# THE UPDATED IAA POSITION PAPER ON ORBITAL DEBRIS

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## ABSTRACT

Being concerned about the space debris problem which poses a threat to the future of spaceflight, the International Academy of Astronautics has issued in 1993 the *Position Paper on Orbital Debris.* The objectives were to evaluate the need and urgency for action and to indicate ways to reduce the hazard. Since then the space debris problem has gained more attention. Also, several debris preventative measures have been introduced on a voluntary basis by designers and operators of space systems. The updated *IAA Position Paper on Orbital Debris* takes into account the evolving space debris environment, new results of space debris research and international policy developments. It has been approved by the Board of Trustees of the IAA at its session on October 3, 2000, in Rio de Janeiro, Brazil. This paper is an abbreviated version of the updated IAA Position Paper.

## 1 INTRODUCTION

Since 1957, mankind has performed more than 4,000 space launches into Earth orbit. The large number of spacecraft, rocket bodies, and other hardware ssociated with these missions will eventually either: (1) reenter the Earth's atmosphere, (2) escape from Earth orbit into deep space, or (3) remain in Earth orbit (Fig. 1).

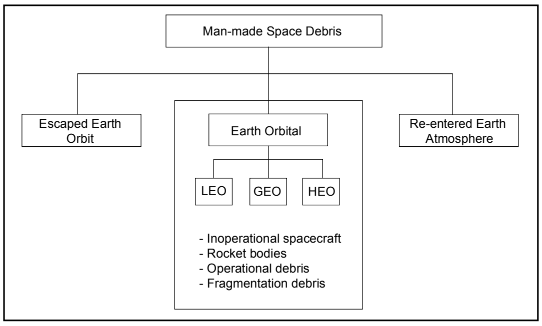

Fig. 1. Debris categorization: Man-made space debris may escape Earth orbit, reenter Earth's atmosphere, or remain in Earth orbit. This position paper is primarily concerned with Earth orbiting debris. LEO = low Earth orbit up to 2000 km altitude; GEO = geostationary orbit, altitude 35786 km; HEO = high Earth orbit (apogee above 2000 km).

After over 40 years of international space operations, more than 26,000 objects have been officially cataloged, with approximately one-third of them still in orbit about the Earth (Fig. 2). "Cataloged" objects are objects larger than 10-20 cm in diameter for LEO and 1 m in diameter in higher orbits, which are sensed and maintained in a database by the United States Space Command's Space Surveillance Network (SSN). Statistical measurements have determined that a much larger number of objects (> 100,000) 1cm in size or larger are in orbit as well. These statistical measurements are obtained by operating a few special radar facilities in the beam-park mode, where the radar is pointed in a fixed direction relative to the Earth.

The purpose of this Position Paper is to review the population growth of man-made objects in Earth orbit, with emphasis on orbital debris and on the hazard presented to current and future space operations, and to assess preventative measures for debris reduction. It should also convey clearly the urgency of taking action to control the growing orbital debris population and to make recommendations for possible methods to initiate selected control options. This paper recommends certain initiatives that could be implemented immediately to mitigate and control future debris generation.

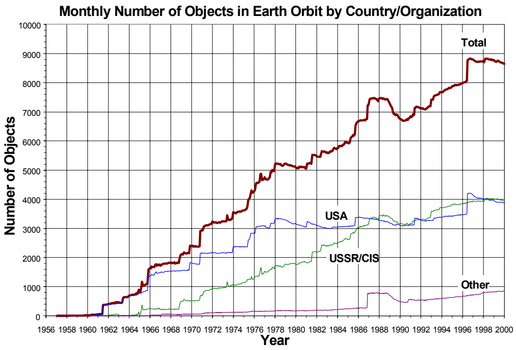

Fig. 2. Cataloged objects in orbit: objects larger than 10-20 cm in diameter for LEO and 1 m in diameter in higher orbits. The status as of Jan. 1, 2000 is shown.

Surveillance Network. In addition to the approximately 8600 cataloged objects as of 1.1.2000, an additional nearly 1000 uncataloged objects were also being tracked in Earth orbit.

Orbital debris is herein 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. Orbital debris includes non-operational spacecraft, spent rocket bodies, material released during planned space operations, and fragments generated by satellite and upper stage breakup due to explosions and collisions. Only about 6% of the cataloged objects are operational satellites. About one-sixth of the objects are derelict rocket bodies discarded after use, while over one-fifth are non-operational payloads. Pieces of hardware released during payload deployment and operation are considered operational debris and constitute about 12% of the cataloged population. Lastly, the remnants of the over 150 satellites and rocket stages that have been fragmented in orbit account for over 40% of the population by number. These proportions have varied only slightly over the last 25 years. Small- and medium-sized orbital debris (size ranging from 1/1000 mm to 20 cm) include paint flakes, aluminum oxide particles ejected from solid motor boosters, breakup fragments, and coolant droplets from leaking nuclear reactors.

Orbital debris continually passes through space shared with functioning fragile and expensive spacecraft, manned and unmanned, performing vital navigation, communications, remote sensing, surveillance and scientific missions. It is clustered around regions where space activity has been the greatest: LEO and GEO. This presents a variety of problems to the spacefaring community, from the possibility of catastrophic collision to the corruption of astronomical observations and intermittent interruption of RF paths. The first confirmed accidental collision between two catalogued objects occurred in July 1996. The functioning French satellite CERISE was damaged when a fragment from an Ariane rocket body collided with the spacecraft' gravity- gradient attitude control boom. Some near misses between operational spacecraft including the Space Shuttle and large debris have also taken place. As near-earth space becomes more cluttered, we can expect these incidents to occur more often.

The issue of man-made objects which have returned to Earth through uncontrolled reentry merits some considerations. Most reentering spacecraft and upper stages are destroyed by entry heating. In some cases solid pieces may reach the Earth's surface (e.g. Skylab, Kosmos 954, Salyut-7/Kosmos-1686, Delta II second stage in 1997 and 2000). In general, very few pieces of reentering debris have been recovered. Incomplete destruction during uncontrolled reentry may, however, occur more frequently. More research is needed in modeling the disintegration process.

The natural meteoroid environment, which is successfully countered by established spacecraft design features, is employed as a reference by which the orbital debris hazard can be placed into proper perspective. Orbital debris markedly exceeds the meteoroid population for objects of all sizes except for a region below 1mm and is now considered the primary particulate design environment for manned and unmanned space systems.

Some space agencies are striving to generate fewer debris by applying debris mitigation measures. However, there will be no net benefit if only one spacefaring nation introduces preventative measures. Space is a public domain, and if it is to be protected so that all can continue to exploit its unique attributes, there must be concerted and cooperative action among all spacefaring nations. In part, this is necessary to make economic competition equitable, but it is also necessary to keep valuable operational regions technically and economically viable for the future.

Since operational lifetimes are generally much shorter than the orbital lifetime of both LEO and GEO satellites, it becomes clear that some active control of these regions of space must be required. Unfortunately, because these have been the most widely used regions of space, they also have the largest population of orbiting objects. In LEO, both inadvertent and a few deliberate explosions have added significantly to this spatial population. New developments such as constellations of communication satellites will increase the population further. To minimize collisions among objects large enough to generate substantial further debris, some active control will be required.

## 2 PRESENT STATUS

The distribution of orbital debris may be quantified by the spatial density, SPD, measured in average number of objects per cubic kilometer. Fig. 3 plots the SPD of tracked objects for LEO. The collision risk in LEO is much higher than in GEO because of the higher relative velocities and the much smaller regional volume. Today about 9 percent of the tracked object population resides in GEO or near GEO orbits. In total, about 800 cataloged objects have been inserted in the geostationary ring. Almost 200 upper stages and several separated Apogee Boost Motors (ABM) are located in the geostationary ring or its vicinity.

During the space age, the cataloged population (all altitudes combined) has grown at nearly a net linear rate of 210 entries per year. The only natural removal mechanism is atmospheric drag, whose effect decreases with altitude (see Table 1).

TABLE 1. Lifetime of circular orbits: For an average-type satellite the lifetime for several circular orbits is shown.

| Orbit altitude (km) | Lifetime |
|---|---|
| 200 | 1-4 days |
| 600 | 25-30 yrs |
| 1000 | 2000 yrs |
| 2000 | 20 000 yrs |

Unfortunately, at altitudes higher than about 1000 km, it is barely effective. Most objects put into these regions will stay for hundreds to millions of years. The consequence is a steady accumulation of mass at higher altitudes. The major concern with orbital debris is that it might strike an operational satellite or another massive object, causing any of a wide variety of detrimental consequences. If a trackable object in LEO were to strike another trackable object in LEO (like an operational satellite) both would most likely be destroyed, due to the large relative kinetic energy available.

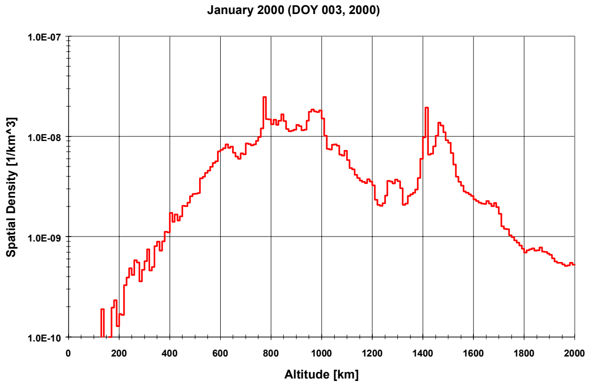

Fig. 3. The spatial density of the cataloged objects is displayed in LEO as function of altitude (NASA JSC, 2000).

Debris in the 1 - 10 cm size range, though too small to be tracked by operational systems and to be sensed by most ground systems, are large enough to cause catastrophic damage to many satellites. Particles of this size have been produced by the thousands from many of the 150 known spacecraft and rocket body breakups to date. Another source of debris in the centimeter size range are RORSATs. There is strong evidence from radar observations, that several tens of thousands of NaK droplets of about 1 - 3 cm size are in near-circular orbits around 700 - 1000 km altitude. The probable origin is coolant adjacent to the core reactor at the time it is ejected to neutralize the power system. Another source of non-fragmentation debris are solid rocket motors. These contain about 15% of their mass aluminum as catalyst. During the firing most of the aluminum results in aluminium oxide with a typical particle size of 10 micrometer. About 1% of the propellant mass may turn into slag particles which may reach centimeter size.

At altitudes where atmospheric drag is less pronounced, the population of objects in the 1 -10 cm size range may be much larger than the trackable population, possibly by factors as large as two to ten. Radar measurements from Haystack indicate that in some low-altitude bands the population of centimeter-sized objects may be about an order of magnitude larger than the catalogued population.

Orbital debris in the 1 mm - 1 cm size range may produce mission-degrading effects on spacecraft which they encounter. These objects are more numerous than larger ones in orbit even though there have been few, if any, actual measurements of impacts by fragments of this size. On the other hand, numerous measurements of impacts by fragments smaller than 500 microns have been recorded on surfaces exposed to the space environment. During 1992 - 1998, 236 impactors could be identified on the U.S. Shuttle orbiter windows (many more impacts occurred, but the nature of the impactor could not be determined). Of these, 54% were debris and 46% were meteoroids. Aluminum accounted for only slightly more than half of the debris, followed by paint, stainless steel, etc. Small particle impacts on the U.S. Space Shuttle require replacing on average one of the eight main windows after each flight.

The risk to operational assets in orbit varies by altitude, inclination, spacecraft characteristics, and year. As an example, for a 20 square meter cross section satellite at 850 km, the probability of a collision with a trackable object is 1:10,000 per year. An operational satellite in this region will have a 99.9% probability of surviving a 10 year mission without being struck by a cataloged object.

The probability that any two trackable objects will collide (collision rate) in this altitude region, 800-1000 km, during one year is 1:100. At this level of hazard it is likely (greater than 50% chance) that a collision-induced breakup of a trackable object by another trackable object will occur in the next 10 to 15 years. It has been estimated that there are 10 to 15 times as many 1 - 10 cm orbital debris fragments in LEO as there are trackable objects.

The present hazard to satellites in orbit from debris varies depending on altitude, mission, satellite construction, etc. Manned missions require shielding due to reliability and safety considerations. The International Space Station (ISS) will be protected by about 200 shields. Sensitive parts of satellites may also need protection. The Radarsat spacecraft of the Canadian Space Agency became the first unmanned satellite to incorporate shielding to counter the projected debris collision hazard.

The most distressing aspect of the orbital debris problem is that it is getting worse in those regions most extensively used and could grow out of control at some altitudes and inclinations in the sense that collisions among the cataloged objects could become a significant debris growth factor. Because of the time and cost necessary to modify designs and operations practices, the debris problem will have a significant time lag between the recognition of the issues and the effect of changes. For this reason it is prudent to initiate action as soon as practical.

## 3 THE FUTURE ENVIRONMENT

The growth of the known Earth satellite population is an important parameter for the prediction of the future state of the orbital debris environment. Fig. 4 illustrates the annual number of successful launches to Earth orbit and beyond.

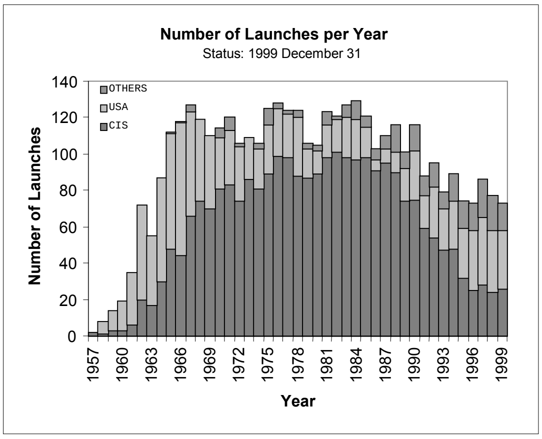

Fig. 4. Annual number of successful launches to Earth orbit (ESA, 2000).

The evolution of the orbital debris environment cannot be precisely predicted due to changing technologies and applications. The deployment of new commercial LEO communications networks may influence significantly the growth rate of the cataloged space object population.

Although only one accidental hypervelocity collision between cataloged objects (the CERISE spacecraft and a fragment of an Ariane upper stage in 1996) is known, future collisions are inevitable. Moreover, the rate at which these collisions will occur and the number of long-lived debris which will be produced will vary substantially depending upon space launch traffic characteristics, the adoption of debris control measures, projected over a period of 100 years by different environment models for three basic scenarios are depicted in Fig. 5.

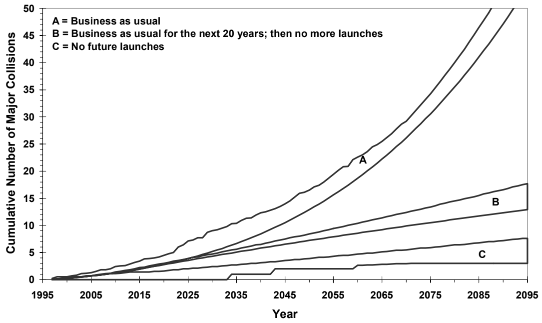

Fig. 5. Projected number of collisions among catalogued objects

The business as usual scenario (normal rate of satellite launches and explosions with only modest debris mitigation measures adopted) results in about 45 collisions during the first 90 years. The rate of collisions at the end of the projection period is increasing markedly.

At some point the number of debris created by accidental collisions may become the dominant term in the growth of the population of objects greater than 10 cm in diameter, i.e., the tracked satellite population. Before that occurs, collision-produced debris will drive the smaller object population. Fig. 6 indicates the potential increase in objects larger than 1 cm in diameter for a single scenario (business as usual) evaluated by three different satellite population models.

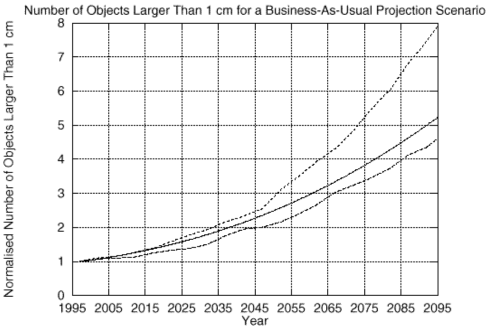

Figure 6. Projected population growth (objects larger 1 cm). The three curves show the results of three different debris population models.

The population growth with respect to the initial population is displayed (normalized number). NaK droplets from the RORSATs and slag from solid rocket motor burns are not considered. Again, the wide range models, and none of the models anticipate dramatic changes in space launch techniques or applications.

Currently, the total number of man-made objects in Earth orbit, resulting from fragmentations and RORSATs, larger than 1 cm size is estimated as 100,000 - 150,000. This number excludes solid rocket motor slag particles.

At some point, perhaps in the distant future, the creation of debris by collisions may exceed the loss of debris by reentry due to atmospheric drag or other natural forces. In such a case, the debris population will continue to grow even if new launch activities are terminated. Unless new technologies enable the efficient removal of debris, the debris population would continue to increase in an uncontrollable manner.

Altitudes where atmospheric decay forces are slight, i.e. above 800 km, and where space is congested, will probably be the first to exhibit the effects of collisional debris growth. The advent of larger LEO constellations may add a new dimension to long-term environment projections as a consequence of their potential vulnerability to satellite breakup debris.

## 4 DEBRIS CONTROL OPTIONS

The need to change the manner in which space missions (launch, deployment, operations, and termination) are conducted has been debated at length. All investigations addressing the long-term evolution of orbital debris conclude that, without changes to the way many space missions are performed, regions of near Earth space will become so cluttered by debris that routine operations will be severely hampered. The amount of debris can be controlled in one of two ways: debris prevention or debris removal. Table 2 shows individual techniques under each of these categories.

TABLE 2. Methods to reduce the growth of the debris population

| PREVENTION | REMOVAL |
|---|---|
| Passivation<br>Mission-related objects (e.g. retention of covers and separation devices)<br>Transfer to disposal orbit (reorbiting) | Retrieval<br>Deorbiting (propulsive maneuvers, tether, drag augmentation, solar sail, laser) |

An important category of debris prevention methods is passivation of hardware to avoid breakup by explosion. Passivation denotes the removal of all stored energy

venting propellants and pressurants and to open-circuit the batteries so that the object becomes inert. For LEO rocket bodies, the expulsion of propellants and pressurants has been used successfully in the past and provides a significant measure of safety for the future. Most of the rocket vehicles routinely perform these expulsion procedures already to reduce the chances of future fragmentation events. Several examples can be given: the Delta second stage is burned to depletion after deployment of the payload and execution of a maneuver to avoid a collision. Since flight V59 all Ariane upper stages have been vented, irrespective of the type of orbit. The Japanese H-1 and H-2 second stages vent main-engine residual propellants and gas-jet propellant after completion of payload separation. The Chinese Academy of Sciences has also implemented similar procedures on some of the Long-March upper stages. ISRO (India) is studying such passivation methods for their launchers. The Russian Proton fourth stages are also vented in GEO after spacecraft separation.

On several previous occasions the overcharging of a battery on a satellite has caused small breakup events, and precautions are now generally taken to prevent this type of occurrence.

Another debris preventative measure is to avoid mission-related objects (or operational debris). These are pieces of hardware released during payload deployment and operations. Prevention methods already in limited use include: application of debris catchers for explosive bolts, fewer releasable parts, and multiple payloads on a single launch. These have been incorporated on several launch vehicles to date.

Another important category of preventative action is reorbiting into a disposal orbit. For example, GEO satellites at end-of-life may be boosted as high as several hundred kilometers above GEO to prevent continual interaction with other objects in the GEO belt. The re-orbiting move is presently the only practical way to reduce the collision risk in GEO. This procedure has been performed over 100 times. Some of the maneuvers have been incomplete due to poor fuel estimation, which left defunct payloads in slightly elliptical orbits that pass through the GEO region. Although much study is required on the use of movements to super-synchronous disposal orbits by GEO satellites, such as determination of the minimum altitude increase or improved propellant gauging, the orbit raising move should be continued. A minimum orbit raising altitude of 300 - 400 km above GEO is normally sufficient. The velocity requirement for reorbiting is 3.63 m/s, or equivalent to about a month's station-keeping budget, for every 100 km altitude increase. A multiple-burn strategy should be adopted which takes into account uncertainties in the propellant estimate. In the long run, a more permanent disposal method must be considered. Unfortunately, not all operators follow the procedure of transferring geostationary satellites at end-of-life to the disposal orbit.

Retrieval means to return to Earth without damage spacecraft or other space hardware by a space vehicle capable of atmospheric entry, e.g. the U.S. Space Shuttle or Soyuz capsules. Examples of retrieved space hardware are Palapa-B, Westar-6, LDEF, EURECA, SFU and a solar array from the Hubble space telescope. However, these objects were retrieved for reasons other than debris mitigation. Also, the retrieval capabilities of the Space Shuttle are limited to altitudes below about 600 km. The retrieval of large derelict objects is expensive and difficult, but it is certainly more difficult and expensive to recover the debris created from the fragmentation of such an object.

In LEO the use of propulsive maneuvers, drag augmentation, solar pressure movement, or tethers for deorbit may require the development of hardware not presently available and may impose a performance penalty. Drag augmentation hardware might include inflatable devices that would rigidize upon deployment, presenting a much greater cross-sectional area to the atmosphere to increase the drag forces on the object. Drag augmentation will work best for low altitude missions, below 600 - 700 km, even though it would provide some lifetime reduction for altitudes as high as 1200 km. However, drag augmentation may increase the probability of collision with debris and, therefore, may not provide a net benefit.

Propulsive maneuvers to force deorbit, or at least a reduction in orbital lifetime, may be immediately possible for some rocket stages but not for the majority of large derelict hardware already in orbit. Fig. 7 illustrates the propulsive mass penalty to deorbit an object from a circular orbit. Orbit lifetime reduction (instead of immediate deorbiting) will reduce the propulsion requirements. Debris removal has been used in the Russian and Soviet manned program through the deorbiting of Progress supply vehicles and space stations into oceanic areas.

Minimization of GTO Lifetime: The geostationary transfer orbit (GTO) is a highly eccentric orbit with the perigee normally at low altitude (180 - 650 km) and the apogee near the geostationary orbit. A characteristic of these orbits is a long-periodic change in the altitude of the perigee caused by gravitational perturbations of the Earth, Sun and Moon. The orientation of the orbit in space with respect to Sun and Moon determines whether the perigee altitude will increase or decrease. The desired effect is an initial decrease of the perigee altitude, leading to increased air-drag perturbations, and ultimately to orbit decay. Unfortunately, the launch time of a geostationary satellite is usually dictated by other factors (thermal aspects, attitude sensors, eclipse time) related to the spacecraft design, which can be in conflict with minimum GTO lifetime. However, through appropriate choice of the initial perigee altitude (180 - 250 km), lifetime in GTO can be significantly reduced. For some launchers the performance may be significantly reduced.

Additionally, the ability to move objects that have never had any propulsive capability, years after their use, presents a difficult problem. A remotely controlled "space tug" deployed to rendezvous with and deorbit large derelict objects might provide an effective means to remove debris. This concept is feasible with existing technology, but cost considerations have precluded it from use thus far.

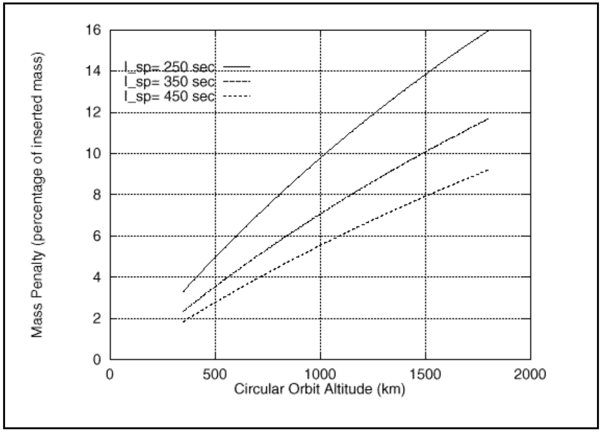

Fig. 7. Mass penalty for deorbit from circular orbits: For different values of specific impulse, the mass penalty is displayed.

Another method by which a derelict object may be moved is a solar sail, which would use solar radiation pressure to change its orbital elements. This technique would create a very slow change in orbital elements, but would be equally effective across a wide range of altitudes. It should be noted, however, that the use of drag augmentation and solar pressure devices will increase the physical area, and thus the collision cross section, of the object that is being removed.

The use of a tether may assist object removal in a number of independent ways: either via momentum exchange at either deployment or retrieval or via electromagnetic drag. In any case, the use of a tether will require some hardware development and manufacture, plus the inherent operational reliability problems of adding other types of hardware to already complex systems.

The use of some type of sweeper mechanism has been discussed on numerous occasions. There are several types of technology efforts that must be initiated in support of this type of removal method. First, some material must be developed that will be able to withstand the impact of orbital debris, absorbing or reducing the particle's energy without releasing more debris than the sweeper has collected. Second, a passive device would sweep up anything in its path without any regard for ownership or present operational status, so some type of control mechanism must be developed. Third, the size of a sweeper may have to be several kilometers in diameter for it to be effective, which could pose some structural construction difficulties. These considerations may make such systems impractical.

Another potential method for the removal of debris objects is the use of ground-based or space-based lasers. Two approaches have been studied: 1) complete destruction (vaporization) of the object with the energy imparted by a laser, and 2) accelerated orbital decay. Both approaches, however, are not yet mature for application. Problematic issues are the knowledge of the trajectory of the object to be removed, energy transfer efficiency, minimum pulse power requirement, and cost.

## 5 IMPLEMENTATION OF DEBRIS CONTROL METHODS

There is a need to initiate internationally-accepted debris control measures at the source to preserve useful orbital regions for functioning spacecraft, but there is debate as to the timing and level of options. One good way to determine what types of techniques and designs to select is to perform a series of thorough cost-benefit tradeoff studies. Though these analyses are vitally important to ascertaining the relative merit of proposed options, this committee supports the position that there are several actions that should be initiated immediately to ensure the future viability of space travel, and these will be listed at the end of this paper. The loss of only a few operational spacecraft from orbital debris collisions and/or the abandonment of certain altitude bands may exceed the expenditures suggested by the control options identified in this paper.

The control options to be considered fall into three categories: those feasible now, technically and operationally, which therefore should be applied immediately; those requiring changes in hardware or operations and should be applied in the near future; and those requiring technology development and would enable full debris control in the long-term.

### 5.1 Options Category I

Category I comprises those options that will have the greatest impact on population control and that require no technology development and have minimal cost impacts. Some performance reduction may, however, result. These have first priority for implementation. Most have already been effected voluntarily. If a particular option requires major hardware changes for a specific space system, then for that specific space system the option shall be considered category II.

The Category I Options aim at preventing the creation of orbital debris, but do not change the total mass in orbit. They are:

1. No deliberate breakups of spacecraft which produce debris in long-lived orbits.

2. Minimization of mission-related debris. In many cases cost-effective engineering solutions are available with low cost for implementation. In several cases, however, the costs will no longer be minor as significant design changes will be needed (e.g., yo-yo devices).

3. Passivation of upper stages and spacecraft in any Earth orbit at the end of mission.

4. Selection of geostationary transfer orbit (GTO) parameters to minimize orbital lifetime of upper stages by keeping the GTO perigee at a low altitude, below 250 km, and, possibly, by constraining the time of launch. This can, however, mean a significant reduction of the launcher performance in some cases.

5. Reorbiting of geostationary satellites at end-of-life to a disposal orbit. A minimum altitude increase of 300 km above GEO is proposed depending on spacecraft characteristics.

6. If the separation of an ABM (Apogee-Boost Motor) from a geostationary spacecraft is needed, then the separation should occur in a super-synchronous orbit at least 300 km above the geostationary orbit.

7. Upper stages used to move geostationary satellites from GTO to GEO should, as a minimum, be inserted into a disposal orbit at least 300 km above the geostationary orbit and passivated.

### 5.2 Options Category II

Category II comprises those options that require either changes in hardware or operational procedures. However, no new technology developments are needed. Category II options aim at removing used upper stages and defunct spacecraft from LEO, thus eliminating a major debris source. The options below provide candidate quantitative values.

Removal of large or compact objects which could partially survive entry heating, and where the hazard on ground due to reentering fragments exceeds acceptable limits, should be accomplished with a deorbiting maneuver to ensure atmospheric entry over oceanic areas during the next perigee pass.

Removal of objects which will completely burn up ground due to reentering fragments does not exceed unacceptable limits, may be accomplished by placing these objects in orbits with limited lifetime, say 25 years. Hence, in these cases, natural perturbations will be exploited. The proposed Category II options are:

1. For spent upper stages and defunct spacecraft in orbits with a perigee lower than 2000 km altitude, the orbital lifetime should be limited to 25 years.

2. Upper stages and satellites in orbits with a perigee above 2000 km altitude should be transferred at completion of their mission into a disposal orbit (as a temporary measure) with sufficient altitude clearance from operational spacecraft.

### 5.3 Options Category III

Debris control options of category III aim for a systematic removal of spacecraft and upper stages at end of mission. These options require new developments and, in general, suitability of the method (technical feasibility, cost-efficiency) must be demonstrated.

Examples for Category III options for systematic deorbiting or removal are:

1. Removal with an orbiting maneuvering vehicle. This approach requires straightforward engineering, but has not proven cost-effective at this time.

2. Removal of objects with drag devices. This option will require investigations into its efficiency and suitability. Despite the shorter lifetime the collision probability remains unchanged. The procedure will be most effective for altitudes below 1000 km.

3. Removal with tethers. This is an interesting concept which needs further engineering feasibility studies. Grappling of the debris object (e.g., tumbling object with significant rotational energy) and attitude control are two problem areas which must be addressed.

4. Destruction by laser or use of a laser to accelerate the orbital decay. This concept may be useful but it must be performed so that it does not create additional objects.

5. Debris catchers/sweeper. These devices may be feasible if discrimination or avoidance between debris and useful spacecraft can be realized.

### 5.4 Approaches to Implementation

Essentially, there are two approaches to implementing debris control measures, a technical approach and a legal approach. The technical approach contemplates discussions within national and international engineering communities leading to recommendations of certain standards of conduct. Such standards may refer to spacecraft design or operational procedures. Institutional frameworks supporting these technical discussions may range from nongovernmental organizations (such as IAA and other international groups or national technical and professional groups) to international or national working groups established by national or international space agencies.

The legal approach contemplates the use of legal instruments (including treaties, resolutions, laws, regulations, executive orders, etc.) to adopt and enforce certain standards of conduct. Legal instruments may codify standards already recommended by the engineering community or may rely on other technical guidance. It is only through some legal process, national or international, that a standard can become binding on a particular State or space operating entity. However, not all legal instruments are binding, such as resolutions or recommendations.

Given the complexity of the debris problem, it is particularly important that the legal action be preceded by discussions in, and recommendations by national and international engineering communities. Legal action would be premature without a thorough understanding of the many facets of the debris problem.

Since orbital debris, and more generally space debris, touch policy aspects of States (economical aspects, safety, national security) eventually international space law may be needed, which requires the involvement of governments.

The following approach with three parallel avenues is strongly supported:

1. Technical discussions within the framework of professional and learned societies, such as the Committee for Space Research (COSPAR), the International Academy of Astronautics (IAA), the International Astronautical Federation (IAF), and the International Institute for Space Law (IISL). They have an important role of education, facilitating exchange of opinion and establishing common understanding of the issue on a worldwide scale.

2. Technical discussions within a global working group of spacefaring nations and space agencies. This working group should also include contacts with international space organisations, e.g. International Telecommunication Satellite

Maritime Satellite Organization (INMARSAT). This global working group exists since 1993, when space-faring nations and space agencies have created the Inter-Agency Space Debris Coordination Committee (IADC) in order 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 has four working groups (measurements, modelling, protection, mitigation). IADC aims at reaching technical consensus on future mitigation measures.

3. Discussions at the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) leading ultimately to a "Code of conduct", international standards, or space law addressing space/orbital debris.

Bilateral and multilateral coordination meetings among space-faring nations have been held for several years. From these meetings, which are mostly taking place within the framework of the IADC, a consensus as to the nature of the issues and the need for action to control the growth of orbital debris has emerged.

The UNCOPUOS has formulated a number of treaties and resolutions regulating space activities. Since 1994 the problem of space debris has been formally included on the agenda of the Scientific and Technical Subcommittee of UNCOPUOS. Several presentations have been made by space-faring nations, the IADC and IAA. A multi-year work plan has been established and a report on space debris has been issued.

## 6 SUMMARY

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 space environmental hazard. Third, to extend discussion of the debris issue by other international groups to exercise the techniques and dialogue necessary to begin to formulate international agreements on this topic.

Since clean-up in space, i.e. the systematic removal of derelict objects, is currently not a cost-effective solution, the efforts have to be focused on preventing the generation of debris.

The following actions are recommended for immediate application in a first phase (Options Category I):

1. No deliberate breakups of spacecraft which produce debris in long-lived orbits.

2. Minimization of mission-related debris.

3. Passivation of all rocket bodies and spacecraft which remain in orbit after completion of their mission.

4. Selection of transfer orbit parameters to insure the rapid decay of transfer stages within 25 years.

5. Reorbiting of geostationary satellites at end-of-life (minimum altitude increase 300 km).

6. Separated ABM's used for geostationary satellites should be inserted into a disposal orbit at least 300 km above the geostationary orbit.

7. Upper stages used to move geostationary satellites from GTO to GEO should be inserted into a disposal orbit at least 300 km above the geostationary orbit and freed of residual propellant.

Since the above measures will not be sufficient to avoid an unacceptable growth of the debris population, more effective measures will be required, such as deorbiting from LEO of spacecraft and rocket upper stages at completion of their mission.

## 7 REFERENCE

IAA Position Paper on Orbital Debris, Acta Astronautica, Vol. 31, pp. 168-191, Pergamon Press, 1993.