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Autopilot Synthesis and Analysis using H_∞ Optimal Control

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This presentation provides an overview of an autopilot synthesis and analysis framework developed in MATLAB/Simulink based on H_∞ optimal control methods. The framework was developed to address questions regarding controllability of an early-stage flight vehicle design in the context of an outer mold line (OML) trade study.

Current methods for addressing the controllability of preliminary vehicle designs typically involve "static" analyses, including analyses of stability/control derivatives and trim deflections/hinge moments. These analyses are relatively inexpensive and can be done quickly with only preliminary component models. However, they provide only a qualitative understanding of robustness/performance tradeoffs that fundamentally characterize vehicle controllability in a broad sense. Quantitative characterization of robustness and performance is typically relegated to later stages in the design process and involves time-consuming gain tuning and dynamic stability analysis across expensive Monte Carlo simulations.

To push quantitative characterization of autopilot design earlier in the design process, this framework implements a modular design and makes use of H_∞ optimal control methods across a given controller architecture. The former enables rapid exploration of competing subcomponent model designs and the latter provides efficient multivariate controller tuning and analysis given known performance specifications and uncertainty models. In contrast to Monte Carlo sampling, H_∞ methods enable synthesis and analysis across the continuous space of modeled uncertainty using efficient solution methods, thus enabling rigorous quantification of robustness over a larger design space. Specifically, this framework iteratively applies structured μ-synthesis [1, 2] and μ-analysis for tuning to robust performance and analyzing robust stability, respectively. This occurs across numerous relevant flight conditions and across various competing subcomponent models with minimal manual input from the user, enabling rapid autopilot design turn-around to inform broader early-stage system design.

This presentation provides an overview of the framework with an emphasis on formulating the H_∞ optimal control problem, including discussion on encoding performance specifications as frequency-dependent weighting functions and representing uncertainty in the H_∞ framework. The presentation also covers application of the framework to the OML trade study and provides corresponding autopilot synthesis and analysis results.

References:

[1] P. Apkarian and D. Noll, "Nonsmooth H-infinity Synthesis," *IEEE Transactions on Automatic Control,* vol. 51, no. 1, pp. 71-86, 2006.

[2] N. A. Bruisma and S. M, "A Fast Algorithm to Compute the H∞-Norm of a Transfer Function Matrix," *System Control Letters,* vol. 14, pp. 287-293, 1990.

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