4th International Workshop on Space Debris Re-entry

Uncertainty Dispersion Analysis of Atmospheric Re-Entry

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Abstract

The re-entry of man-made objects is more and more of interest. The prediction of possible impact zones and its dispersion is necessary to evaluate the risk and the possibility of unforeseen occurrences and prevention measures. When analysing the re-entry into Earth's atmosphere one must consider that it is subjected to specific uncertainties. These uncertainties derive from the model of the atmosphere as it depends on measurements from one particular day or period and is only an approximation. Additionally the landing dispersion depends on the chosen initial conditions e.g. altitude, velocity and flight path angle of the re-entry as well as on the approximated spacecraft parameters for its aerodynamic behaviour.
Conventionally, for this purpose a Monte-Carlo dispersion analysis is executed, simulating a large number of trajectories using a random sampled set of initial conditions and parameters, to predict a landing zone and a landing dispersion. A more computational efficient way is to utilise the Stochastic Liouville Equation. By this method, the temporal evolution of given dynamics is analysed using a given distribution in the initial conditions and parameters, resulting directly in probability density functions stating the probability over time of each state of the dynamics. Since all statistical moments are preserved in the probability density function, the covariance matrix at the end time of the re-entry can be derived, which in this case specifies the dimensions of the landing ellipse.
Main focus is laid on the introduction of the Stochastic Liouville Equation and its characteristics as an alternative for the Monte-Carlo analysis. Additionally some exemplary simulation results for the ballistic re-entry of an uncontrollable object into Earth's atmosphere are presented.

Keywords
Re-Entry, Uncertainty Estimation, Landing Ellipse, Stochastic Liouville Equation

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