Acta Astronautica 127 (2016) 482–490

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/aa

# Comparing long-term projections of the space debris environment to real world data – Looking back to 1990

Jonas Radtke*, Enrico Stoll

*Institute of Space Systems, Technische Universität Braunschweig, Hermann-Blenk-Str. 23, 38108 Braunschweig, Germany*

ARTICLE INFO

*Article history:*
Received 22 February 2016
Accepted 18 June 2016
Available online 21 June 2016

*Keywords:*
Space debris
Long-term evolution

ABSTRACT

Long-term projections of the space debris environment are commonly used to assess the trends within different scenarios for the assumed future development of spacefaring. General scenarios investigated include business-as-usual cases in which spaceflight is performed as today and mitigation scenarios, assuming the implementation of Space Debris Mitigation Guidelines at different advances or the effectiveness of more drastic measures, such as active debris removal. One problem that always goes along with the projection of a system's behaviour in the future is that affecting parameters, such as the launch rate, are unpredictable. It is common to look backwards and re-model the past in other fields of research. This is a rather difficult task for spaceflight as it is still quite young, and furthermore mostly influenced by drastic politic changes, as the break-down of the Soviet Union in the end of the 1980s. Furthermore, one major driver of the evolution of the number of on-orbit objects turn out to be collisions between objects. As of today, these collisions are, fortunately, very rare and therefore, a real-world-data modelling approach is difficult.

Nevertheless, since the end of the cold war more than 20 years of a comparably stable evolution of spaceflight activities have passed. For this study, this period is used in a comparison between the real evolution of the space debris environment and that one projected using the Institute of Space System's in-house tool for long-term assessment LUCA (Long-Term Utility for Collision Analysis). Four different scenarios are investigated in this comparison; all of them have the common starting point of using an initial population for 1st May 1989. The first scenario, which serves as reference, is simply taken from MASTER-2009. All launch and mission related objects from the Two Line Elements (TLE) catalogue and other available sources are included. All events such as explosion and collision events have been remodelled as close to the reality as possible and included in the corresponding population. They furthermore have been correlated with TLE catalogue objects. As the latest available validated population snapshot for MASTER is May 2009, this epoch is chosen as endpoint for the simulations.

The second scenario uses the knowledge of the past 25 years to perform a Monte-Carlo simulation of the evolution of the space debris environment. Necessary input parameters such as explosions per year, launch rates, and the evolution of the solar cycle are taken from their real evolutions. The third scenario goes a step further by only extracting mean numbers and trends from inputs such as launch and explosion rates and applying them. The final and fourth scenario aims to disregarding all knowledge of the time frame under investigation and inputs are determined based on data available in 1989 only. Results are compared to the reference scenario of the space debris environment.



## 1. Introduction

Long-term projections of the space debris environment are commonly used to assess the trends within different scenarios for the assumed future development of spacefaring. A generic flow chart of long-term projections of the space debris environment is shown in Fig. 1.

The most common approach for these is to start using a deterministic initial population valid for a certain epoch. Simple populations based on the TLE catalogue or populations created for statistical space debris environment models, such as MASTER-2009 [4] or Ordem 3.0 [10], are mostly used. For the future evolution of this population, models for all important effects are needed. These include the long-term trajectory propagation, a model for the atmospheric density, an algorithm to calculate the collision probability, and a model to generate debris from fragmentations. Most prominent models for the collision probability

* Corresponding author.
*E-mail address:* j.radtke@tu-braunschweig.de (J. Radtke).

http://dx.doi.org/10.1016/j.actaastro.2016.06.034
0094-5765/

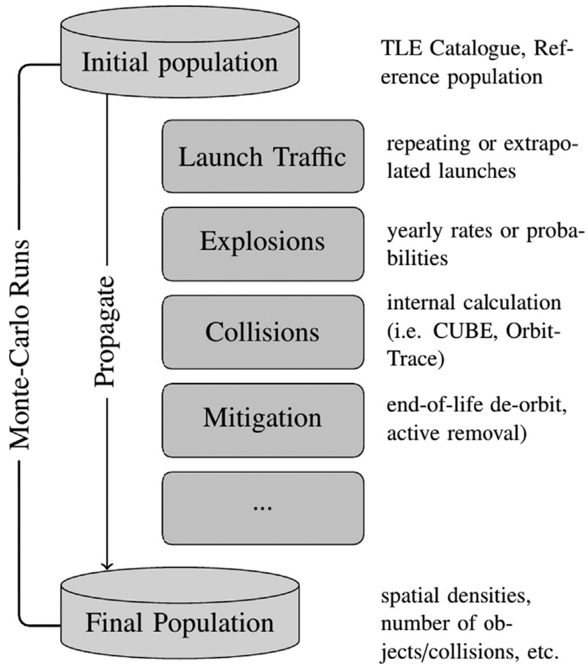


**Fig. 1.** Generic flow chart of long-term projections of the space debris environment.

calculation are NASA's CUBE algorithm [13] and the Orbit-Trace method, based on an approach described in Öpik [27]. For the generation of debris objects from a fragmentation, the most widespread model is the NASA Break-Up model [6].

All these models require input data, which for the future evolution need to be assumed. These data include the initial population, physical parameters such as the evolution of the solar activity, but also scenario specific parameters, such as assumptions for a future launch traffic (meaning how many objects of which type are launched into what kind of orbit), the probability of explosion for a certain type of object, the implementation of Space Debris Mitigation Guidelines (SDMG), and the application of measures, such as Active Debris Removal (ADR). The initial population is projected into the future. To account for uncertainties in the modelling process, especially in the trajectory propagation, events in the future are performed randomly. A collision, for example, is triggered by a random number draw compared to an internally calculated collision rate. This can be applied to other parameters, for example to the orbital parameters of objects launched in the future or to the evolution of the solar activity.

The single simulations are performed in the frame of many Monte-Carlo runs. Depending on the models used and the scenarios to be investigated, the number of runs can vary between some tens to several hundreds. Models like these are in wide use throughout international space agencies. Well known models include the Italian SDM code [21], the British Damage [12], ESA's Delta [15], NASA's LEGEND [14], CNES' MEDEE [2] and IRAS' LUCA, the tool used in the frame of this study [17].

As there are many model parameters with partly high uncertainties involved, the simulation results are usually used to assess the effectiveness of certain events or measures on the space debris environment. Example for events can be the inclusion of fragment clouds from certain events [19] or the impact of performing active debris removal [5]. As the effects of some of these events and measures are clearly below the statistical variations of the produced results, in recent years the idea came up to investigate the uncertainties of all single modelling and input parameters and from this to gain a better insight on the overall uncertainties of the projections. First studies on these have been presented in Dolado-Perez et al. [1] and Virgili et al. [24].

## 2. Approach

This paper does not aim at investigating the uncertainties in the simulations, but rather at assessing whether the current approach for the simulations is capable of predicting today's space debris environment when reproducing the 20 years of spaceflight between 1998 and 2009. This time frame has been chosen for several reasons: Firstly, during this time span the impacts of predicted assumptions can be seen and several events happened during this time-frame. Secondly, with the collapse of the Soviet-Union in 1991, a drastic change in the overall space flight was introduced, which shall not be investigated in the frame of this paper. And lastly, the latest validated MASTER reference population exists for May 2009, which can conveniently be used as the reference for the performed study. Overall, this paper is arranged as follows: At first, an overview of the required input parameters for the space debris environment modelling is given. Following, based on the described input parameters, four different approaches for the simulation are shown:

1. A deterministic approach, for which all events in the space debris environment are covered exactly as they were performed. This is done using MASTER-2009 [4].
2. One semi-statistic scenario, simulated with LUCA, in which all Launch and Mission Related Objects (LMRO) are considered based on catalogue data. The number of explosions are identical to the real numbers but the types and objects are chosen randomly. Collisions are computed internally and performed randomly.
3. One smoothed scenario, simulated with LUCA, in which the whole population is build from initial populations in May 1989. The number of objects launched per year is real, as the evolution of the solar activity. A mean rate over the years has been used for explosions; collisions are again calculated using the internal routine.
4. Two extrapolated scenarios, simulated with LUCA, in which only parameters as known in the beginning of the 1990s were taken into account. All other parameters, such as the launch traffic and the evolution of the solar activity, are projected based on data available at that time.

Basically, the real parameters driving the long-term evolution are neglected step-by-step and replaced by the data that was available in 1989.

All simulations with LUCA have been performed using 48 Monte-Carlo runs. All input parameters are summarised in Table 1.

## 3. Historic evolution of the input parameters

To project the evolution of the space debris environment, next to the physical models, which will not be explained in more detail at this point, several parameters drive the long-term evolution of the space debris environment. In this paper, the following ones will be considered:

**Table 1**
Sources for inputs of the different scenarios.

| Input | Reference | Semi-statistic | Smoothed | Extrapolated |
|---|---|---|---|---|
| Population | MASTER-2009, May 1st 1989 | | | |
| Sol. Act. | Real | | | Prediction |
| Launches | Catalogue | | Mean trend | Extrapolated |
| SDMG | Catalogue | | Real | none |
| Explosions | Real events | Real number | mean trend | Extrapolated |
| Collisions | Real events | Calculated and triggered internally | | |