Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle

Significant aerospace research has focused on bending the cost curve of space exploration through the development of reusable launch vehicles (Sippel, Manfletti, and Burkhardt, 2006). Reusable vehicles are capable of launching, delivering their payload, and propulsively landing back on Earth (O'Connell, 2018). However, the investments in reusable technology have been primarily directed towards large, liquid-fueled boosters, which has left the rapidly growing suborbital launch market without reusable technology (Gstattenbauer, 2006). The goal of this project is to develop a reusable, suborbital, solid-fueled, proof-of-concept launch vehicle with propulsive landing capabilities.

The vehicle created in this research required the development of a novel, 3D printed propulsion system which uses four solid-fueled motors. The design provides pitch, yaw, roll, and throttle control to the vehicle by vectoring each motor in one axis tangent to the circumference of the airframe. The design is centered around the ability to throttle the vertical thrust component, as this is necessary to enable precision landings. Many existing solid-fueled propulsion systems lack this critical feature (McCauley, Fletcher, & Crane, 2012). A flight computer was developed using a Cortex-M4 processor, an inertial measurement unit, a barometric pressure sensor, two relays, dual-redundant power supplies, and three Lithium-Polymer batteries. The software for the flight computer was developed to compute an array of Proportional Integral Derivative (PID) control loops to stabilize the vehicle across all axes. The core of this project was determining the optimal PID stabilization coefficients by building an accurate physics simulation of the vehicle in MATLAB, where a transfer-function based PID optimization algorithm was used to calculate the optimal values.

Four real-world landing tests were attempted and after each test, the P, I, and D values were refined in accordance with updated computer simulations. The optimal PID coefficients were determined to be 1.5, 0.3, and 0.95, respectively. In experimentation, these coefficients enabled the stabilization algorithm to keep the vehicle an average of 7.98º from vertical. Although a completely successful propulsive landing is in progress, the advanced hardware, software, procedures, propulsion system, and simulations developed through this research will undoubtedly facilitate future research in developing reusable rockets for the suborbital launch market.

Figure 1

To test the landing phase of flight, the vehicle is dropped from a drone. Although the vehicle did not remain upright after this landing attempt, important data was recorded which greatly improved subsequent trials.

References

Gstattenbauer, G. J. (2006, March). *Cost Comparison of Expendable, Hybrid, and Reusable Launch Vehicles*. Retrieved from DTIC Online database. (Accession No. a451291)

McCauley, R. J., Fletcher, W. G., & Crane, D. J. (2012). Throttle Control of an Extinguishable Solid Propellant Thruster System - Mars Lander [PDF]. *Universities Space Research Association*, 1. Retrieved from https://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4264.pdf

O'Connell, C. (2018, February 6). *Launch, land, repeat - reusable rockets explained.* Retrieved June 11, 2019, from https://cosmosmagazine.com/space/launch-land-repeat-reusable-rockets-explained

Sippel, M., Manfletti, C., & Burkhardt, H. (2006). *Long-term/strategic scenario for reusable booster stages. Acta Astronautica, 58(4), 209–221.* doi:10.1016/j.actaastro.2005.09.012