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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

Addendum

1. The Secretary-General addressed a note verbale, dated 4 August 1995, to all Member States, inviting them 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 1 November 1995 and 31 January 1996.

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REPLIES RECEIVED FROM MEMBER STATES

Germany*

[Original: English]

With regard to the importance of the space debris problem for all spacefaring nations, Germany was highly satisfied with promoting "Space Debris" to the status of priority agenda item in the Scientific and Technical Subcommittee of UNCOPUOS. In order to focus the considerations of this agenda item, Germany was constructively involved in designing the work plan (1996 to 1998) adopted at the thirty-second session of the Scientific and Technical Subcommittee.

Germany gives high priority to contributing significantly to the deliberations under this agenda item and to the mentioned work plan. For this purpose, Germany has regularly contributed reports on national space debris research for UNCOPUOS. The last report has been issued as UN Doc. A/AC.105/593/Add.1 of 24 January 1995. It contained a description of space debris research activities together with an elaboration of the space debris strategy of the German Space Agency DARA.

German research activities are either conducted on a national footing or are funded under contracts with the European Space Research and Technology Centre (ESTEC) and the European Space Operations Centre (ESOC) of the European Space Agency (ESA). The research activities are largely concentrated in (a) the Institute for Space Flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IfRR/TUBS) and (b) the Research Establishment for Applied Science of Wachtberg-Werthhoven (FGAN).

These two institutions have continued their work with the following main results:

- IfRR/TUBS has continued its activities in the field of modelling and model validation. The work on the ESA MASTER (Meteoroid and Space Debris Terrestrial Environment Reference) Space Debris Model has been finalized.1 A number of CD ROMs containing the model data and the application software has been delivered to ESA/ESOC for the purpose of reviewing and testing. The public distribution of ESA MASTER is scheduled for early 1996.
- Space debris related studies at FGAN are aiming primarily at the investigation and development of radar techniques and analysis methods to detect, classify and identify space objects in low Earth orbits (LEO), geostationary orbits (GSO), and geostationary transfer orbits (GTO).2 3 4 Radar data of selected space objects are gained in the tracking mode of operation using the Tracking and Imaging Radar (TIRA). From these data the physical properties are derived like size, shape, dimensions, intrinsic motion, mass, orbit, and orbital lifetime. Radar observations of defined space volumes in the beam-park mode of operation are providing data on the population density. For model validation this information can be compared with

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*This reply has been reproduced without formal editing.

[1] Final Report of ESOC-Contract 10453/93/D/CS, ESA/ESOC(MAS), 1994.

[2] Magura, K. and Mehrholz, D.: „Measurement and analysis techniques for satellite observations used at FGAN-FHP“. Technical Report No. 8-93, FGAN-FHP, Wachtberg-Werthhoven, December 1993.

[3] Leushacke, L., Mehrholz, D., Perkuhn, D.,Peters, H.G.: „Radar detection of mid-size space debris“. Final report No. 6-94, ESA/ESOC Contract No. 10182/92/D/IM, FGAN-FHP, Wachtberg-Werthhoven, November 1994.

[4] Leushacke, L. and Mehrholz, D.:“Determination of physical characteristics of space debris“. Final Report No. 6-95, DARA Contract No. 50 ST 9003, FGAN-FHP, Wachtberg-Werthhoven, July 1995.

results from space debris environmental models. The activities are funded mainly by DARA and ESA/ESOC.

A detailed report on the activities of these two institutions is given in sections A and B below.

I. Space debris modelling and prevention (IfRR/TUBS)

A. Space debris modelling

The work on the ESA MASTER Space Debris Model has been finished at IfRR. A number of CD ROMs containing the model data and the application software has been delivered to ESA/ESOC for the purpose of reviewing and testing. The public distribution of ESA MASTER is scheduled early 1996.

B. Future increase of orbital debris and prevention of additional debris generation[5]

The role of space debris modelling has changed and been extended significantly within the last years. It started as a tool for the purpose of describing the current status of orbital debris, but more and more it gains importance concerning the analysis of future scenarios and in relation with debris mitigation measures. It is worth noting at this stage that the analysis of future scenarios is affected by a number of influences beyond the purely mathematical description of the problem, e.g.

- the actual future launch rate
- the reliability of collisional break-up models
- statistical deviations esp. for initially low collision probabilities.

Hence, the absolute outcome of the model for a certain scenario is always subject to uncertainties, however one can use the analysis of future scenarios e.g. in order to compare the effectiveness of debris mitigation measures relative to one another and to evaluate certain trends.

At IfRR/TUBS a study funded by the German Space Agency DARA has been finalized, which has analyzed a number of future scenarios under the above-mentioned conditions considering objects > 1 cm in diameter up to an orbital altitude of 2000 km. A special statistical long term model is used for this purpose.

A number of modifications have been introduced to improve the long term models used so far. First of all the initial population > 1 cm has been taken from the ESA MASTER Model (Epoch = 1995.0), which is an up-to-date analysis tool. This leads to a reduced number of initial objects > 1 cm compared to the previously used population. This is due to more realistic simulation of the historical break-ups in MASTER. But not only the initial number of objects was reduced. Also the total mass in orbit was assumed to be smaller due to somewhat more realistic and conservative assumptions concerning the masses of spent satellites and rocket bodies. These are catalogued objects, which are not subject to any kind of simulation, but taken from deterministic sources. The new initial population rather underestimates the effects of interactive collisions than suggesting an unrealistic threat, so it produces a conservative scenario for the future.

A number of debris mitigation scenarios has been analyzed, in detail there are:

Business as Usual:	●	current launch rate and in-orbit break up rate
	●	no overall debris mitigation measures
Scenario A:	●	explosion prevention* from 2005

[5] Bendisch, I. and Rex, D. „The long-term evolution of orbital debris - new findings concerning collisional cascading", 46th IAF Congress, Oslo, Norway, October 1995 (paper-no. IAA.-95-IAA.6.4.08).

- reducing the orbital lifetime of spent s/c to 25 years after their active missions as follows: 30% from 2000, 75% from 2005, 100% from 2010

Scenario B:
- explosion prevention* from 2000
- reducing the orbital lifetime of spent s/c as follows: 100% from 2000

Scenario C:
- explosion prevention* from 2010
- reducing the orbital lifetime of spent s/c as follows: 30% from 2005, 50% from 2015, 100% from 2020

Scenario D:
- complete explosion prevention from 1995

* One explosion per year assumed due to the number of rocket bodies still in orbit

For the simulation shown in Fig. 1 post-operational orbital lifetimes of 25 years were assumed to be permitted. It can be seen from Fig. 1 that debris mitigation according to the realistic scenarios A to C is able to reduce population to less than 50% compared to the 'Business as Usual' case. On the other hand this would represent a growth by a factor of four within the next 100 years related to the current population.

Fig. 1 The effectiveness of debris mitigation

Fig. 2 gives a population breakdown for the 100 years 'Business as Usual'. It can be seen that explosions contribute substantially to the growing population. But the fragments from background collisions, i.e. collisions among the basic population including explosion fragments, gain importance with time. After about 70 years they are dominating the population. Feedback collisions, i.e. collisions where one or both objects are fragments generated by previous collisions, will not play any significant role within the next 100 years, according to this conservative model.

Fig. 2 Population break-down for 100 years 'Business as Usual'

It might be argued that the prevention of explosions in space can be applied to avoid a significant growth of the population > 1 cm with time. Fig. 1 shows the results if complete explosion prevention is assumed (curve 5, scenario D) from the very beginning (1995). The additional explosion fragments disappear, but the collision rate is not effected by this measure. There are as many fragments generated by collisions as shown in Fig. 2 for the scenario including explosions. This is due to the fact, that the larger objects will be responsible for the generation of most of the collision fragments in the future. However, most of the explosion fragments are small (< 10 cm).The following conclusions have been obtained at IfRR by the most recent application of the models for the future:

- It could be shown that within the next 100 years collision fragments will dominate the population > 1 cm. Collisional cascading will not set in during 100 years, since most of the destructive collisions will occur between the members of the background population and not between collision fragments.
- The current population assumed is less sensitive concerning interactive collision than stated in former analysis. Nevertheless, the necessity of debris mitigation is proven. Only by a sophisticated debris management the future spaceflight activities can be continued without any unacceptable collision risks, esp. in the 800 km to 1100 km altitude regime.
- Besides explosion prevention, the reduction of the orbital lifetimes of spent satellites and rocket bodies to about 25 years is a necessary and appropriate debris mitigation measure. It can be reached by propulsive lowering of the perigees of orbits or by propulsive de-orbiting.
- Within the next 100 years the population > 1 cm will grow by a factor of 3 to 4, even if the above mentioned mitigation measures will be performed consequently.

B. Radar detection and measurement of orbital debris (FGAN)

The FGAN Tracking and Imaging Radar (TIRA) is primarily used to investigate methods and techniques for classification and identification of aircraft and satellites. To a certain extend TIRA is additionally used to gain radar data of orbital debris. For that mainly two modes of operation have been developed: a tracking mode of operation to measure selected objects in LEO, GSO and GTO and a beam-park mode of operation to collect data on the population of space objects in defined space volumes.

TIRA consists of a narrowband tracking radar and a high resolution imaging radar. Both radars are supported from a 34-m parabolic antenna. Methods and algorithms have been developed to analyse narrowband radar signatures, to compute radar images from high resolution radar data, and to estimate physical properties of space objects like size, shape, dimensions, intrinsic motion, mass, orbit, and orbital lifetime. These methods and techniques need further improvement and refinement to cope with mid-size space debris (size 1-50 cm).

1. Radar detection of mid-size space debris

The main objective of an ESA-Study (ESA/ESOC Contract, 2/93 - 12/94) focussed on the investigation of cost-effective modifications to the L-band tracking radar of the TIRA system to detect and track space debris larger than 1 cm in LEO for the improvement and verification of space debris environmental models.

Several approaches to search for small targets at high ranges in defined space volumes were analysed. Based on the findings concepts for hardware modifications together with requirements for improved radar observation and data processing techniques were developed.

The feasibility of the suggested concept was tested by operating the TIRA system for 24 hours in the beam-park mode of operation on 13/14 December 1994.[3] The following radar and optical stations participated in this measurement campaign:

Radar:	FGAN, Wachtberg-Werthoven, Germany Fylingdales Radar, United Kingdom,
Optical:	RGO, Herstmonceux, United Kingdom AIUB, Zimmerwald, Switzerland.

The purpose of the campaign was to detect in a specific volume near 800 km altitude all objects of a minimum size, and to compare the detections with those predicted by a space debris model. The minimum size of detectable objects with the FGAN TIRA system at that altitude was about 3 cm. A preliminary analysis indicated a significant larger number of detections compared to the predictions from the ESA MASTER model (for the Haystack radar (USA) the MASTER model underpredicts slightly the number of detections). The analysis of the several hundred Gigabytes of data is still ongoing at FGAN.

2. Determination of physical characteristics of space debris

The objective of a NASA/FGAN joint research investigation (DARA Contract, 1/90-6/95) was to characterize and compare debris shape, size intrinsic motion, mass, and orbital lifetime from different types of satellite breakups, for example, from collision and from explosions.

The FGAN TIRA system was employed to measure a number of 30 debris objects (sizes larger than 50 cm) selected by NASA, of six small metal spheres of the NASA experiment ODERACS-I (orbital debris calibration spheres, diameter of 5 cm, 10 cm, and 15 cm), as well as of three small metal spheres (diameter of 5 cm, 10 cm, 15 cm) and dipoles (two wires of 13.1 cm length and 0.1 cm diameter) of the ODERACS-II experiment.

A total of 44 objects (including radar calibration satellites) were frequently measured and analysed resulting in estimates of size, shape, intrinsic motion, mass, orbit, and orbital lifetime. The results are useful for modelling drag effects of the high atmosphere, for validation of fragmentation events, for concept development of space based detection and warning methods, and for considerations of active removal techniques.

3. Advanced radar techniques for space debris observation

The purpose of an ESA-Study (ESA/ESOC Contract, 2/95-3/98) is to enhance the detection performance of the existing FGAN TIRA system to detect and track mid-size space debris in LEO (size 1-50 cm) in order to validate and improve the current environmental models.

Within this study all necessary hardware-upgrades and developments of special observation techniques as well as signal and data processing algorithms will be carried out. It is hoped that space debris of 2 cm size will be detected in 1000 km range. Activities were started to investigate, how this detection performance can be further improved with bistatic radar experiments.

Radar measurements of ARIANE upper stages in GTO will help to understand the generation of space debris due to fragmentation in these orbits. Estimates of mass and ballistic coefficient could help to answer the question what the reasons are for the debris creation processes.

Radar measurements of debris objects of 1 m size and larger in GEO have been carried out with the FGAN TIRA system to investigate size, intrinsic motion, and the accuracy with which the orbit of these objects can be computed. The activities were performed in cooperation with the Astronomical Institute of the University of Bern (AIUB), Switzerland.

4. Reentry predictions of high risk space objects

The objective of this activity is to provide the Federal Minister of Interior during reentry of high risk space objects with reliable predictions of reentry windows (time and ground track), estimations of object's attitude, and risk assessments. Within cooperation agreements FGAN provides ESA/ESOC tracking radar data of high risk space objects to support European reentry predictions.

C. Other research activities

Although the decision on an European contribution to the International Space Station has been made, activities in the field of shielding and impact analysis of the station construction elements have not yet been resumed in Germany.

Beside some industry-funded investigations, related to debris impact protection measures of pressure vessels and to the shielding effectiveness of composite materials, few ESA/ESTEC funded studies are under execution: the Ernst-Mach-Institute (EMI) investigates the phenomena of hypervelocity impacts on CMCs (Ceramic Matrix Composites) and on flexible thermal insulations. Furthermore the study from the preceding year at EMI related to the investigations of the conditions of catastrophic failure of pressurized vessels under debris impacts is still running. The ESA-study "Shaped charges for hypervelocity impact testing“ at the Battelle Research Institute is also still running.

Just at the end of 1995 few hypervelocity impact shots with the shape charge facility of TDW (Gesellschaft für verteidigungstechnische Wirksysteme mbH) have been performed, funded by DARA, to investigate the suitability for debris impact simulation and phenomena at velocities higher than 15 km/sec. The evaluation of these tests has not yet been closed.