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MULTI-DISCIPLINARY DESIGN AND TRAJECTORY OPTIMISATION OF A SINGLE-STAGE-TO-ORBIT VEHICLE

Abstract

The Single-Stage-To-Orbit (SSTO) vehicles represent an alternative to the more conventional expandable launchers as a means to carry payload and crew into space. By emphasizing on full re-usability in their design and employing an airline-like approach, where the costs of development are amortized over repeated flights, these vehicles promise to dramatically reduce the cost per kilogram of access to space. However, the design process for this new generation of space-access vehicles is complex and involves various coupled disciplines. An integrated multi-disciplinary approach is thus paramount in order to accurately evaluate their performance at the lowest computational costs. The overarching aim of the research described in this paper is to develop an automated multi-disciplinary design and optimisation tool that will aid in the preliminary design of the next generation of vehicles flying at hypersonic speeds. This paper outlines the application of the aforementioned design tool to the un-powered re-entry phase of a complex geometry, named cFASTT-1, which is representative of future winged-hypersonic vehicle configurations. In the present work, a trajectory optimiser has been coupled with a reduced-order aerothermodynamic model dubbed HyFlow. HyFlow is an engineering-level tool for predicting the surface pressure and aero-heating of three-dimensional complex hypersonic vehicle configurations immersed in either continuum or rarefied flows. The code has been successfully validated against experimental data, CFD and DSMC analyses. HyFlow can predict the aerodynamic forces, moments and convective heating required for the design of an optimal re-entry trajectory. This lower fidelity approach is computationally less expensive than numerical simulations and cuts the computational time down to a level suitable to foresee its integration within a trajectory optimisation loop. An optimal control strategy is applied to the re-entry phase of the cFASTT-1 vehicle. During the re-entry, the control has to steer the vehicle on a feasible trajectory, constrained by acceleration and controllability limits. A multi-objective optimisation on a re-entry atmospheric phase is performed to minimize the maximum heat flux around the stagnation point, and to minimize the peak heat load. The control laws, which optimise the trajectory, are the angle-of-attack and the bank angle. Operational constraints on the load factor are also taken into account. The used optimisation technique is based on a mixed formulation which combines a population-based stochastic algorithm with a deterministic gradient-based method. Future extensions of the tool include the definition of a sophisticated propulsion model and a shape optimisation loop.