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Assessing component impairing at mission level

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Abstract

Whilst the amount of debris around the Earth steadily increases, the danger of collisions between debris and operating man-made space systems becomes a major issue. Whilst on the one hand fine physical simulation allows predicting accurately failure occurrences or manoeuvre consequences, and on the other hand fine behavioural models allow apprehending the services expected from a given system as an organisation of functions performed by various agents, it is difficult to have both approaches work together. This paper proposes a bridge between both approaches by developing a model describing in a unified way dependencies, redundancies, and interactions between physical components concurring to ensure elementary functions of a system, and shows how this approach was applied to the assessment of remedial measures to space debris issues for space assets.

Keywords: Space systems; System of systems; Performance assessment; Vulnerability assessment; Simulation exploitation

1. Introduction

Space debris, i.e. non-operating man-made objects found in orbit around the Earth, have increased since the beginning of space exploitation to a critical point where the space environment has become unstable and debris population grows by itself as the result of debris collision [18]. Fig. 1 shows a monthly average number of objects seen in Earth orbit, sorted by object type: active spacecrafts are in blue, mission or launching related debris in green and orange, and on top of that the purple curve shows fragmentation debris. The figure evidences the phenomenon of exponential growth of fragmentation debris, which make up the most part of objects in orbit. Since two catastrophic events in the late 2000s, awareness has increased about this major threat for operating man-made space systems, and several remedial measures to be enforced are been considered by major space actors so as to reduce space mission risk and ensure sustainable space activities. These measures rely on models of long-term debris environment evolution [26] coupled together with risk assessment tools.

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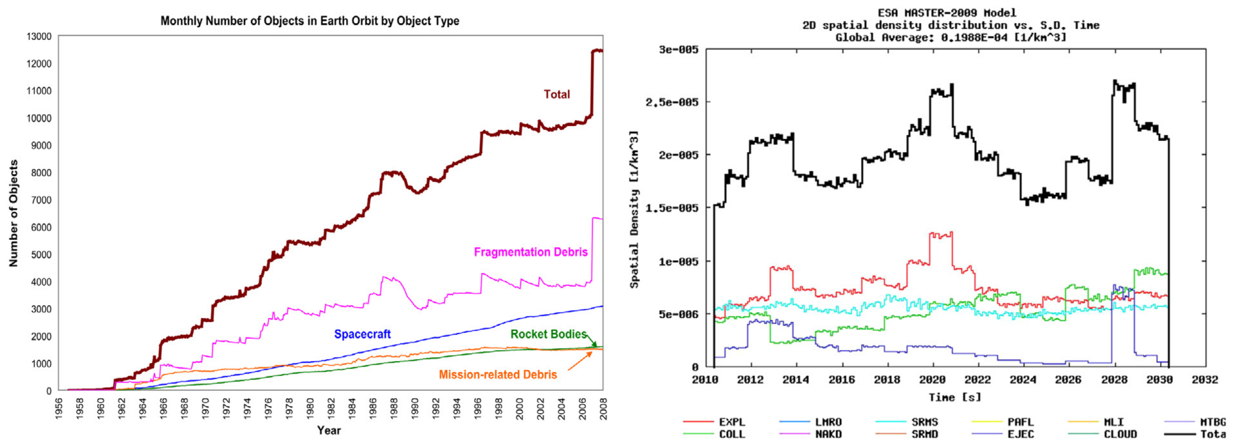

Fig. 1. Space debris: monthly number by type [20] (left) and density (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Projections using software MASTER [8], a debris flux simulation tool developed on behalf of ESA[1] and experimentally checked using data from ISS[2] maintenance, show that the steady growth of space debris in the past years is a tendency that will be kept in the future. Fig. 1 shows the monthly number of objects in orbit around Earth, with calculated previsions until 2030 (the total curve is particularly relevant here). The situation is particularly dire in orbits closest to Earth, where debris population has been increasing for more than 50 years of space activity. Recent simulations indicate that the in-orbit population, wracked by the Kessler syndrome, is instable and will grow for the next centuries [18]. Even with a 90% implementation of the commonly adopted mitigation measures, based on the initial population of 2009 provided by ESA, the debris population in orbits closest to the Earth is expected to increase by an average of 30% in the next 200 years [19].

The physics of the phenomenon is well-understood and allows producing fine simulations and credible projections confirmed by feedback information coming from servicing missions on existing space systems (e.g. returned parts of Hubble's solar panels after space repair [12]) or from observed effects on the satellite or on its trajectory – e.g. impact on Jason-1 deduced from attitude and electrical current disturbances [21] – or, for larger debris, from Earth observation and debris cataloguing. This leads to fine simulations such as MASTER 2009, which provide detailed information on debris fluxes (and is the source for the data on Fig. 1), which can in turn be used as an input to physical simulations assessing the effects of debris.

However, this evaluation is to be performed at several levels, with different methods each implementing a different physics and extremely varied effect models. Hence, obviously, the exploitation of this knowledge is not easy at all, especially with the purpose of providing recommendations about the future effects of the various remedial measures that can be considered [25]. In order to address this issue, an important aspect to be taken into account is the mission of the system, i.e. more specifically the services provided by the system to its users or customers on the ground. Indeed, the availability of these services throughout time is the only criterion that can be used to compare objectively the effects of various debris issues and various remedies.

Such methods have been discussed in previous works [4,13–15], where the ATLAS[3] approach is presented. It relies on a modelling of the behaviour of the system leading to the service being provided to the ground by a temporal logic of the interval family [9,10,27] based on Allen's operators [1,2], leading to a logic tree describing the organisation of the different elementary functions of the system, over which an availability metric is computed, allowing the computation of a vulnerability index [3,7,11,16], which defines a risk of mission performance degradation due to effects of both trackable and untrackable space debris on a complex space system [17].

The purpose of this research is to connect these two different fields of expertise: on the one hand, there exist fine physical simulations providing a good knowledge of the way components evolve in their environment and information

[1] European Space Agency.
[2] International Space Station.
[3] Analysis by Temporal Logic of Architectures of Systems.

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