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Advances in Space Research 57 (2016) 1652–1663

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Analysis of the consequences of fragmentations in low and geostationary orbits

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Received 25 March 2015; received in revised form 6 May 2015; accepted 24 May 2015
Available online 29 May 2015

Abstract

The present distribution of intact objects is a good proxy to quantify the catastrophic collision risk and consequences in the coming decades. The results of a large number of long term simulations of the LEO environment perturbed by the collisional fragmentation of massive objects are used to identify the main driving parameters of the long term collisional evolution of the debris population and measure the danger represented by "typical" classes of space objects. An evaluation norm, able to highlight the differences between comparative long term evolution scenarios and to give a quantitative measure of the effects of specific parameters affecting the evolution, is devised. It is shown how, for collisional fragmentations in LEO, due to the highly stochastic evolution of the LEO environment, even the fragmentation of a massive spacecraft might not be able to alter the long term evolution of the LEO population beyond the intrinsic statistical variability associated with the Monte Carlo procedure. Among the parameters determining the long term effects of a collisional fragmentation in LEO, a combination of mass and altitude of the event appears to be the driving factor. In GEO, the situation is different, and the addition of a massive fragmentation lives a signature on the environment that is detectable throughout the investigated time span, with the mass being the only factor important to asses the long term consequences of a collisional fragmentation.

Keywords: Space debris; Fragmentations; Long term evolution

1. Introduction

The present distribution of intact objects is a good proxy to quantify the catastrophic collision risk and consequences in the coming decades. For this reason, it is important to understand the effects of selected "typical" collisional fragmentations on the long term evolution of the debris population, as a function of the main driving parameters, with the goal of measuring the danger represented by "typical" classes of space objects. To tackle this problem, the European Space Agency (ESA/ESOC) financed a contract, named *Assessment Study for Fragmentation Consequence Analysis for LEO and GEO Orbits* foreseeing a large number of long term simulations to analyze the effects on the circumterrestrial environment of many different collisional fragmentations.

All the long term simulations were performed using either SDM 4.2 (Rossi et al., 2009) or DAMAGE (Lewis et al., 2012). They are two well known long term evolution codes, developed in Italy (SDM) and in the United Kingdom (DAMAGE) in the last decades. The two codes allow a very detailed and accurate modeling of the debris environment in Earth orbit, taking into account all the

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http://dx.doi.org/10.1016/j.asr.2015.05.035
0273-1177/

main sources and sinks terms affecting the future evolution of the debris population. As a validation, the two models were subject to several international comparisons with similar software suites developed by other research groups and space agencies worldwide, both within the framework of the Inter-Agency Space Debris Coordination Committee (IADC) studies (Liou et al., 2013) and also in the course of the study presented here. In the following, both results obtained with SDM 4.2 and with DAMAGE will be shown alternatively, where deemed significant.

2. The simulation strategy and the Reference scenario

The main simulation strategy consisted in comparing the long term evolution results of a Reference scenario with those of a number of scenarios where a number of different spacecraft were supposed to collisionally fragment in selected epochs. That is, in the long term runs, at the selected epochs a given spacecraft was "artificially" fragmented by a simulated collision and the clouds of fragments were added to the simulation. Comparing the long term evolution in the cases with and without the additional fragments generated by the artificially introduced fragmentation, the effect of the particular fragmentation on the environment was evaluated.

As a reference, a long term evolution scenario was simulated for a time span of 200 years. With Reference scenario, we mean that the traffic launch repeats an 8-year cycle representing the current launch pace, that is the new launched objects are inserted into orbits similar to those populated in the recent past. An 8-year operational lifetime is assumed for future spacecraft, no new explosions are considered and no avoidance maneuvers are performed. A post mission disposal scenario according to the 25-year rule is adopted, with a 60% compliance to this rule. That is, given all the spacecraft that do not re-enter naturally in 25 years, only 60% of them are actually de-orbited at end-of-life. The above assumptions are common to most of the recent studies of the long term evolution of the space debris population. As in most of the modeling works, there are of course uncertainties related to these assumptions, e.g. the traffic launch cannot be predicted accurately for 200 years in the future, as well as the solar activity, etc. Nonetheless the above assumptions represent good, standard hypotheses that are well suited to produce an "average" reliable future environment appropriate for the purpose of the present study. The Reference scenario was simulated with 50 Monte Carlo (MC) runs both with SDM and DAMAGE and the results were compared, in order to have a reliable Reference scenario against which the fragmentations cases could be compared. In all the simulation the objects larger than 10 cm are considered. Whereas particles smaller than 10 cm can, in some peculiar cases (i.e., small targets and high impact velocities), generate catastrophic fragmentations, it was observed in previous studies that the long term collisional evolution is mainly driven by the objects larger than 10 cm that can generate large debris clouds, upon fragmentation of large targets.

Figs. 1 and 2 show the main results for the Reference scenario. The left panel of Fig. 1 shows the average number of objects larger than 10 cm in LEO with SDM (thick blue line) and DAMAGE (thick red line), along with the respective 1-sigma curves (thin lines). It can be noticed how the two codes give remarkably comparable results after the long term evolution, with both averages lying well within the 1-sigma bars of the other model. This gives a clear indication that the two models can be used alternatively in the course of the study, leading to comparable and reliable results. The small jump in the blue line around the year 2115 is due to a chance accumulation of large fragmentations happening around that epoch in a few MC runs.

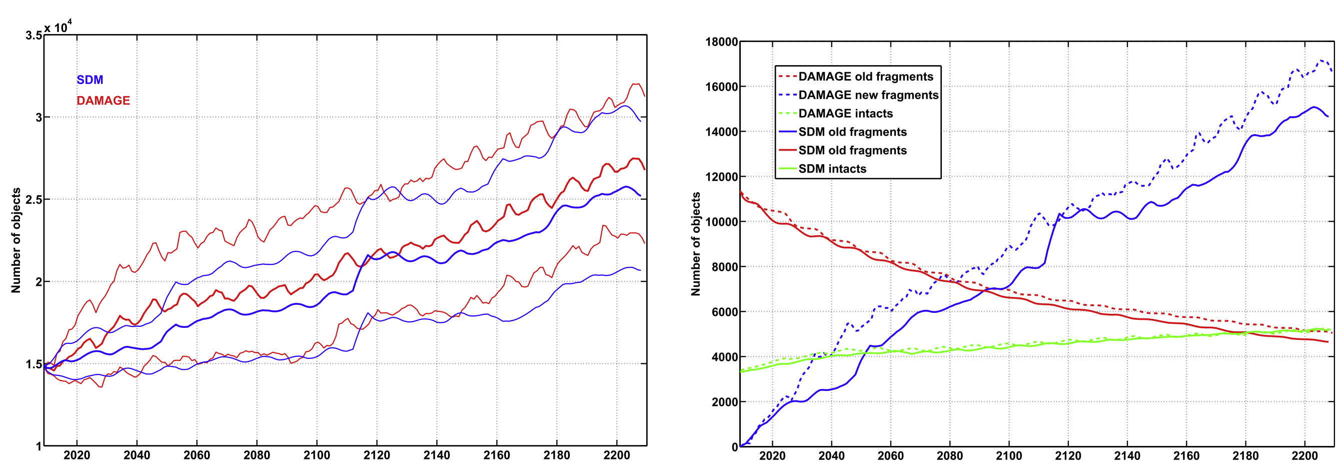

Fig. 1. Left panel: average number of objects larger than 10 cm in LEO in the Reference scenario computed with SDM (blue thick line) and DAMAGE (red thick line). The thin lines (of the corresponding colors) show the 1-sigma uncertainty intervals for both codes. Right panel: Breakdown of the population according to the type of objects: the green lines refer to the intact objects, the red line to the fragments already present in the environment at the 2009 initial epoch and the blue line shows the fragments produced during the simulated time span. The solid lines show the results of SDM while the dashed lines show the results of DAMAGE. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)