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Decay and Re-Entry Analysis of Space Debris

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ABSTRACT

This contribution gives an overview of some activities and results obtained within the framework of several research projects on the analysis of space debris propagation and decay, and atmospheric re-entry. Different approaches have been applied to perform sensitivity analyses and quantify the uncertainties related to the re-entry time (decay analysis), as well as the impact point and the associated casualty risk (atmospheric re-entry analysis).

Within the framework of the decay analysis, the work to characterize and propagate the uncertainties on the atmospheric re-entry time of the GOCE (Gravity field and steady-state Ocean Circulation Explorer) satellite, done with the framework of an ESA ITT project, is presented [1, 2]. Non-intrusive techniques based on Chebyshev polynomial approximation, and the Adaptive High Dimensional Model Representation multi-surrogate adaptive sampling have been used to perform uncertainty propagation and multivariate sensitivity analyses when both 3 and 6 degrees-of-freedom models were considered, considering uncertainties on initial conditions, and atmospheric and shape parameters. Two different uncertainty quantification/characterization approaches have been also proposed. In this case, the same surrogate approaches previously used for uncertainty propagation allowed the development of the Boundary Set Approach and the Inverse Uncertainty Quantification. Moreover, the use of meta-modelling techniques to obtain a very fast characterisation of the probability density function of the atmospheric re-entry time of satellites and space debris, when a range of initial conditions and model uncertainties, as well as characteristics of the object are considered, has been investigated [3]. Two meta-modelling approaches have been considered and preliminarily tested. The first approach directly maps the initial and model uncertainties, as well as the characteristics of the considered object and the characteristics of the atmosphere, into the parameters of the skew-normal distribution that characterises the re-entry time windows. The second approach maps the initial conditions, the atmospheric and object characteristics into the re-entry time and a probability density function of the re-entry time is built via Monte Carlo sampling of the achieved meta-model.

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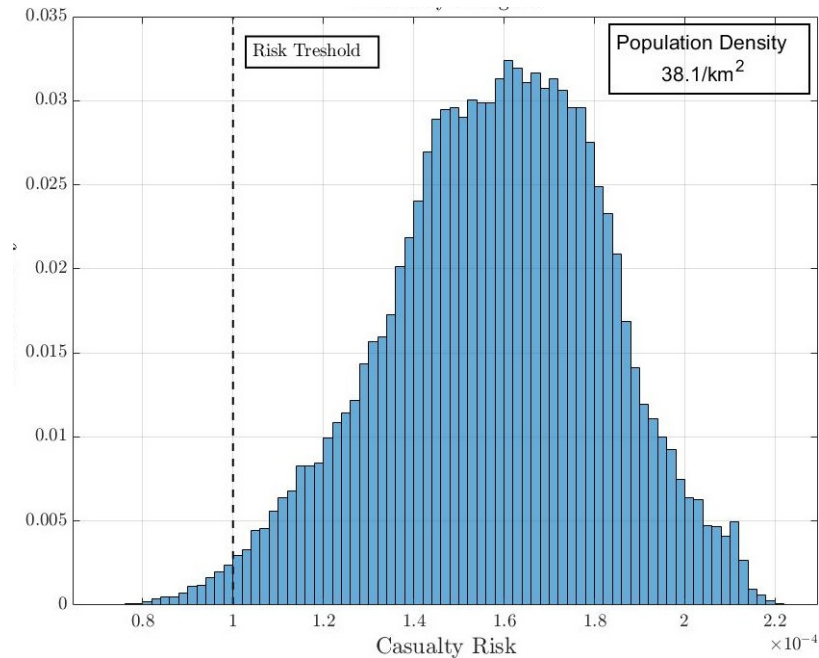


Figure 1: Histogram of the averaged population density casualty risk

Within the framework of the atmospheric re-entry analysis, since well-known tools developed for satellite and debris re-entry perform break-up and trajectory simulations in a deterministic sense and do not perform any uncertainty treatment, we have developed and proposed surrogate based methods for the efficient probabilistic analysis of atmospheric re-entry cases. Both aleatory and epistemic uncertainties that affect the trajectory and ground impact location are considered [4, 5]. The method is applicable to both controlled and uncontrolled re-entry scenarios, and the results show that the resulting ground impact distributions, both with and without fragmentation, are far from the typically used Gaussian or ellipsoid distributions. The approach, when combined with information such as the population density, can directly give the statistical analysis of the re-entry casualty risk as defined by the guidelines proposed by the IADC, NASA, and ESA (see Figure 1) [6].

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