

Executive Summary

As AeroMavs pursues higher altitudes, the uncontrollable acceleration of solid rocket motors subjects the vehicle to extremely large dynamic pressures at low altitudes, risking structural failure. To address this, the Hybrid Division at UT Arlington is developing a throttle system that takes advantage of a hybrid motor's inherent controllability — combining upstream valve controls with electromagnetic pintles to maximize throttle authority and mitigate the chance of flameout. The target is reducing thrust to 20% of nominal output while maintaining stable combustion through Max Q. The first test campaign (HX-1), conducted on April 5th, 2026, completed both a hydrostatic test and a cold flow test, successfully validating the fuel system and characterizing injector mass flow rates across three orifice sizes. However, the final integrated system test is not yet complete due to delays in procuring necessary components and collecting sufficient data for full throttle characterization — both of which will be addressed in the next campaign.

Background

High dynamic pressure ($q = \frac{1}{2}\rho v^2$) during ascent can cause rapid unplanned disassembly through structural buckling if thrust is not managed. Solid motors cannot be throttled, but hybrid engines — which separate oxidizer flow from the fuel grain — offer an inherent throttling pathway by simply regulating oxidizer mass flow rate. Reducing oxidizer flux causes the diffusion flame to contract, lowering fuel regression and thrust. However, this must remain within O/F ratio bounds to avoid flameout. Previous work by NASA, Northrop Grumman, and researchers including Whitmore and Ruffin has demonstrated throttle ratios from 4:1 (simple valve) to 10:1 (pintle injector). AeroMavs' proposed solution combines an upstream valve for coarse control with an Actuated Nitrous Injector (ANI) pintle for fine oxidizer modulation, targeting a 5:1 throttle ratio under a closed-loop PID architecture.



Figure 1. Actuated Nitrous Injector with two nitrous feed lines

Experimental Setup

The HX-1 test system consisted of a nitrous oxide feed line, a solenoid valve, two pressure transducers, a Kunkle relief valve, and a custom aluminum injector manifold with swappable injector orifices. The nitrous tank was suspended on an S-type load cell to measure real-time mass loss throughout each firing. Electronics were managed via a pair of HELTEC ESP32 microcontrollers communicating over RF, with data logged to a laptop running PuTTY. Prior to cold flow, a hydrostatic test was performed using water pressurized to 800 psi to verify structural integrity and calibrate the pressure transducer across 7 data points. Three injector sizes were tested during cold flow — 2.6 mm, 3.02 mm, and 3.69 mm — over 6 total firings of varying duration. Tank mass was recorded before and after each firing to derive experimental mass flow rates.

Experimental Test Plan

Two analytical models were developed pre-test to bracket expected performance. The ideal model applies Bernoulli's equation to compute inviscid mass flow rate as a function of injector area and pressure drop, providing an upper bound. The viscous (real) model uses a full pipe resistance formulation — iterating friction factors via the Haaland equation — across the three-step manifold geometry to produce a more realistic prediction. The ratio of actual to ideal flow yields the discharge coefficient C_d , and actual to theoretical yields a viscous correction factor. Post-test, experimental mass flow rates are computed from measured tank weight loss divided by firing duration. These values are entered into both MATLAB models to extract C_d and correction factors for each injector. The resulting empirical data will directly inform injector sizing for the HX-1 hot fire and will serve as baseline characterization data for the throttling control system.

Experimental Results

Six cold flow tests were conducted with an initial tank mass of 17.64 lbs. Tests 2 and 4–6 produced measurable mass loss: Test 2 (20 s, 2.6 mm injector) lost 1.11 lbs at 700 psi; Tests 4 and 5 (10 s each, 3.02 mm) each lost 0.55 lbs; and Test 6 (200 s, 3.02 mm) consumed the remaining 3.43 lbs at 250 psi. Tests 1 and 3 recorded zero mass loss, indicating the solenoid did not fire or the Nitrous line was closed. Discharge coefficients and viscous correction factors are pending final MATLAB analysis. Manifold inlet pressure ranged from 750 psi at the start of testing down to 0 psi at tank depletion, confirming a blowdown regime throughout. The pressure transducer calibration from the hydrostatic test successfully provided a linear voltage-to-pressure mapping used to interpret all cold flow data.

Conclusions

Campaign HX-1 successfully validated the AeroMavs fuel system, established an empirical baseline for injector discharge behavior, and demonstrated reliable remote operation of the solenoid valve and data acquisition system. The hydrostatic test confirmed structural integrity at 800 psi, and the cold flow test generated usable mass flow data across two of the three target injector sizes. Key lessons — including the need for a structured per-injector test plan, standardized repeat-fire procedures, and a locked packing protocol — have been documented and will be incorporated into Campaign 2 planning. Next steps include completing the C_d and correction factor analysis in MATLAB, selecting the optimal injector size for hot fire based on target O/F ratio and chamber pressure, and integrating the ANI pintle system for throttle testing. The manifold face seal design requires revision to reliably hold pressures above 1000 psi in preparation for hot fire conditions.

References

1. R. A. Frederick, "A historical systems study of liquid rocket engine throttling capabilities," AIAA, NASA, 2010.
2. S. A. Whitmore, "Hybrid rocket throttling." Accessed: Aug. 29, 2025.
3. B. Austin, "Variable thrust, multiple start hybrid motor solutions for missile and space applications," AIAA, Air Force Research Laboratory, 2010.
4. D. Yan, "Simulation of thrust control by fluidic injection and pintle in a solid rocket motor," Aerospace Science and Technology, 2020.
5. A. Ruffin, "Development of a cavitating pintle for a throttleable hybrid rocket motor," EUCASS, 2017.
6. S. Heo, I. Kim, Y. Yoon, and B. J. Lee, "Spray structure of a multi-slit type throttleable gas-liquid pintle injector," Physics of Fluids, vol. 37, 08 2025