EUROPEAN ACTIVITIES ON SPACE DEBRIS

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ABSTRACT

The Agency's objectives in the field of space debris have been defined by the Council of ESA in 1989. ESA's debris related activities comprise research, application of debris reduction measures, and international cooperation, both on a European and worldwide level. The research activities address the knowledge of the terrestrial particulate environment, risk assessment of manned and unmanned space missions, and protective and preventive measures. An overview will be given of major debris research activities of ESA which cover the DISCOS database of space objects, the MASTER reference model for the space debris and meteoroid environment, the ESABASE/DEBRIS analysis tool for predicting impacts and resulting damage on a 3-D spacecraft geometry, shield design aspects and risk assessment for the ESA module of Space Station Alpha, and debris mitigation and risk reduction measures. Since space debris is a world-wide problem ESA pays great attention to international cooperation and coordination. ESA is a founding member of the Inter-Agency Space Debris Coordination Committee (IADC).

1. INTRODUCTION

In 1989 the Council of ESA adopted a resolution on Space Debris (ESA/C/LXXXVII/Res. 3 (final) "Resolution on the Agency's policy vis-a-vis the Space Debris issue") and approved ESA/C(89)24, rev.1 "ESA Activities for Space Debris", where the Agency's objectives in the field of space debris are formulated:

- to minimise the creation of space debris to ensure free access to space and reduce the risk for manned and unmanned space flight;
- to reduce the risk on ground due to re-entry of space objects;
- to reduce the risk for geostationary satellites;
- to acquire through its own facilities and in cooperation with other space agencies the data on space debris which are necessary to assess the extent of the problem and its consequences;
- to study the legal aspects of space debris.

Already before 1989 ESA has addressed space debris issues, e.g. the collision risk in the geostationary orbit and the reentry of risk objects (Ref.1). ESA's space debris activities are reviewed every three years by Council and adapted to new developments.

Despite reduced launch activities and application of debris control measures, the space debris population in orbit is steadily growing with a corresponding increase of the hazard. New aspects are introduced with the planned use of multi-satellite constellations in low Earth orbit (LEO), which presents an increasing challenge for space debris mitigation. As a consequence the priorities of the Agency's space debris policy as adopted in 1989 will also have to be directed towards paying more attention to the near Earth orbit region with its more dense debris population.

This paper gives an overview of ESA's debris related activities, which comprise research, application of debris reduction measures, and international cooperation, both, on a European and worldwide level. Most of these activities are carried out in ESA's member states by specialized research groups and industry (Refs.2-4).

2. SPACE DEBRIS RESEARCH ACTIVITIES

2.1 The Terrestrial Meteoroid and Debris Environment

The objective is to gain a more comprehensive knowledge of the space debris population in terms of size and spatial distribution and to upgrade the European capabilities for obtaining the necessary observations. Main areas for research are the altitude band between 300 km and 1500 km, the geotransfer space at low inclination, and the geostationary orbit.

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The Agency has established the DISCOS space debris data base at ESOC for its own use and entities in the Member States (Ref.5). It supplies information on the currently catalogued objects and is a basis for risk assessments and understanding of the evolution of the debris environment. Among other data DISCOS contains currently some 2'300'000 records of the NASA Two-Line Elements (TLE) which are orbital element sets of all known (about 8'500) catalogued space objects[1]. Upgrading of the DISCOS debris database is ongoing.

Further to the DISCOS data base a comprehensive ESA meteoroid and debris reference model (MASTER[2] model) has been completed (Refs.6-10). The model which will become available for general distribution on a CD-ROM in 1997, describes the debris and meteoroid environment from LEO to the geostationary orbit (GEO) for a minimum size of 0.1 mm. The model is based on the catalogued population and on the known breakups of spacecraft and rocket upper stages in orbit. It constitutes a common basis in Europe for debris-related analyses in industry, research institutes and space agencies. The meteoroid model has been upgraded by the Max-Planck-Institute for Nuclear Physics, Heidelberg (Refs.11,12). Recent dust measurements of interplanetary probes (Galileo and Ulysses) have been taken into account. Validation and upgrading of ESA's MASTER model for space debris is ongoing. Methods for the calculation of the long-term evolution of Earth orbiting debris (up to 100 years) have been developed (Refs.13,14).

Significant contributions have been made to the knowledge of small-size (micron to millimeter) particles with EURECA and the returned solar array of the Hubble space telescope (HST) (Refs.15,16). All outer surfaces were systematically surveyed for impacts. Observed impact features range in size from about 3 microns to a maximum of 7 mm of shattered cover glass. Thousands of craters were visible with the naked eye. About 150 impacts have completely penetrated the solar array of the HST. The observed number of impacts agrees largely with the models for craters smaller than about 1 mm and exceeds the predictions for the larger craters. In several European institutes samples from EURECA and the HST solar array have been analyzed for impact residues and hypervelocity calibration tests have been performed. The EURECA and HST impact data will be made available in an electronic database.

Experiments on micro-debris and cosmic dust are also carried out on the MIR space space station, e.g. ESEF on EUROMIR. Furthermore, the spare cosmic dust detector of the Ulysses mission has been placed on the Russian geostationary EXPRESS-2 spacecraft (launch 26 September 1996). This allows to monitor the micro-debris particles in the geostationary orbit.

Efforts will be made to improve the capabilities of small-size particle detectors in order to gain more accurate information on relevant parameters (e.g. impact velocity and mass). The development of a standard in-situ detector for small-size particles is planned.

Current space debris models in LEO suffer from significant uncertainties for objects smaller than about 50 cm. This is of particular concern for spacecraft which require protection, as shielding against objects larger than 1 cm is technically not feasible. Therefore, a study was conducted to investigate the feasibility of detection and tracking of mid-size debris (1 - 50 cm) with the radar facilities of FGAN (Forschungsgesellschaft für Angewandte Naturwissenschaften), located at Wachtberg (Germany). FGAN operates a high power radar system TIRA (tracking and imaging radar) which is able to track and image aircraft, functioning satellites and space debris (Ref.17). It is composed of three main sub-systems: a 34-meter parabolic dish antenna, a L-band tracking radar (1.333 GHz, wavelength 22.5 cm), and a Ku-band imaging radar (16.7 GHz, wavelength 1.8 cm). Test campaigns have been conducted with the ODERACS experiment (Orbital Debris Radar Calibration Spheres of 5 cm, 10 cm and 15 cm diameter), launched from the US Space Shuttle in February 1994 into orbits near 350 km altitude.

A 24 hours measurement campaign in low Earth orbit was carried out on Dec. 13-14, 1994 with the FGAN radar facilities. The purpose of the campaign was to detect in a specific volume near 800 km altitude all objects above a minimum size, and compare the detections with those predicted by a space debris model. The minimum size of detectable objects with the FGAN radar at that altitude is near 2 cm. Post-processing of the data (300 Gbyte) shows 281 detections. 72 of them are cataloged objects. The MASTER model underpredicts the detections by a factor of 2. For the observations of the Haystack radar (USA) the MASTER model overpredicts slightly the number of detections. Such measurement campaigns

[1] The minimum size of the catalogued (or trackable) objects is about 10-50 cm in LEO and about 1 m in the geostationary orbit (GEO). They are tracked by radar and optical sensors of the United States' Space Command.

[2] Meteoroid And Space Debris Terrestrial Environment Reference Model

(beam park observation of radars) are excellent methods for the validation of the MASTER model in the several centimeters size range.

An even more powerful experiment has been carried out in November 1996: COBEAM-1/96, a bi-static radar experiment with FGAN transmitting and receiving and the world's largest steerable radio telescope at Effelsberg receiving. It allowed to collect information on centimeter-size objects in LEO (Ref.18).

A 1 meter aperture Zeiss telescope is being installed at the Teide observatory in Tenerife. The telescope will serve primarily as check-out facility for the optical link between ARTEMIS and SPOT-4 (SILEX experiment). The large field of view optical system dedicated to space debris investigations will be equipped with a 4096 x 4096 pixel CCD camera. The minimum size of detectable objects is expected to be 2 - 6 cm in LEO and 20 - 40 cm in GEO. With this telescope which is planned to become operational in 1997, European space debris observation capabilities in geostationary transfer orbits and the geostationary orbit will be substantially improved.

It should be noted, however, that in the area of space surveillance and knowledge of the environment Europe is still heavily dependent on external sources. European ground-based observation capabilities (radar, optical) can be improved through optimum use of national facilities (e.g. radar and optical facilities in France, Germany, Switzerland and United Kingdom) and ESA facilities (e.g. 1-Meter Zeiss telescope on the Teide Observatory).

Another area of activity are space-based observations. Studies have shown that with small aperture (10 cm) optical instruments information can be gained on the mid-size debris population (1 to 50 cm).

2.2 Risk Analysis

An example of the growing hazard in space is the situation of ESA's Earth observation satellites ERS, which are in sun-synchronous orbits at 770 km altitude. During a five-years period the chance of an ERS satellite to collide with a 1 cm size particle - which could lead to severe damage or destruction - amounts to 1 to 2 %. A proximity analysis with current data from the DISCOS database has shown, that during a period of a few days several near-misses (typical minimum distance 0.3 to 2 km) between ERS and other catalogued space objects (satellites, rocket stages, large fragments) occur. A collision with a large object would very likely be fatal for ERS because of the large impact velocity (on average near 13 km/s). For ERS-1 & ERS-2 proximity predictions are being carried out routinely.

ESABASE/DEBRIS is ESTEC's 3D software tool for the impact risk analysis (number of impacts and damage assessment) of manned and unmanned spacecraft due to debris and meteoroids. For potential damage assessment and post-flight analysis ESABASE/DEBRIS has been applied to various projects, e.g. EURECA, HST, Columbus COF, ENVISAT, ISO and XMM. ESABASE/DEBRIS will be further upgraded for application to the Agency's programmes. This includes implementing new damage laws, new results in material response under impact, and advanced methods for risk assessment.

As space debris may endanger the function or the survival of large space vehicles, detailed risk assessments have been conducted for the Columbus Orbiting Facility. The overall Space Station protection requirement against meteoroids and debris asks for a probability of at least 81% over 10 years of operation of no penetration of critical items such as propellant tanks and manned modules.

2.3 Debris Protection and Mitigation

The flux of space debris in LEO has reached such a level that shielding of manned vehicles is needed. The growing amount of man-made objects in LEO may, however, also require the protection of sensitive parts of unmanned spacecraft, e.g. the electronic boxes of Earth observation spacecraft. In order to understand how to protect against space debris, first the effect of debris on spacecraft structures must be investigated. Generic work on hypervelocity impact tests and protective measures for manned vehicles (shield design) have been carried out at several facilities within the Member States (Refs.19,20). Upgrading of impact test facilities and numerical methods is necessary for realistic simulations of the space environment and its effect on space systems. Experimental tests and numerical simulations should extend on impact direction and velocity, pressure regime, and type of materials.

The ESA technological activities in the field of shielding against space debris are divided into three domains:

- characterization of material
- development of advanced test techniques
- validation of computer codes for hypervelocity impact simulation.

Characterization of materials covers the determination of impact damage laws for insufficiently documented materials or configurations. Carbon fiber reinforced plastics (cfrp), multi-layer insulations and sandwich panels with cfrp facings and aluminium honeycomb cores have been tested. New materials for reentry vehicles are studied: ablative materials such as AQ60 developed by Aerospatiale, carbon-carbon, carbon-sic and flexible external insulations which are made of silica felt and Nextel.

Experimental work is being performed to study hypervelocity impacts on pressurized vessels. Boundaries between simple impact holes and catastrophic burst are being determined for gas filled pressure vessels made of aluminimum and titanium.

The experimental simulation of impact conditions expected in LEO requires test techniques able to accelerate projectiles at least up to velocities around 11 km/s. Two techniques have been developed. Shaped charges are used to generate cylindrical projectiles, while multi-stage active disk launchers accelerate flat disks up to the required velocity. These advanced techniques are mostly used to obtain experimental impact data on state of the art shields. These data are compared with computer codes impact simulations in order to validate selected codes.

In the shielding area research activities have focused on the selection of optimum materials and the design of shields with minimum mass for a given safety and damage tolerance. The objective is to reach cost-effective protection of unmanned spacecraft in LEO and to design shield and protection of manned vehicles, e.g. the planned ESA module of the International Space Station Alpha, in compliance with the safety requirements of the Agency.

The Columbus shielding performances have been quantified experimentally on limited size unpressurized flat samples in the velocity range between 3 and 7 km/s. The baseline configuration (double bumper) limits efficiently the damage of the pressurized module for particles below 0.5 - 1.2 cm size.

The debris preventative measure of venting the Ariane upper stage has been carried out routinely from flight 59 (V59, Sept. 1993) onwards, regardless of the type of the target orbit. Debris mitigation measures for Ariane V (passivation of upper stage) are being prepared and implemented (Ref.21).

First steps for the reduction of mission-related objects are being applied by projects. During the operational lifetime of ENVISAT the creation of mission-related objects will be precluded. At end-of-life controlled venting of pressure vessels and residual fuel, discharge of batteries, and shut-down of the power system are foreseen.

Several geostationary satellites have been reorbited into a graveyard orbit above the geostationary orbit (the figures in bracket indicate the achieved altitude increase and the year of reorbiting, Ref.22): GEOS-2 (260 km, 1984), OTS-2 (318 km, 1991), METEOSAT 2 (334 km, 1991). ECS-2 (335 km, 1993), OLYMPUS (-213 km, 1993), METEOSAT 3 (940 km, 1995), METEOSAT 4 (833 km, 1995). ESA's policy is to reorbit into a graveyard orbit with a perigee located at least 300 km above the geostationary orbit. Due to a spacecraft failure OLYMPUS could not be inserted into a graveyard orbit above the geostationary ring. The approach taken by ESA has been confirmed by the adoption by ITU of the recommendation ITU-R S.1003 on the environmental protection of the geostationary orbit.

At the occasion of the uncontrolled reentry of the equipment module of the Chinese spacecraft 1993-063H in October 1993, ESOC provided forecasts to ESA's Member States on time and location of the reentry based on data from European facilities, US Space Command, and Russia. Important radar data were obtained from the radar facility of FGAN at Wachtberg-Werthhoven (Germany). The experience gained and cooperation established during this campaign will be helpful to cope with similar events in the future. The reentry module 1993-063A reentered in March 1996 in the South Atlantic Ocean. Because of the thermal protection system, the spacecraft did only partially burn up during the atmospheric entry.

ESOC provided also information to its Member States at the time of the uncontrolled reentry of Kosmos 398 in December 1995. Kosmos 398, a spacecraft with a mass of several tons, has been launched in 1971 as part of the Soviet Lunar Programme.

Currently, the growth of the space debris population is determined by launch operations and in-orbit breakups (explosions). Accidental collisions are not yet a growth factor. However, current practices could lead to a self-sustaining proliferation process as a consequence of collisions among large objects. More efficient mitigation measures have to be considered, which may include removal from space of rocket bodies and spacecraft after completion of their mission (Ref.23). Therefore, strategies for deorbiting of spacecraft and rocket upper stages in LEO have to be elaborated. Such measures will have far-reaching implications with regard to design and cost of space systems. Thorough cost-benefit trade-offs will be needed to identify the suitable disposal of decommissioned spacecraft and rocket stages. The issue of disposal orbits must be carefully examined. Reorbiting should only be considered as an interim measure, since useful spatial regions will not be accessible. Ultimately, removal from orbit will be required.

ESA has defined in 1988, as part of the safety policy, a specific requirement for prevention of debris creation in PSS-01-40. The PSS documents, which represent formal standards for space system design, are in the process of being replaced by the European Cooperation for Space Standardisation (ECSS). Suitable standards addressing the space debris issue have to be introduced in ECSS for design and operation of space systems.

Future efforts will focus on the development of an ESA Debris Mitigation Handbook (Ref.24). The Handbook will introduce the space debris problem to designers and operators and advise on debris mitigation concepts.

3. HARMONIZATION IN EUROPE AND INTERNATIONAL COOPERATION

As space debris is a global problem which only can be solved by a joint effort, discussions and cooperation with Member States, other space agencies and relevant organizations are of great importance.

Harmonization has proceeded at European level between Member States and worldwide cooperation between ESA and other space agencies within the framework of the Inter-Agency Space Debris Coordination Committee (IADC).

Coordination meetings are being held regularly with the national space agencies ASI (Italy), BNSC (United Kingdom), CNES (France) and DARA (Germany). Main issues are the harmonization of European space debris research activities and the coordinated use of national facilities for space debris observation (radar, optical), hypervelocity impact tests, analysis of material returned from space and the identification of methods and approaches for debris reduction. The research programmes are closely coordinated between the national Space Agencies and ESA such as to avoid duplication and reduce overlapping of effort.

The Inter-Agency Space Debris Coordination Committee (IADC) with its current members ESA, Japan, NASA, RKA (Russia), BNSC (United Kingdom), CNES (France), CNSA (China), DARA (Germany), and ISRO (India), offers a forum for discussion and coordination of technical space debris issues. The primary purpose of the IADC is to exchange information on space debris research activities, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities and to identify debris mitigation options. IADC comprises a Steering Group and four technical Working Groups dedicated to specific areas: i) measurements of the environment, ii) data base and environment, iii) protection, iv) mitigation. Within the framework of this cooperation the participants exchange relevant technical information and experience related to space debris and prepare common strategies to counter the space debris problem. Current activities focus on

- a joint debris database
- the analysis of a significant new debris source in the heavily used near Earth orbital region of 700 km to 1100 km altitude which could be attributable to RORSATs[3],
- improved meteoroid and debris models,
- debris mitigation in GEO transfer orbits,
- optical observations and global inventory of the geostationary ring,
- debris management practices in the geostationary ring.

IADC is instrumental in providing the technical know-how and the technical and financial feasible strategies for debris control.

As an active member of IADC, ESA is contributing to cooperative activities, such as the establishment of a common data base, the execution of common observation campaigns, and the identification of mitigation measures.

Since 1994 the topic *space debris* has been on the agenda of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). In these sessions technical presentations to the space debris issue were given by ESA. The S&T Subcommittee adopted in 1995 a multi-year work plan:

- 1996: Measurements of space debris and effects of the environment on space systems
- 1997: Modeling of the space debris environment and risk assessment
- 1998: Space debris mitigation measures (protection, prevention, removal).

ESA is supporting the technical discussions at the Scientific and Technical Subcommittee of

[3] Radar Ocean Reconnaissance Satellites

UNCOPUOS. ESA is contributing to the multi-year work plan 1996 - 1998, which addresses all major technical aspects of space debris.

4. CONCLUSIONS

ESA has recognized the serious nature of the space debris problem since many years. ESA has adopted a systematic approach towards the problem, which is based on research, application of mitigation measures, and international cooperation.

In order to deal with the space debris problem in an effective manner, cooperation among all spacefaring nations is required.

Current risk levels due to space debris are low but are increasing.

Despite debris reduction measures number and mass of debris objects are increasing.

New developments such as multi-satellite constellations could strongly influence the space debris environment.

Ultimately more efficient debris control measures will be needed, such as selective removal from orbit of used upper stages and decommissioned spacecraft.

A critical issue are graveyard orbits.

Expendable space transportation systems are a major debris source. Reusable launch systems would eliminate this source.

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Chapter 2

Measurements of Space Debris and Meteoroids