Experimental Hydrodynamics Model for First Wall Protection in IFE Reactors

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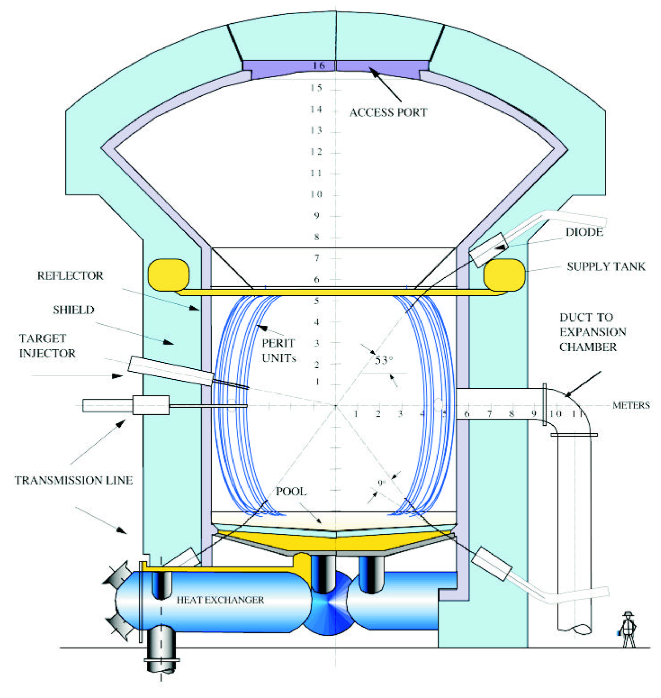
Schematics of the key features of Proposed IFE reactors

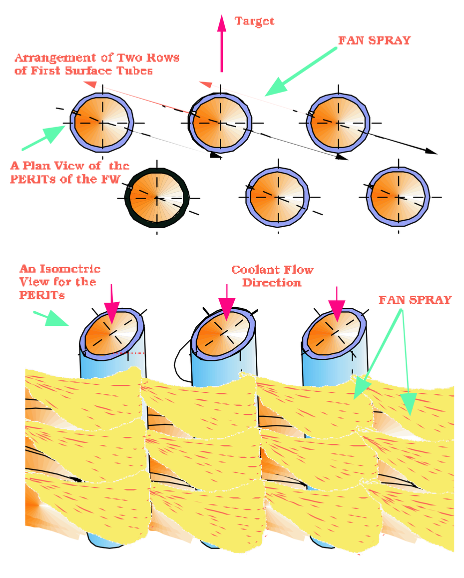
An inertial fusion energy (IFE) reactor design has been proposed as an energy production source for the future..
The figure on the right shows a schematic of the LIBRA-SP facility which includes many of the common features inherent in IFE reactor designs. Some of these common features are:

- The use of light/heavy ion beams, lasers, or X-rays to ignite a deuterium-tritium (DT) fuel, resulting in the release of highly energetic particles followed by a shock-wave.
- Hollow, cylindrical cooling tubes located on the internal perimeter of the reactor vessel (which are filled with a coolant such as LiPb) serve several purposes.
  - Protect the first structural wall of the reactor by absorbing debris from the ignition of the DT fuel.
  - The LiPb can be used to breed tritium which can be used to make more DT fuel.
  - The LiPb carries heat away from the reactor chamber to the heatexchanger, where water is turned to steam and used to power a turbine to create electricity.
- Two types of proposed cooling tubes are:



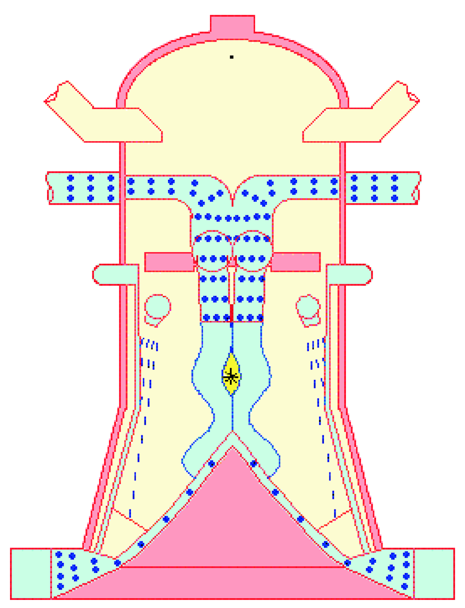
Cross-Section of the LIBRA-SP Target Chamber

PERIT (PErforated RIgid Tube)



First Surface Protection by Fan Spray

HYLIFE-II



PERIT design for cooling and protection of the first walls of the cooling tubes in an IFE reactor involves fans of LiPb which form jets tangential to the tubes. The fans create a sheet that protects the tubes and leads to the production of tritium.

HYLIFE-II is an IFE power plant that uses a heavy-ion driver. The chamber uses liquid jets of Flibe (a fluorine, lithium, beryllium molten salt) to protect the fusion chamber from neutrons. This results in long lifetime components and low environmental impact.

- The goal is to determine if the cooling tubes in the reactor design will be able towithstand the high impact and diffraction of a shock wave created by ignition of the DT fuel.

Objectives

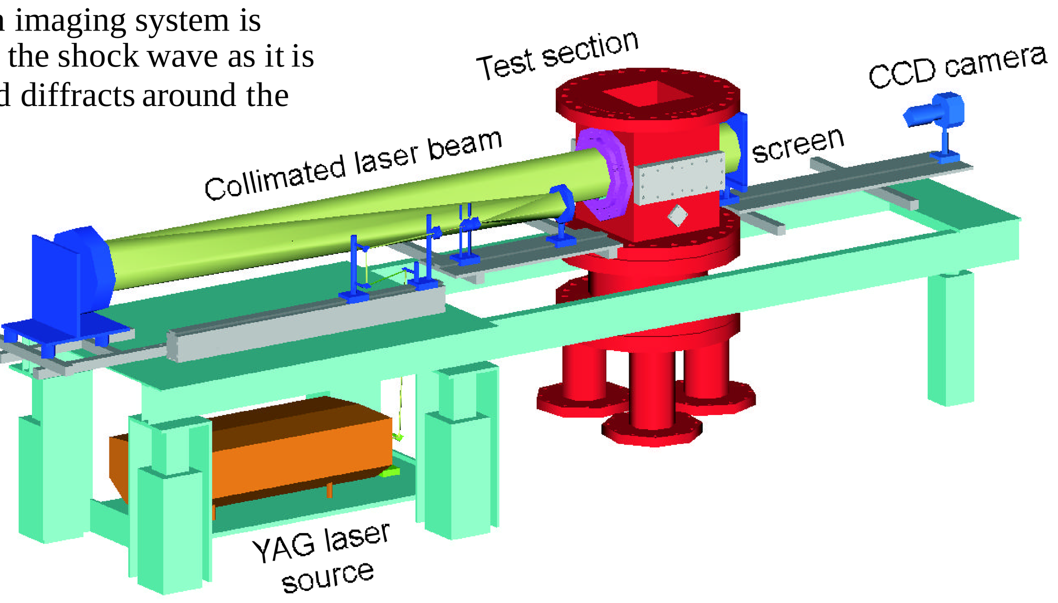
To study the impulsive force from a shock wave on a cylindrical body to model an IFE reactor setting.

- Use pressure transducer data to determine the pressure distribution around the cylinder.
- Use this data to determine the direction and strength of the forces acting on the cylinder during the shock interaction.
- Use the experimental data to compare and validate numerical simulations of shock interactions with blunt bodies.

To study the instability and breakup behavior of the shock accelerated water sheet and the impulsive force from such on a wall and a cylinder body in an IFE reactor .

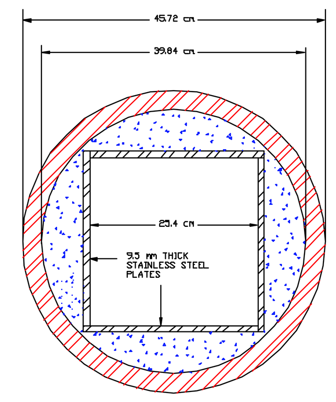
Optical Diagnostic

A shadowgraph imaging system is used to capture the shock wave as it is incident on, and diffracts around the cylinder.

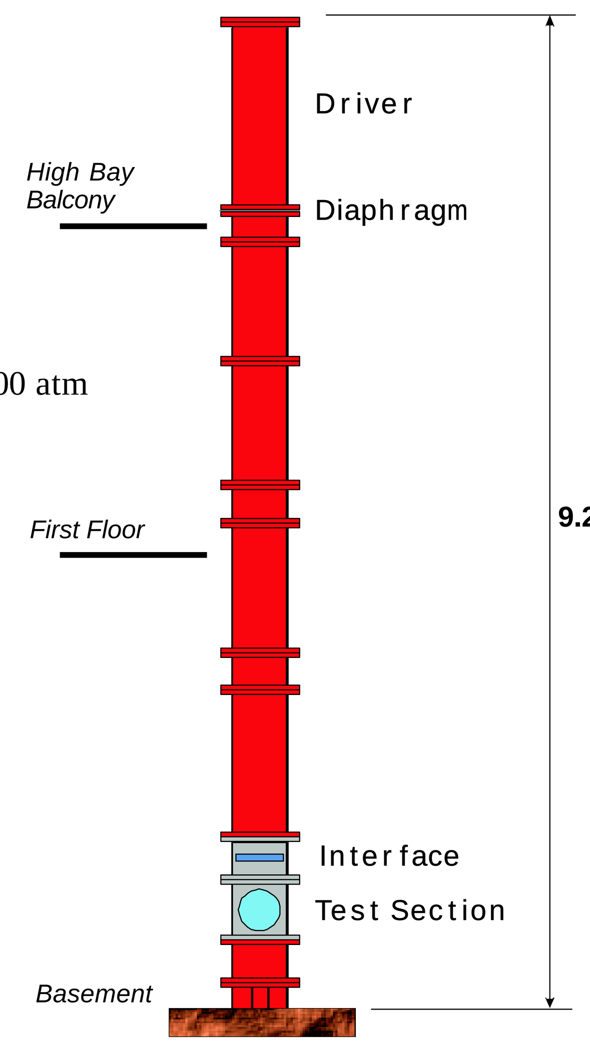


Schematic of Shock-Tube

Total Length 9.2 m
Driven Length 6.8 m
Square DrivenArea 0.25 m
Maximum Driver Pressure 200 atm

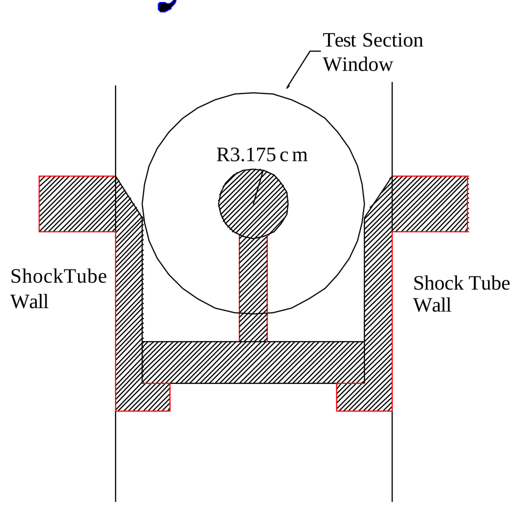


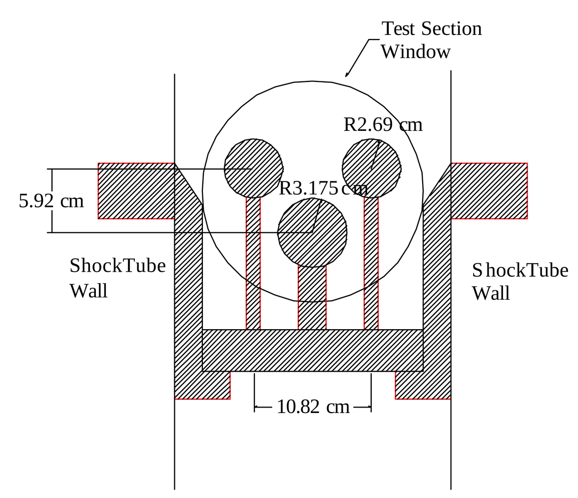
Cross-section view of the shock-tube. Inside is a square tube filled the void with concrete.



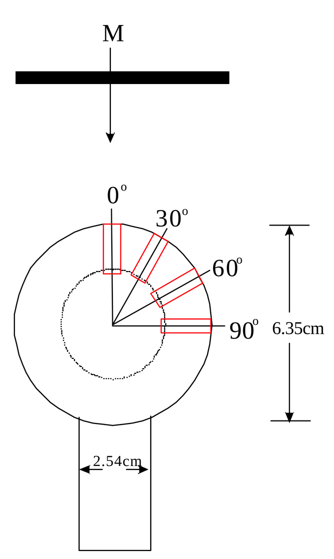
Above is a schematic of the entire shock tube. This tube differs from other shock tubes in that it is capable of producing large Mach number shocks into a large square cross-sectional driven area at initially atmospheric pressure.

Cooling Tubes Modeled as Cylinders





There are two configurations studied experimentally for modeling the shock wave loading of the cooling tubes. Initially, a single cylinder was mounted in the center of the test section. The next set of experiments included two cylinders mounted above the center cylinder to study the effect one bank of cooling tubes would have on the next.



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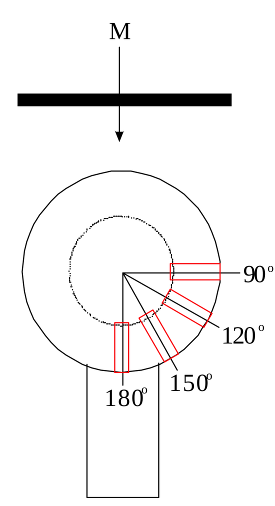
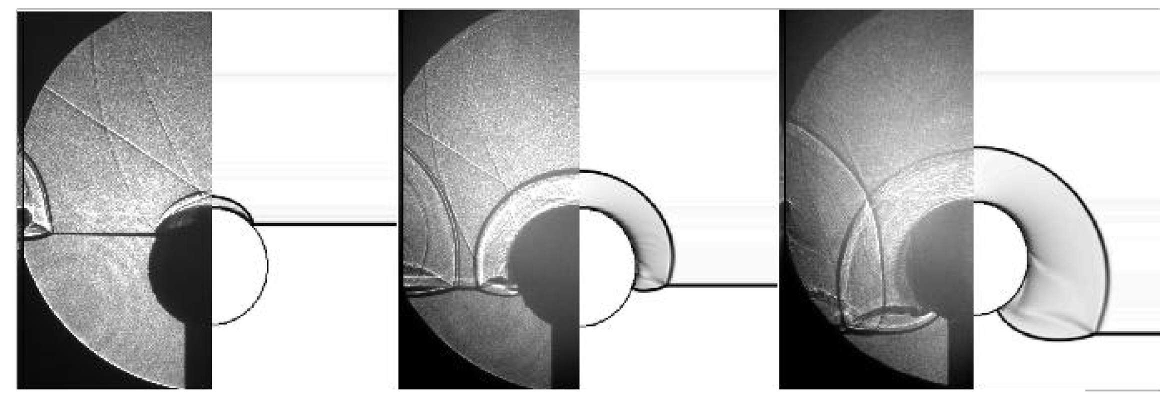


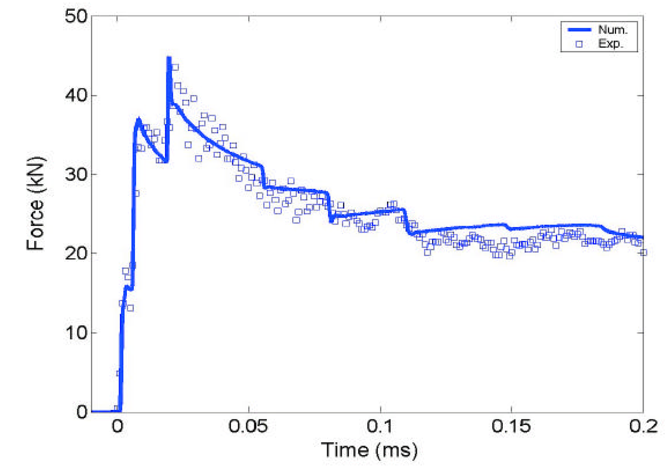
B

- Four pressure transducers are flush mounted in increments of 30° from the top of the cylinder, to yield pressure measurements at 0°, 30°, 60° and 90°.
- The cylinder can be rotated by90°, as shown in figure B, to yield three more pressure measurements at 120°, 150° and 180°.
- Twoaccelerometers are mounted perpendicular to each other to measure the acceleration and frequency response of the cylinder.

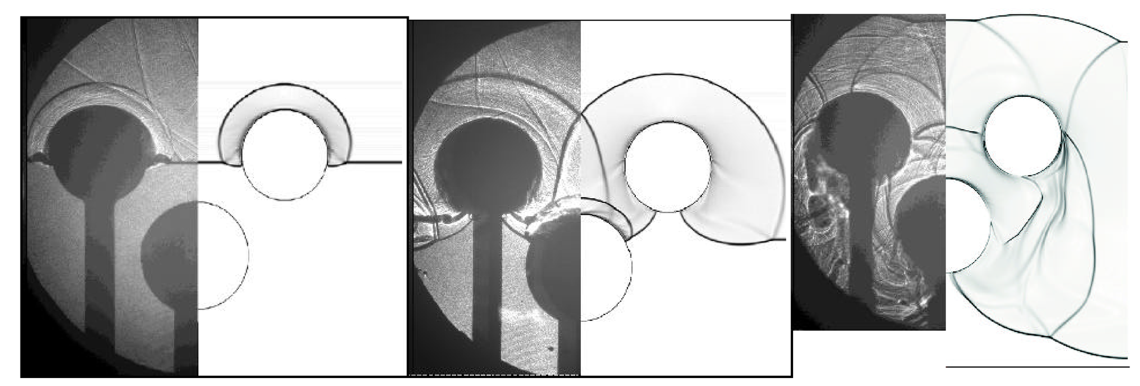
Diffraction Patterns and Impulsive Force



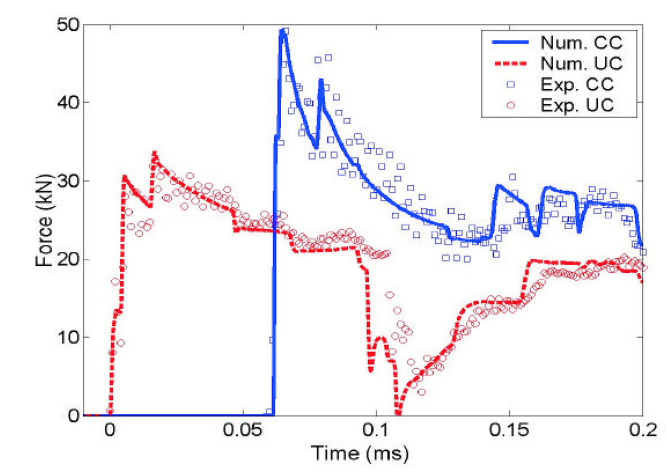
11 µs 47 µs 83 µs



These are shock diffraction pattern results for the single cylinder and three cylinder experiments. Time zero corresponds to thetime the initial planar shock wave is first incident on the top of the cylinder (the upper cylinder in the three cylinder configuration). Shock diffraction patterns are compared experimentally (the left images) with the results of the numerical simulation (right images). The geometry of the shock diffraction compares well atthe earlier times, with viscosity (not incorporated in the code) and three-dimensional effects coming into play at the later times.



36 µs 77 µs 191 µs

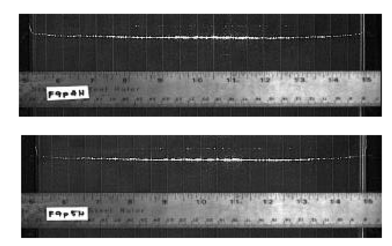


The vertical downward force onthe cylinders is calculated by integrating the pressure measurements around the cylinder as a function of time. It is seen in the three cylinder configuration that the lower (center) cylinder is subjected to a much higher force than the upper cylinder, or the single cylinder configuration. Thehigher force is due to the shock strengthening that occurs as the initially planar shock goes through the area contraction between the two upper cylinders.

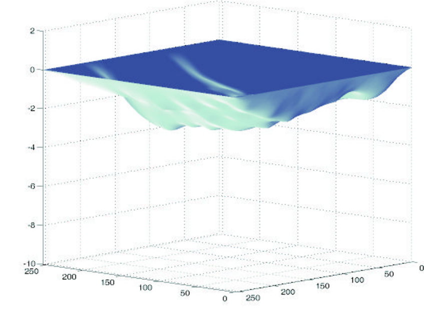
Water Sheet Interface

Water is the simplest model to study the hydrodynamics behavior of the liquid metal used in IFE reactors since it has comparable hydrodynamics properties to the liquid metal. Flibe in the HYLIFE-II reactor has approximately twice the density of water and roughly the same viscosity, at 650 °C (1140 °F). 400cc ofwater is siting on a mylar film supported by fishing line suspended across the cross-section as shown in the picture below. Initial deflection of the water sheet is measured usinglaser sheet and then a 3D mapof the deflection is constructed

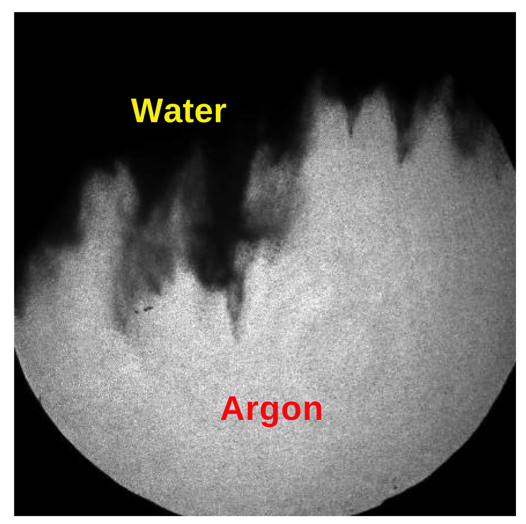
mylar film to support water

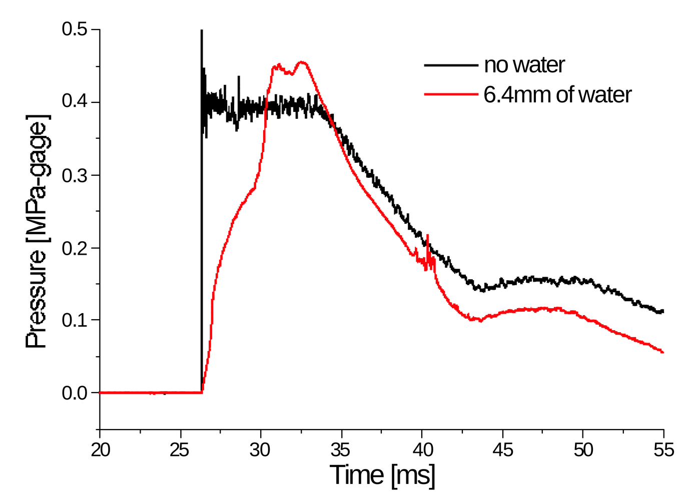


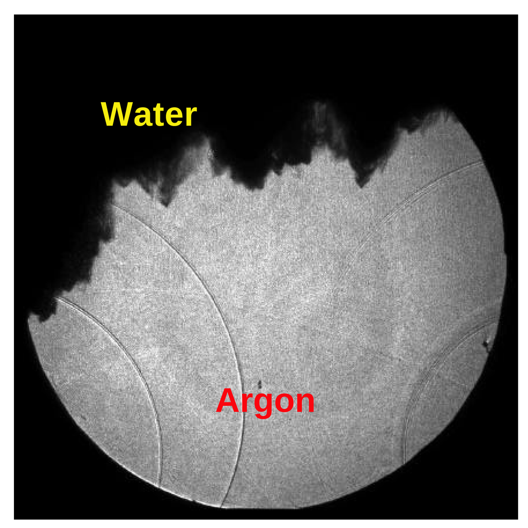
Initial deflection measured by laser sheet

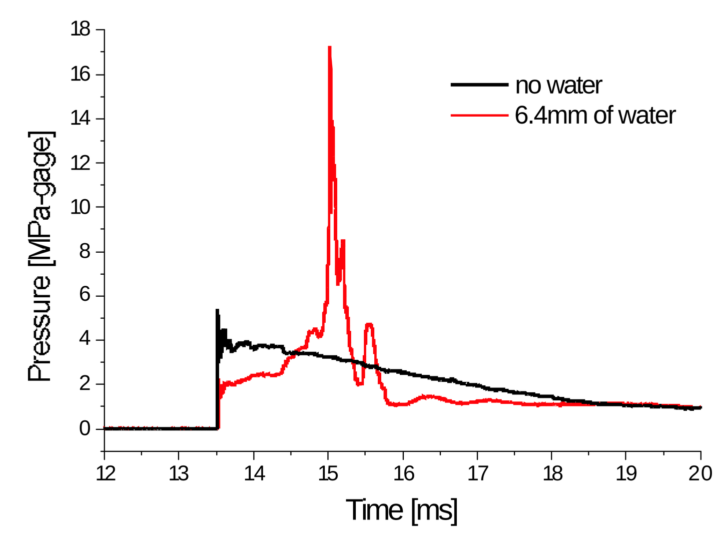


3D map of the lower surface can be calculated









The water sheet interface is inserted into the interface section as shown in the shock-tube schematic. Then a planar shock wave hits thewater interface which accelerates the water down into the test sectionwhere the picture is taken. The first picture on the left is a shadowgraph image of the water interface being accelerated by a Mach 1.38 shockwave. Plot of pressure history at the bottom of the shock-tube shows that the peak pressure is sightly higher in the presence of the water interface. However the overall impulse (area under the plots) is qualitatively comparable to theno water case. The lower picture on the left is a shadowgraph image of the water interface after being accelerated by a Mach2.65shock wave. The liquid-gas interface becomes more clear since the higher pressure is pushing the liquid through the gas. The pressure peak at the bottom in the present of water is much higher than the nowater case, but again, the impulses are qualitatively comparable. This water sheet interface will be used to hit the cylinder in the same way as the shock cylinder experiments in order to study the hydrodynamics behavior of liquid breakup around the cooling tubes.