SPACE DEBRIS MITIGATION : CONTRIBUTION AND PROPOSALS

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ABSTRACT

Starting from a comparison between the earth pollution due to man life, which requests very large efforts to be suppressed, we propose to take as soon as possible measures to reduce the space pollution. Without strong actions and decisions, this pollution will increase dramatically in the next decades, and could lead to exponential increase of the collision risks.

So, it is recommended that international laws should be discussed and negociated, then implemented by all space users. If we wait too much time to take these actions, the number of debris and inactive spacecrafts will increase rapidly, and the space cleaning is, for now, an activity without solution, and all possible methods will probably be very difficult and expensive (even with technology improvement).

A research and development program has to be settled to reduce sensitivity of all spacecrafts to debris collision risks and to reduce the debris generation.

1. INTRODUCTION

During centuries, human waste management was not considered as necessary. With the increase of scraps quantities associated to industrial era, mankind became recently aware (some decades ago) that something has to be done firstly to suppress dangerous thrash deposits, and secondly to deal with them immediatly after their production. The methods and technologies used are sometimes sophisticated, expensives, but generally their feasibility is proven.

The problem is greater for nuclear wastes, it looks like to the space pollution one in terms of danger duration, but it is, a priori, more dangerous for human life.

For pollution in space, it seems that rapidly the danger of lack of management of debris and unused spacecrafts can lead to catastrophic failures. Less than 40 years after the first articificial satellite has been launched, the first noticeable collision in space occured on July 24th 1996 (even there is some probability that catastrophic collision have occured in the past, it is the first collision foreseen in advance and seen quite in real time. That occured even if the calculated probability of occurence of such an event was very low) with a partial destruction of French "Cerise" spacecraft. The biggest difference of the space pollution compared to an earth pollution is that for now, we have no knowledge of corrective methods as far as the debris or uncontrolled spacecraft are in orbit. Over that, the life duration of such materials is very long (decades and even often centuries). So, without strong actions, we will leave a polluted and even a non usable outer space to our sons and grandsons.

2. EVALUATION OF THE PROBLEM

Today, 40 years after the first launch of an earth satellite, around 8000 objects are orbiting into earth artificial orbit (size > 10 cm), including around 400 active satellite, and probably around 110000 dangerous parts (> 1 cm) are also orbiting (ref 7), with some high concentration at specific height.

If we try to look in the future, we can make an extrapolation of the number of spacecrafts to be launched, put into orbit and operated.

2.1 Geostationary orbit

The launch figure commonly admitted is a mean value of 30 commercial spacecrafts per year with a life duration of 12 or more years plus meteorological or military ones. Associated to each launch, we find some parts coming from the launcher or separation devices (even if it is generally agreed that the number of these parts should be reduced). The life duration of an object at this altitude is of the order of several thousand years. Today around 600 objects are identified, how many at 21st century end (6000, 8000, more ?).

Even if it is assumed that due to relatively low speed of these spacecrafts, the collision effects shall be small, it is quite sure that two spacecrafts weighting several thousand of kilograms colliding with a relative speed of several m/s shall suffer damages due to the spacecraft configuration (solar panels, antenas, external thermal blankets, sensors, etc...). Most operators have agreed in this regions to reboost at a higher altitude the spacecrafts at end of life, but this is not a law mandatorily applicable to all operators.

2.2 Low earth orbit

In this domain, we find several types of orbit (around 6000 objects identified).

. Station ones (around 300 to 500 km) : the life duration of debris is short (some weeks to years). The risks are a collision with a spacecraft and mainly a collision with a manned spacecraft or vehicule and a direct risk for human

Proceedings of the Second European Conference on Space Debris, ESOC, Darmstadt, Germany, 17-19 March 1997, (ESA SP-393, May 1997)

life. The increase of flight number will increase the risk, even if for a majority of flights, avoidance actions are possible (change of launch window, launch trajectory, orbit modification, etc...) to avoid identified objects, but before modification of the orbit, one has to be sure that this modification reduces really the risks and the avoidance shall become difficult if debris number increases.

. Sun synchronous orbits (quasi polar, 600 to 1000 km) , number to be increased due to apparition of new users and new missions

. Constellations (some are M.E.O.) : it is in this field that we can now foresee the bigger increase in the spacecraft number for the next years. If we look to the projects (some still projects, others under completion) we can find the following (ref. 6, 7).

NAME	ORBIT	NUMBER	OPERATIONAL B. O. L. MASS (KG)	DEORB.
- GLOBALSTAR	L.E.O. (1410 km)	48	450	
- ECO8 (Brazil)	(2000 km)	8	420	
- IRIDIUM	L.E.O. (780 km)	66	690	Foreseen
- I.C.O.	M.E.O. (10355 km)	10	2600	
- ODYSSEY	M.E.O. (10354 km)	12	2000	
- ORBCOM	L.E.O.	26	43	
- SKYBRIDGE (Sativod)	L.E.O. (1300-1400 km)	64	1000	
- TELEDESIC	L.E.O. (700 km)	840 (230 ?)	700	Foreseen
- NAVSTAR	(20200 km)	27	450 (+ ?)	

We assume that these numbers are "operational" numbers at a given time. As these are operational spacecrafts, they will have to be replaced at end of life. We can assume that 10 to 20 % more spares have to be launched. After some decades, their number will probably be a lot greater if no deorbiting action is taken. What figure can we use for the next century ?

2.3 - Other orbits

Overall the projects already presented, we can find scientific projects with specific orbits existing or under study. These projects, due to scientific requirements, specific constraints, specific requirements, can have to use orbits which are not yet used for today applications or missions. The collision risk all along these orbits have to be maintained at a low level.

One can also assume that in the next decades, new space applications, new missions can appear, and lead to another strong increase of objects in L.E.O. or M.E.O. around the earth.

3. LEGAL ASPECTS

To day, there is no international laws applicable to all the space users concerning : debris production, debris resistance, spacecraft behaviour at end of mission,etc...

A lot of activity is done (ref. 7), mainly in the US, Europ and Japan. But, if there is a lot of organizations involved (NASA, NSTC, DOD, DOT...), with multilateral groups and committees (IADC...), the reality today is that there are only some "agreements", recommendations or agencies standards which are not yet mandatorily applicables. In all cases, these standards will be applicable only for the projects where the agency is the customer. They are not mandatory for all commercial projects. If we examine the space market evolution, we can notice that :

- 20 years ago 95 % of spacecraft were produced under an agency contract.

- Now, around 20 % of spacecrafts are produced under an agency contract.

- What about the future ?

Even more, some proposals contained in the standard agencies projects appears inacceptable (ref. 3 - page 6) "*Altitude range from 1300 km to 1400 km may be a candidate tentative graveyard region. Fortunately NASDA don't have plan to operate spacecraft in the range of 1000-1500 km so far*". If we consider that life duration at this altitude is around one century or more, are promotors of such graveyard orbits sure that during this period they will not include such orbits in their activity plans ? We see that a lot of projects are planning to work at this level (constellations). What about their spacecraft safety ? The orbit of a free flying object at this altitude will be modified by external forces (radiation pressure, sun and moon gravitation...) and their potential hazard will be increased for spacecrafts with other orbits, while their Perigee/Apogee altitude shall be continuously modified.

One transient possibility of auto regulation can be the risk assessment studies made by projects initiators. Due to the number of spacecrafts they have to launch and control in the same kind of orbit the risk of a collision between their "products" could reach an inacceptable level, and they could be obliged to do something to protect their operational spacecrafts. This is the option which seems to be taken by Teledesic and Iridium Groups. But, as the disposal of spacecrafts after end of life is a costly operation, it would be decided only if found economicaly acceptable. One cannot base the deorbiting policy only on economical calculations made by the project initiator.

So, in front of such problems, the only mid and long term solution will be to have international laws or agreement which will have to be applicable by all space operators (agencies, commercial...). These rules have to be carefuly assessed, in order on one side to reduce the cost and constraints on new projects and on the other side to reduce to an acceptable level the risks associated to all future projects (which would not probably be easy to estimate). The best way to work out such law is probably the UN-COPUOS working group on space debris.

4. PROPOSALS FOR FRENCH SPACE AGENCY

Apart from legal aspects which have to be studied by lawyers, and decided at international level. We propose to have research and development studies in order to be prepared for debris management and mitigation. These activities have to have several focal points :

- have software and datas to quantify the collisions risks,

- reduction of spacecraft sensitivity to collisions and reduce debris production,

- manage spacecraft at end of life.

4.1 Evaluation of collision risks

This activity requires several tools.

We have first to know the debris size and orbit. For this, tracking devices, datas exchanges, center coordination has to be improved. After that, it is necessary to develop and give to projects engineers an evaluation tool to compute an estimation of the collision probability for their mission or their spacecraft. Some tools are now available, associated to debris database (NASA-96, MASTER, etc...). For instance, ECSS has to recommand a procedure for risks evaluation. These models have to be validated by inter comparison.

4.2 Reduction of spacecraft sensitivity

Some actions are going on in the US and in Europe (mainly ESA contracts) :

- to develop test facilities (accelerations of charges to orbital speeds),

- to make tests on hardware or technologies,

- to develop simulation softwares for impact effects determination.

These activities are now, mainly associated to manned flights activities. These effects are of course of first importance as men are on board, but the tests results, the methodology to reduce the risks could probably be used also for spacecraft design and developments. For instance, as shielding effects can be obtained by blankets, one can use another spacecraft architecture, to reduce the risk of complete failure associated to a debris impact. One can also think about separation of redundants circuits as we can find in aircrafts. One can reduce the effects of a single debris to a portion of a function or sub-system.

On another hand, we have also to work on debris generation reduction. Several debris sources can be identified. The first one concerns the parts corresponding to launch activities (separations,...) or deployments. An effort has been made but this parts number can be reduced again by systematic utilization of tethered parts remaining attached to main large parts. The second source concerns the inflight material degradation process. For instance, external coatings are eroded by atomic oxygen and aluminized mylar or kapton can release small material parts, which generate a cloud around the spacecraft, then, due to their area/mass ratio, their orbit will vary.

According to preliminary studies, the life duration of such debris can vary from some days to centuries for low/medium altitude depending on area/mass ratio. Even in low earth orbit, for large parts, the reentry date prevision is a very difficult exercise. For instance, three years ago, during first Hubble repair mission, several parts have been left into orbit, the assumption being made at this time that their in orbit life duration will be short. Now three years after, it seems that they will stay in orbit for several more years.

The third source is the debris generation associated to inorbit collisions. The first collision occured (CERISE) generated apparently only (by chance) two parts : the operationnal spacecraft and the stabilization mast. But the result, if the collision occurs on a pressurized vessel, or with a large debris generates a lot of debris (≅ 700 for PEGASUS). We have to think about new architecture or technologies which would reduce the number of debris generated in case of collision.

4.3 Manage spacecraft at end of life

The possibility to put spacecraft on a graveyard orbit at end of life has been often proposed (ref. 2, 3). This solution has to be carefully assessed taking into account spacecraft orbits variations after they became inactive, spacecraft number evolution in the future (very difficult to define as far as estimations have to cover next centuries), emergence of new projects, new useful orbits, etc... The best technical option in terms of debris mitigation, is to modify the orbit in order to reduce the spacecraft life duration. A 25 years delay has been proposed by NASA (ref 2). It is a good base for discussion, but needs to be confirmed.

The estimation of in-orbit life duration (spacecrafts or debris) is a very difficult exercise, and has to be improved. If we look at the evolution of catalogued debris following an event (explosion ?) (ref. 7), we can found the following figure :

ORBIT		CREATED		REMAINING	
		N. EVENTS	N. DEBRIS	N. EVENTS	N. DEBRIS
P < 500 km	Ap < 2000 km	52	2086	6	35
	Ap > 2000 km	10	151	9	79
		4	0	-	-
500 < P < 1000		42	4345	42	1650
> 1000		18	1467	18	1140
TOTAL		126	8049	75	2904

Note : Event 118 - 29/Jun/61 Ap 995 Pe 880 Debris created : 298 Debris remaining 34 years after : 200
Event 694 - 27/Nov/63 Ap 1785Pe 475 Debris created : 19 Debris remaining 32 years after : 9

A complete study using debris size, evolution of remaining debris number at different dates etc... (if these values are available) could give very useful datas for life duration estimation.

For instance, we can see that even with a low perigee, depending on apogee altitude, the life duration can change a lot (higher apogee gives longer life duration).

Another problem appears associated to the spacecraft reentries : the risk of damages while the spacecraft or its components came through the atmosphere and hits the ground. In case of damage, the responsibility of the spacecraft owner or operator can be searched for. Some treaties or conventions say thinks about these risks, but it has to be proven that the accident comes from a space debris and to found the "owner" of the space debris.

People are becoming more sensitive to this (ref. 5), reentry of Delta 2 tank etc...

Concerning this subject, we can associate also all the launcher parts or components which can be left into an orbit after a spacecraft launch. For several years, efforts have been made to tether such parts, but this effort has to be increased.

In order to avoid explosion of a tank or a pressure vessel at end of life, it is some times proposed to evacuate their fluid into space. A part from the fact that these fluids (very often chemically agressives) will constitute a cloud (what components, what density ?), a spacecraft coming through this cloud could support damages (think about atomic oxygen effects on coatings !). It would probably be better to use these propellants through the nozzles to reduce the perigee height and so far reduce the spacecraft life duration after end of life.

5. CONCLUSIONS

The debris and orbiting objects management will became more and more difficult and expensive in the future. If nothing is done in the incoming years (international laws, applicable standards, development of specific technologies and methods etc...), the collision risks for in orbit spacecrafts will increase dramatically in the future, and the recovery of a safe situation (if feasible) will require a lot of time, work and money. As we say in French : "Mieux vaut prévenir que guérir".

So we propose :
- prepare laws upon space debris mitigation,
- deorbit spacecraft at end of mission while it is possible,
- reduce debris generation.

6. REFERENCES

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