

Executive Summary

- High-speed schlieren videos were obtained of shocks propagating in a 1-inch square cross section shock tube containing an optical test section using schlieren visualization.
- High-speed camera was used to clearly record shock wave's passage through a 3-inch test section using pressure transducer data as a trigger.
- Given shock wave images, an algorithm was developed to process the photos using the Canny edge detection and image subtraction methods.
- From this algorithm, optical time-of-flight velocity and x-t diagram were produced.
- This process refines optical time-of-flight analysis techniques for shock tunnel applications.

Background

- Shock tubes commonly used to deliver an impulse of high velocity gas.
- Schlieren imaging visualizes variations in fluid density of flow passing through optical windows
- Goal of the experiment was to develop time-of-flight (ToF) shock wave calculation program using high-speed schlieren images to demonstrate its repeatability and accuracy

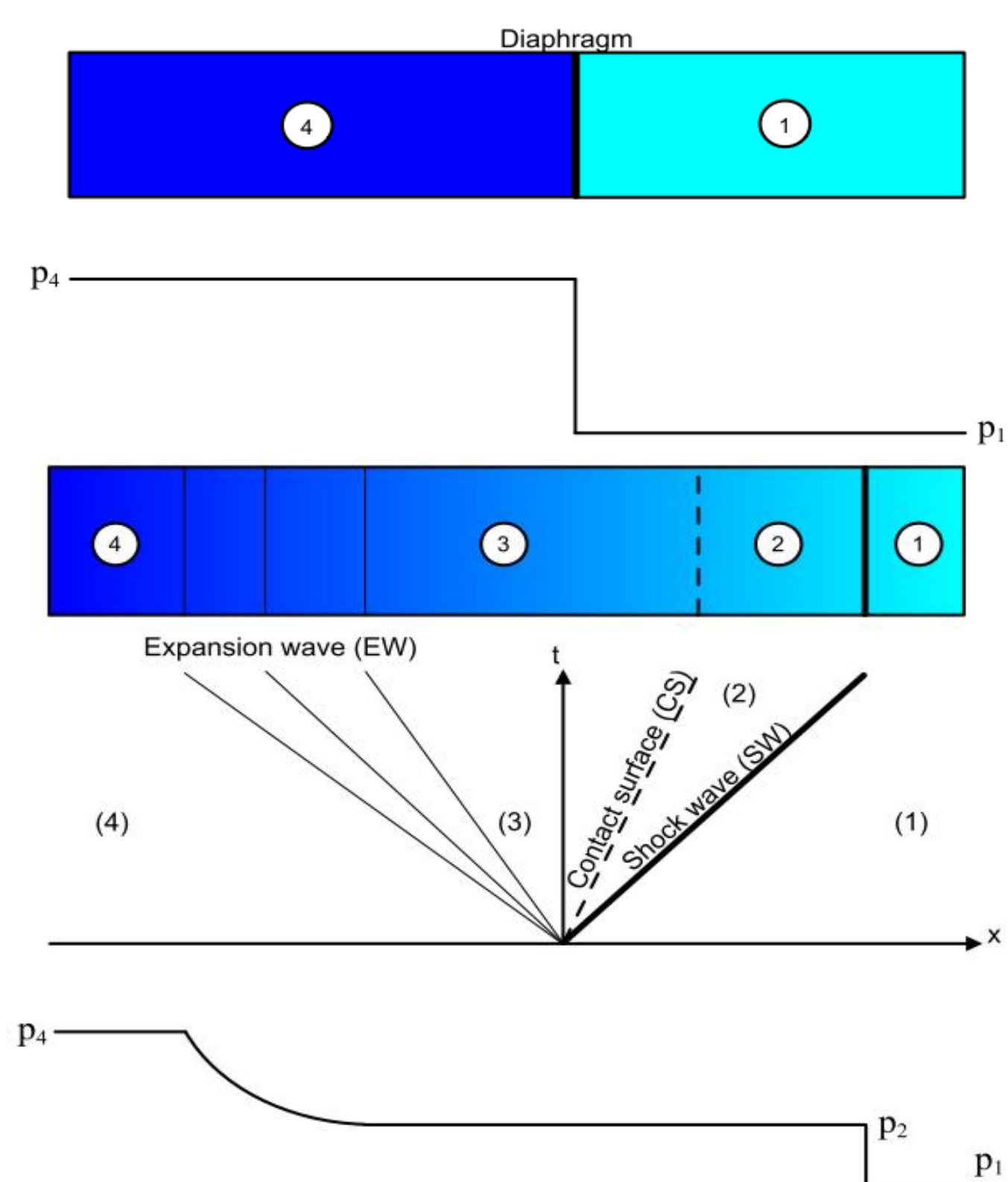


Figure 1. Shock tube model before and after diaphragm rupture

Experimental Setup

- Schlieren system utilized two tables that held source optics and receiving optics, respectively. Source table included a high-wattage white LED under active cooling, a condenser lens, an aperture, and a parabolic collimating mirror. The receiving table included an identical mirror for focusing, an adjustable knife edge holder, and a focusing lens to direct all light into the high-speed camera.
- The shock tube contained a high-pressure driver section, a low-pressure driven section, and an optical test section. The driver and driven sections separated by a mylar film diaphragm.
- Finally, high frequency response pressure transducers were installed along the length of the shock tube to collect pressure data for theoretical calculations.

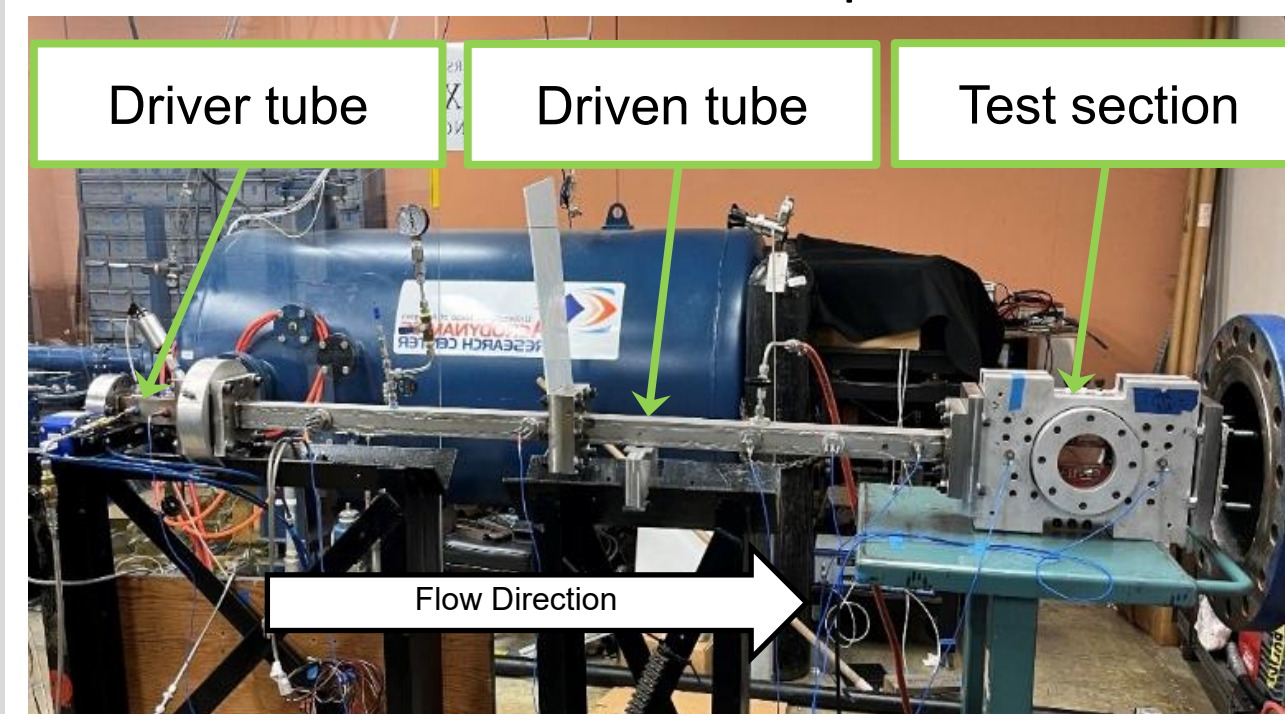


Figure 2. Shock tube setup

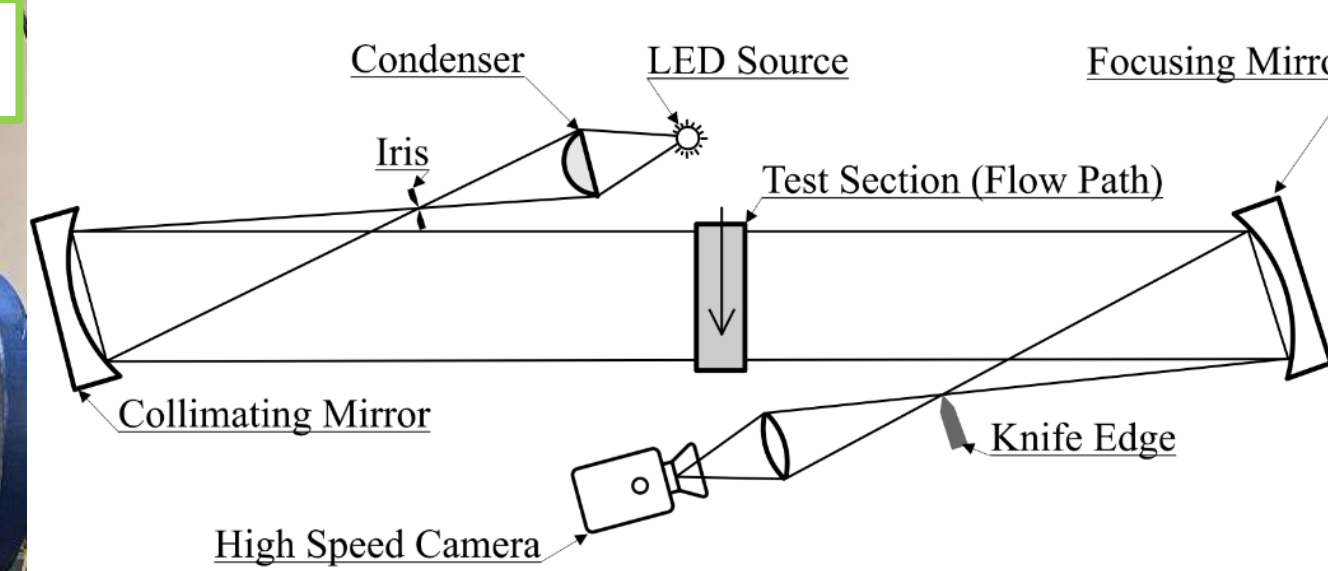


Figure 3. Schlieren setup schematic

Experimental Test Plan

- Shock tube driven section evacuated to 6 psia and driver section filled with nitrogen gas. LabVIEW program monitors and displays driver pressure while continuously sampling the high frequency transducers at 2.5 Mhz until the first transducer in driven section detects a pressure spike from shock wave arrival
- Once pressure spike detected, the pre-trigger and post-trigger data is collected while 5V TTL signal simultaneously sent to high-speed camera to trigger recording
- High-speed camera set to record 128 images at 400,000 FPS and 0.75 μ s shutter speed

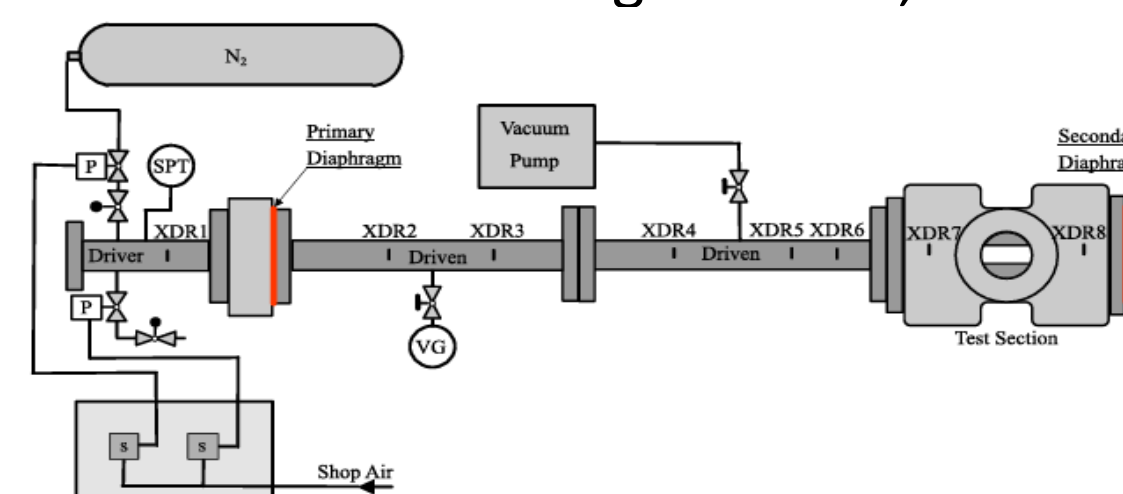


Figure 4. Shock tube schematic

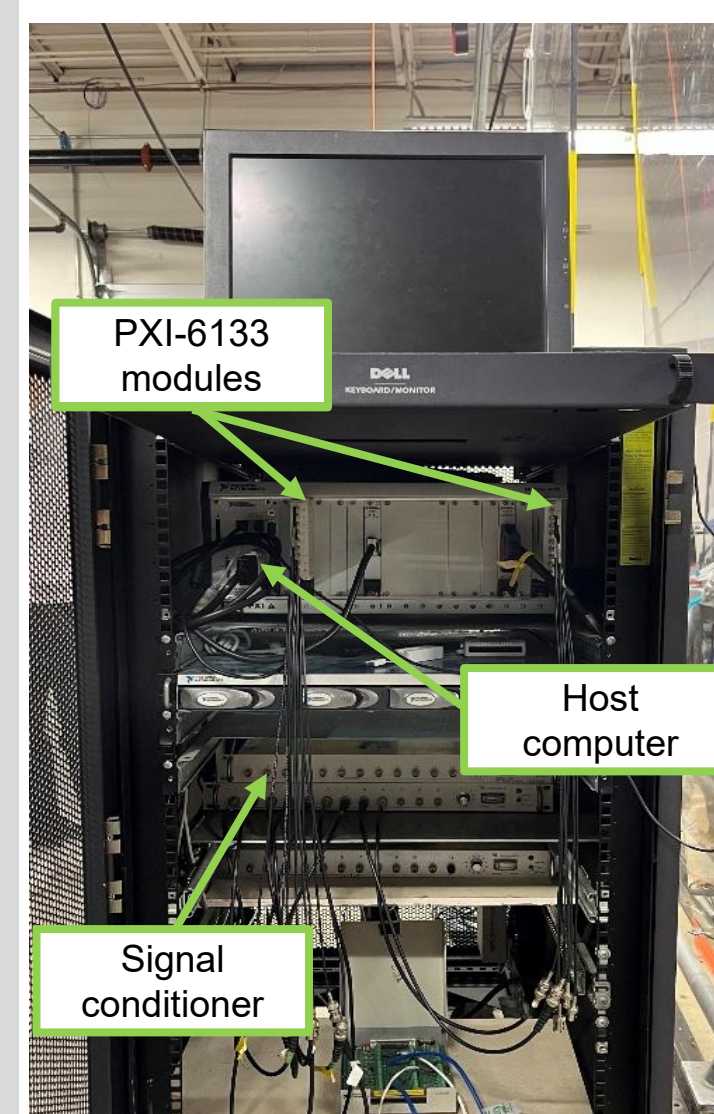


Figure 5. Data acquisition system

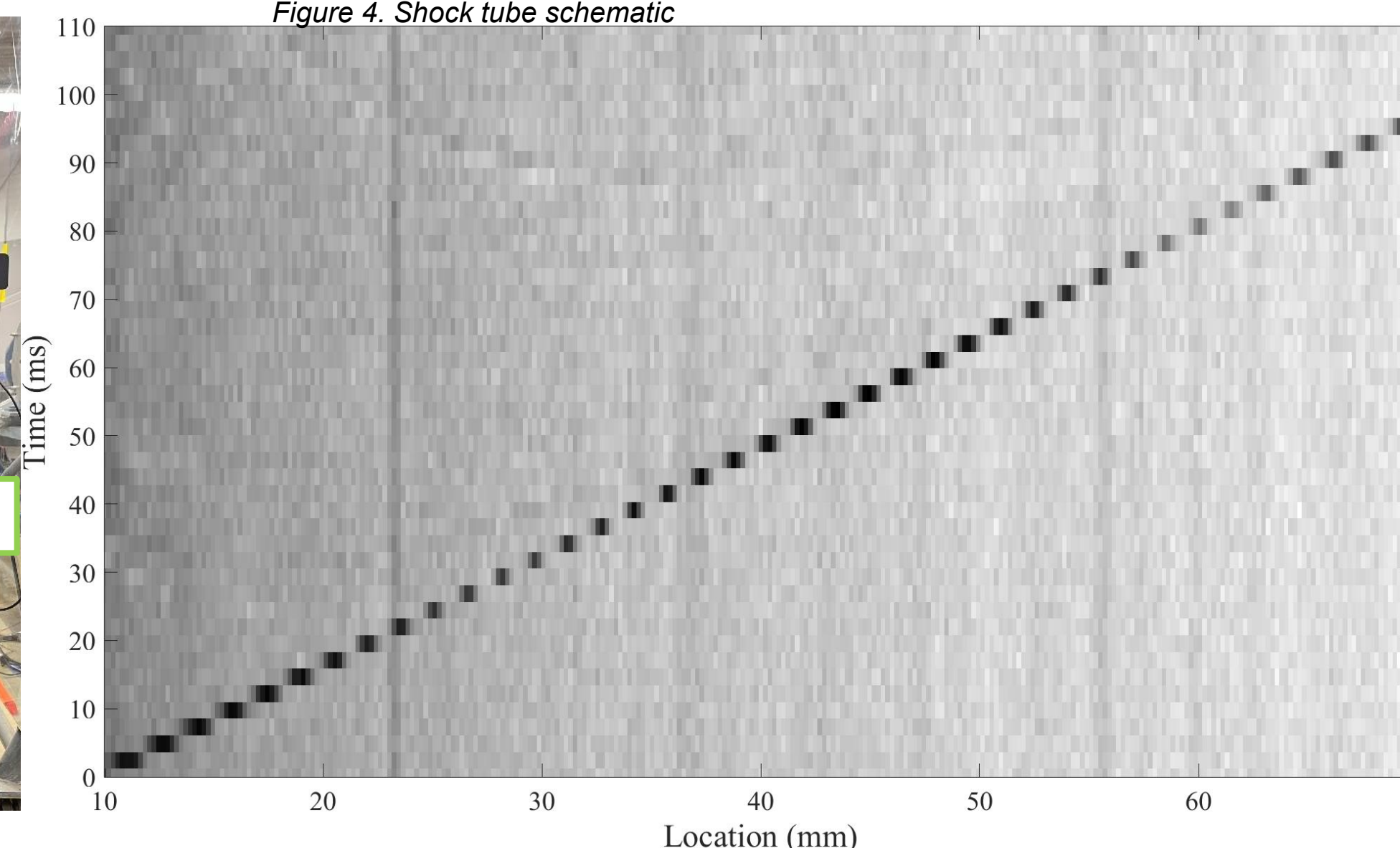


Figure 6. Experimental x-t diagram

Experimental Results

- Calibration image taken before each test and used to determine pixel to millimeter conversion factor
- Provided schlieren high-speed images from experiment, images containing shock waves were selected, subtracted and processed using Canny operator to detect edges
- Relative pixel displacement between shock wave leading edges then calculated, converted to physical distance with help of calibration procedure and compared to theory

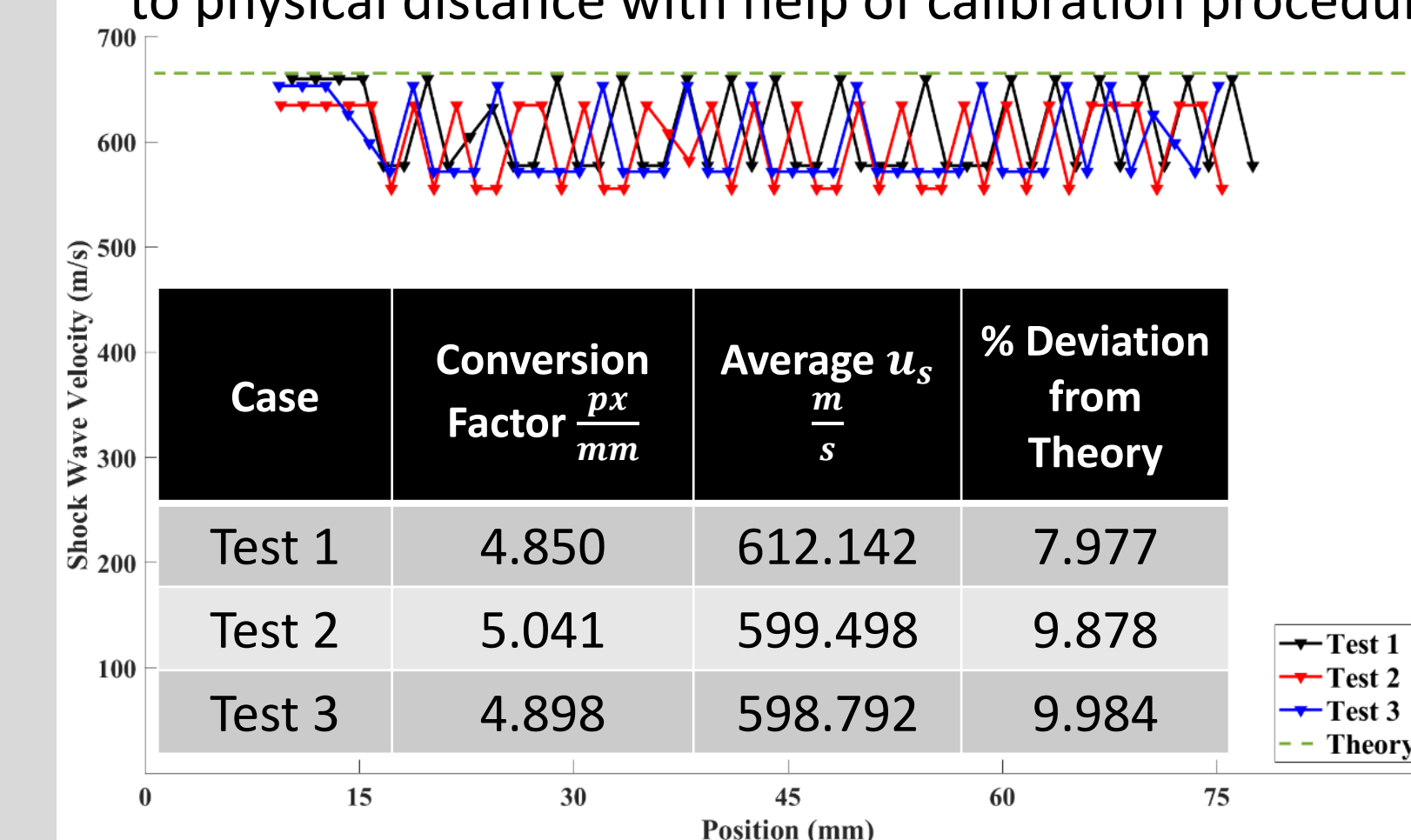


Figure 7. Comparison of shock wave relative velocities, average velocities, and percent deviation from ideal for three tests



Figure 8. Single frequency Ronchi ruling calibration target used for experiment

Conclusions

- This experiment investigated the use of the Canny edge detection algorithm as a tool in calculating time-of-flight shock wave velocities for shock tubes.
- Digital image subtraction was shown to alleviate the impact of window scratches and imperfections on edge detection algorithm.
- Through correlation of detected edge pixel locations in the shock wave images to physical distances using a calibration procedure, average shock wave velocities of 3 tests were calculated and compared to theoretical shock wave velocity found through initial fill conditions.
- Lastly, schlieren images of shock wave propagation were post-processed digitally to create an experimental x-t diagram of the shock wave trajectory

References

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