HOW TO INTEGRATE SPACE DEBRIS ISSUE INTO THE ENVIRONMENTAL ASSESSMENT OF SPACE MISSIONS?

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ABSTRACT

Life Cycle Assessment (LCA) has been identified by actors of the space industry as the most adequate tool in order to measure the environmental impact of space missions. Nevertheless, the scope of the current studies adopts a "cradle to launch pad" approach and does not take into account the end-of-life disposal of the spacecraft. With an expected growth of satellites launches associated with an increasing space debris population for the next decades, End-of-Life management is a central issue.

Hence, our challenge is to integrate orbital space use into LCA to broaden the scope of LCA for space systems. The main goal is the development of a new LCA indicator regarding the potential debris creation during the orbital lifetime of a spacecraft. The present paper proves the relevancy of this approach by presenting the impact chain linking orbital space use and environmental impacts. This is the first step on the way to creating a new indicator in compliance with the LCA framework which will provide additional information about life-cycle at early design-phase level.

1 INTRODUCTION

Industrial stakeholders and agencies in space sector are concerned by a set of environmental laws and legislation which are evolving fast (REACh, WEEE; RoHs etc.). In this way, space actors have to improve their good practices adopting an eco-friendly approach while maintaining the safety and competitiveness of European industry. It becomes compelled to design all new space missions in order to ensure a sustainable production and end-of-life management of the spacecraft. For instance, the French Space Operation Act mentions that environmental impact studies and measures shall be conducted in order to avoid, reduce or mitigate the adverse effects on the environment and on outer space.

By focusing on only few specific criteria (e.g.: avoiding REACh impacted substances), too many technologies are claimed to be "green technologies" without matching with essential criteria. Life Cycle Assessment (LCA) has been identified as the most appropriate methodology to evaluate the environmental impact of space activities by Airbus Safran Launchers, ESA "Clean Space initiative", and others actors of the space industry. According to ISO 14040 [1], LCA is a methodology to assess the potential environmental impacts of a product, technology or service through the overall life-cycle, i.e., from raw material acquisition to waste management, including production, transport, storage, integration and use phases. It seeks to quantify all physical exchanges with the environment, sometimes termed the 'cradle to grave' approach. As a multi-criteria methodology, LCA studies avoid the 'burden shifting pollution' which consist in transferring impact from an environmental impact category to another one, or from a life cycle stage to another one.

Concerning LCA for space activities, the priority has been given for the harmonization of practices among the actors of the European space industry. The goal is to establish a common framework to be used by European space agencies and industries when performing spacecraft design, including development and implementation of dedicated databases and tools for space activities. Guidelines and good practices helping to perform LCA studies have been released by ESA with a dedicated Handbook: "Space System Life Cycle Assessment guidelines" [2].

In addition, a main sustainability concern related to space debris should be investigated: if the end-of-life disposal is not managed, the risk of collision with other space objects will increase. In case of collision, a partial or a total loss of functionality will occur and a new mission will have to be re-planned aiming at offsetting this loss. Moreover, the space debris environment into Earth's orbit should compel to reinforce the space surveillance effort and undertake more and more collision avoidance manoeuvres.

Given this situation, there is now an opportunity to make the link between space debris concerns and the eco-design of the space vehicle using LCA methodology. LCA studies of space missions should indicate trade-offs not only between typical impact categories (toxicity and climate change for example), but also with regard to space debris related impacts, as it is an important issue for the sustainability of space activities. For this purpose, we first review the current LCA studies dealing with

Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office
Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)

space systems and their current methodological limitations. Then, we demonstrate how Earth's orbital space is a valuable resource that should be safeguarded from the threat of space debris. From this first analysis, we present an impact pathway linking orbital use to resource issues. This pathway is a first step towards the elaboration of a dedicated indicator which will provide additional information about life-cycle at a design-phase level.

2 LIFE CYCLE ASSESSMENT OF SPACE MISSIONS

2.1 Overview of current studies

Several LCA studies, dealing with space activities, have already been performed or are being performed. They are funded by industrial stakeholders as Airbus Safran Launchers, or national and international agencies including ESA and CNES. Some of the most complete studies are listed hereafter:

– A study on European launchers (Vega, Soyuz and Ariane 5 ES/ECA) based on the functional unit related to one launch from Kourou launch pad. Production and assembly stages of the launcher, launch campaign and launch event has been assessed. The study has been conducted by ESA with the support of Bio Deloitte in 2011[3].

– As a follow-up to this study, ESA Clean Space and Bio Deloitte performed LCA of four entire space missions: Earth-observation, telecommunications, meteorological and science. These studies include launcher, satellite, and ground support activities [4], [5].

– Studies to compare alternative space propellants; manufacturing processes and space materials for Ariane 5 and future Ariane 6 have been carried out by the 'Eco-design Alliance for Advanced Technologies' managed by Asplan Viak and supported by Airbus Safran Launchers.

– A new large study called GreenSat, proposed by ESA, is currently on-going. The objective of this activity is to redesign a space mission, using ecodesign principles in order to reduce its environmental impacts by 50% on at least three environmental indicators without an increase on others. This will be done by showing proof of concept of a set of ecodesign options to be integrated into the study case space mission.

Also, in order to integrate Eco-design into complete space mission level, the Ariane 6 program requires the use of LCA in the early stage of the design of the new European heavy launcher. Indeed, Airbus Safran Launchers is carrying a LCA of Ariane 6 launcher in exploitation phase with the aim of reducing the environmental impact of the launcher from Ariane 5 ECA basis.

2.2 Extending the scope of LCA for space missions

The space sector deals with strong particularities: long development cycles, several integrated manufacturing units, low production rates and resort to very specialized materials and processes. Therefore, strong efforts still have to be done in order to characterize the overall life-cycle of a space mission (Figure 1).

Today, on-orbit operations and complete post mission disposal stages are not addressed. The scope of the studies adopts a "cradle to launch pad" approach and does not take into account the end-of-life management of the space objects. With an expected growth of satellites launches associated with an increasing space debris population for the next decades, End-of-life management will be a central issue.

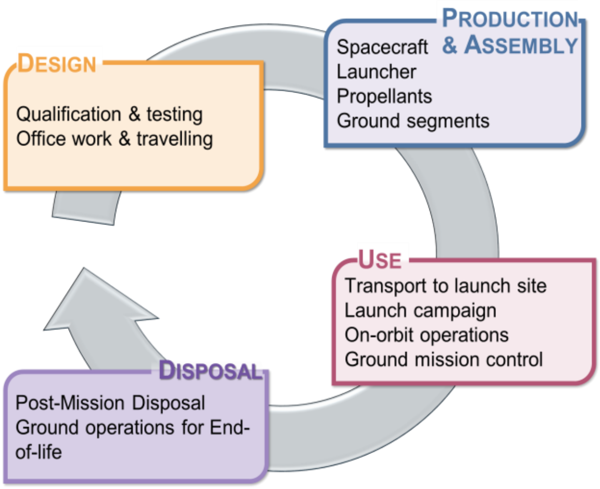

Figure 1. Life-cycle of a space mission

Three main sustainability concerns related to spacecraft disposal can be highlight:

- If the end-of-life disposal is not managed, the risk of collision with other space objects will increase. In case of collision, a partial or a total loss of functionality will occur and a new mission will have to be re-planned aiming at offsetting this loss. In addition, the global environment into Earth's orbit should compel to reinforce the space surveillance effort and undertake more and more collision avoidance manoeuvres.

- Atmospheric re-entry after the end of the mission (or due to natural decay) causes a partial or total demiseability of materials due to combustion and sublimation. The environmental impacts induced by the re-entry into the high atmosphere are not addressed today and need further developments [6].

- The remaining parts of the spacecraft fall down on-ground or into oceans. Local impacts on ecosystem is not well understood and need also to be investigated in terms of hazardous pollutants emissions.

Via the internal R&T project « Eco-Space » dealing with eco-design and Life Cycle Assessment, Airbus Safran Launchers is carrying out a large project in partnership with the CyVi group from the University of Bordeaux. Their common work attempts to improve the consideration of these environmental concerns into the traditional LCA methods aiming at covering the overall Life Cycle.

The priority has been given to the integration of space debris related impacts during on-orbit life and End-of-Life Disposal within the LCA framework. The main goal is the development of a new LCA indicator regarding the potential debris creation during the orbital lifetime of a spacecraft.

3 CONSIDERING SPACE DEBRIS RELATED IMPACTS IN THE LCA FRAMEWORK

3.1 Framework description

Our main challenge is the development of a new LCA indicator in compliance with the LCA framework regarding the potential debris creation during the orbital lifetime of a spacecraft.

The Life Cycle Assessment framework is described by the Figure 2. The latter shows the link between the inventory of elementary flows in the system under study and their potential environmental impacts and damages related to the induced environmental mechanisms. The description of how the starting points (substance flows and physical changes) are connected to final environmental damages is called an impact pathway [7].

A point positioned along the environmental mechanisms can be chosen as an indicator, often referred to the "midpoint" whereas the ultimate environmental damages are referred as endpoints. According to ISO 14040, endpoints are classified into three environmental concerns: natural environment, human health and resources. They are referred to "Areas-of-Protection" (AoP), i.e., the entities that we want to protect due to their value for society.

3.2 Area-of-Protection 'Resources'

A specificity when dealing with on-orbit space objects is the fact that the near-Earth space is not included as such in the ecosphere, which complicates the perception of environmental impact of spacecraft on their end-of-life. However, according to [7], damages into the AoP 'Resources' are characterized as a reduced accessibility/usability of the resource in the future. Moreover, an anthropocentric point of view should be adopted in order to assess environmental impacts dealing

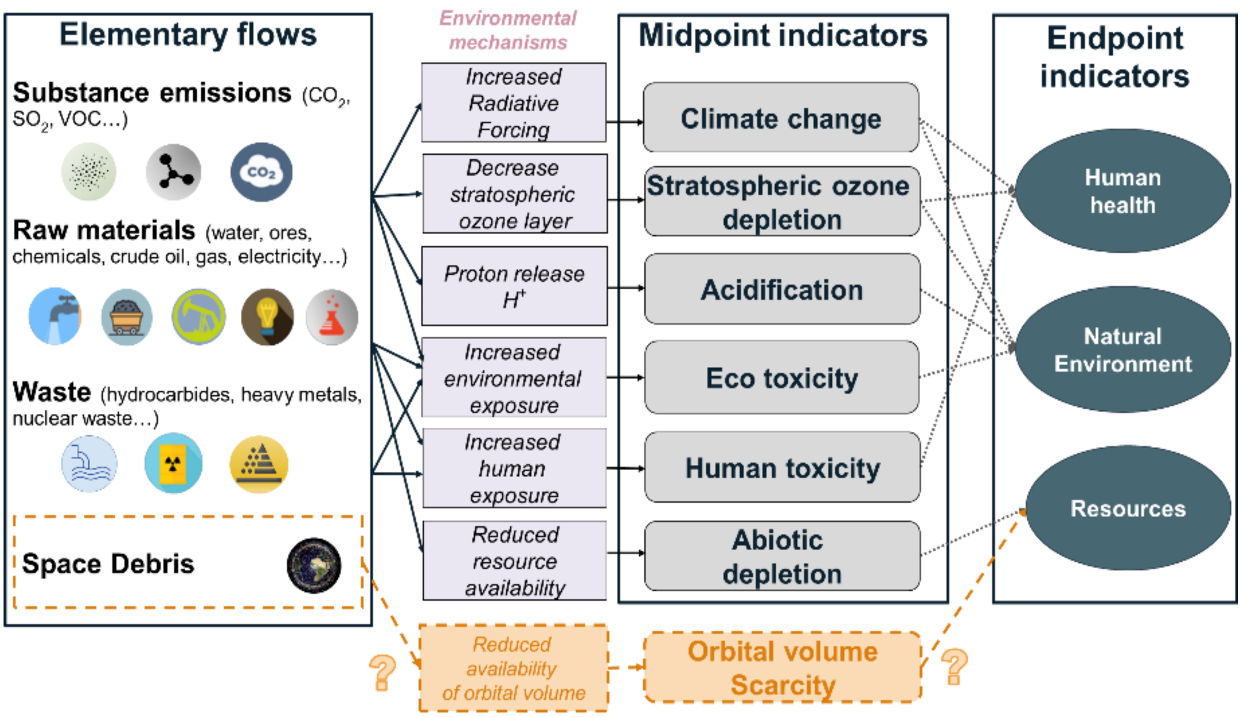

Figure 2. Towards an integration of space debris in the LCA framework

with ‘resource use’. In this way, most of the abiotic resources have only a functional value. It means that resources are seen as a support providing services to man-made environment and economy but do not have any intrinsic value [8]. This is in line with the current OECD vision considers “natural resources as natural assets (raw materials) occurring in nature that can be used for economic production or consumption” [9].

3.3 Considering orbital volume as a resource

The safeguards of operational space orbits, where man-made objects are launched, is a crucial approach to ensuring the services on Earth provided by satellites (e.g., communication, GPS, and earth observations). Hence, the functional value of the operating orbits is to support satellite activities that lead to the creation of economic value.

The presence of debris and dead spacecraft leads to a decrease of the orbital resource availability enhancing the risk of collision and then propagation of new clouds of debris. The lack of access to this resource in the future (scarcity) could be handled as environmental and socio-economic impacts. Consequently, we propose to characterize the impact of space debris through an impact pathway so that the potential damage at the Endpoint ‘resources’ can be assessed based on the reduction of the availability of the concerned orbital volume in the future.

4 IMPACT PATHWAY PROPOSAL

In order to create a new LCA indicator, a clear mechanistic link, described as an impact pathway (i.e. a causal chain), must be established. The structure is exposed hereafter in the Figure 3.

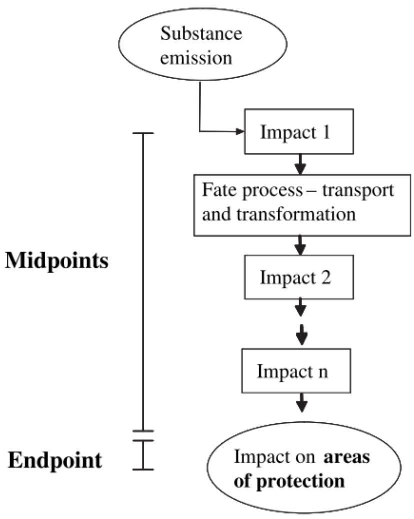

Figure 3. Schematic presentation of an impact pathway, as presented by [10]

We propose to characterize the impact of space debris through the pathway presented below (see Figure 5) so that the potential damage to the AoP ‘resources’ can be assessed based on the reduction of the availability of the concerned orbital volume in the future.

4.1 Life-cycle inventory and elementary flow

Several parameter categories listed in the Life Cycle Inventory (LCI) will directly contribute to the elementary flow: (i) orbital parameters of the space object provide the coordinates of the targeted orbit; (ii) the cross-sectional area of the object is a key design parameter used to estimate the occupied volume into the orbit; (iii) space debris mitigation parameters can be used to address the end-of-life scenario (i.e., natural decay or direct re-entry) and indicate the estimated lifetime of the space object in orbit.

Based on these inputs, the elementary flow can be represented as the product of the occupied orbital volume, over its lifetime into the targeted orbit, expressed in m^3*.years*. The overall on-orbit lifetime is covered by the nominal time of the mission (use phase) plus the time of the end-of-life phase (during which post mission disposal is performed).

4.2 Midpoint characterisation: ‘Orbital scarcity’

The operating orbits have to be considered as a support providing a functional value i.e. a ‘safe space’ for spatial activities. Space debris in the orbits reduces the availability of ‘safe space’ which increase the orbital scarcity.

Each orbit presents a different state of scarcity which allows to classify and differentiate them accordingly. Consequently, the overall useful volume can be divided in equal cells, each one with different scarcity levels. Two main physical approaches can be considered to characterise the scarcity in a local cell (Fig.4):

a) The space density, which is expressed as the number of space objects in a given volume cell. The unit is the number of debris per km^3. It depicts the availability at a given time of the targeted orbital volume. However, even into a ‘crowded’ orbital region, the order of magnitude of such orbital density is in average less than 1 object of 10 cm or more in a cube with sides measuring 100 km (i.e. 10^{-8} $object.km^{-3}$).
b) The flux of space debris, which represents the number of space debris passing through a targeted cell during a certain period of time. It is expressed as the number of debris divided by the crossed section during a certain period of time (i.e. $units.m^{-2}.year^{-1}$). This dynamic approach is justified by the large distance covered by a space debris in a short period

of time due to its velocity. Hence, it seems to be the more relevant option in order to characterise the scarcity.

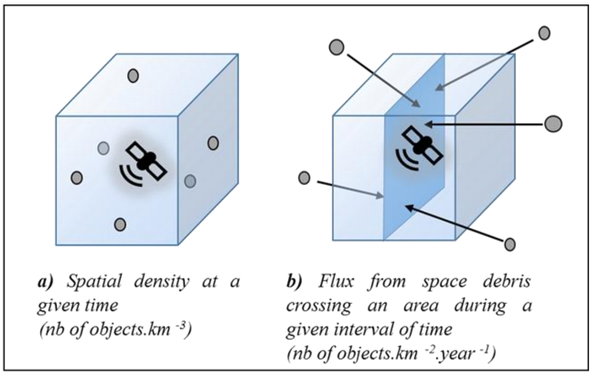

Figure 4. Physical approaches: spatial density versus flux from space debris

The presence of a new object coming from the space mission under study (i.e. upper stage, spacecraft or related-mission objects) will present a marginal change in term of occupied volume into an identified local cell.

Nevertheless, a collision may occur between the new targeted object and the flux of space debris crossing the occupied volume. The annual probability of collision during the on-orbit lifetime of the spacecraft has to be studied but also the consequences of this break-up in term of debris cloud propagation. If such events occur, the orbital regions will be durably and massively affected by the clouds of debris as shown by former events, as Iridium33-Cosmos2251 collision. In this case, non-marginal changes will affect the state of scarcity for other operational orbits.

4.3 Towards an endpoint characterisation based on the cost increase for space activities

If the availability of the targeted orbits becomes constrained, consequences occur in all areas of the supply chain. In the case of regular augmentation of the orbital population, the consequences should involve a substantial increase in the overall cost due to the space debris environment. The cost associated to space debris environment are linked to direct and indirect costs. An indirect cost is one that occurs due to having debris in orbit, but is not unique to the particular mission. Considering direct costs, if a collision occurs between an operational satellite and a debris element, leading to a partial or a total loss of functionality, a new mission must be re-planned to offset this loss. Additional consumption of energy and resources generating environmental impacts will result from the manufacturing of the new payload and the related launch campaign. In a global approach, these issue could lead to an overall increase in costs, not only in terms of access to space but also related to devices and services provided to society that require satellite data.

5 CONCLUSION

In this paper, we show the importance of integrating space use and space debris in Life Cycle Assessment. We propose a new framework for considering the use of

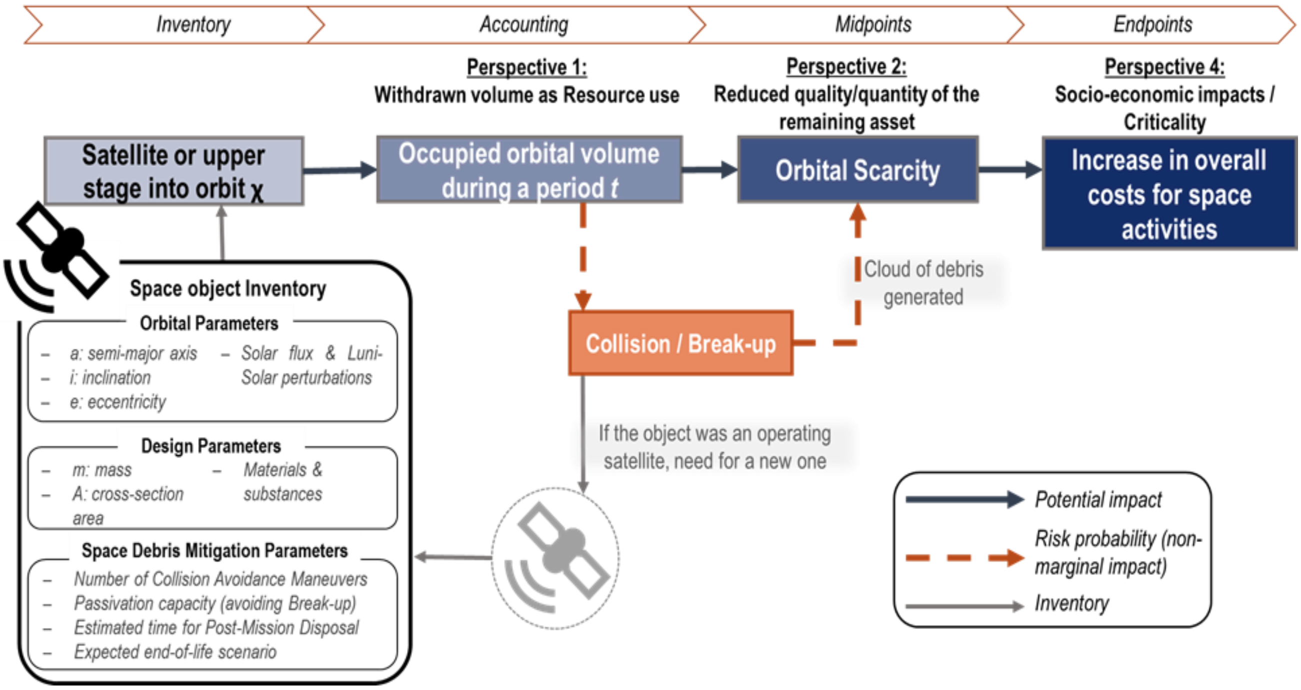

Figure 5. Impact pathway proposal

orbits in near Earth space for human activities. An impact pathway has been proposed.

In the next steps, the main parameters affecting the impact chain should be highlighted and then translated as potential factors characterizing compliance with the present framework. This development will broaden the scope of a classical LCA for space missions, introducing additional information at a design-phase level. In this way, the impacts of space missions during in-orbit lifespans of the space objects will be understood and can be compared among several case studies.

In this way, Airbus Safran Launchers is committed to the ESA Clean Space Initiative and contributes to the big challenge for space industry: keeping the competitive advantage for Europe and decreasing the environmental footprint on Earth and Space.

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