UNITED
NATIONS

A

General Assembly

Distr.
GENERAL

A/AC.105/680
1 December 1997

ENGLISH
ORIGINAL: ENGLISH/
FRENCH/SPANISH

COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

NATIONAL RESEARCH ON SPACE DEBRIS

SAFETY OF NUCLEAR-POWERED SATELLITES

PROBLEMS OF COLLISIONS OF NUCLEAR-POWERED SOURCES WITH SPACE DEBRIS

Note by the Secretariat

CONTENTS

V.97-28662 (E)

INTRODUCTION

1. In its resolution 51/123, paragraph 32, of 13 December 1996, the General Assembly considered it essential that Member States pay more attention to the problem of collisions of space objects, including nuclear power sources, with space debris, and other aspects of space debris, and called for the continuation of national research on that question, for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris. To the extent possible, the Assembly considered that information thereon should be provided to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.

2. The General Assembly, in paragraph 22 of the same resolution, invited Member States to report to the Secretary-General on a regular basis with regard to national and international research concerning the safety of nuclear-powered satellites.

3. The Secretary-General addressed a note verbale dated 7 August 1997 to all Member States, inviting them to communicate to the Secretariat, by 30 September 1997, the information requested above so that the Secretariat could prepare a report containing that information for submission to the Subcommittee at its thirty-fourth session.

4. The present document was prepared by the Secretariat on the basis of information received from Member States and international organizations as of 30 November 1997. Information received subsequent to that date will be included in addenda to the present document.

REPLIES RECEIVED FROM MEMBER STATES*

Canada

[Original: English]

With regard to nuclear power sources and space debris issues, the Government of Canada is referring to the information provided last year and available in document A/AC.105/659.

Chile

[Original: Spanish]

Chile does not possess spacecraft that utilize nuclear power sources and has not considered the use of such technology in the future. In that connection, it is appropriate to mention the experience with the fall of the Russian probe Mars 96 into the Pacific Ocean as regards the investigation and the search carried out for debris and for evidence of radioactive contamination.

With regard to the minimization of space debris, the experience of the *Fuerza Aérea de Chile* with mini-satellites of the FASat series is in accordance with the application of the practices adopted by the United Kingdom company Surrey Satellite Technology Limited, as follows:

- Securing to the structure, whether of the launch vehicle or of the satellite itself, all the components or parts that might lose their original fastenings during the process of placing in orbit, including the remains of components subject to breakage.

- Use of materials suitable for space in that they do not suffer damage as a result of outgassing or of other environmental conditions that might result in the creation of debris, including the surface treatment of the materials concerned.

- Ensuring that all the structural fastenings and all the parts of the satellite as a whole are capable of withstanding the mechanical conditions of the launch, placing in orbit and subsequent operation, and of maintaining the integrity of the structure.

France

[Original: French]

The text of the French contribution has been incorporated into the document on space debris mitigation techniques (A/AC.105/681).

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*The replies are reproduced in the form in which they were received.

Indonesia

[Original: English]

The Government of the Republic of Indonesia pays great attention to the problem of space debris and its related aspects. In facing this problem Indonesia is now developing an Indonesian Orbital Debris Monitoring System (IODMS) which includes four main models: Traffic Model (TM), Break-up Model (BM), Decay Model (DM) and Flux Model (FM). The IODMS is a dedicated monitoring model for man-made space debris, but it takes into account the natural space debris information (figure I).

Figure I. Development scheme of the Indonesian Orbital Debris Monitoring System

The Indonesian Orbital Debris Monitoring System is now under development. The final four outputs of the system will become the main inputs for the space debris mitigation action programmes as well as for the national space policy including policy on impacts of space debris.

It was inescapable that orbital debris would become an environmental issue requiring models and measurements to understand this new environment. The models and measurements developed are identical in many respects to the models and measurements used to understand the interplanetary meteoroid environment. Both the meteoroid and orbital debris investigators can, and have, benefited by sharing data and modelling techniques.

The IODMS will generate information on orbital debris as follows:

- Traffic list
- Particle size, density, orbit
- Atmospheric state
- Spacecraft orbit
- Perigee, apogee and time
- Flux, velocity, expected impact geometry
- Detection rates
- Number and location of collisional break-ups.

Based on the above generated information, action programmes (both prevention and mitigation) on space debris and its related aspects could be developed.

The IODMS development status is still a basic concept with a number of limited capabilities of software, hardware and human resources. Specifically, the said capabilities include among others: Solar Activity Model and Atmospheric Global Circulation Model, Meteoroid Environment Model, measurement instruments (e.g. Meteor Wind Radar, MF Radar, Wind Profiling Radar, Bounder Layer Radar, optical telescopes) and a number of scientists who have experience in developing models. Output of the above models and observational data acquired by using the instruments will become inputs for the IODMS. Indonesian specialists will develop the necessary models by either integrating the existing technology or developing their own. At this time Indonesia has the necessary knowledge and expertise on the development of FM, DM and TM, but is still limited for developing BM, especially on the intensity of explosions including both the low and the high intensity explosions.

Models have predicted that the orbital debris environment could exceed the meteoroid environment in certain regions of low Earth orbit. Observations have confirmed this prediction, and have shown that the effects are dependent on the pointing direction and size regime. The observations are also revealing sources of debris that were not predicted.

Based on the existing observations in Indonesia, there was indication that from 11 to 20 December 1992, “space debris rains” occurred above the southern hemisphere in the region of Indonesia (figure II). These indications were also shown by the number of meteor echoes in 1992 and 1993 (figure III). A number of detected spikes are not associated with any known meteor showers. The most likely explanation for the pattern of those spikes, based on the echo distributions on longitude versus latitude plane (figures II and III) is man-made debris. Unfortunately, there is no information on launching activities during these periods. Further investigations involving the orbital monitoring system are required to confirm this conclusion.

An ever-increasing measurement programme is essential towards understanding and controlling the growth in the future orbital debris environment. For the purpose of developing the above scheme (the IODMS), the Government of the Republic of Indonesia invites cooperation and/or exchange of data/information for mitigating the orbital debris as well as their negative impacts.

Figure II: Echo distribution on longitude versus latitude plane

Two straight line echo distributions around latitude -65° and -70° are suspected to have originated from man-made space debris.

Figure III. Number of meteor echoes as a fraction of time

Number of meteor echoes as a fraction of time, observed with the Meteor Wind Radar, at Serpong, Indonesia. A number of detected spikes are not associated with any known meteor showers.

Japan

[Original: English]

A. Introduction

The Space Activities Commission of Japan (SAC) mentioned Japan's policy on space debris in the report on Japan's Space Long Term Vision published in July 1994 as follows: "Japan will aim to develop such systems that will leave as little space debris as possible."[1] Based on this policy, SAC revised the Fundamental Policy of Japan's Space Activities on 24 January 1996.[2] It contains the first Japanese policy statement on the preservation of the space environment.

The National Space Development Agency of Japan (NASDA) became aware of the risk of collision with debris and began to study it from 1985. The most comprehensive research was conducted from 1991 to 1993 in cooperation with the Japan Society for Aeronautical and Space Sciences (JSASS).

Systematic and organized activities have been performed since 1990 when the JSASS founded the Space Debris Study Group.[3] The Study Group of over 30 members from space-related organizations and industries issued an interim report in January 1992 and a final report in March 1993. Some recommendations in the reports have been continuously studied by two newly formed JSASS Study Groups.

Japan (NAL, NASDA, ISAS, and other space-related organizations) has also been a member of the Inter-Agency Space Debris Coordination Committee (IADC) since 1992 and has studied debris through exchange of information and discussion at the IADC, IAF, COSPAR and other international and domestic conferences.

This report is a brief overview of recent activities in Japan concerning measurement, database, mitigation of and protection from debris.

B. Measurement and detection

1. SFU post flight analysis

The JSASS, National Aerospace Laboratory (NAL) and other organizations are jointly performing the post-flight analysis of the Space Flyer Unit (SFU). SFU is an unmanned, reusable, sun-pointing, three-axis stabilized satellite. It is the first satellite of the kind built in Japan. It is octagonal in shape, measures 4.46 m in diameter and 3 m in height, and weighs about 4 tonnes. SFU was launched by the third H-II flight, on 18 March 1995, and was retrieved by the Space Shuttle STS-72 on 13 January 1996. SFU was operated on a circular orbit at an altitude of 500 km and inclination of 28.5 degrees. Preliminary results in impact surveys are summarized as follows:[4, 5]

- 337 impacts with diameters greater than 200 m have been observed in visual surveys
- 180 impacts with diameters greater than 200 m have been observed in high-resolution surveys of some surfaces
- The largest impact is located on the infrared telescope Multi-Layer Insulation (MLI), with perforation of diameter of 4.5 mm.

NAL continues detailed surveys and all the data will be made available to the public and archived in accordance with IADC rules. The database is available through the NAL Web site (http://www.nal.go.jp) and is constantly being updated.[6]

2. MFD evaluation of space environment and effects on materials (ESEM)

A flight demonstration test for the first Japanese robot arm of the Japanese Experiment Module (JEM), known as the Manipulator Flight Demonstration (MFD), was conducted on Space Shuttle flight STS-85 in August 1997. NASDA has performed the ESEM experiment of MFD in cooperation with NASA's Langley Research Center. A cosmic dust collector, mounted on top of the MFD experimental apparatus in the Shuttle payload bay, was exposed in space in the Shuttle flight direction for approximately 50 hours. A post-flight analysis is being conducted now.

3. System study on the on-orbit debris observation satellite

Since September 1996, JSASS has studied an optical measurement system for an on-orbit debris observation satellite in cooperation with NASDA. The purpose of the study is to define requirements of a small satellite system to determine the orbits of small debris near the geostationary orbit. The report includes the following contents:[7]

- Design of the orbit suitable for a debris observation satellite
- Method to improve accuracy of observations
- Detailed optical design for observations
- Study on a Breadboard Model (BBM) specification for on-board data-processing system
- Study on a BBM specification for ground data-processing system
- Study on a BBM specification for an observation satellite.

C. Modelling and database

NASDA has taken steps to develop a space debris database system named Space Debris Orbit Analysis Test System (DOANATS). DOANATS consists of two subsystems. One is the database subsystem that accumulates orbital data of space objects, and the other is the subsystem that analyses these orbital data.

The database subsystem acquires the orbital data from the United States Two Line Element Data from the Remote Bulletin Board System (RBBS) of the Goddard Space Flight Center. The re-entry time of each object is computed by the orbit analysis subsystem and registered in the database subsystem.

The orbit analysis subsystem contains the following four functions to determine the hazard of each space debris.

- Re-entry prediction function to estimate each space debris' re-entry time into the Earth atmosphere

- Collision analysis function to detect space debris that has high risk to collide with certain space systems

- Debris dispersion simulator to simulate orbital behaviour of the fragments generated by explosion or collision of space objects

- Orbit analysis function to provide some tools that are useful for analysis of the orbital data to space debris researchers.

D. Protection

NASDA has conducted a series of impact tests, by using a two-stage hydrogen light-gas gun, to design the JEM Stuffed Whipple bumper and a carbon-fibre reinforced plastic tube for the arm of the JEM Remote Manipulator System.[8]

NAL has conducted shaped-charge tests in collaboration with Mitsubishi Heavy Industries (MHI) and Chugoku Chemicals. The charge is 7.0 cm in diameter and 14.7 cm in length. The liner angle is 30 degrees. The thickness of aluminium liner is 2.1 mm. The copper inhibitor, which has a hole diameter of 15 mm, was selected through intensive parametric studies of inhibitor and reactive plate methods. A single cylindrical jet without a trailing jet was obtained by using this inhibitor. The mass of the tip jet is approximately 1.9 g, and the velocity obtained is approximately 10.6 km/s.[9] Comparisons between numerical results and experimental ones were presented at the Second European Conference on Space Debris.[10] NAL and MHI are planning to refine the inhibited shaped charge for JEM impact tests.

E. Mitigation

1. Standard

NASDA began to study to establish the Space Debris Mitigation Standard in 1993. The study was conducted in coordination with the orbital debris research project at NASA Johnson Space Center (JSC) to define guidelines and to establish criteria that would make NASA programmes compatible with the guidelines.

The draft of NASDA Debris Mitigation Standard was repeatedly presented at IADC to coordinate with other organizations, which was also reviewed by JSASS[11] and NASDA. Finally NASDA has established “the NASDA Space Debris Mitigation Standard” (NASDA-STD-18) on 28 March 1996.[12] Details of the NASDA Standard were presented at the thirty-fourth session of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space.[13] Prior to the establishment of the NASDA standard, NASA established NASA Safety Standard 1740.14 “Guidelines and Assessment Procedures to Limit Orbital Debris Generation”. A comparison between the NASA and the NASDA standards was shown at the 20th International Symposium on Space Technology and Science held in Gifu, Japan, from 19 to 20 May 1996,[13] which showed that these two standards had the same fundamental principles, although the NASA standard was scientifically oriented and the NASDA standard was rather engineering-oriented.

“NASDA Space Debris Mitigation Standards” requests mitigation measures to limit the orbital debris generated during launch, on-orbit operation, and after the mission of space objects.

The standard is based on the following concepts:

- The worst cause of deterioration of the orbital environment is on-orbit break-up of space objects caused by collision with a large object, accidental explosion and intentional destruction
- Preservation of the environment of the Geostationary Orbit (GEO) is particularly important because natural forces cannot clean up the debris in GEO
- Preservation of the environment of Low Earth Orbit (LEO) is also important because of its usefulness for various missions such as Earth observation and satellite communication.

From the above concepts, the Standard includes the following mitigation measures:

- Passivation of spacecraft and upper stages after their mission
- Reorbiting of spacecraft from GEO to other orbit after their mission
- Relocation of space objects in Geostationary Transfer Orbit (GTO) to prevent collision with space objects in GEO
- Minimization of debris released during normal operations of spacecraft and space objects

- Disposal of spacecraft from LEO after their mission.

2. Implementation and practices

Before the establishment of NASDA-STD-18, NASDA had carefully considered the development of space systems in order to mitigate the generation of orbital debris.

The upper stages of H-I and H-II launch vehicles were designed not to generate operational debris and to prevent on-orbit break-ups caused by residual energy. They were also given the reboost function after separating their payloads, which was effective to avoid long-period interference in the useful orbit. GEO satellites were also designed and operated to conduct reorbit manoeuvre at the end of the mission to preserve the GEO environment.

F. Conclusion

For the purpose of protecting the space environment, Japan will develop advanced R & D activities focusing on new fully-reusable transportation vehicles, based on a novel design concept obtained by the results of development of an advanced H-II launch vehicle and HOPE-X technologies.[1] It is needless to say that protection of space environment from space debris is necessary to ensure current and future human space activities. We need to take action now, while the space debris problem is still manageable and the costs of dealing with it are fairly low.

Notes

[1]"Toward creation of space age in the new century", Report on Japan's Space Long-Term Vision, Space Activities Commission, July 1994.

[2]Fundamental Policy of Japan's Space Activities, revised on 24 January 1996.

[3]S. Toda, "Some topics of space debris researches in Japan", 34th Session STSC UNCOPUOS, February 1997.

[4]M. J. Neish and others, "Micrometeoroid and space debris impacts on the space flyer unit and hypervelocity impact calibration of its materials", ESA SP-393, Proc. Second European Conference on Space Debris, May 1997, pp. 177-182.

[5]M. J. Neish and others, "Hypervelocity impact damage to space flyer unit multi-layer insulation", 7th Symposium of Materials in the Space Environment, 16-20 June 1997, Toulouse, France.

[6]S. Deshpande and others, "SFU micrometeoroid and space debris impact archive", 7th International Space Conference of Pacific-basin Societies, 15-18 July 1997, Nagasaki, Japan.

[7]"Report on the detailed study on the precise optical measurement system for on-orbit debris observation system" (in Japanese), Japan Society for Aeronautical and Space Sciences, March 1997.

[8]K. Shiraki, F. Terada and M. Harada, "JEM Design Progress for the Micro-Meteoroid and Orbital Debris Protection", 96-m-21, 20th ISTS Gifu, Japan, 19-25 May 1996.

[9]M. Kobayashi and others, "Study of hypervelocity impact testing with shaped charge".

[10]M. Katayama and others, "Numerical study of jet formation by shaped charge and its penetration into bumpered target", ESA SP-393, Proc. Second European Conference on Space Debris, May 1997, pp. 411-416.

[11]R. Reynolds, A. Kato, J. Loftus and D. Kesseler, “Guidelines and assessment procedures to limit orbital debris generation”, 96-m-15V, 20th ISTS Gifu, Japan, 19-25 May 1996.

[12]Space Debris Mitigation Standard (in Japanese), NASDA-STD-18, 28 March 1996.

[13]A. Kato, “NASDA space debris mitigation standard”, 34th Session STSC UNCOPUOS, February 1997.

Sweden

[Original: English]

Sweden does not conduct any national research of its own on space debris, but supports the activities undertaken within the United Nations, ESA and other forums. Technical design studies are being carried out by industry (Saab Erickson Space) on payload separation systems in order to mitigate the creation of new debris.

United Kingdom of Great Britain and Northern Ireland

[Original: English]

The United Kingdom plays an active role in dealing with the space debris problem. It has a comprehensive research programme looking at all aspects of debris and participates fully at national level through a United Kingdom Coordination Group, at European level through ESA, and at international level within the Inter-Agency Debris Coordination Group and the Committee on the Peaceful Uses of Outer Space. The programmes are coordinated by the British National Space Centre.

The British National Space Centre co-sponsored the Second European Conference on Space Debris held at the European Space Operations Centre (ESOC) during March 1997. The United Kingdom contributed 19 papers to the Conference addressing all debris issues ranging from measurements of the environment to modelling and recommended mitigation practices and technologies to perform these procedures. These papers are contained in the conference proceedings[1] produced by ESA.

The studies and resulting publications derived from United Kingdom organizations involved in debris research are given below.

A. University of Kent

The University of Kent through the Unit for Space Sciences provides a major contribution in all aspects of space debris research. In addition to participating in the Second European Conference on Space Debris, the group took part in the Hypervelocity Impact Symposium held in Germany in October 1996 and the Euromir Meeting in Paris in January 1997.

Building upon its experience of inferring encountered microparticle populations from examination of retrieved surface impact morphologies from the Long Duration Exposure Facility, the Unit has extended these skills to consider other retrieved objects such as the Hubble Space Telescope solar array. While significant effort has in the past focused upon damage caused by impactors incident upon the front face of the array, little attention has been addressed to the morphology of impacts on the rear of the array. The analysis compared 215 *in situ* space impacts with 41 impacts simulated in the laboratory. The morphology observed for the *in situ* impacts was reproduced by laboratory experiments permitting empirical ballistic limit relationships to be derived.

This analysis was extended to the EUropean REtrievable CArrier (EURECA) arrays[2] and measured over 1,350 impact images altogether. The impact sites were grouped by morphology and cumulative flux size distributions derived. Relationships were identified linking impactor size to ballistic limit and elliptical impacts were investigated.

An important element of *in situ* measurement of impacts is the comparison of observed impact distributions with those predicted by the environment models. The more advanced models represent directional and temporal variations in the populations and unlike retrieved surface analysis, dedicated detectors such as TiCCE (Timeband Capture Cell Experiment) can provide a method[3] of comparison for meteoroid stream models and assessment of asymmetries in the sporadic background of meteoroids, an important element in decoding the natural and man-made populations of particles.

In addition to identifying the velocity and direction of impact of particles encountered in space, an additional tool in discriminating between man-made and natural objects is determination of impactor density which is different for the two families of objects. Using impact relations for both thin and thick targets it has been demonstrated that impactor density can be derived and such an approach has been applied to both the Long Duration Exposure Facility and EURECA TiCCE data sets.[4] This analysis has also helped to identify new empirical relations linking impactor with surface damage observed on LDEF, MIR and EURECA.[5]

There is growing concern about the effect that the Leonid meteoroid stream could have on operational spacecraft during the expected storm event of November 1998/99. The Unit for Space Sciences has identified that the characteristic of the Leonid stream and its arrival in Earth orbit have the potential to generate or trigger discharge events. The Unit was closely involved in the investigation of the probable loss of the Olympus satellite in 1993 due to the impact of a Perseid meteoroid and concludes that several catastrophic events could occur during the expected peak of the Leonid stream at the end of the century.[6]

The value of having access to data sets from various spacecraft in different orbits at different times permits comparison to be made between flight conditions and for more comprehensive population characteristics and impact damage equations to be derived. When compared with impact simulations performed in the laboratory a clearer picture of the potential risk to satellite systems posed by microparticles can be developed.[7]

The Unit has a long heritage in developing and flying in-orbit sensors to detect the microparticle population. DEBIE (Debris In Orbit Evaluator) is one such sensor. The DEBIE instrument combines piezoelectric microphones with impact plasma sensing and foil penetration. It is a low-cost unit suitable for flight on any spacecraft and thus could potentially offer the capability to map and monitor the evolving microparticle environment in those orbits used by operational spacecraft.[8] The versatility of the design and its low resource requirements make it suitable for both Earth orbiting missions and interplanetary space.[9]

There is still discussion on the origin and nature of an apparent excess flux of either space debris or micrometeoroids in Earth orbit. The Unit has carried out extensive examinations of potential capture processes whereby interplanetary fluxes may be captured into Earth orbit by gravity/atmosphere. The studies suggest that the Sun has a significant influence on these capture processes and Sun angle and solar cycle variations can be very important.[10]

Important comparisons between meteoroid populations and debris populations at altitudes of importance to operational spacecraft enable designers to apply appropriate protection strategies. At altitudes of 500 km and below, the Unit has shown that micrometeoroids are more prevalent than man-made debris.[11]

An issue that is beginning to receive greater attention is the population of secondary debris injected into orbit as a consequence of primary impactors striking spacecraft surfaces. This is important not only for representing new sources within environment models but also for ensuring that the populations inferred from retrieved surface analyses are not overestimated where secondary impact sites are confused with primary impact sites. The Unit has identified this secondary impactor phenomenon from analysis of the Hubble Space Telescope solar array.[12]

B. University of London

Complementary to the Unit for Space Sciences at the University of Kent, the University of London team at Queen Mary and Westfield College are developing models to represent the sources of microdebris encountered in space. This is a combination of ultraviolet degradation, atomic oxygen erosion, and hypervelocity impact. A series of empirical models are being developed to identify the amount of microdebris deposited into space as a function of orbital altitude and inclination, duration in orbit, spacecraft surface materials and the external space environment that was encountered.[13]

This work is supported by research into novel techniques for representing the collision dynamics and frequency for different populations of objects in orbit. One of the most promising approaches is that of Direct Simulation Monte Carlo which uses techniques derived from rarefied gas computations. The evolved environment predicted by this model approach and the flux observed on the Long Duration Exposure Facility for small impactors show good agreement.[14]

C. University of Southampton

The University of Southampton has concentrated on collision events and risk analysis over a shorter time frame. A set of modelling programmes called the Space Debris Simulation suite[15] considers the consequences of collision or explosion-induced break-ups and the short-term evolution of the resulting debris cloud. Using a generalized approach to the method of probabilistic continuum dynamics the software is able to follow the trajectories of the resulting fragments to determine the likelihood of collision with other objects, and if a collision were to occur, the level of damage that might be expected.

The model has been used to carry out proximity analyses for the break-up of a launch vehicle and an orbiting surveillance/remote sensing platform. Clear lessons can be learnt regarding the best choice of parking orbit and disposal orbit for launch vehicle upper stages in order to minimize the likelihood of fragments resulting from a break-up presenting a collision hazard to nearby assets.[16]

The method has further been applied to the novel case of a constellation of 800 satellites in low Earth orbit. The study considered the possibility of a collision-induced break-up and explosion. The objective was to identify the probability that the loss (break-up) of a satellite in one of the planes of the constellation would lead to the loss of a satellite in the same or adjoining planes, and possibly initiate a collisional cascade within the system. It was clear that the design of the constellation, number of satellites, planar distribution, orbital altitude and inclination, phasing and satellite size are the main parameters involved.[17]

D. Matra Marconi Space

Industry in the United Kingdom has begun to recognize the importance of dealing with debris at the design phase of a programme in order to minimize the costs of incorporating debris-related elements in platform configuration. A sound scientific programme aimed at understanding the fundamental physical processes of hypervelocity impact and how this relates to realistic spacecraft materials is considered of prime importance. Matra Marconi Space have exploited the experience of the Unit for Space Sciences at the University of Kent in order to understand how solar array materials respond to hypervelocity impact.[18]

With the support of a Royal Society Research Fellowship, Matra staff collaborated with NASA experts to investigate some of the fundamental impact processes. Comprehensive test programmes using light gas guns and relevant diagnostics were used to characterize in a rigorous manner the velocities distributions of secondary ejecta.[19] This research is also of interest to the planetary community in understanding the formation of bodies within the solar system.[20] Matra also collaborated with ONERA-CERT of France in order to carry out hypervelocity impacts simulations to distinguish between the morphology of impact sites created by elliptical impactors and impact sites created by oblique incidence spherical impactors.[21]

E. Century Dynamics

Century Dynamics have a unique capability to investigate the processes of hypervelocity impacts through development of the AUTODYN-2D™ hydrocode. In conjunction with the Unit for Space Sciences at the University of Kent, a programme of tests was performed to compare the response of brittle materials to a range of hypervelocity impact conditions. This work is very important because it allows a comparison to be made to assess the accuracy of the hydrocode simulation results but also provides a tool with which the designer can begin to investigate the response of characteristic spacecraft materials to impact by debris and meteoroids.[22]

One of the problems of using hydrocodes for the simulation of hypervelocity impacts is the computer-intensive nature of the solution. A balance between efficiency and accuracy must be accomplished in order to ensure that computation is a realistic and feasible tool for spacecraft design. Century Dynamics have invested a large amount of time and expertise seeking the most appropriate methodologies and solutions customized to particular applications.[23] This analysis can also include consideration of the use of particular customized processors.[24] In collaboration with the Defence Evaluation and Research Agency, Century Dynamics are developing the Smooth Particle Hydrodynamics approach to solve impact cases where a gridless technique is more appropriate.[25]

F. Defence Evaluation and Research Agency

The Defence Evaluation and Research Agency is responsible for the technical coordination of the United Kingdom's space debris research programme. In addition, the Agency has developed a number of software analysis tools.

The first is a suite of software called IDES (Integrated Debris Evolution Suite) which is able to provide an assessment of the future collision risk that will be encountered by spacecraft. The software is able to model all launch and orbital activity including collisions, explosions, separations, and shedding. It is also able to propagate the orbits of the objects introduced into the space environment and consider the influence of gravitational perturbations, atmospheric drag and the influence of the Sun and Moon. A comprehensive testing programme has been carried out to ensure that the predictions agree well with observations. Using a combination of radar tracking data for larger objects and retrieved surface analysis for smaller objects, good correlation is found between predictions and observations.[26]

The confidence derived from good comparison with actual data has encouraged the users of IDES to use it in predictive mode. This has enabled the impact of future planned systems to be determined. The influence of low Earth orbit satellite communication systems on the growth of debris in orbit has been investigated in a series of studies.[27] It has been demonstrated that the coupling between the large number of new satellites and the background debris population will significantly increase the growth rate of objects in orbit. It is also clear that the constellation satellites themselves will be victims of collisions.[28]

Complementary to this environment modelling tool, a risk/design tool called PLATFORM is being developed to synthesize the predicted population data and configure a satellite to ensure its survivability from collisions with these objects. The approach represents the satellite as a combination of individual elements and positions these to provide maximum protection to the satellite components.[29] The PLATFORM model uses a novel element termed SHIELD[30] which uses genetic algorithms to determine the optimal configuration of a spacecraft based on the encountered environment and design constraints such as thermal and mass balancing. The combination of IDES and PLATFORM represents a powerful tool for design satellites to meet future technological challenges posed by space debris.

Notes

[1]ESA SP- 393, *Second European Conference on Space Debris,* published by ESA Publications Division, ESTEC, Noordwijk, Netherlands, ISBN 92-9092-255-9, 1997.

[2]M. K. Herbert and J.A.M. McDonnell, *Morphological Classification of Impacts on the EURECA and Hubble Space Telescope Solar Arrays*, Proceedings of the Second European Space Debris Conference, ESOC, Darmstadt, Germany, 17-19 March 1997, ESA SP-393.

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[4]D. J. Gardner, J.A.M. McDonnell, *Meteoroid and Debris Properties From Thin and Thick Targets*, Proceedings of the Second European Space Debris Conference, ESOC, Darmstadt, Germany, 17-19 March 1997, ESA SP-393.

[5]D. J. Gardner, N.R.G. Shrine, J.A.M. McDonnell, *Determination of Hypervelocity Impactor Size From Thin Target Spacecraft Penetrations*, Proceedings of the Second European Space Debris Conference, ESOC, Darmstadt, Germany, 17-19 March 1997, ESA SP-93.

[6]J.A.M. McDonnell, N. McBride, D. J. Gardner, *The Leonid Meteoroid Stream: Spacecraft Interactions and Effects*, Proceedings of the Second European Space Debris Conference, ESOC, Darmstadt, Germany, 17-19 March 1997, ESA SP-393.

[7]G. Drolshagen, W. C. Carey, J.A.M. McDonnell, T. J. Stevenson, J.-C. Mandeville, L. Berthoud, *HST Solar Array Impact Survey: Revised Damage Laws and Residue Analysis, Advances in Space Research*, vol. 19, No. 2, p. 239-251, 1997.

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[9]M. R. Leese, J.A.M. McDonnell, M. J. Burchell, S. F. Green, H. S. Jolly, P. R. Ratcliff, H. A. Shaw, *DEBIE - A Low Resource Dust Environment Monitor*, Proceedings of the Second European Space Debris Conference, ESOC, Darmstadt, Germany, 17-19 March 1997, ESA SP-393.

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REPLIES RECEIVED FROM INTERNATIONAL ORGANIZATIONS

International Law Association

[Original: English]

Full text of the International Law Association contribution will be available during the session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.

International Telecommunications Satellite Organization

[Original: English]

A. Introduction

INTELSAT incorporates self-imposed policies and procedures to properly decommission "expended" satellites and to prevent the generation of space debris. The existing policies and procedures on the general satellite designs, launch operations, satellite operations, satellite anomalies, and satellite decommissioning are shown below.

B. General satellite designs

- INTELSAT satellite procurement documentation specifies designs which minimize outgassing and debris generation during transfer orbit deployments and in-orbit operations.
- INTELSAT utilizes satellite designs that are self-contained and generate no orbital debris.
- Satellites are equipped, when possible, with measurement devices to assist in determining end-of-propellant conditions.

1. Launch operations

- A dialogue is maintained with United States Space Command/NORAD; INTELSAT furnishes launch information and orbital parameters upon request.

2. Satellite operations

- Detailed satellite propellant budgets are maintained, including a record of all manoeuvres. Mathematical models are employed to calculate propellant usage and predict remaining reserves. These models are continually updated with flight data.
- A propellant uncertainty margin is used to "hold back" on-board propellant reserves and guarantee that satellites are not stranded in orbit.
- Multiple ground stations are used to track and command satellites in order to provide full redundancy during in-orbit operations or emergency conditions.
- Satellite telemetry is continually monitored and compared against preset limits. Alarms are utilized to alert ground teams of any anomalies.

- Battery capacity and power subsystem performance is continually monitored on all satellites. Emergency procedures are in place to "shed load" when low battery or power conditions are noted.

- Contingency plans and procedures are available for emergency response; on-call engineering staff are available for immediate 24-hour consultation.

- INTELSAT abides by standard protocols during orbital relocations and coordinates all activities with the other satellite owners/operators.

3. Satellite anomalies

- Contingency plans call for immediate orbit raising and decommissioning of any satellite that is likely to be stranded in the geosynchronous orbital arc. The Director of Satellite Engineering Support and Processes has authority for this decision; no other approvals or authorizations are required.

4. Satellite decommissioning

- At decommissioning, all satellites are placed into a safe, passive mode. This includes depressurization and venting of propellant systems as part of orbit raising, discharge of batteries, and turning off of all RF units to preclude interference with any other satellite owner/operators.

- For older satellites, sufficient propellant is held back for decommission orbit raising to a minimum altitude of 150 km above geosynchronous. This manoeuvre is normally done in multiple parts over several days to guarantee a good parking orbit. For newer satellites, starting with INTELSAT VI, a minimum decommissioning altitude of 300 km has been adopted. Because of conservative propellant budgeting INTELSAT normally exceeds the targeted decommissioning altitude.