SPACE DEBRIS ENVIRONMENT REMEDIATION CONCEPTS

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ABSTRACT

Long-term projections of the space debris environment indicate that even drastic measures, such as an immediate, complete halt of launch and release activities, will not result in a stable environment of man-made space objects. Collision events between already existing space hardware will within a few decades start to dominate the debris population, and result in a net increase of the space debris population, also at sizes which may cause further catastrophic collisions. A collisional cascading may ultimately lead to a run-away situation ("Kessler syndrome"), with no further possibility of human intervention.

The International Academy of Astronautics (IAA) has been investigating the status and the stability of the space debris environment in several studies by first looking into space traffic management possibilities, and then investigating means of mitigating the creation of space debris. In an on-going activity, an IAA study group looks into methods of active space debris environment remediation. In contrast to the former mitigation study, the current activity concentrates on the active removal of large objects, such as defunct spacecraft, orbital stages, and mission-related objects, which serve as a latent mass reservoir that fuels initial castastrophic collisions and later collisional cascading. The paper will outline different mass removal concepts, e.g. based on directed energy, tethers (momentum exchange or electro-dynamic), aerodynamic drag augmentation, solar sails, auxiliary propulsion units, retarding surfaces, or on-orbit capture. Apart from physical principles of the proposed concepts, their applicability to different orbital regimes, and their effectiveness concerning mass removal efficiency will be discussed.

1. INTRODUCTION

In the early 1990's the International Academy of Astronautics (IAA) convened an ad hoc expert group of 13 internationally known orbital debris specialists to examine the state of the near-Earth, man-made space object population and to predict its potential evolution and the subsequent effects on future space operations. The results of this comprehensive effort led to IAA's first *Position Paper on Orbital Debris* in 1993 (updated in 2001 [1]). One of the central findings in the paper was that "all investigations addressing the long-term evolution of orbital debris conclude that, without changes to the way space missions are performed, regions of near-Earth space will become so cluttered by debris that routine operations will not be possible."

Under the heading of "Debris Control Options", the paper identified the two fundamental means of controlling the future space environment: debris prevention and debris removal. Since the magnitude of the artificial Earth satellite population would not pose a significant near-term threat to world-wide space operations, the curtailment of the creation of new orbital debris, which is less technologically and economically challenging than its removal, was deemed the highest priority. During the following 15 years, with the adoption of international orbital debris mitigation guidelines, such as those of the Inter-Agency Space Debris Coordination Committee (IADC [2]) and the United Nations [3], and with the implementation of explicit orbital debris mitigation practices, the rate of growth of new orbital debris from many key sources was reduced.

The means of removing in-orbit debris were briefly investigated by the IAA ad hoc expert group. The *IAA Position Paper on Orbital Debris* specifically noted retrieval, propulsive maneuvers (deorbit), drag augmentation, solar sails, tethers, sweeping, and laser as potential debris removal techniques. However, the paper also concluded that the development of hardware not presently available might be necessary before an affordable and effective debris removal technique could be employed. In its 1999 *Technical Report on Space Debris*, the UN reiterated the threat that the accumulation of objects in orbit would pose

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to space operations "without remediation of the debris environment or operational changes, the growing number and cross-section of resident space objects would increase the likelihood of collisions, which in turn could generate new debris."

After the release of its initial *Position Paper on Orbital Debris*, the IAA established a Space Debris Subcommittee, which addressed a variety of issues related to orbital debris. One of its projects at the end of the 1990's was to update the IAA position paper, taking "into account the evolving space debris environment, new results of space debris research, and international policy developments". The updated IAA *Position Paper on Orbital Debris* was approved in October, 2000, almost exactly seven years after the initial treatise [1]. Remediation of the near-Earth space environment was still seen as a principal long-term objective, but technology and/or cost considerations hampered the development and deployment of proposed debris removal techniques. In 2006 the IAA released two new reports related to space debris and the sustainability of space operations. The IAA *Cosmic Study on Space Debris Mitigation* [5] promoted the concept of zero debris creation zones and focused on space debris mitigation guidelines for both spacecraft and launch vehicles. As with the initial IAA *Position Paper on Orbital Debris* in 1993, the new paper concentrated on means to reduce or eliminate the creation of orbital debris, rather than on the removal of existing orbital debris.

The IAA *Cosmic Study on Space Traffic Management* [7] also addressed the orbital debris environment which currently presents one of the greatest external threats to safe and reliable space operations. The study found that "derelict spacecraft and orbital stages now outnumber active spacecraft by more than 5 to 1". However, the report also concluded that "the retrieval of non-operational spacecraft and orbital stages now in orbit will likely remain a considerable challenge, both technically and economically, during the next decade or two. Several concepts have been proposed, but thus far, none have met feasibility and cost-benefit criteria." - The purpose, therefore, of the present study is to re-evaluate the numerous concepts for removing from Earth orbit resident man-made debris, both large and small, at any altitude, to preserve the near-Earth space for future generations.

2. THE CURRENT DEBRIS ENVIRONMENT

The orbital debris environment in 2009 is the product of more than 4,600 launches and 245 on-orbit break-ups that led to about 13,500 objects which are unclassified and accessible through the catalog of the US Space Surveillance Network (SSN) (see Fig.1). These objects represent some 5,800 tons of on-orbit mass (see Fig.2). Some 10 to 20 tons of material from different sources are expected to exist at sub-catalog sizes. Only 6% of the catalog entries are operational spacecraft, while 40% are non-functional but intact objects, and 54% are fragments, mainly resulting from explosions. 73% of the objects are in low Earth orbits, 8% are in near-geostationary orbits, and 21% are in intermediate highly eccentric and medium Earth orbits. Since 2007 the SSN catalog has experienced two significant step increases: (1) on Jan. 11, 2007, the Chinese FengYun 1C satellite was intercepted in an ASAT test, generating 2,500 catalog objects of which 2,300 were still in orbit 2 years later; (2) on Feb. 10, 2009, the first accidental hypervelocity collision between two intact catalog objects (Iridium 33 and Cosmos 2251) generated more than 1,200 cataloged fragments (another 300 awaiting cataloging) in two separate clouds. Both of these events have produced a long-lasting increase in spatial object densities, and hence in collision risk, at altitudes between 750 km and 900 km (see Fig. 3).

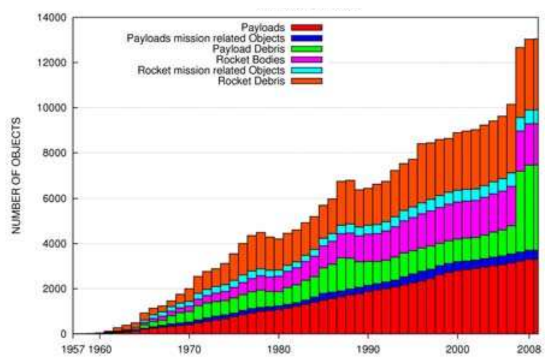

Figure 1: *Evolution of the number of trackable, on-orbit objects since the beginning of space flight.*

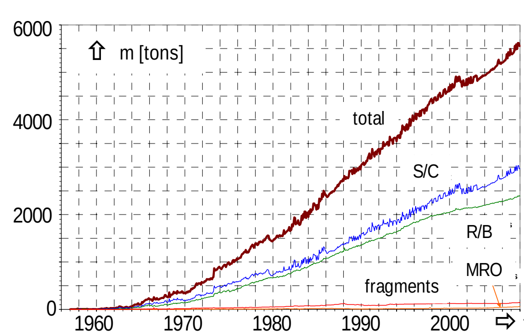

Figure 2: *Evolution of the mass of on-orbit objects since the beginning of space flight.*

Due to the significant share of orbital debris in low Earth orbits (LEO) the number density distribution of objects in Fig. 3 does not match well with the mass distribution versus altitude in Fig. 4. The shift in the altitude distribution of perigees and apogees of LEO objects in Fig. 3 and Fig. 4 reflects the dominance of near-circular orbits (74% have an eccentricity below 0.01). There is a concentration peak between 700 km and 900 km, with up to 1,200 objects and 350 tons of mass per 50 km altitude bin. 73% of all objects and 40% of the entire on-orbit catalog mass is residing in the LEO regime.

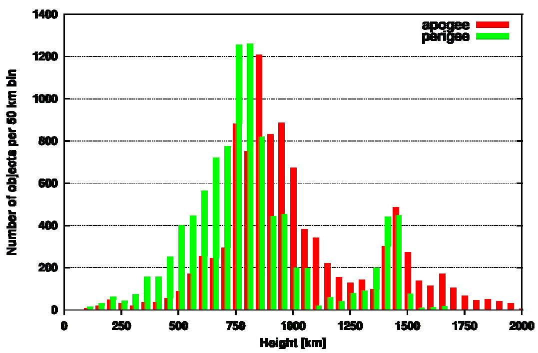

Figure 3: *Distribution of trackable, on-orbit objects in the LEO regime (count per 50 km altitude bin).*

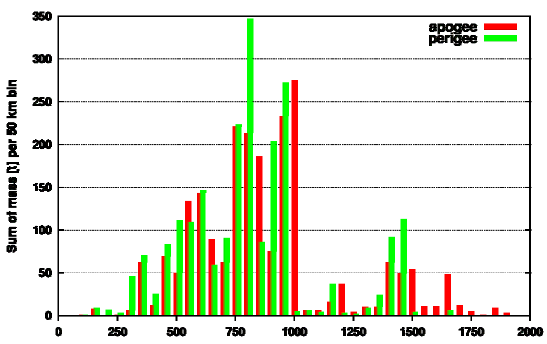

Figure 4: *Distribution of the mass of on-orbit objects in the LEO regime (tons per 50 km altitude bin).*

In the vicinity of the geostationary orbit (GEO) only two fragmentation events are know to have occurred (though there is evidence in observation data of ~10 events in total). The small share of corresponding GEO fragments in the US SSN catalog results in a good match of the number distribution and mass distribution versus altitude in Fig. 5 and Fig. 6. Even more so than for LEO, the orbits close to the GEO tend to be near circular (95.6% have eccentricities below 0.01). Up to 520 objects and 1,200 tons of mass are concentrated in a 100 km altitude bin centered on the GEO altitude. In the GEO regime, both object counts and mass contributions are dominated by intact objects. Only 8% of all objects, but 33% of the entire on-orbit catalog mass are residing in the GEO vicinity.

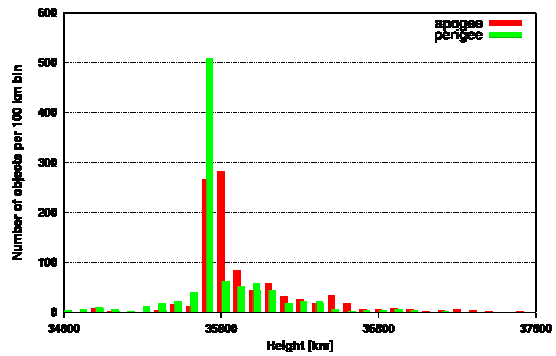

Figure 5: *Distribution of trackable, on-orbit objects in the GEO regime (count per 100 km altitude bin).*

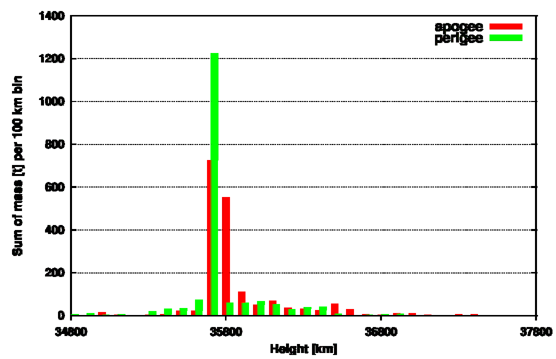

Figure 6: *Distribution of the mass of on-orbit objects in the GEO regime (tons per 100 km altitude bin).*

Fig. 7 and Fig. 8 show the number density and mass concentration of cataloged space objects as a function of inclination for all orbit altitudes. LEO objects mainly have inclinations in the range $28^\circ \leq i \leq 100^\circ$, with concentrations at 65°, 74°, 82° and 98° with up to 2,100 objects (at 98°) and 650 tons of mass (at 82°) per 1° bin. In the GEO vicinity, about 300 objects in a 1° bin next to the equator account for more than 900 tons of mass. A similar amount of mass is distributed within $1^\circ \leq i \leq 15^\circ$, in abanndoned GEO orbits.

In fact, just 3% of the space (1.3% for LEO and 1.7% for GEO) contains as much as 73% of the entire on-orbit mass (40% for LEO and 33% for GEO), which is predominantly concentrated in catalog objects.

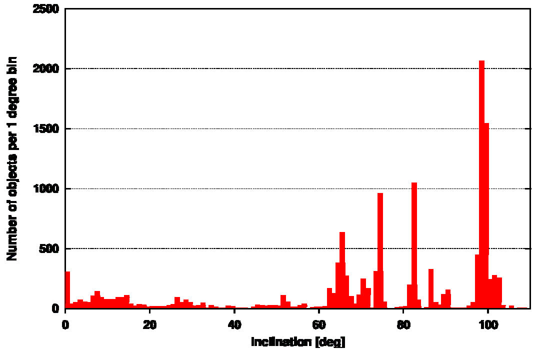

Figure 7: *Distribution of trackable, on-orbit objects across all orbital regimes (count per 1 deg inclination bin).*

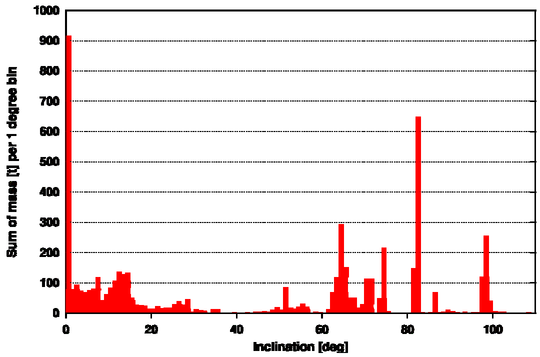

Figure 8: *Distribution of the mass of on-orbit objects across all orbital regimes (tons per 1 deg inclination bin).*

3. DEBRIS ENVIRONMENT FORECAST

The current orbital debris environment probably consists of more than 20,000 objects larger than 10cm, of which 13,500 are in the unclassified US SSN catalog. A collision with such objects is likely to cause a catastrophic disintegration when exceeding a specific energy input of about 40 J/kg. For massive targets, such events will result in fragments that again have the potential to cause catastrophic collisions. Orbital debris below 10 cm in size, however, can cause the destruction and/or mission termination of an operational spacecraft, but they will not result in a catastrophic break-up, and hence not proliferate the uncontrolled increase of hazardous fragments which may trigger collisional cascading in densely populated altitude regions ("Kessler syndrome").

Orbital debris environment predictions with NASA's LEGEND tool (see Fig. 9) indicate that even an immediate halt of all launch activities will result in an increase of collision events. The resulting population of collision fragments larger than 10 cm will outnumber the slowly declining explosion fragment population by the year 2080, and exceed it by a factor of two 60 years later. The mass reservoir of intact objects will concentrate in about 2,000 spacecraft, orbital stages and mission-related objects (of about 2,500 today).

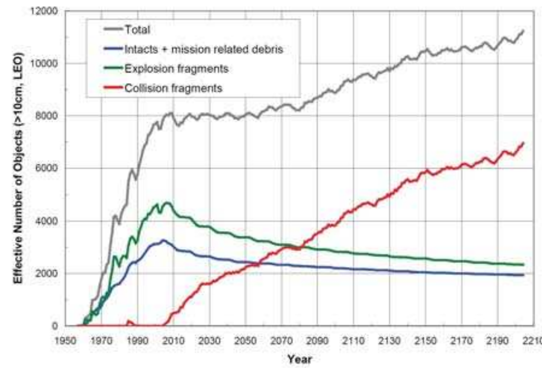

Figure 9: *Long-term forecast of the effective number of orbital debris of 10 cm or larger in LEO, based on 50 Monte-Carlo run (the "effective" count is weighted with the resident probability in LEO, ref. [8]).*

4. DEBRIS ENVIRONMENT REMEDIATION

Analyzes of the long-term evolution of the orbital debris environment indicate that the only means of sustaining the environment at a safe level for space operations will be by active removal of currently existing mass in orbit, and by end-of-life de-orbiting or re-orbiting of future space assets. In an IAA initiative on space debris environment remediation different techniques of in-orbit mass removal are presently being investigated. First results of this study will be outlined in the following.

It should be noted that for most disposal options of uncontrolled objects a related remover or service vehicle will need to have adequate maneuvering, rendez-vous and disposal capabilities to cover several potential targets. In the case of drag augmentation (see 4.1), solar radiation pressure (see 4.2), tether systems (see 4.3 and 4.4), and solid motor attachments (see 4.6), the secure mounting of the removal device on an unprepared target, and the activation of the removal device must be assured.

4.1 Drag Augmentation Devices

The main cause of natural orbit decay is related to the energy dissipating airdrag. The instantaneous decay rate is directly proportional to the area-to-mass ratio of the object. Hence, increasing the cross-sectional area of a LEO satellite will reduce its orbital lifetime. Fig. 10 shows how an active modification of the m/A ratio of LEO objects can affect their orbital lifetime, with or without the support of perigee-lowering maneuvers.

Drag augmentation devices are particularly attractive for micro-satellites, which often have no, or only limited maneuvering capabilities. One such example is the 200 kg French MICROSCOPE satellite procured by CNES to perform fundamental physics experiments by 2011. From its nominal near-circular, Sun-synchronous orbit of 790 km altitude its orbital decay would normally take about 67 years (a propulsion system cannot be tolerated due to sloshing problems). Analysis has shown that two light-weight (2 × 5 kg) membrane booms, deployed at the end of the mission by an inflatable mast, could more than double the mean aerodynamic cross-section, causing a re-entry within 25 years, as required by international guidelines. The extra mass for the drag augmentation device (booms, masts and inflation system) is on the order of 14 kg (7%).

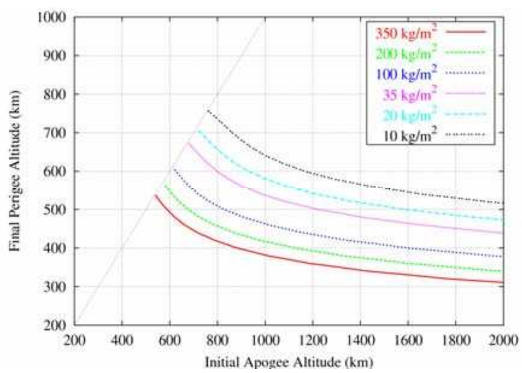

Figure 10: *Required perigee lowering to achieve a remaining orbital lifetime of less than 25 years for an object with a given mass-to-area ratio, and for an initially circular orbit [6]. The no-maneuver results are depicted along the dotted line for circular disposal orbits.*

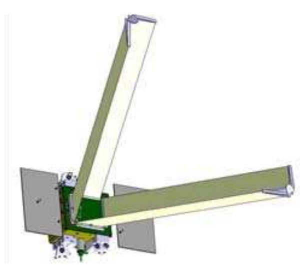

Figure 11: *Deployable drag augmentation device for the MICROSCOPE satellite (courtesy CNES).*

4.2 Solar Sails

Solar radiation pressure exerts a force through photons impinging on a surface in space. The effectiveness of this momentum exchange increases with the reflectivity of the material. It is mostly exploited for orbit changes. For a randomly tumbling plate or for spherical balloon orbit changes will mainly result in periodic eccentricity changes, with no loss of orbit energy per se. However, due to the increased airdrag at lower perigee altitudes, the orbit will slowly decay and eventually re-enter (as for the early Echo satellites). Using an oriented, planar solar sail, a controlled rotation can result in a continuous, low-level thrust in the velocity direction (for re-orbiting), or opposite to it (for de-orbiting). Fig. 12 shows a deployable, light-weight solar sail of 20m × 20m produced under NASA contract.

Solar sails, unfortunately, do not work well in low Earth orbit, below about 600-800 km, due to atomic oxygen erosion and air drag. Above that altitude they provide very small accelerations that can take months to build up to useful velocity changes. Solar sails have to be large in size, and the related payload size and mass must be small. Due to their large area and the long time spans needed for orbit changes, solar sails are also prone to space debris impacts. While most of them might be without consequences, those affecting control surfaces and mechanisms or very light structural elements, could lead to the failure of the mission, or of the post-mission disposal. These drawbacks, coupled with the challenging deployment and control concepts, do not yet render solar sails a promising method for the removal of large objects from the LEO region.

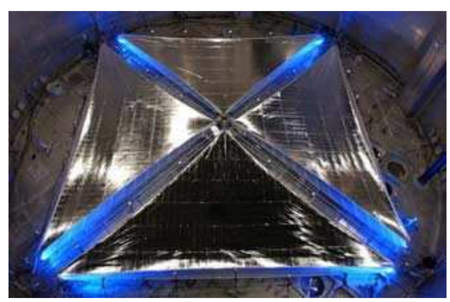

Figure 12: *Concept of a 20m × 20m deployable solar sail (courtesy NASA).*

4.3 Momentum Exchange Tethers

When two sizeable objects in LEO are connected by a tether, and if this tether is reeled out along the local vertical (see Fig. 13), then different orbital velocities and perturbing accelerations cause a swinging motion, primarily within the common orbital plane. If the tether is then cut at the time of its highest retro-grade ΔV, then the lower object will obtain a lower perigee (e.g. for direct de-orbit, or for release into a reduced-lifetime orbit), and the upper object will obtain a higher apogee. Such a tether system is in principle suited for sizeable de-orbit masses, even at higher LEO altitudes. However, the concept requires to rendez-vous with a de-orbit candidate and to attach a tether at a possibly tumbling object. Moreover, the required tether lengths are on the order of 10 km for a perigee lowering by 100 km, and for a vertical deflection angle of the in-plane oscillation of 30º. The related tether loads are significant, and the tether design is technologically demanding. For a net gain, the active remover satellite would have to de-orbit more than one large object, and also dispose of itself.

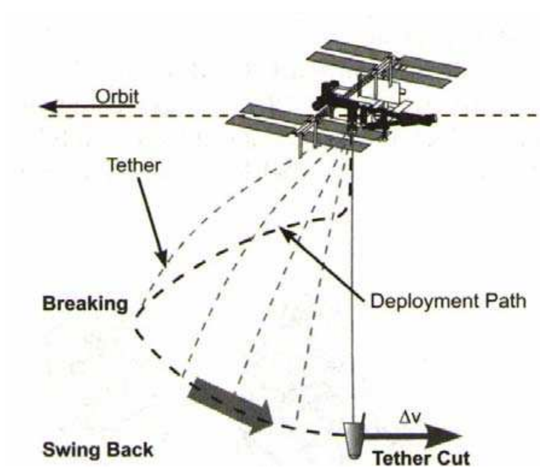

Figure 13: *Principle of a momentum exchange tether [4].*

4.4 Conductive Tethers

The principle of an electro-dynamic tether (EDT) is illustrated in Fig. 14 (left). An electromotive force is generated within a conductive tether deployed from a space vehicle as it moves through the Earth's field in its orbit. If a pair of plasma contactors at either end of the tether emits and collects electrons, an electric current flows through the tether by closing the circuit via the ambient plasma. The tether then generates a Lorentz force via interaction between the tether current and the geomagnetic field. This force acts as a deceleration, opposite to the direction of flight, and hence it reduces the orbital lifetime by dissipating orbital energy. The efficiency of this method depends on the average magnetic induction, and it thus decreases with $1/r^3$ and with $\cos i_m$, where r is the geocentric radius, and i_m is the mean geomagnetic inclination of the orbit. The resulting, reduced orbital lifetime is proportional to r^6, $1/\cos^2 i_m$ and $1/L^2$, where L is the tether length.

An electro-dynamic tether is a promising de-orbit concept due to its relatively simple design, its low system mass, and its efficiency even at high LEO altitudes. A conductive aluminium tether with a system mass fraction of 2.5% as compared to the client object can reduce the lifetime of a high-inclination low-LEO constellation at 780km altitude from 100 years to less than 1 year (e.g. for Iridium). For a medium-inclination high-LEO constellation at 1,400km the orbital lifetime can be reduced from 9,000 years to less than 2 months (e.g. for GlobalStar).

Fig. 14 (right) shows the implementation concept of JAXA's "Micro Remover". A piggyback satellite, launched with a primary payload, will rendezvous with a near-by, large-size object in a crowded LEO altitude and inclination band. The small satellite will have an extendable robotic arm for capturing the non-cooperative target. It will then reel out an EDT to produce a retarding Lorentz force. The small satellite itself will become the end-mass of the tether, and it will finally re-enter with the main object.

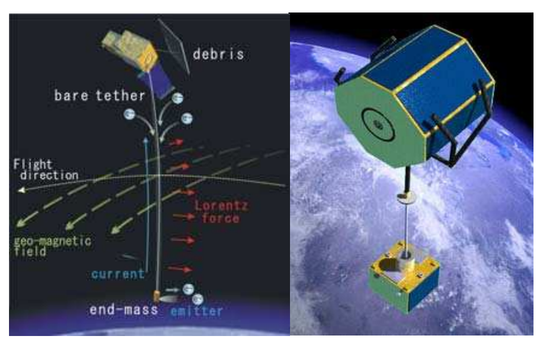

Figure 14: *Principle of a conductive tether and its application for de-orbiting (courtesy JAXA).*

4.5 Disposal via Capture

All previously discussed disposal procedures relied entirely on natural forces to remove mass from densely populated orbital regions. Alternatively, a remover spacecraft could rendez-vous with a client object, connect to it, and de-orbit it to direct re-entry or to a reduced-lifetime orbit. Alternatively the remover spacecraft could re-orbit the client object to a disposal ("graveyard") orbit region.

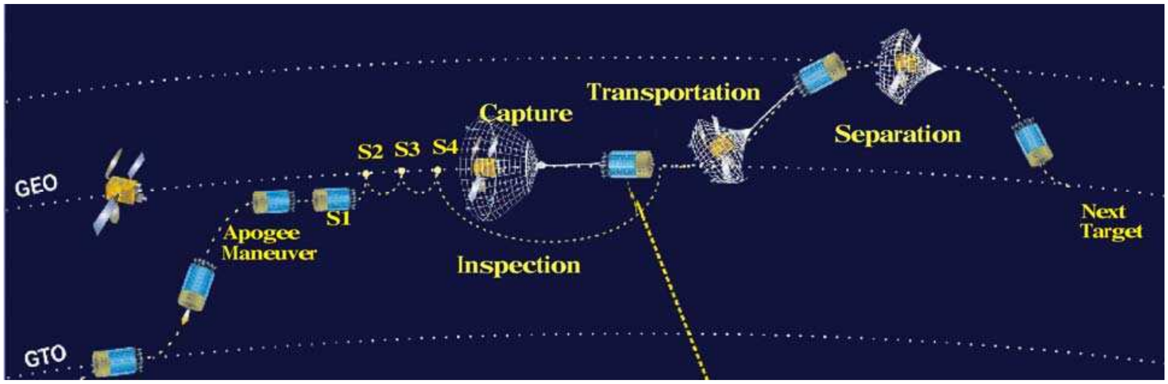

Figure 15: *Concept of a remover satellite for tugging GEO objects to a GEO disposal orbit (courtesy EADS Astrium).*

Fig. 15 shows the remover satellite concept "ROGER" that was conceived by EADS/Astrium for removing dysfunctional satellites, injection stages, or mission-related objects from the GEO ring. The remover spacecraft of 3.5 tons mass could be launched as a secondary payload into a GTO orbit, from which it injects itself into the GEO ring. It then rendez-vous with a client object, inspects it via video cameras, and casts a net over the object. The net is then tightened via reels in the end-masses while leaving it connected to the remover spacecraft by means of a tether. The whole compound is then tugged into the GEO graveyard orbit, where the tethered net enclosing the debris object is released.

With an overall propellant mass fraction of 77% and 20 disposable nets (or, alternatively, 10 disposable nets and 2 re-usable, tethered gripper devices) the ROGER remover satellite could perform up to 20 GEO disposal missions. While this concept is particularly attractive for GEO, it could also be employed in densely populated LEO regions.

4.6 Further Debris Remediation Concepts

Instead of tugging a piece of debris to its disposal orbit, a service satellite could mount a solid rocket motor (SRM) on a target object in a rendez-vous operation. The SRM, which may include an attitude control system, is then fired to induce a de-orbit. Such SRM-based systems are known to have a good fuel efficiency (i.e. thrust per mass) and robustness. Problem areas may remain in the secure mounting of such high-thrust motors on unprepared client objects and in attitude maintenance during the thrust phase.

Laser technologies are often referred to as potential means for debris risk mitigation and environment remediation. Such Lasers may be ground-, air-, or space-based, as a trade-off between system size and efficiency. The high-power Laser would be locked onto a debris object to vaporize surface material and cause a small thrust to alter the orbit, and also reduce its lifetime. This technique, however, requires a very accurate pointing of the Laser beam, and a beam lock and energy input over a sufficient time span, at adequate power levels. Even if these demanding requirements are met, the system will only be suited for small catalog objects. Moreover, issues of arms control (for air- and ground-based Lasers) and UN Treaties (for space-based Lasers) must be observed. Fig. 16 shows the concept of a space-based Laser.

Figure 16: *Space borne laser (courtesy Martin Marietta).*

As another option for debris remediation, magnetic sails could use a magnetic field to deflect the plasma of the solar wind in order to accelerate or decelerate a spacecraft. This technique could be applied within the Earth's magnetosphere to decelerate a payload to re-entry, or accelerate a payload to escape velocity. A magnetic sail would be generated with a loop of superconducting cable, to sustain an electric current in the loop via solar-electric power (the cable would be stored onboard the spacecraft until deployment). The magnetic field created by the current in the loop stiffens the cable into a rigid circular shape. Charged particles encountering the magnetic field are deflected, and momentum is imparted to the loop. In the solar wind, the magnetic sail will accelerate the spacecraft in the direction of the wind. Employing the magnetic sail in non-axial configurations produces a force perpendicular to the solar wind that can be used for low-thrust orbit maneuvers. The thrust level decreases with $1/r^4$ and for low orbit inclinations. The technical feasibility of the concept for debris mitigation is not evident.

Sweeping debris objects from space by means of retarding surfaces is an often quoted option. The concept would rely on a large thin film or ball of low density material, deployed in an altitude regime of high spatial object densities. As an object passes through the material, momentum is lost, energy is transferred, and the orbit of the impactor is lowered, and its lifetime is reduced. However, objects of any origin and composition would be affected, including operational satellites and large-size, non-operational but intact objects. It is possible that such colliding objects would be fragmented, and thus contribute to a deterioration of the environment.

4.7 Recommended Remediation Activities

Long-term forecasts of the present space object population over 200 years indicate that even an immediate halt of launch activities will result in an unstable LEO environment in some altitude and inclination bands as a consequence of about 20 catastrophic collisions within the next 200 years (see [8, 9, 10] and Fig. 9). The following orbit regimes are particularly vulnerable due to large mass concentrations at these altitude and inclination bands (see Fig. 4 and Fig. 8), long orbital lifetimes, and high relative velocities. This is where most catastrophic collisions are predicted to occur (orbit regimes are listed in descending order of criticality according to [10]):

- H = 1000 km ± 100 km at i = 82º ± 1º :
  ~290 large-size removal candidate objects
- H = 800 km ± 100 km at i = 99º ± 1º:
  ~140 large-size removal candidate objects
- H = 850 km ± 100 km at i = 71º ± 1º:
  ~40 large-size removal candidate objects

Using the baseline of no further launches for all analyzed cases, the removal of 5 objects per year is assumed from any one of the 3 critical LEO orbit regions by one remover mission for each group of 5 objects, until the source of candidate objects is exhausted in all 3 regions. This approach leads to a growth reduction, but not to a stabilization, because the reproduction of critical-size objects by collisions more than neutralizes the gain from removals. To overcome this trend, mass must be removed from densely populated orbits as soon as possible. This can be accomplished by simultaneous removal efforts in all 3 high-risk orbit regions. Simulations show that a removal rate of 3 to 5 large objects per year can stabilize the critical orbit regions. The removals do not need to be through direct re-entry, but may also occur within a 25-year remaining lifetime (e.g. by perigee lowering and/or drag augmentation).

In order to be efficient, removal missions must be initiated soon, and efforts must be concentrated on a few critical altitude and inclination bands in LEO. The earlier mass is removed, the higher the reduction in the number of catastrophic collision will be. A delayed implementation of remediation measures, and even an immediate start at a less focused, constant removal rate, with an identical overall number of removals, would result in an unnecessary growth of the critical-size debris population, the removal of which will entail extra cost, as well as technical and operational complications due to the spreading of mass of originally intact objects over a large number of smaller, yet critical fragments.

5. CONCLUSIONS

In LEO and GEO, covering just 3% of the volume used by Earth satellites, 73% of all mass is concentrated. In particular the LEO regime will experience collisional cascading in some altitude and inclination bands within the next 100 to 200 years, even if all space flight activities are stopped immediately. The seeds of this runaway process can be identified in the latent mass reservoir of some 400 to 500 large-size, intact objects, that are concentrated in a few orbit families. These objects should be removed as soon as possible, by efforts concentrated in the near-term future, with initial annual removal rates of 10 to 15. A delay of the removal process will entail a non-linear cost increase, with a risk of loosing control of the debris environment in some orbit regimes. However, prior to implementing debris remediation measures on a global scale, technical, operational, legal and economical problems must be overcome.

The first hypervelocity collision between two intact objects on Feb. 10, 2009, involving Iridium-33 and Cosmos-2251, is an early indication that collisional cascading might set in. The risk of secondary catastrophic collisions due to collision-induced fragments has already increased notably, particularly on sun-synchronous orbits at altitudes of 700 km to 900 km. ESA's remote sensing satellites ERS-2 and Envisat, due to their proximity to the Iridium-33/Cosmos-2251 collision altitude of 780 km, have experienced a related risk increase of catastrophic collisions by almost a factor 2.

The International Academy of Astronautics will soon complete its study on "space debris environment remediation" in which it will outline the most feasible concepts for mass removal from endangered orbit regions, and analyze the effect of their implementation on the stability of the long-term orbital debris environment.

ACKNOWLEDGEMENTS

The IAA activity on space debris environment remediation is an international project, with more than 23 contributing authors from 9 different nations. Their inputs to the present paper are gratefully acknowledged.

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