Clean Space Project

Is there a business opportunity?

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3 international accreditations

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Master 2 – OP Aerospace Management

TABLE DES MATIERES

ABSTRACT

Thousands of small sized pieces of space debris are gravitating around earth orbit.

Such debris are a huge threat for satellites in low earth orbit.

The amount of debris in Low Earth Orbit (LEO) is exponentially increasing with, in short medium term, potential collisions among large and extra-large debris population. For medium size debris (between 1 to 10 cm^2), some solutions are studied be more effective and affordable but nothing is available for now. This is why research and technology activities in this sector are becoming the cornerstone of worldwide space policy in order to protect launchers and satellites but also securing long term commercial activity. This initiative also intends to protect the environment from chain reaction of debris production. Indeed, as you will see later, the increase of debris will be exponential in the next decades and will lead to an overcrowded and polluted low orbit space.

In our presentation, we model several existing solutions to launch satellites in order to reduce space debris or - at least - stabilize their number and therefore prevent their exponential evolution.

While several professionals and specialized press have made lots of studies on this subject, we think this is the first report that analyses economic and technical issues jointly and provide recommendations in order to mitigate debris proliferation in LEO.

HISTORY

According to ESA, satellites in orbit around Earth are used for many activities, including space science, Earth observation, meteorology and climate, telecommunication, GPS navigation and human space exploration. They offer a unique resource for collecting scientific data, which leads to big competition for research and exploitation, both scientific and commercial.

However, in the past decades, with increasing space activities, a new and unexpected hazard has started to emerge: space debris.

In almost 50 years of space activities, more than 4900 launches have placed some 6600 satellites into orbit, of which about 3600 remain in space; only a small fraction - about 1000 - are still operational today.

This large amount of space hardware has a total mass of more than 6 300 tons. Not all objects are still intact. More than 21,000 space objects Earth orbits (as of September 2012) in total are regularly tracked by the US Space Surveillance Network (SSN).

ORBITAL DEBRIS DEFINITION

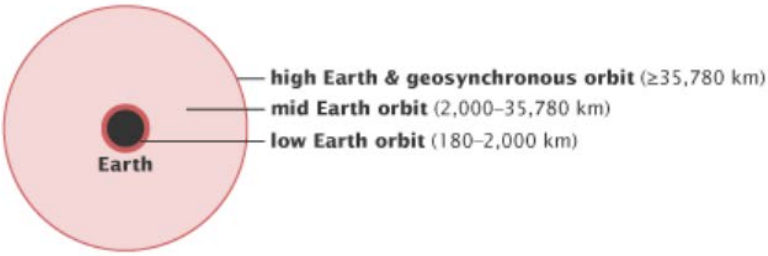
Orbital debris is space pollution.

The National Aeronautics and Space Administration (NASA) and the Inter-Agency Space Debris Co-ordination Committee (IADC) define debris as non-functional human-made space objects. Initially, debris are created from the upper stages of expended launch vehicles when a satellite is launched. This is similar to terrestrial pollution "jointly-produced" with manufactured goods. Additional debris are created by the satellites themselves, because they reach the end of their productive lives or because of impacts with debris or with other satellites.

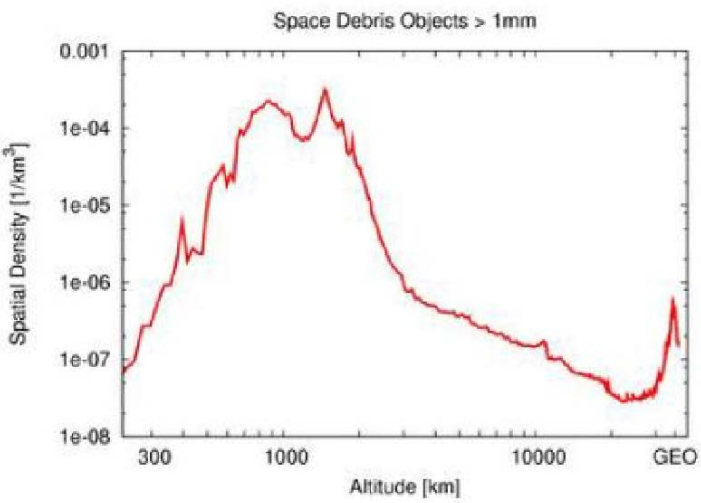
Another definition of Orbital Debris could be "a satellite out of control from the ground". Indeed, large satellites have technical solutions to avoid space debris on their orbit, but the smallest satellites are not able to and could naturally damage other satellites.

Debris are typically located in one of three possible orbits: LEO, MEO or GEO.

- LEO (Low-earth orbit) comprises the region between 180 and 2000 km above the surface of the Earth. 49% of existent satellites are in LEO.
- GEO (geostationary orbit) is 36000 km and beyond with 41% of the satellites.
- MEO (mid-earth orbit) comprises the region between LEO and GEO with 6% of the satellites.



So, debris density is obviously higher in LEO and GEO orbits:



More than 90% of operational satellites occupy the two following orbital regions, and share these regions with orbital debris (Union of Concerned Scientists, 2012):

- 470 in LEO with more than 10,000 trackable pieces of debris;
- 424 in Geosynchronous Earth Orbit (GEO) with around 1,000 trackable pieces of debris.

In LEO, data is acquired using ground-based radars and optical telescopes, space-based telescopes, and analysis of spacecraft surfaces returned from space. Beyond LEO, it is more difficult to measure and follow the space junks smaller than 1 meter and this is why density might be lower in GEO. Actually scientists are not able to count and follow all the debris in GEO.

However, 30% debris in LEO also are decommissioned satellites, spent upper stages and mission-related objects (launch adapters, lens covers, etc.) - that is to say big pieces of debris.

Therefore, **we mainly focus on LEO debris** in this report.

Debris can damage or destroy communication, weather, navigational, governmental, and military satellites. On multiple occasions, for example, astronauts from the International Space Station have evacuated to an emergency escape capsule because debris threatened to impact the Space Station. (eg Schwartz 2010)

OVERVIEW OF THE SPACE JUNKS ENVIRONMENT

LIFETIME OF DEBRIS

The orbital lifetime of debris before atmospheric drag is as follows:

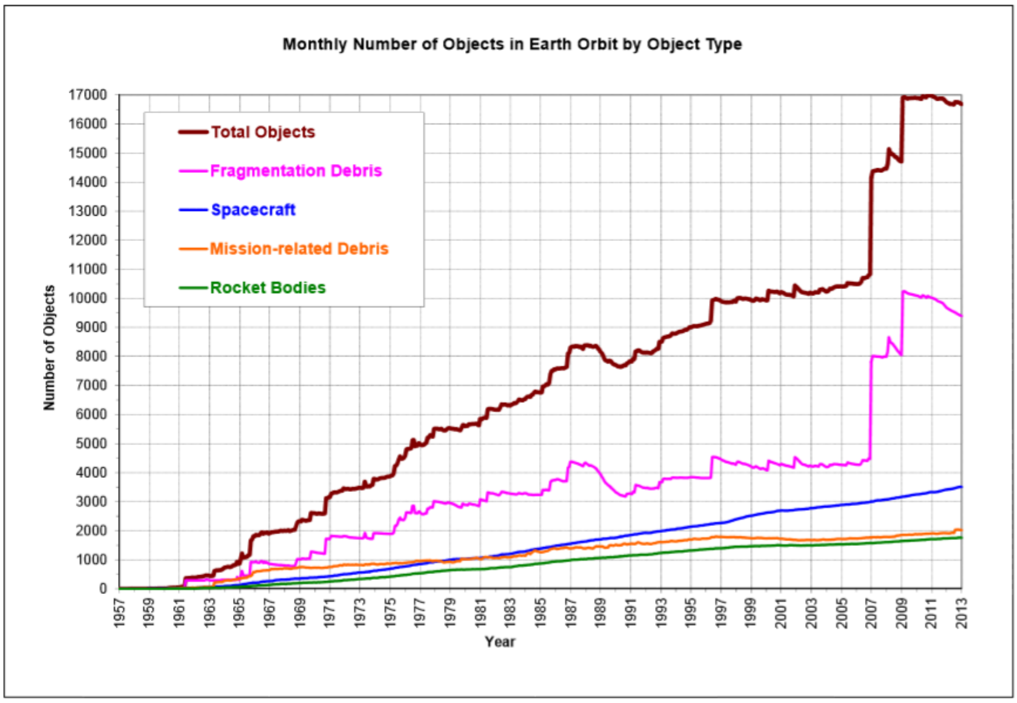
- Few months at 400km altitude;
- 25 years at 600km altitude;
- Several centuries above 800km altitude.

This suggests many years and centuries would pass before the region is self-cleaned (assuming no additional debris is added during that time).

For example, the debris released during the first breakup event in 1961 accounts for 1% of debris still on-orbit. Two events created a large increase of orbital debris:

- The chinese test on the defunct Fengyun-1C satellite in 2007, creating 3,000+ debris.
- The accidental collision of Iridium-33/Cosmos-2251 in 2009, creating 2,000+ debris.

Most of these debris are still on-orbit. See hereafter the latest chart, as of January 2013.



Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

As we can understand thanks to the chart above, the rate of orbital debris generated in LEO by launch, collisions, and other events currently exceed the rate of debris removed naturally by the Earth's atmospheric drag.

The NASAs Orbital Debris Program Office (ODPO) stated, "The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future".

KESSLER SYNDROME

Unlike standard terrestrial pollution where human can physically clean it, space debris propagates additional pollution. For instance, a collision between a satellite and a piece of debris, or even between two pieces of debris, creates additional debris which further increases the likelihood of other debris creating collisions.

Kessler (1991) proposed the possibility of a sufficiently dense debris cloud that would lead to a cascade of collisions, ultimately rendering space unusable.

The probability of such an event is unknown, although the probabilities increase in the density of the debris field. A recent National Academy of Sciences report states that:

> "...the current orbital debris environment has already reached a "tipping point." That is, the amount of debris, in terms of the population of large debris objects, as well as overall mass of debris currently in orbit, has reached a threshold where it will continually collide with itself, further increasing the population of orbital debris. This increase will lead to corresponding increases in spacecraft failures, which will only create more feedback into the system, increasing the debris population growth rate. The increase thus far has been most rapid in low earth orbit (LEO), with geosynchronous earth orbits (GEOs) potentially suffering the same fate, but over a much longer time period. The exact timing and pace of this exponential growth are uncertain, but the serious implications of such a scenario require careful attention…"

Committee for the Assessment of NASA's Orbital Debris Programs; National Research Council, (2011).

DEBRIS SIZE

Currently, there are approximately 21,000 human-generated (radar tracked) pieces of debris measuring over 10 cm, 600,000 (untracked) pieces of debris between 1 and 10 cm, and over 100,000,000 (untracked) pieces of debris between 0.1 and 1cm in earth orbit.

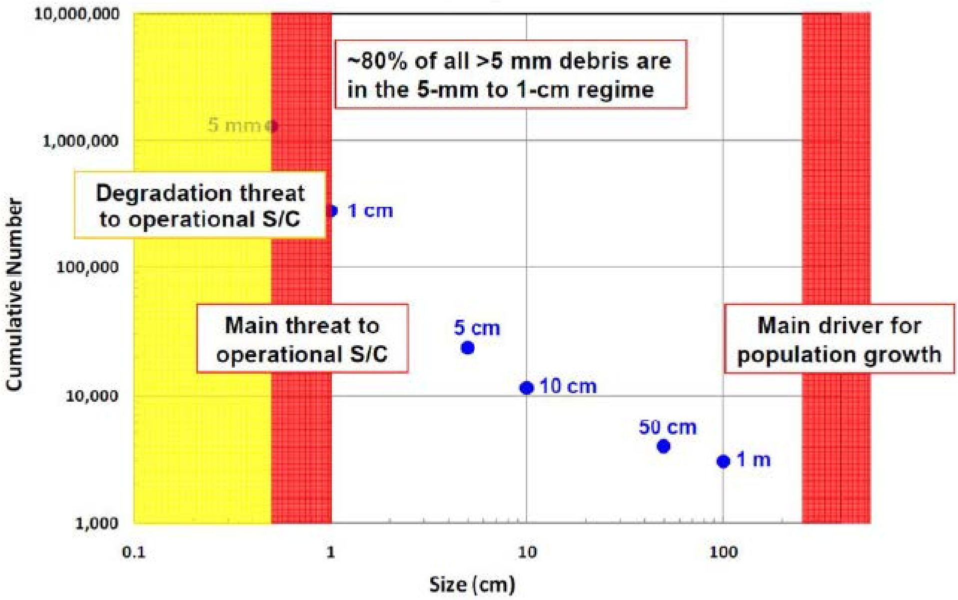
Size	Definition	Trackable	Damage
Small	<1 cm diameter	Not trackable	Can damage or potentially destroy a satellite. Increase production costs to support potential damages.

Medium	Between 1cm and 10 cm diameter	Cannot be earth-tracked	Can destroy a satellite and are particularly dangerous since they are not currently tracked.
Large	Between 10 cm & $8m^2$	Can be tracked by earth stations. Satellites can engage in maneuvers to potentially avoid a collision.	It will destroy a satellite and generate significant amounts of additional debris.
XL	$>8m^2$	"	"

Example of XL debris is the 2002-009A Envisat and the 2009-068B Delta IV Rocket Booster with cross-sectional areas of $19.9m^2$ and $19.8m^2$ respectively.

Small debris are often the result of on-orbit breakups.

According to the figure hereafter, the Active Debris Removal (ADR) efforts have to focus on debris between 5mm to 1cm (to reduce the direct impact on operational spacecraft) as well as on debris larger than 2m, in order to stop the increase of the debris number (by in-orbit breakups). (Liou 2012)



DEBRIS ORIGIN

According to NASA:

- 42% of total debris is fragmentation debris (resulting primarily from the break-up of satellites).
- 22% is non-functional spacecraft.
- 19% is mission related debris.
- 17% is rocket bodies.

All the major nations launching satellites are contributors to orbital debris. According to the Space Surveillance Network (SSN) catalog and the North American Aerospace Defense Command (NORAD) (16000+ objects tracked), more than 90% of the orbital debris by number belong to Commonwealth of Independent States, United States of America (USA) and China combined.

Here is the breakdown as of November 22th (2013): (space-track.org)

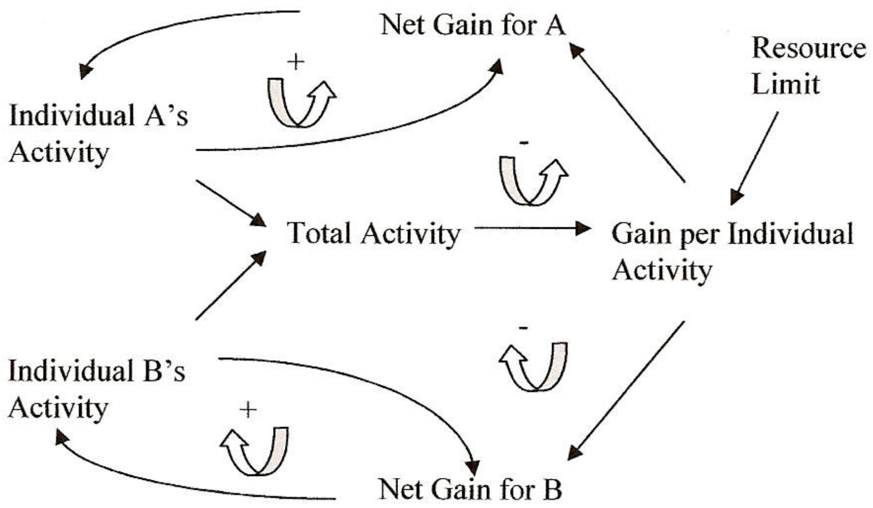
Country / organization	Payload	Rocket Bodies	Non-operational satellites and other debris	Total Objects
CIS (ex Soviet Union)	1469	1003	3758	6230
USA	1130	657	3211	4998
China	156	77	3545	3778
France	59	135	311	505
Japan	134	44	44	222
India	56	19	101	176
ESA	49	7	38	94
Others	722	36	81	839
Total	3775	1978	11089	16842

ECONOMIC FACTORS

First, space is considered as common resources and is naturally over-consumed by competitive firms relative to the social optimum, as long as private marginal benefits exceed marginal costs. This over-use comes to the expense of other firms or the resource itself. Indeed, they do not take into consideration the damaging effects of increased debris generated by launch vehicles on other satellites.

Similarly, competitive firms tend to select more polluting technology because they only compare individual marginal benefits and costs of their technology choice and fail to take into account social benefits and costs.

These findings were observed by G. Hardin (1968) who explained the Tragedy of the Commons.



According to this finding, main levers are in theory training (or experience), self-regulation or official regulation.

The latest finding is that debris do not impact significantly the satellite costs neither insurance yet. Indeed, only one debris collision is responsible for a significant financial loss (Iridium/Cosmos in 2009).

This suggests that the policy makers need to address both of these negative externalities in order to effectively address the problem of space pollution.

LEGAL & POLITICAL FACTORS

HISTORY

Since the beginning of the space conquest, the spacefaring nations signed several agreements.

First, in 1967, the Outer Space Treaty, formally the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, is a treaty that forms the basis of international space law. The treaty was opened for signature in the United States, the United Kingdom, and the Soviet Union on 27 January 1967, and entered into force on 10 October 1967. As of May 2013, 102 countries are states parties to the treaty, while another 27 have signed the treaty but have not completed ratification.

Main content: the Outer Space Treaty represents the basic legal framework of international space law. Among its principles, it bars states party to the treaty from placing nuclear weapons or any other weapons of mass destruction in orbit of Earth, installing them on the Moon or any other celestial body, or to otherwise station them in outer space.

Then, in 1972: the Convention on International Liability for Damage Caused by Space Objects, also known as the Space Liability Convention, is a treaty that expands on the liability rules created in the Outer Space Treaty of 1967. Because relatively few accidents have occurred resulting from space objects, the treaty has never yet been invoked. However, in 1978, the crash of the nuclear-powered Soviet satellite Cosmos 954 in Canadian territory nearly led to a claim under the Convention.

Main content: States bear international responsibility for all space objects that are launched within their territory. This means that regardless of who launches the space object, if it was launched from State A's territory, or from State A's facility, or if State A caused the launch to happen, then State A is fully liable for damages that result from that space object. However, the fault must be proven.

The latest international treaty was signed in 1975: Convention on registration of objects launched into outer space. The states signed this treaty for transparency regarding the weaponization of Space. Therefore, they agreed on registration of all the space objects trackable.

The NORAD is the best (high content) international monitoring system currently.

ISSUES

Actually there is no case law for space accidents (like Iridium/Cosmos in 2009 or smaller) because of several legal and political barriers:

- The victim must prove the fault - technically difficult from ground;
- The space object database is American and politically not reliable for international negotiation. Moreover, the American government is reducing the budget of space surveillance - which impacts the data quality;
- The state are responsible for any damage so the negotiations are heavy and long (Public/Private partnership);
- The political will is weak.

Regarding the space clean-up, there is no legal framework. However, the IADC states agreed to reduce the number of debris by pushing the satellites away from their orbit at the end of their life.

Moreover, legal barriers prevent external companies from cleaning up the space because they need three levels of authorizations:

- Launch country of the space object;
- Registration country of the space object;
- Space object owner.

Finally, another real issue is the technology exportation - because the cleaner needs to know the technology inside the satellite in order to extract it from its orbit, this will not lead to a happy ending politically.

CONCLUSION

Many technical, economic, legal and political barriers prevent the LEO from being cleaned up. However, we could in theory face these obstacles if all the space players were working together in order to reduce space junks:

Economic, legal and political factors are directly linked to the states and international laws. Unions must continue working on an official regulator. Moreover, as soon as debris will significantly impact direct costs, competitive firms will lobby the governments.

Then, regarding the technical issues, many solutions are already born on-paper. Whereas no demonstration was shown, scientists are ready.

SEVERAL METHODS TO GET RID OF THE DEBRIS

Most of Active Debris Removal (ADR) technologies are equipped with a capturing component, which grapples and controls the debris to deorbit them. The most critical task of the capturing device is to grapple the debris in a safe and secure manner without causing more damages and therefore debris.

We will see in this chapter the different methods who might be used to clean up space of the major large debris and determine which one could really suit.

'THE SPACE GARBAGE COLLECTOR'

The removal of large and XL debris requires a unique solution that could control deorbit maneuvers. Indeed, atmospheric friction is not sufficient to completely burn out the object during the descent and might cause important damages on earth.

The extra-large orbital debris are typically rocket bodies and ineffective satellites characterized by an area greater than 9-11 m² and a weight between 600kg to 1,2 Tons. Only in Sun synchronous orbit (600-1000 km), more than 200 operational satellites are currently threatened by large and extra-large debris; This orbit is the top priority for debris removal.

So far, this garbage collector is the most plausible and effective option for cleaning space of its biggest debris.

As we said earlier, the most critical action of the capturing device is to grapple the debris in a safe and secure manner without causing any more extra debris. Single arm devices capture and manipulate debris using a grapple tool. These robotic arms are mature enough concepts for orbital debris capture.

For this technology, the size of debris considered typically varies from large to extra-large. The capability of the vehicle in terms of debris size is also limited by the size of the vehicle itself.

The total production cost (not regarding development cost) of a robotic arm can vary between 60 million USD and 120 million USD (1kg ==> 100,000 USD).

This technology has been validated in space, and new demonstration missions are in progress.

Steps to connect and deorbit debris:

1. The device meets with the extra-large debris using the launcher propulsion and an extra small amount of fuel from itself.
2. The device capture the debris with its robotic arm and stabilizes it
3. The device which is connected will deorbit the debris using fuel propulsion.
4. Then starts the re-entry into the atmosphere that will burn out the satellite and the collecting device due to the extreme heat encountered during the fall.

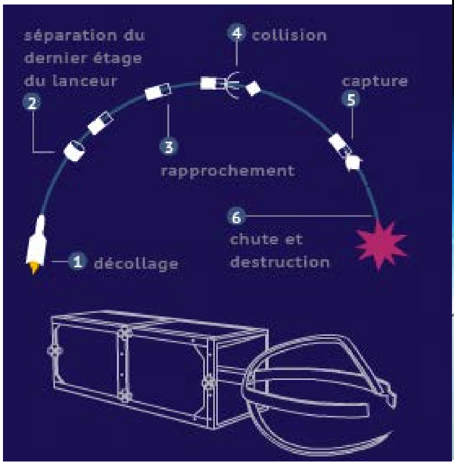
This collector will have the mission to intercept and carry back on earth space debris weight between 600 kg to 1 ton. It weight will be less than 1 ton due to the fact that the satellite will only have to carry a grapple and an articulated arm. We found out that the weight of the garbage collector should be around 600 kg.

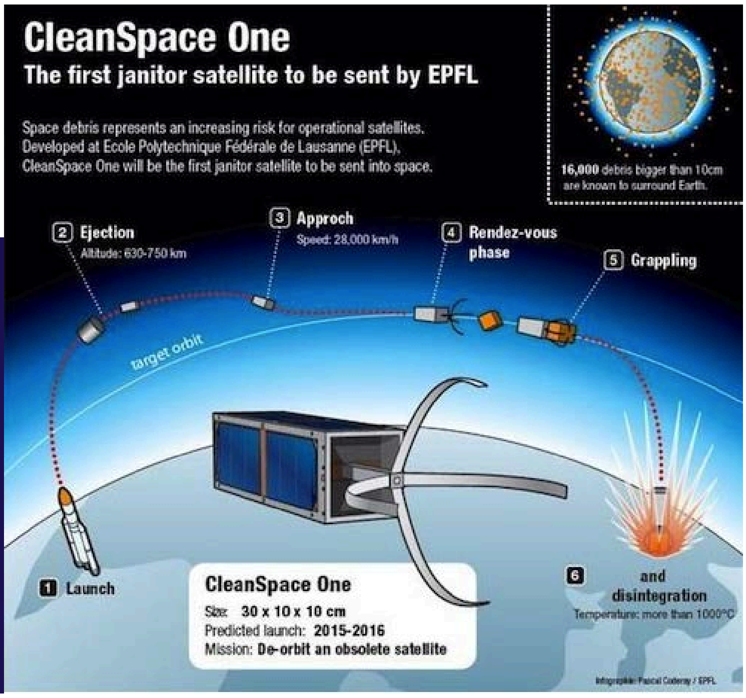
This project could clean up the space of its bigger debris within 38 years at a rhythm of one launch a week and 160 years at a rhythm of one per month.

At a rhythm of 1 by 1, around 2000 launchings must be needed to clean up the 2000 biggest debris (up to 1 ton).

But, we found that if we launch only 5 satellites a year, we could at least stabilize the number of space debris. The cost of this stabilization will be at least USD 330 millions $ per year (Launching costs + Satellite production : 60 + 6 = 66 million). This does not include a risk of failure.

This solution despite the fact that it is the most effective will have a prohibitive cost that will be developed later.





Xtra Large Debris Satellite	
Technologie demonstration	50
On-Orbit Validation	60
First application/satellite	60
Sub-Total	170
Every new application/satellite	50
Every new launch	120

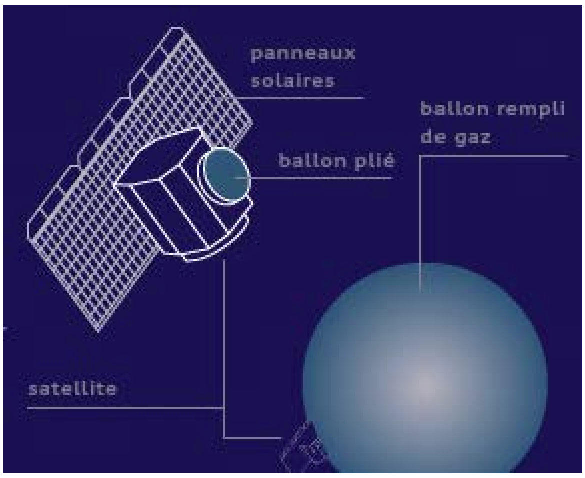
GAZ BALLOON

This solution suggests hooking up a gas balloon to the satellite. This one will inflate at the end of the satellite life.

The major advantages of inflatable structures are their low costs, the deployment reliability, a low storage volume, and a contain weight.

The balloon is lighter than the fuel needed to deorbit the satellite, making them cost-effective and easy to implement.

By changing the deflation level of the balloon during the earth return, the impact location on the ground can be controlled with more or less precision.



FISH NET

Nets are considered the most feasible devices due to the fact that they are less susceptible to be damaged by debris and will not rotate after capture.

The objective here is to capture operating satellites without being damaged, while single-arm robotics can be damaged by inadequate clamping structures on the debris pieces, which could overstress them.

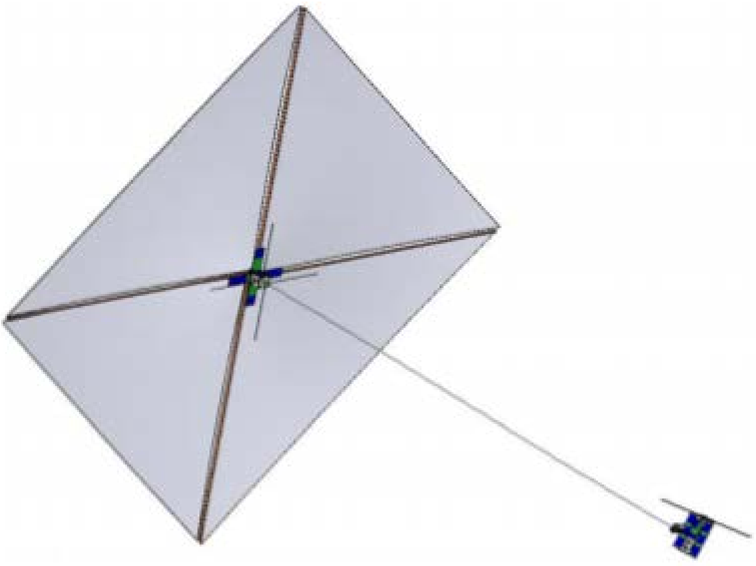
On the other hand, their weakness remain their big size that will make them more likeable to be crushed and holed by small debris.

Another hypothesis could be to deploy a giant net attached to a single satellite whom mission is to slow down lot of debris around 10 cm; the problem is that this solution is ineffective for larger debris.

➔ How does this net work?

The net is supposed to turn around the Earth, and collect the orbital trash. Once the net is full, gravity would pull it down to Earth — and it will burn up as it reentered the atmosphere.

Nets are not reusable due to their inherent single use characteristic as you can understand.



EDDE: ELECTRODYNAMIC DEBRIS ELIMINATION

The ElectroDynamic Debris Eliminator (EDDE) is a low-cost solution for LEO space debris removal. EDDE can remove nearly all the 2000 objects of more than 2 kg that are now in 500-2000 km orbits. EDDE is a propellant less vehicle that reacts against the Earth's magnetic field. It can climb about 200 km a day and change orbit plane at 1.5°/day.

It is a compact and light satellite: 100 kg, and capture debris with a mechanical grappler.

After catching and releasing one object, EDDE can climb and change its orbit to reach another object in a few days, while avoiding other radar tracked objects.

After capture, the device drags the debris down and releases them into controlled reentry.

Around 10 EDDE vehicles of 100kg could remove nearly all 2000 tons of LEO orbital debris in 7 years. But for now, it remains a project in progress.

CHEMICAL PROPULSION DEORBITING SYSTEMS

Chemical propulsion systems are reliable technologies used for active deorbiting of debris. The concept is to attach a thruster to a satellite piece we know will become debris. As so, it can be controlled to deorbit it and during the descent, minimize the possibility to harm population on the ground. According to studies, chemical propulsion might be the most effective method to deorbit debris in LEO.

We might note that this system will only prevent space junk addition of new satellites pieces and will not be able to clean space from already existing debris.

The propulsion system offers an interesting solution to the LEO orbital debris problem, especially for large and extra-large debris. The advantage of using this type of system is that the point of re-entry can be controlled, and that deorbit time can be reduced to few hours.

The mass and complexity of the chemical propulsion deorbiting kits is comparable to a small spacecraft, but it is more flexible and efficient in terms of mass and fuel consumption.

The bad point is that building this device with an adapted shape and powerful enough thruster cost around 30,000 USD per kg of mass removed from orbit; so for 1 ton of debris it will cost 30 M USD; which is around a third of a satellite launch price.

It will also take a huge space in the launcher and will take years for engineers to develop a prototype.

Therefore, this solution is not ready for use.

Chemical Propulsion Deorbiting System	
1 kg	30 000
600kg satellite	18 000 000
R&D	20 000 000

CONTACTLESS DEORBITING TECHNOLOGY

LASER

Lasers technology is one of the most popular solutions to remove debris of 10 cm diameter, with a possibility to adapt their capability to debris from 1 to 25cm with a 5 KW laser.

One of the first laser-based debris removal proposals was published in 1989 by NASA engineer Metzger. He suggested a nuclear powered laser to alter the orbital parameters of debris, reducing its orbital cycle with re-entry into the Earth's atmosphere to burn it, or push further in the space (between 2500 km and 30000 km).

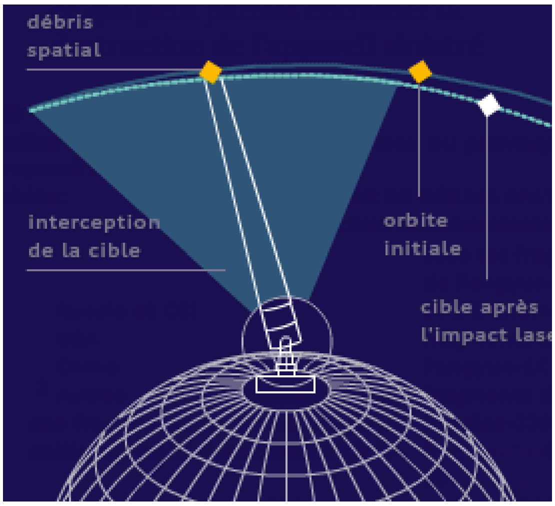
The laser could also impact debris and modify their orbit in order to prevent collisions.

Because this solution cannot destroy the debris and could improve the number of smaller debris, NASA's plan is to move the debris out of the satellites orbit. The laser would be installed on the North or South pole, where we attain a thinner atmosphere, and would send pulses of photon pressure to push objects out of the way.

The main point of this technology is that it is way cheaper than the others; around 1 million USD for a laser and 1,000 USD for each “shot”.

The main problem is that such a system would have to be built with "international collaboration”, because of evident security and responsibility implications.

In the past, numerous proposals with laser have been made. Despite the lower requirements and a cheap functional cost, this solution is not considered as it facse a strong opposition from every powerful country due to its potential use as space weapon to annihilate spaceships or planes.



Nuclear Powered Laser	
Production costs	1 000 000
Every shot	1000
10 shots / day	10 000
One year use	3 650 000
Total debris removed	**3650**

SOLUTIONS

As explained in the latest chapter, a solution is proposed for each debris category from medium to extra-large. Contactless and combinations of capturing and deorbiting/re orbiting technologies lead to the following selection of solutions:

- Lasers for medium debris;
- Net capture and inflatable balloon mechanism (called SpiderSat) for large debris;
- Robotic arm(s) with chemical propulsion deorbiting system for extra-large debris.

Actually, medium debris are not tracked accurately and engineers are not able to act yet. Because they are not tracked, they are very dangerous. Regarding bigger debris, adequate removal solution can be implemented within the next years/decades.

Moreover, legal and political issues are the main challenges currently.

HOW MUCH DOES IT COST TO START CLEANING SPACE?

In order to simplify the understanding of the cost issue, we will only introduce the most relevant solution.

Cost details for the space garbage collector solution in million USD:

Xtra Large Debris Satellite	
Technologie demonstration	50
On-Orbit Validation	60
First application/satellite	60
Sub-Total	**170**
Every new application/satellite	6 - 12
Every new launch	60 - 120

Note: In addition to these numbers we must take into consideration the Research and Development budget which should be about at least the price of two satellites

We established that the development cost would be 170 million USD for the entire program.

Every new satellite built would cost 6 to 12 million USD and every new launch, on the calculation of 10 000 /20 000 USD per kilogram (for 600 kilos), which means 60 to 120 million USD.

Cost details for Chemical Propulsion Deorbiting Systems:

We saw that to deorbit one kilo of space junk with a thruster it will cost 30,000 USD, so for an extra-large debris of 600 kg; the tag price will be 18M USD.

Research & Development: 20M USD

Chemical Propulsion Deorbiting System	
1 kg	30 000
600kg satellite	18 000 000
R&D	20 000 000

Cost details for the laser solution:

- Producing a nuclear powered laser will cost around 1M USD
- Every shot cost 1,000 USD, 10 times a day : 10,000 USD/day
- One year utilization: 3, 65 M USD for 3650 debris removal.
- R&D costs are not taken into account.

Nuclear Powered Laser	
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Every shot	1000
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To sum up, for small debris, the current solution (Fish Net) is not in our view enough effective (Few debris impacts for the time spent).

We saw that little debris are impossible to track currently, and, as the fish net is not efficient enough we will focus on medium and large debris. For Medium-sized debris, using a powered nuclear laser appears to be the best cost/efficiency ratio.

For large debris already inLEO, the Giant Space Collector or "Clean Space 1" seems to be the most exploitable solution. Despite its high cost per launch, it will be the most effective way to face the Kessler syndrome.

SCENARIOS

➔ Who will pay?

If the world wants to solve the debris problematic, it is necessary to take actions against polluting behaviors. The four scenarios below could provide a positive answer to the debris problem. Unfortunately these four options face legal, political or technical issues.

Consequently, these options will require an international agreement to be settled.

TAX ESTABLISHMENT

Financing the “Clean Space” project is a fundamental question. To our opinion, the best way to finance this project is to introduce a tax towards market actors.

This tax could impact:

- Manufacturers
- Launchers
- Operators
- Operators customers
- Final Users

The problem is that such tax has to be set up by all the using countries proportionately to their involvement in space activities. But because of different interests among the countries such agreement will have only few chances to succeed.

Moreover, such tax will probably have repercussions on the final users and could weaken the all sector.

CREATE A PUBLIC FUND / STATE FUNDING

Because this problematic impacts public interests, it should be relevant for a state to create a public fund to finance the cleaning of the space. If the result of the Kessler syndrome conclusion happens, lots of orbits will be inoperable because of the debris. Given that, how mankind could do without major technological advances like GPS (Global Positioning System, etc.) which is involved in many applications (Banking System Coordination for example)?

Unfortunately it is necessary to convince all the main countries involved in space activities to finance these operations. A state would not finance this project alone. Sure some initiatives with a global dimension were taken like the Inter-Agency Space Debris Coordination Committee but it is not enough to face this large problematic of the space debris. It could be relevant to give this responsibility to the United Nations in order to get in touch all the nations concerned by this problematic.

INCREASE OR DECREASE INSURANCE PREMIUM

Currently, the debris number does not impact the level of the insurance premium because of the low probability of an important breakdown caused by a debris. That is why, actors of this sector are not interested in taking over these parameters in the calculation of their insurance rate. It will be interested to increase the rate of the insurances (compulsory tax?) in order to create an impact for all the space actors. This rate will take in consideration the risk factor involved by the Kessler syndrome. This action could encourage actors to react to the space debris problem.

DO NOTHING

The most pessimistic solution.

In our opinion that is what is going to happen in the next decades except if one of the three solutions above is settled. Of course, it is the cheapest solution but it does not solve the problem.

PUBLIC AWARNESS FOR CHANGE

In order to gather financial and political support to solve the orbital debris problem, decision makers outside of the space community and General public have to be aware of this problematic. Once, the public opinion will realize the importance of the situation, a real reaction could enter into effect.

Raising awareness outside the space community is challenging! So, when does this problem come to the attention of the general opinion? As long as everything is alright, nobody cares about the problem. However, if a disaster happens, opinion gets aware and starts a reaction: “Bad news make the News”. This is the role of medias and public magazines.

Consequently, should we wait for a collision involving a big disaster before taking this risk in consideration? Of course not!

But as long as nothing happens, who cares?

Another way to underline the problem of orbital debris is to increase perception of space applications. Make understand to our civilized population what space brings to us in terms of service and comfort (Telecommunication, Global Navigation systems, broadcasting systems…)

By increasing knowledge about the importance of space debris and the economic impact that it could cause, will help to influence all the stakeholders to find a solution.

RECOMMENDATIONS

2013 – 2016

Cooperation between the space agencies to reach agreements and get informations about the costs of cleaning space, surveillance and mitigation.

Development of Orbital Debris Removal Guidelines by the IADC.

IT resources to get debris trajectory prediction have to be strongly improved and shared globally.

Launchings have to be strictly controlled in order to avoid intentional destruction in space (except if the object is on a re-entry trajectory). To make this realizable, and to make sure satellites will be place in safe orbit, names and details of nations and operators who do not follow guidelines should be published in reports such as the FAA (Federal Aviation Administration publications) and at the ITU (International Telecommunication Union).

US, first, should make its national industry compliant with its Orbital Debris Guidelines by following a national law. Once the US will impose these conditions to the national market, other countries could follow this example by creating similar laws based on IADS and UN guidelines.

Medias and magazines should also encourage more often these good actions by explaining the risks of the current situations and the cost of it.

2016 – 2020

ICAO (International Civil Aviation Organization) should develop international standards for space traffic management.

The ISO should create international standards for the certification of the vehicles and satellites launched to clean space

Non-functional satellites and post-mission launch vehicle should be cleaned from LEO, with a re-entry trajectory.

2020 - 2053

Develop and implement an orbital debris capture mission that can use chemical propulsion systems to deorbit extra-large debris on a controlled re-entry trajectory.

CONCLUSION

Space debris is obviously an important topic since we can read more and more articles, thesis and watch movies regarding this issue.

Indeed, debris, by breaking down parts of satellites; reduce the realized value of space activities by increasing the probability of damaging existing satellites or other space vehicles.

Debris issued from collisions (between debris and satellites) or from launch waste damage firms' final products and are propagating themselves. Moreover, the number of debris is increasing quickly (Kessler syndrome) and might become a huge cloud that could prevent all companies from launching anything.

As far as competitive firms are not interested in reducing the number of debris and pushing the existent satellites away of their orbit, no private solution will be found. The real issue of space debris proliferation is to overtake a difficult and complex international legislation but also to create a reaction of the general opinion. Once everybody will be aware of the danger of space debris, governments and companies will suffer pressure by the society and could start a real reaction towards this problem.

We understand, with regards to the Tragedy of the commons, official regulation and governments is the unique solution to reduce this economic threat.

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