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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 nuclear-powered sources with space debris

Note by the Secretariat

Contents

I. Introduction

1. In its resolution 52/56, paragraph 29, of 10 December 1997, 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 General Assembly, in paragraph 18 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 space objects with nuclear power sources on board.

3. The Secretary-General addressed a note verbale, dated 17 July 1998, to all Member States, inviting them to communicate to the Secretariat, by 30 September 1998, the information requested above, so that the Secretariat could prepare a report containing that information for submission to the Subcommittee at its thirty-sixth session.

4. The present document was prepared by the Secretariat on the basis of information received from Member States and international organizations as of 1 December 1998. Information received subsequent to that date will be included in addenda to the present document.

II. Replies received from Member States*

Canada

Canada attaches considerable importance to the issue of space debris. However, given that the scope of activity in space debris is beyond the capabilities of Canada, the country has chosen to focus its research and analysis efforts. Two areas of interest, in which work is advancing, include debris monitoring and damage avoidance.

In the area of debris monitoring, Canada led an international team in 1997 to measure the Leonid meteorite flux. After a successful campaign and instrumentation verifications, plans are now taking shape for Canada to lead a much larger and more integrated campaign for Leonids 98. Although not specifically part of the orbital debris population, the meteoroid population constitutes a significant segment of the mass distribution of incoming particles for which protective measures must be provided. The primary optical observation will be located in Outer Mongolia, with a secondary optical and microwave sensing location in northern Australia. Real-time data links to North American sites are planned so as to provide data to commercial operators. The forthcoming Leonid shower is expected to be the largest experienced to date, since significant space assets have been placed in orbit.

Damage protection and avoidance work on composite structures such as the Multi-spectral Scanner are continuing with the use of hyperactivity in the United States of America and the United Kingdom of Great Britain and Northern Ireland. The aim of these studies is to develop better protection techniques for future hardware.

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

United Kingdom of Great Britain and Northern Ireland

The United Kingdom continues to play a key role in dealing with the space-debris problem. It has a wide- ranging research programme looking at important aspects of debris and participates fully at national level through a United Kingdom Co-ordination Group, at European level through the European Space Agency (ESA), and at international level within the Inter-Agency Debris Co-ordination Committee (IADC) and the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). The programmes are coordinated by the British National Space Centre (BNSC).

BNSC co-sponsored a workshop on space hazards hosted by the United Kingdom Defence Evaluation and Research Agency (DERA) at Farnborough on 21 and 22 October 1998. This involved leading researchers in the debris field from Europe and addressed issues such as basic research into space debris, through the development of models, to final exploitation by industry of guidelines.

A United Kingdom coordination meeting took place on 29 January 1998 at the Royal Greenwich Observatory (RGO), Herstmonceux Castle, involving: Advanced System Architectures, BNSC, Century Dynamics, DERA, Fluid Gravity Engineering, the Ministry of Defence, Matra Marconi Space, RGO and the universities of Cranfield, Kent, London and Southampton. Presentations were given on a diverse range of subjects covering: activities at the previous IADC meeting in Houston, Texas; progress in developing debris-tracking equipment; advances in, and results from, new debris/meteoroid models; and research activities relating to debris shielding.

The United Kingdom participated fully within IADC at meetings in Houston during December 1997 and at a Steering Group meeting in Nagoya, Japan, on 15 July 1998.

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. A high profile is maintained through attendance at a number of major international forums, including: the thirty-second Scientific Assembly of the Committee on Space Research (COSPAR),[1, 2, 3, 4] and the Hypervelocity Impact Symposium 1998.[5, 6] Research activities continue to focus on: the design and development of *in situ* debris detectors; analysis of impact results from detectors and retrieved spacecraft surfaces; and characterization of composite spacecraft materials under hypervelocity impact conditions. Each of these is discussed in more detail below.

Debris detectors. Progress on three flight opportunities has been maintained, and space instrumentation developed, through the production of a compact and cost-effective space sensor, DEBIE. A Finnish consortium is assisting in one of these opportunities, providing for manufacture in readiness for flight in 2000 on ESA's PROBA launch. Tests at Kent on a 2 MV microparticle accelerator have established impact plasma yields, design data, and data rates, thus enabling optimization of costs and data-handling. This flight opportunity also provides for data analysis at Kent. On the second opportunity, the STRV 1C satellite, Kent's development and test programme has established a schedule with October 1998 flight unit hardware. The flight—now scheduled for August 1999—will be in time for the advent of the Leonids Meteoroid shower in November 1999. Selected for a flight opportunity in the International Space Station arena, the third opportunity for DEBIE's flight will provide for directional information of microdebris flux and meteoroids in the vicinity of large space structures.

Analysis of retrieved surfaces. The solar array returned to Earth from the Hubble Space Telescope (HST) in 1993, after 3.62 years of space exposure at approximately 600 km altitude, and continues to offer an opportunity to document further the constitution of space debris and micrometeoroids in low Earth orbit. Hypervelocity impact into space hardware of particles from either of these populations leave little evidence of the original impactor, and so defining the original nature of the impactor is difficult. However, recent work to re-evaluate the HST solar cells, by employing analytical electron microscopy techniques, has achieved some success in this regard. This research has highlighted that post-flight investigations of space-exposed hardware can yield much valuable information on the debris population. As a consequence, Kent (under contract to ESA) has derived updated debris fluxes at low Earth altitudes for space debris models of the National Aeronautics and Space Administration (NASA).

Impact characterization of composite materials. In addition to characterizing the debris environment, Kent has also been active in determining the consequences of hypervelocity debris impacts on spacecraft structural materials. Typically, these materials comprise aluminium or woven composite material face-sheets. For the majority of spacecraft in low Earth orbit, they provide the primary shielding protection against space debris and meteoroid particle impact. Results of an impact test programme using Kent's two-stage light gas gun showed that the threshold for perforation of the chosen composite targets was strongly dependent on impact angle. The next phase in the research will concentrate on the construction of a ballistic limit equation, which will be a valuable additional piece of information to aid in the satellite structure design process.

B. University of London

The University of London debris research team at Queen Mary and Westfield College are developing models to represent the sources of microdebris encountered in space. This modelling work is complementary to that of the University of Kent. 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.

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,[7] 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. More recently, the model has been used to provide a statistical uncertainty analysis to improve debris impact risk assessments of Space

Shuttle windows.[8] The software predicts that for the majority of Shuttle flights between 0 and 2 windows will need replacing as a result of debris impact.

C. University of Southampton

The University of Southampton continues to concentrate on collision events and risk analysis over a shorter time-frame. A set of modelling programs called the Space Debris Simulation suite 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. Recently, the model has been used to carry out an analysis of the break-up of an object in the proximity of the International Space Station, and assess the probability of a damaging impact. This work is being reported at the forty-ninth International Astronautical Congress (a major international forum widely attended by the space community).

D. Matra Marconi Space

United Kingdom indutry continues to recognize the deleterious effects of the space debris environment on satellites. Matra Marconi Space is leading a consortium comprising the University of Kent and DERA to research improved methods for implementing cost-effective shielding on unmanned spacecraft. The work has resulted in the construction of two baseline shield designs,[9] which will be impact-tested using the University of Kent light gas gun. Results from the tests will establish the effectiveness of different shield configurations for debris penetration resistance. Ultimately, this will ensure that United Kingdom and European satellite manufacturers can adopt the most robust and economic debris protection in the design of future satellites.

E. Century Dynamics

Century Dynamics maintain their unique capability to investigate the processes of hypervelocity impacts through continued development of the AUTODYN-2D™ hydrocode. In conjunction with the Unit for Space Sciences at the University of Kent, they have completed a programme of simulations to investigate the response of brittle materials to a range of hypervelocity impact conditions.[10] This work is very important because it allows a comparison to be made to assess the accuracy of the hydrocode simulation results, and also provides a tool with which the designer can begin to investigate the response of characteristic spacecraft materials to impact by debris and meteoroids.

Century Dynamics continue to address the computer-intensive nature of hydrocode modelling by assessing the correct balance between speed and accuracy. As part of this process, they have collaborated with DERA to implement new techniques, such as Smooth Particle Hydrodynamics,[11] in their models. Finally, Century Dynamics are at the forefront of development of material models for strong, lightweight materials such as Nextel and Kevlar.[12] These materials are being increasingly used in spacecraft designs, particularly for debris-shielding, and so it is important to understand their impact characteristics through this work.

F. Defence Evaluation and Research Agency

DERA is responsible for the technical coordination of the United Kingdom's space-debris research programme. In addition, the Agency is developing a number of software analysis tools.

The first is a suite of software called Integrated Debris Evolution Suite (IDES),[13] 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. This validation process is an ongoing task, as the space-debris environment is highly dynamic in nature.

The confidence derived from good comparison with actual data to date 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 (constellations) on the growth of debris in orbit continues to be investigated through a series of studies.[14] 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 more susceptible to collisions. The effect of introducing debris-mitigation measures, such as de-orbiting of satellites at end of life, is also being studied.[15] The mitigation scenarios currently proposed appear to offer only a partial solution to the growth of the debris environment and the associated satellite collision risk.

Complementary to this environment modelling tool, a risk/design tool called PLATFORM is being developed to synthesize the debris population data predicted by IDES and determine the distribution of debris impacts on a target satellite as it orbits through the environment. From this impact data, and knowing the configuration of the target satellite, PLATFORM is able to calculate the survivability of the satellite. The PLATFORM model is linked to a novel module termed SHIELD,[16] which is being designed to identify the optimum choice of shielding and configuration of individual elements of a satellite. The optimization process uses a genetic algorithm, which is ideally suited to the consideration of design constraints such as maintaining the satellite's mass and thermal balance. The combination of IDES and PLATFORM/SHIELD represents a powerful tool for designing satellites to meet future technological challenges posed by space debris.

Notes

[1] G. A. Graham and others, "The collection of micrometeoroid remnants from low Earth orbit", presented at the thirty-second COSPAR Scientific Assembly, held in Nagoya, Japan, in July 1998.

[2] J.A.M. McDonnell and others, "APSIS—Aerogel position-sensitive impact sensor; Capabilities for *in situ* collection and sample return", presented at the thirty-second COSPAR Scientific Assembly, held in Nagoya, Japan, in July 1998.

[3] J.A.M. McDonnell, N. McBride and S. F. Green, "Meteoroids and small-size debris in LEO and at 1AU: results of recent modelling", presented at the thirty-second COSPAR Scientific Assembly, held in Nagoya, Japan, in July 1998.

[4] E. A. Taylor and others, "Space debris impacts on HST and Eureca solar arrays compared with LDEF using a new glass-to-aluminium conversion", presented at the thirty-second COSPAR Scientific Assembly, held in Nagoya, Japan, in July 1998.

[5] G. A. Graham and others, "Natural and simulated hypervelocity impacts in solar cells", presented at the Hypervelocity Impact Symposium, held in Huntsville, Alabama, United States of America, in November 1998.

[6] E. A. Taylor, M. K. Herbert and J.A.M. McDonnell, "Hypervelocity impact on carbon-fibre-reinforced plastic/aluminium honeycomb: comparison with Whipple bumper shields", presented at the Hypervelocity Impact Symposium, held in Huntsville, Alabama, United States, in November 1998.

[7] L. Wang and J.P.W. Stark, "Direct simulation of space debris evolution", to be published in the *Journal of Spacecraft and Rockets*.

[8] L. Wang and J.P.W. Stark, "Direct simulation of space shuttle space-debris flight damage", paper No. IAA-98-IAA.6.4.02, presented at the forty-ninth International Astronautical Congress, held in Melbourne, Australia, in September/ October 1998.

[9] J. E. Wilkinson, P. H. Stokes, G. G. Swinerd and R. Walker, "Implementation of a new approach to optimise satellite debris protection", presented at the twenty-first International Symposium on Space Technology and Science, held in Omiya, Japan, in May 1998.

[10] E. A. Taylor and others, "Hydrocode modelling of hypervelocity impact on brittle materials: depth of penetration and conchoidal diameter", presented at the Hypervelocity Impact Symposium, held in Huntsville, Alabama, United States, in November 1998.

[11] C. J. Hayhurst and others, "Numerical simulation of hypervelocity impacts on aluminium and Nextel/Kevlar Whipple shields", presented at the Hypervelocity Shielding Workshop, held in Galveston, Texas, United States, in March 1998.

[12] C. J. Hayhurst and others, "Development of material models for Nextel and Kevlar-epoxy for high pressures and strain rates", presented at the Hypervelocity

Impact Symposium, held in Huntsville, Alabama, United States, in November 1998.

[13] R. Walker, P. H. Stokes, J. Wilkinson and G. G. Swinerd, “Enhancement and validation of the IDES orbital debris environment model”, submitted to the *Space Debris* journal for publication in the first issue (February 1999).

[14] R. Walker, R. Crowther, J. Wilkinson, P. H. Stokes and G. G. Swinerd, “Orbital debris collision risks to satellite constellations”, presented at the IAF International Workshop on the Mission Design and Implementation of Satellite Constellations, held in Toulouse, France, in November 1997.

[15] R. Walker, R. Crowther, M. Cosby, P. H. Stokes and G. G. Swinerd, “The long-term impact of constellations on the debris environment after the implementation of debris mitigation measures”, presented at the forty-eighth International Astronautical Congress, held in Turin, Italy, in October 1997.

[16] P. H. Stokes, R. Walker, J. E. Wilkinson and G. G. Swinerd, “Novel modelling solutions for debris risk reduction”, presented at the thirty-second COSPAR Scientific Assembly, held in Nagoya, Japan, in July 1998.