Experimental Study of a Shock-accelerated Water Layer

With imaging and velocity measurement

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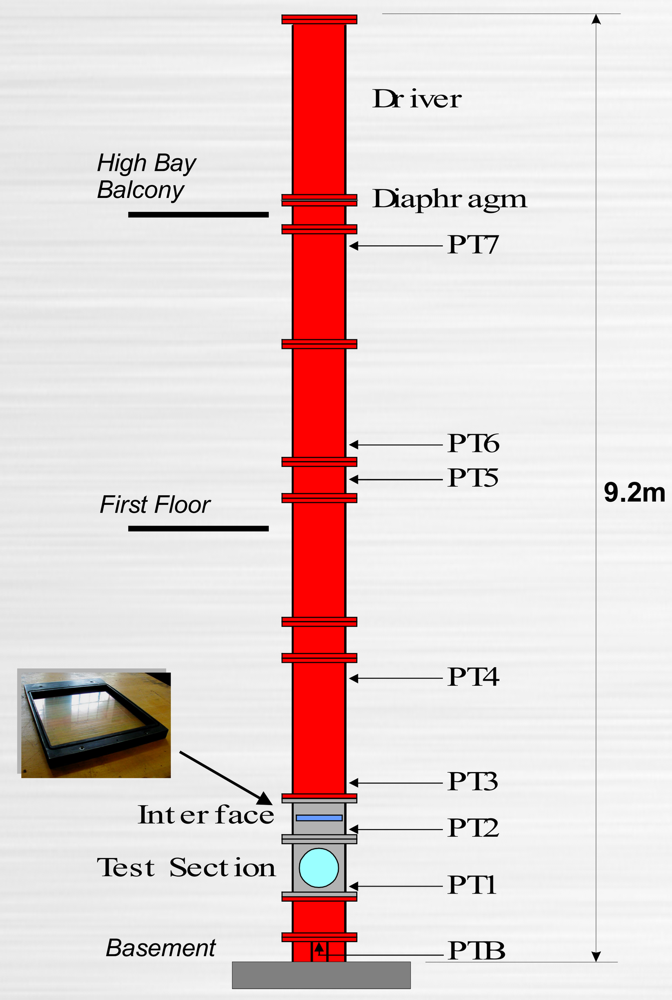
Introduction

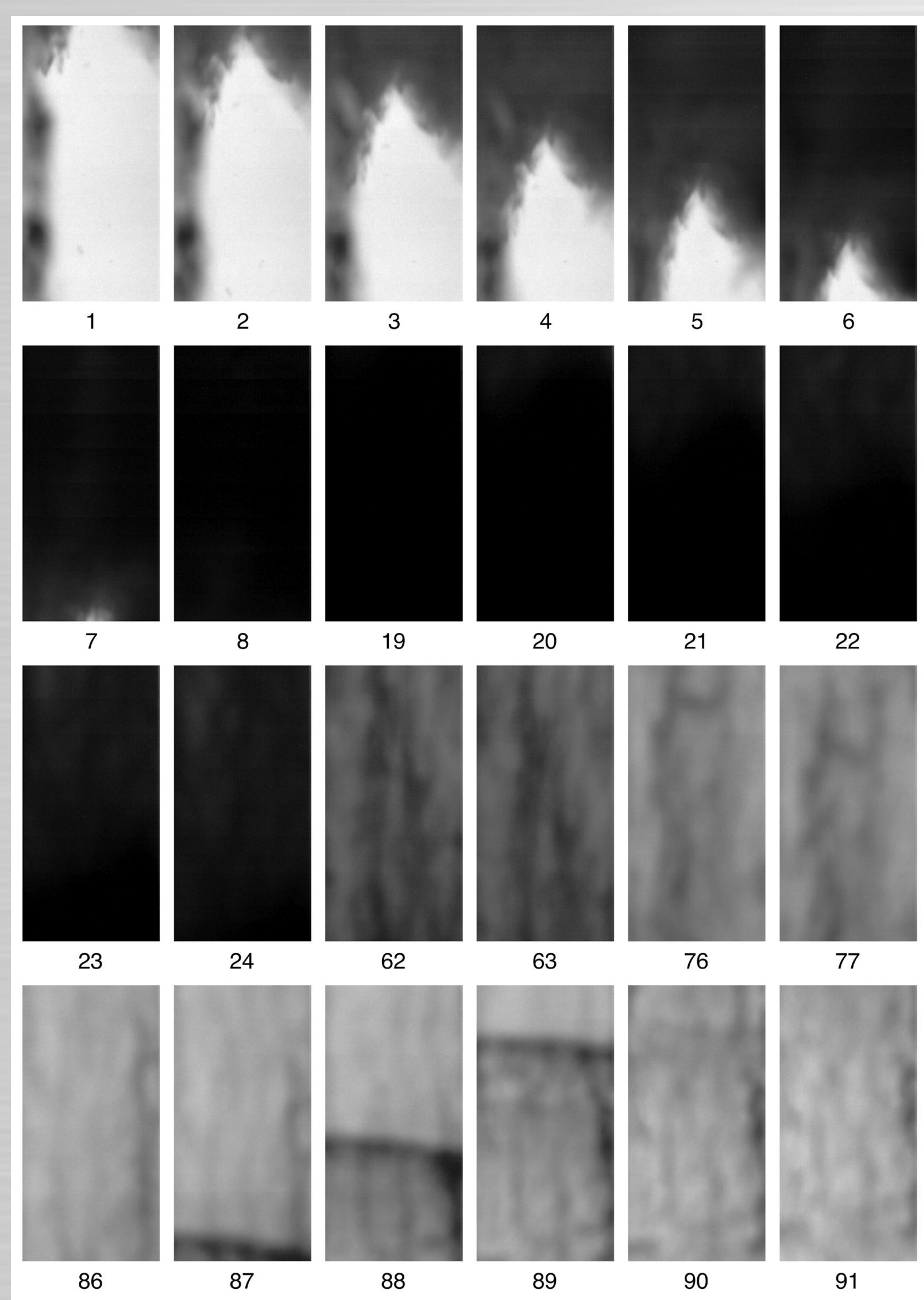
- A large vertical shock tube is used to experimentally investigate a flat water layer subjected to a shock wave.
- The shock wave accelerates the shocked liquid layer down the shock tube where it is imaged in the test section to study the shock induced breakup.
- Pressure history along the tube and the end-wall are measured to study shock mitigation and impulsive force due to the water layer.

The Shock Tube

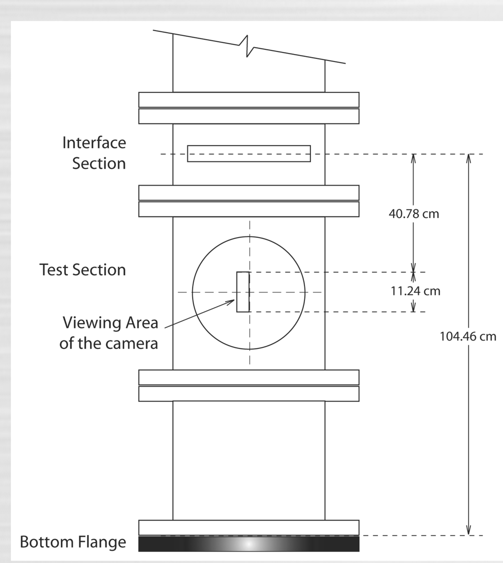
- 9.2 m long, vertically oriented.
- Square internal cross section, 25 x 25 cm.
- Up to Mach 5 into atmospheric air.
- Water layer supported by 1 μm Mylar film.



High-speed Cinematography



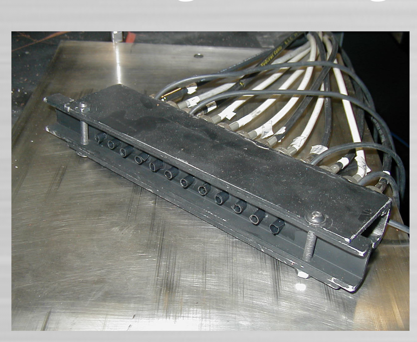
- High-speed digital camera at 30,000 fps
- 128 x 256 pixel resolution
- Back lighting with continuous white light source
- Field of view: 3.8 x 7.6 cm
- Image sequence from M=3.04 shock onto 12.8 mm thick water layer

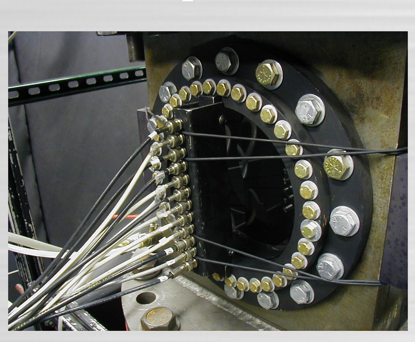


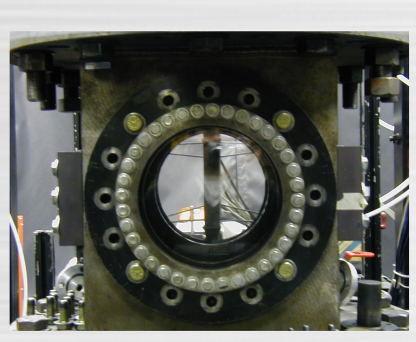
- Frame 1-7: leading edge
- Frame 19-24: trailing edge
- Frame 87-90: reflected shock

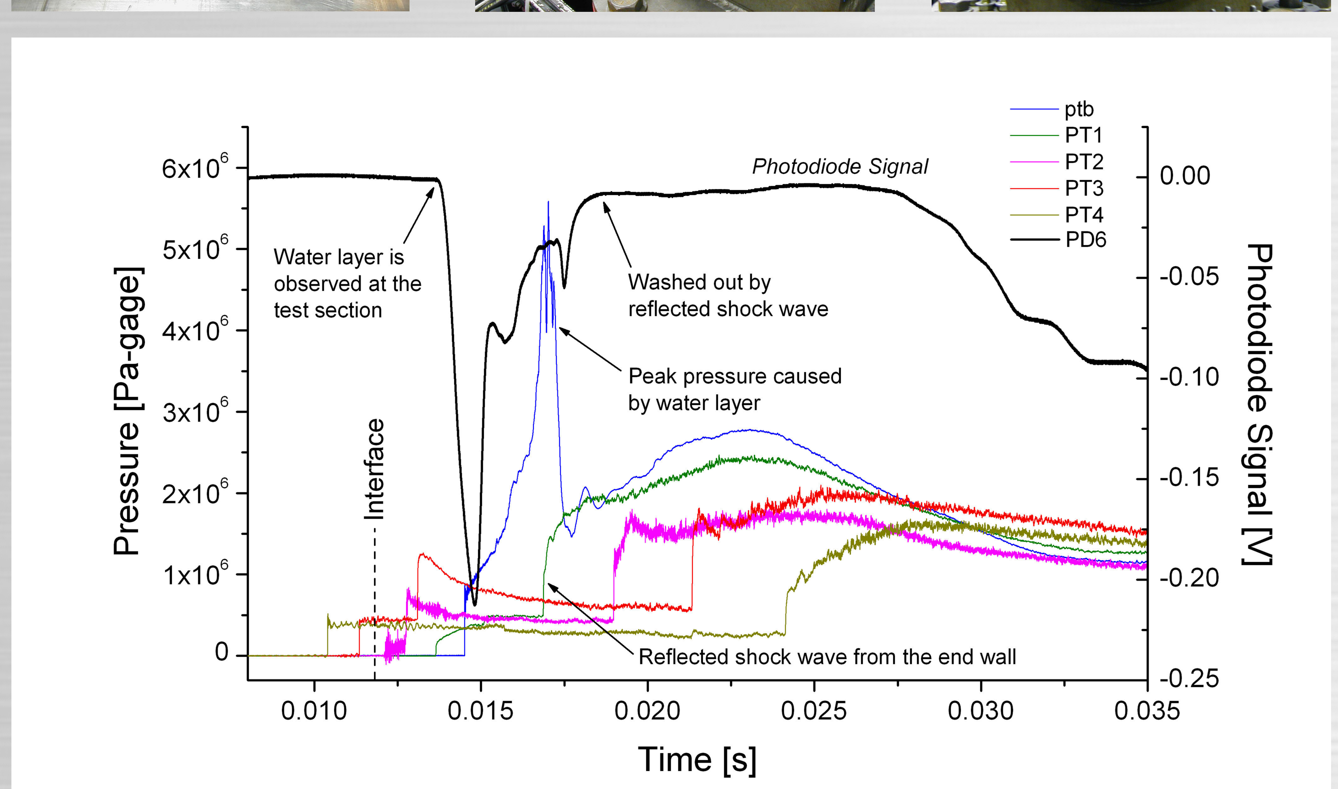
Velocity Measurement: away from the end-wall

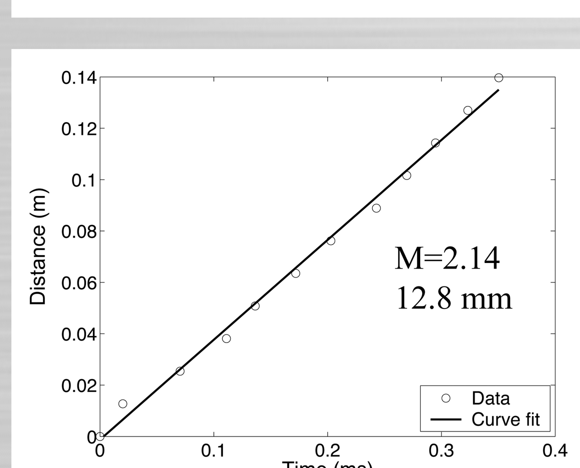
- Photodiode array: 12 sensors, 1.27 cm apart.
- Backlight through semi-transparent screen.









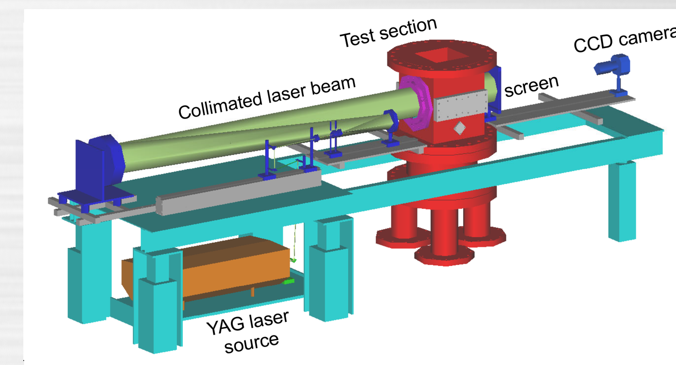


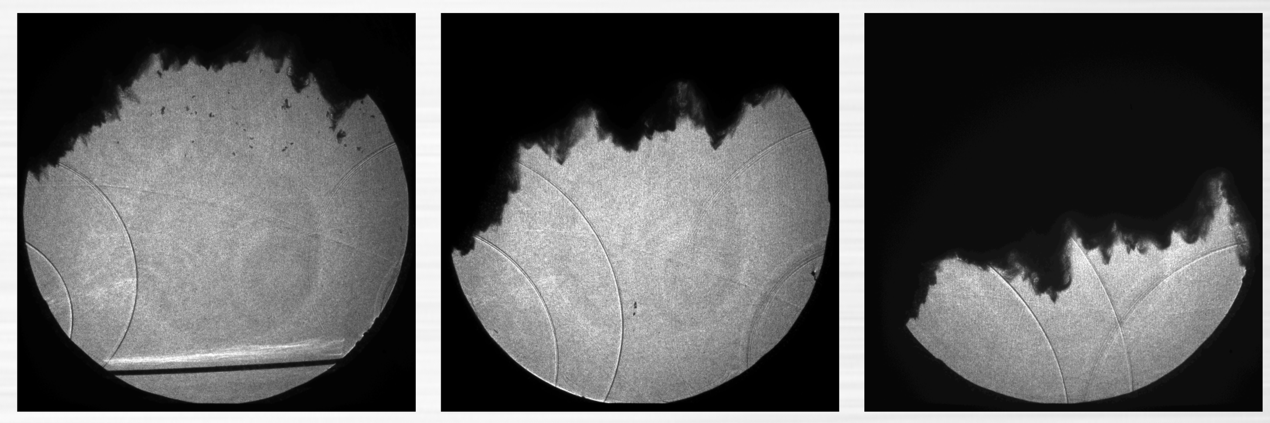
- Tests at M=2.14 and M=3.20, 46 cm below initial position.
- The leading edge of the water travels at nearly constant speed (shocked-gas particle velocity ±12%) regardless of the initial thickness.
- Water layer decelerates as it approaches the end-wall.

Imaging Techniques

Shadowgraphy

- Nd:YAG laser (532 nm), 10 ns pulse.
- Beam expanded and collimated to 25 cm diameter.
- Image focused on semi-transparent screen and recorded with a scientific grade high resolution CCD camera.





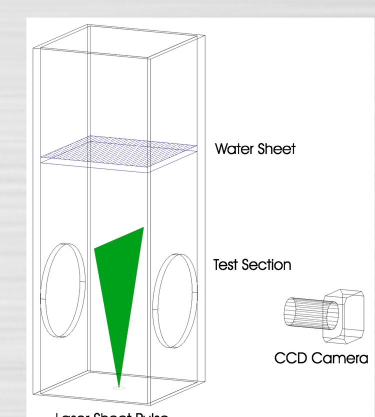
1.32 ms *1.43 ms* *1.47 ms*

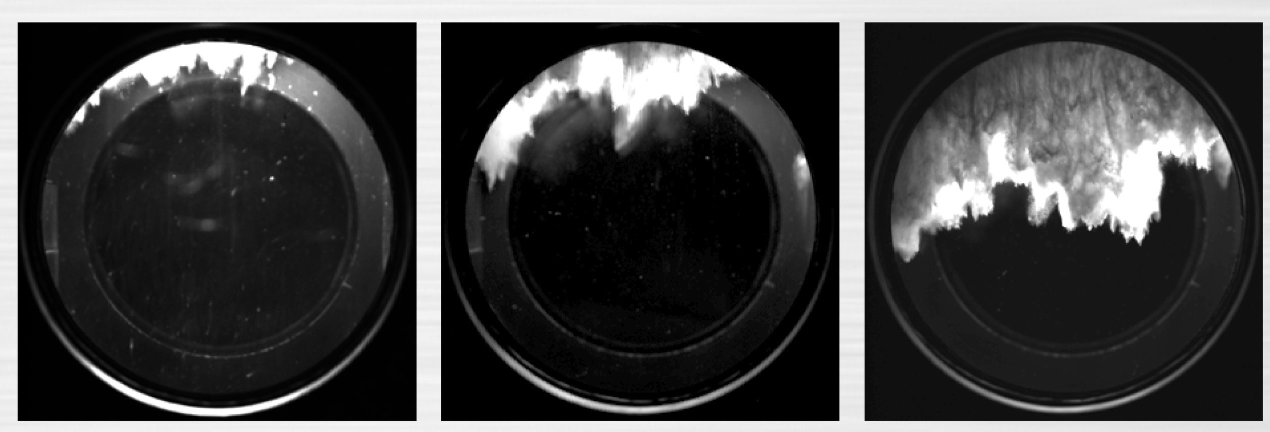
- M=2.68 in argon.
- initially 6.4 mm thick of water.
- Time measured from initial shock-water contact.

- A projection (2nd derivative of density) of the entire shock tube cross section, including the shock wave, is visible with this technique.

Planar Imaging

- Nd:YAG laser (532 nm), 10 ns pulse.
- Expanded to a laser sheet with 15° divergence and 1 mm thickness.
- Mie scattering/absorption by water.
- Cross sectional image recorded with scientific grade CCD camera.

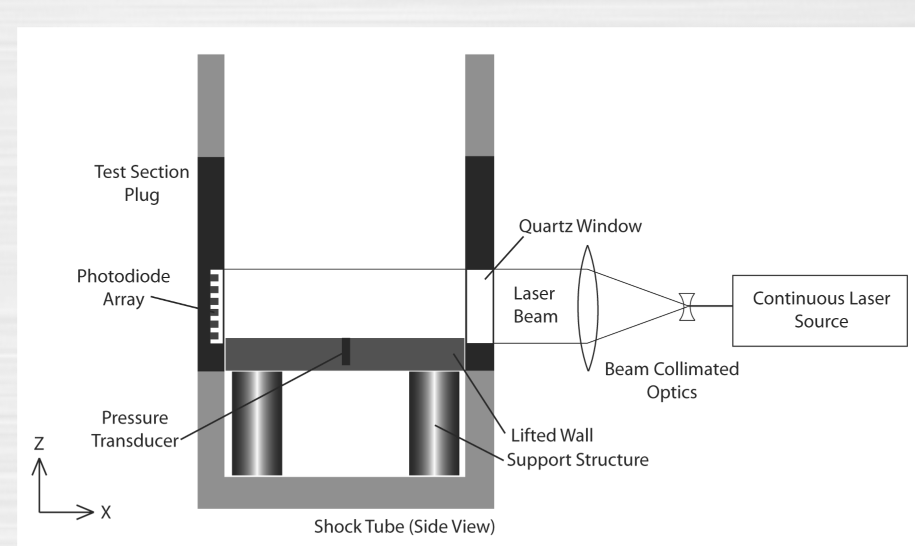




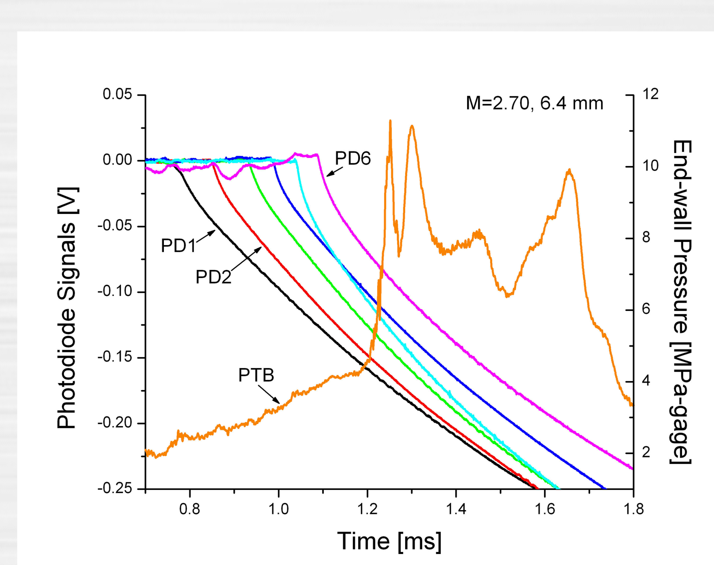
2.12 ms *2.31 ms* *2.62 ms*

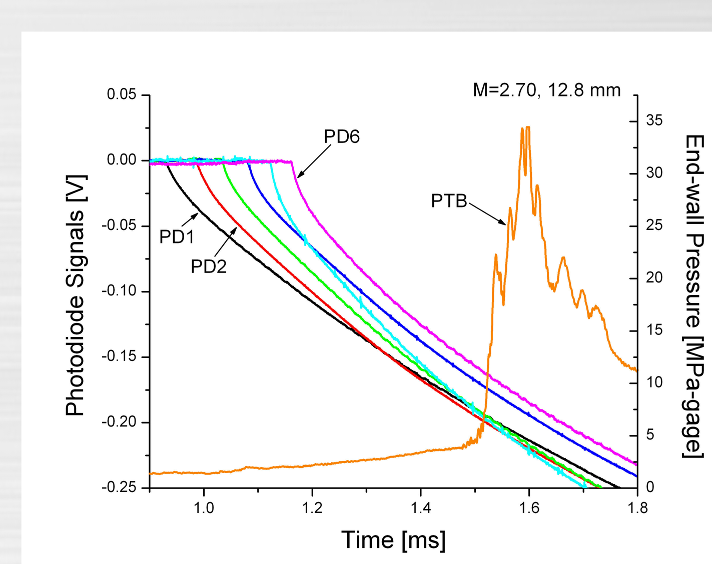
- M=2.14 in argon.
- Initially 12.8 mm thick of water.
- Time measured from initial shock-water contact.

Velocity Measurement: near the end-wall



- A false wall inserted on the bottom flange to determine velocity on impact.
- 6 blue light sensitive photodiodes, 1.17 cm apart.
- Illuminated by a collimated continuous argon-ion laser beam (mixed wavelength 457.9-514.5 nm).

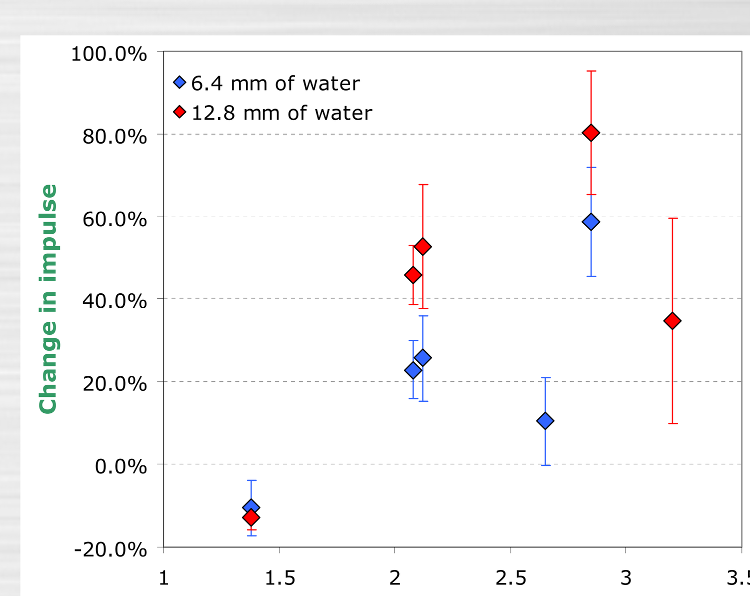




- The leading edge of the water travels 65% more slowly than the particle velocity for a 6.4 mm layer and 52% more slowly for the 12.8 mm layer due to the reflected shock.
- Due to interaction with reflected shock, water layer slows down before reaching the end-wall.

End-wall Impulse

- Pressure measurements at the end-wall are integrated over time.
- The impulse is compared to a test without water at the same Mach number.
- At M=1.38, the impulse decreases
- At higher M, the impulse increases by up to 90% due to the water layer.



Future Work

Since the main body of the water layer is not visible in either shadowgraphy or planar imaging, X-ray radiography will be used to measure the volume fraction of the layer. This will yield a quantitative measure of the mixing within the layer. A new interface section of the shock tube will accommodate several layers of water for studying the mitigating effects that multiple layers may provide compared with a single layer.