

Restricted Adaptation, Structured Learning, and Closed-Form Constraint-Aware Solutions for Advanced Guidance, Control, and Autonomy

Heather Hussain and Joseph Gaudio, *The Boeing Company*

Abstract: Adaptive, learning-enabled, and constraint-aware control methods are increasingly relevant to aerospace applications, but their deployment in flight-critical systems requires explicit guarantees on feasibility, convergence, stability, and robustness. This presentation examines complementary approaches for integrating adaptation, learning, and constraint satisfaction into aerospace control architectures while preserving formal structures and leveraging classical analysis techniques. We first consider data-driven learning and optimization over parameterized control structures, in which the learning problem is isolated to gains or parameters within a structured controller rather than direct black-box policy learning. This formulation reduces search complexity, facilitates incorporation of sparse objectives and hard constraints, and better preserves physically meaningful properties of the guidance or control law. The second approach focuses on control barrier functions (CBFs) as a formal mechanism for enforcing state and input constraints for linear time-invariant (LTI), multi-input multi-output (MIMO) applications. In particular, the Boeing-developed closed-form optimal CBF min-norm solution enables classical stability and robustness analysis in a piecewise sense, making it especially well-suited for flight-critical systems, where analytic guarantees and closed-loop performance verification are essential. Moreover, whereas CBF augmentation is traditionally computed by solving an optimization problem at each control step, the closed-form formulation obviates the need to run an optimizer in the control loop, thereby reducing computational burden, ensures solution feasibility, and improves implementation suitability for real-time aerospace systems. The presentation will discuss how restricted adaptation, structured learning, and closed-form barrier-based constraint enforcement can lead to trustable GNC-enabled autonomy architectures that are more amenable to the necessary analysis and validation steps required for certification.

Bio: Dr. Heather Hussain is a Guidance, Navigation, Controls, and Autonomy Engineer at The Boeing Company. Before joining Boeing, Heather received the B.S. degree and M.S. degree in mechanical engineering from the Rochester Institute of Technology, Rochester, NY, USA, in 2012, and the Sc.D. degree in mechanical engineering at the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA. Her work experience spans the aerospace and consumer electronics industries—namely, in Product Design at Apple Inc., as a hypersonics research Scholar at the Munitions Directorate of the Air Force Research Laboratory, and most notably her work in the design and development of advanced guidance and control algorithms for GNC-enabled autonomy at The Boeing Company. She is the 2023 recipient of the Dave Ward Memorial Lecture

Award. Ms. Hussain's research interests lie in robust adaptive control theory and real-time optimal guidance methods.

Dr. Joseph Gaudio is a Senior Research Engineer in Boeing Defense, Space and Security specializing in advanced autonomy, guidance, and control research, innovation, and technology transition. He is a lead architect of Networked, Collaborative Autonomy (NCA) algorithms for multi-agent systems, and has over a decade of experience in the aerospace research community. Dr. Gaudio received his PhD from the Massachusetts Institute of Technology (MIT), and is a Senior Member of IEEE and AIAA.