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Will space run out of space? The orbital debris problem and its mitigation*

Dietrich Rex

Institute for Flight Mechanics and Spaceflight Technology, Technical University of Braunschweig,
Hans-Sommer-Strasse 5, 38106 Braunschweig, Germany

Abstract

An appraisal of current and future risks from space debris is presented with the aid of calculations carried out by the MASTER model. The efficacy of various technical options – such as fuel venting, de-orbiting and use of a graveyard orbit – for counteracting the problem is discussed. The article then focuses on governmental and international cooperative measures and looks at the recent work done by subcommittees of the UN COPUOS. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Thanks to the application of space technology, we enjoy global telephone, television and data networks, improved weather forecasting, astronomical insights into unprecedenced depths of the universe, global views from space of our unique Earth, making us realize our responsibility to preserve it. We have got so used to these benefits of spaceflight that we cannot but believe in its ongoing positive evolution. Most of us are unaware of the problems which might come up from overcrowding of low Earth orbits (LEO) and of the geostationary orbit (GEO) with man-made space objects: the possible space debris crisis. We speak of 'astronauts' (star travellers) and forget that present space activities are not reaching the stars in the universe, but are mainly restricted to LEO altitudes below 2000 km and to GEO at about 36 000 km, relatively small regions which are indeed so densely populated with man-made objects that collisions already happen.

There would be no such risk of collisions if only the roughly 450 satellites presently in use were on orbit. However, they have to share space with thousands of abandoned satellites, spent rocket upper stages and with millions of debris objects of all sizes between less than a millimeter and some meters in diameter originating from on-orbit explosions and other disintegrations. New sources of such debris have been identified only in recent months: some former Soviet orbiting nuclear reactors lost their liquid metal (NaK) coolant forming ten thousands of solidifying droplets in the centimeter size region, and mostly western solid rocket motors ejected slag particles at the end of their burn, contributing to the same size population over the decades. Thanks to the work of the International Academy of Astronautics there is an internationally agreed upon definition of space debris:

> 'Orbital debris (space debris) is defined as any man-made earth-orbiting object which is non-functional with no reasonable expectation of assuming or resuming its intended function or any other function for which it is or can be expected to be authorized, including fragments and parts thereof.'

2. Orbital distribution of man-made objects

Larger orbiting objects (bigger than around 10 cm) can be detected by big radar stations, mainly by the US-SPACECOM system with some contributions also by other countries. The US radar catalogue, characterizing the orbits of some 8000 objects of that size, constitutes the main data source for research work in this field. Moreover, smaller pieces with sizes of some millimeters

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to some centimeters are detected on a statistical basis by specially dedicated US radar campaigns, to which also the German FGAN radar contributes. Statistical data on millimeter- and submillimeter-sized particles are obtained by the evaluation of impacts on satellite surfaces retrieved from space (US and ESA data). Apart from the US catalogue for objects larger than 10 cm, the measured data are far from being complete in covering all sizes, altitudes and from a continuous coverage in time.

This incomplete data situation leads to the necessity of describing the whole orbital population by a mathematical model of all generation and elimination processes and of the orbital dynamics, run on a computer. Such a model characterizes all properties of the orbital population continuously in time and therefore, with appropriate assumptions of future spaceflight, has the ability to describe possible future evolutions. Short-term and long-term predictions are usually achieved by a variation of the mathematical approach. Several such space debris models exist.

The Institute for Flight Mechanics and Spaceflight Technology of the Technical University of Braunschweig (IFR TUBS), Germany, has, on ESA contract, developed the computer code MASTER (Meteoroid and Space Debris Terrestrial Environment Reference Model), building on previous extensive investigations in the field and on a long-term coordination of work with the NASA Johnson Space Center, made possible by contracts from the German Space Agency, DARA. The MASTER code is now available to European industry and other institutions world wide. It is being compared with NASA's ORDEM 96 and EVOLVE models.

An essential feature of the MASTER model is the subsequent simulation of the roughly 130 explosions having taken place in Earth orbits, the generation of the debris clouds resulting from such explosions and their validation on the basis of major fragments recorded for each explosion (US SPACECOM), and also in the extrapolation of the orbits of all debris objects up to the present moment. Fig. 1 demonstrates how the exploded fragments are distributed several hours after the explosion as a result of the additional velocity gained from the explosion. Subsequent distribution of the debris orbits of an exploded cloud in the years following an explosion — a process affected by the gravitational disturbances of the flattened earth — are shown in Fig. 2, while Fig. 3 depicts the simultaneous decrease in the number of explosion fragments of the cloud and their decay as

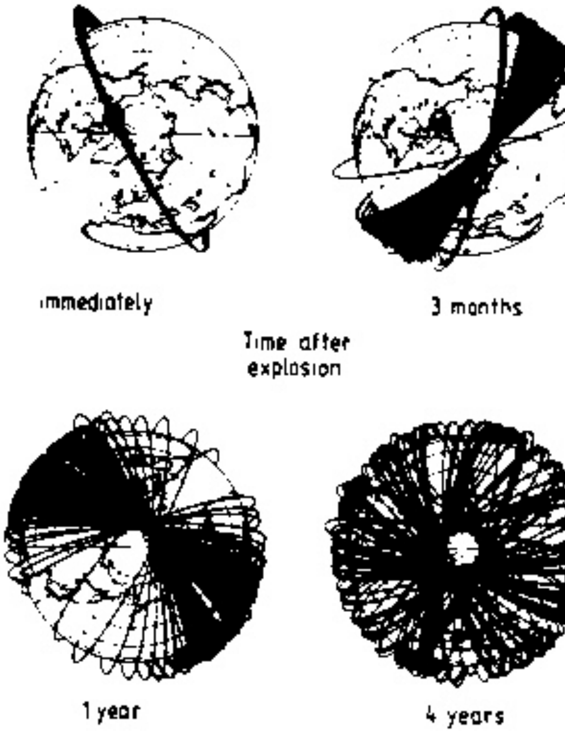

Fig. 2. Propagation of fragment orbits.

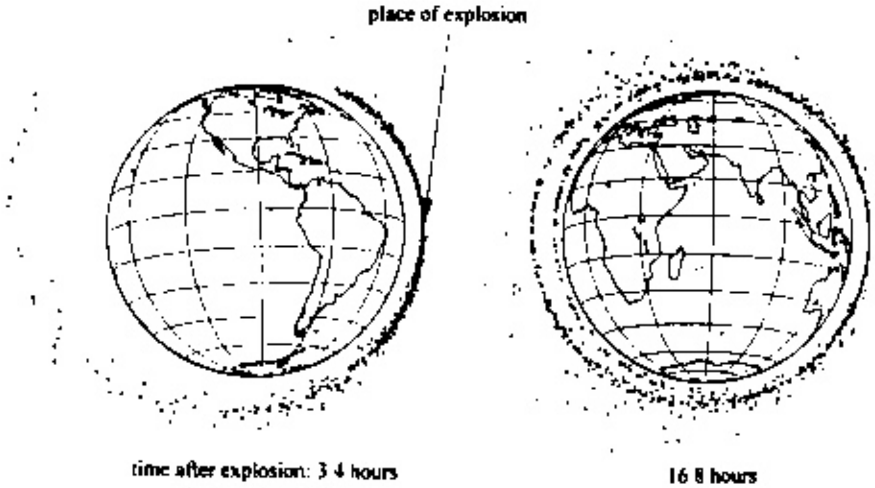

Fig. 1. Fragment propagation of an exploded cloud several hours after the explosion event.

a result of atmospheric drag. This is represented by the object flux, in this case as a function of altitude. This orbital decay, which for the example in Fig. 3 takes about 50 years, may in lower-altitude orbits proceed over a time of several weeks or months, but takes centuries or even millennia for orbits beyond an altitude of 800 km. As the geostationary orbit at 36 000 km lacks any residues of a retarding atmosphere, all objects taken there or produced there through fragmentation will accumulate and stay there for all time, which explains why this area is so highly sensitive to permanent overcrowding. If ever the geostationary orbit were to be overcrowded to such an extent that it could no longer be used because of the excessive collision risk, it would then be lost for ever. Subsequent clearing measures would not be feasible — neither technically, nor economically. Fortunately, for the time being there is not yet such a real risk, and measures designed to limit the GEO object population have already been initiated (see below).

The **MASTER** model includes a description of the altitude distribution of the orbital populations as in Fig. 4 for objects lager than 1 cm. Resulting from historical launches and break-ups, two debris clusters have been produced — at altitudes between 800 and 1000 km and at 1500 km. Due to the almost complete absence of an atmospheric drag, the latter range in particular will be most affected in the future by increasing debris clusters, while the decrease in object density below an altitude of 700 km can be attributed to the self-cleaning effect which is highly effective here. Without this effect, the density within this range would by now be enormous, with an extreme peak at about 280 km.

Fig. 5 shows the altitude distribution on a logarithmic scale so as to be able to plot the curves for all object sizes

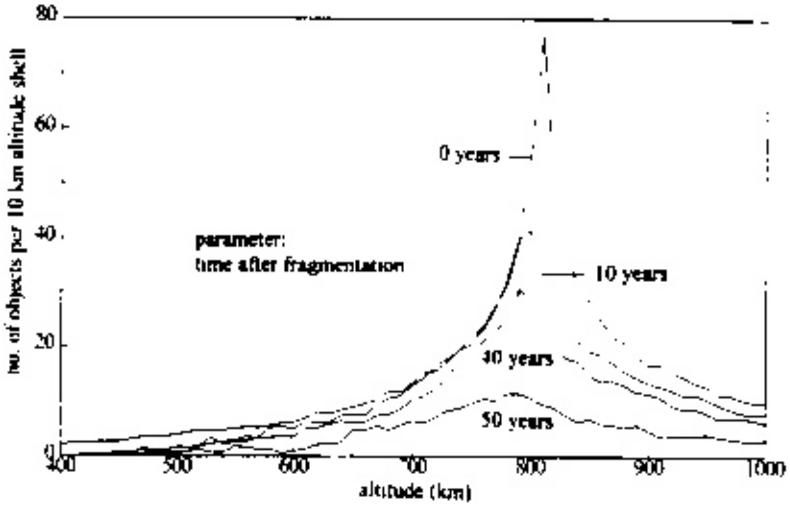

Fig. 3. Decay of a fragment cloud

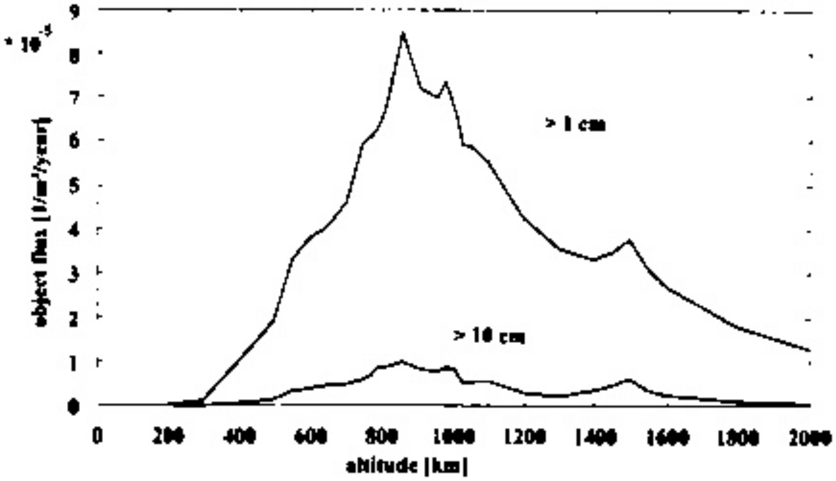

Fig. 4. Altitude distribution of orbital objects larger than 1 and 10 cm, resulting from spaceflight activities

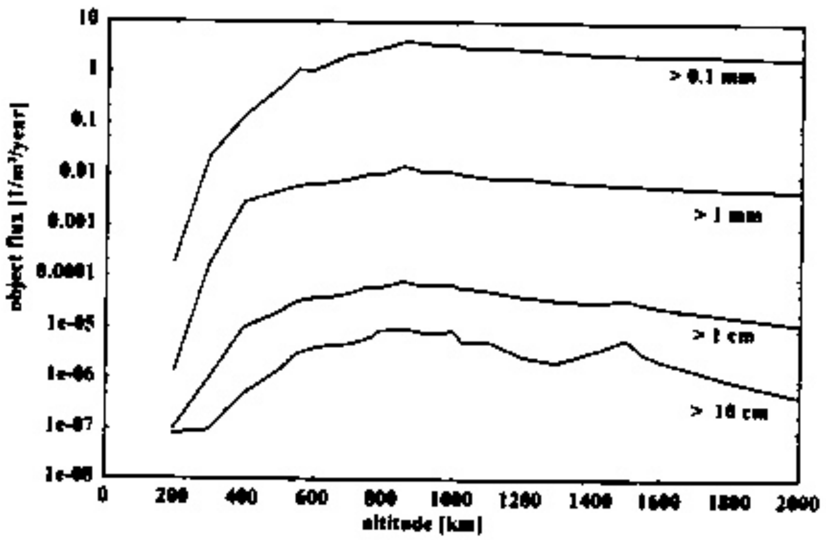

Fig. 5. Altitude distribution as in Fig. 4, in this case with a logarithmically graded ordinate (for all size groups).

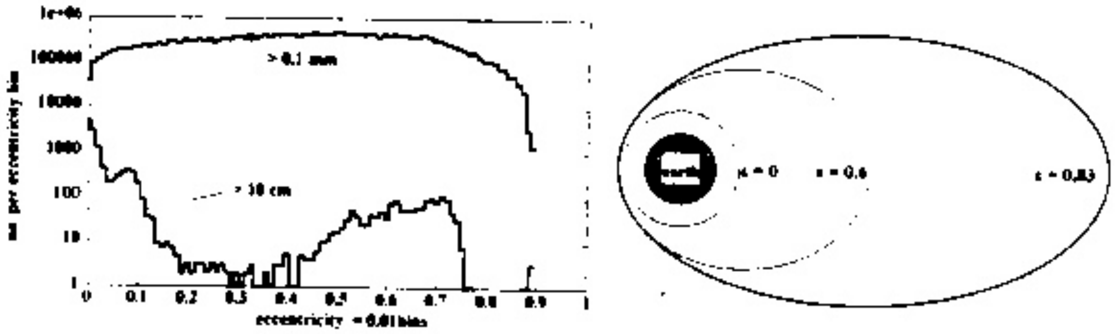

Fig. 6. Distribution of orbit shapes of debris objects (left). Larger objects are concentrated at $e \approx 0$, small objects at $e \approx 0.5$ to 0.7; eccentricity e describing the orbit shape (right).

in one graph. It is evident that for the small objects (0.1 mm plus) the distribution across altitudes is represented by a rather flat curve, which means that the entire altitude range is almost uniformly affected. On the whole, these small particles are the result of explosions which catapulted them at great additional velocity into a wide range of orbits. The small fragments therefore assumed highly elliptical orbits, while the majority of satellites circle on near-circular orbits. This becomes apparent from the eccentricity e in Fig. 6.

3. Collisions on Earth orbits

3.1. The collision risk

At LEO altitudes the situation is presently quite chaotic, as can be illustrated by Fig. 7, especially when considering that a mere 1.5% of the orbits contained in the US-radar-catalogue has been plotted there (more data would overcharge the graph). There are no traffic regulations whatsoever, so that the picture resembles a stochastic criss-cross of movements. We rely on pure chance, hoping that the orbital objects will not collide. This approach may have been justified in the early days of spaceflight, when only a few space objects orbited the Earth, when every successful launch was applauded and no-one had any intention of additionally burdening spaceflight activities by dictating collision-free orbits, which in effect would have meant to establish traffic rules. But today, with about 10^{13} objects larger than 0.1 mm orbiting the earth this results in frequent impacts of tiny particles on all satellites, while the probability of collision with larger objects has reached such a level that the situation requires serious attention.

In Fig. 8, this situation is highlighted by the mean time elapsing between two impacts on a 100 m² satellite (e.g. a satellite with solar generators, or a manned element of

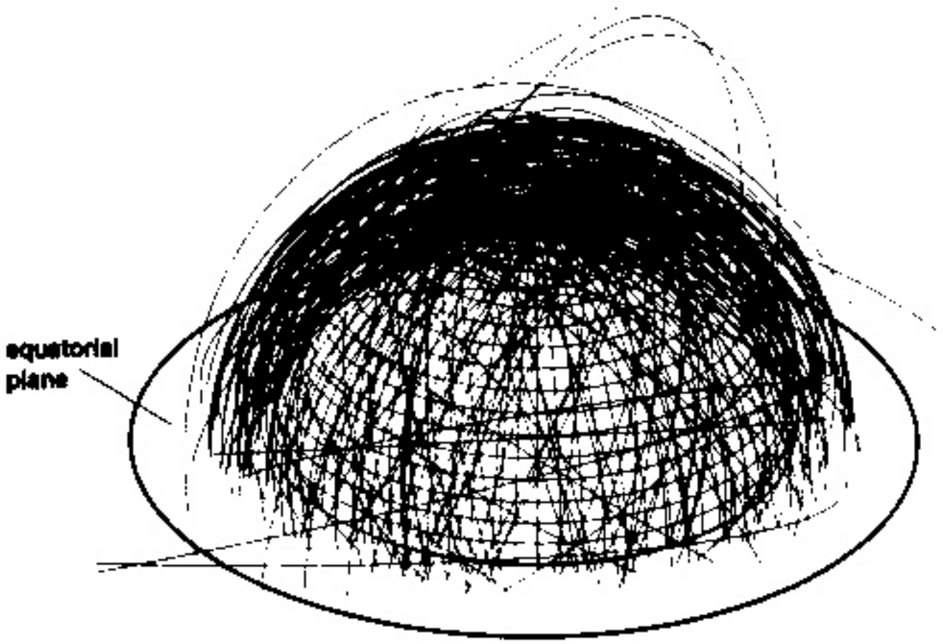

Fig. 7. Representation of 1.5% of orbits presently occupied by objects larger than 10 cm. Whether or not collisions occur is left to chance.

circular orbit altitude	debris objects of size 1 mm	1 cm	10 cm (objects in the radar catalogue)
500 km	1 ... 10 years	350 ... 700 years	15000 years
1000 km	0.3 ... 3 years	70 ... 140 years	2000 years
1500 km	0.7 ... 7 years	100 ... 200 years	3000 years

uncertainty of data

Fig. 8. Mean time intervals between objects of size d (and larger) impacting on a satellite of 100 m² cross-sectional area orbiting at an altitude as given in column 1.

the space station) at different orbital altitudes. The figure given for $h = 1000$ km $d = 1$ cm implies that the likelihood of such a satellite being hit, and destroyed, by an object larger than 1 cm within its 10-year mission is about 10%. The actual risk is hence for the time being not extremely high, but it should not be forgotten that, with such a collision, several hundred million dollars may be lost. Also, this risk is clearly on the rise, as will be shown below.

Let us take a look at another example, the manned module of the international space station, which will be set up at an orbital altitude below 500 km as from 1998. Despite all multiple shielding (see below), the impact of an object larger than 1 cm would pierce the cabin wall and could, because of the sudden pressure loss, result in the death of astronauts. According to the table, this happens about every 500 years or with a probability of about 6% during the 30-year mission: an unacceptably high risk for the astronauts. The station will (not least for this reason) orbit at a lower altitude where, as shown in Fig. 4, the object density is lower. In addition, it will manoeuvre (!) to avoid collision, and a system of bulkheads and escape routes will provide additional precautions against the consequences of a pressure loss.

3.2. Collision direction and velocity

When putting oneself into the situation on board a satellite (or on board the space station), objects of space debris need not be expected to impact from all sides. A possible geometry for two objects colliding on orbits at the same altitude but in different orbital planes is illustrated in Fig. 9. It follows from the orbital plane distribution of the actual objects and their eccentricity distribution that the impact velocity vector (differential velocity vector) is almost in the horizontal plane (in parallel with the earth surface beneath), where it has for each orbital altitude and each orbital plane of a given satellite a characteristic angular distribution. Some examples are given in Fig. 10 — again based on the MASTER model. Such results provide an important basis for designing the space station shield.

3.3. Consequences of an impact: shielding

As the impact velocities of orbital objects hitting upon the space station or a satellite are enormous (cf. Fig. 10),

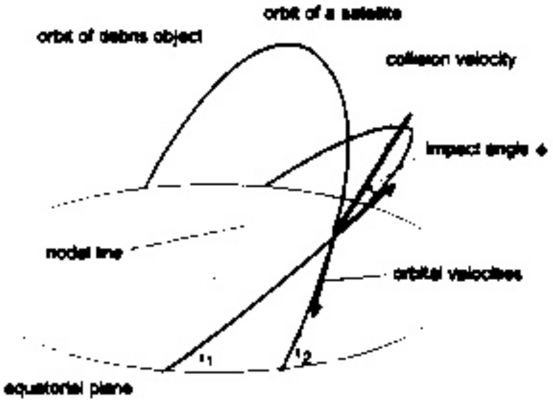

Fig. 9. Collision geometry of two orbiting objects colliding.

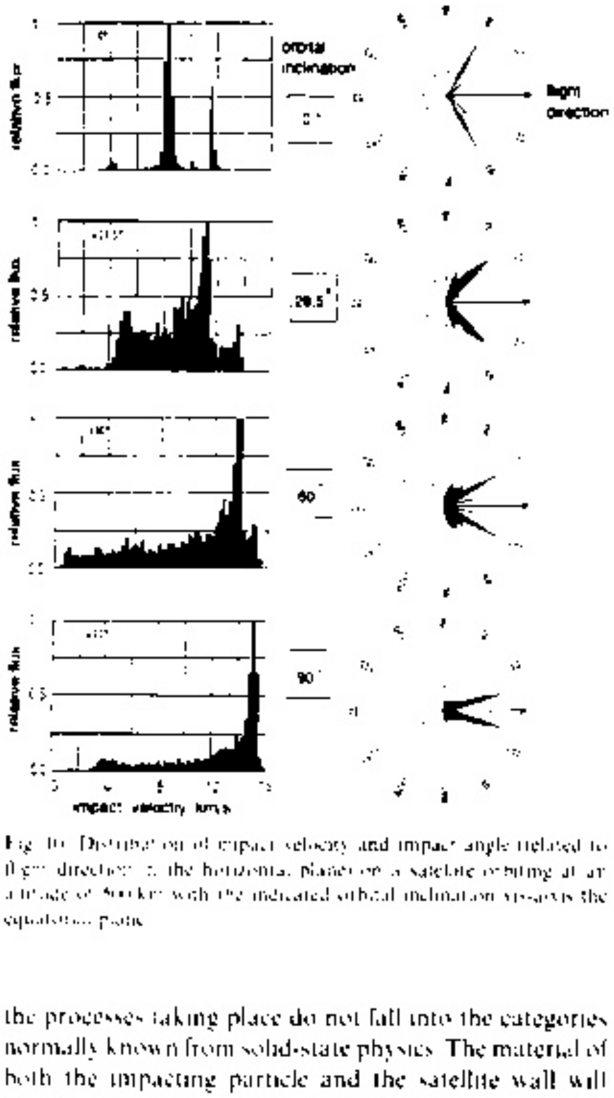

Fig. 10. Distribution of impact velocity and impact angle (related to flight direction) in the horizontal plane on a satellite orbiting at an altitude of 800 km with the indicated orbital inclination vis-a-vis the equatorial plane.

the processes taking place do not fall into the categories normally known from solid-state physics. The material of both the impacting particle and the satellite wall will liquefy, or even evaporate, it may even ionise, and the metal droplets, solidifying again will splash into the inside of the satellite. The accompanying shock waves can tear apart the entire satellite structure. Just one telling comparison: the energy content of an impacting particle having a mass of 1 g compares by approximation to the explosion energy of 10 g of dynamite – and the effect is similarly dramatic. To simulate such impact processes in experiments on the ground, e.g. to be able to develop shields against space debris, objects in the order of a centimetre have to be accelerated to velocities of 10 km/s (or 36 000 km/h). Such 'shots' are about the upper limit of what is possible and reached in the military field for armour-piercing projectiles. What is actually applied is the method of military 'shaped charges', so that terrestrial experimentation can be employed for developing space station shields and for demonstrating their effectiveness for projectiles up to 1 cm in size.

In designing shields, advantage is taken of the fact that impacting particles whenever they penetrate a wall, decompose into an array of droplets which, when hitting a second wall, do much less harm than the original compact particle (cf. Fig. 11). Sophisticated double and multilayer systems with interlayers of fabric or foamed material are being used, and this is also the shielding structure employed for the manned modules of the planned space station.

4. Future developments: How can the space debris crisis be staved off?

4.1. *When carrying on as in the past*

If the available models are to provide calculations for the future, a large number of assumptions has to be entered. How many space launches will there be per year? What are the altitudes? Of what size are the satellites? How many more explosions will occur? How many mission-related objects will accompany each launch?

It is quite logical to assume that spaceflights will continue as before – the 'business as usual' scenario. All model calculations for this scenario made at great expense in the US, in England, Germany and Japan agree (except for deviations in detail) on the following: within, say, the next two decades there will be an increasing number of collisions between all the space objects orbiting the earth. This derives from the fact that the number of collisions increases on the whole as the square of the number of orbiting objects (with otherwise identical size, orbit and altitude distributions). These collisions generate additional orbital debris objects that have to be added to the number of objects launched and produced by explosions – which are likewise on the rise. Fig. 12 illustrates this situation.

After about 50 years, the number of collision fragments will outweigh the number of all the other objects. In the course of time, large collision fragments will in their turn trigger new collisions bringing a total disintegration of

Fig. 11. Impact of a particle, about 0.5 mm in size at a velocity of approx. 10 km/s on the double wall as indicated below, decomposed into many droplets upon penetrating the first wall (lower photograph); the droplet cloud impacting on the second wall with some droplets piercing the wall (upper photograph).

the hit objects in their wake: this is then comparable to a self-sustained chain reaction, which in the long run (and even without any further launches) would lead to a situation not unlike that of the debris rings around Saturn and Jupiter (although at a much lower mass content). But even an increase in object density to more than 10 times the present level within 100 years (as shown in Fig. 12) would presumably paralyse spaceflights, as the risk for new satellites and the financial load thus incurred would simply be too high.

It is virtually impossible to cut this population just by 'collecting' objects; a 'vacuum cleaner in space' is physically not feasible. To take objects aboard a vehicle like the US Space Shuttle would require a gigantic number of highly cost-intensive missions and is therefore for economic reasons beyond all limits of feasibility. In view of the long orbital life of the objects at altitudes of 1000 km and beyond, it is useless to wait for the drag-induced self-cleaning effect to make itself felt. It will not provide an answer. Should spaceflights continue as before, humankind would overcrowd near-Earth space permanently and to such an extent that this space is no longer available for space projects. Since forecasts to this effect are fraught with uncertainties, it shall at this point be left open whether this situation will have been reached in 70 or 130 years' time. What is certain is that it will be reached.

4.2. Countermeasures

What can be done to mitigate the debris growth or halt it altogether? In view of the sources of space debris as outlined before, there are two fields where countermeasures are conceivable:

4.2.1. Avoiding explosions in orbit

To date, explosions have been responsible for most of the space debris, which is why they have to be stopped by all means. To this end, all that must be done is for residual fuel to be discharged from all rocket upper stages once they have separated from the satellite. Opening a valve will make the fuel evaporate into space. This measure is relatively simple and low in cost, although not entirely devoid of problems, as the outside observer may think. To reduce space debris, residual fuel venting is now routinely practised with all European Ariane rockets and the US Delta rockets, and Japan has followed suit. The rockets of other nations do not as yet provide for this remedy, and there will be a transition period of many years until explosions can be avoided completely. But even then, exploding upper stages will not entirely be a thing of the past. Some of the upper stages exploded in former times had been in orbit for more than 15 years, and such events could continue for some time to come. Deliberate design can help to reduce the number of satellite explosions, although complete elimination will prove to be more difficult.

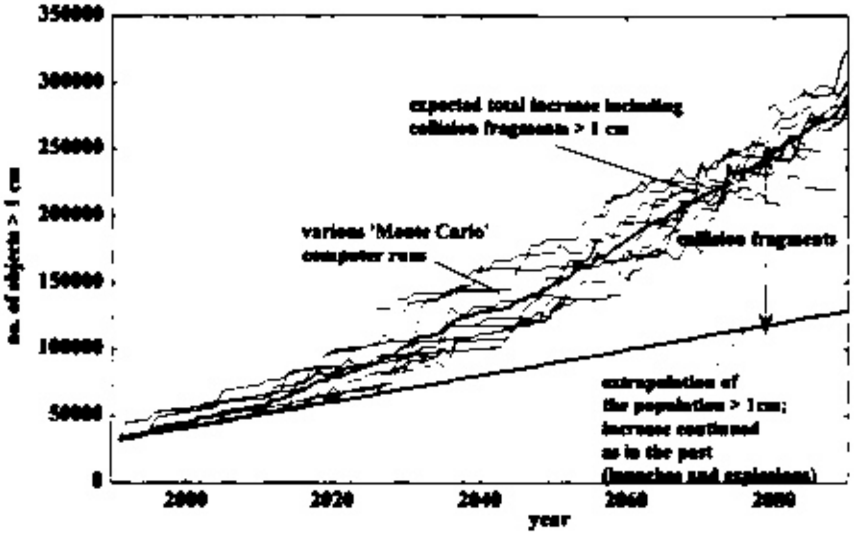

Fig. 12. Typical increase in the number of orbital objects larger than 1 cm over the next 100 years, assuming spaceflights to continue as before. In addition to the linear increase attributable to launches and explosions (as before) there is a progressive rise in collision fragments

This measure will substantially reduce the number of small objects (explosion fragments). However, collisions producing a lot of fragments mainly involve larger impacting objects (satellites, rocket upper stages), whose number will not go down just by avoiding the explosion risk. This explains why explosion avoidance will be highly effective in the short run, whereas in the long run it cannot prevent the actual number of collisions from growing.

4.2.2. De-orbiting large objects

Rocket upper stages and satellites could in the future be designed to comprise thrusters and fuel allowing them to perform a braking manoeuvre to make them crash into one of the Earth's oceans. That manoeuvre would be performed at the end of their active life – for rocket upper stages immediately after delivery of a satellite, for satellites at the end of their missions. As a consequence, orbits are always cleared again, and there can be no accumulation of space objects. On the other hand, this measure will – depending on the object's orbital altitude – increase costs by up to 15%, if the initial altitude is less than 1000 km. At 1500 km plus, such a manoeuvre will hardly be economically feasible. Also, satellites that do not possess any manoeuvring thrusters would have to be redesigned.

The cost situation can be slightly abated by just lowering the orbital altitude by means of the retro-thrust, the remaining braking action being taken over by the then denser atmosphere. In their approach to space debris mitigation, the US intends to rely mainly on this method. But as this is not a controlled manoeuvre, the object need not necessarily re-enter the denser atmosphere above an ocean and, unless it burns up completely, may consequently cause harm on Earth.

4.3. Efficiency of countermeasures

It becomes apparent from Fig. 13 that the measures as outlined here, if taken together, will effectively solve the problem of space overcrowding. Assuming the present population of objects below a size of 1 cm to be 100 000, different scenarios are used to determine how many of these objects will populate space after a period of 50 years. The most extreme – and for that reason obviously not serious – measure of space debris mitigation would be to completely and immediately abandon any further space activities. Although in this scenario 1, the number of launched and explosion-related objects will go down (self-cleaning effect), collisions that will statistically take place within this 50-year period will generate new debris so that the total number will remain on more or less the same level. When continuing spaceflights as in the past, scenario 2, the amount of space debris, and hence the collision risk, will almost have quintupled by the end of these 50 years, an increase that would be mitigated by the different avoidance strategies in scenarios 3 and 4.

In the most far-reaching scenario 4, the number of objects will still rise to twice the present number within 50 years, but after that there will be almost no further rise (not visible here). Scenario 2, for an unmodified continuation of space programmes on the contrary, will see a further progressive rise after the end of the 50-year period.

The measures outlined as strategies to prevent continued overcrowding of near-Earth space, in particular the elimination of launched objects by means of their

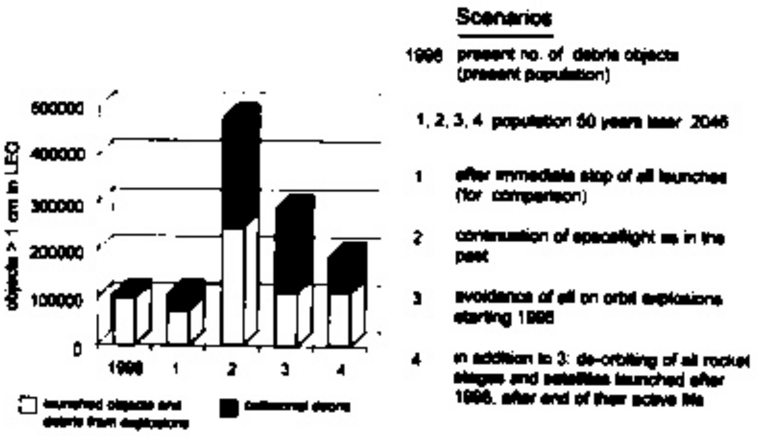

Fig. 15. Effectiveness of strategies 1–4 for space debris mitigation. Left: development in object numbers (across all altitudes) after a 50-year period and for the scenarios as defined on the right.

own retro-thrusters, will add to the cost of future space programmes. But this cost increase of up to 20% for some missions will have to be accepted in the future in order to preserve near-Earth space for further missions. However, even though this insight is technically no longer questioned and would also economically be accepted, there is one major obstacle impeding general introduction of the necessary debris mitigating strategies: the fierce international competition dominating space missions, which today are primarily commercial undertakings. Only if and when clearly defined technical standards of debris mitigation are binding for, and contractually accepted by, all nations, will such measures be feasible without at the same time distorting the competitive situation. This has given rise to the negotiations in this field, in particular in the UN, which are described later.

4.4. Measures designed to counteract overcrowding of the geostationary orbit

Special aspects govern the geostationary orbit (GEO) on which almost all communication satellites and some of the weather satellites are positioned about 36 000 km above Earth's equator (and this means far beyond near-Earth orbits considered so far) in such a way that they stand still in relation to the Earth's surface. Here, no braking effects come to bear that might deprive them of any of their energy, which is why all the objects taken to GEO remain there – literally for all eternity. As a consequence, the population of GEO satellites either still operated or already abandoned has risen constantly since the first days of spaceflight. The current GEO satellite density above the geographic longitude is depicted in Fig. 14. There are up to six objects per each angular degree; it should, however, be noted that on GEO, one angular degree corresponds to the curve length of about 736 km. For GEO, the collision risk is at present only about one-tenth that of near-Earth space; because of small objects that have so far escaped detection, it may, however, also be higher. As the time-related rise in object density is even more rapid here than in near-earth space, GEO, which is so immensely important for space programmes, can easily become overcrowded for all time and thus unfit for further use.

The spacefaring nations became aware of this risk quite early on, and they have – as yet without binding effect – applied the following strategy: at the end of their active missions (normally after seven to ten years) GEO satellites will, with fuel specifically saved for this purpose, be taken to a 'graveyard orbit' some 300 km above GEO. Here they will be 'buried' by fuel venting and battery discharging – a remedy that will solve the problem for the coming decades. But in the long run, overcrowding might eventually entail collisions also in the graveyard orbit, the fragments of which may in turn again affect GEO. For the 300 km lifting manoeuvre, about 3% of earnings that might have been achieved with the satellite are waived, and about 140 satellites have already been taken to the graveyard orbit on a voluntary basis. The satellite position thus cleared in GEO is, however, often occupied again by the same user, which shows that a certain self-interest cannot be denied here.

5. Problem awareness at the governmental and international levels

5.1. Governmental measures

On the instigation of his scientific and technical advisers, US President Ronald Reagan decreed, in February 1988, the presidential policy that 'all space sectors will seek to minimise the creation of space debris ...'. This was the first time that the objective of near-Earth space preservation had reached the highest political

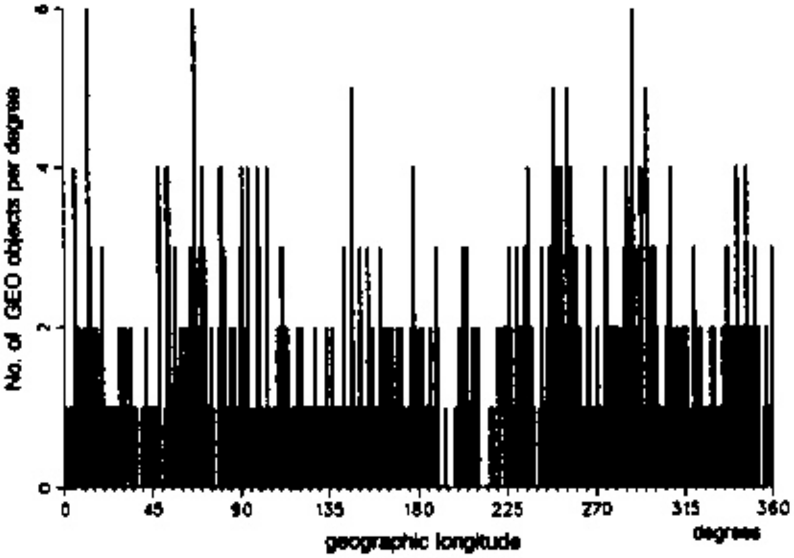

Fig. 14. Occupation density of known satellites on the geostationary orbit (GEO) per each angular degree. Whether additional smaller objects (fragments) exist, is not known. Source: ESOC.

levels. For NASA and other US organisations this was tantamount to a directive, in response to which they prepared common papers that might finally flow into domestic legal regulations on the avoidance of space debris. In doing this, the USA is taking the lead, ahead of all other nations.

From about 1985 a process has been initiated that shifts the awareness of a dawning space debris crisis from scientists to the decision makers, the politicians. Scientists have made a great contribution to this effect. The renowned University of Chicago, for instance, organised as part of a programme to commemorate the 100th anniversary of its foundation a three-day symposium 'Preservation of Near Earth Space for Future Generations' to which experts from all over the world were invited for an exchange of opinion with space jurists and NASA and DOD administrators. The work done in Europe in this connection was presented by the author.

But let us turn back some years. The European Space Agency (ESA) was one of the first big space agencies to have set up, in 1987, a Space Debris Working Group which in 1988 presented the first Report Space Debris issued by a government organisation. This group of ten space debris experts of all European nations (and ESA staff) continues to exist under the name ESA Space Debris Advisory Group; it gives its opinion on ESA space projects as regards the space debris aspect and gives its appraisal of the European research programme in this field. The Group has since the beginning been chaired by the author (re-elections so far are on a two-year basis). In 1989 the USA followed suit with their Report on Orbital Debris by Interagency Group (Space), which was drawn up by a NASA, DOD, DOT and NOAA interagency group and was updated in 1996 by a follow-up report. Both the European and the American reports represent the official view, highlighting the technical particulars of the space debris problem, and they recommend measures designed to mitigate the problem.

Following the above ESA report, the supreme decision-making body in ESA – the ESA Council – took up the space debris issue and the ESA Council Resolution '*vis-à-vis* the Space Debris Problem' was decreed.

In the wake of the US Presidential policy directives and the above interagency reports, NASA has recently, in a NASA Management Instruction and in the NASA Safety Standard (which took several years to produce), presented detailed technical data on debris avoidance for all US space ventures, be they government or private enterprise projects. These papers do not just aim at explosion avoidance strategies, but also at the elimination of abandoned objects from their orbits, or, as a minimum requirement, a limitation of their orbital life to less than 25 years. Currently, this Standard is being passed through the different decision-making bodies of NASA and at US ministerial level, and it remains to be seen to what end these good intentions will come. ESA has prepared similar papers, the ESA Space Debris Mitigation Handbook and some provisions in the European Cooperation For Space Standardization, ECSS, on which coordination processes are under way among ESA and the European space industry.

5.2. Towards international agreements

What is certain is that such measures will not be introduced unilaterally and without due consideration of other nations and space agencies. Against the background of a world-wide economic competition no country will accept additional costs for measures of space debris avoidance if it cannot be sure at the same time that competitors will pursue the same course. Governments and space agencies have hence at an early stage aimed at clarifying the issue and any countermeasures at an international and interagency level. The knowhow of almost the entire spacefaring world is being pooled in the Interagency Space Debris Coordination Group (IADC), which is constituted by NASA, ESA, the Russian, Japanese, Chinese and other space agencies – that is to say, under government authority. The conferences, held at six-monthly intervals (with the author taking part as an ESA observer) can be expected to produce technically founded, economically viable and efficient measures designed to counteract a continued increase in space debris, which, when presented, will already have received the approval of the main spacefaring nations.

This would be an important step in the final process of uniting humankind in this field. Following a resolution taken by the General Assembly of the United Nations, since 1995 space debris has been an official item on the agenda of one of the United Nations space committees – the Scientific and Technical Subcommittee (STSC).

In the UN, the space committee proper is the Committee on the Peaceful Uses of Outer Space (COPUOS) which is supported by two subcommittees, namely the Scientific and Technical Subcommittee already mentioned and the Legal Subcommittee, LS. The actual work is done in the two subcommittees, the main committee confirming this work on the political level. According to normal procedure, a matter is first discussed in the Scientific and Technical Committee, the Legal Committee may process it into a legal text, which, once confirmed in the Main Committee, is passed by the General Assembly. The safety principles on the use of nuclear power sources (NPS) in space, for instance, to which Germany contributed decisively, went through these very stages until adopted by the General Assembly in 1992.

A similar procedure can perhaps be expected to be applied to the space debris problem, which is why the first wording of the issue in the Scientific and Technical Subcommittee is gaining a similar importance as the text on NPS at the time. The Committee has decided on a fixed schedule of three (or four) years, during which the items 'space debris measurements', 'space debris modelling' and 'measures of space debris mitigation' will be covered in this order. At the two-week meetings held in Vienna in February each year, the 65 delegations present their opinions, and the technical papers submitted by experts of the different nations are discussed. It is intended to draw up a technical STSC report, which finds the support of all the UN nations and defines suitable mitigation measures to counteract continued overcrowding of near-Earth space. The outstanding role the UN assumes in this context has to be seen in the unanimous consensus between all nations on the way in which space debris jeopardises future space projects. In this situation, it might for the first time be possible to arrive at a global and thus a radical solution to the problem.

In February 1996, the author was elected chairman of the Scientific and Technical Subcommittee of the UN Space Committee, the vote, like all committee decisions, being a unanimous vote by all the delegations. Although there are 16 items on the agenda, many delegations presently give priority to the space debris issue. As chairman of the committee, I would like to see the task successfully concluded within the envisaged period; perhaps I will also see the United Nations use concerted action to avert the threat future spaceflight has to face with the overcrowding of near-Earth space and GEO.

But new problems are dawning in near-Earth space: constellations of up to several hundred new satellites planned for one single project (world-wide communication via cellphones) have to be examined with a view to their influence on possible collisions. Global management of near-Earth space seems to remain one of mankind's permanent tasks.

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