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ADJOINT-BASED SMALL SOLID ROCKET MOTOR OPTIMIZATION TOOL

Abstract

The purpose of this work is to develop an optimization tool useful for the preliminary design of small solid rocket motors. The direct numerical simulation of the reciprocally interacting three-dimensional flow, combustion and heat conduction processes is not appropriate for engineering purposes. The mathematical model used in this work is a combination of two different sub-models. Thus, in the combustion port, due to small Mach number, a pressure based differential model is used. This model is obtained by coupling the mass and total energy conservation laws with the state equation and with the fuel regression rate. We assume that the gas pressure and density do not vary along the combustion port, hence, resulting in a system of two differential equations. Further, in the post-combustion chamber and in the nozzle, the flow is governed by the 1-D Euler equations of gas-dynamics. These flow equations are spatially discretized using a cell-centered Godunov type finite volume method. The discretized equations are coupled to the differential derived for the combustion port using internal boundary conditions. The time advancement of the full numerical solution is based on the use of a second order implicit scheme based on the dual time approach. This model is used to calculate some performance indexes relevant for small solid thrusters: thrust, total impulse and specific impulse. These performance indexes are depending on a large number of functional and constructive parameters. In the preliminary design, only one of these indexes must be optimized. The objective of the optimization is also to obtain either small diameter (relevant in building correction devices to fit a specific vehicle) and/or minimum total mass thrusters (also relevant in the overall mass budget of the controlled vehicle).The optimization process requires the efficient calculation of the derivatives (sensitivities) of the performance index with respect to the parameters. This is done using an adjoint approach. The adjoint model is obtained analytically starting from the governing equations and it is solved numerically using an algorithm similar to that used for the base case problem. The advantage of the adjoint approach is that with only one supplementary run of the code all the sensitivities can be calculated. Obviously, it requires a large amount of work for the development, coding and verification of the adjoint calculation. The numerical sensitivities of the total impulse calculated with the aid of the adjoint function are in good agreement with those obtained through recalculations.