

Pterodactyl: Guidance and Control of a Symmetric Deployable Entry Vehicle using an Aerodynamic Control System

Wendy A. Okolo*, *NASA Ames Research Center, Moffett Field, CA 94035, USA*
Breanna J. Johnson†, *NASA Johnson Space Center Houston, TX 77058, USA*
Benjamin W. Margolis‡, *NASA Ames Research Center, Moffett Field, CA 94035, USA*
Daniela Rocca-Bejar§, *NASA Johnson Space Center Houston, TX 77058, USA*
Sarah N. D’Souza¶
NASA Ames Research Center, Moffett Field, CA 94035, USA

Abstract

The NASA-funded Pterodactyl project seeks to advance the state-of-the-art for varying entry vehicle types by developing unconventional guidance and control technologies for Deployable Entry Vehicles (DEVs) that can be applied to different entry vehicle configurations. Prior work by the authors [1–5] involved developing both traditional and novel integrated guidance and control solutions for a Pterodactyl Baseline Vehicle (PBV), a variant of an asymmetric DEV called the Lifting Nano ADEPT (LNA) [6]. In the prior studies, two different guidance schemes were designed and implemented for the PBV: (i) traditional bank angle guidance developed using the Fully Numerical Predictor-Corrector Entry Guidance (FNPEG) and (ii) novel angle of attack and sideslip ($\alpha - \beta$) guidance developed using FNPEG with Uncoupled Range Control [4]. Using Linear Quadratic Regulator (LQR) optimal control methods with state-feedback integral control designs, these guidance trajectories were designed to be tracked using (i) a conventional propulsive entry vehicle control hardware architecture - reaction control systems (RCS) and (ii) novel non-propulsive entry vehicle control systems - aerodynamic flap control system (FCS) and moving mass control system (MMCS) [1].

The novel FCS and MMCS architectures were designed to track $\alpha - \beta$ guidance commands while the RCS was designed to track bank angle commands. It was discovered that the asymmetric DEV, the PBV, experienced a non-zero induced roll moment due to sideslip that the FCS and MMCS architectures had limited capability to trim out. These two architectures were designed to provide independent angle of attack and sideslip commands with limited consideration for roll moment generation to trim. As a result, for the PBV, the FCS and MMCS configurations as designed, were limited in providing the control authority needed to track an $\alpha - \beta$ guidance trajectory [1]. These results form the motivation for the work presented in this paper - utilizing an aerodynamic control system to track $\alpha - \beta$ guidance commands for a symmetric DEV with the expectation that a symmetric entry vehicle will have zero or significantly reduced roll moment due to sideslip that the FCS can handle when tracking an $\alpha - \beta$ guidance trajectory.

To demonstrate the feasibility of a novel guidance and control architecture on a DEV, we utilize a symmetric DEV, the PBV-II, for (i) the novel $\alpha - \beta$ guidance development using FNPEG with Uncoupled Range Control and (ii) LQR control design using eight aerodynamic control surfaces. This paper demonstrates that the novel uncoupled $\alpha - \beta$ guidance tracking can be achieved using aerodynamic control surfaces on a symmetric deployable entry vehicle configuration.

*Aerospace Research Engineer, Intelligent Systems Division, MS 269-1, AIAA Member

†Aerospace Engineer, Flight Mechanics and Trajectory Design Branch, EG5, AIAA Member

‡Graduate Pathways Student, Systems Analysis Office, MS 258-1, AIAA Member

§Student Intern, Flight Mechanics and Trajectory Design Branch, EG5

¶Aerospace Flight Systems Engineer, Systems Analysis Office, MS 258-1, AIAA Member

Acknowledgments

The authors acknowledge the support of the Pterodactyl aerodynamicist, Brandon Reddish, and the mechanical design lead, Bryan Yount, for their data, insight, and contributions to the body of work presented in this paper. The authors would also like to acknowledge the support of the NASA Space Technology Mission Directorate (STMD) Early Career Initiative Program Manager, Ricky Howard, the NASA STMD Entry Descent & Landing Principal Technologist, Michelle Munk, and all internal and external Pterodactyl mentors who have supported this effort and provided valuable feedback and recommendations.

References

- ¹Okolo, Wendy A., M. B. W. D. S. N. and Barton, J. D., “Pterodactyl: Development and Comparison of Control Architectures for a Mechanically Deployed Entry Vehicle,” *AIAA SciTech 2020 Forum*, AIAA, Orlando, FL, January 2020.
- ²Margolis, B. W., Okolo, W. A., Nikaido, B. E., Barton, J. D., and D’Souza, S. N., “Control and Simulation of a Deployable Entry Vehicle with Aerodynamic Control Surfaces,” *Astrodynamics Specialist Conference*, 2019.
- ³Margolis, B. W., Okolo, W. A., and D’Souza, S. N., “Control Design & Sensitivity Analysis for a Deployable Entry Vehicle with Aerodynamic Control Surfaces,” *International Astronautical Congress*, 2019.
- ⁴Johnson, B. J., Rocca-Bejar, D., Lu, P., Nikaido, B. E., Yount, Bryan C., D. S. N., and Hays, Z. B., “Pterodactyl: Development and Performance of Guidance Algorithms for a Mechanically Deployed Entry Vehicle,” *AIAA SciTech 2020 Forum*, AIAA, Orlando, FL, January 2020.
- ⁵D’Souza, S. N., Okolo, W. A., Nikaido, B. E., Yount, B. C., Tran, J., Margolis, B. W. L., Smith, B. P., Cassell, A. M., Johnson, B. J., Hibbard, K. E., Barton, J. D., and Hays, Z., “Developing an Entry Guidance and Control Design Capability using Flaps for the Lifting Nano-ADEPT,” *AIAA Aviation and Aeronautics Forum and Exposition*, 2019.
- ⁶Directorate, N. S. T. M., “Center Innovation Fund 2016 Winners Nano-ADEPT Lifting: Design Development for a Lifting Flight Test Demonstration,” 2016.