Shock Loading of IFE Reactor Cooling Tubes

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Department of Engineering Physics

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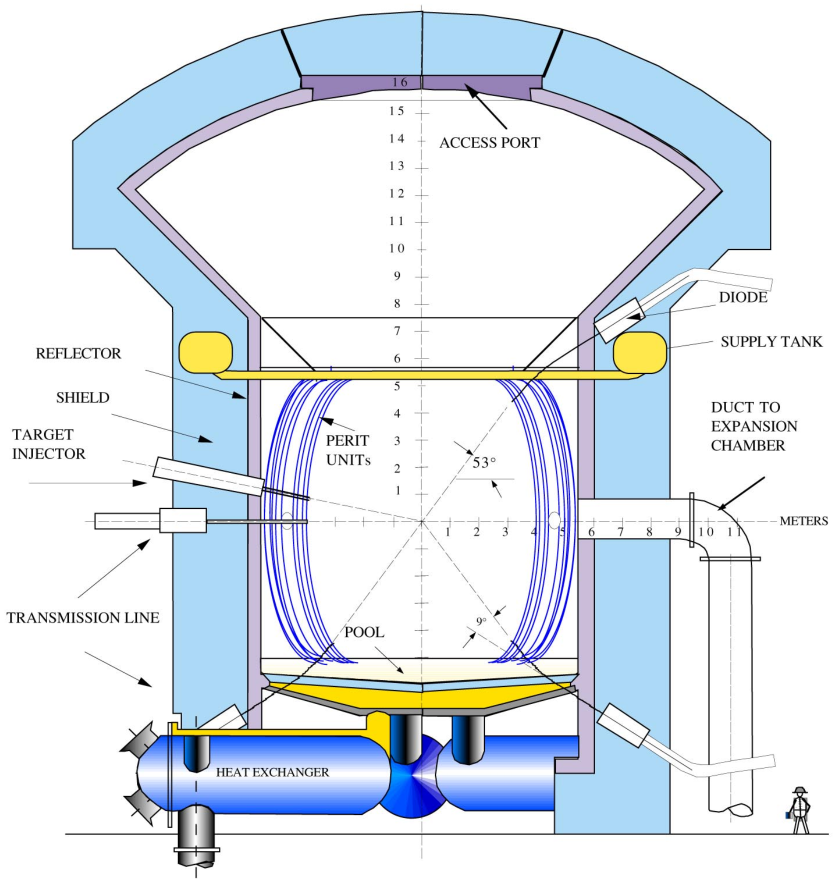
Outline

- Inertial Fusion Energy Reactor Concept
- Repetitive Shock Loading of First Wall
- Experimental Model of First Wall
- University of Wisconsin Shock-Tube Laboratory (WiSTL)
- Experimental Discussion
- Numerical Discussion
- Results: Pressure, Shadowgraph Images, Force Loading

IFE Reactor Concept

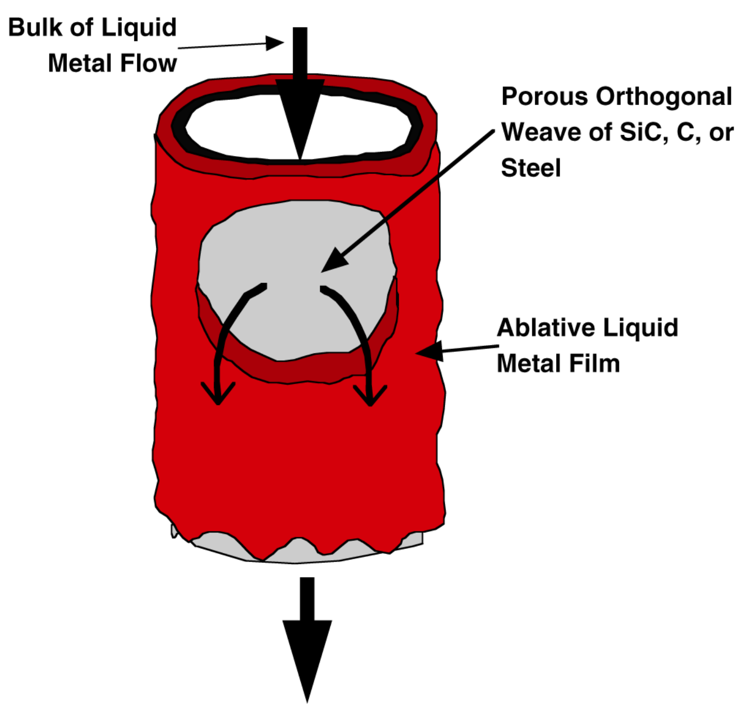


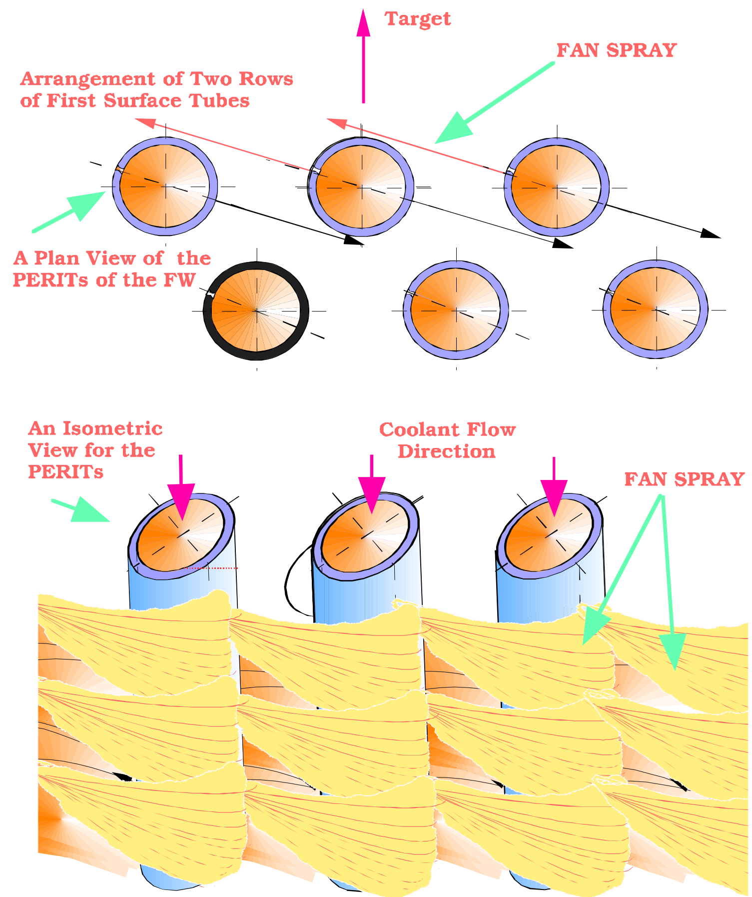
Cross-Section of the LIBRA-SP Target Chamber

LIBRA-SP concept design for inertial fusion energy (IFE) reactor. The DT pellet is injected from the top and detonated at the center of the chamber. The tubes on the walls of the chamber carry liquid metal to absorb the heat and particles. These tubes must also be able to withstand the impulsive loading of the shock wave from the fusion reaction.

Concepts for Cooling Tubes

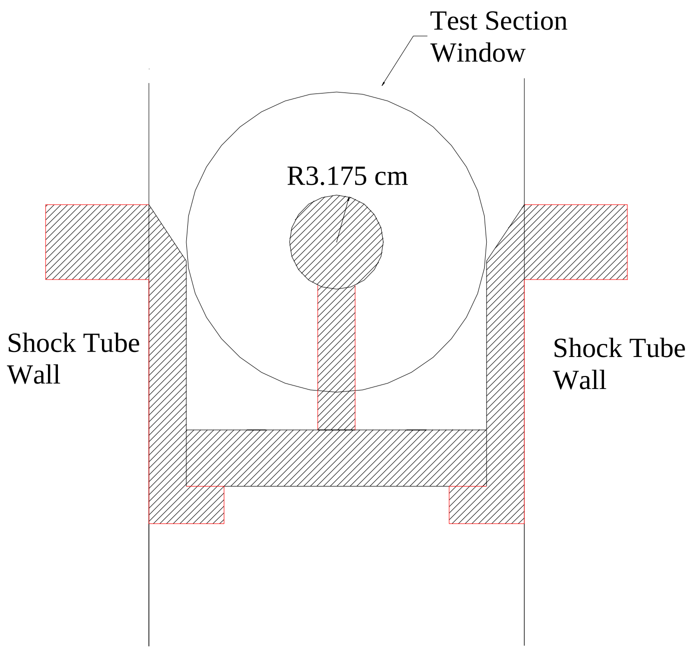
Two designs of the cooling tubes are shown. One uses a porous wall and the other uses jets to create a liquid metal sheet. The layout of the multi-wall tube bank is shown.

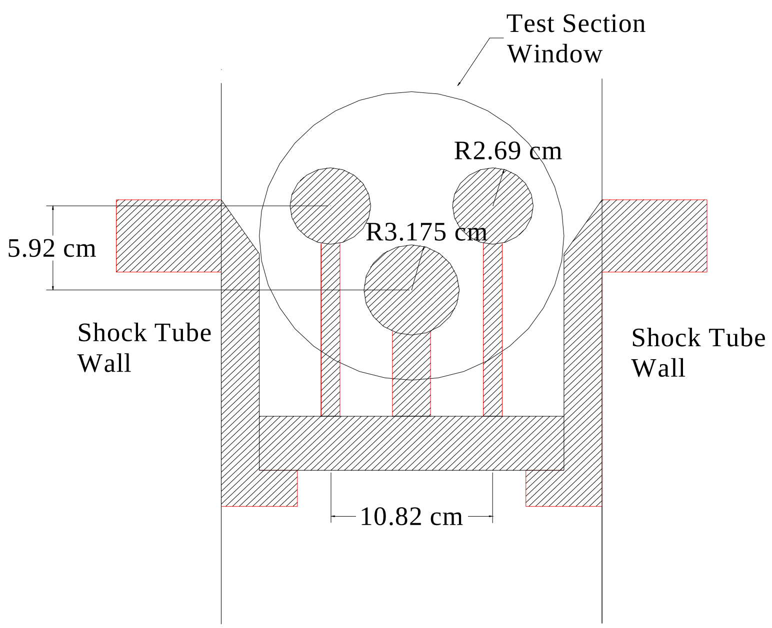




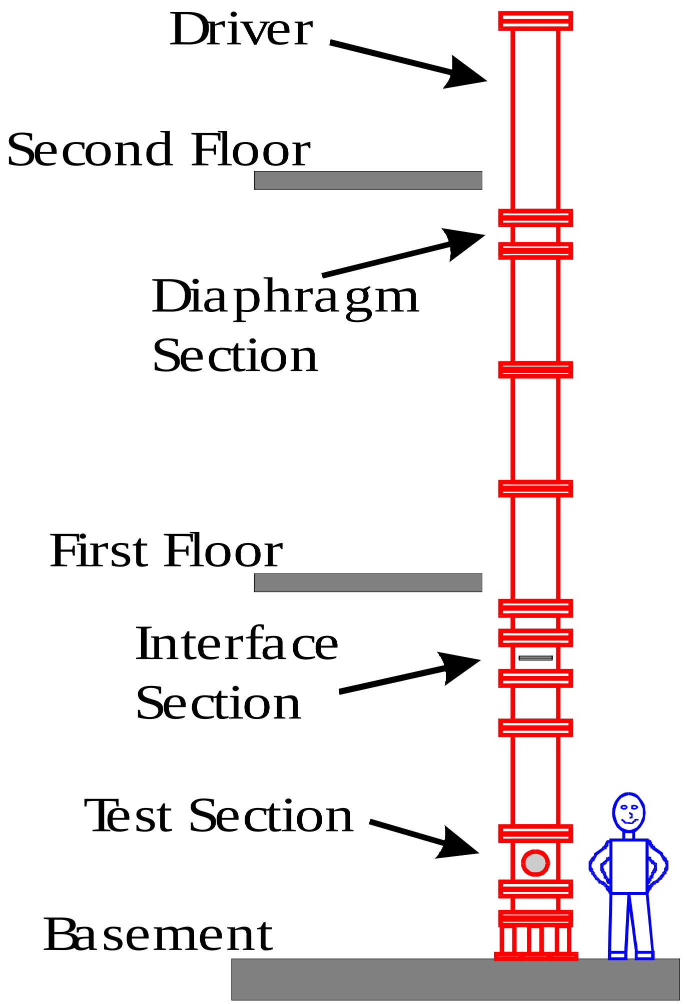
First Surface Protection by Fan Spray

Cooling Tubes Modeled as Cylinders



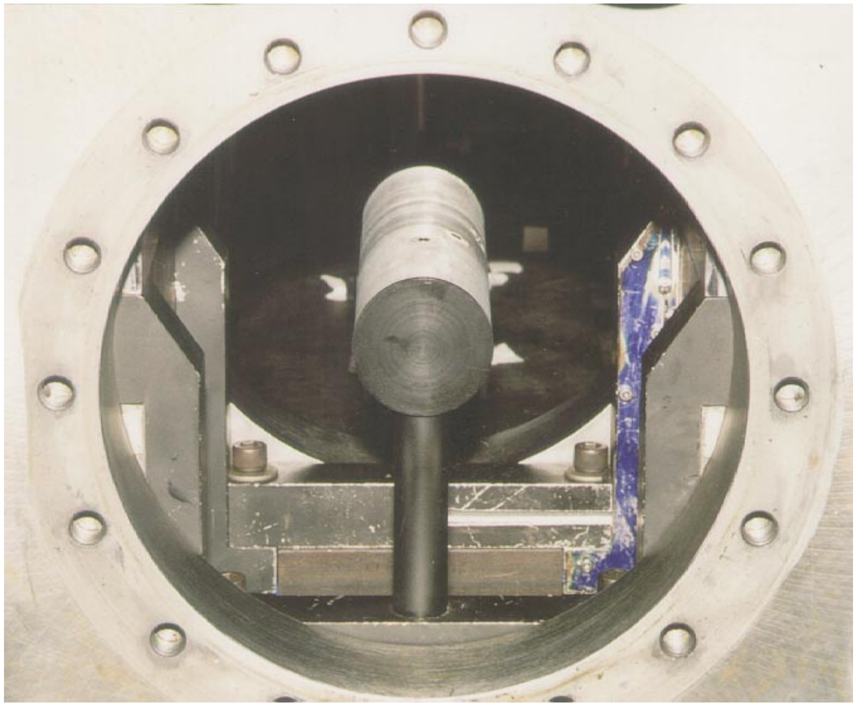


WiSTL (Wisconsin shock tube laboratory)

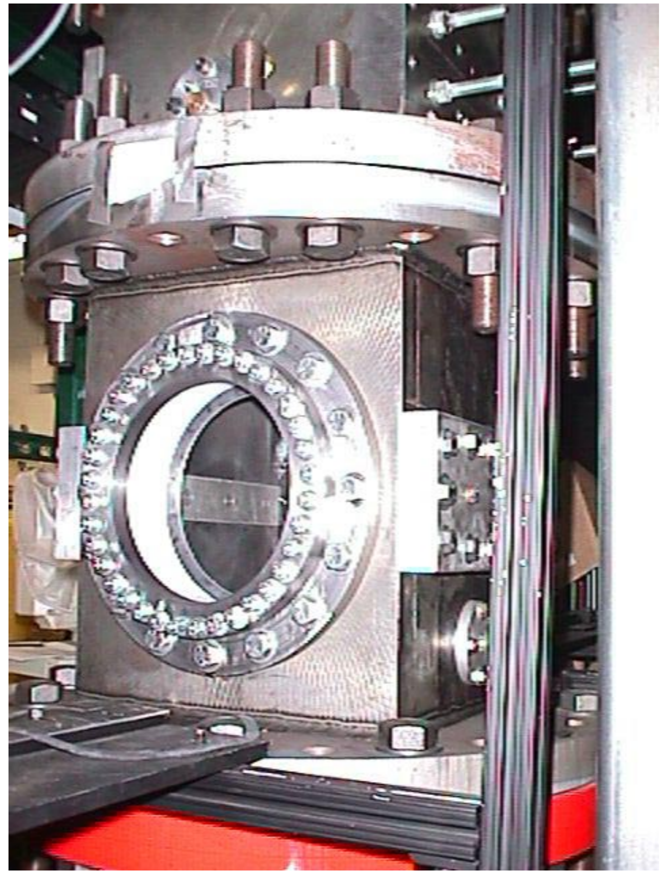


- Vertical Orientation
- Large Internal Square Cross-Section (25 cm square)
- Total Length=9.3 m
  Driven Length=6.8 m
- Structural Capacity 20 MPa
- Modular Construction
- Combustion Driver

Test Section Details

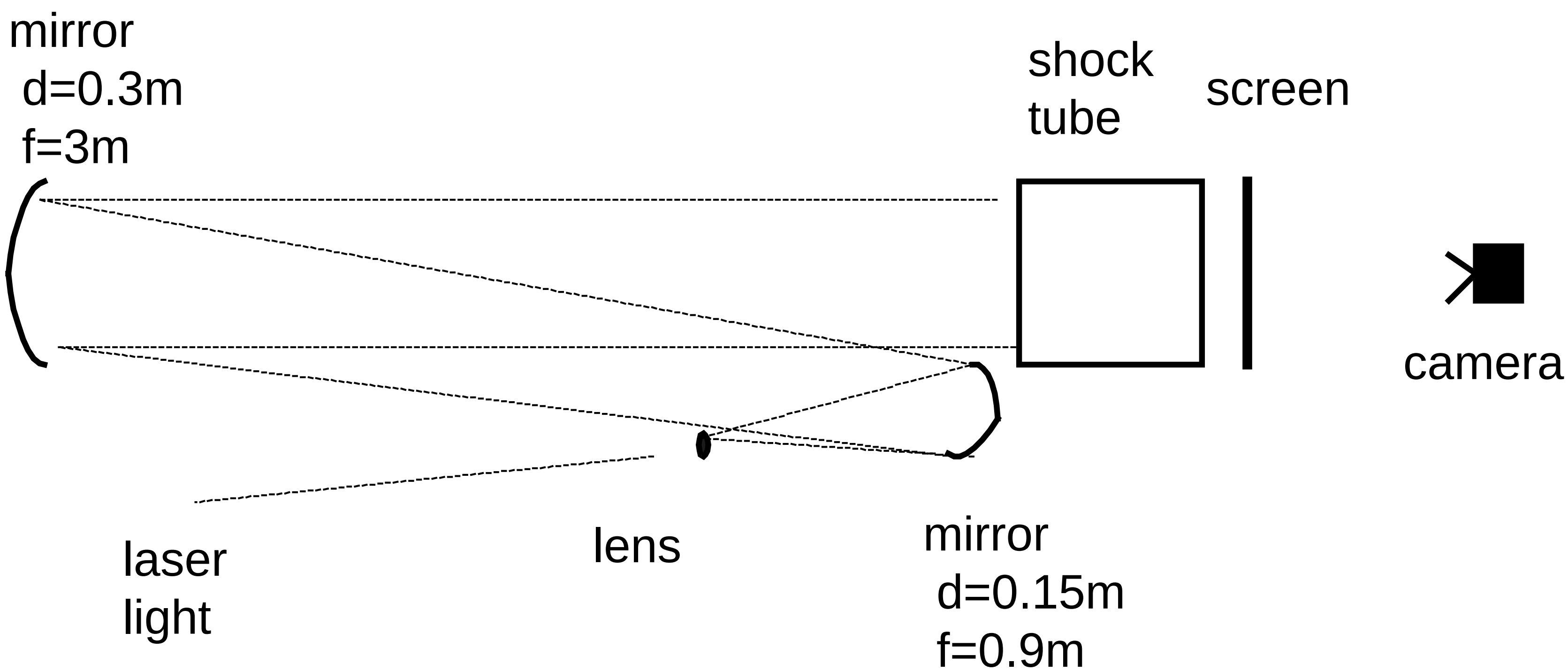


Single Cylinder Installed



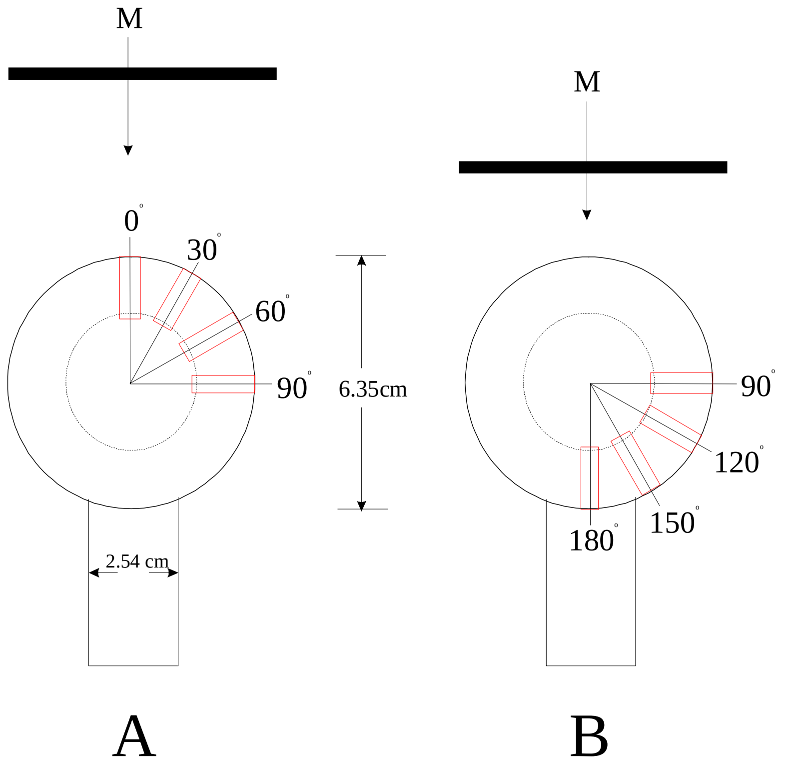
Window Installed

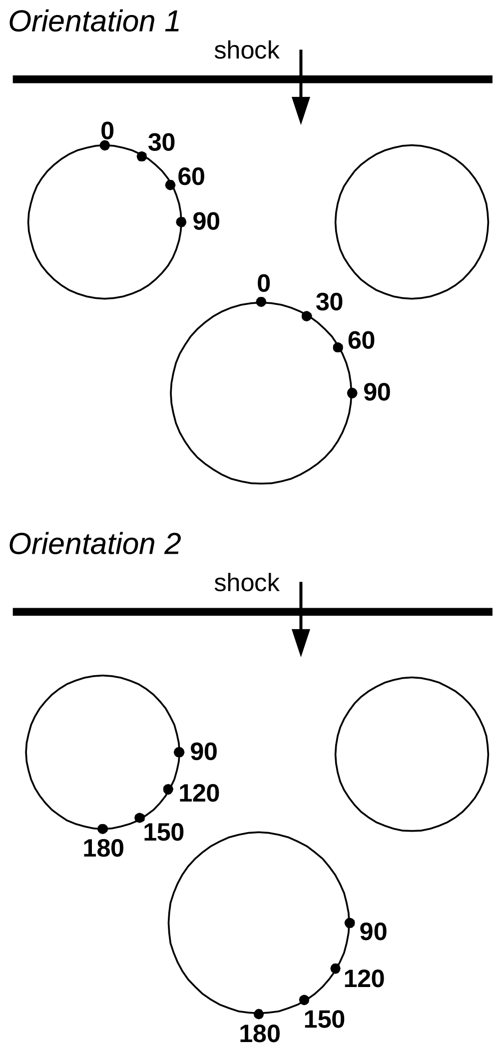
Shadowgraph Imaging



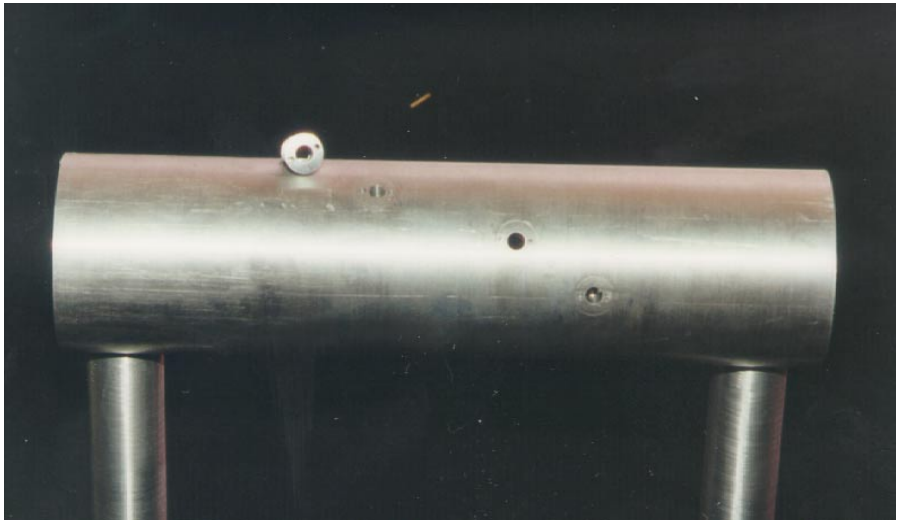
Nd:YAG, 10ns Pulse Laser (timed from incident shock)
1024x1024 CCD Camera

Experimental setup and pressure transducers

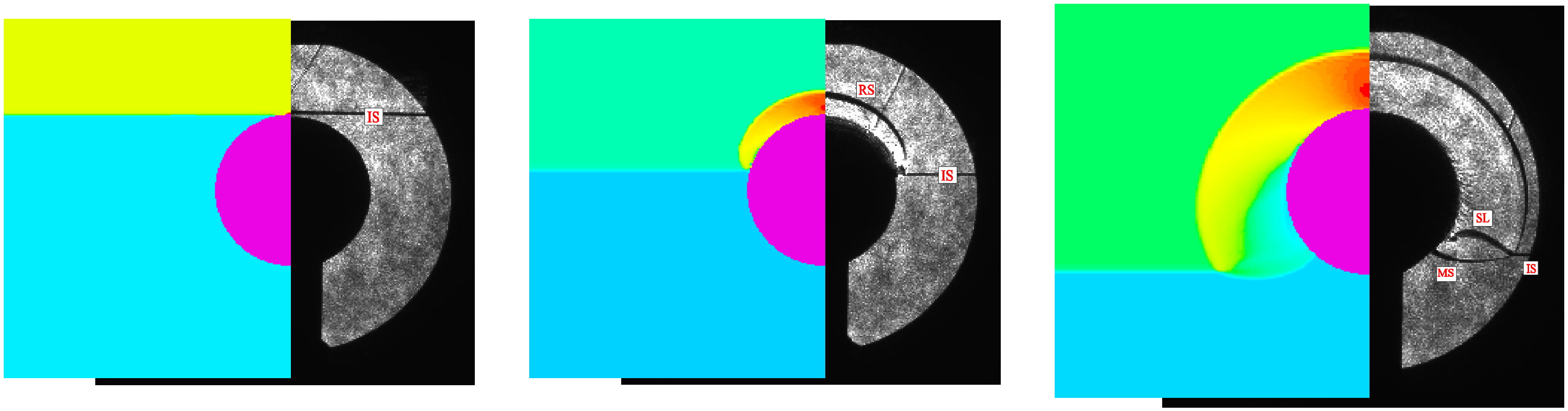




Flush mounting of pressure transducers



Single cylinder data (Issw22, London 1999)



Density contour plots from the numerical simulation using RAGE compared to the experimental shadowgraphs. The times of the numerical simulations are t=0, t=0.03 and t=0.08 ms after a 1.85 Mach shock (in air) makes contact with the cylinder. The experimental images were taken at a time of t=0, t=0.05 and t=0.09 ms respectively.

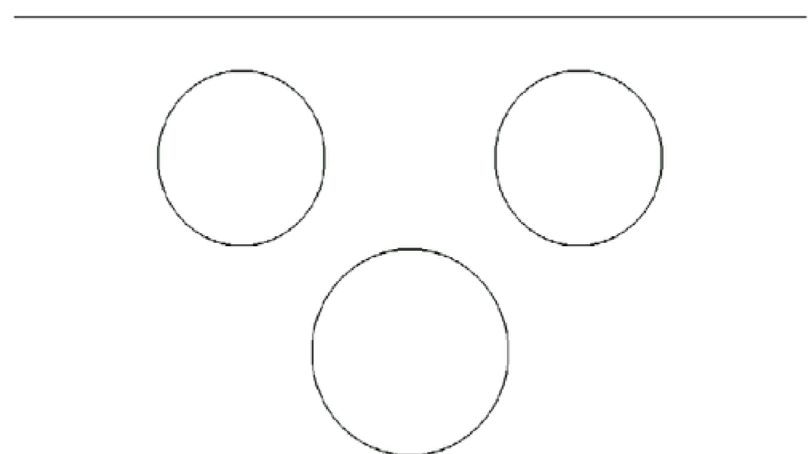
Shock-tube Experimental Setup

- $M \approx 2.75$ Argon
- Helium used as driver
  - 20 gage steel diaphragm
  - $P_{rupture} \approx 1.8$ MPa
- Wall mounted pressure transducers to measure shock speed and trigger laser pulse
- Digital oscilloscopes record pressure data

Shock Time Series (Numerical)

Shock travels downward resulting in complex diffraction patterns

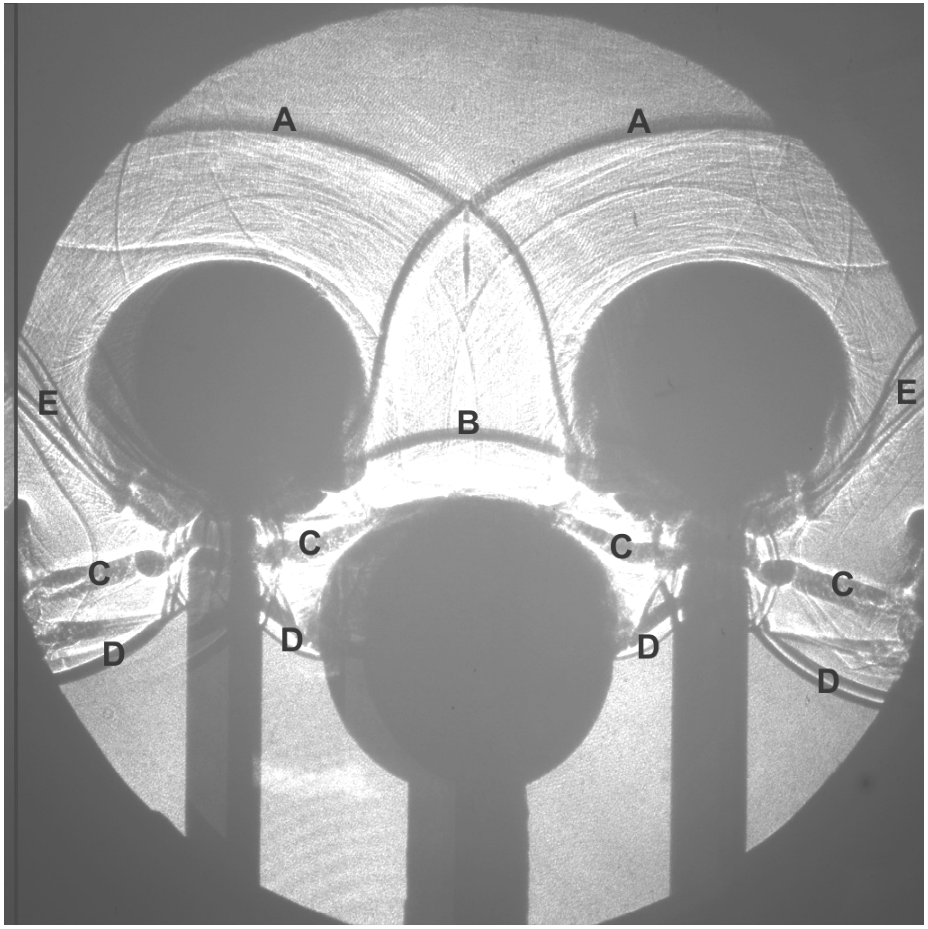
Times Between Frames≈18 μs (Length of Animation is 270 μs)



(click to play movie)

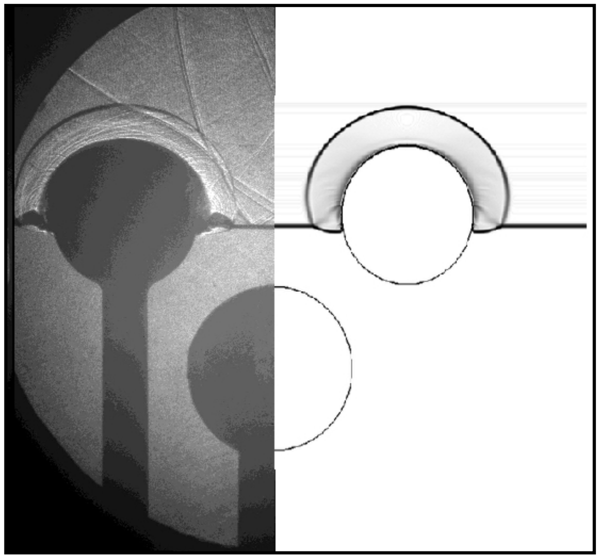
Experimental Result

Shock diffraction pattern at $t_{image} \approx 99\ \mu s$, as measure from incident shock location at top of upper cylinder

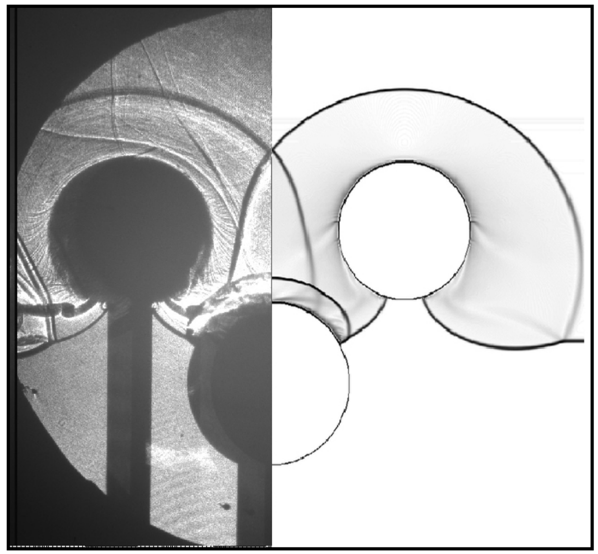


A. Reflected shocks from upper cylinders
B. Reflected shock off lower cylinder
C. Contact discontinuities
D. Transmitted shock
E. Gradients due to wall interactions

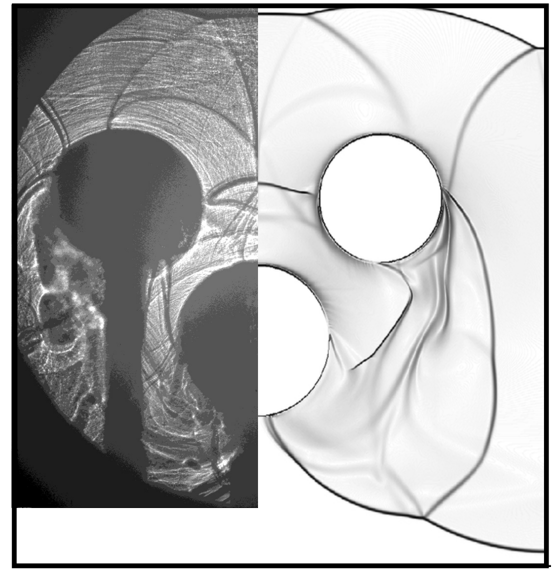
Diffraction Patterns



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



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

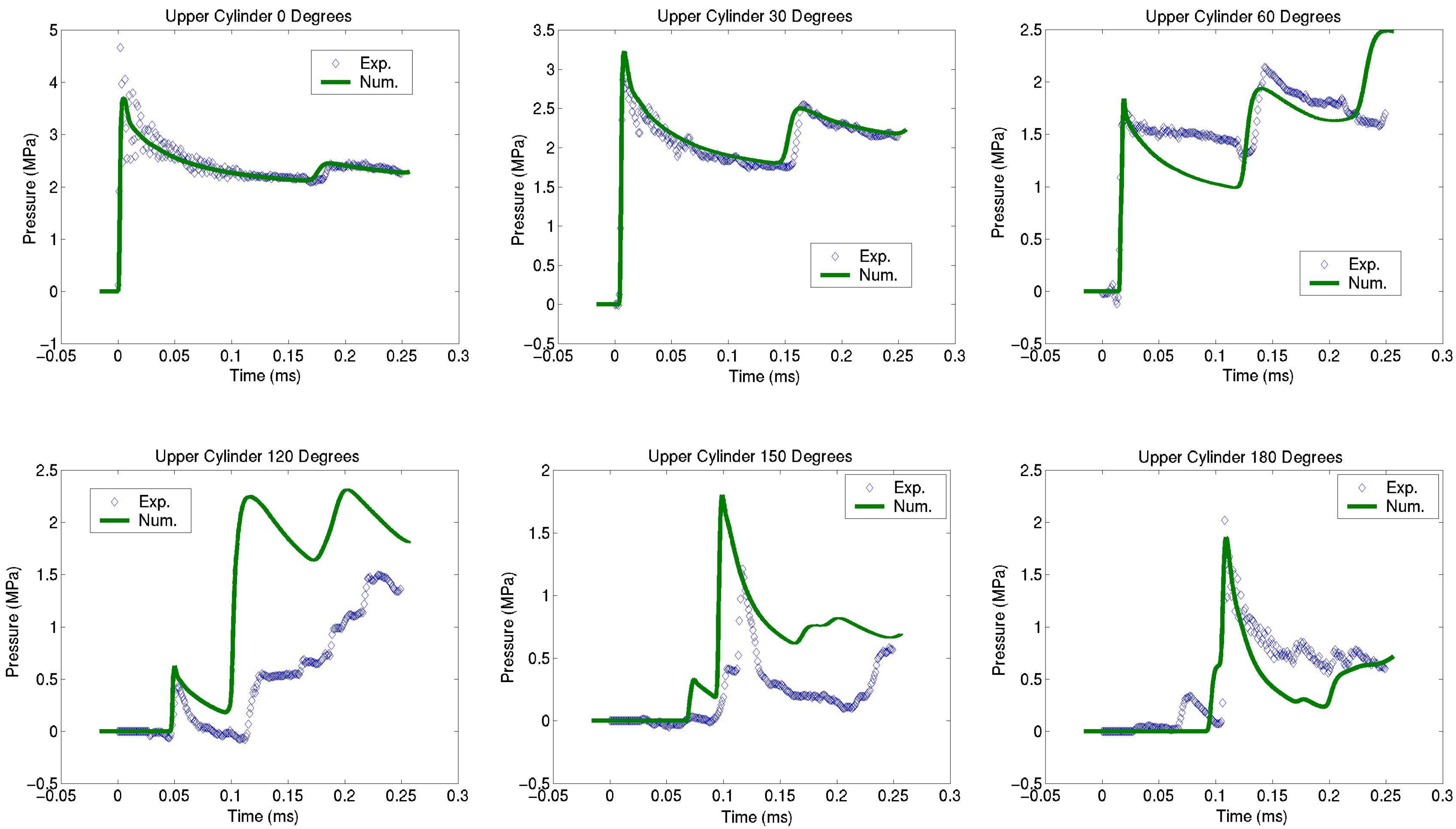


$t_{image} \approx 191\ \mu s$

Numerical Model

- Exact Riemann solver at cell interfaces, Godunov integration method
- Time dependent, two-dimensional, inviscid Euler equations
- Cartesian grid
- Adaptive time step (based on maximum wave speed)
- 25.4 cm square domain, grid 1018x1018, 0.25 mm spatial resolution
- Boundary conditions: reflective EW (shock tube walls) and extrapolate NS
- 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

Upper Cylinder Pressure Results



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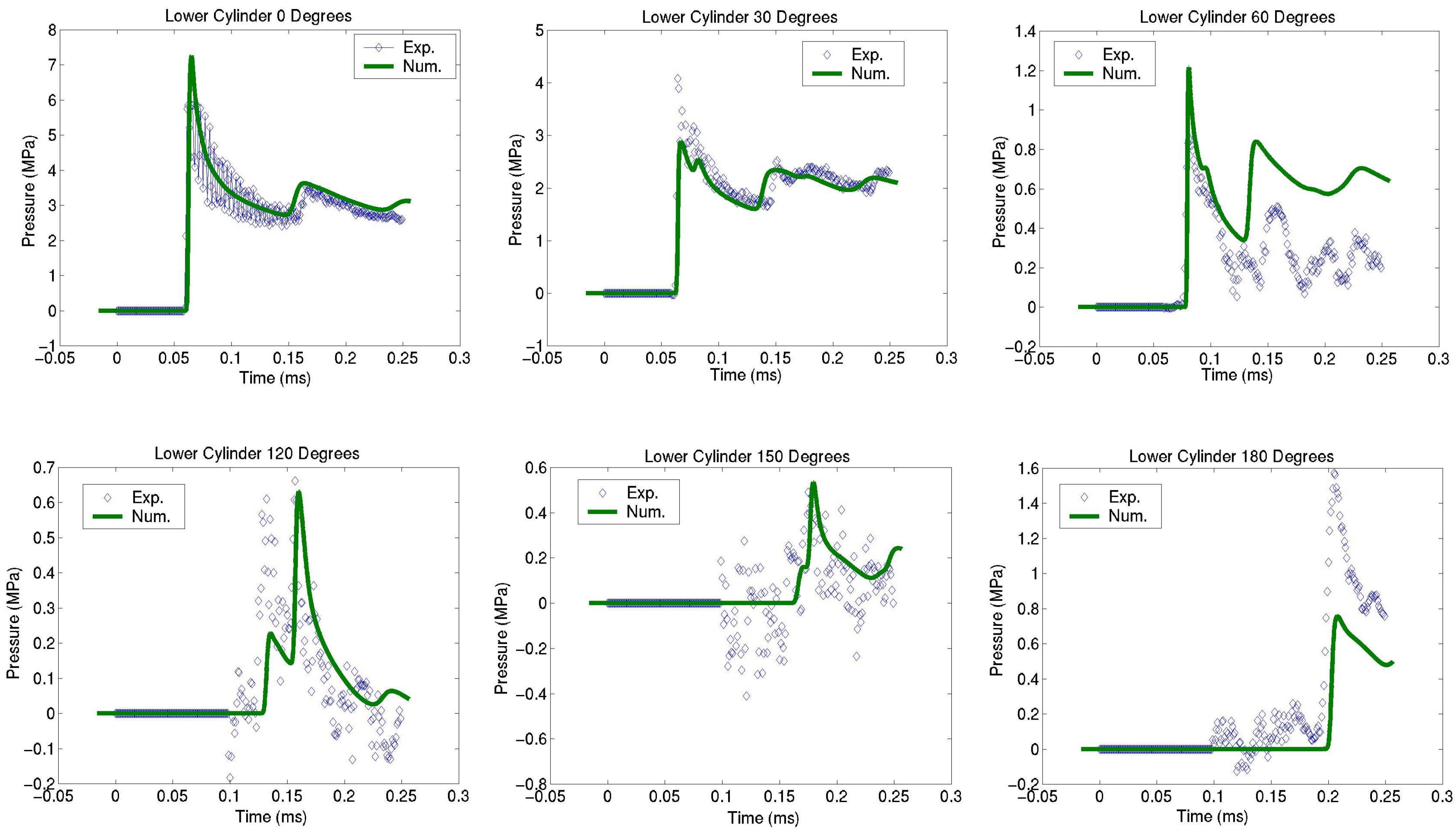
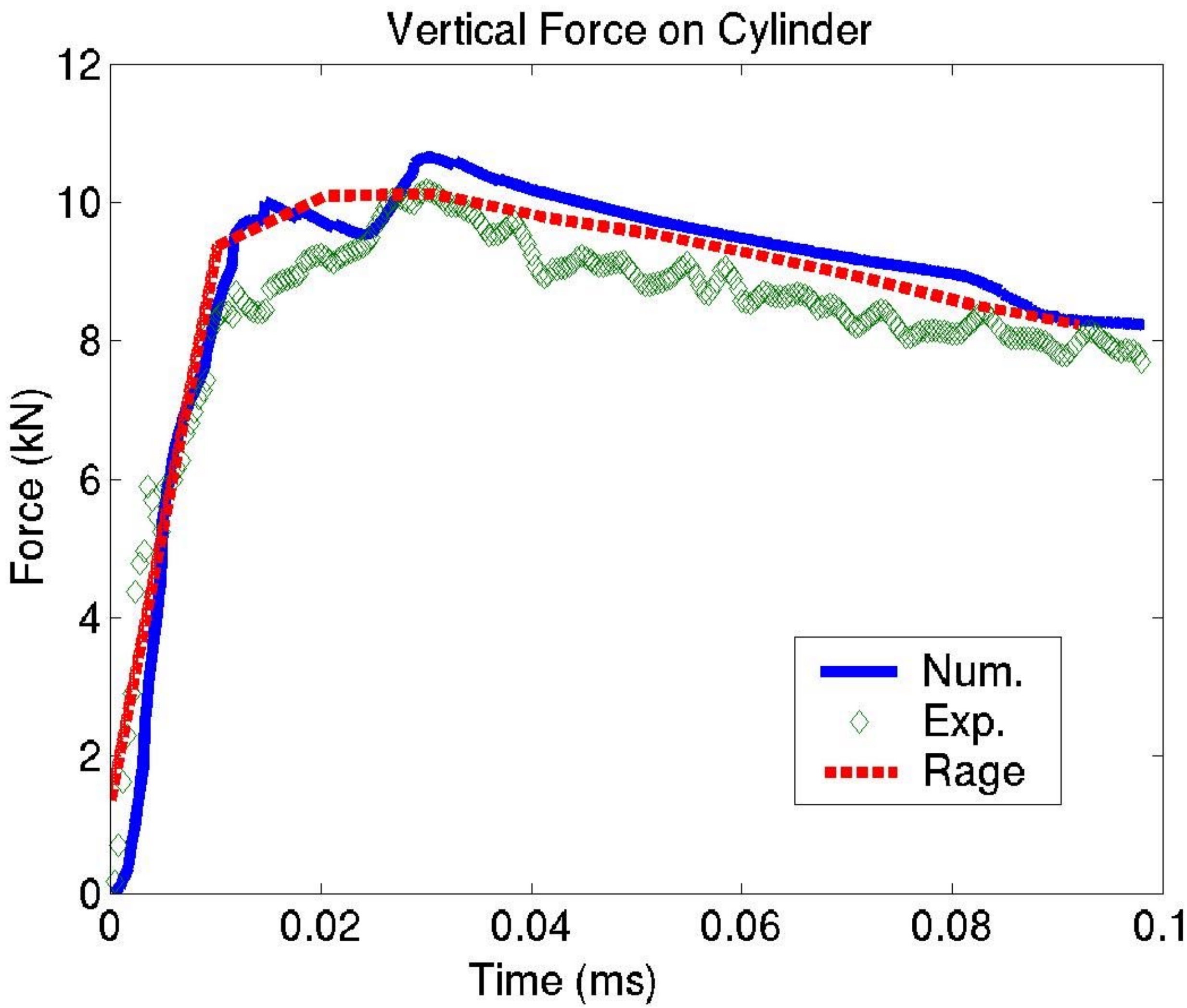
UW - Shock-tube

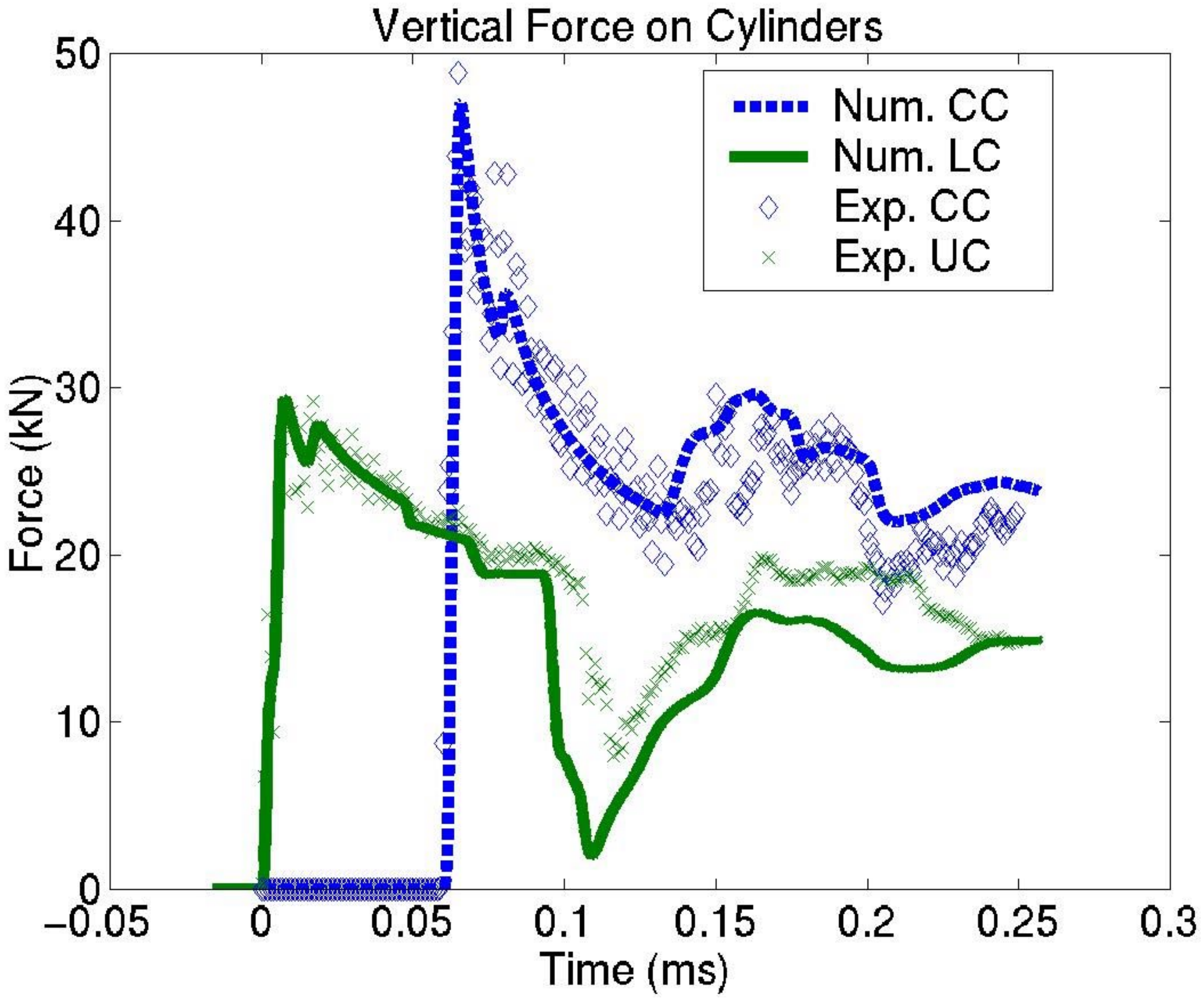
Lower Cylinder Pressure Results



Force on single cylinder



Vertical Force on Cylinders



Conclusion

- Cooling tube model arrangement successfully shock loaded
- Second series of tubes see higher structural loading
- Numerical results similar to experimental
- Study other tube arrangements and protection mechanisms