Shock Interface and Shock Structure Interactions

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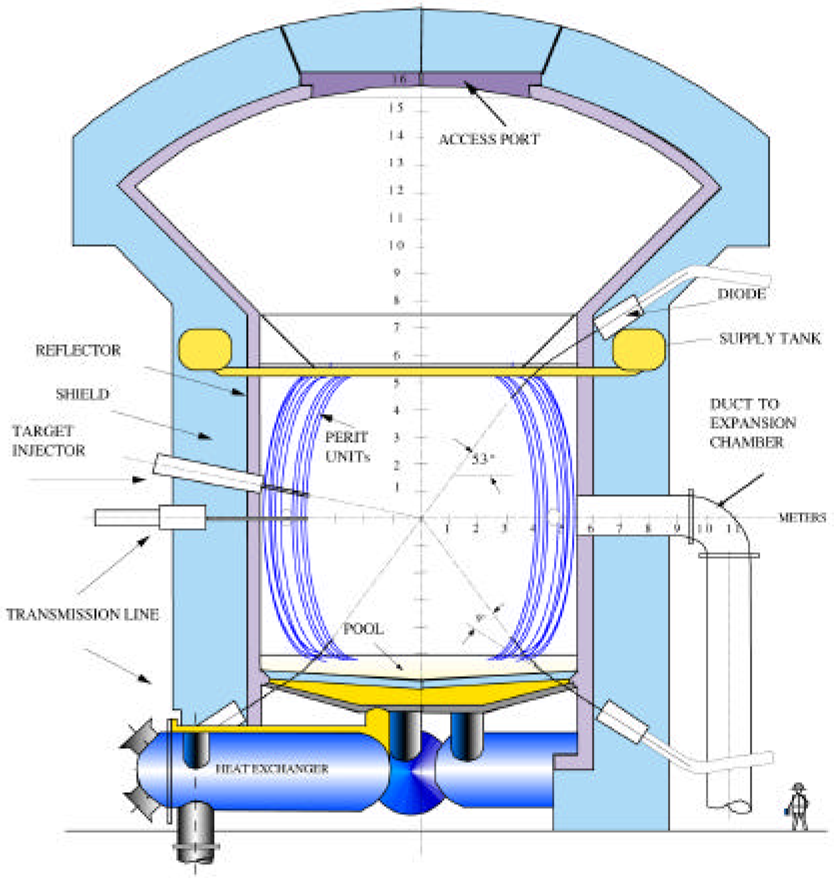
Outline

- Motivation
- University of Wisconsin Shock-Tube Laboratory (WiSTL)
- Discussion of numerical model
- Discussion of shock structure-interactions
- Shock - Interface Interactions
- Future Directions
- Conclusions

IFE Reactor Concept



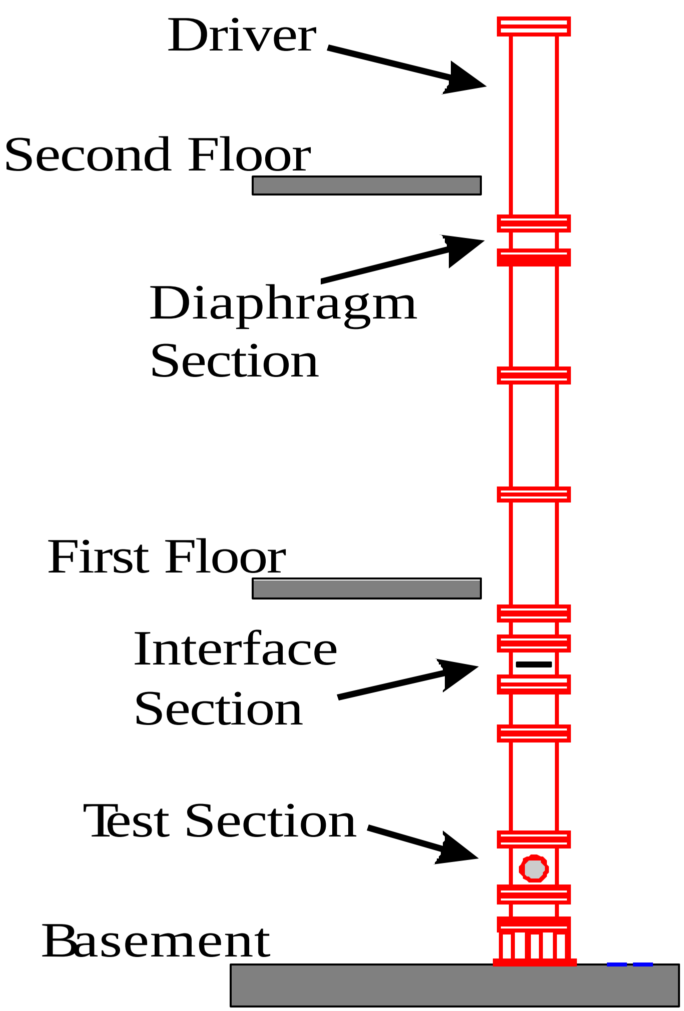
Cross-Section of the LIBRA-SP Target Chamber

•Many types of IFE target chambers experience significant hydrodynamic motion.

•In gas protected chambers the target X-rays and debris ions stop in the gas, however there energy generates a blast wave that consists of both a shock and radiation wave where the strength of both is a function of the opacity of the gas.

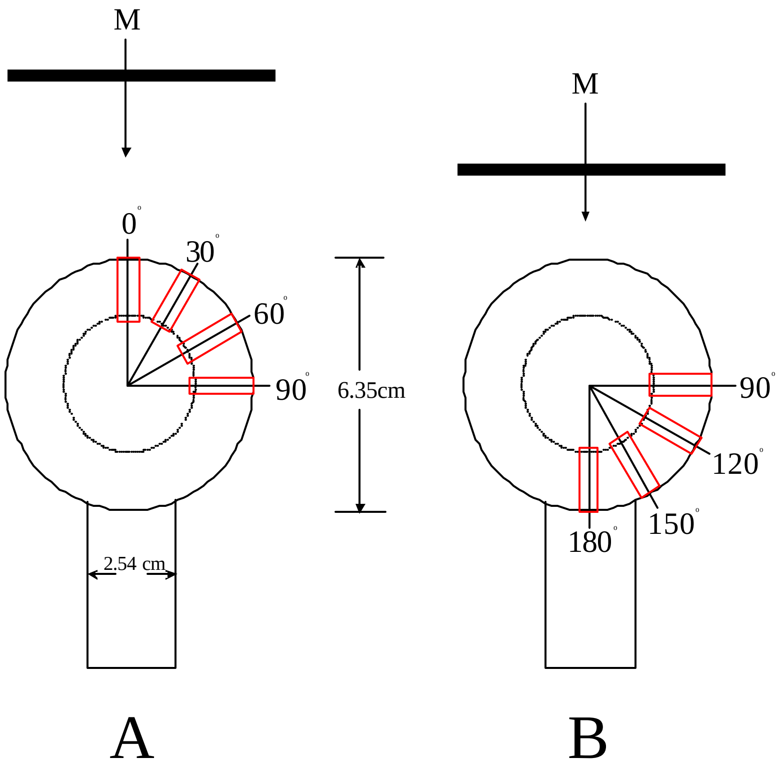
•Liquid-protected target chambers that are initially at low gas density produce significant gas densities by vaporization of some of the liquid.

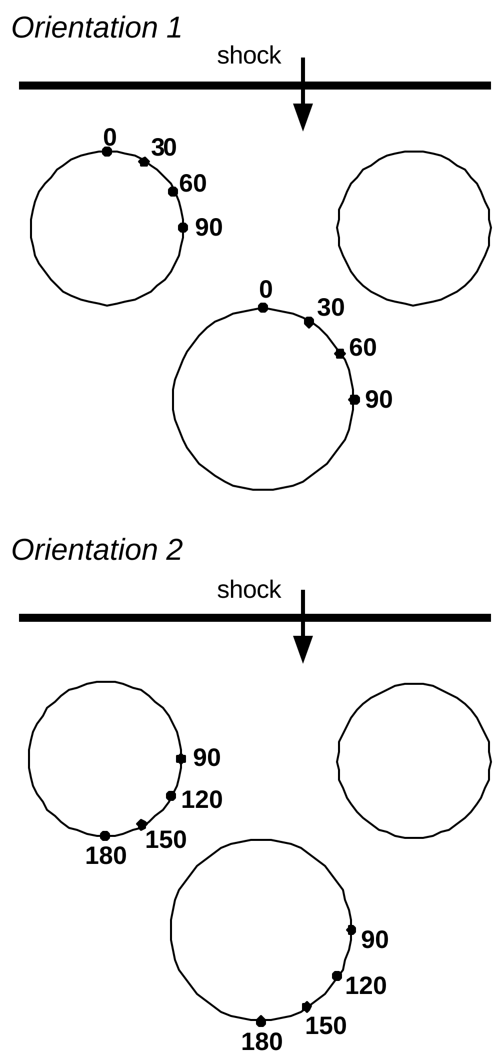
WiSTL (Wisconsin Shock Tube Laboratory)



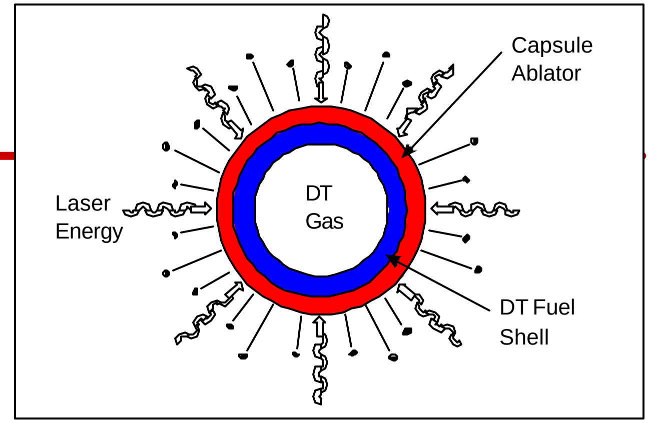
- Vertical Orientation
- Large Internal Square Cross-Section (25 cm square)
- Total Length=9.3 m
- Driven Length=6.8 m
- Structural Capacity 20 MPa
- Modular Construction

Shock cylinder interactions

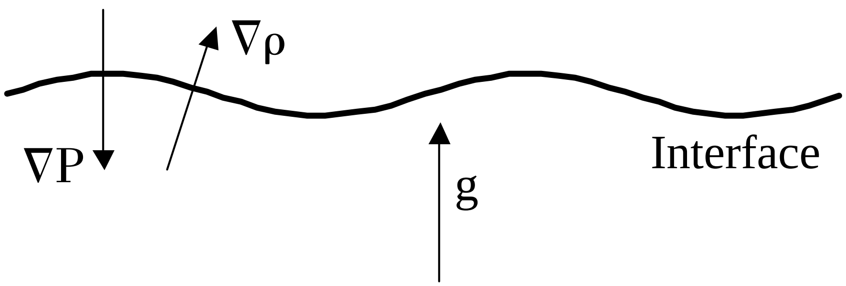




RT and RM Instabilities

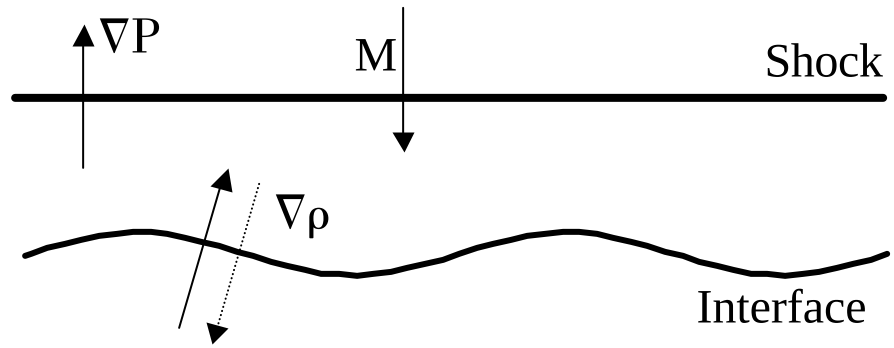


$$\left(\frac{1}{r^2}\nabla r \times \nabla P\right)$$



Rayleigh-Taylor instability

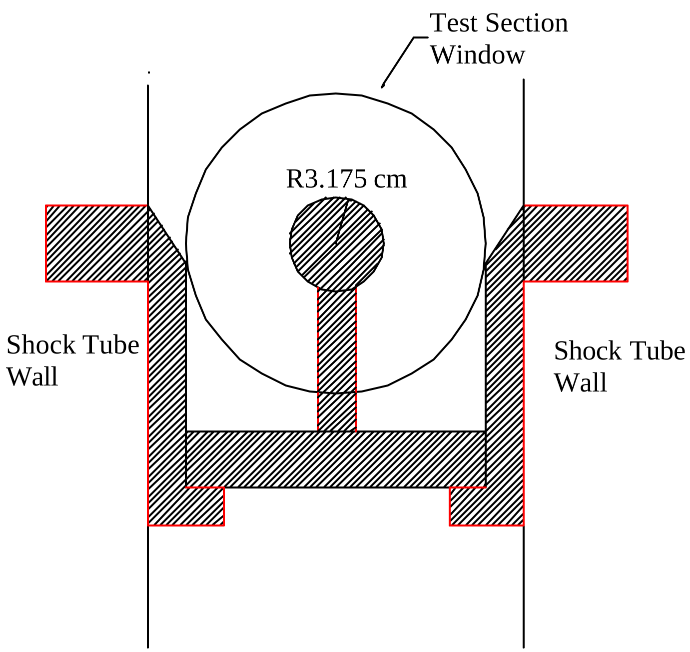
- Constant acceleration of light fluid into heavy fluid

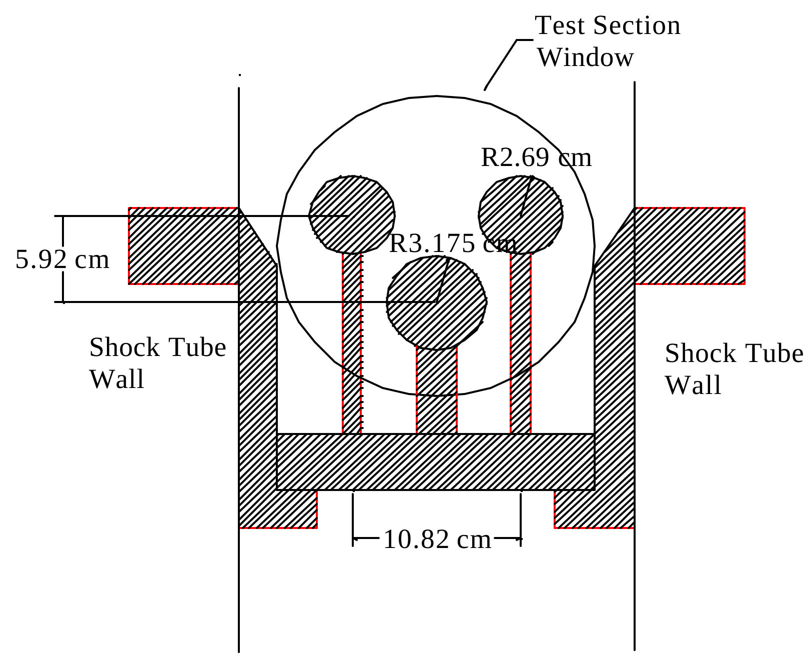


Richtmyer-Meshkov instability

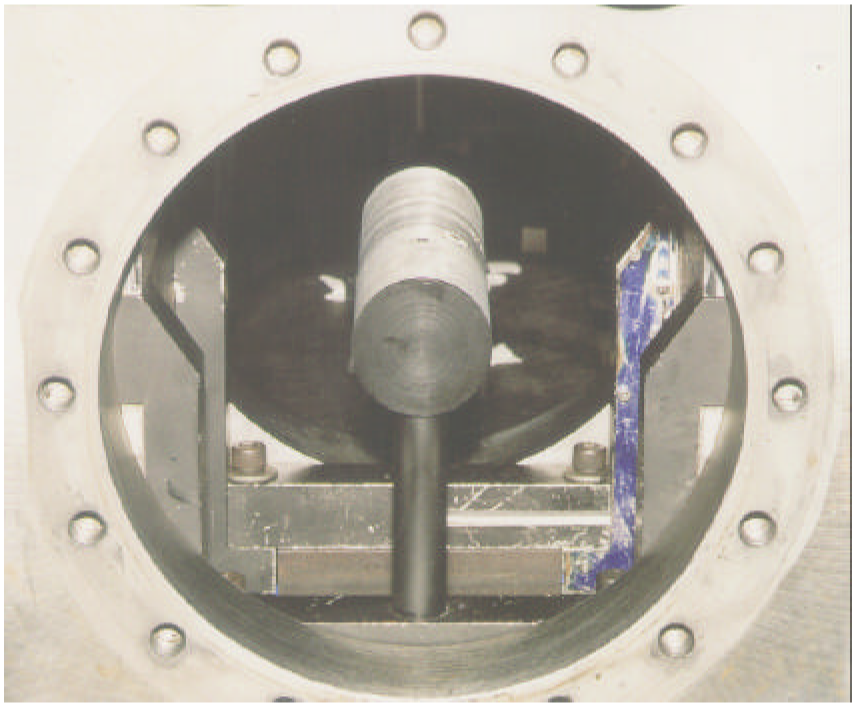
- Propagation of a shock across a density interface
- Instability exists independent of the direction of propagation of shock

Cooling Tubes Modeled as Cylinders

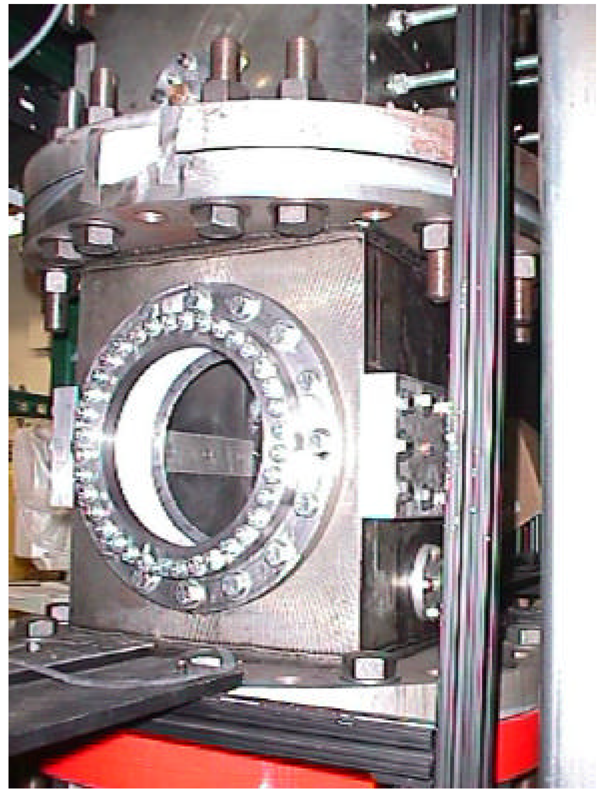




Test Section Details



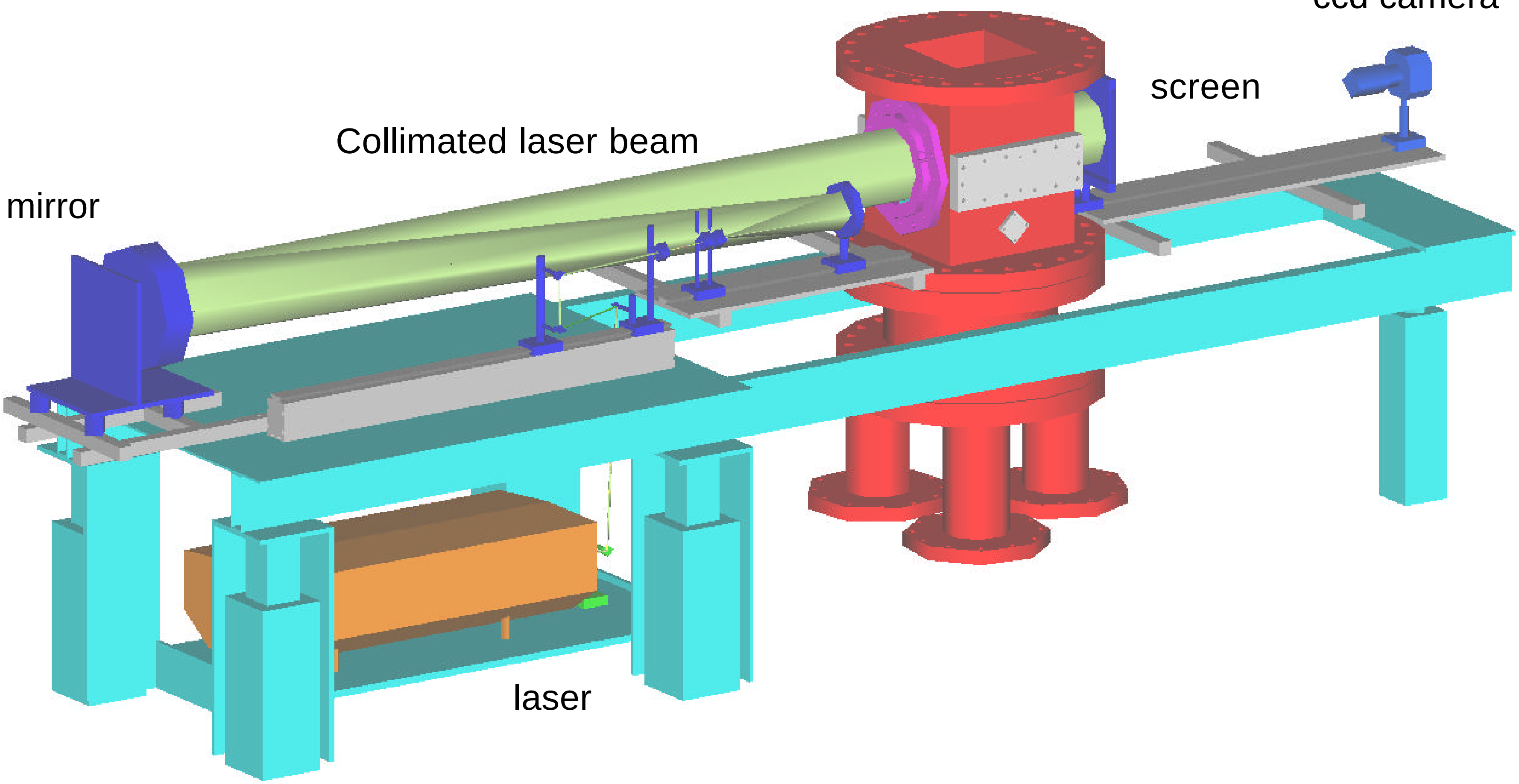
Single Cylinder Installed



Window Installed

Test section: 24 cm diameter, 9 cm thick fused quartz window(s)

Shadowgraph Imaging



Nd:YAG, 10ns Pulse Laser (timed from incident shock)
1024x1024 pixel array CCD Camera

Numerical Model

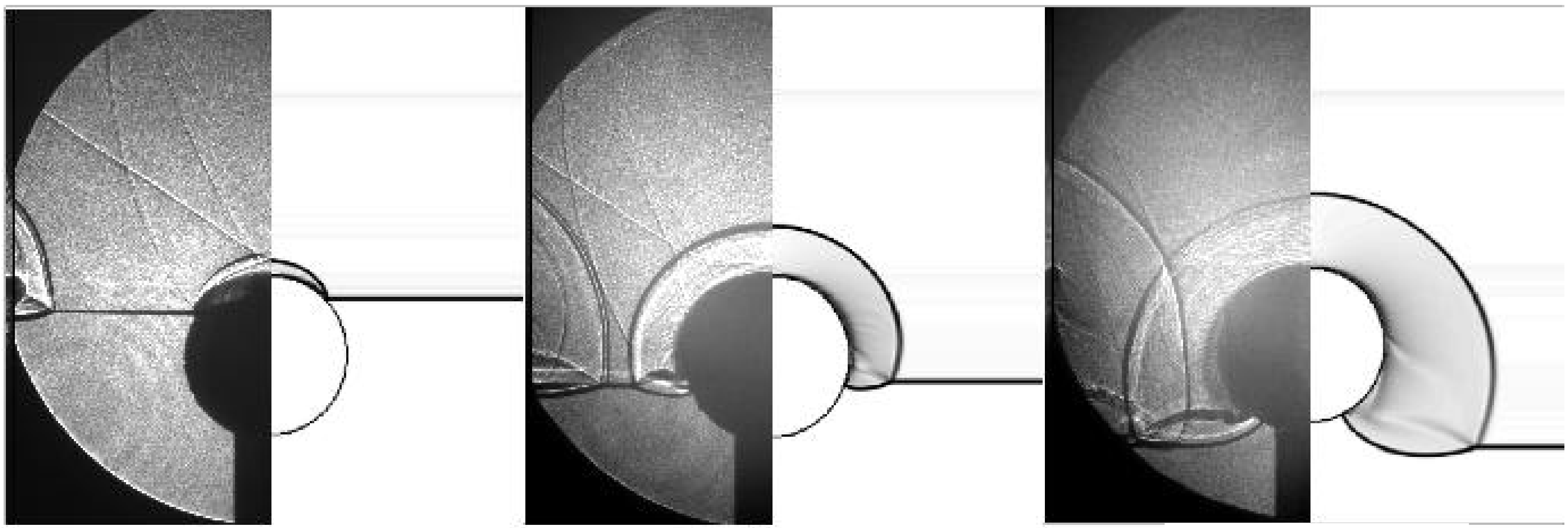
- Transient, two-dimensional Euler equations
- Godunov scheme + Pike's (1993) fast exact Riemann solver at cell interfaces
- PSM (Piece-wise Spline Method) for data reconstruction of fluxes, fourth-order accuracy achieved
- Cartesian grid, time step based on CFL condition (CFL=0.6) for stability.
- Computational domain: 35.4 x 25.4 cm; Mesh size: 0.25 mm (1418 x 1018)
- Boundary conditions: reflective EW (shock tube walls) and extrapolate NS (in and out)
- Initial conditions: top 5 cm is shocked Argon (M=2.75), rest of domain is Argon at STP
- Cylinders modeled as circles with reflective boundaries

Experimental Result

M=2.75, Rupture P = 1.8MPa
Shock diffraction pattern at t_{image}=99 μs, as measure from incident shock location at top of upper cylinder

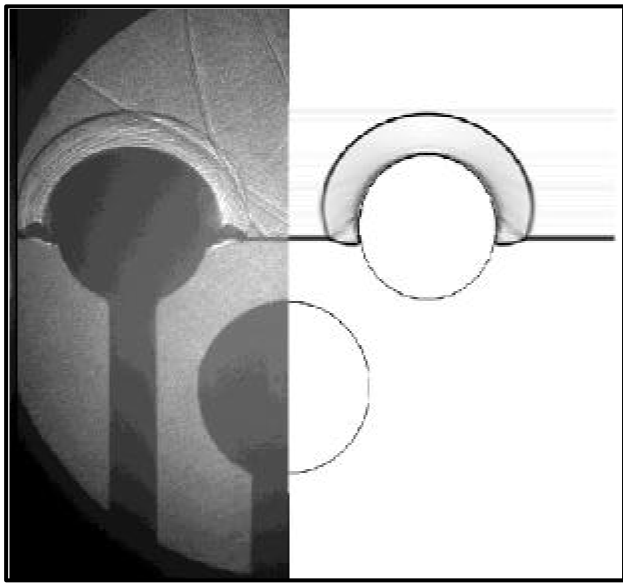
A. Reflected shocks from upper cylinders
B. Reflected shock off lower cylinder
C. Contact discontinuities
D. Transmitted shock
E. Gradients due to wall interactions

Diffraction Patterns – Single Cylinder

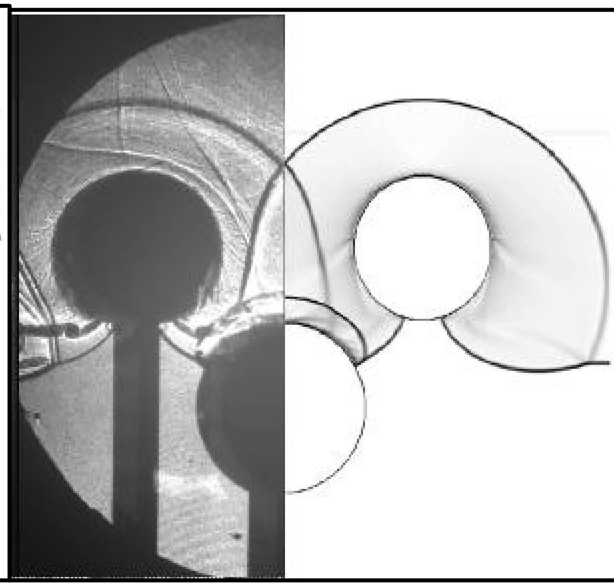


$t_{\text{image}} \approx 11\ \mu s$ $t_{\text{image}} \approx 47\ \mu s$ $t_{\text{image}} \approx 83\ \mu s$

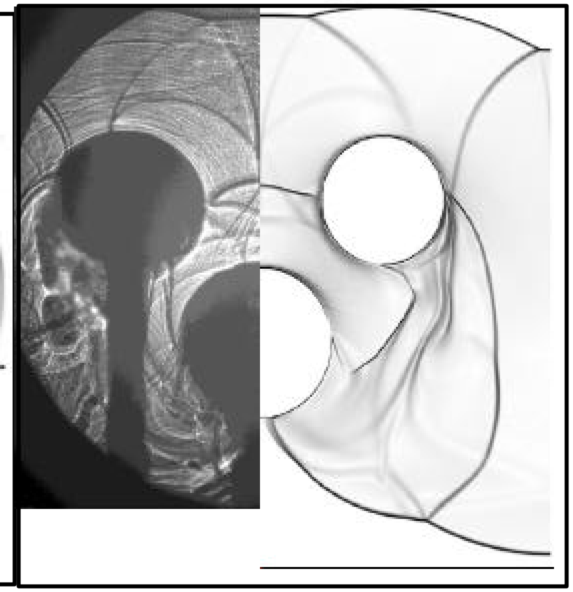
Diffraction Patterns – Three Cylinders



$t_{image} \approx 36\ \mu s$

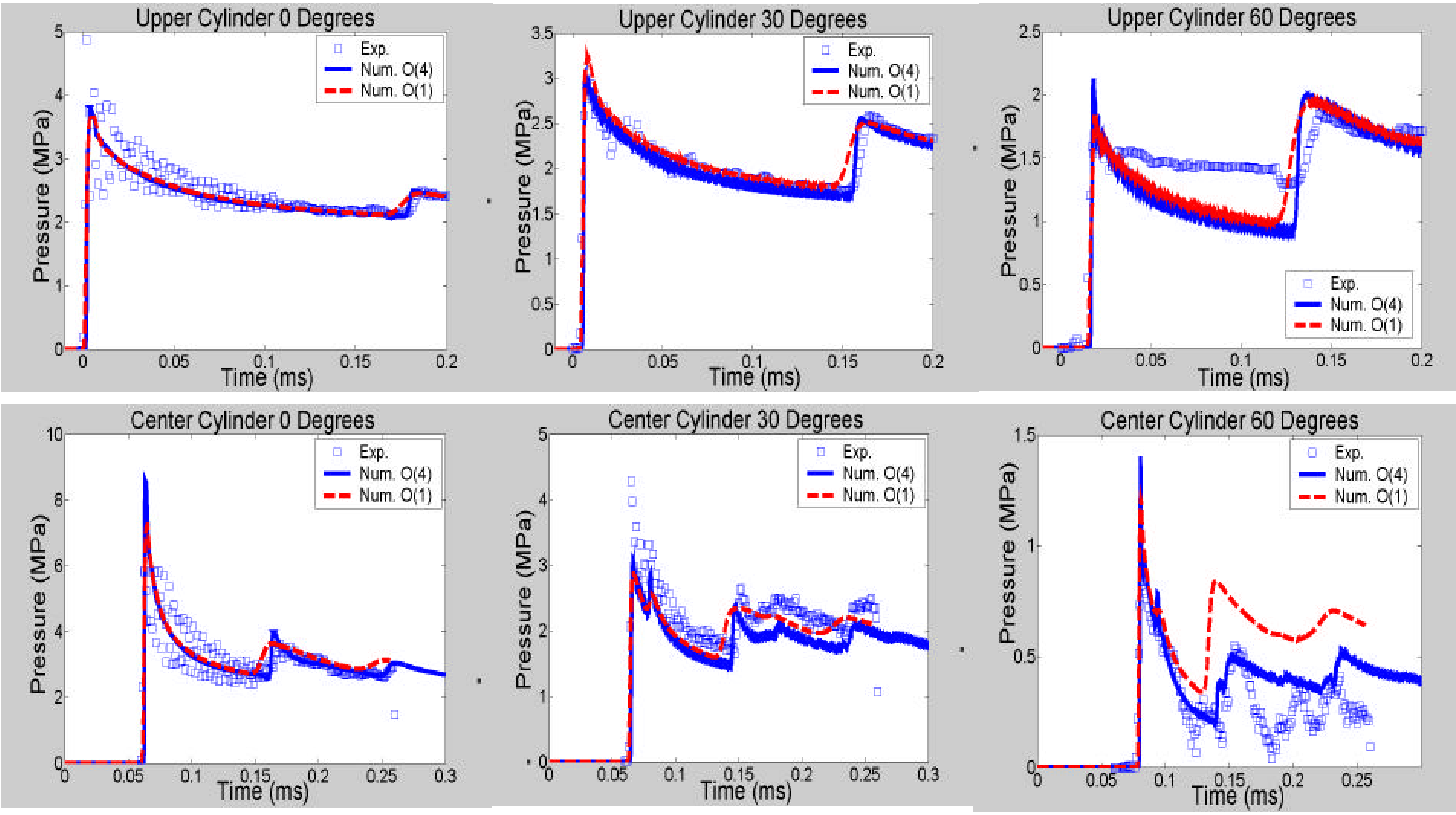


$t_{image} \approx 77\ \mu s$

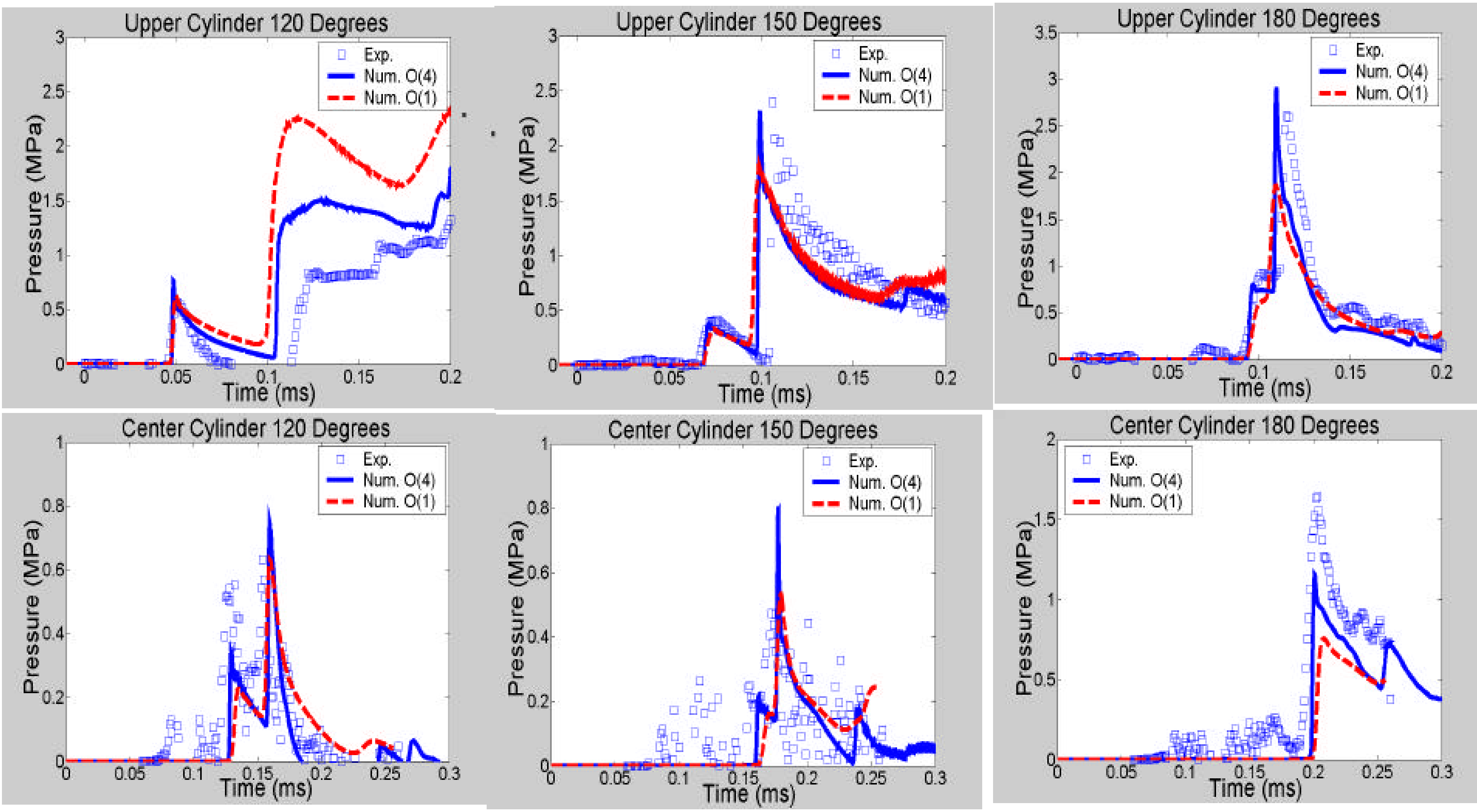


$t_{image} \approx 191\ \mu s$

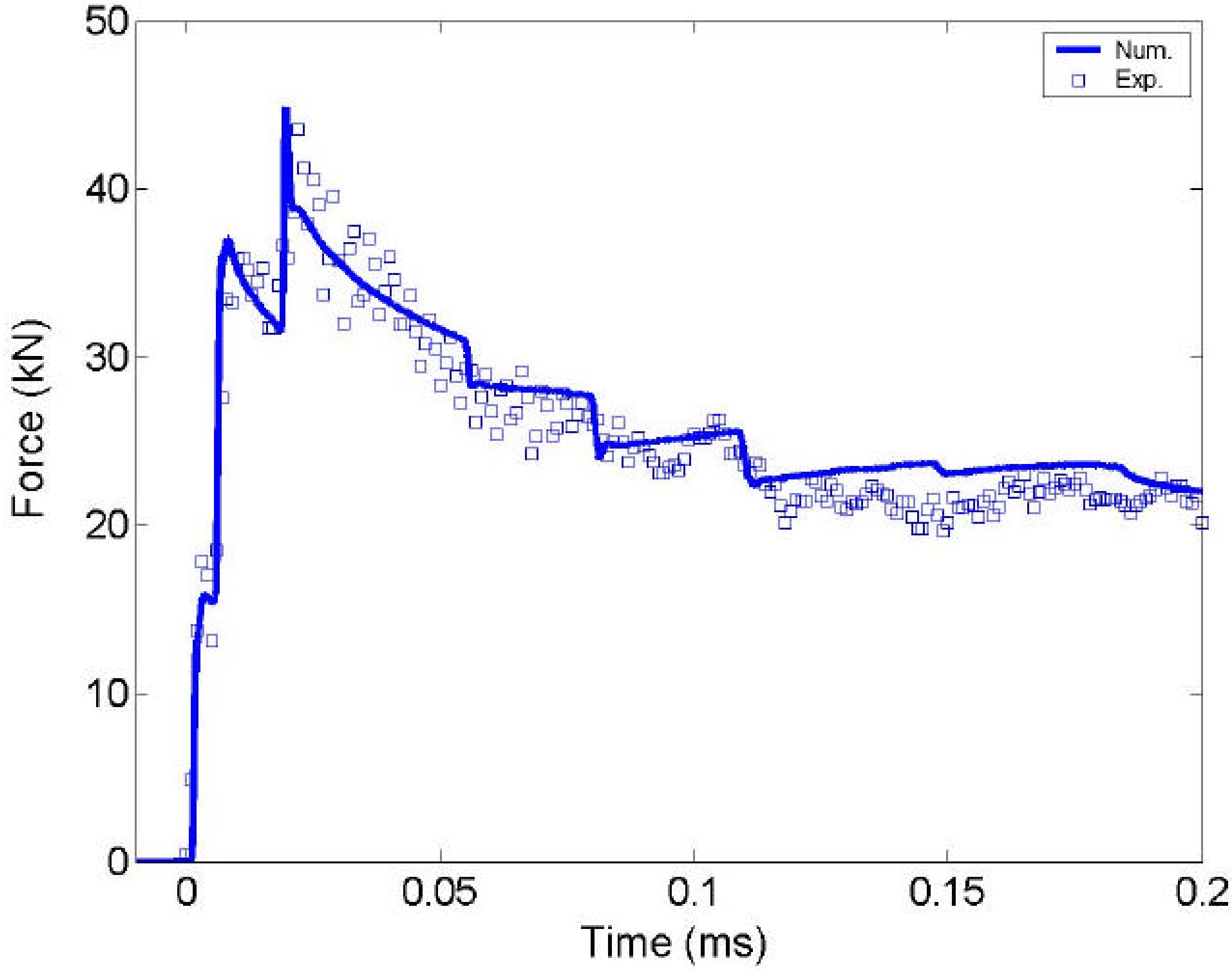
Pressure Data for Three Cylinders: 0, 30 and 60°



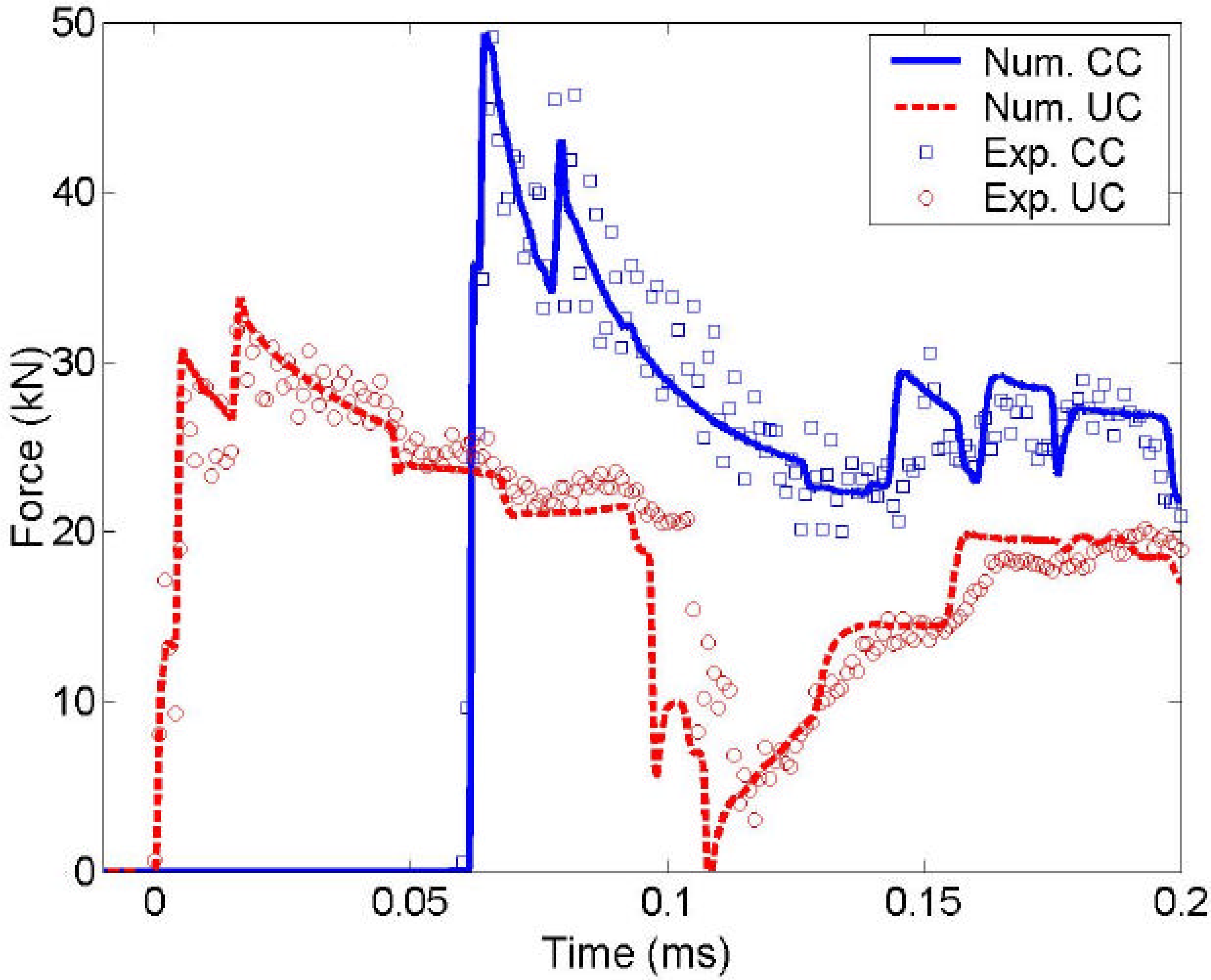
Pressure Data for Three Cylinders: 120, 150 and 180°



Vertical Loading of Single Cylinder



Vertical Loading on Three Cylinders



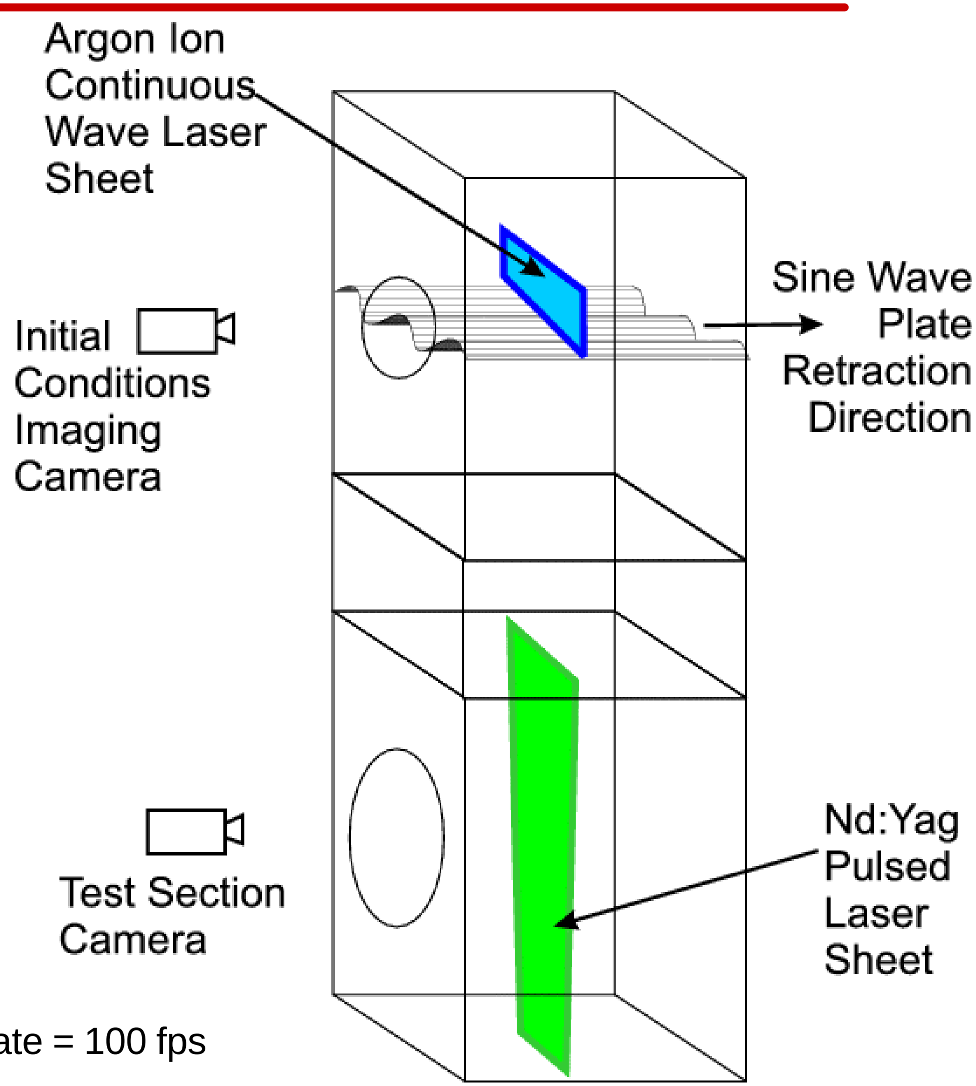
Shock Interface Interactions

Dynamic imaging of the interface, prior to being shocked, provides interfacial initial condition data for each RM experiment.

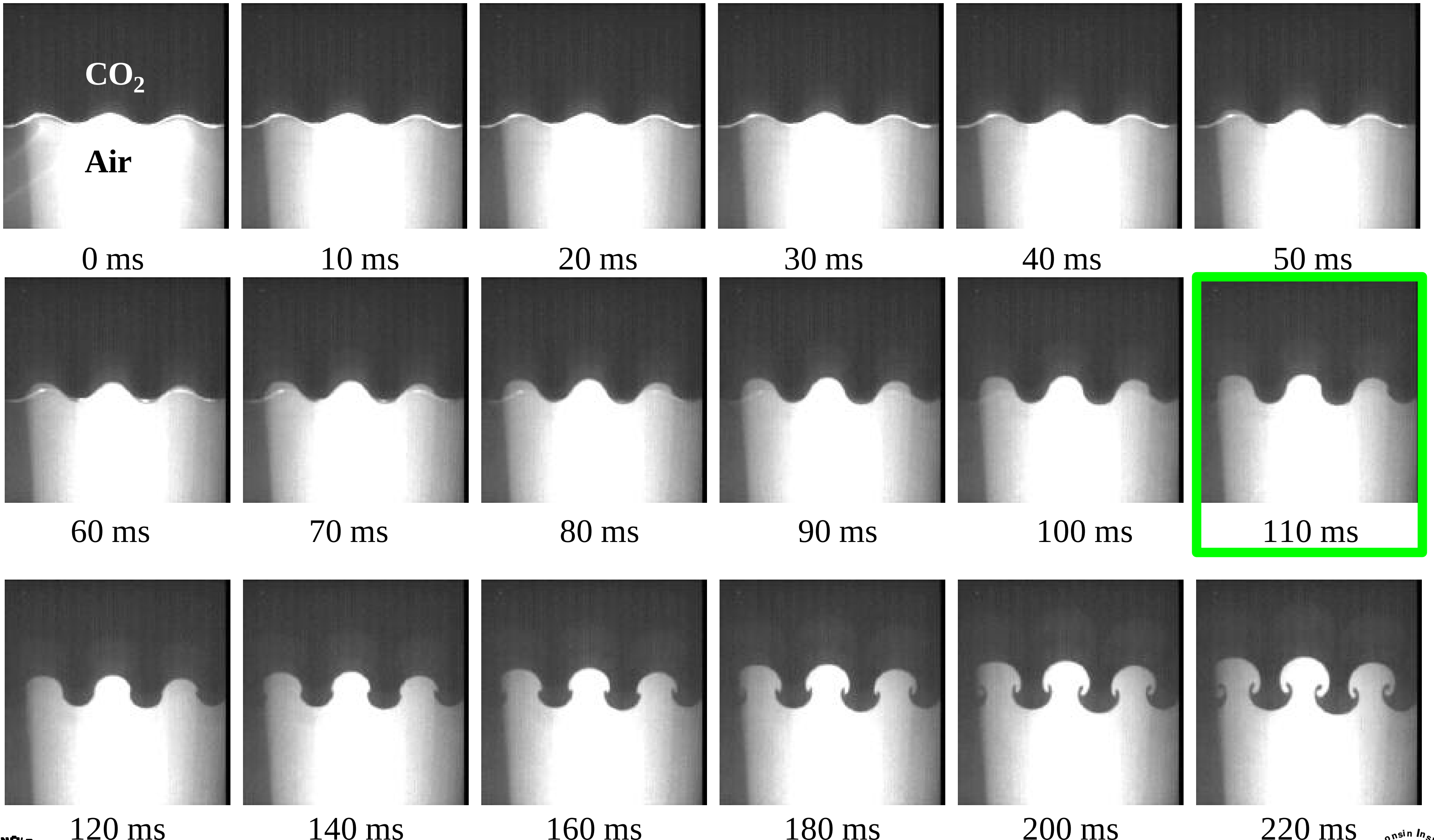
Provides the interface geometry of the initial condition which may be used in a numerical simulation.

Amplitude = 3.18 mm
Wavelength = 38.1 mm
h_0/l = 0.083

- Plate retraction along the line of sight
- Planar Mie scattering visualization
- Heavy gas over lighter gas configuration
- Ar^+ cw laser
- CCD camera: 256 x 256 pixel array, frame rate = 100 fps

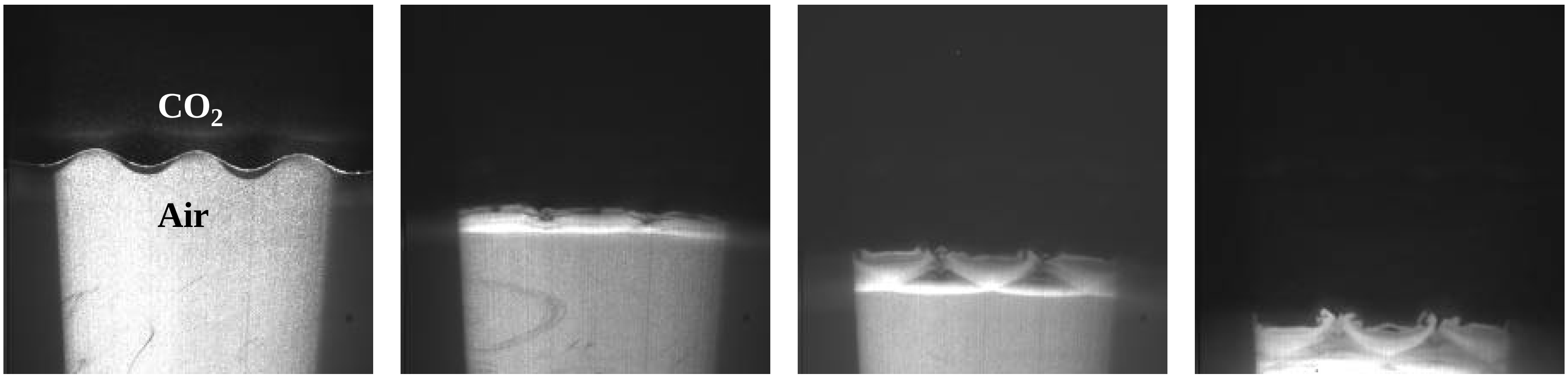


τ_{RT}≈110 ms for RM Initial Condition



R-M instability visualization results

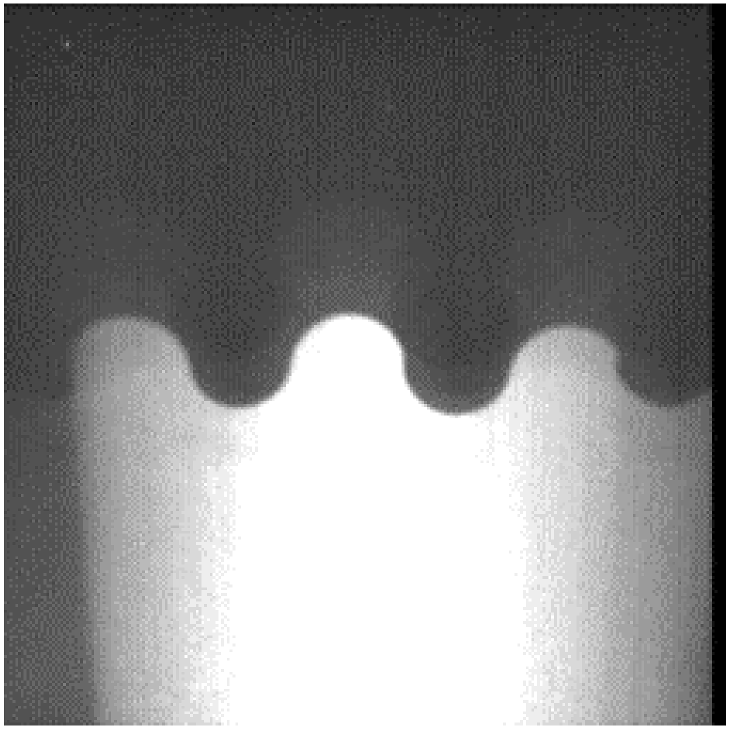
- Very early interaction of the shock wave with the sinusoidal interface
- Development of phase reversal (Heavy/light configuration)



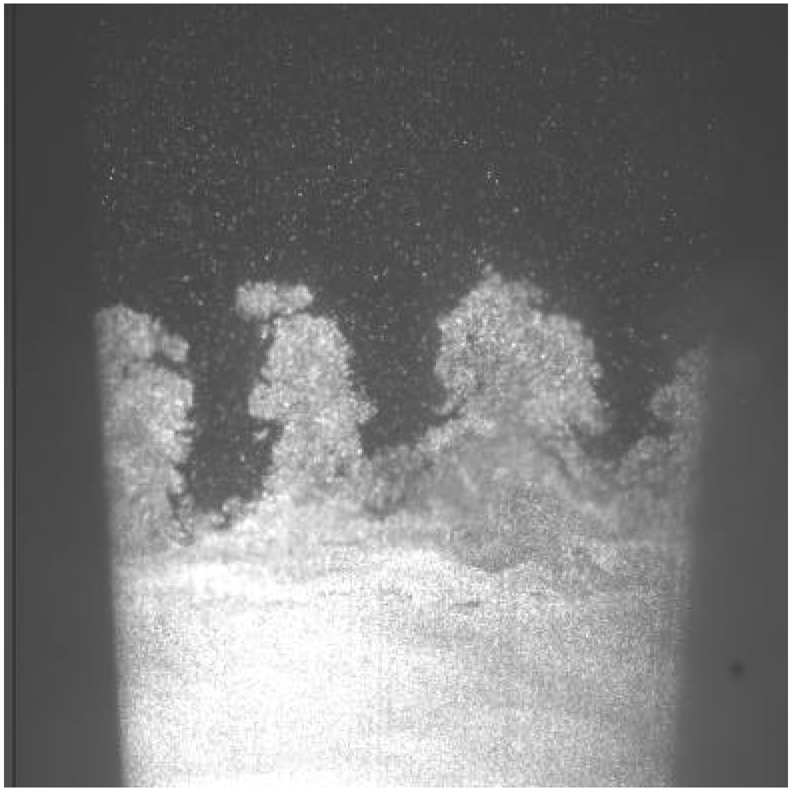
(a) (b) (c) (d)

- (a): Pre-shocked interface (Note the location of peaks and troughs)
- (b): Shocked interface ~ 5 μs after initial shock acceleration
- (c): Shocked interface ~ 36 μs after initial shock acceleration
- (d): Shocked interface ~ 39 μs after initial shock acceleration

Shocked Interface with Initial Condition



$\tau_{RT} \approx 110$ ms

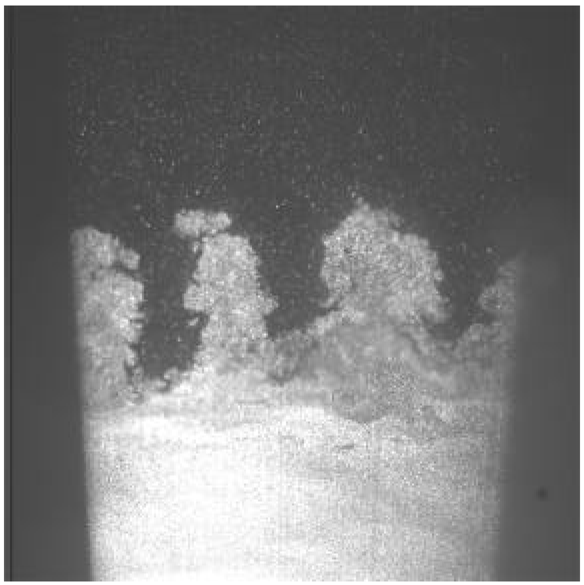


$\tau_{RM} \approx 646\ \mu s$

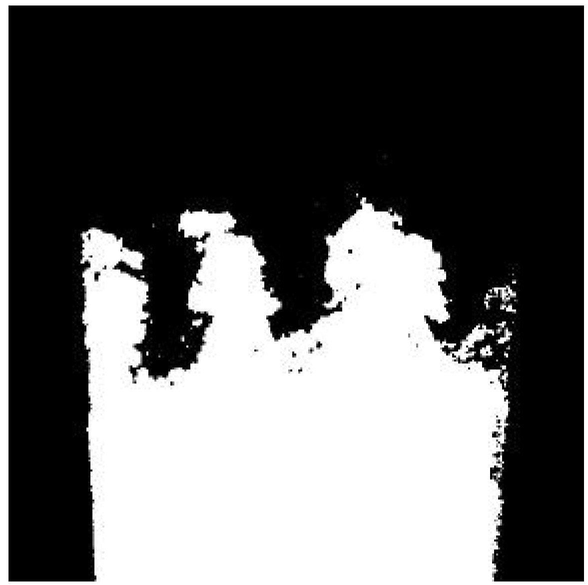
- Initial condition well into nonlinear regime ($h_0/l > 0.2$)
- Phase inversion of shocked interface

Image Analysis

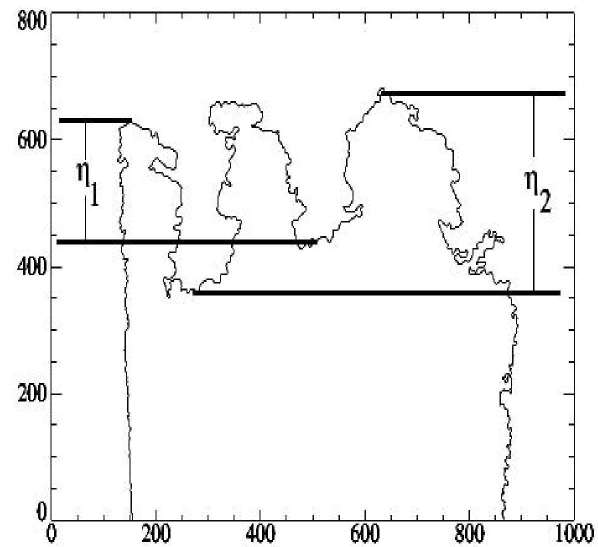
- Removal of “outlier” noise from nominally dark region
  - Application of median filter to minimize blurring
- Extract interfacial contour, measure peak-to-peak amplitude



(a)



(b)

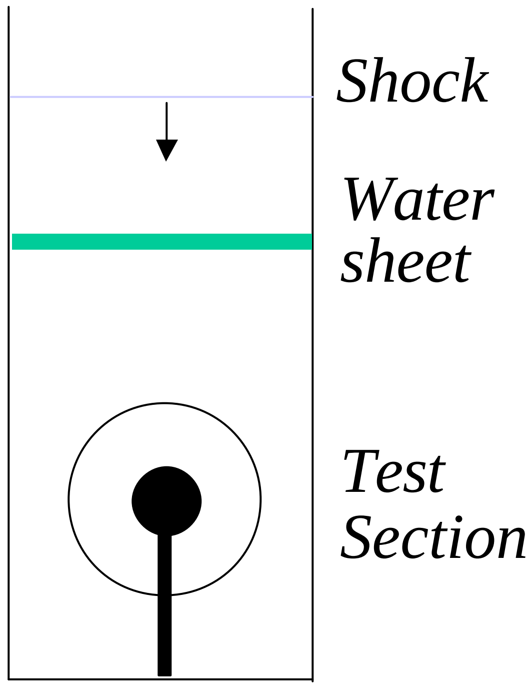


(c)

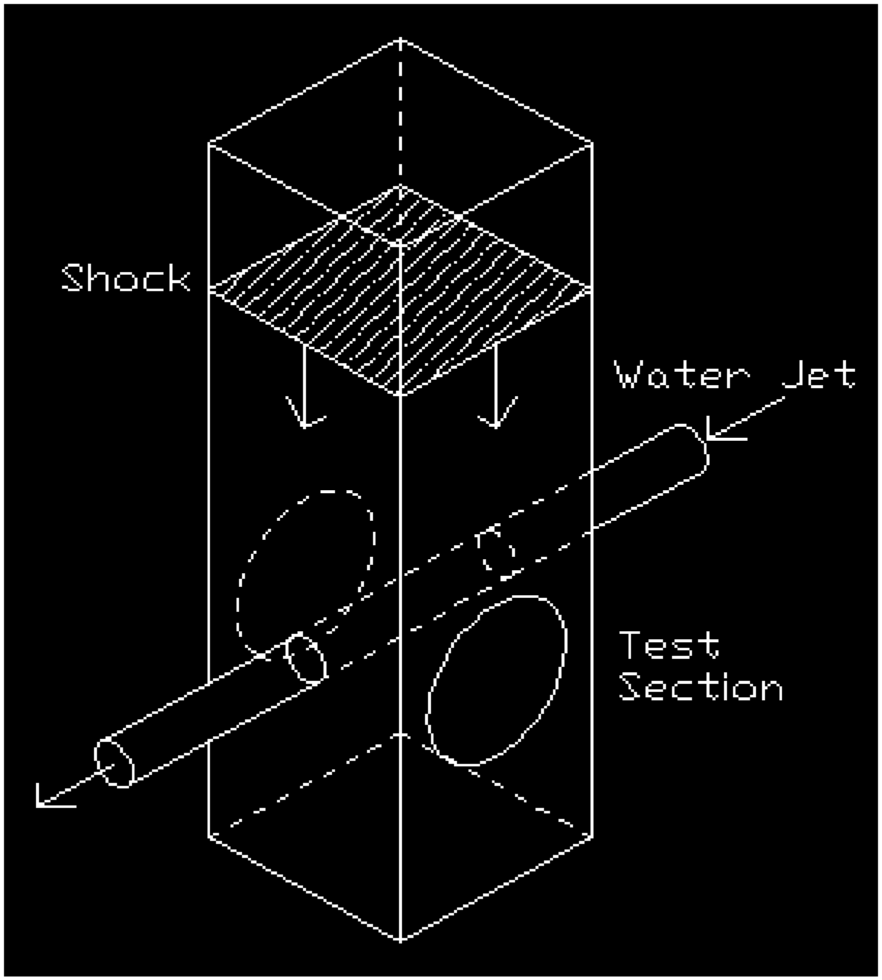
- (a): Raw experimental image, enhanced in contrast
- (b): Filtered and normalized image
- (c): Extracted interfacial contour

Future Directions

In a vertical shock tube, a shock is driven to hit a film-supported water sheet above the test section where a cylinder is located. All the pressure measurements and imaging will be taken with several techniques at the test section.



Study of Water Jet Break Up



Some design of ICF reactor use jets of liquid metal as a coolant to cover the fusion target.

Study the hydrodynamic behavior of liquid jet break up and recovery time after the disruption.

Conclusion

- Several experiments are being conducted to study the hydrodynamics associated with possible ICF chamber and target designs.
- Experiments have been conducted to study the shock diffraction and impulsive force on single cylinder and cylinder array to help in numerical model validation and to aid in the structural design of chamber components .
- Experiments have been performed to study the hydrodynamics of target implosions and to determine the RM and RT growth rates
- Future work will concentrate on; numerical studies to find the optimum arrangement of cooling tubes, more precise measurement of the initial conditions and further diagnostics to measure velocity distribution in the RT and RM instability and to look at shock liquid interactions and break-up.