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CONVERSION OF A TWO-STAGE EXPENDABLE ROCKET INTO A REUSABLE SYSTEM AND ANALYSIS OF ITS RE-ENTRY DYNAMICS

Abstract

The recent trend to increase space access is to be coupled with the economic and environmental sustainability of space activities, thus driving the aerospace industry towards innovative solutions. Among these, Reusable Launch Vehicles (RLVs) emerged as promising contenders, addressing both economic and environmental concerns. This work deals with a preliminary study aimed at assessing the feasibility of converting a two-stage Expendable Launch Vehicle (ELV) into an RLV by recovering its first stage. Taking SpaceX's Falcon 9 as a benchmark, the study implements three retro-propulsion maneuvers: the first one (boost-back burn) is used for adjusting the velocity components of the first stage to desired values after the separation of the second stage; the second one (entry-burn) brakes the first stage free fall into the atmosphere; the third one (landing burn) achieves vertical landing with almost zero speed. A constraint-optimized redesign algorithm, integrating mass, structural coefficients, and velocity variations, is proposed alongside a comprehensive re-entry dynamic analysis. The analysis, employing a 2-D motion model of the first stage, incorporates four fixed fins acting as passive stabilizers at the top of the stage, and selects how many engines must ignite to optimize thrust (aligned to the body axis of symmetry) during retro-propulsion maneuvers. Mission-specific data, such as nominal payload and insertion orbit, are essential inputs for the algorithms, which output estimates for additional structural mass required for re-entry and landing mechanisms, propellant needs for retro-propulsion maneuvers, and updated payload mass. By optimizing ignition timing based on descending Mach number and altitude, the study identifies the most effective sets of altitude-Mach numbers for the minimization of the propellant. Iterative refinement ensures convergence of the output values. Additionally, a thermal model is developed to assess thermal loads on the external structure during re-entry, with particular emphasis on the effect of the retro-propulsion maneuvers and on the hot gasses produced by them. The study culminates in the development of a versatile code capable of conducting preliminary analyses for first-stage redesign and re-entry. This versatility permits to extend the approach to the selection of different reference missions based on total velocity requirements, according to the rocket fundamental equation, as well as to the evaluation of different retro-propulsion maneuvers to assess mechanical and thermal loads, providing a robust background for future investigations.