at JSC were obtained in the standard meteor survey mode and also at vertical incidence for head echo studies. Many hours of radar observations were obtained from both the H frame radar and from the new 5 antenna interferometer radar. The H frame was used as the illuminator for both systems. The 5 antenna interferometer will be used to get better position accuracy for the meteors. This will allow unambiguous determination of whether or not a given meteor is a Leonid and will also allow an off-axis correction to be made for antenna gain, so that a more accurate meteor size can be estimated.

Preliminary examination of the data is very exciting. The most interesting data involves the vertical incidence, head echo observations. Traditional meteor radars have been relatively low powered and could only detect most meteors if they looked perpendicular to the meteor trail. However, high-powered meteor radars like NASA's can also detect the meteors head on (hence the name head echo). Analysis techniques have been published for the determination of meteor density from head echo data. Since the density of the meteor is the major unknown in meteor physics, this type of observation has great scientific interest. From a NASA programmatic standpoint, the density of the meteor is also of great interest, since the projectile density is a major parameter in shield penetration and hazard calculations.

In summary, the 1997 observations of the Leonids were very successful. However, many months of analysis will be required to reduce the data. Intermediate results will be published in this newsletter as they occur.

Optical Streak Detection

Herbert A. Zook and Jer-Chyi Liou

In an article by Zook entitled "On the optical detection of meteoroids, small near-Earth asteroids and comets, and space debris," published in 1988 in **Lunar and Planetary Science XIX** (pp. 1329-1330), a procedure was described where a computer could be used to detect a faint image spot moving in time across an optical detector. This procedure required a computer to sum pixel brightness along all possible straight lines in 3-dimensional space-time, where "space" was the 2-dimensional detector surface in units of "pixels," and "time" was in units of exposure times, or "frames." A "straight line" sum so obtained was to be compared with the corresponding sum when no signal, or moving image, was present; the latter is called the "background sum."

When a sunlit object moves across a telescope's field of view (fov), a corresponding image moves across a detector surface placed at the focal plane of the telescope. This moving image is called a "streak." The "sum" that tracks this image motion is then compared with the background sum and, if high enough (above some preset threshold), a true signal due to an actual moving object is presumed present. The procedure is logically equivalent to "looking along" each line, and when the "look" brightens up enough above the noise that is always present, the image motion is due to an actual object moving across the field of view.

J.-C. Liou has now programmed a computer to turn the above theoretical construct into an actual working and successful program. This program has been applied to data taken with a digital CCD camera that views a channel plate image intensifier placed at the focal plane of the 3-meter diameter liquid Mercury mirror telescope near Cloudcroft, New Mexico. The original data were taken at 30 frames/sec in a 640x480 format. This was later reduced to a 160x120 format by Glen Jolly who did 4x4 pixel binning. "Streaks," to the naked eye, seemed to nearly retain the relative brightness above background in the reduced format that was seen in the original 640x480 format. This is not unexpected if streaks in individual frames are at least 4 pixels long. In a 4x4 bin, the mean background brightness is increased by a factor of about 16 (at least if all pixels are of about the same brightness), but as the "noise" only increases as the square root of the background, the noise is increased by only a factor of 4. But, if the streak in each frame is at least 4 pixels long, then the streak brightness is also 4 times as great, so that the streak signal-to-noise ratio remains the same. Of course the streak in each "reduced" frame is now only about 1 pixel long.

After completing the initial programming, Liou's program could easily discriminate the bright streaks from the background, but it was not at first possible to detect dim streaks (those just barely visible to the naked eye) with the program. As it was known that the moving star background (due to the Earth's rotational motion combined with the fixed vertical pointing of the liquid mirror) created noise problems beyond the usual Poissonian noise, a program was created to remove all the bright moving stars; this program worked extremely well. It was then found that the main remaining source of noise was contributed by pixels at the edge of the 110 pixel wide circular fov of the telescope-camera system. This noise was eliminated by only analyzing a 64x64 sub-array within the 110 pixel wide circle. Although a larger square within the circle could obviously be analyzed, the 64x64 array was chosen as it would almost completely simulate the upcoming 64x64 "raw" CCD array that we expected to operate at 200 frames/sec (which now only looks like it can not operate efficiently at a faster frame rate than 100 frames/sec). Using the 64x64 sub-arrays in combination with the streak detection program, all four very dim streaks stood out well above the background. Work is now underway to improve processing efficiency.

Abstracts from Papers

No abstracts at this time.

Editor's Note

Robert Reynolds

As 1997 drew to a close the orbital debris community was presented with an increasing demand for more measurements and improved models. A very successful meeting of the Interagency Space Debris Coordination Committee (IADC) was held in Houston in December. Getting international cooperation on projects such as GEO observations is, as you can guess, a difficult problem, but the IADC is acting effectively to make this happen. Also, the International Space Station Program is moving forward and the community must use the capabilities it has developed to support this continued manned presence in space. Our understanding of the environment has matured significantly since the inception of the Mir and Shuttle program, and we need to put this added knowledge to use to forecast hazards from the background environment, from new breakups, and, if necessary, from events associated with the space station itself.

Interest is increasing in the commercial use of LEO, and the need to develop the right type of models to address debris issues for constellations and other users sharing the space environment is an important development area. Besides presenting the Government orbital program to industry, the role of constellations in future debris environment development will be a topic of the U.S. Government Orbital Debris Workshop for Industry to be held in Houston January 27 - 29.

Check the desired box, complete form and mail to
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