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# ACCURATE MODELING AND NEAR OPTIMAL ASCENT TRAJECTORY OF MICROSATELLITE LAUNCH VEHICLES VIA FIREWORK ALGORITHM

**Abstract**

Multistage launch vehicles of reduced size, such as “Super Strypi” or “Sword”, are currently investigated for the purpose of providing launch opportunities for microsatellites. Currently, microsatellites are launched according to timing and orbit requirements of the main payload. The limited costs of microsatellites and their capability to be produced and ready for use in short time make them particularly suitable for ready-on-demand requests, such as facing an emergency. As a result, launch vehicles for the exclusive use of microsatellites would be very useful. This work considers the Scout rocket, a four-stage launch vehicle of reduced size used in the past. Its aerodynamics and propulsion are modeled with high fidelity, through interpolation of reliable, accurate available data. For the purpose of reducing the rocket complexity and size, as well as the launch cost per kg of payload, simplification of the rocket subsystems is advisable, and this includes also the guidance system and the related algorithm. In fact, open-loop guidance was actually employed during real Scout flights. In this research, open-loop guidance is investigated, under the assumption that the aerodynamic angle of attack is constant for the each of the first three stages. Instead, for the upper stage the terminal optimal ascent path leading to orbit injection is determined through the use of a specific implementation of firework algorithm, in conjunction with the Euler-Lagrange equations and the Pontryagin minimum principle. Firework algorithms represent a recently-introduced heuristic technique inspired by the firework explosions in the night sky. The concept that underlies this method is relatively simple: a firework explodes in the search space of the unknown parameters, with amplitude and number of sparks determined dynamically. The succeeding iterations preserve the best sparks. The firework algorithm has several original features that can ensure satisfactory performance in parameter optimization problems, because both local search and global search are effectively performed through combination of various stochastic operators. With regard to the problem at hand, the unknown parameters are (i) the aerodynamic angles of attack of the first three stages, (ii) the coast time interval, (iii) the initial values of the adjoint variables conjugate to the upper stage dynamics, and (iv) the thrust duration of the upper stage. The numerical results unequivocally prove that the methodology at hand is rather robust, effective, and accurate, and definitely allows evaluating the performance attainable from multistage launch vehicles with accurate aerodynamic and propulsive modeling.