The Danger of Space Debris: Legal Issues and Solutions Associated with Active Debris Removal

*Joanna Langlade**

1. Introduction

After 61 years of space activities and more than 5400 successful rocket launches, mankind has created a considerable amount of space debris. Only about 21,000 out of the 29,000 debris objects larger than ten centimetres orbiting around the earth are being tracked regularly by the United States and Russian space surveillance systems. Smaller pieces of debris cannot be traced from earth but are also estimated to be in very high numbers: approximately 750 000 from one to ten centimetres and 166 million from one millimetre to one centimetre.[1] These objects are concentrated in low Earth Orbit (LEO), which is situated at an altitude between 160 and 2000 kilometres above the earth's surface.

There is no internationally agreed definition of space debris and it is not mentioned in any of the five United Nations (UN) space treaties.[2] However, reference can be made to numerous guidelines defining space debris as "all

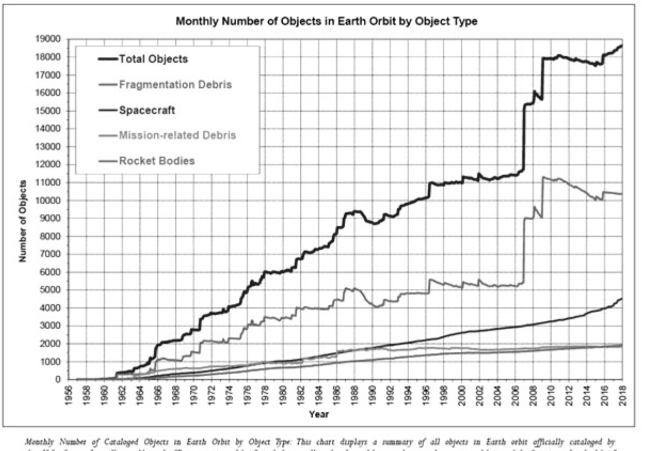
* *Alumna of the Leiden University Advanced LL.M. in Air and Space Law.*

1 ESA, 'Space Debris by the Numbers', http://www.esa.int/Our_Activities/Operations/Space_Debris/Space_debris_by_the_numbers, (all websites in this paper have been accessed and verified on 11 December 2018).

2 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (adopted on 27 January 1967, entered into force on 10 October 1967); Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (adopted on 22 April 1968, entered into force on 3 December 1968); Convention on International Liability for Damage Caused by Space Objects (adopted on 29 March 1972, entered into force on 1 September 1972); Convention on Registration of Objects Launched into Outer Space (adopted on 14 January 1975, entered into force on 15 September 1976); Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (adopted on 18 December 1979, entered into force on 11 July 1984).

man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional”.[3] A non-operational satellite, a launcher or even a screwdriver can be debris.

At the start of the space age, States launched objects without thinking of the debris they would eventually generate. Originally, debris thus emanated from mission-related objects or breakups that may or may not have been intentional. The density of objects in earth orbit largely increased in 2007 and 2009, as is demonstrated in Figure 1.[4] The latter displays the United States (US) Space Surveillance Network number of catalogued objects in earth orbit by object type. The causes of these large increases were the intentional destruction by China of one of its weather satellites with a ground-based missile and the first accident between two functioning satellites, also known as the Iridium-Cosmos collision.[5] Currently, the main contributors to the growth of the debris environment are collisions, particularly in LEO.



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.

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3 Inter-Agency Space Debris Coordination Committee, Space Debris Mitigation Guidelines (September 2007); United Nations Office for Outer Space Affairs, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (2010).

4 Source: National Aeronautics and Space Administration, Orbital Debris Quarterly News, Vol.2, Issue 1 (2018), at 10, online: https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv22i1.pdf.

5 The Diplomat, ‘China Conducted Anti-Satellite missile test’, 9 July 2014, http://thediplomat.com/2014/07/china-conducted-anti-satellite-missile-test/; Science et Avenir, ‘Collission inédite de deux satellites’, 12 February 2009, https://www.sciencesetavenir.fr/espace/collision-inedite-de-deux-satellites_32974.

Space debris is dangerous and problematic for current and future space activities. Firstly, it causes a threat to functional spacecraft in orbit, such as the European Space Agency (ESA) Sentinel 1A spacecraft, which was hit by a millimetre-sized space particle in 2016, resulting in a 40-centimetre diameter hole in its solar array. In addition, it endangers the individuals that are on manned spacecraft such as the International Space Station (ISS), which performs manoeuvres several times a year to avoid collisions with debris.[6] In August 2018, an object, probably a piece of debris or a micrometeorite, hit the ISS, creating a 2-millimetre hole in the Russian part of the station. If the air leak had not been noticed, the crew would have run out of air in just 18 days.[7] In the words of ESA, if a single 1-centimetre object collided with a satellite, it would lead to an explosion with the "force of an exploding hand grenade".[8] Secondly, there is the risk that the low Earth Orbit will become unusable, which is in conflict with the reality that more and more space objects are being launched. Space X, for instance, recently received the authorisation from the US Federal Communications Commission to launch 4425 satellites.[9] With regard to small satellites, which are difficult to track, their increase in number is also exponential. For example, Innovative Solutions in Space (ISIS) launched 101 small satellites in February 2017 and it is forecasted that 2400 micro and nano satellites will be launched by 2023.[10]

There is now a consensus among scientists that we have reached a critical point where the LEO region is so congested that debris will continue to be created even if we stopped launching satellites tomorrow. In this regard, reference can be made to the *Kessler syndrome*, established by a former scientist from the National Aeronautics and Space Administration (NASA),

6 The Guardian, 'We've left junk everywhere: why space pollution could be humanity's next big problem', 25 March 2017, https://www.theguardian.com/science/2017/mar/26/weve-left-junk-everywhere-why-space-pollution-could-be-humanitys-next-big-problem.

7 The Telegraph, 'International Space Station astronauts plug leak with finger and tape after being hit with debris', 31 August 2018, https://www.telegraph.co.uk/science/2018/08/30/international-space-station-leaking-air-hit-space-debris/.

8 ESA, 'ESA's Active Debris Removal Mission: E.DEORBIT, http://www.esa.int/spaceinvideos/Videos/2016/05/ESA_s_active_debris_removal_mission_e.Deorbit

9 Federal Communications Commission, 'FCC Authorizes SpaceX to Provide Broadband Satellite Services', 28 March 2018, https://www.fcc.gov/document/fcc-authorizes-spacex-provide-broadband-satellite-services.

10 Space Daily, 'ISISpace gets 101 CubeSats launched during record breaking PSLV launch', 15 February 2017, http://www.spacedaily.com/reports/ISIS_gets_101_CubeSats_launched_during_recordbreaking_PSLV_launch_999.html; Ian Christensen, 13 April 2017, 'Small Satellites Starts-Ups & Financing Small Satellites – Opportunities & Challenges for New Actors in Space', European Space Agency, Small Satellites Tech, Business and Regulatory Industry Workshop, Erasmus Auditorium, ESTEC, Noordwijk.

Donald Kessler. His theory states that at one point random collisions will happen between pieces of space debris due to their quantity, which will "generate more debris at a rate faster than it can be removed from orbit by the Earth's atmosphere (atmospheric drag)".[11] Thus, as the French astronaut Thomas Pesquet stated when addressing this problem, "similar to climate change, we must act now and cannot wait until it is too late".[12]
Space debris is a threat, but measures exist to fight it. ESA and other actors are energetically developing one of them, namely active debris removal (section 2). The purpose of this paper is to address the legal aspects of active debris removal (section 3) and provide practical recommendations to entities wishing to perform it (section 4).

2. Tackling the issue of space debris

2.1 Debris mitigation and post-mission solutions

Two main solutions exist to the debris problem: debris mitigation and post-mission solutions such as active debris removal.
Measures on debris mitigation are already well developed and implemented. They can be found in numerous international guidelines, such as the guidelines of the Committee on the Peaceful uses of outer space, endorsed by the General Assembly of the UN in 2007.[13] These guidelines have key recommendations such as limiting debris release during operations or reducing accidental collisions in orbit,[14] the latter constituting the idea of space traffic management. Some countries, including Austria, Canada, Germany, Japan, and Nigeria, also have national laws on debris mitigation, making such rules binding.[15]
Regarding post-mission solutions, the one that is currently used is post-mission disposal. The most common rule for LEO is that an object should not remain in orbit for more than 25 years after mission expiration. One idea circulating is that the period should differ depending on the mission. For instance, if an object is just launched as a precursor mission, it should be placed in a low altitude orbit and de-orbit half a year after its end of

11 Secure World Foundation, *Handbook for New Actors in Space* (Integrity Print Group 2017), at 34-35.
12 The Clean Space Blog, 'e.Deorbit: it is time to make active debris removal a reality for the European space sector', 30 January 2017, http://blogs.esa.int/cleanspace/2017/01/30/e-deorbit-it-is-time-to-make-active-debris-removal-a-reality-for-the-european-space-sector/.
13 UN General Assembly Resolution 62/217, 22 December 2007, UN Doc. A/RES/62/217.
14 See *supra* note 3.
15 UN Office for Outer Space Affairs, 10 January 2017, 'Compendium: Space debris mitigation standards adopted by States and International Organizations'.

mission.[16] One post-mission disposal technique is controlled re-entry. It is used when parts of a space object are expected to survive re-entry and the casualty risk is greater than ten^{-4}. The idea is to keep enough fuel to place the object, at its end of life, on a trajectory that will send the remaining debris to an unpopulated area, such as the Pacific Ocean. It is used mostly for satellites of more than one tonne or space objects containing certain materials that do not combust during re-entry, such as tungsten. Another possibility is to place debris in a graveyard orbit where it will not interfere with functional satellites. However, this is not a long-term solution, as "the cumulative debris mass eventually will create a new environment problem in the graveyard orbit".[17]

Another post-mission solution is active debris removal (ADR), which is the topic of this paper. No formal definition of ADR will be given in order not to restrain its possible applications in the future, but the current research implies that it consists of actively removing debris from orbit most likely with an external vehicle. In practice, this would involve a 'chaser' that would grapple a large piece of debris and bring it into a lower orbit to allow for re-entry. The idea is to use ADR for large objects that are likely to cause future debris because, in order to stabilise the debris growth, it would be necessary to remove between 5 and 10 large objects a year. Regarding small debris pieces, other technologies are being examined, for instance, ground-based lasers that would slowly shift objects into orbits where re-entry can occur.[18] The idea of active debris removal is in full development and several initiatives are starting to gain momentum.

2.2 Active debris removal initiatives

Initiatives exist both at the European and national level.

ESA's Clean Space team was working on an active debris removal mission called 'e.Deorbit'. The plan was to target an eight tonne ESA satellite in low orbit, capture it and safely burn it up in a controlled atmospheric re-entry. The launch of the chaser was scheduled for January 2024. It was considered important to remove 'Envisat', the earth-observing satellite in question, from space as otherwise, given its current trajectory, it would stay in orbit for another 180 years and constitute a danger to space and earth. Firstly, there is approximately an 18 per cent chance that it will breakup, generating a considerable amount of debris. Secondly, its re-entry would not be controlled,

16 Bertil Oving, 13 April 2017, 'The SMILE Project', European Space Agency, Small Satellites Tech, Business and Regulatory Industry Workshop, Erasmus Auditorium, ESTEC, Noordwijk.

17 J.-C. Liou, Engineering and Technology Challenges for Active Debris Removal, 4th European Conference for Aerospace Sciences (EUCASS), Saint Petersburg, Russia, 2011, 4-8 July.

18 C. Bonnal, Active Debris Removal activities in CNES, Jaxa Workshop on Space Debris, Chofu, Japan, 2013, 21-24 January.

while it is estimated that about four tonnes of the object would not burn up in the atmosphere. The pieces of 'Envisat' might thus fall in random locations on earth, creating a risk for humans.[19] Different concepts were under consideration for the mission: using a net, a robotic arm or a harpoon. All techniques have their advantages and disadvantages. However, since a greater number of companies have shown interest in it, the balance shifted in favour of the robotic arm.[20] Recently, due to a lack of funding, Clean Space unfortunately decided to stop the mission. Notwithstanding, it might make it evolve into a more general in-orbit servicing mission.[21] Despite this decision, Clean Space has demonstrated that ADR technologies can be developed.

There is also the 'CleanSpace One' project in Switzerland, which was developed by the engineering centre of the *école polytechnique* of Lausanne in cooperation with the Swiss space centre. For their first test they will try to capture 'SwissCube', a ten-centimetre Swiss satellite, and bring it into the Earth's atmosphere. One of the main challenges is to determine the position of the satellite, due to its small size, so localisation will have to be done in space.[22] In June 2017, Japan also conducted a mission to remove debris, but it was unsuccessful. Scientists from the Japan Aerospace Exploration Agency (JAXA) wanted to deploy a long cable from a satellite to grab a piece of space debris and remove it from orbit, however the mission planners were unsuccessful in deploying the cable.[23] More recently, in June 2018, the RemoveDEBRIS Spacecraft was deployed from the ISS. It began its experimental phase on 16 September 2018 and demonstrated that debris removal is feasible.[24]

Initiatives to remove space debris exist and ADR is quickly developing, they are nevertheless facing some barriers. Firstly, there are non-legal challenges to overcome, such as costs or technology. Secondly, there are political barriers. If a piece of debris can be removed, an active satellite could also be removed,

19 Andrew Wolahan, 13 April 2017, 'ESA Clean Space: Ecodesign, Space Debris Mitigation and Active Debris Removal', European Space Agency, Small Satellites Tech, Business and Regulatory Industry Workshop, Erasmus Auditorium, ESTEC, Noordwijk.

20 Tiago Soares, 9 March 2018, beSpace 6th Space Diner, Planetarium, Brussels, Belgium.

21 The Clean Space Blog, 'From active debris removal to in-orbit servicing : the legacy of e.Deorbit, 26 November 2018, http://blogs.esa.int/cleanspace/2018/11/26/from-active-debris-removal-to-in-orbit-servicing-the-legacy-of-e-deorbit/?fbclid=IwAR1VbGP4vze CUbZJT-d25yxDjw_G2ipSuYqTGSzM_SORbmBFl_rhQonR3aE.

22 Ecole Polytechnique Fédérale de Lausanne, 'CleanSpace One', 30 January 2018, https://espace.epfl.ch/CleanSpaceOne_1.

23 G. Dvorsky, 'A Japanese Effort to Remove Hazardous Space Junk Has Failed', 2 June 2017, http://gizmodo.com/a-japanese-effort-to-remove-hazardous-space-junk-has-fa-1792040971.

24 The Guardian, 'Spacewatch : floating 'space junk' captured', 20 September 2018, https://www.theguardian.com/science/2018/sep/20/spacewatch-floating-space-orbiting-junk-surrey-university-captured.

for instance for military purposes. Furthermore, there are also legal aspects to be taken into account.

3. Active debris removal: legal aspects

None of the UN space treaties specifically mention debris. This seems logical, as debris was not an issue when they were drafted in the 1960s and 1970s, but this makes it challenging to deal with debris from a legal perspective.

Nevertheless, existing legal aspects need to be taken into account when considering active debris removal. In the first instance, it is interesting to discuss whether there is an obligation for States to remove space debris. Then, two specific aspects of space law will be examined: ownership of space objects and liability for damages.

3.1 An obligation to remove debris?

Among the legal questions arising in the context of ADR, one key point is whether States have a legal obligation to remove space debris. The answer is *a priori* negative. However, as it will be examined, there could be an existing legal basis for creating such an obligation or such a basis might be created in the future. The obligation to remove space debris may exist under the space treaties, environmental law, international guidelines or national space law.

First, although the space treaties do not mention debris, as they often give minimal guidance, much room is left for interpretation. Pursuant to Article IX of the Outer Space Treaty (OST),

> In the exploration and use of outer space (...) States Parties to the Treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space (...) with due regard to the *corresponding interests of all other States* Parties to the Treaty.[25]

According to Article 31(1) of the Vienna Convention on the Law of Treaties, “a treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose”.[26] One of the purposes of the OST is “progress of the exploration and use of outer space for peaceful purposes”, as stated in its preamble. If we take an extensive interpretation of Article IX of the OST, it could be used as a legal basis to oblige states to reduce, and even remove their space debris in order to permit “other States to participate in the exploration and use of outer space with minimal risk from debris”.[27]

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25 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (adopted on 27 January 1967, entered into force on 10 October 1967).

26 Vienna Convention on the law of treaties (adopted on 23 May 1969, entered into force on 27 January 1980).

27 Royal Aeronautical Society, ‘Space debris: The legal issues’ https://www.aerosociety.com/news/space-debris-the-legal-issues/.

Secondly, such an obligation might exist on the basis of environmental law, as space debris might be detrimental to the earth's and space environment and the International Court of Justice is of the opinion that:

> The existence of the general obligation of States to ensure that activities within their jurisdiction and control respect the environment of other States or *of areas beyond national control* is now part of the corpus of international law relating to the environment.[28]

Finally, ADR could become a requirement in the future under international guidelines or in binding national laws obliging States to conduct ADR operations, as national laws already exist for debris mitigation.[29] In France, for example, there is a 2008 decree requiring launchers to be designed so that they can be de-orbited in controlled atmospheric re-entry after the end of the launch phase.[30]

On this point, it can be concluded that there is no clear-cut international law binding States to remove space debris but that a legal basis for such obligation could be created in the future. Following the examination of this question, it is important to discuss two major legal aspects of ADR: ownership of space objects and liability for damages.

3.2 Ownership of space objects and liability for damages

3.2.1 Ownership of space objects

According to Article VIII of the OST "a State party to the treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object (…) while in outer space". This means that even if a space object has become non-functional, it still has an owner. Consequently, for active debris removal purposes, a State, agency or private entity cannot remove a piece of debris without the consent of its owner. This appears to be logical as States could tamper with another's functioning satellites for political or military reasons if debris removal was free of authorisation. The downside of this requirement is that it could bar the activity of an entity, whether private or public, that would voluntarily remove debris.

3.2.2 Liability for damages caused by an active debris removal mission

Damage may occur during an ADR mission, whether in outer space, during atmospheric re-entry or at the time of impacting the surface of the earth, if the space object did not completely burn up in atmospheric re-entry.

28 International Court of Justice, 8 July 1996, Advisory Opinion, *Legality of the threat or use of Nuclear Weapons, Advisory Opinion*, I.C.J. Reports 1966, p.226, para. 29.

29 See *supra* note 15.

30 Loi n. 2008-518 du 3 juin 2008 relative aux opérations spatiales.

In the case of damage caused by a space object on the surface of the earth or to aircraft in flight, pursuant to Article II of the Liability Convention, the launching State shall be absolutely liable to pay compensation, which means that liability is not fault-based. Concerning damage caused to a space object of a third country while in outer space, liability is fault-based. According to Article III of the Liability Convention, in the event of damage caused in outer space to a space object of one launching State by a space object of another launching State, the latter shall be liable only if the damage is due to its own fault or the fault of persons for whom it is responsible. A launching State, pursuant to Article I of the liability Convention, is the State that launches, procures the launch or from whose territory or facility a launch takes place. This means that several States, or space agencies in accordance with Article IV of the Convention, can jointly qualify as a launching State for the same space object and be liable together. In case of damage, the injured party can claim compensation from the launching State of its choice, and it will be for the latter to turn to the other launching States to ask for indemnification.
If we imagine that State A performs active debris removal on a non-functional satellite owned by State B, and the damage is caused to the functional satellite of State C during the operation, Article III of the Liability Convention would apply and State C would have to: prove that damage was caused to its space object; identify the space object that caused the damage and who the launching State of that object is; prove that there was fault; and prove that the damage was caused by the fault. If the first element does not seem problematic, we only need to look at the second one (identification) to see how it can be complex to talk of liability for damages in the context of ADR. Indeed in such a scenario, how is it possible to tell whether it was the chaser of State A or the space debris from State B that caused the damage, and attribute liability?

4. Recommendations and long-term solutions

The main recommendation concerning ownership of space objects is that an actor performing ADR should preferably own the space object that it intends to remove. A good example is the e.Deorbit mission for which ESA was targeting one of its own satellites. If not, the entity should always obtain the authorisation of the owner of the space object that it intends to remove. Otherwise, it might be held liable.
In terms of long-term solutions, a system facilitating the grant of permission could be helpful, such as a standard UN authorisation form. Taking this even further, another solution would be to take inspiration from the law of the sea. The Nairobi Convention of 2007 provides a “legal basis for States to remove, or have removed, shipwrecks that may have the potential to affect adversely the safety of lives, goods and property at sea, as well as the marine

environment".[31] Such a provision could similarly exist in international space law as a legal basis for States to remove debris from other States. This would also be helpful for small pieces of debris, which cannot always be identified and linked to an owner.

Concerning liability for damages caused by an ADR mission, as is recommended for ownership, the entity performing the removal of the space debris should preferably be the owner of that space object. Moreover, the space debris and the chaser removing the object should ideally involve the same launching States.

In a scenario implicating various owners and launching States, it is recommended to conclude an agreement before the operation between the owner of the space object that is being removed and the actor carrying out the removal. The launching States of the debris and the launching States of the chaser should also seek an arrangement in order to distribute liability for the eventual damages that may result from the mission. This also needs to be considered in the context of insurance.

Ultimately, a clear legal framework should exist to deal with space debris. A solution could be to amend the UN space treaties or to create a new international treaty concerning space debris and active debris removal. This might not be feasible in practice, as States have become more reluctant to sign treaties compared to the period after the Second World War. An alternative is to integrate ADR in the already existing mitigation guidelines.

5. Conclusion

It has been demonstrated that active debris removal has become necessary. Even though there has not been a successful debris removal mission yet, advances in technology are evolving quickly and we are likely to see a capability in the next few years. As emphasised in this paper, there are nevertheless some legal aspects, especially ownership and liability issues, that need to be taken into consideration before performing active debris removal.

Humankind has already damaged the environment of Earth and of its orbits. Is it not time to be preventive and protect the universe beyond, especially when billionaires start launching debris into outer space?[32]

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31 International Maritime Organization, 'Nairobi International Convention on the Removal of Wrecks', http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/Nairobi-International-Convention-on-the-Removal-of-Wrecks.aspx; Nairobi International Convention on the Removal of Wrecks (adopted on 18 May 2007, entered into force on 14 April 2015).

32 The Guardian, 'We've trashed the oceans ; now we are turning space into a junkyard for billionaires', 11 February 2018, https://www.theguardian.com/commentisfree/2018/feb/11/weve-trashed-oceans-now-turning-space-into-junkyard-for-billionaires-elon-musk-tesla.