Paper ID: 41062
oral
student

ASTRODYNAMICS SYMPOSIUM (C1)
Orbital Dynamics (2) (9)

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VERIFICATION OF PLANETARY PROTECTION REQUIREMENTS WITH SYMPLECTIC METHODS AND MONTE CARLO LINE SAMPLING

Abstract

The uncertainty over the orbit of an interplanetary spacecraft or an upper launcher stage may cause impacts with Earth or another celestial body within a period of 50-100 years. The probability of these events can be significant enough to represent a risk for human activity or biological research. Planetary protection requirements have been created to set an acceptable limit to the impact probability estimated during the mission design phases.

Due to the long propagation times, numerical errors may build up and make the representation of the spacecraft state unreliable, especially with strongly non-linear dynamics. The quality of the numerical integration is commonly improved by using high order methods, but more efficient integration schemes may be necessary to ensure a sufficient long term accuracy. The estimation of the impact probability is usually performed via Monte Carlo Simulation methods, where the use of a sufficiently large number of propagations ensures an accurate approximation, but at the cost of very intense computational efforts. Improved simulation techniques are thus required to obtain robust estimations with a reduced number of input samples and integration time.

This paper proposes a different approach to improve numerical propagation and probability sampling in planetary protection analysis. The starting point for this research is the SNAPPshot tool suite for the verification of the compliance to planetary protection requirements developed at the University of Southampton in the framework of an ESA study. In our work, an improved accuracy of the numerical solution and a qualitative behaviour closer to the actual evolution of the dynamic system are obtained by introducing symplectic integration methods, which include conservation of prime integrals in their definition, and additional energy-preserving schemes. Impact probability is instead estimated more efficiently with the use of Line Sampling by solving a lower number of one-dimensional integrals along an "important direction" pointing toward the impact region of the uncertainty domain.

These two improved approaches to planetary protection analysis will be explained, and applied to different interplanetary mission cases to show their performance in terms of accuracy and computational cost. Some study cases are chosen among the ones already considered in [1], to perform a comparison with some reference results. Additionally, the application to JUICE ESA mission will be showed as a mission with very sensitive orbital dynamics and therefore very demanding planetary protection analysis.

[1] Letizia, Van den Eynde, Colombo, "SNAPPshot. ESA planetary protection compliance verification software. Final report", ESA 2016