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DESIGN AND MULTI-OBJECTIVE OPTIMIZATION TOOL FOR THE PRELIMINARY DEFINITION OF EXPENDABLE AND REUSABLE LAUNCH VEHICLE ARCHITECTURES

Abstract

The design of a good preliminary launch vehicle architecture is the first step that allows to start a complete system loop during which all the details of the launch vehicles are deeply analyzed. Various approaches have been used in this field to obtain preliminary design. Firstly, it is necessary to generate a candidate architecture which can satisfy specific high-level requirements, such as nominal performance in a reference orbit which is assumed as the sizing requirement in this work. The design and the optimization of the configuration can be performed adopting several approaches. A possible solution design can be carried out minimizing the structural mass or the product recurring cost. Given that the main objective of this work is to satisfy the performance high-level requirement another approach is adopted. This is based on payload mass maximization, which allows to maximize the LV performance while the Gross Lift-Off Weight is minimized. This double objective leads to select a multi-objective optimization approach based on global search optimization algorithms (Differential Evolution and Multi-Swarm PSO). The optimal results will lay on a curve (i.e. GLOW vs Payload Mass) and will consist of a family of solutions corresponding to all the non-dominated solutions (i.e. Pareto front) among the ones found by the global optimizer. The trajectory is simulated (also including first stage re-entry if required) by means of an internal tool developed in Avio, whose logic has been presented during IAC 2023. The main trajectory parameters are included among the optimization variables (e.g. vertical flight duration, pitch-over duration, pitch-over rate, etc.). In addition to trajectory parameters, the other quantities which are optimized are the propellant masses, the number of engines, the stages diameters, the propulsive parameters (i.e. chamber pressures, expansion ratios, propellant ratios), the thrust-to-weight ratios at lift-off and at ignition of upper stage and finally the payload mass. Dedicated models are adopted to directly link the geometrical characteristics of the vehicle to its mass budget and to define the propulsive characteristics of the vehicle. The cases of study are expendable and partially (i.e. only first stage) reusable Two-Stage-to-Orbit Launch Vehicles fully based on LOx-CH4 liquid propulsion. The optimal architectures, which determine a family of solutions lying on the corresponding Pareto front, are identified and their main features are presented (i.e. propulsive data, structural coefficients, nominal performance in reference mission, geometrical dimensions). Finally, the user can select the preferred architecture according to the high-level performance requirement.