The impact of Space Law and space debris mitigation measures on the debris scenario around the Earth

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Abstract. In face of the growing exploration of space by humanity, at first this work aims to synthesize a little information from Space Law based on legislations and discussions on the subject. Going further, the main focus of the project are the space debris and its mitigation guidelines of the United Nations Committee on the Peaceful Uses of Outer Space. The possible consequences of non-compliance with these standards for orbits around the Earth have been investigated and the scenario at the date of approval of the document implementing the guidelines at the UN has been compared with the current scenario in order to verify the impact of the measures summarized therein on the missions launched since then.

1. Introduction

Even before the start of the Space Age, there were many concerns about the space exploration regulations. The first known record about this was made by the Belgium jurist Emile Laude, in 1910. Throughout its development, especially after the launch of Sputnik, Space Law remained essentially legal until the end of the last century. All the five main treaties made so far by the Committee on the Peaceful Uses of Outer Space (Copuos) dealt almost exclusively with political and diplomatic issues, which is reasonable as all of them were written during the Cold War. [1]

It was only in the 1990s that a technical issue of space began to gain relevance in the sessions of the committee. The first work [2] on the threat of space debris to space exploration activities was published on 1978, leading the scientists and engineers to a series of discussions inside and outside the Copuos, which culminated in the creation of the committee’s space debris mitigation guidelines, in 2007. [3]

Since then, all member states of Copuos – which includes all nations and international organizations with significant space exploration programs – are subject to several voluntary standards regarding the minimization of the risk of generation of new debris. The main objective of this work is to evaluate the impact of the measures summarized by these guidelines to the orbits around Earth.

2. Brief historical review of Space Law

Before the Second World War, the efforts to develop space activities regulations basically didn’t exist. There were only a few concerns. The end of the war and the consequent beginning of the Cold War left the scientists in a very uncomfortable position, since the tension between East and West seemed to prevent any dialogue, even in the scientific area. As a result, researchers...
from the space industry founded the International Astronautical Federation (IAF) in 1950, in an attempt to resume contact. At the time, the federation was one of the very few meeting places of the two sides of the space race, where the first discussions related to Space Law took place. [4]

Seven years later, the famous Sputnik I was launched, marking the beginning of the Space Age. Its success caused a major turnaround in the power dispute, as the Soviet Union has proven itself capable of launching anything – like weapons of mass destruction – anywhere on the planet with its R7 rocket that has taken the innocent Sputnik into its orbit.

The dispute was soon balanced by the launch of the Explorer satellite by the United States, which led the two superpowers to a tie, a new stage of confrontation that led to a certain rapprochement between the two sides that would have been inconceivable before. Negotiating was not only an option but also a necessity. It is in this context that the bases of the regulation of space activities began to be established. “Thus, Space Law is a child of the Cold War, but of a phase of the Cold War that allows and requires certain understandings for the benefit of both parties to the potential conflict.” [5]

The first step in that direction was the creation of Copuos in 1959, which originally had 24 members, including the two main powers at war. In the following years, the world watched impatiently the race to the moon, whose development led to the most important document governing the principles of Space Law, known as “Outer Space Treaty”. In general terms, it ensures the equal use and exploration of space by all countries, preventing appropriations and expanding the United Nations Charter to the space environment.

After that, four other Copuos treaties have been signed, from 1968 to 1979, most of them just expanding the topics defined by the Outer Space Treaty. Together, these five treaties form the basis of Space Law with regard to political issues. In the mid-1980s, the two superpowers decided to remove the military topics from Copuos, transferring them to the UN Disarmament Commission and then to the UN Conference on Disarmament. This act deprived Copuos of the most crucial agenda for which it has been created. [6]

The end of the Cold War brought a new unilateral hegemony to the world which provided an even tough scenario for the development of Space Law in political terms. On the other hand, that was the time when a technical subject started to take place in Space Law discussions for the first time: the space debris. Although the first major publication on the impact of debris dates back to the 1970s, [2] it was only in the 1990s that the issue began to be widely debated in the Copuos sessions.

Thirteen sessions after the one that included space debris in its agenda for the first time, the space debris mitigation guidelines were finally adopted by the Copuos, in 2007. These guidelines were also endorsed by the committee a few months later and will be discussed in the following topics. [3]

Despite its unilateral beginning, the world of the twenty-first century has been increasingly moving towards a multilateral hegemony. With the extraordinary economic growth of previously unimpressive powers like China – whose gross domestic product (GDP) has surpassed that of the United States [7] – and India, this trend seems inevitable.

Another indicator of this tendency is the giant technological explosion that has been expanding in the new century, with the emergence of the most diverse devices and applications in countless countries – developed or not, – besides a growing adoption of services that depend on space technologies.

In this sense, it is crucial to intensify international cooperation in the exploration and use of space, increasing its participation and benefits to more and more countries. For this to be possible, it is necessary to improve the processes of global governance of space activities. This involves the encouragement and prestige of multilateral bodies, such as the Copuos, and an opening of the channels of access to its work, especially its legal subcommittee. [5]
The most important event of the last years regarding Space Law occurred in the course of this work. Organized by the UN Office for Outer Space Affairs, the UNISPACE+50 took place 50 years after the first United Nations conference on the exploration and peaceful use of space in 1968.

The meeting was held in Vienna, the same venue of the first event, and provided a unique opportunity for the international community to consider future paths of space cooperation for humanity.

The UNISPACE+50 high summit met between June 20 and 21 and endorsed a resolution promoting the strengthening of international cooperation in the peaceful use of space and encouraging space activities to serve the goals of sustainable development.

The resolution, approved by the General Assembly in December 2018, further invites the Copuos to develop the Space2030 agenda, based on the results presented at UNISPACE+50, and its implementation plan. The agenda also aims to promote cooperation among States and sustainable development in the space environment. [8]

3. Space debris

For the purposes of this work, space debris are defined as “all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional.” [3] This definition comes from the Copuos mitigation guidelines and covers a number of different objects, including small fragments to whole satellites.

Although they usually pass unnoticed for the general population, space debris are a constant threat to the services of which human activities depend all the time. That is the reason why all major space agencies in the world already have divisions and projects to deal with this problem. This is the case of NASA, ESA, JAXA and CNSA, for instance.

In fact, studies on the danger of debris for space objects have been made since the 1970s, as mentioned before. In 1978, Kessler and Cour-Palais published an article [2] in which they concluded that if the growth in the number of debris identified until then was maintained, an even more dangerous population of debris would be generated around the year 2000 as a result of random collisions between the cataloged objects.

The article also concluded that this new source of debris would rapidly pose a greater hazard than that of natural meteoroids. After a longer period of time, the flow of debris would grow exponentially as a function of time, even though new objects were no longer thrown into space. This process would be similar to the one that created the asteroid belt, but in a much smaller time interval.

32 years later, Kessler himself published another article with three other scientists. [9] This time, the projections from 1978 were compared with the observations made until 2010. Basically, the researchers consulted the graphic published annually by the NASA Orbital Debris Program Office to discover the actual growth of the number of objects in space by that time. This information was important because the 1978 projections considered different scenarios according to this growth rate.

The updated version of this graphic is shown at Figure 1. [10] As it shows, the value found was approximately 320 objects per year, which corresponds to the lowest rate considered in the projections of 1978, as shown in Figure 2.

Both figures are just updated versions of the ones found in the 2010 article by Kessler et al. No other significant collisions have been detected since 2010, so that it can be concluded that the projections from 1978 for the lowest growth rate have been optimistic until about 2018, when the projection curve finally exceeded the cumulative number of collisions.

Also in 2010, other projections were released by NASA Orbital Debris Program Office. One in particular, published in the January 2010 issue of the Orbital Debris Quarterly News, [11] draws attention to the expected exponential trend since the first studies in the area.
from 100 Monte Carlo statistical method runs, it brings the averages and uncertainties to the expectations regarding the number of objects in three types of terrestrial orbits for the next 200 years in a non-mitigation scenario. With all these predictions, it is evident the need to observe the Copuos mitigation guidelines.

4. Space debris mitigation guidelines
As previously mentioned, the problem of space debris began to be discussed in the Copuos in 1994. In 1999, the subcommittee responsible for this issue handed a detailed report about space debris to the committee and agreed to establish a plan of action to create mitigation guidelines that should be followed voluntarily by the space agencies of all nations two years later.

In accordance with that plan, the Inter-Agency Space Debris Coordination Committee submitted its proposals for mitigation of debris in consensus with all its members. As a matter of fact, these and the Copuos proposals just reflected practices already developed by a considerable number of nations and international organizations, inviting all the member states to implement such measures in their space programs.

In the following years, the opinions of the member states of Copuos were heard until the final text was accepted by all of them and endorsed in the General Assembly resolution 62/217 of 22 December 2007. Thus, the seven mitigation guidelines are:

(i) Limit debris released during normal operations;
(ii) Minimize the potential for break-ups during operational phases;
(iii) Limit the probability of accidental collisions in orbit;
(iv) Avoid intentional destructions and other harmful activities;
(v) Minimize potential for post-mission break-ups resulting from stored energy;
(vi) Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission;
(vii) Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission.

If they were followed to the letter, the guidelines would surely have avoided the biggest event already registered in terms of generation of debris – the Chinese ASAT test that destroyed the
Fengyun-1C satellite – and could have avoided other big events, like the collision between the satellites Iridium 33 and Cosmos 2251. [12]

5. Evolution of the debris scenario
As the term “space debris” includes a number of different objects, it is convenient to classify the debris in some way. The most usual method to do that uses the size of the debris as a criterion. For this work, basically only debris larger than 10 cm in diameter and in orbits around Earth were considered, as they are widely detectable and traceable. A few smaller debris may have been counted as well, but they do not represent an expressive number in the results.

In order to ascertain the compliance of the mitigation standards by each nation, the analysis made in this project intends to identify the source of each debris in order to quantify and locate each one of them. This identification was made from the NORAD satellite catalog (SATCAT) data and from the two-line element sets of all objects of interest. [13] For a consistent comparison, the time interval considered goes from December 2007, when the mitigation norms were approved, to September 2018, when the study was made.

The first analysis is purely quantitative, comparing the number of debris of each nation on each date. To better understand the effect of the measures contained in the mitigation standards, the numbers of new debris were separated between debris generated by pre- and post-2007 missions. The results of this analysis are presented in Figure 3.

Figure 3. Evolution of the number of debris in orbit by source.

Analyzing the complete scenario, the quantity of space debris cataloged in Earth orbits rose from 11,071 in December 2007 to 16,340 in September 2018, an increase of 5,269 objects or 47.59%. Of these new debris, 1,390 (26.38%) were generated by missions launched after 2007, while the others resulted from the fragmentation of pre-existing debris, from accidental collisions between objects launched before 2008 and even from the end of life of missions launched until 2007.

Note that by far the largest number of debris already in 2007 and also the largest increases since then are in the account of China, the United States and the Commonwealth of Independent States (CIS) – this one with majority participation of Russia. This is the reason why the next analysis, which considers the location of the debris, covers only these three sources.
Much of the growth in the number of debris from pre-mitigation missions of Russia and the
United States was caused by the collision between the Iridium 33 and Cosmos 2251 satellites.
The major concern, however, is the still high number of debris generated by post-mitigation
missions of the CIS and China. In these missions alone, both nations were responsible for about
500 new debris each.

A second quantitative analysis can be done by comparing the number of debris from each
source with their respective numbers of operational objects in orbit. To counteract the post-
mitigation scenario, an interval of the same duration, – of 11 years, from 1997 – was considered,
using data from the December 2007 version of the satellite catalog. In this way, the periods from
1997 to 2007 and from 2008 to 2018 are compared exactly as they were cataloged at the time
they were finished. In the case of 2018, the version considered is that of September, as already
reported.

The data supporting this analysis are shown in Table 1, which covers the six major sources
of debris already identified in Figure 3. At first sight, the number that most catches the eye is
852.33 debris/active objects from China in the pre-mitigation period. As it is known, this very
high number is due to the destruction of the Fengyun-1C satellite.

Turning attention to the total numbers, it is possible to observe a significant 12-times
improvement in the number of debris/active objects, a number that is clearly influenced by
the effects of Fengyun-1C. Nevertheless, disregarding the 2,316 debris – cataloged until 2007 –
of this event, the total number of debris per operational objects between 1997 and 2007 would be
4.37, which is still considerably higher than the 1.07 of the following period. Here it is possible
to identify an excellent advance in the mitigation of debris.

Also the specific cases show very favorable results, since all sources in the table reduced their
numbers of debris/active objects. In particular, the United States obtained a surprising number
of 0.27 debris per active object, – the lowest among the six largest origins, – which is even more
significant considering that this same country had the largest number of objects cataloged in
operation in the period after 2007.

The negative highlight in this latest period is France, whose number of debris/active objects
was more than 10 times above the global average. Another relevant harmful point is the CIS
number of 4.52, which is not as large as that of France, but is more threatening than the French
reality, considering the number of missions launched by the ex-Soviets.

Finally, leaving aside the quantitative analyses, there is also the spatial analysis of the debris,
that just considers the debris orbital elements available at their respective TLE sets from 2007
and 2018. The positions of all the debris of each desired origin were obtained in the X, Y, Z
coordinates of the geocentric equatorial system, in order to allow the construction of scatter plots for both dates. After a few tests, it was chosen to present such results as follows: a graph focused on medium and geostationary orbits for each source (Figure 4) and a single graph focused on low orbits containing all the debris from the three sources (Figure 5).

![Graphs of MEO and GEO space debris scenario evolution.](image)

**Figure 4.** MEO and GEO space debris scenario evolution.

With this new analysis, it is visible not only the significant increase already detected in the previous study but also a great dispersion of the debris, which started to occupy much more planes than they occupied previously. This scattering confirms categorically the projections made shortly after the incident with Fengyun 1-C and the collision between Iridium 33 and Cosmos 2251.

6. Conclusion
Although the development of space law has been dormant since before the end of the Cold War, the multilateralism in the world today already shows a prospect of improvement in this
framework, which is reflected, for example, in the resolution defined in the last year during UNISPACE+50. However, only time will be able to show the true practical effects of the Space2030 agenda in the direction of the space activities of the countries in general.

On the other hand, the data obtained in this project were able to show in a rather incisive way that basically all the nations with a higher level of space activities took efficient space debris mitigation measures on the missions launched from 2008 onwards, that is, the period after the adoption of the mitigation guidelines. This is reason for a great celebration, no doubt, but a still very cautious celebration, given the significant number of inoperative objects that continue to pollute the Earth orbits and which only tends to increase because of the collisions that can occur between themselves at any moment.

In view of this, it is vital that new ways of removing space debris - especially those from more densely populated orbits - continue to be designed and implemented. However great efforts have been shown in reducing space junk generation, they are far from sufficient to ensure a future free of catastrophic interference from debris in space missions in general.

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