Experimental Investigation of a Shock-Accelerated Liquid Layer
with Imaging and Pressure Measurements

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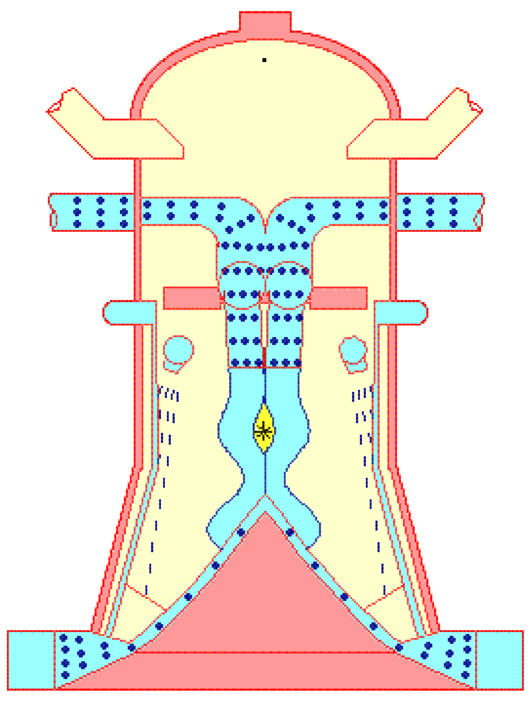
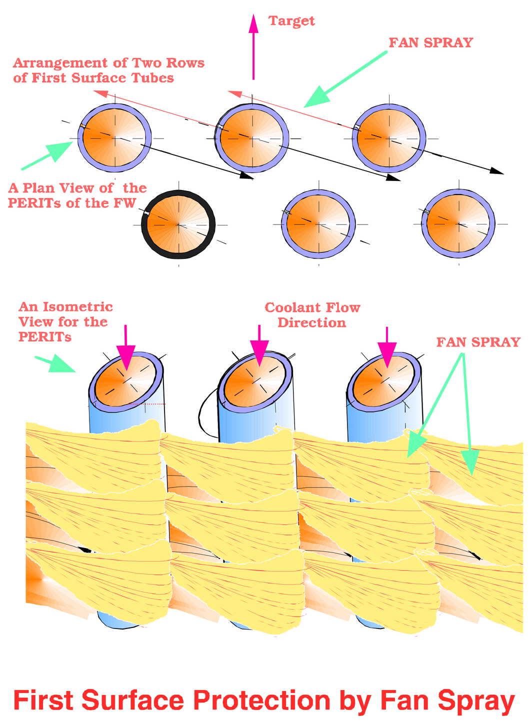
Introduction



HYLIFE-II design*



PERIT design

The inertial fusion energy (IFE) reaction results in a blast wave that emanates from the center of the reaction chamber to the first wall of cooling tubes. One proposed idea to protect the first wall from fusion debris is to unitize liquid wall protection.

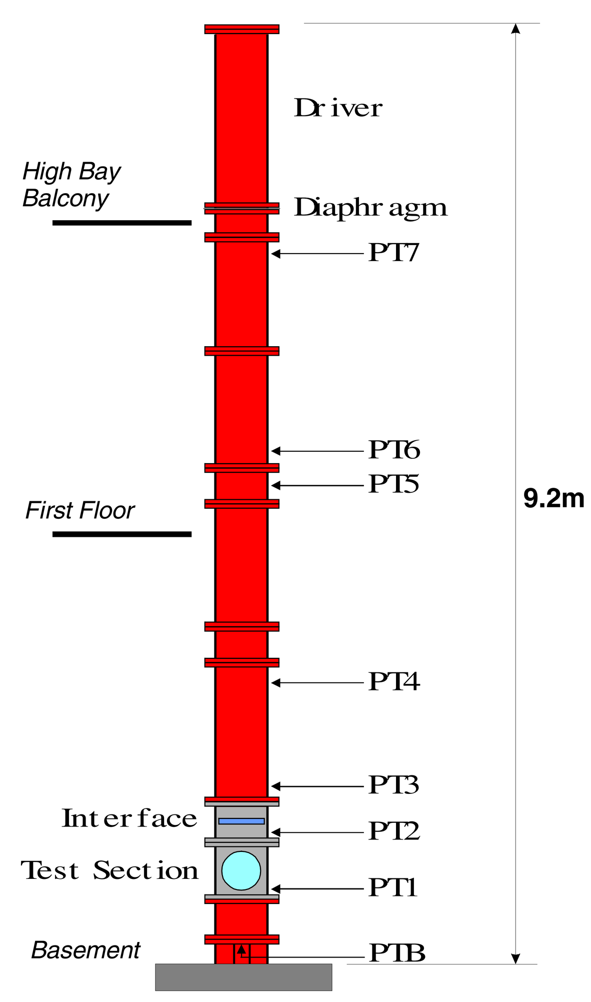
** Ref: www.nuc.berkeley.edu/thyd/icf/chamber.html*

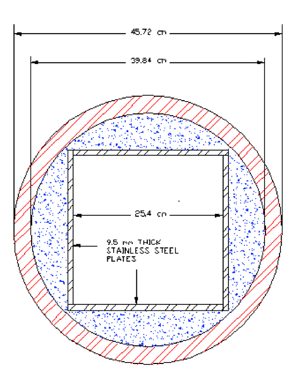
One issue associated with this concept is the pressure loading of the reactor first wall from the shock-accelerated liquid layer. To study this a shock tube is used to experimentally investigate a flat liquid (water) layer subjected to a shock wave. The shock wave accelerates the shocked liquid layer down the shock tube where it is imaged in the test section to study breakup. The pressure histories are digitally recorded to determine the impulsive force.

Shock Tube Experiment

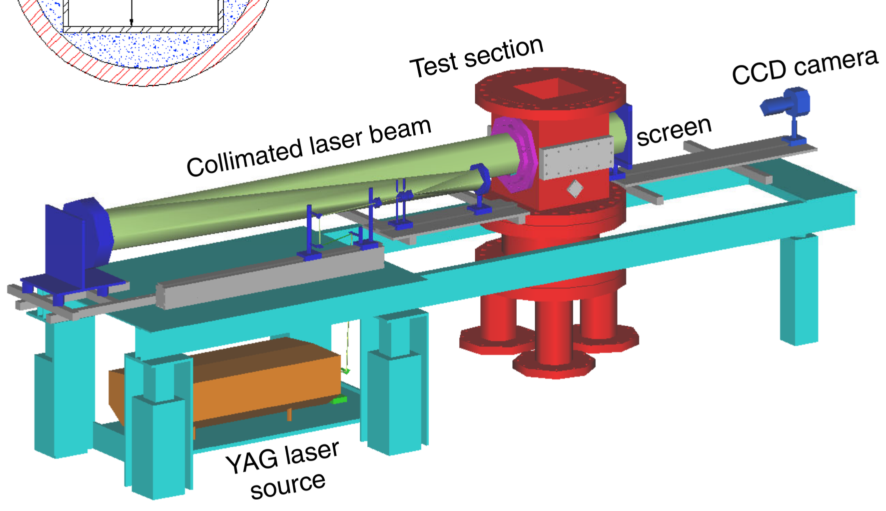
The driven section is filled with argon at atmospheric pressure and the water layer is located in the interface section. Pressure transducers are flush-mounted along the inside wall, labeled PT1-7, and the end-wall (PTB) of the shock tube to measure dynamic pressures.

- The flat water layer is supported in a square frame with a thin mylar film and nylon supporting wires.
- Two thicknesses of water layers are studied (6.4 mm and 12.8 mm) at several different Mach numbers ranging from 1.34 - 3.20.

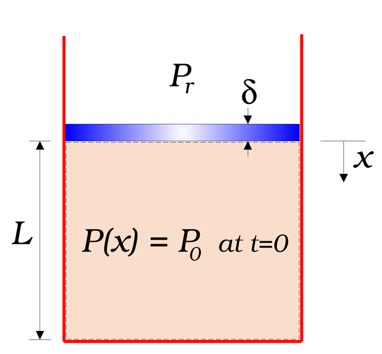




Shadowgraphy technique is used to image the shock-water layer at the test section. A laser pulse is used as a light source and the image is taken with a CCD camera. The laser beam is expanded to the diameter of the test section windows, collimated, and then steered through the test section on to a screen where the CCD camera images.



Theoretical Model

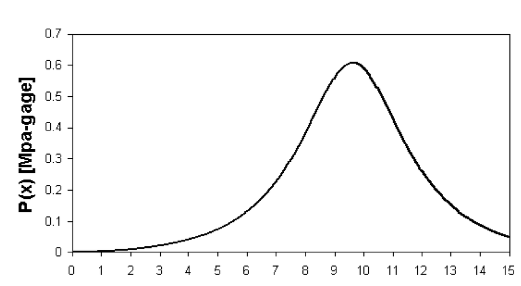


$$P_r - P(x) = \rho\delta \frac{d^2x}{dt^2}$$ Force balance

$$P(x) = P_0\left(\frac{L}{L-x}\right)^{\gamma}$$ Isentropic assumption

$$\frac{d^2x}{dt^2} = \frac{1}{\rho\delta}\left[P_r - P_0\left(\frac{L}{L-x}\right)^{\gamma}\right]$$ Equation of motion

Assumptions
- water layer behaves like solid piston
- no gas leaves the control volume
- Pr = constant
- isentropic process
- there are no dissipative processes

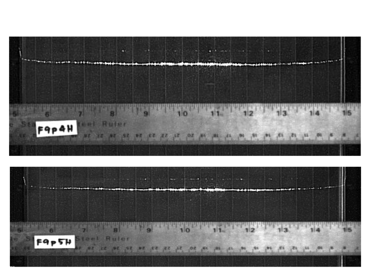


Solution at M=1.34 with 6.4 mm of water

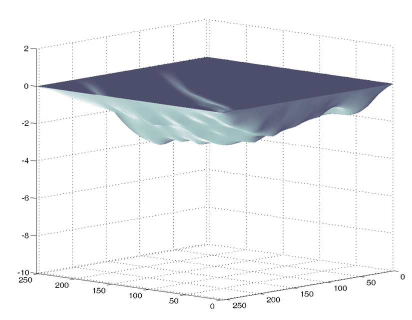
The water layer can be modeled as a solid piston accelerated by a high pressure reservoir, Pr, into a closed volume at lower pressure. Pressure in the control volume, P(x), increases as the piston moves downwards.

Initial Condition

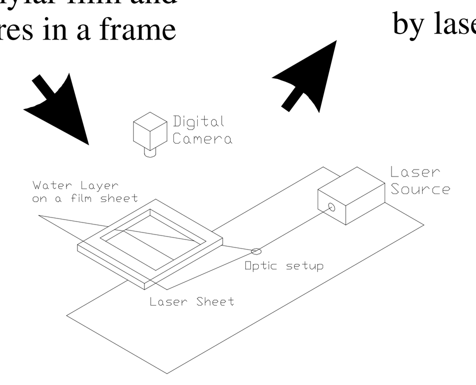
0.54 micron mylar film and supporting wires in a frame support water



Initial deflection measured by laser sheet

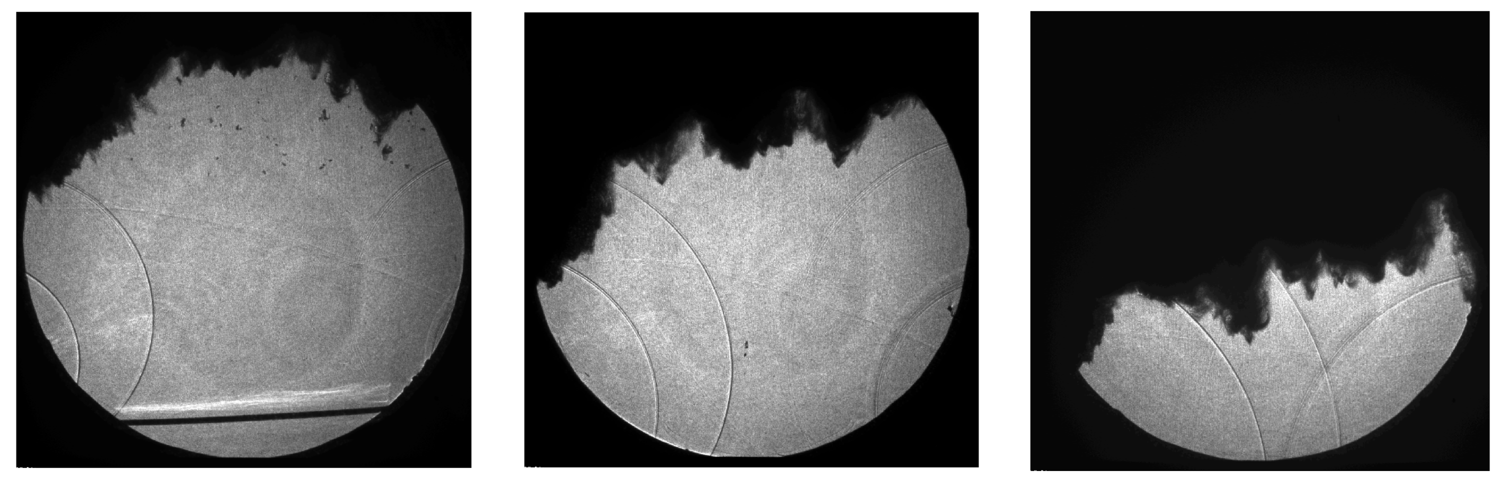


3D reconstruction of the initial water layer



A laser sheet is used to measure deformation of the initial shape of the water layer. Several slices of the layer are measured and a 3D reconstruction of the initial water layer is obtained.

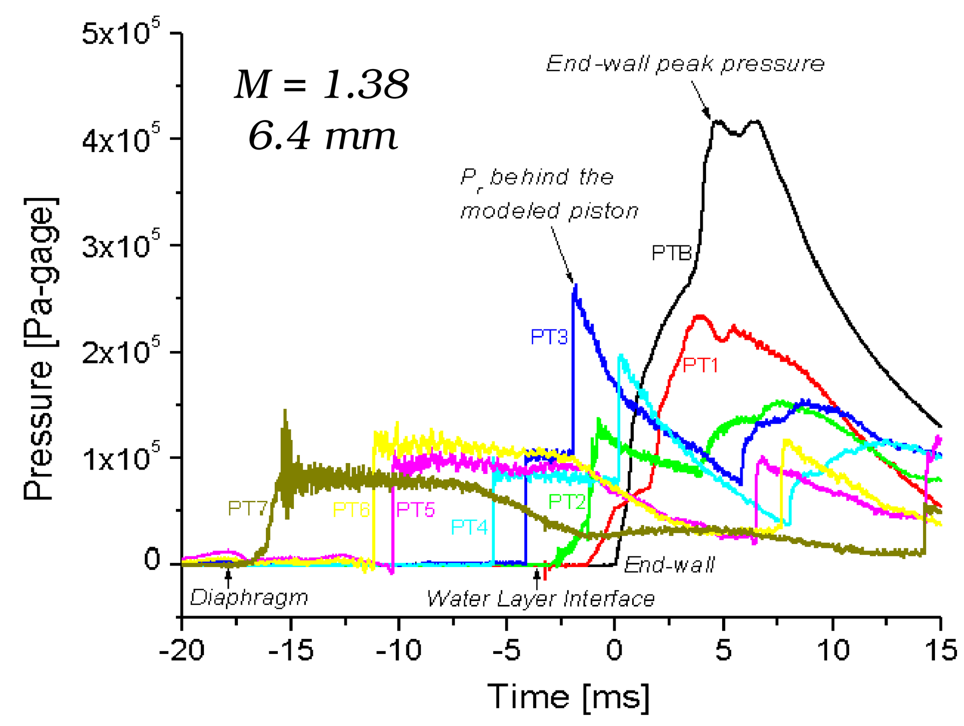
Shadowgraph Images



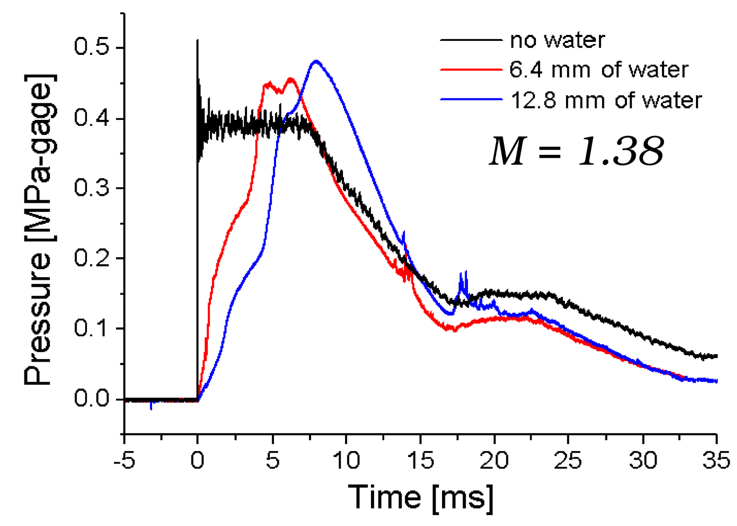
1.32 ms *1.43 ms* *1.47 ms*

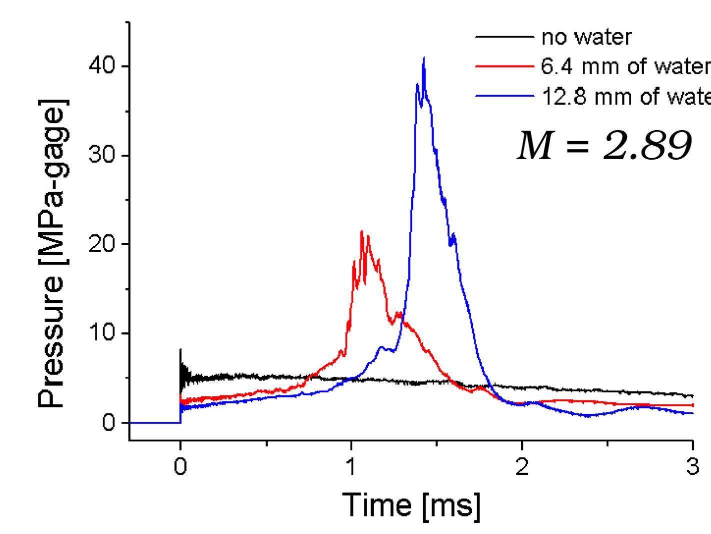
The above series of shadowgraph images documents the water layer (M=2.68, 6.4 mm of water) breakup at different times (from separate tests) after being accelerated by the shock wave. Times shown below the images indicate ages of the accelerated water layer after being shocked. Breakup of the water layer can be observed.

Pressure Measurements



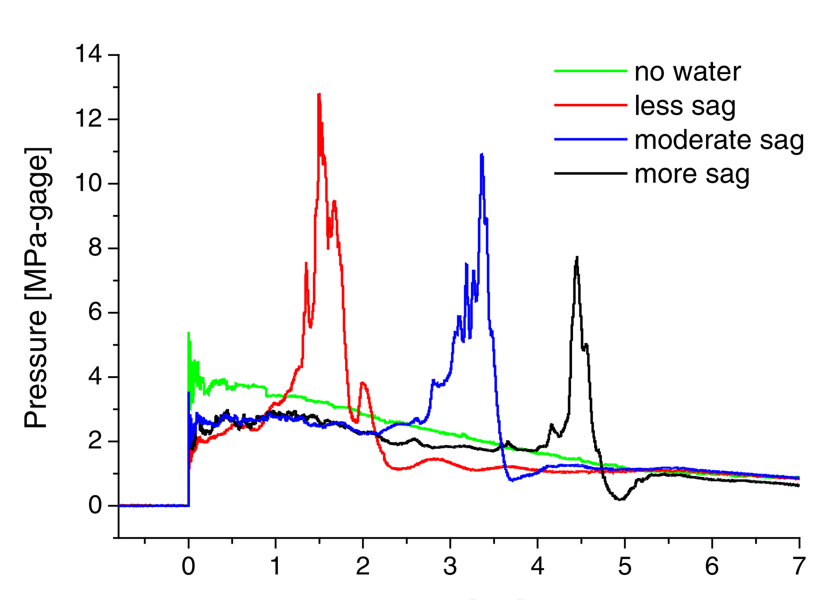
Pressure traces at different position along the shock tube are shown on the left. After the shock wave transmitted through the water layer, the shock becomes weaker as seen in PT2. The transmitted shock wave stabilizes itself before hitting the end-wall as seen in PT1 and PTB.





End-wall pressure traces at two different Mach numbers are shown above. At M=1.38 with the water layer in the interface section, the end-wall pressure rises more gradually compared to the experiment without the water layer. At M=2.89, the end-wall pressure changes more dramatically when the water layer is present. The end-wall pressure in the case of strong shock rises in two steps; the first step caused by the transmitted shock wave and the second step caused by the accelerated water layer. The peak pressure increases significantly at high Mach numbers.

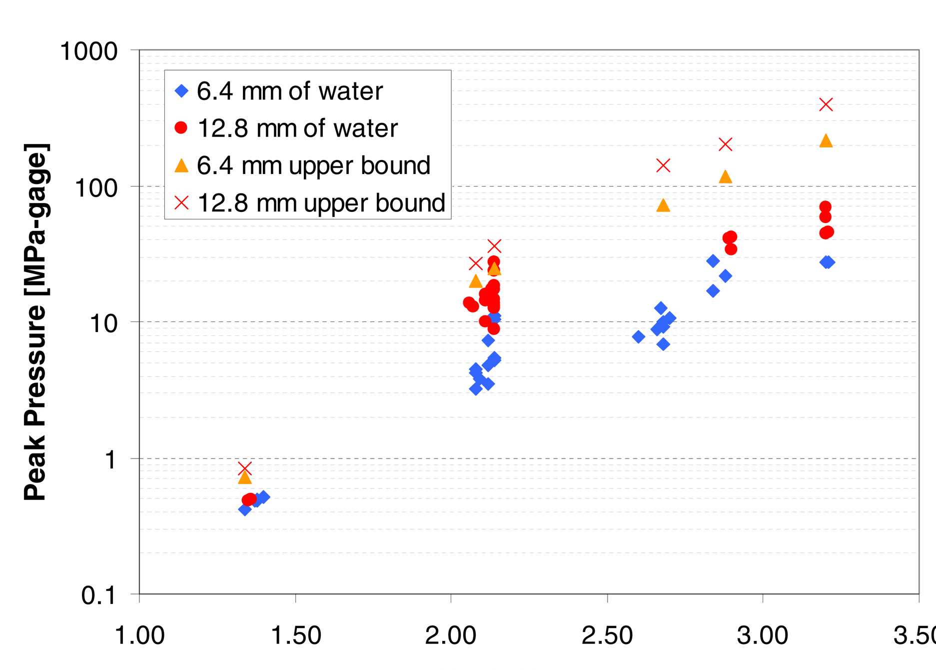
Effects of Initial Conditions



End-wall pressure traces resulting for different initial water layer shapes are studied at M=2.65. The amount of sag is varied by changing configuration of the support materials. Delay of the peak pressures are clearly observed. The greater the initial sag, the longer the delay of the peak pressure. Total energy is conserved by decreasing the peak pressure when the peak is more delayed.

Peak Pressure vs. Mach Number

Many shock water layer experiments have been conducted at several Mach numbers, and the end-wall peak pressures are plotted as a function of the incident shock speed. The peak pressures from the theoretical model are plotted as upper bounds.



As observed in the pressure traces:
- a thicker water layer results in a higher peak pressure
- a stronger incident shock wave results in a higher peak pressure
- the experimental peak pressures are always less than those from the theoretical model as expected.

Significantly high peak pressure to the end-wall resulting from the accelerated water layer at high Mach number (M>2.0) may present a serious challenge in designing the reactor first wall and cooling tubes.