# SUMMARY OF THE FIRST EUROPEAN CONFERENCE ON SPACE DEBRIS

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## Abstract

At the initiative of the European Space Agency (ESA), the First European Conference on Space Debris was held in Darmstadt, Germany, from 5 to 7 April 1993 gathering more than 250 experts from 17 countries. The conference was cosponsored by the national space agencies Agenzia Spaziale Italiana (ASI), British National Space Centre (BNSC), Centre National d'Etudes Spatiales (CNES) and Deutsche Agentur für Raumfahrt-angelegenheiten (DARA). The conference was primarily focusing on technical aspects of space debris, however, in a number of mutually complementary papers legal issues were addressed.

## 1. Introduction

The purpose of the First European Conference on Space Debris was to provide a forum for the presentation of results from research on space debris, to assist in defining future directions for research, to identify methods of debris control, reduction and protection and to discuss international implications and policy issues.

In thirteen sessions more than one hundred presentations were given, covering mostly technical aspects of space debris but also policy and legal issues. At the end of the conference a round table discussion explored the possibilities to control and regulate space debris. At the conference a highly qualified exposure was given of Russian activities and experience. This paper summarizes the main issues and conclusions. For details consultation of the conference proceedings (Ref.1) is recommended which contain a nearly complete collection of the presented papers.

## 2. National and International Activities

In the introductory session overview papers were given on the debris-related activities in NASA, the Russian Space Agency, Japan, and Europe.

G. Levin presented NASA's Orbital Debris Program Plan covering the period until 1996 to measure, model, mitigate and protect against orbital debris in low Earth orbit (LEO) and geostationary orbit (GEO). He reviewed the background, objectives, approach and schedule of each main area of the Program Plan. He announced that a *Technical Assessment Study* will be carried out, which is planned to be completed end 1994. The objective is to develop an improved technical baseline on orbital debris with the participation of technical experts from around the world. For this purpose the Committee on Space Debris has been formed in July 1993 by the National Research Council of the National Academy of Sciences and the National Academy of Engineering.

A. Krasnov gave a comprehensive overview on research activities in Russia, which include space surveillance, modeling, damage analysis for space vehicles, hypervelocity impact test, protection and debris control. He suggested the use of space-borne opto-electronic sensors to detect and track the (from ground)



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non-trackable population. He emphasized the need for international cooperation as an instrument to establish and apply effective debris control standards.

S. Toda outlined debris-related activities in Japan, where the Space Debris Study Group was founded in 1990 by the Japan Society for Aeronautical and Space Sciences. The objectives were to promote space debris related research, to stimulate public awareness, and to provide guidelines to cope with the issues in the space debris field. The Study Group prepared a report covering observation, modeling, protection and economic and legal aspects. A number of actions were identified to preserve the safe orbit environment.

The author described European efforts in the space debris field and outlined planned activities for the period 1993 - 95. ESA, in cooperation with its member states, has initiated a study programme and other technical activities with the aim to improve the knowledge of the environment, to assess the risk for space missions, to develop protection techniques and to apply debris preventative measures.

## 3. Measurements Pertaining to the Space Environment

There are four classes of measurements which were discussed at the conference: radar, optical, infra-red, and in-situ. The radar stations of the US and Russian space surveillance system observe space debris as a corollary activity to their primary task of monitoring activities in space. The catalogues of the two systems are consistent with one another in the major observations but there are some differences because of the locations of the instruments and the criteria used to identify objects. Because debris is not their primary task the observations are less complete for objects smaller than about 30 - 50 cm in low Earth orbit.

Some of the US radars are operated in special modes to make specific debris measurements. The Haystack radar (Massachusetts) is providing the basis for highly accurate measurements of the environment in low Earth orbit. This instrument is capable of detecting 4 mm objects at 500 km. There are now some 1600 hours of data being analyzed to evaluate the statistical models of debris in LEO. Experiments have also been conducted with the Deep Space Network radar at Goldstone (70-m antenna). This radar can detect metallic objects as small as 1.8 mm at an altitude of 600 km. The German FGAN radar (34-m antenna) is complementing the US observations by imaging debris and identifying size and shape so that more reasonable assumptions can be made as to mass, geometric cross-section and ballistic coefficients. Investigations are also made to detect and track mid-size debris (1 - 50 cm). The Japanese MU radar is also being used to confirm the statistical models.

Optical instruments are used to observe both LEO and the geostationary orbit. In LEO there are a number of objects which are detected optically but are not in the radar catalogue. Most of these are small but some are of significant size as judged from their apparent brightness. It is not surprising that some objects are visible in the optical spectrum but not by radar: many materials in spacecraft have poor dielectric properties and thus radar reflectivity but are optically bright. Conversely there are objects such as wire segments that have strong radar returns but poor optical reflectivity.

The geosynchronous orbit is monitored by optical telescopes operated by the US, Russia, France, Japan, Switzerland and the UK. The US and Russian systems are used to support the same operational surveillance roles in GEO that the radars support in LEO. All of these groups are examining the feasibility of campaigns to detect debris in the geosynchronous region. The observations and analyses to date appear to be experimental rather than operational activities.

In order to calibrate radar and optical sensors, calibration experiments are carried out using targets in space. In August 1992 two PION spheres (33 cm diameter) were released in LEO from a Russian Resurs-F spacecraft. As the orbits decayed due to air-drag, the spherical targets were tracked by ground-based sensors such as radars. From the radar return signal the size of the object can be determined and compared with the true size. These campaigns also provide information on the density of the upper atmosphere and help to improve reentry prediction methods. Similarly, NASA is preparing the ODERACS experiment (ODERACS = Orbital Debris Radar Calibration Spheres) to provide calibration targets in LEO. Six spheres of 2 inches, 4 inches and 6 inches diameter are planned to be deployed from a Space Shuttle. Spheres of the same size have different surface properties.

The infra-red astronomical satellite IRAS is the only on orbit remote sensing instrument suitable for debris observation. IRAS performed astronomical observations in 1983 from a sun-synchronous orbit at 900 km altitude. Its primary purpose was to provide a survey on infra-red objects of the universe. The data, however, also offer information on the debris environment above 1500 km altitude. A systematic analysis of the IRAS data by the Space Research Organisation of the Netherlands (SRON), Groningen, has led to the production of a complete set of observations pertaining only to orbital debris.

In-situ data are obtained from dedicated detectors and from returned surfaces exposed to the space environment. This includes windows, tiles and the carbon-carbon leading edges of NASA's Space Shuttle, the Long Duration Exposure Facility (LDEF), and EURECA. These devices are especially useful in defining the environment in the micron and submillimeter range because particles of this small size cannot be detected by remote sensors. Such evaluations are quite labor intensive and require long periods of analysis. They are the only method available to distinguish the natural from the man-made debris with some certainty. The residues of the impacting particles are analyzed using x-ray spectroscopy in order to determine their chemical composition. Scientists in the U.S. made an important discovery with LDEF. The Interplanetary Dust Experiment (IDE), which was designed to detect particles ranging in size from 1 to 100 microns, registered often impacts occurring in bursts typically lasting for 3 to 5 minutes. These debris clouds can be explained by fragmentations in eccentric orbits at high inclination, such as Molniya-type orbits. Furthermore, the higher than expected number of man-made debris impacts on the trailing side points to the existence of particles in low-inclination elliptical orbits, such as geostationary transfer orbits.

At the first Hubble Space Telescope servicing mission, which is scheduled for December 1993, the solar arrays are planned to be replaced and returned to Earth. This will provide additional data on the debris and meteoroid population at a higher altitude (610 km) than LDEF and EURECA.

An indication of the degrading space environment are the damaged windows of the U.S. Space Shuttle. Until April 1992, a total of 23 Shuttle windows have been replaced due to pitting. 90% of this pitting was caused by orbital debris impacts.

The most notable development in the measurement area is the increase in optical observations of the geostationary orbit. This is a significant contribution towards the characterization of the debris environment in this important orbital region. The very small number of known breakups in GEO is likely to be a consequence of the limited detection capability (1 meter). An improvement of the detection capabilities is highly desirable.

The opinion was expressed that ESA and its member states should strengthen the effort with regard to development and operation of tracking sensors. Information could be gained on specific regions in space and results could be shared with interested groups.

## 4. Modelling the Space Debris and Meteoroid Environment

Modelling refers to the process by which the space debris environment is described by a set of mathematical expressions which normally require the use of computers. The model provides the spatial distribution of space debris including information on size, density, albedo, and other properties of the objects. For a number of activities the space debris model contains the basic information, e.g. prediction of the evolution of the debris population, assessment of the effects of debris mitigation measures on the population, design of spacecraft shields, etc.

Current models contain more than 7000 catalogued objects, about 50,000 to 100,000 objects larger than 1 cm size, and billions of objects larger than 0.1 mm. The estimated total mass of man-made orbiting objects within 5000 km of the Earth's surface is now about 3,000,000 kg.

Space debris originates from three main sources, namely the launch vehicle upper stages left in orbit, satellites left in orbit after their mission, and the fragments produced from either of the former two categories. Other sources are solid rocket motors which generate aluminum oxide particles in the typical size range of 1 - 50 microns.

The majority of small-size debris objects is the result of on-orbit fragmentations or breakups. 116 breakups have occurred since 1961. Despite the various efforts to avoid fragmentations, during the past two years a number of breakups of rocket upper stages have generated debris in long-living orbits and densely populated regions in space (e.g. 1968-81E near the geostationary orbit with about 20 trackable fragments, 1992-93B at 850 km altitude with more than 200 trackable fragments).

The primary input to environment models are measurements. Due to the limited detection capabilities of tracking sensors, the information on objects smaller than about 10-50 cm is obtained through mathematical descriptions of the more than 110 known rocket and spacecraft fragmentations. These mathematical descriptions, which are called breakup models, are not very accurate. As a consequence, current debris models suffer from considerable uncertainties in the lower size region. In order to improve current breakup models for small size debris population, a fragmentation experiment was successfully carried out with a scaled model of the tank of the Ariane upper stage.

The current terrestrial space debris environment is largely governed by normal space operations and breakups. Based on the current data, the collision rate among catalogued objects is about 20 years. Analyses show, however, that collisions will be the decisive factor in the future, if proper debris control measures are not taken. In some altitude bands, particularly in those regions which are most heavily used, e.g. low Earth orbit (900 - 1500 km altitude) and the geostationary orbit, the collision risk could reach unacceptable levels due to the ever-increasing number of man-made objects. D. Kessler has introduced the term *critical density* for the equilibrium situation between generation and removal of fragments. A critical situation will arise when debris generation by collision will exceed the removal of fragments by natural or other causes. Some investigations conclude, that in the 900 - 1100 km altitude band this state has already been reached. For example, in this altitude band the collision rate of 1 cm objects with catalogued objects is about 3 collisions within 10 years.

## 5. Impact Tests and Shielding

With the current situation of space debris the need arises to define a proper way to protect space vehicles against serious consequences caused by impacts. The importance to understand the mechanisms from the impacts and from there to define effective means for protection, i.e. shielding, has been addressed in the conference.

The papers presented clearly indicate that major progress has been achieved both in terms of testing as well as design and analysis.

Several test facilities in Europe, U.S. and Russia are now utilised to perform high-velocity impact testing to simulate space debris impact. With the evaluation of these test results, the related analysis techniques and computer codes have been refined. This provides for improved capabilities to advise for proper design of shielding were necessary.

Practical light-weight shielding concepts are also under development for protection against smaller size debris (e.g. for RADARSAT). By increasing the thickness of several electronic boxes protection of their content can be achieved.

Interesting results have been presented for the break-up phenomena on pressurized vessels. Further testing is recommended to better understand the zipper-effect for manned modules.

Assessment of hardware returned from orbit such as LDEF and the STS Orbiter have been used for calibration of the simulation techniques and useful results have now been made available.

All these activities contribute towards more realistic methods for the design of shielding and thereby protection against debris impact.

## 6. Risk Analysis

Impacts by debris may lead to damage of varying degree: from surface degradation to continuous erosion to catastrophic impact. Several analytical tools have been developed to assess the hazards and risk caused by debris and meteoroids. An example is ESA's ESABASE/DEBRIS analysis tool which calculates for a given orbit and spacecraft geometry the number of impacts of small-size debris and meteoroids. The damage on the spacecraft surface can be assessed through analytical methods which provide characteristics of penetration, crater size, etc. as function of the particle size, density and impact velocity.

Investigations conclude that for a typical remote sensing spacecraft like ERS-1 the probability to collide with an object larger than 1 cm during a 5 years period amounts to 1-2%. ERS-1 is in a sun-synchronous orbit at 770 km altitude.

## 7. Debris Mitigation

Mitigation was a key topic during discussions at the conference. Mitigation deals with methods and practices which will directly contribute to minimize the hazard of space debris. It should be noted that the space debris problem is not severe today. It will, however, become critical if it is not dealt with in a timely manner.

Clean up of debris is neither technically practical nor economically feasible. The thrust of the action must be directed towards preventing the creation of debris.

With regard to launch vehicles, removal of residual propellant from upper stages is increasingly applied (e.g. Ariane, Thor-Delta, H-I). This is an important measure, as it eliminates one of the major debris sources.

In a Russian-USA paper the debris creation of the fourth stage of the Proton launch vehicle (SL-12) was investigated. On several occasions, 18 - 96 months following successful launch, up to 60 trackable debris were observed. The cause of the fragmentation seems to be an auxiliary engine operating with hypergolic propellant.

In two papers the debris preventative measures of Ariane 4 & 5 were outlined. The passivation of the Ariane 4 third stage has been implemented on V35 (SPOT-2), V44 (ERS-1), and V52 (TOPEX/POSEIDON). From flight V59 onwards (SPOT-3, September 1993) passivation will be systematically applied for all missions.

Likewise, efforts are made to prevent satellite explosions through passivation of energy storage devices at end of life (batteries and propellant containers).

Measures are also introduced to reduce the number of mission-related objects, such as separation bolts, instrument covers, and clamp-bands.

Two papers described mitigation aspects of multi-satellite constellations in low Earth orbit for communication (e.g. the IRIDIUM project). It is planned to deorbit[3] each satellite at the end of its operational life.

Several papers addressed the long-term overcrowding of low Earth orbits and the necessity and effectiveness of debris mitigation measures. In order to avoid cascading effects caused by hypervelocity collisions, deorbiting of rocket upper stages and satellites at the completion of their mission will eventually be needed.

A worthwhile objective is the development of enabling technology for reusable launchers for the most frequently used orbital destinations.

Mitigation practices are becoming a top level requirement in space organizations.

In a paper the ESA approach was presented for debris preventative measures and safety aspects. ESA developed its debris preventative requirements in 1988. They were recently reviewed, leading to the identification of a set of debris control measures aimed at complementing the current requirements.

An important development is the NASA Orbital Debris Handbook. This handbook establishes guidelines for limiting the generation of orbital debris and supports the assessment of effectiveness of debris mitigation procedures.

[3] To deorbit a space vehicle means to bring it on a trajectory which passes through dense regions of the atmosphere. In general, if no special provisions are made, the vehicle will burn up completely (destructive reentry). For this purpose, a reentry trajectory over a large ocean area is selected. Deorbited vehicles may reach the Earth's surface intact if thermal protection is used, e.g. manned spacecraft or reentry capsules returning material from space.

A summary of the Orbital Debris[4] Position Paper of the International Academy of Astronautics (IAA) was presented. The paper, which is the result of the effort of an ad hoc group of experts, is in the process of being approved by the IAA. The objective of this paper is threefold. First, to make clear how significant and severe the continued deposition of orbital debris into the near Earth environment is to the future use of space for all mankind. Second, to provide some clear guidelines as to how the international community might wish to proceed in order to combat this growing environmental hazard. Third, to assist in the preparation of international agreements on this topic. Several debris control measures are recommended for immediate application in a first phase. These measures focus mainly on the prevention of debris.

At international level, CCIR discussed the importance of the geostationary orbit environment protection, leading to a draft (Ref.2) which requires satellite reorbiting into a graveyard orbit located at least 300 km above the geostationary orbit. The draft is in the process of authorization to be issued as a recommendation in near future.

Minimum standards for the design and operations of space vehicles are needed. They must be efficient in order to cope with the growing problem of debris. They must be realistic and take into account the cost of the mitigation measures and balance of competition.

Spacefaring nations in response to the increasing hazards represented by orbital debris are adopting a number of mitigation measures to protect future spacecraft and to protect the space environment from further degradation. Mitigation actions to date have been procedural and passive. They have been initiated by consensus and enlightened self-interest. In the future mitigation measures will require active design and operations considerations. Such measures will probably require some international agreements with the force of treaty law in order to assure equitable competition among the current spacefaring nations and be enforceable for new entrants.

## 8. Regulations and Legal Aspects

The papers presented on the legal aspects give a good survey of the various angles from which the subject under investigation should be approached.

The opinion was expressed, that space debris, as an issue of great concern to all spacefaring nations, should be globally dealt with by the United Nations Committee for the Peaceful Uses of Outer Space (UNCOPUOS). National studies on space debris have been submitted to the UNCOPUOS Scientific and Technical Subcommittee for a number of years already.

The set of UN principles on the safe use of nuclear power sources in outer space, adopted on 14 December 1992 by the United Nations General Assembly in Resolution 47/68 might serve as a model as to how to negotiate a difficult subject on an international level and as to how to bring those negotiations to a successful end.

In one paper, with reference to the Principles 21 and 22 of the 1972 Stockholm Declaration on the protection of the environment, the space debris matter was put in the context of international environmental law. Though, in regard to space debris, there is as yet no international legal regulation, adjustment to existing international legal regimes - for air, water and land - might serve as a way to implement the present policy considerations by the USA, Russia, Japan, and ESA in regard to space debris.

A survey of existing legal instruments related to the subject under discussion reveals that general principles of law, and in particular general principles of international space law, if interpreted according to their intention, might, together with the updating of some of those principles, lead to mitigating the increase of the space debris population. For example, strict interpretation of the Registration Convention 1975, Article IV par. 2, might lead States, international organizations and private entities to enhanced awareness of the space debris problem.

The major provisions in international space law for protection of the outer space and Earth environments are Article IX of the Outer Space

[4] Space debris denotes in general man-made debris. Orbital debris is space debris which is orbiting the Earth. Space debris is a larger category which includes also reentering debris.

Treaty and Articles 7 and 15 of the Moon Agreement.

One central issue is that of liability for damage as a consequence of pollution by space debris. The text of the Liability Convention 1972 Article 1.a. seems to be insufficient to cover the present pollution of outer space.

Space debris and its potential effects raise several issues which cannot be conveniently categorized as belonging to the domains of either space law or environmental law. Special considerations are needed for such issues, e.g. use of nuclear power sources, Earth orbits as natural resources and military or hostile use of space debris.

## 9. International Cooperation

Bilateral consultations between space organizations on the debris issue have regularly taken place since 1987.

At the occasion of the First European Conference on Space Debris, representatives of NASA, the Russian Space Agency, Japan, and ESA have met at ESOC, Darmstadt, on 2-3 April, 1993, for the first multilateral discussion on debris. It was agreed to establish a Space Debris Coordination Committee which would regularly meet (semi-annually) and which would be supported by technical working groups dedicated to four specific areas:

1. Measurements
2. Data base and environment
3. Testing and shielding
4. Mitigation.

Within the framework of this cooperation the four parties will exchange relevant technical information and experience related to space debris and will prepare common strategies to counter the space debris problem.

In particular, the need was recognized to establish a common data base of the space debris environment which is planned to be supported by the surveillance networks and observation facilities of all four participants.

In the absence of internationally agreed regulations and conventions on space debris mitigation and control, the aforementioned cooperation can be considered as a significant step toward a common approach on space debris control between four major space operators.

## 10. Conclusions of the Conference

The main conclusions of the conference are:

- Ground-based observations with radar and optical facilities reveal the existence of about 7000 objects (larger than 10 cm) in space, which do not represent an immediate and excessive danger. However, the risk of collisions with orbital debris is steadily growing and adequate measures have to be taken in order to keep the debris hazard for manned and unmanned missions within safe limits. Of most concern are the long-term prospects of the debris hazard, particularly in those regions in space which are most heavily used, e.g. low Earth orbits (900 - 1500 km) and the geostationary belt (about 36,000 km altitude).

- Significant efforts are in progress to characterize and improve the knowledge on the mid-size debris population (1 - 50 cm size objects). The knowledge on the spatial distribution of this size category is rather inaccurate, particularly at higher altitude. In the geostationary orbit only objects of at least 1 meter size are currently detected. Breakups in this important region in space may have occurred unnoticed.

- Knowledge on the meteoroid and sub-millimeter debris population is improving through analysis of satellites returned from space (LDEF, EURECA). The impact pattern on LDEF points to the existence of debris particles in elliptical transfer orbits, e.g. geostationary transfer orbits (GTO). This indicates a deficiency of current debris models which do not consider fragmentations in GTO. Some impacts on LDEF occurred in bursts typically lasting 3 to 5 minutes. This phenomenon could result from debris orbiting in confined regions (debris clouds).

- Shielding is an effective method to protect against particles up to about 1 cm size. Shielding against larger particles is currently not practical. Directions of future research are accelerators with higher velocity and projectile mass, improved numerical methods for the simulation of hypervelocity impacts and light-weight shielding. Another research area is surface material which will not produce damaging debris as a result of HVI (secondary ejecta).

- Clean-up of debris is neither technically practical nor economically feasible. The thrust of the action must be towards preventing the creation of debris. Several preventive measures have been identified and implemented in space activities, such as releasing residual propellant in rocket upper stages to preclude a subsequent explosion generating many fragments, and the reorbiting at higher altitudes of geostationary satellites at the end of their mission in order to avoid collision with operational satellites. Further possibilities include destructive reentry into the atmosphere to burn up the spacecraft or selection of orbital parameters to limit the lifetime.

- Currently, the only practical method to dispose of geostationary satellites at the end of their mission is a graveyard orbit located at least 300 km above the geostationary orbit. An interesting option for geostationary satellites is the stable plane at about 7 deg. inclination. An advantage is the low relative velocity among objects in this orbit. A disadvantage is the daily North-South motion of about 14 deg.

- The space debris problem can only effectively be solved by international cooperation. Consultation and cooperation between space agencies are increasingly taking place.

In view of the high interest this ESA initiative has stimulated, it is envisaged to hold a second conference on the debris issue in about 3-4 years from now.

## 11. References

1. Flury W. (Ed.), Proceedings of the *First European Conference on Space Debris* , ESA SD-01, Paris, France, 1993.

2. CCIR Working Party 4A. Environmental Protection of the Geostationary Orbit (Draft new recommendation). Document 4/141-E, 17 June 1992.