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ABORT CAPABILITY EVALUATION FOR MULTI-STAGE SPACE TRANSPORTATION SYSTEMS

Abstract

Reducing cost while enhancing safety are crucial development goals of space transportation systems. At present, multi-stage-to-orbit transportation systems mainly consist of multi-stage expendable launch vehicles and partial reusable launch vehicles including booster reusable and orbital reusable vehicles. Control reconfiguration and guidance adaptation might not be able to guarantee mission success under non-fatal failure conditions, and abort capability evaluating with trajectory reshaping that can fully use degraded performance of vehicles is necessary. A common mission abort capability evaluation method for multi-stage launch systems is constructed to analyze abort capability of both boost stage and the upper stage under a unified framework. Abort logic and rapid abort trajectory reshaping/generation algorithm constitute the main parts of abort capability evaluation. Trajectory reshaping algorithm proposed is based upon hybrid optimal control and direct trajectory optimization strategy using pseudospectral (PS) knotting method, and can be used for global trajectory optimization/generation problems which employ complex dynamic models with various path constraints and boundary conditions of multi-stage multi-phase flight missions. Multi-stage launch systems are typically multi-agent systems and trajectory planning can be modeled as hybrid optimal control problems with stage separation events formulated as event conditions or linkage conditions. The Derived hybrid optimal control problem, which includes categorical variables, can be decomposed into a feasible integer programming subproblem and an ordinary optimal control problem that can be discretized into a nonlinear programming problem over an appropriately chosen set of nodes (such as the Legendre-Gauss-Lobatto nodes) through the PS knotting method. In order to develop the abort capability evaluation framework, we provide details for a benchmark hybrid problem associated with a two-stage launch system consists of a reusable booster and an expendable upper stage. Abort capability is evaluated for the two-stage launch system under the failures of booster's main engines including thrust loss and locked engine throttle. Several strategies are adopted to ensure rapid generation of emergency trajectories that maximize orbit injection ability of the upper stage while ensuring the reusable booster return to a feasible landing site safely. Numerical simulation shows that the proposed framework can be used for multi-stage aerospace transportation systems to evaluate the integrated abort capability efficiently and to generate optimal emergency trajectories rapidly.