# A New Rocket Nozzle Design To Improve Performance at High Altitudes

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The next generation of space exploration requires more efficient propulsion. Current rockets use bell-shaped nozzles, which lose efficiency at high altitudes due to flow underexpansion. This increases mission costs and reduces payload capacity. Multiple altitude-compensating nozzles (ACNs) have been developed as a solution. Among these, the dual bell nozzle has a simple design and is considered to be one of the best existing ACNs. The plug nozzle is another ACN that can adapt to different altitudes by moving its pintle, and recovers lost efficiency in vacuum. For this project, I developed a novel hybrid nozzle (a dual bell nozzle with a movable pintle) and compared it to the plug and dual bell nozzles. All three nozzles were 3D printed and tested at CU Boulder's Engine Test Room using liquid CO2 with a pressure of 1300 psi to simulate exhaust gases. Average thrust values and 95% CI were calculated for different chamber pressures. At lower altitudes (<400 psi), all nozzles performed similarly with the most thrust produced by the dual bell and the hybrid nozzle (pintle extended). At higher altitudes (>600 psi), the hybrid nozzle (pintle retracted) produced up to 120% more thrust than the dual bell nozzle. These results suggest that the hybrid nozzle is a more efficient alternative to existing nozzles and can improve propulsion at high altitudes, reduce cost, increase payload, and potentially move space exploration further. Future research should explore a moveable pintle to respond to pressure changes and a nozzle with smaller area ratios.

**Awards Won:**

Air Force Research Laboratory on behalf of the United States Air Force: Glass trophy and USAF medal for each recipient

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