Supersonic Nozzle Experiment

Designing and Implementing Apparatus for Studying Compressible Flow

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ABSTRACT

The purpose of this project was to design a compressible flow experimental apparatus for the Fluid Mechanics Laboratory at Walla Walla University. This was accomplished through the design and implementation of a high-pressure tank system that blows out through a converging-diverging nozzle. This system was then instrumented with pressure and temperature sensors, outfitted with a schlieren imaging system to observe the shockwaves created, and a software package allowing user-friendly operation of the experiment.

INTRODUCTION

In the Walla Walla University Fluids Mechanics laboratory, there are experiments designed to help students understand pipe flow, channel flow, and external flow. Until this year, however, there have been no experiments that demonstrate compressible flow, a major area of study within Fluid Mechanics. Dr. Doug Thomsen, a professor of mechanical engineering at Walla Walla University, has been working with students to fill this educational gap in the laboratory for the last three years. The goal for this year was to finish the experiment and prepare it to be used in the Fluid Mechanics laboratory the following school year. The project consisted of 5 primary sections: **assembly and installation, optical instrumentation, pressure and temperature instrumentation, software development**, and **educational materials**.

DESIGN PROCEDURE: ASSEMBLY AND INSTALLATION

For the experiment to run, the tank needed to be pressurized to 600 psi both safely and practically. This was accomplished by attaching a **booster pump** to the shop air in the fluid mechanics laboratory to raise pressure from 120 psi to the needed 600 psi. Additionally, the tank needed to be raised up so that the nozzle would be visible to students at eye level. This required the design and construction of a table for the tank to sit on, and another table for the optical instrumentation to operate from, which were constructed based on similar projects [1]. Once the tank was placed on the table, it was attached to the wall using Swagelok fittings and piping from McMaster Carr. The entire assembly is shown in **Figure 1**.

Figure 1 – Fully Assembled Device

DESIGN PROCEDURE: OPTICAL INSTRUMENTATION

Optical instrumentation was required for the project so students who run the experiment can see compressible flow phenomena, and shockwaves in particular, in a visual manner. To accomplish this, a schlieren imager was designed and constructed to capture the shockwaves emerging from the nozzle during the experiment [2], as shown in **Figure 2**. A point light source, knife edge, camera, and two double-convex lenses were used, with supporting equipment to align and brace each component in place.

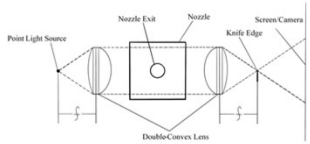

Figure 2 – Hand-drawn diagram of a Schlieren Imager

DESIGN PROCEDURE: PRESSURE AND TEMPERATURE INSTRUMENTATION

For a true study of compressible flow in the nozzle, pressure needed to be measured in the tank and at various points along the nozzle, along with a measurement of temperature in the tank. Isentropic, compressible flow, and normal shock equations were used to determine ranges and accuracies necessary for the sensors [3], and then a data-acquisition system was designed and implemented as shown in **Figure 3** to facilitate measurement straight from the device to an analog-to-digital converter.

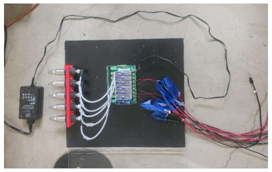

Figure 3 – Data-Acquisition System

DESIGN PROCEDURE: SOFTWARE DEVELOPMENT

To create a meaningful lab experience, a custom software package was necessary. The software reads raw data from the physical instrumentation system and optical instrumentation camera, processes it, and displays it in a visually appealing and comprehensible manner. At a high level, the software had four main objectives: display live video feed, provide live pressure and temperature data, record and save live sessions, and provide an option to export sensor data in a user-friendly format for further processing and analysis. One window is shown in **Figure 4**.

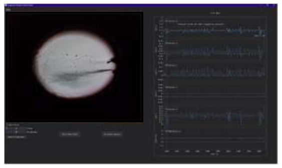

Figure 4 – Live Data-Collection Session Diagram

DESIGN PROCEDURE: EDUCATIONAL MATERIALS

A laboratory handout was generated in order to aid in this process in order to inform the students how to conduct the experiment or interpret its results. The handout carefully describes how to calibrate the pressure sensors, fill the tank, stop the filling process, run the air through the nozzle, and drain the nozzle afterwards. It also describes the theory of compressible flow as applied to converging-diverging nozzles in great detail, with additional information and visual aids included about oblique shockwaves that were not covered in Fluid Mechanics class, one of which is shown in **Figure 5**. Finally, explicit instructions on what to do for the laboratory report were written and are included in the handout.

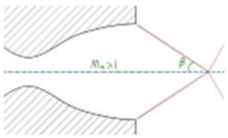

Figure 5 – Illustration of an oblique shockwave from the laboratory handout

RESULTS

Once all of the components of the project were complete, they were each tested individually. The instrumentation components appear to work well. However, the booster pump is not currently functional and must still be repaired. Additionally, the software for viewing the data is almost complete, but has not yet been tested with the instrumentation to ensure proper synthesis of the different systems. The project was mostly completed according to expectations and was ultimately a success.

SUMMARY

During the design of this project, the following tasks were completed. A high-pressure tank was placed on a custom wooden table, and then connected to a booster pump to allow it to be pressurized to 600 psi. Then, optical, pressure, and temperature instrumentation was designed and installed on the supersonic nozzle to observe compressible flow phenomena numerically and visually. Finally, software was created to allow students to view this data easily.

REFERENCES

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[2] Mazumdar, Amrita. "Principles and Techniques of Schlieren Imaging Systems." June 18, 2013. *Department of Computer Science*, 1–16. https://doi.org/https://doi.org/10.7916/D8TX3PWV

[3] White, Frank M. 2016. *Fluid Mechanics.* New York: McGraw-Hill.

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