Development of a variable geometry thrust vectoring nozzle for a hobby sized rocket motor

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Introduction

Thrust vectoring is a steering technique that offers control over the orientation of a rocket whilst in flight. The primary method of thrust vector control is mechanical deflection, where components are mechanically moved on the rocket to deflect the thrust generated by the rocket, causing side forces that steer the rocket while in flight.

Research has been done to find optimized methods of thrust vector control, primarily through variable geometry nozzles (Ikaza, D., 2000). Variable geometry nozzles are a type of rocket nozzle capable of altering their geometry, classifying them as a subset of thrust vector control. No record is available of implementing a variable geometry nozzle on a hobby sized rocket motor. Thus, the purpose of this project is to demonstrate that variable geometry nozzles are capable of thrust vectoring on a hobby sized rocket motor. If this purpose is met, then variable geometry nozzles can be utilized on a smaller scale.

Materials and Methods

To demonstrate that variable geometry nozzles are capable of thrust vectoring on a hobby sized rocket motor, a variable geometry nozzle and a hobby sized rocket motor was constructed. Autodesk Fusion 360 was used to model all components. 3D printed polylactic acid (PLA), Baltic Birch Plywood, ceramic fiber, and ASTM-A500 carbon steel were the primary building materials. A render of the entire motor and the aluminum motor test frame is pictured in Figure 1.

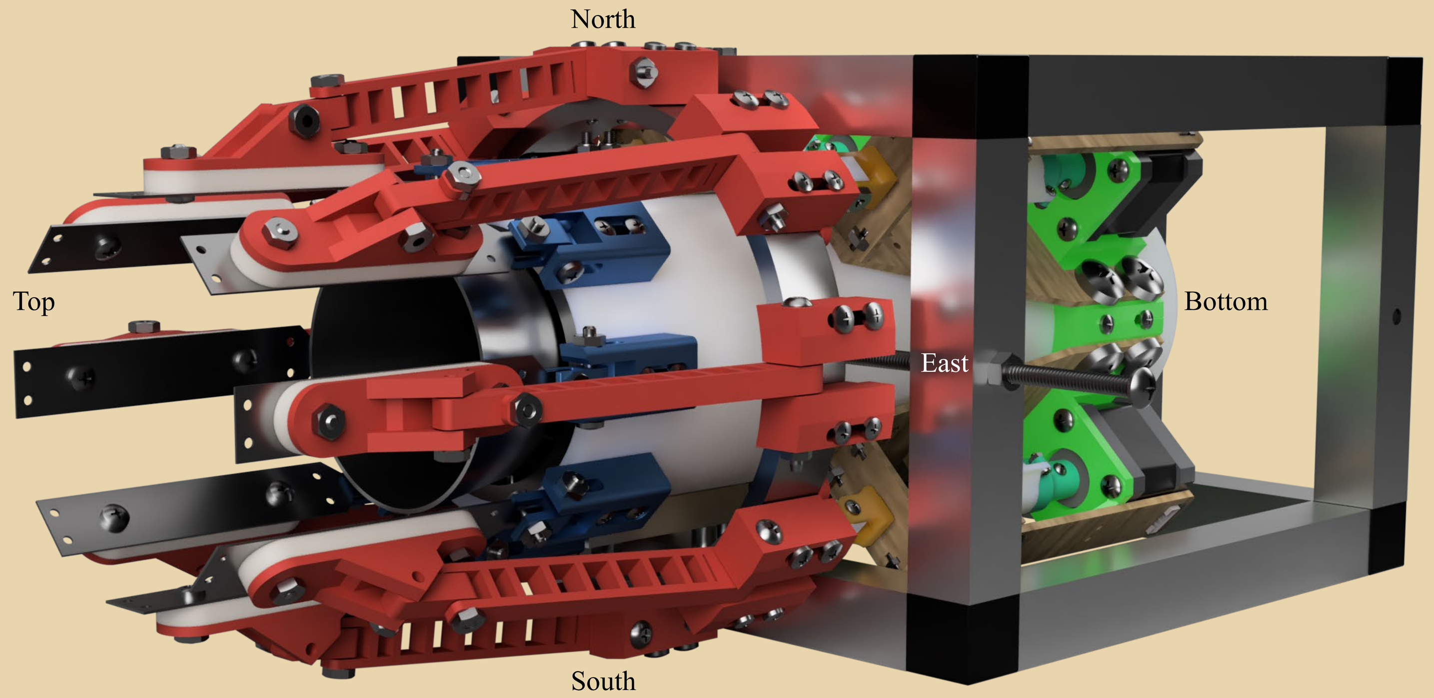


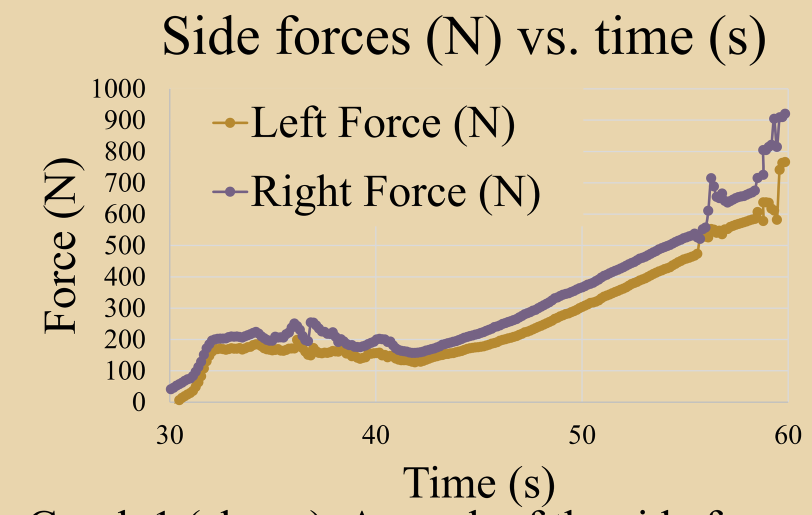
Figure 1 (above): A rendering of the rocket motor, variable geometry nozzle, and the gimbal ring and stepper motor system. The blue components attach the plates to the motor with a universal joint. The red components also attach the plates to the gimbal ring with a universal joint. The green and wooden components house the stepper motor linear actuator system. The red, green, and blue components are PLA, the white components are ceramic fiber, the wooden components are Baltic Birch plywood, and the grey components are ASTM-A500 carbon steel. The rocket body was welded together by Mr. Andrew Webster. The entire system measured approximately 19″ tall.

Materials and Methods (continued)

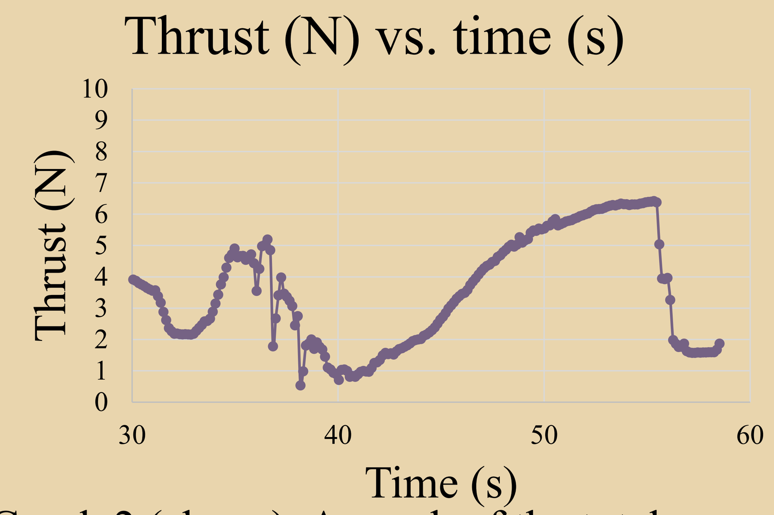
A load cell was placed on the front of the frame and attached to the bottom of the motor to record the total thrust generated by the motor. Two additional load cells (not visible in Figure 1) were placed on the insides of the north and south frame to attach to the motor and measure any side forces which occur during thrust vectoring. These side forces are what enable the steering of a rocket during flight. Two 1/4″-20 bolts were used to hold the motor in place on its east and west sides.

An Arduino Nano connected to a laptop running PuTTY was used to collect data from the load cells, and a BigTreeTech SKR V1.4 Turbo was used to power the stepper motors. The propellant used was a 65%, 33.5%, and 1.5% mixture of potassium nitrate, sorbitol, and carbon prepared via dissolution and boiling in a pan. The propellant was boiled, dried, reliquefied, and poured into the motor case and left to dry for seven days. To ignite the propellant, a nichrome wire was packed into the motor core with crumbled propellant and powered by an 18 V battery. The nozzle was set to an angle of 15° for the duration of the test.

Results



Graph 1 (above): A graph of the side forces experienced by the rocket motor during the test burn.



Graph 2 (above): A graph of the total thrust generated by the rocket motor during the test burn.

Graph 1 reveals that both sides of the rocket motor experienced nearly identical forces during the test, which demonstrates that the variable geometry nozzle did not thrust vector properly. Graph 2 is a graph of the total thrust generated by the rocket motor during testing. Due to issues with the load cells, the side forces are greatly exaggerated.

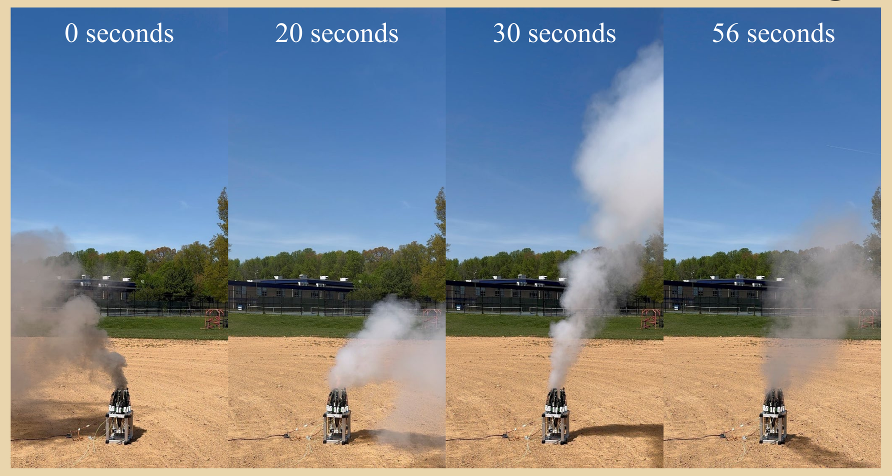


Figure 2 (left): Images of the entire system during testing. Time stamps are available for when the picture was taken. Zero seconds is when the propellant began burning and data collection started, and 56 seconds is when the motor experienced a drop in thrust, signifying the end of the test fire.

Results (continued)

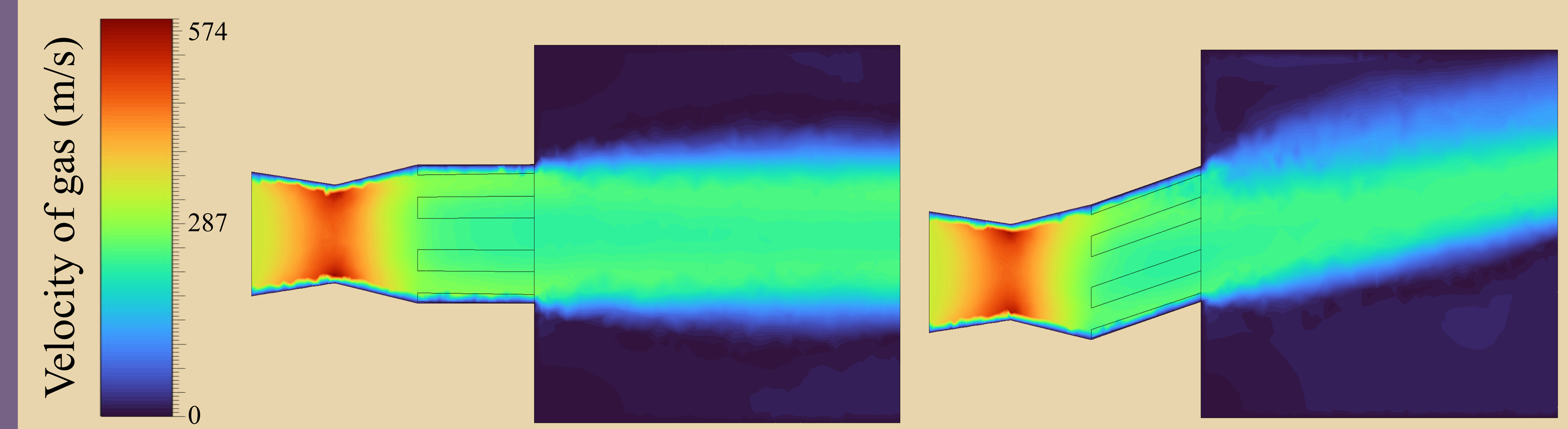


Figure 3 (above): To verify measurements by the load cells, computational fluid dynamics was used to simulate the system. An image of the Ansys Fluent output for simulating the test burn in the variable geometry nozzle at an angle of 0° and 15° is provided. The parameters were determined by Adeniyi et al. (2021) and calculations using ProPEP 3 and are as follows: density of 111.4 kg/m^3, specific heat of 1146 J/kg × K, inlet pressure of 0.191 Mpa, gas velocity of 339.8 m/s, temperature of 1666 K, and outlet pressure of 0.101 Mpa. The simulation was run 200 times for accuracy.

Conclusion

The purpose of this project was to demonstrate that variable geometry nozzles are capable of thrust vectoring on a hobby sized rocket motor. Although the variable geometry nozzle failed to demonstrate its thrust vectoring capabilities in the real-world test, the nozzle was successful in the simulation, as it is clearly visible in Figure 3 that the gasses exiting the nozzle are at an angle when the nozzle is set to an angle of 15°. The nozzle most likely failed during real world testing due to design errors, as the original nozzle design consisted of interlinking plates attached between the 8 original nozzle plates, which was omitted from this model due to their complex design. This eventually resulted in the plastic components on the nozzle plates suffering heat damage during testing, which can account for the unsubstantial data revealed in Graph 1. Even in controlled testing, the load cells showed high side forces, likely due to a loss of elasticity in the strain gauge. Thus, it is safe to conclude that variable geometry nozzles are capable of thrust vectoring on hobby sized rocket motors; however, their complexity makes them largely impractical for such use cases. Future research should attempt to simplify this design to make it more attainable in real world applications.

References

Adeniyi, G. O., Nkere, I., Adetoro, L. M., & Sholiyi, O. S. (2021). Performance analysis of a dual-fuel sugar based solid rocket propellant. *European Journal of Engineering and Technology Research*, *6*(2), 34–41. https://doi.org/10.24018/ejeng.2021.6.2.2347

Ikaza, D. (2000). Thrust vectoring nozzle for military aircraft engines. *Indistria de Turbo Propulsores S.A.*, 534.1–534.10. https://icas.org/ICAS_ARCHIVE/ICAS2000/PAPERS/RESERVED/ICA0534.PDF