United Nations A/AC.105/708/Add.2

General Assembly

Distr.: General
25 February 1999

Original: English

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

Addendum

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V.99-81326 (E)

I. Introduction

1. The Secretary-General, in a note verbale dated 17 July 1998, invited all Member States to provide information on national research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-powered sources with space debris.

2. The present document contains information provided in replies received from Member States between 30 January and 23 February 1999.

II. Replies received from Member States*

Germany

[Original: English]

1. Germany maintains a strong commitment to space debris research. The activities are either conducted on a national footing or are funded under contracts with the European Space Technology Research Centre and the European Space Operations Centre (ESOC) of the European Space Agency (ESA), which is financed through contributions of its member States, with Germany providing a share of around 25 per cent. These space debris-related activities in Germany are concentrated largely in the Institute of Flight Mechanics and Space Flight Technology of the Technical University of Braunschweig (IFR/TUBS) and the Research Establishment for Applied Science of Wachtberg-Werthhoven (FGAN). In addition, other research activities are also being carried out, for example, in the German space industry.

2. The following sections of the present report are accordingly structured and cover space debris-related research activities on modelling; radar observation and data analyses; and other space debris-related research activities.

3. The report describes activities carried out since the previous submission (see A/AC.105/680/Add.1 of 2 February 1998). During that period, the German Aerospace Centre (DLR) held a workshop on the review of the national space debris strategy on 22 October 1998. The main characteristics of this new strategy are:

(a) Coordination of the space debris-related activities of German industry and science as well as DLR's own activities;

(b) Formulation of an autonomous contribution for an integrated European space debris strategy in ESA, including the available entities in Germany;

(c) Development of capacity for the performance of risk analysis, where national interests are affected;

(d) Drawing up of proposals and recommendations for debris avoidance and mitigation;

(e) Design of monitoring methodologies for nationally or governmentally subsidized or financed space projects with regard to avoidance of debris generation as well as compliance with international requirements and regulations;

(f) Collaboration of DLR in the formulation of international regulations and agreements, including representation of German interests on international committees (such

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

as ESA Space Debris Coordination, the Inter-Agency Space Debris Coordination Committee (IADC) and the Committee on the Peaceful Uses of Outer Space.

4. The national strategy was presented at the annual meeting of IADC. A DLR-led delegation participated in the meeting, with five representatives coming from various institutions in Germany. An expert from FGAN currently chairs Working Group 1 (Measurements).

5. Germany strongly supports the activities in the Scientific and Technical and Legal Subcommittees of the Committee on the Peaceful Uses of Outer Space aimed at finalizing the work on the report containing the results of the multi-year work plan on space debris. The report should be adopted at the 1999 session of the Scientific and Technical Subcommittee in order to be presented at the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), to the intergovernmental conference as well as at the Technical Forum. The German delegation to UNISPACE III as well as the German experts attending the Technical Forum will be ready to contribute actively to the discussion of the report and to deliberations on the further discussion of the space debris issue in the Committee on the Peaceful Uses of Outer Space.

1. Space debris-related research activities on modelling

6. In 1998, IFR/TUBS worked mainly on two ongoing space debris-related studies for ESA. Both studies concentrate on the ESA Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) model.

(a) Upgrade of the MASTER model

7. As pointed out in the previous submission (see A/AC.105/680/Add.1), the ESA MASTER[1] model is undergoing an upgrade concerning non-fragmentation debris down to 1 mm in size. That upgrade has become necessary owing to a number of measurements and observations that are indicating that man-made debris is not created exclusively by fragmentation processes. The larger residuals from solid rocket motor burns, the so-called “slag”, as well as coolant droplets (sodium-potassium (NaK)) released from spent nuclear reactors[2] in space have been detected by ground-based radar facilities. [3]These objects are in a size range of larger than about 5 mm up to several centimetres in diameter. A major contribution from those sources can be expected according to the inclination spectrum of detected objects and related spatial densities. In the smaller size ranges, the smaller exhaust products from solid rocket motor burns, particles generated by surface degradation, as well as ejecta[4] resulting from small impacting primary objects are considered to contribute to the small-size man-made debris environment.

8. The background meteoroid branch of the MASTER model, which was originally based on the Divine/Staubach approach, has been redesigned and supplemented by a model for meteoroid streams.[5, 6] Figure 1 depicts the overall model improvements in terms of debris source and size range considered.

Figure 1
Overview of the MASTER upgrade and the non-fragmentation debris sources considered

9. According to the structure of the MASTER model, the non-fragmentation sources have been defined using a high spatial resolution from 200 km altitude (low Earth orbit (LEO)) up to the geosynchronous orbit (GEO) region. All sources have been treated semi-deterministically during the developing phase of the model. Individual objects have thus been generated. These are described by a set of orbital elements classified by epoch of generation and by mass and size. At the following stage of the process, all objects are extrapolated to a common epoch, the so-called "reference epoch". The model will be released officially in the last quarter of 1999.

10. A consequence of the MASTER extension is an increased complexity of the program and therefore also an increased demand for input data acquisition and for output data visualization. As a result, MASTER is currently migrating from a command line program to a state-of-the-art menu-driven application.

11. A graphical user interface is being developed that provides a nutshell for the MASTER binaries. The user will interact with this interface only and the MASTER binaries are executed in the background. The MASTER interface offers the following services (see the example in figure 2):

(a) Provision of an ergonomic and intuitive interface to pass all necessary input data to the MASTER applications;

(b) Execution of MASTER (analyst and engineering application);

(c) Display of graphical distributions of MASTER results either on screen or with postscript devices;

(d) Provision of on-line help to the user.

Figure 2
MASTER graphical user interface

(b) Extension of the MASTER model to predict debris detections

12. The main aim of the study is the development and implementation of a modular software tool for the prediction of crossing rates and statistical detection characteristics of objects below the United States Space Command (USSPACECOM) Satellite Catalog threshold and for the prediction of acquisition times and pass characteristics of deterministic Catalog objects. Predictions will be possible for both radar and optical observation systems with related system constraints, and also for both ground-based and space-based installations. Mathematical methods (for both statistical and deterministic analysis) lead to crossings or predicted acquisitions for a given sensor field of view (and range/range-rate windows in the case of radar systems). Based on the sensor-specific system performance model, the crossing rates are then translated into detection rates and detection size thresholds for a given probability level, assuming predefined shape, material and surface properties of the target objects.

13. The resulting software system, the Program for Radar and Optical Observation Forecasting (PROOF), is highly modular. It includes interfaces to the upgraded MASTER model population (for statistical analysis) and to a Catalog file at a certain date (for deterministic analysis, with data appearing in two-line format and as unique entries for each

object). The software system is capable of verifying individual contributions of the MASTER model population (e.g. NaK droplets) against existing measurement data (e.g. Haystack or COBEAM). The software is also able to assist in the planning of observation systems and campaigns.

14. The PROOF software considers:

(a) All known particulate sources with object diameters larger than 1 µm (the environment defined by the MASTER upgrade population, and by the USSPACECOM Catalog in the case of larger-size objects);

(b) Altitudes between 150 km (sub-LEO) and 38,000 km (super-GEO);

(c) Radar and optical systems, both ground-based and space-based;

and will be released officially in the last quarter of 1999.

2. Radar observation and data analyses of space debris and meteoroids

15. In 1998, space debris- and meteoroid-related activities at the FGAN Research Institute for High-Frequency Physics (FHP) were conducted mainly in the framework of three ESA/ESOC study contracts:

(a) Advanced radar techniques for space debris observation (February 1995-September 1998);

(b) Cooperative debris tracking (April 1997-July 1998);

(c) Development of algorithms for the detection of mid-size debris with radar (April 1997-July 1999).

16. The main objectives of these activities are:

(a) Investigation of improved debris observation and data collection techniques;

(b) Development and implementation of efficient, highly automated techniques and algorithms for data processing, debris and meteoroid detection and analysis;

(c) Support for establishing a unique, clearly defined interface between measurement results and modelling predictions.

(a) Radar observation and data analyses of meteoroids

17. Sensitivity assessments revealed that the Tracking and Imaging Radar (TIRA) L-band radar is currently capable of detecting 2 cm spheres at 1,000 km range, using optimum detection strategies and taking into account all hardware and signal processing modifications and improvements proposed and implemented in the framework of ESA study contracts.[7, 8, 9]

18. The FGAN-FHP TIRA system is used primarily to investigate methods and techniques for classification and identification of spacecraft and aircraft. To a certain extent TIRA is also used to detect meteoroids, to observe their ionization trails and to determine their flux. These trails have a length of about 10 km and are located about 100 km above the ground. Knowledge of their flux is required to assess the risk of hazards to operational satellites by a major stream of activity of the Leonid meteor shower expected on 17 November 1999, for which the National Aeronautics and Space Administration (NASA) of the United States of America predicts an increase in the background flux by a factor of 10,000-30,000. A comparatively small flux of meteoroids is cut out from the stream by the narrow beam of the

TIRA antenna. Therefore even very small meteoroids, which are more numerous than larger ones, have to be detectable in order to achieve a statistically significant number of detections during the measurement time. An attempt to observe the Leonids in 1997 steering the antenna perpendicular to the stream failed.[10] Meteoroids as small as those required cause ionization trails of low electron density into which the incoming wave penetrates. Since the ionization trails have an initial radius of several wavelengths for TIRA, the waves reflected by the single electrons are cancelled to a large extent by interference.[11] This is why radars using a short wavelength like TIRA miss the required small meteoroids, even though a large reflector antenna of 34 m in diameter and high transmitted power of 1.5 MW is used.

19. In 1998, a major goal was to develop an alternative observing mode. This was conducted in the framework of the ESA/ESOC study contract for the development of algorithms for mid-size debris detection with radar (April 1997-July 1999).

(i) Observation of meteoroid flux

20. As an alternative to looking perpendicular to the meteor stream, looking into the stream was investigated in 1998. Again, the antenna is steered to compensate for the rotation of the Earth. It was shown in theory[12] that particles producing an electron line density of $1.74.10^{12}$ m^{-1}, corresponding to a mass as small as approximately 3 µg, can be detected in a distance of 100 km, which suffices to produce a reasonable hourly rate cut out by the radar beam even though the cross section is smaller than in the perpendicular operation mode. The detection algorithms were further improved and automated.

(ii) Measurement results

21. Based on the bad experience gained from the Leonid observations in 1997, the theory of looking into the stream was tested by a measurement campaign for the predicted yearly maximum of the Perseid meteor shower conducted on 12 and 13 August for 15 hours. The number of detections agreed with the number predicted from the hourly rate measured by other observers and geometrical considerations and confirmed the theory. Encouraged by this result, researchers conducted a further measurement campaign for the Leonid meteor shower 17 and 18 November for about 12 hours. Because of the incorrect predictions of the time of maximum flux, the number of detections was lower than expected. Figure 3 shows 4 of the 5 last echoes contained in a detection of a total of 17 consecutive pulses from the Perseid measurement campaign. For each pulse the absolute values of the received signal samples are plotted over the sample number for a sampling interval of 2 µs. A pulse length of 500 µs and a pulse repetition time of 13.75 ms were used. Obviously, interferences occur slightly before vanishing.

Figure 3
Radar echos of four consequent pulses

(b) Radar techniques for fragmentation and damage analysis of larger space debris

22. The TIRA system has been used to assist in an analysis of the problem when unexpected events such as debris collision of an operational satellite causing fragmentation and damage have occurred. In the framework of study contracts, observations have been performed with the L-band and Ku-band imaging radar and the analysis results are being used to support the examination of the causes and amount of damage. Examples in 1998 included the observation and analysis of the Advanced Earth Observation Satellite (ADEOS), launched by the National Space Development Agency of Japan in 1996. With a budget of some US$ 1 billion, the satellite was designed for a lifespan of more than three years. Owing to a malfunction of the power supply system, however, ADEOS has been out of order since 30 June 1997.

23. Under the contract related to advanced radar techniques for space debris observation, ESA requested FGAN to measure and analyse several passages of ADEOS with its TIRA system. In order to examine the cause of the malfunction, a series of radar images with a resolution of 25 cm have been computed. Figures 4 and 5 give examples of computed radar images. Those images clearly show the main body of ADEOS with a dimension of approximately 4 m x 4 m x 7 m. The mounted NASA scatterometer—a characteristic feature

of ADEOS—is also visible. All the radar images also show a number of scatterers at the end of the boom of the solar panel. The solar panel has a length of 24 m, a width of 3 m and a thickness of only 0.5 mm. It was fixed to the boom by stiffeners made of carbon fibre, which should also be visible in the radar images. The lack of such scatterer centres in the images, together with the observed number of scatterers at the end of the boom, gave rise to the assumption that the solar panel was no longer fixed to the boom, but had shifted to its end. This assumption is supported by information from the National Space Development Agency (sensors on the solar panel recorded increases in temperature and vibration).

Figure 4
Radar image of the Advanced Earth Observation Satellite

Figure 5
Intrinsic motion of the Advanced Earth Observation Satellite

24. To study the intrinsic motion of ADEOS, a simple three-dimensional wire-grid model was developed. It was found that ADEOS has a rotation period of more than 800 seconds around the boom and a rotation period of more than one hour around the main body.

(c) Participation in the test campaign to verify the functionality of the Re-entry Database of the Inter-Agency Space Debris Coordination Committee

25. Over recent years, FGAN developed radar techniques and analysis methods for re-entry observations of high-risk space objects. The objective was to provide the German Federal Ministry of the Interior with reliable predictions of re-entry windows (time and ground track), estimations of an object's altitude and risk assessments. FGAN (funded by a DLR contract) was thus well qualified to participate in the test campaign, whose main objective was to verify the functionality of the IADC Re-entry Database. The Re-entry Database was developed and implemented by GMV S.A. of Madrid under ESA contract. As a test object the German satellite Inspektor (object 25100) was selected. The satellite was observed worldwide and from optical and radar observations sets of orbital elements, the orbital lifetime and re-entry windows (time and location) were estimated and stored for comparison in the Re-entry Database.

26. From 27 October to 1 November 1998, FGAN performed a total of 20 radar observations of object 25100, computed sets of orbital elements and estimated orbital lifetime and re-entry windows. All results were stored in the Re-entry Database. On 1 November 1998 at 0906 Universal Coordinated Time (UTC), the very last measurement (the last visible orbit for the TIRA system) was conducted about 12 hours before decay. Using those data a re-entry window of 2138 ±2.1 hours was assessed. A post-analysis performed by ESA and NASA resulted in a re-entry window of 1949 ±2 hours.

3. Other space debris-related research activities

27. Some other space debris-related research activities under ESA contract in the reporting period, in addition to those mentioned above, were:

(a) The upgrade of the 1 m Zeiss telescope (Carl Zeiss, Jena) at the Teide Observatory in the Canary Islands, Spain;

(b) Advanced material models for hypervelocity impact simulations by the Ernst-Mach-Institut (EMI) in Freiburg to find out the dynamic parameters of various materials;

(c) Investigation of the phenomena of hypervelocity impacts on pressurized vessels (EMI);

(d) Studies by EMI of possible reinforcement of the impact shielding of highly exposed areas of the European Columbus Orbital Facility (COF)-module for the International Space Station;

(e) The upgrade of the ESA Database and Information System for the Characterization of Objects in Space (DISCOS) by eta_max in Braunschweig;

(f) Advanced models for spacecraft disintegration during re-entry by Hypersonic Technology Göttingen.

28. Besides these German activities carried out under ESA contracts, the nationally funded activities described below concentrate essentially on supporting risk analyses, studying degradation effects and contributing to IADC.

29. EMI is investigating the damage caused by the impact of micro-meteoroids and debris particles on coarse pointing mirrors of optical communication terminals in orbits with altitudes of 700 km and 1,400 km and an inclination of 48° E. For these orbits the maximum grade of damage was calculated as well as the probability of total destruction by the impact of a solitary particle.

30. At the Rheinisch-Westfälische Technische Hochschule in Aachen, several existing computer codes for risk analyses are undergoing benchmark testing. In addition, the establishment of a server to collect and distribute test results, computer programs and design formulas is in preparation. This work is a contribution to IADC Working Group 3 (Protection).

31. DLR has organized a national workshop to inform those involved in the field of space debris about the national strategy, near-term events (such as the re-entry of the Mir space station and the Leonid meteor showers), the status of work on the ESA Space Debris Mitigation Handbook, the work in the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space as well as in IADC. A representative of the reinsurer Bayerische Rück gave an overview of and background information on insurance and reinsurance in the space business.

32. Germany is a member of IADC and is represented by DLR, which contributes to the Coordinating Committee permanently in the form of exchange of information, preparation of activities in the working groups and coordination of the German delegation. DLR has taken the initiative to establish an IADC-homepage on the Internet. The German delegation to the 16th IADC Meeting, held in Toulouse from 3 to 6 November 1998, consisted of five delegates, one of whom now chairs Working Group 1 (Measurements). The DLR position paper on space debris, which describes the national strategy mentioned above, was also presented to the Meeting.

Notes

[1] J. Bendisch and others, “The consideration of non-fragmentation debris in the MASTER Model”, paper presented at the forty-ninth Congress of the International Academy of Astronautics, held in Melbourne, Australia, in 1998 (IAA.6.3.04).

[2] C. Wiedemann and others, “Debris modelling of liquid metal droplets released by RORSATs”, paper presented at the forty-ninth Congress of the International Academy of Astronautics, held in Melbourne, Australia, in 1998 (IAA.6.3.03).

[3] T. J. Settecerri, E. G. Stansbery and M. J. Matney, “Haystack measurements of the orbital debris environment”, paper presented to the thirty-second Scientific Assembly of the Committee on Space Research, held at Nagoya, Japan, in 1998 (to be published).

[4] J. C. Mandeville and M. Rival, “Review and selection of a model for ejecta characterization”, Technical Report 452200/01 under European Space Technology Research Centre contract (Toulouse, Centre d’études et de recherche de Toulouse/Office national d’études et de recherche aérospatiales, 1996).

[5] N. Divine, “Five populations of interplanetary meteoroids”, *Journal of Geophysical Research*, vol. 98 (1993), pp. 17,029-17,048.

[6] P. Staubach, “Numerische modellierung von Mikrometeoriden und ihre Bedeutung für interplanetare raumsonden und geozentrische Satelliten”, thesis presented at the University of Heidelberg, Germany, April 1996.

[7] L. Leushacke and others, “Radar detection of mid-size space debris”, final report No. 6-94, ESA/ESOC contract No. 10182/92/D/IM (Wachtberg-Werthhoven, FGAN-FHP, November 1994).

[8] L. Leushacke, “First FGAN/MPIfR Cooperative Debris Observation Campaign: experiment outline and first results”, *Proceedings of the Second European Conference on Space Debris, Darmstadt, Germany, 17-19 March 1997* (ESA SP-393).

[9] L. Leushacke, “Mid-size space debris measurements with the TIRA system”, *Proceedings of the Forty-eighth International Astronautical Congress, Turin, 1997*.

[10] J. Rosebrock, “Beobachtung des Leonidenstroms 1997”, *FGAN-FHP Jahresbericht 1997* (Wachtberg-Werthhoven, FGAN-FHP, 1997), pp. 87-92.

[11] D. W. R. McKinley, *Meteor Science and Engineering*, New York, McGraw-Hill, 1961, p. 233.

[12] J. Rosebrock, “Radarreflexionen an unterkritischen Ionisationsschläuchen von Meteoriten bei Sicht in den Radianten”, *FGAN-FHP Jahresbericht 1998* (Wachtberg-Werthhoven, FGAN-FHP, 1998).