Analysis of Rocket Engine Nozzle Flow via a 2 Mirror Schlieren Assembly

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Introduction

The primary goal of this research was to employ the use of a schlieren machine to image and catalogue supersonic flow patterns of rocket engine nozzles, while using pressurized air as the fluid medium. To clarify, a schlieren machine is an optical photography set up, which allows the user to capture fluid motion [6].

Specifically, one of the main objectives was to create a two-dimensional rocket nozzle that could be fitted with glass slides, so that the flow could be observed inside of the part. More generally, the goal was to catalogue images and videos of overexpanded (shock diamond producing) flow, as well as good visual representations of other types of flow. Ideally, these can be used as visual aides for future fluid lectures.

Methodology

Nozzle Design & Fabrication:

The general design of the nozzle would consist of hole for a hose attachment, a settling vessel, the converging-diverging geometry, and slots for glass slides. The most important part about designing the nozzle was ensuring that the minimum area would result in the flow reaching a Mach number of 1. This can be calculated by using the continuity equation; taking into account variables such as mass flow rate, pressure, fluid temperature, and fluid makeup [1]. For testing, a 10 bar air compressor was used. However, 10 bar was the maximum pressure, and it couldn't be sustained. Therefor, the nozzle would have to function at lower pressure values.

The design also had to be optimized for 3D printing, which placed constraints on the orientation of the nozzle. This was most important when considering how various print settings would affect the surface finish of the internal geometry. Additionally, due to the abnormally high pressure the nozzle had to be printed with higher infill and additional layers on the outside of the print.

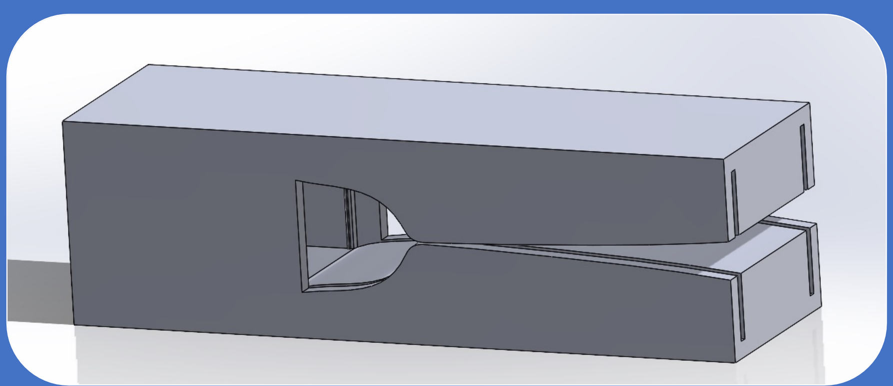

Image 1: Final Nozzle Design (Rendered in SolidWorks)

Results

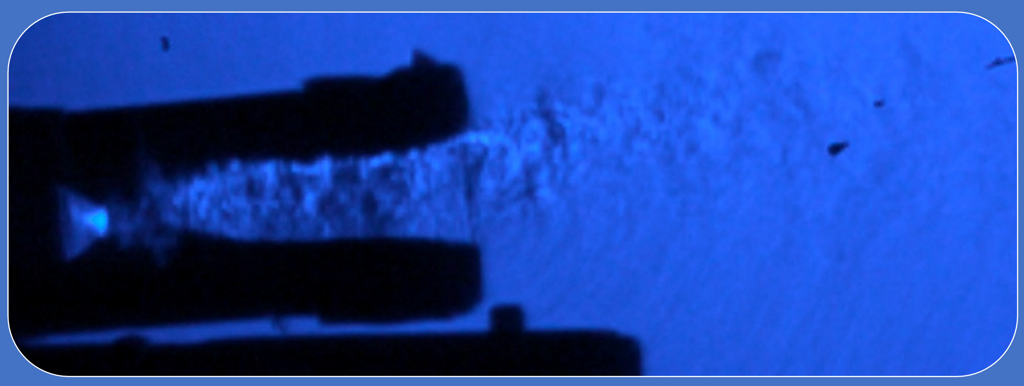

Image 2: Original Nozzle Design, Turbulent flow can be seen inside of the diverging section of the nozzle and and flowing out of the exit.

Image 3: Bottle Nozzle with Pressure Threshold Cap, The bottle built up enough pressure to expel the cap produce a clear shock diamond pattern for a few milliseconds, before the flow returned to turbulence.

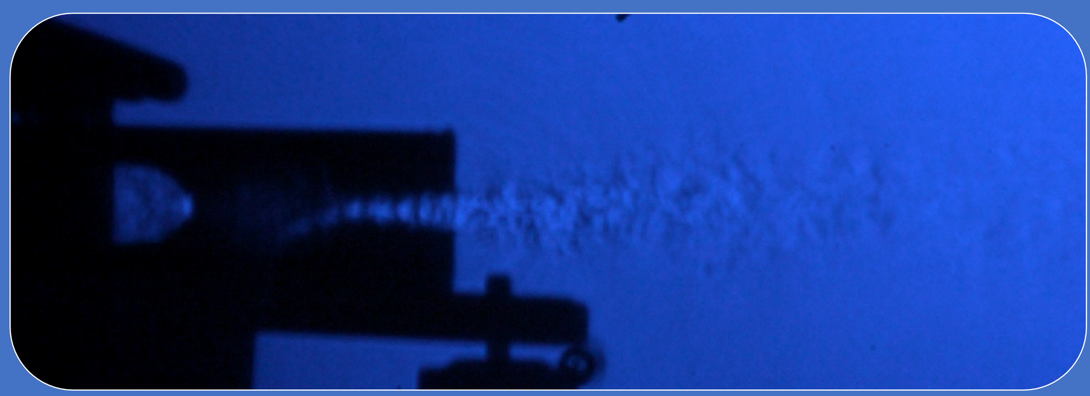

Image 4: Version 2 of Nozzle Design, The converging sections of the nozzle clearly shows turbulent flow. The diverging section of the nozzle appears to display a shock diamond pattern, unfortunately the image isn't clear enough to tell for sure. There is a clear section of turbulent flow coming from the nozzle.

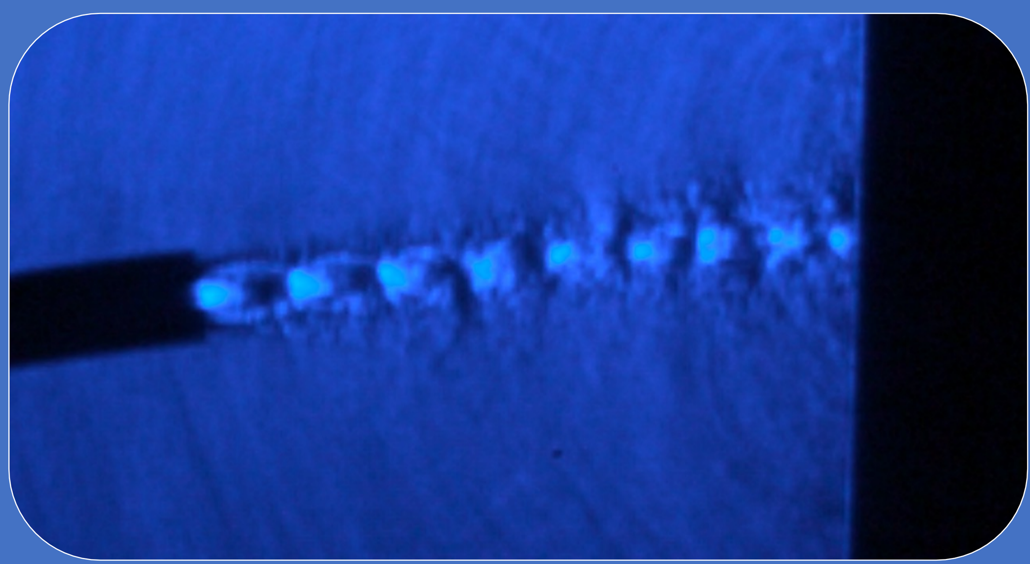

Image 5: The Hose that Carries Pressurized Air to the Nozzle, The hose is exhibiting clear supersonic flow at the exit of the tube.

Methodology

Optical Schlieren Testing:

The version of schlieren set up used for testing was a 2 mirror set up. For the purposes of this experiment, this set up was favorable to the 1 mirror assembly, because it allowed for more room to set up all the testing equipment across a room and it provided a consistent image size [6].

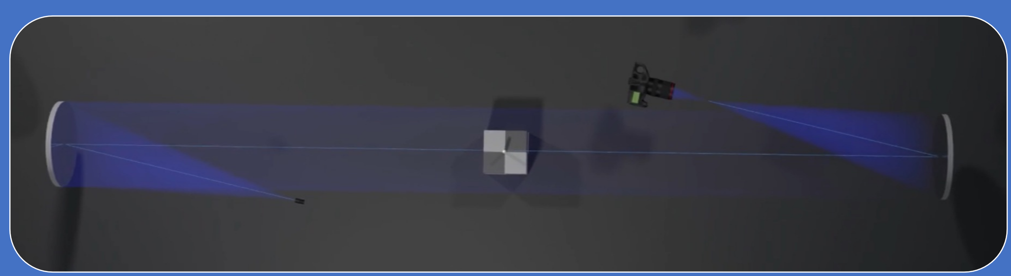

Image 6: Rendered Diagram of 2 Mirror Schlieren Assembly, Made by Dr. Nolan

Conclusion

Overall, the results from the research were unexpected. Both nozzles failed to generate any clear supersonic flow (Image 2 & 3). This was especially surprising for the second version of the nozzle, because its internal geometry was molded from a preexisting nozzle that was know to be fully functional and consistently produce supersonic flow.

The Reason for the results is clear when looking at the tube that connects the air compressor to the nozzles (Image 5). When laying out how the tests that would be conducted it was never considered that the tube that feeds the nozzle would already be producing supersonic flow. With the tube set up as it is, in order for the nozzle for produce shock diamonds. There would have to be a much larger settling chamber that would allow the flow to slow down, and for pressure to build up.

Aside from the unexpected results, the research succeeded in recording a wide variety of different flow variations.

Acknowledgements

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References

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