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Applicability of Space Debris Mitigation Guidelines

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Background

Space debris represent one of the major issues for the future development and exploitation of space by all spacefaring nations.
There are many possible means of reducing the debris hazard to future space operations. These include actions taken as a spacecraft enters orbit, during operations, and after its functional lifetime. Despite the large range of possible techniques, two criteria to evaluate them are mostly taken into account: cost and effectiveness. In this paper, a wide analysis of possible mitigation techniques will be considered relating the potential of a given technique with its applicability and the possibility to become part of specific guidelines.

In 2005 the Scientific-Technical Subcommittee of COPUOS expressed the preference to consider non obligatory guidelines as the most appropriate solution to the problem of space debris rather than a treaty. The working group on space debris promptly developed a document on space debris mitigation using the basis of the technical content of the Inter-Agency Space Debris Coordination Committee (IADC) space debris mitigation guidelines. These guidelines address four areas of concern including:

- Limitation of debris released during normal operations.
- Minimization of the potential for on-orbit breack-ups.
- Postmission disposal.
- Prevention of on-orbit collisions.

Even though the IADC guidelines represent the basis for a new regulatory regime of mitigation, the problem concerning the legal instrument by which the international community would accept these guidelines remains still unsolved.

Economic potential of orbital regions

Some orbital regions, such as the Geostationary Orbit, are already the subject of international agreements and conventions. In particular, GEO is considered as “limited natural resource”[1] to be used on the basis of equitable access. Clearly the geostationary orbit comprises a much more limited volume of space, with more specific geophysical properties, and it is furthermore already relatively congested with operational satellites. However, the properties of other regions of near-earth space are also distinct as far as their potential economic value is concerned, and their value will also potentially be seriously reduced if their exploitation is not carried out efficiently[2].

It must be emphasised that any extension of the application of international regulations to other regions of near-earth space, in order to avoid interference during normal operations with other space objects, will be acceptable only if it may be justified by some appropriate form of cost-benefit analysis. In particular, any costs to which such increased regulation gives rise must be outweighed by measurable benefits to the users and future users of orbital space, notably in reducing the calculated probabilities of collisions occurring between space vehicles[3].

Since the international community lacks consensus to conclude a legally binding instrument, one must look for a solution that is not treaty based[4]. One shall consider that space debris can endanger critical operations upon which the world depends every day, thus the economic interest could be the intrinsic mitigation driver to operate safer space missions.

IADC guidelines represent the basis for a new regulatory regime of mitigation but the problem still remains about the instrument through which the international community would accept these guidelines. According to Mirmina[5], three major options are possible: a voluntary arrangement based on the model used by the Missile Technology Control Regime; a UN-based approach such as the resolutions of the UN General Assembly about NPS; a code of conduct similar to that governing the astronauts aboard the ISS. Guidelines based on a voluntary arherence regime represent the alternative to the international treaty-making process. The advantage is the rapidity and immediate applicability of these instruments instead of a slow process that, sometimes, may not even result in agreement. In fact, the Legal Subcommittee of COPUOS is not expected to agree on commitments concerning orbital debris in the next future and there is no consensus in favor of concluding a treaty on orbital debris since active oppositions are moved[6].

Technical applicability of guidelines

According to studies of the International Academy of Astronautics[7], there are only very limited ways to improve the risks or effects of collisions between debris. The options studied are:

- *Removal of large potential colliders*. However this solution does not seem practically feasible today, due to operational and programmatic constraints.
- *Collision avoidance*. Possible only with large catalogued debris, but requires access to precise orbital data for the largest debris.
- *Shielding*. Possible up to a low energy limit only. In fact, even debris larger than 1 colliding with a spacecraft may have very serious consequences.
- *Mitigation*. At present, it is the most efficient strategy for long term stability of the orbital population.

Some space agencies (Including NASA and ESA) are trying to generate less debris by applying debris mitigation measures often regulated by internal protocols. However, there will be little net benefit if only some space faring nations introduce preventive measures. On one hand, the extention of preventive measures to all agencies and launchers would be necessary to make economic competition equitable, but it is necessary as well to keep operational regions of outer space technically and economically useful 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 mitigation of debris creation in these regions of space is required. Unfortunately, because these have been the most widely used regions of space, they also have the largest population of orbiting objects. Furthermore, new developments such as constellations of communication satellites may increase the population.

Moreover, the usual practices of satellite manufacturers and of operators responsible for in-orbit control of these vehicles may generate space debris. According to the Position Paper on Space Debris Mitigation issued by the International Academy of Astronautics (2005)[7], many satellites are abandoned in their operational orbit or transferred to a disposal orbit without taking other debris prevention measures. Thus, satellites generally remain for a long time in this adverse environment where collisions with space debris or meteoroids and the high temperature changes between Sun passages and eclipses may trigger break-ups. The problem of such satellites is the stored energy that remains after the end of their operational lifetime. In particualr, the most hazardous sources are batteries (that may generate overpressures and even explosions), residual propellant contained in tanks and high pressure gasses within pressure vessels.

Other devices with residual stored energy are momentum devices (gyros, momentum wheels) and solid rocket motors that may produce a high number of particles.

The surface degradation of a space object (paint, etc.) may be another source of debris creation producing a large number of particles.

Option to minimize debris creation

Several possible means of limiting the growth of orbital debris have been proposed and they can be classified, in broad terms, in two categories: debris generation prevention and debris removal, even though the reality is more complicated.

For instance, looking at the short-term, the satellite de-orbiting at the end of life belongs to the debris removal category.

To prevent the on-orbit break-ups (including break-ups caused by chemical reactions and rupture by mechanical energy), the applicable criterion is making passive all forms of energy storage at end of life of the space object. However, the effectiveness of this process is not proven unless the space object is equipped with a specific feedback system that would increase the payload weight and, consequently, the operational cost.

Collision avoidance menouvres

The principle of collision risk monitoring consists in performing a processing operation with several steps. The first step, which is a rough sorting, uses information given by the Two Line Elements in the catalogue of space objects to highlight possible risks while taking significant margins into account.

When a potentially dangerous object is highlighted, tracking measurements are performed using radar or optical telescopes in order to gain more knowledge about the object's trajectory. Since the precise orbit of the satellite is known to its control centre, it is then possible to determine the closest flyby distance and the probability of collision[8].

Cost, benefit analysis

Taking actions such as those suggested in the previous paragraphs may maintain satellite life, but lead to increased satellite cost and mass, increased transportation cost, or reduced satellite capability and loss of benefits. In the case of collision avoidance, operational functions of the satellite are preserved the applicability of this technique is is only possible with large debris that may be tracked and monitored. In order to avoid interference with smaller debris, the first step is to stop the growth of the debris population by introducting preventive mesure to avoid further creation of debris at the end of the operational lifetime of a space object.

The direct effect of the adoption of such mitigation alternative would be a reduction in satellite performance and increased transportation costs.

Debris mitigation has been an ongoing activity for GEO communication satellites as they are normally moved to higher altitudes near end of life in order to reduce the probability of collisions and other forms of interference. At least two mitigation measures have been considered that would affect the financial performance of GEO communication satellite. One would require GEO satellites to be moved to higher altitudes when they reach the end of their useful life; the other would place constraints on transfer orbits by requiring, for instance, transfer stages to re-enter the Earth’s atmosphere and burn up rather than remain in orbit for an undefined length of time. Both of these solutions could have a negative impact on the near and mid-term financial performance of communication satellite business but may have beneficial impacts in the long-term.

With mitigation efforts having only small effects into the future, expenditures cannot be justified today even if they could reduce the economic consequences of debris in the long period (50 to 100 years)[9]?

In summary, to follow a volountary adherence hypothesis to IADC guidelines, there is a need for models that should be used to assess more completely the economic impacts of mitigation strategies and to demonstrate to investors the real benefit coming from the introduction of mitigation measures. However, a volountary adherence regime to the debris reduction techniques does not seem to be an expectable scenario.

Effectiveness of debris mitigation measures

Probably one of the most important mitigation measures has been the increased awareness of the threats posed by the space debris environment and of the many sources of space debris. If this awarness brings the consideration of debris mitigation measures early in the vehicle design phase, this could be a cost-effective way.

Since the early 1980s, the adoption of mitigation measures has had an effect on the growth of the space debris environment. The frequency of significant satellite fragmentations, both accidental and intentional, has dropped, moderating the rate of growth of space debris. For long-lived mission-related debris even a decrease is noticeable. New debris shield technologies and designs have substantially reduced the weight of protection while increasing its effectiveness.

The problem still remains for the rapidly growing populaition of commercial satellites and concerning the hazard posed by smaller debris (the majority of the debris population).

Predictive models elaborated by space agencies cannot provide accurate predictions of the space environment several decades into the future, but they can evaluate the relative influences of different operational practices[10].

Probability of collision in Low Earth Orbit

Low Earth Orbit has been used for many Earth sensing operations since these orbits have an added value for meteorological observations and other remote sensing operations. The risk of collision can be estimated using the probability of collision. For satellites in this orbit, the main hazard is posed by other object located in narrow sets of altitudes and inclinations[11].

However, collision risk in Low Earth Orbit has increased overall. Since 1989 there have been several breakups of satellites and rocket bodies[12]. The probability of collision is function of the relative velocity of the satellite[13], the collision cross-section, the spatial density (how many objects populate a certain space) and the time at the instant of risk calculation[14]. According to estimates, the probability of collision is 1.12/1000 per year[15], thus, roughly, there is one possibility on one thousand for a satellite to collide with another objects. This results, does not take into account other risk deriving from small debris (less than 10 cm of cross section) that represent the majority of the debris population. In this latter case, the risk will be higher.

Perceived risk

Another consideration concerning space debris is related to risk perception. Although there are several possible definitions of risk, people often define 'risk' as 'probability of accident'. Modern technology in general is no longer viewed primarily as a producer of beneficial goods and services, valuable materials and economic products, and wealth and employment. More often, that same technology is held to be a major source of hazards and dangers to public health and welfare, environmental degradation and pollution. That is why space activities in general and space debris in particular are perceived with a high impact on the population and, in particular, on private investors.

Research on the socio-cultural factors that influence the perception of risk by the public has identified and established the following risk factors shown below[16]:

- Pc Control Risk is controllable or uncontrollable by the individual
- Pb Benefit Exposure to risk provides benefit or dis-benefit to the individual
- Pv Volition Exposure to risk is voluntary or involuntary for the individual
- Ps Severity Risk ranges from ordinary or familiar to catastrophic or unknown
- Pm Manifestation Risk results in immediate or delayed effects to the individual
- Po Origin Risk is a consequence of natural or man made events

Each factor can be expressed as a constant representing an accurate assessment of the factor's contribution to perceived risk or more accurately as a probability density function such as a normal, log normal, or exponential probability density function describing the quantitative range of this risk factor. Since the perceived risk of space activities in higher than real, this could have also negative impact on decision making processes concerned by commercial space activities.

Conclusions

The problem of space debris probably represents the main obstacle to the future exploitation of commercial space regions as well as for the exploration of outer space. The IADC mitigation guidelines represent the basis to regulate the proliferation of such a phenomenon but their applicability still remain an issue.

Although several features and procedures have been developed to manage the issue of space debris by protecting spacecrafts and operations and by avoiding further deployment of debris, the applicability of such technical countermeasures would affect the economic operational lifetime of space objects.

Therefore, a voluntary adherence regime would result in a economic loss for those industries applying these recommendations. Other options would be the adoption of regulations by the International Telecommunication Union, by the extention of the regulatory regime already in use for the Geostationary orbit or the improvement of other internal legal instruments, possibly on a regional basis, to be addressed to agencies, launchers and private space operators.

References

[1] Art. 33 of the International Telecommunication Convention (ITC) considers that the Geostationary Orbit is a "limited natural resource (which) must be used efficiently and economically so that countries or groups of countries may have equitable access [...]".

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[3] *Idem,* p. 167.

[4] Mirmina, *Reducing the proliferation of orbital debris: alternative sto a legally binding instrument*, American Journal of International Law, Vol.99 N.3, 2005, pp.649-653.

[5] *Idem*, p.654.

[6] Primarily, oppositors consider that further work is necessary to understand the technical aspects of space debris, according to Mirmina, see note below.

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[12] Fengyun 1-2R/B on 4 october 1990, Cosmos 2101 on 30 november 1990, DMSP-10 on 1 december 1990, Cosmos 2125-32 R/B on 5 march 1991, Nimbus 6 R/B on 1 may 1991, Cosmos 2153 on 6 december 1991, Cosmos 1603 on 5 september 1992. See ref. 11. p.485.

[13] A typical value for LEO is about 10Km/s.

[14] For a comprehensive summary see Johnson and McKnight, *Artificial space debris*, Orbital book company, Malabar, Florida, 1991.

[15] Dittberner, Fudge, Huth, Johnson, McKnight – See ref. 11, p.486. Calculations are considered for the year 1993.

[16] Slovic, Fischoff and Lichtenstein, *Facts and fears: understanding perceived risk. Societal risk assessments: how safe is safe enough?,* Edited by Richard C. Schwing and Walter Albers, Jr. Plenum Press, New York, 1980