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MULTI-PHASE LANDING TRAJECTORY OPTIMIZATION FOR STARSHIP-LIKE VEHICLES

Abstract

Starship is a new generation of reusable space transportation system developed by Space Exploration Technologies Corporation (SpaceX). Because of unique aerodynamic configuration and propulsion control strategies, the landing process is largely different from traditional reusable rocket, which has three typical phases:1) gliding reentry with near-90 angle-of-attack for rapid aerodynamic deceleration;2) flip maneuver to achieve rapid attitude transition from horizontal to vertical configuration;3) powered vertical descent to enable precise soft landing. This unique landing approach poses new challenges to the trajectory optimization, which must integrally consider large-scale attitude maneuvers, complex constraints, and decision-making on phase transition points to achieve maximum performance. This paper proposes a novel generalized Newton/parallel iteration-based convex optimization method to solve this multi-phase problem efficiently and reliably. First, a multi-phase programming model is established, in which the attitude dynamic for each phase is additionally incorporated and the engine gimbal angle, thrust as well as the phase transition time are treated as the optimization variables. Furthermore, a generalized Newton iteration technique is introduced to successively convexify the nonlinear dynamics and various constraints, which indeed eliminates the state in the optimization process that will greatly reduce the optimization scales as compared to traditional successively linearization method. In addition, a parallel iterative strategy is adopted to decouple the convexification of whole dynamics, where the sub-dynamic for each phase can be independently convexified with the generalized Newton method, and then a unified convex subproblem is formulated and solved by using the interior-point constraints. This strategy not only further reduces the computational complexity of iterative operations but also enhances the convergence robustness. Finally, numerical examples are provided to verify the performance of the proposed method in the presence of free/specified phase transition time.