Nonlinear Adaptive Dynamic Inversion Control for Hypersonic Vehicles
Doctoral Dissertation Defense

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Abstract

Because of the widely varying flight conditions in which hypersonic vehicles operate and certain aspects unique to hypersonic flight, the development of control architectures for these vehicles presents a challenge. Previous work on control design for hypersonic vehicles often has involved linearized or simplified nonlinear dynamical models of the aircraft. This dissertation retains the nonlinear dynamics in the design of the controller for a generic hypersonic vehicle model and develops a nonlinear adaptive dynamic inversion control architecture with a control allocation scheme. A robustness analysis is performed on the initial controller design, which shows that the controller is able to handle time delays, perturbations in stability derivatives, and reduced control surface effectiveness while maintaining tracking performance.

One particular safety concern in hypersonic flight is inlet unstarts, which not only produce a significant decrease in the thrust but also can lead to loss of control and possibly the loss of the vehicle. This dissertation focuses on the prevention of inlet unstarts that are triggered by an altered flow that fails to pass through the throat of the engine because the aircraft has exceeded limits on angle-of-attack and sideslip angle. To prevent undesirable inlet unstart events, the nonlinear adaptive dynamic inversion control architecture is given the ability to enforce state constraints. Because several phenomena can cause inlet unstarts, the control architecture also is tested to determine if the controller is able to maintain reference trajectory tracking and to prevent the loss of the vehicle should an inlet unstart occur. Additionally, a fault-tolerant control capability is added to the control architecture so that the vehicle can handle the failure of one or more control surfaces.

The tracking performance of the nonlinear adaptive dynamic inversion control architecture is analyzed for the cases of enforcement of state constraints, control surface failures, and inlet unstarts. In all three cases, the control architecture is able to track reference trajectories with minimal to no degradation in performance. Limitations were discovered in the case of the controller that enforces state constraints in terms of the trajectories that can be tracked when combined with fault-tolerant control. However, the results indicate that the nonlinear adaptive dynamic inversion controller is able to achieve tracking performance in the presence of the uncertainties and inlet unstart conditions studied in this dissertation.