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ROBUST OPTIMISATION OF NEO DEFLECTION STRATEGIES UNDER MIXED ALEATORY AND EPISTEMIC UNCERTAINTY

Abstract

This paper proposes a method for the robust optimisation of a number of Near Earth Object (NEO) deflection strategies under a mix of aleatory and epistemic uncertainty. The developments in this paper extend previous work by the authors in two important directions: it provides a unified framework for the treatment of aleatory and epistemic uncertainty; it optimises the robustness of multiple-deflections strategies to avoid both a direct impact and resonant returns. The former extension is key to account for realistic models of uncertainty in the physical properties of NEOs, while the latter is fundamental to understand the uncertainty introduced by deflection technologies.

In the planning phase of a deflection mission, there is a considerable amount of uncertainty that affects decisions. This uncertainty is mostly epistemic as it comes from the incomplete knowledge of the physical properties of NEOs and of the effectiveness of the deflection technologies. Therefore, early decisions require accounting for this epistemic uncertainty and cannot rely uniquely on the estimation of the impact probability. This paper addresses the effect of mixed aleatory/epistemic uncertainties on the performance of six different NEO deflection strategies: Nuclear Interceptor, Kinetic Impactor, Laser Ablation, Gravity Tractor, Ion Beaming and Smart Clouds. The last strategy is a Kinetic Impactor fractionated into multiple ones that hit the NEO nearly at the same time. This technique reduces the risk of failure and of unwanted outcomes of the deflection action in the case of loosely cohesive bodies.

The paper will first introduce a model of the epistemic and aleatory uncertainty in the physical properties of NEOs and the deflection methods. Then it will present a robust optimisation, under mixed aleatory/epistemic uncertainties, of a sample of deflection scenarios. Two robust performance indices will be considered: the impact probability of post-deflection and the corresponding confidence on the successful execution of the deflection, where the confidence comes from the degree of epistemic uncertainty on both deflection strategy and NEO properties.

The deflection achieved by slow-push techniques will be calculated with an analytical solution of the perturbed Keplerian motion. The uncertainty quantification will be achieved by first building a surrogate of the deflection states and then using an adaptive sampling of the surrogate to compute the post-deflection impact probability and the associated confidence interval. A robust min-max optimisation technique will then be applied to minimise the post-deflection impact probability by acting on the system level parameters defining the deflection technology.