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SIX-DEGREE-OF-FREEDOM TRAJECTORY OPTIMIZATION FOR POWERED LANDING OF REUSABLE ROCKETS

Abstract

Rockets are typically destroyed on their maiden voyage. Recently, to significantly reduce the cost of space exploration, making rockets practically reusable has gained worldwide attention. In this study, the trajectory optimization problem for powered landing of reusable rockets associated with a six-degree-of-freedom (6DOF) dynamics model including the effect of aerodynamic forces will be considered. There are two main reasons why a 6DOF model is utilized. On one hand, the attitude of rockets should be taken into account in this trajectory optimization problem due to the thin and long profile of rockets. On the other hand, generally, control moments firstly control attitude angles and rates of rockets in terms of rotational dynamics. Subsequently, the attitude angles and rates will determine the angle of attack and the bank angle which affect the translational motion. Therefore, to be consistent with the practical flight process of rockets, the 6DOF model coupling the rotational and translational motions of rockets is indispensable. In this study, 6DOF trajectory optimization for powered landing of reusable rockets is performed based on finite-element approaches with Radau collocation. The rocket is actuated by a single gimbal rocket engine with lower and upper thrust bounds. The 6DOF trajectory optimization problem coupling low-frequency translational and high-frequency rotational equations of motion is naturally large, and the governing equations are highly coupled and highly nonlinear. Thus, attaining a converged solution to the 6DOF problem is quite sensitive to the initial value guess. Compared with general trial and error, an automatic initialization strategy is presented to simultaneously generate the initial value guess and the initial mesh of the finite-element approach. Then, a coarse solution to the 6DOF problem can be obtained according to the initial setting given by the initialization strategy. To obtain a finer solution, a mesh refinement strategy based on error estimation of non-collocation points and a constant Hamiltonian profile is proposed. The mesh refinement strategy gives a sufficient approximated solution compared with the optimal solution to the original continuous problem, and can accurately capture the breakpoints of the bounded control variables. The simulation results show that the proposed direct trajectory optimization framework with two dynamic optimization strategies can effectively and efficiently address the 6DOF powered landing problem of reusable rockets in a systematic way.