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COUPLED THERMODYNAMIC AND STRUCTURAL OPTIMIZATION OF A CRYOGENIC UPPER STAGE INTO GEO

Abstract

The space launch industry is a very competitive business, especially nowadays with many private companies entering the marked. Due to economic pressures, existing launch vehicles are under constant evolution to minimize cost, maximize payload capabilities, and enhance reliability. Entire new developments from scratch and the introduction of fundamentally new technologies and design approaches have become rare. Furthermore, difficulties to establish realistic test conditions on Earth and related high cost of generating experimental data in a developing phase eventually thwart technical innovations and call for advanced simulation methods at once. From an engineering point of view, it is desirable to quickly asses new designs, materials and fundamental changes of geometries over a complete mission, to find potential weak spots and advantages over established practices. This work presents simulation and optimization results gained from the CLauSO (Cryogenic Launcher Stage Optimization) toolbox applied to a launcher mission to the geostationary Earth orbit (GEO). These results yield indications for optimal designs for a given mission. The toolbox has previously been developed and verified with two demonstrator tanks. It couples thermodynamic and structural simulations in order to optimize parameters like insulation and wall thicknesses, tank volumes and so forth, with the overall objective of mass reduction, or payload increase, respectively. Thermodynamic aspects covered by this method are: fluid motion, thermal stratification, evaporation of cryogenic propellants, self-pressurization in the tanks, atmospheric flight, surface radiation, and heat conduction in various materials. The structural mechanics part features bulkhead, cylinder, and connector ring components, optimized for given load scenarios and factors of safety. These components may be designed with isotropic, orthogrid, or sandwich wall structures to withstand yielding, rupture and various types of buckling. The coupled approach allows e.g. to trade off insulation mass versus higher propellant masses to account for losses due to increased evaporation. More propellant on board requires more storage volume and will increase the structural mass as well. Furthermore, pros and cons of common bulkhead structures versus separate tanks for fuel and oxidizer may be evaluated with respect to space and structural savings as well as complex thermodynamic interferences due to a common bulkhead.