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PARTICLE SWARM OPTIMIZATION OF ASCENDING TRAJECTORIES OF MULTISTAGE ROCKETS

Abstract

Multistage rockets are commonly employed to place spacecraft and satellites in their operational orbits. If the rocket characteristics are specified, the optimization of its ascending trajectory consists in determining the optimal control law that leads to maximizing the final mass at orbit injection. The numerical solution of a similar problem is not trivial and has been pursued with different approaches, for decades. Indirect methods, such as the gradient-restoration algorithm and the shooting method, or direct techniques, such as direct collocation, direct transcription, and differential inclusion, are to name a few. This paper is concerned with a different approach based on swarming theory. The particle swarm optimization technique represents a heuristic population-based optimization method inspired to the natural motion of bird flocks. Each individual (or particle) that composes the swarm corresponds to a solution of the problem and is associated with a position and a velocity vector. The formula for velocity updating is the core of the method, and is composed of three terms with stochastic weights. As a result, the population migrates toward different regions of the search space taking advantage of the mechanism of information sharing that affects the overall swarm dynamics. At the end of the process the best particle is selected and corresponds to the optimal solution to the problem of interest. The three-dimensional trajectory of the multistage rocket is assumed to be composed of four arcs: (i) first stage propulsion, (ii) second stage propulsion, (iii) coast arc (after release of the second stage), (iv) third stage propulsion. The Euler-Lagrange equations and the Pontryagin minimum principle, in conjunction with the Weierstrass-Erdmann corner conditions, are employed to express the thrust angles as functions of the adjoint variables conjugate to the dynamics equations. The use of these analytical conditions coming from the calculus of variations lead to obtaining the overall rocket dynamics as a function of only eight parameters: (a) the six initial values of the adjoint variables, (b) the coast duration, and (c) the last stage thrust duration. As a result, the swarming algorithm can consider a parameter set composed of eight unknown parameters. The basic version of the swarming technique, which is used in this research, is extremely simple and easy to program. Nevertheless, the algorithm proves to be capable of yielding the optimal rocket trajectories for a variety of cases with great numerical accuracy.