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MULTI-LOOP GAIN-SCHEDULING CONTROL OF FLEXIBLE AIR-BREATHING HYPERSONIC VEHICLE

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Abstract. *For a flexible air-breathing hypersonic vehicle model, this paper is concerned with the application of linear control theory to address its complex control problem over wide range of flight conditions. Because of the complexity of the numerical nonlinear model of the vehicle dynamics, a curve-fitted model in closed form is created. Based on the analytical model, a linear parameter-varying (LPV) model is derived for dynamic analysis and control design. A brief dynamic analysis of the vehicle is conducted to reveal its key dynamic characteristics. Under the guidance of the open-loop analysis, a multi-loop control architecture is proposed to decompose the full control problem into three lower-order sub-problems, which are solved at different frequency band. The control design combines pitch rate loop, attitude loop, and trajectory loop as sequential feedback structure, and the rate gyro placement is also a part of the control design procedure. The resulting flight control system is scheduled with dynamic pressure and Mach number to accommodate the variations of flight conditions. The effectiveness of the control strategy is demonstrated on the full nonlinear model of the vehicle dynamics.*
Keywords: Hypersonic, Gain-scheduling, Linear parameter-varying (LPV), Multi-loop

1. **Introduction.** With the recent success of NASA's X-43A experimental vehicle, air-breathing hypersonic vehicles may offer the potential for reliable and affordable access to space and high-speed civil transportation. The design of guidance and control systems for air-breathing hypersonic vehicles is still an open problem due to the peculiarity of the vehicle dynamics. The aerodynamic, propulsive, structural and control features are interactively dynamical over a wide range of frequencies because of the flexible airframe/engine integrated configuration. The vehicles are statically unstable in pitch mode, and exhibit non-minimum phase behavior in the flight path angle dynamics. The hypersonic flight regime shows a decoupling of pitch attitude and flight path responses to pitch control inputs. In addition, the dynamic characteristics of the vehicles vary significantly due to the wide range of flight conditions, fuel consumption and thermal effects on the structure. The overwhelming complexity of the vehicle dynamics makes the guidance and control research highly difficult for hypersonic vehicles.

The most recent results available in the literature mainly concentrate on the longitudinal plane as only the longitudinal models of the vehicle dynamics have been developed with increasing complexity. For linearized versions of these models, several results available in the literature consider control solutions of various approaches. More specifically, classic and multivariable linear control [1], $\mathcal{H}_\infty$ design and μ-synthesis [2], $\mathcal{H}_\infty$-based eigenstructure assignment design [3] and linear parameter-varying control of structural dynamics [4] are studied for early models developed in [5, 6]. Recent research efforts have