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Committee on the Peaceful Uses of Outer Space

National research on space debris, safety of nuclear-powered satellites and problems of collisions of sources with space debris

Note by the Secretariat

Contents

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I. Introduction

1. In its resolution 53/45, paragraph 31, of 3 December 1998, the General Assembly considered it essential that Member States pay more attention to the problem of collisions of space objects, including those with 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 Secretary-General addressed a note verbale, dated 30 August 1999, to all Member States, inviting them to communicate to the Secretariat, by 31 October 1999, the information requested above, so that the Secretariat could prepare a report containing that information for submission to the Subcommittee at its thirty-seventh session.

3. The present document was prepared by the Secretariat on the basis of information received from Member States and international organizations as of 10 December 1999. Information received subsequent to that date will be included in addenda to the present document.

II. Replies from Member States

Cyprus

[Original: English]

Regarding the issue of space debris and the question of the use of nuclear power sources in outer space, the Government of Cyprus has the honour to inform the Secretary-General that it has no comments to offer.

Ireland

[Original: English]

Ireland recognizes the growing problem of space debris and the associated risk of collisions, and would support actions to research and promote appropriate standards for control and disposal of materials placed in space.

Thermoelectric nuclear power sources are used occasionally by various agencies, for example for deep-space missions where solar photo-electric energy is inadequate, and Ireland would support action to research and promote strict standards and safeguards for such power sources.

Israel

[Original: English]

Israel has no activity whatsoever using nuclear power sources in outer space.

Republic of Korea

[Original: English]

Regarding the issue of space debris, the Republic of Korea has suggested a “launcher’s pay principle” whereby the advanced countries that are producers of space debris should be responsible for the debris in outer space. This is consistent with the current tendency in environmental policy on the ground. Countries that have put space debris in outer space such as France, the Russian Federation and the United States of America, should take the leading role in disposal of debris, establishing standards, and seeking mitigation measures. They also need to support developing countries to reduce the space debris in the future by establishing an international fund to support those activities.

The use of nuclear power sources should be limited strictly except for special missions such as deep-space missions. In such inevitable cases, safety design and standards need to be established. Those technologies need to be shared between the developed and developing countries to keep our Earth and outer space safe and clean.

The Netherlands

[Original: English]

As regards the identification of terrestrial processes and technical standards that might be relevant to nuclear power sources in outer space, the Netherlands does not undertake any activities in this field. It is therefore impossible for the Netherlands to further reflect on the factors that might distinguish nuclear power sources in outer space from terrestrial nuclear applications.

United Kingdom of Great Britain and Northern Ireland

[Original: English]

A. Introduction

The United Kingdom continues to play a key role in addressing the space-debris problem. This is achieved at the national level through the United Kingdom Space Debris Coordination Group and at international level through the Inter-Agency Space Debris Coordination Group (IADC) and the United Nations Committee on the Peaceful Uses of Outer Space. The British National Space Centre continues to coordinate the United Kingdom’s involvement in these forums.

The most recent United Kingdom Coordination Group meeting took place in April 1999 at the Defence Evaluation and Research Agency (DERA). It was attended by all the major United Kingdom debris research groups from industry and academia, including: Century Dynamics, the United Kingdom Defence Evaluation and Research Agency, Fluid Gravity Engineering, the Ministry of Defence, Matra Marconi Space (MMS), and the Universities of Kent, London and Southampton. Presentations were given on a diverse range of subjects covering: activities at the previous IADC meeting in Toulouse; progress in developing debris tracking equipment; advances in, and results from, new debris/ meteoroid models; and research activities relating to debris shielding.

Internationally, the United Kingdom participated in a full meeting of the IADC in Toulouse in November 1998, and at a meeting of the IADC Steering Group in Vienna in July 1999.

During the past year, the United Kingdom has conducted the following space-debris research and development activities.

B. Measurement of the debris population

1. Debris detectors

Real-time detection in space offers valuable insight into the space-debris and meteoroid environment. The detection method typically utilizes the energy of an impacting particle to trigger a measurement and, consequently, destroy the physical entity of the particle. The Unit for Space Sciences and Astrophysics, University of Kent at Canterbury, has maintained progress on three flight opportunities for a space-debris detector known as DEBIE. A Finnish consortium is assisting in the first of these opportunities by providing for manufacture in readiness for flight on the European Space Agency (ESA) PROBA spacecraft, which is due for launch in mid-2000. The flight sensors are due at Kent for calibration in November 1999. On the second flight opportunity the DERA Space Technology Research Vehicle (STRV 1C satellite), Kent has calibrated the flight sensors and delivered all flight hardware in August and September 1999. All units have been integrated onto the spacecraft, and launch is scheduled for the first quarter of 2000. The final flight opportunity is on the International Space Station (ISS). The ESA Technology Exposure Facility will be launched in June 2002, with a flight duration of three years and subsequent return to Earth. Consequently, this will provide an opportunity for post-flight inspection of the retrieved surfaces.

Kent has also been exploring the use of a new detection technique, called the Aerogel Position Sensitive Impact Sensor (APSIS), which will combine real-time detection with retrieved sample analysis.[1] By measuring the position and time of the impact on a retrievable collector, post-flight scanning and residual analysis can provide chemical and physical data on the impactor. Furthermore, if combined with the velocity vector of the spacecraft at the instant of detection, it can yield the trajectory in the appropriate orbital reference frame. Results of system requirements analysis favour the deployment of APSIS as a large-area detector, which makes it an ideal candidate for ISS.

2. Analysis of returned surfaces

As with *in situ* detectors, the analysis of returned surfaces from space provides valuable data on the space environment. Most recently, Kent has analysed solar cells from one of the solar arrays on the Hubble Space Telescope, which was returned after 3.62 years in space. Analytical scanning electron microscopy was used to successfully identify the origin of 23 out of 29 of the impact craters on the selected cells. The observed chemical classification of the impact residues, in terms of meteoroid to debris, corresponded well with flux model predictions. Additionally, the residue results have also been critically evaluated by comparing them with ground-based impact tests on solar cells using the Kent light gas gun (LGG). This has confirmed that similar textures and chemical effects are produced in the craters, thereby giving confidence in the results of the microscopy analysis. Various papers on this work have been presented at conferences and in respected journals.[2, 3]

C. Debris environment modelling

Modelling of the debris environment, its long-term evolution, and the potential risks it causes to possible future space systems continues to be a major activity among debris researchers in the United Kingdom. The effect of continually introducing new assets into near-Earth space, and therefore the consequences for the debris environment, is also a key research area.

1. Modelling of debris sources

One of the most difficult aspects of modelling the debris environment is to accurately model the populations of small-size debris (< 1 mm). Current models significantly under-predict the debris populations at those sizes. One of the main reasons is that the models do not include all of the sources of debris. For example, the generation of paint flakes from in-orbit spacecraft surfaces has not yet been considered. Research at Queen Mary and Westfield College, University of London, under funding and guidance from DERA, has however enabled the production mechanisms for microdebris to be investigated. A model of microdebris generation is being developed, which considers the effects of atomic oxygen, thermal cycling and ultraviolet radiation. Measurements have taken place experimentally to identify the role of each of these physical phenomena, and the issue of initial surface preparation and defects has been used to generate statistical distributions for the size of potential microdebris objects. Ultimately, it is intended that the derived model will be incorporated into debris environment and evolution models, such as the DERA Integrated Debris Evolution Suite (IDES), thereby eliminating one of the main causes of under-prediction.

2. Modelling the current debris environment in geosynchronous Earth orbit

Whereas models of the current debris environment in low-Earth orbit (LEO) are becoming quite thorough, at geostationary altitudes (i.e. in geosynchronous Earth orbit (GEO)) there is much more uncertainty. A consortium comprising Kent, DERA, the National Office for Aerospace Studies and Research (ONERA) (Toulouse), the Max Planck Institute (Heidelberg) and the University of Maryland has been awarded an ESA contract to extend modelling of space debris and other environmental factors from LEO to GEO. The work is ongoing and will be reported on next year.

3. Long-term evolution of the debris environment

The DERA IDES debris model has recently been enhanced and revalidated as measurement data on new sources of debris and new debris environments have become available. The model's reference epoch has been updated to 31 March 1998 owing to the integration of a new historical launch-related object database covering launches from 1957 to mid-1998 and the additional simulation of fragmentation events occurring since the model's previous reference epoch of 1 January 1996. IDES now includes a newly developed sodium-potassium liquid coolant droplet source model that has led to dramatic improvements in the accuracy of the model predictions for the centimetre-sized debris environment. The enhanced IDES debris model has been used extensively to study the long-term evolution of the LEO debris environment in detail, including the influence of LEO satellite constellations and debris-mitigation measures. Following late receipt of some test case data from the National Aeronautics and Space Administration (NASA) of the United States, the IDES model has provided the British National Space Centre (BNSC) with input to an international long-term LEO model comparison study being conducted within the IADC. The completion of this basic comparison study will pave the way for more sophisticated comparisons, based on a similar framework and common model input data. These more advanced IADC studies may lead to international consensus on important issues such as the effectiveness of different debris-mitigation measures as implemented by the general satellite population and by commercial satellite constellation systems.

The success of the DERA IDES model has led ESA and the European Space Operations Centre (ESOC) to issue a contract to develop a version of IDES for their uses. The new model, which is to be delivered to ESA in early 2000, is called Debris Environment Long Term Analysis (DELTA). DELTA will rely on an initial debris population derived by the ESA Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) model, recently updated by the Technical University of Braunschweig, Germany. DELTA will provide long-term projections of the >1 mm LEO debris environment and associated mission collision risks over the next 100 years. Major advances within DELTA have been made in the speed and accuracy of long-term orbit propagation; the high resolution of the future launch traffic model; the breakdown of the model predictions by different debris source components; and the direct prediction of the collision cascading process. Overall, the ESA DELTA model should be state-of-the-art and offer more advanced capabilities than other models.

At Queen Mary and Westfield College, University of London, researchers have continued to develop their innovative Direct Simulation Monte Carlo (DSMC) debris model. It provides a statistical analysis capability to predict the long-term evolution of the orbital debris environment, with the aim of improving space vehicle risk assessment. The objective is achieved by assuming that debris can be modelled by employing sample particles to represent the real debris population. Based on standard particle kinetic theory, the debris collision probability is evaluated rigorously. The combination of a spacecraft break-up model, a collision probability model and a debris particle de-orbit aerodynamic drag model allows debris population growth to be predicted. The DSMC model has been validated by comparing predictions with results from the Long Duration Exposure Facility (LDEF) satellite's impact experiments. Simulations from the model have also been used to predict the number of Space Shuttle windows requiring replacement, and the predictions are compared with actual data. Recently, work has begun to expand the environment model to include natural micro-meteorites. The DSMC debris model research has been published in a major space journal.[4]

Research at the Department of Aerospace Engineering, University of Glasgow, has focused on investigating the long-term evolution of a large constellation of nanosatellites in Earth orbit using closed-form analytical methods. The work is of growing interest given that nanosatellites are seen as a low-cost means of enabling a diverse range of innovative mission applications. Future nanosatellite systems may comprise many thousands of satellites, each with a mass in the range 0.001 kg to 1 kg. It is likely that the satellites will have no active control, so environmental effects such as air drag will shape the evolution of the constellation. The modelling work at Glasgow aims to evolve the mean spatial density of a typical constellation under the action of air drag, while considering in-orbit satellite failures and the deposition of new satellites to replenish the constellation. One of the most interesting findings shows that, under certain circumstances, the nanosatellite number density will decrease with time, but its peak will become biased to higher altitudes. Estimates of the required rate of deposition of new nanosatellites to maintain the constellation can also be derived using the technique. The research is due to be published in a respected journal.[5]

4. Short-term debris risks to space assets

The University of Southampton actively undertakes short-term debris risk assessments of major space assets. Recently, these have included collision hazard analyses of a constellation of 800 satellites (based on the original Teledesic configuration) and of the new ISS. Both assessments used the space debris simulation (SDS) software model, which was developed at Southampton under contract to DERA. For the constellation risk assessment, two potentially threatening scenarios were considered: (a) fragmentation of one of the constellation satellites; and (b) a break-up of a constellation launch vehicle. It was found that the collision risk to the constellation is low in the short term. Of the scenarios examined, the collision-induced break-up of a constellation satellite posed the greatest threat to the system. For the ISS risk assessment, the threat from a fragmentation of an upper stage or spacecraft in a neighbouring orbit was considered. Based upon the case studies considered, impact probabilities in the short term that were due to ISS encounters with the fragmentation debris cloud were found to be up to four orders of magnitude higher than those due to the background debris population. The results of these studies have been published in a respected journal and reported at major international conferences.[6, 7]

D. Spacecraft debris protection

The protection of spacecraft from the impact of hypervelocity debris is another research area in which the United Kingdom is actively involved.

1. Hypervelocity impact testing

A consortium comprising MMS, DERA, Kent, and Fluid Gravity Engineering is nearing the end of a two-year ESA contract to investigate cost-effective debris shielding solutions for unmanned spacecraft. Because of the constraints placed on the design of typical spacecraft in terms of both costs and mass, there are a limited number of credible shielding options available. The consortium has proposed a new set of debris-shielding solutions that should improve the survivability of future spacecraft, including replacing the standard single-layer aluminium honeycomb structure, typical of many spacecraft, with a double layer, and adding layers of Beta cloth to multi-layer insulation thermal blankets covering the satellite structure. Sample shields have been manufactured and subjected to a range of hypervelocity impacts using LGG. Results from these tests have enabled the derivation of ballistic limit equations for each new shield type. These equations ensure that the performance of the shields can be predicted when applied to a satellite. During the remainder of the contract period, a cost-risk benefit analysis will be performed to quantify the cost-effectiveness of the shielding solutions. Finally, guidelines will be produced to advise designers of spacecraft systems on the most appropriate choice and location of shielding for a particular spacecraft design.

2. Satellite survivability modelling

DERA has continued to develop an innovative software model called SHIELD. The purpose of SHIELD is to identify the optimum debris-protection strategy for a particular satellite mission. It will do so by using a genetic algorithm to automatically search through and evaluate many thousands of competing possibilities for the configuration of equipment inside a three-dimensional geometrical representation of the satellite body, together with the many choices and locations for applying shielding to the satellite. The evaluation process utilizes a newly formulated survivability metric to rapidly determine the effectiveness of each solution. One of the inputs to this metric is a Monte Carlo-generated distribution of penetrating debris impactors on the satellite body, which in turn has been derived from directional debris flux data generated by the IDES model of DERA. The metric is constructed in such a way that it can reveal whether critical items are sufficiently well-protected by neighbouring equipment and whether the benefits from adding shielding justify the extra cost and mass. In this way, the model can determine the best solution for providing maximum protection to critical equipment. It is envisaged that the model could ultimately become an additional engineering tool for use during the earliest phases of a satellite project when there is sufficient flexibility for design changes. Version 0.1 of SHIELD has just been completed and is now ready for validation. The work has been published as an invited paper at a major space conference, and in a respected British defence journal.[8, 9]

3. Hydrocode modelling

The design of improved bumper shields using novel materials such as Nextel and Kevlar is essential in order to minimize the impact risks to future long-life space missions, particularly those requiring a manned presence. It is therefore essential to characterize the response of these new materials to hypervelocity impact in order to ensure optimal shield design. By necessity, hydrocode software simulations are required to verify the performance of the shields at the velocities typical of orbital debris impacts (> 10 km/s). To do this, hydrocodes utilize material models under conditions of high pressure and strain. Material models have already been developed for aluminium, a standard material on a spacecraft, but not for Nextel and Kevlar. A British company, Century Dynamics, under contract to ESA, has been developing material models for these particular materials. The quality of the derived models has been demonstrated by comparing hydrocode simulations with impact tests. A paper describing the research has been presented at a major international symposium and was subsequently nominated for the best paper award.[10]

Century Dynamics has also invested significant effort in improving their own hydrocode software called Autodyn. Long-term research and development into a technique known as smooth particle hydrodynamics (SPH) is continuing through a combination of internal investment and funding from the Ministry of Defence and DERA. Most notably, a three-dimensional SPH capability has now been implemented in Autodyn and validated. Autodyn is now becoming highly regarded throughout the world, with both ESA and NASA purchasing licences for large computer installations during the last year.

Notes

[1] J. A. M. McDonnell and others, "Aerogel position-sensitive impact sensor: capabilities for in-situ collection and sample return", preprint.

[2] G. A. Graham and others, "Hypervelocity impacts in low Earth orbit: cosmic dust versus space debris", *Advances in Space Research*, vol. 23, No. 1 (1999), pp. 95-100.

[3] G. A. Graham and others, "Natural and simulated hypervelocity impacts into solar cells", to be published in *International Journal of Impact Engineering*.

[4] L. Wang and J. P. W. Stark, "Direct simulation of space debris evolution", *Journal of Spacecraft and Rockets*, vol. 36, No. 1 (January-February 1999).

[5] C. R. McInnes, "A simple analytical model of the long term evolution of nanosatellite constellations", to be published in *Journal of Guidance, Control and Dynamics.*

[6] G. G. Swinerd, S. P. Barrows and R. Crowther, "Short-term debris risk to large satellite constellations", *Journal of Guidance, Control and Dynamics*, vol. 22, No. 2 (1999), pp. 291-295.

[7] G. G. Swinerd, S. P. Barrows and P. H. Stokes, "Short-term debris risk to the International Space Station arising from a spacecraft fragmentation", presented at the Forty-ninth International Astronautical Congress, held in Melbourne, Australia, 28 September-2 October 1998, paper No. IAA-98-IAA.6.4.04.

[8] P. H. Stokes and others, "Novel modelling solutions for debris risk reduction", *Advances in Space Research*, vol. 23, No. 1 (1999), pp. 231-241.

[9] P. H. Stokes and others, "Protecting satellites against orbital debris", *Journal of Defence Science*, vol. 4, No. 2 (1999), pp. 121-131.

[10] C. J. Hayhurst and others, "Development of material models for Nextel and Kevlar-epoxy for high pressures and strain rates", paper presented at the Hypervelocity Impact Symposium, held in Huntsville, Alabama, United States, in November 1998, paper No. 1044.