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Analysis of Novel Concepts for the Return of Upper Rocket Stages

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Abstract
With the significant rise in the number of orbital rocket launches by about 15% or more annually in the next decades, not including space tourism, the risk of collisions with uncontrolled space objects in certain orbits increases. Solutions include removing existing objects and modifying future missions. Concepts for space debris disposal involve destructive reentry, but this may not be sustainable as it prevents reuse or recycling and can cause environmentally and climatically harmful effects, such as damage to the ozone layer [1,2]. However, sustainability and ecological impact are becoming important issues in the space industry. Also, large space structures like upper rocket stages, which make up half of debris-generating objects, burn incompletely in 5-40% [3] of cases when performing uncontrolled re-entry, which can end up either in disposal over the sea or as a serious hazard on the ground.

A shift to non-destructive, controlled re-entry of spacecraft systems after use by using appropriate entry, descent and landing systems (EDL) represents a solution to the aforementioned problem. In addition, this would also be a first decisive step towards at least partial reusability, which is of great economic importance especially for upper stages [4].

One approach for such a non-destructive system is a deployable entry system, that uses deployable surfaces to generate air resistance for controlled entry and as a heat shield. Deployable systems allow for new trajectories with reduced maximum loads, improved decent control and low power consumption. Additionally, they provide high flexibility for integration into existing transport system. While inflation-deployable systems such as HIAD [5] or KLAUS [6] are relatively well developed and are also being researched for the return of upper stages, rigidly deployable systems such as ADEPT [7] have not yet been investigated for disposal missions. However, the deployement of rigid structures may have advantages through potential synergies with existing structures or successive unfolding processes for trajectory optimisation. This study discusses, based on a technology review, the suitability of rigid deployable entry systems for such disposal missions. Existing approaches for rigid deployable entry systems are analysed and system- and design-parameters are discussed, that may be beneficial for optimising the trajectory. Furthermore, the review results are used in the development of a numerical tool for mission analysis of deployable entry systems for disposal missions. Based on this study, the potential of rigid deployable entry systems for disposal missions can be evaluated and possible design approaches can be identified.

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