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Imaging of Density Interfaces Accelerated by Strong Shocks

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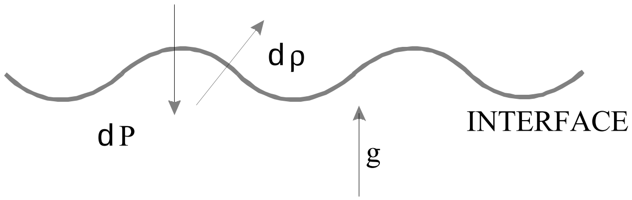
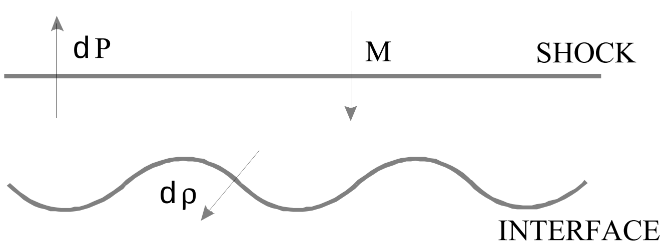
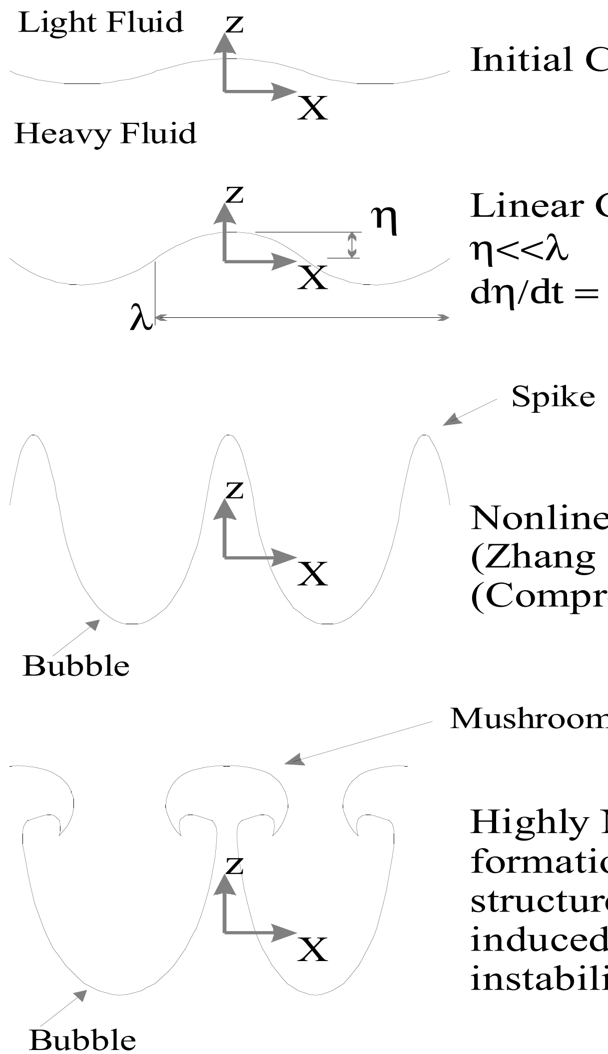
Richtmyer-Meshkov Instability



A. Rayleigh -Taylor Instability



B. Richtmyer - Meshkov Instability



Initial Condition

Linear Growth Regime
$\eta << \lambda$
$d\eta/dt = k(v)A\eta_o$

Nonlinear Growth
(Zhang and Sohn 1997 Phys. Fluids)
(Compressibility effects)

Highly Nonlinear Growth; formation of mushroom structures due to vortex generation induced by Kelvin - Helmholtz instabilities

Objectives

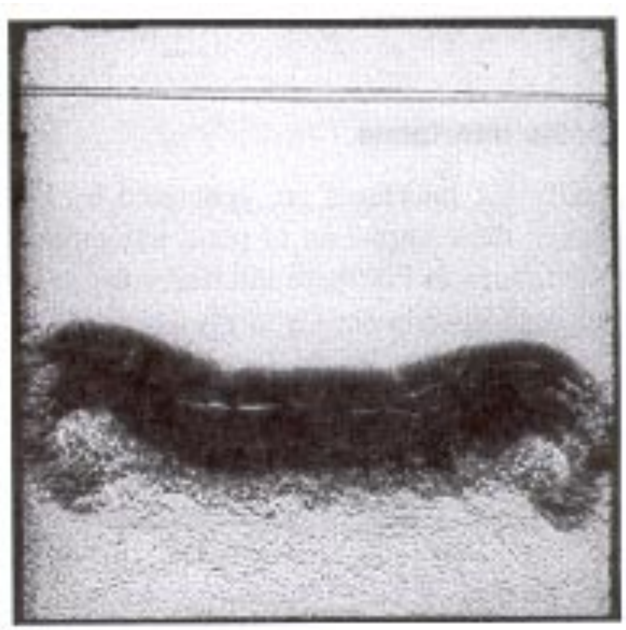
• Study the R-M instability in the non-linear regime of growth.

• Strong incident shocks to investigate the effect of compressibility on the instability growth.

• Minimize the effects of wall vortices on the instability growth for reshocks.

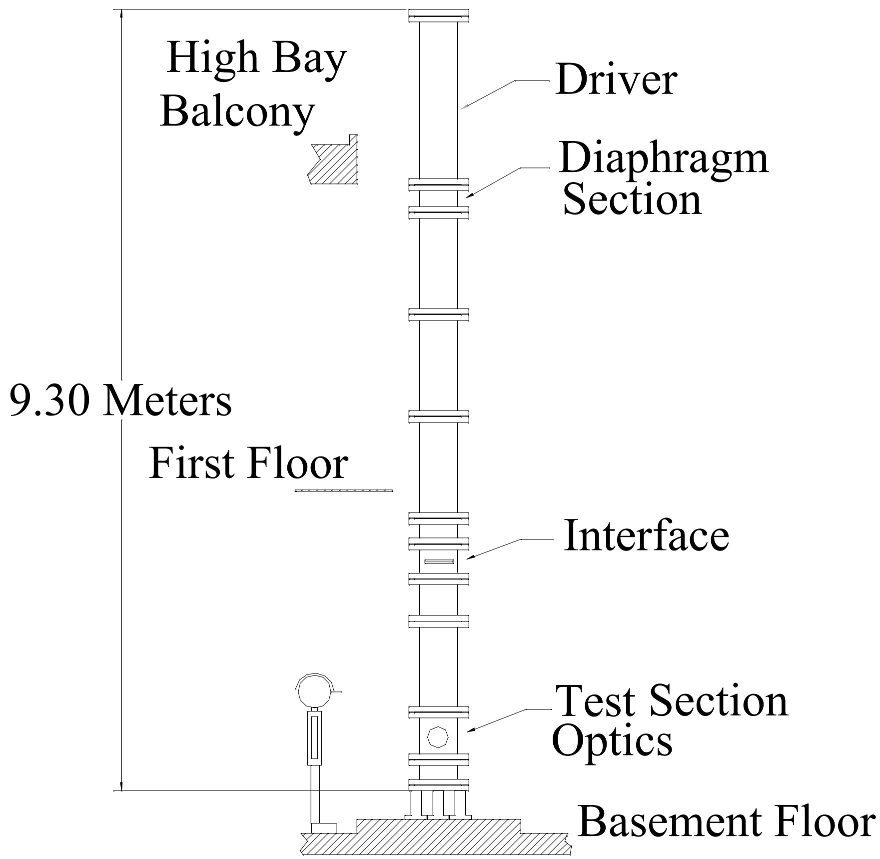
• Apply planar imaging techniques (Mie and Rayleigh scattering) to obtain quantitative data for instability growth and R-M induced mixing.

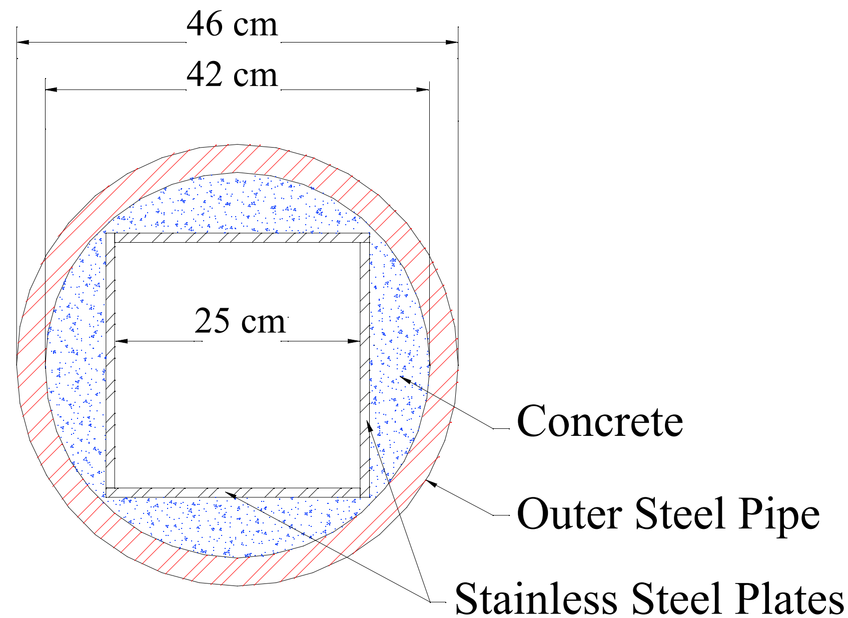
Image of a Wall Vortex



Schlieren image of a wall vortex generated at a shocked interface as a result of reflected shock-boundary layer interaction (Bonazza, Physics of Fluids 8(9), 1996). Such a vortex exerts strain on the interface and creates uncertainties in the growth rate measurements.

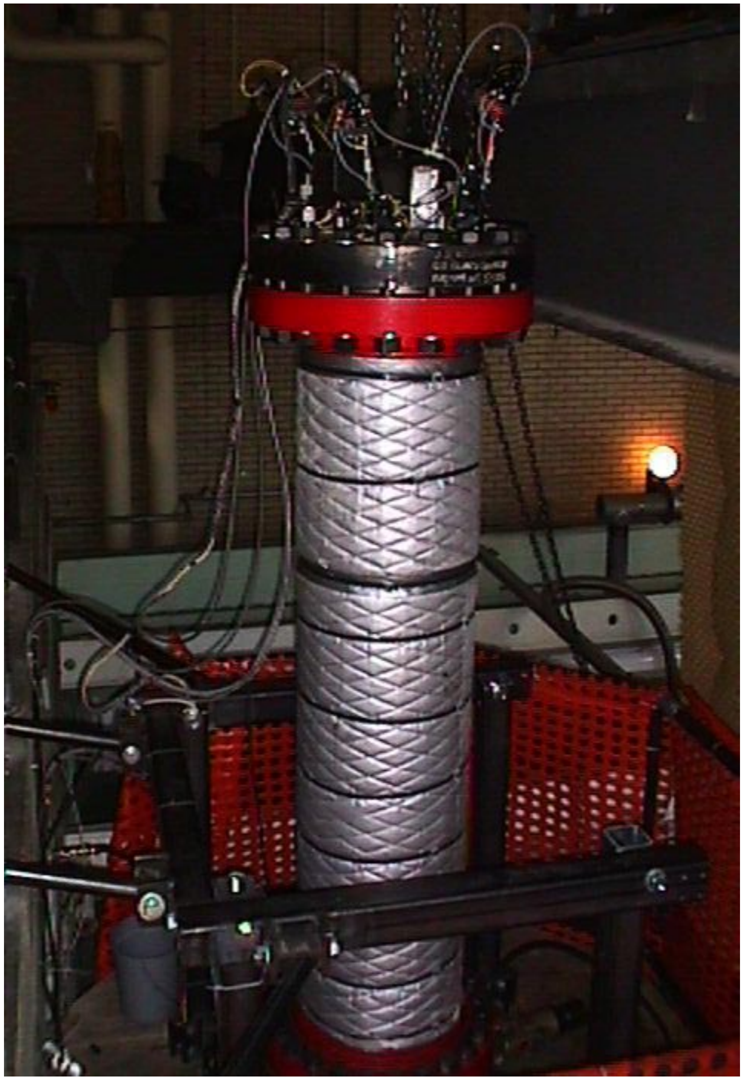
Description of the Wisconsin Shock Tube

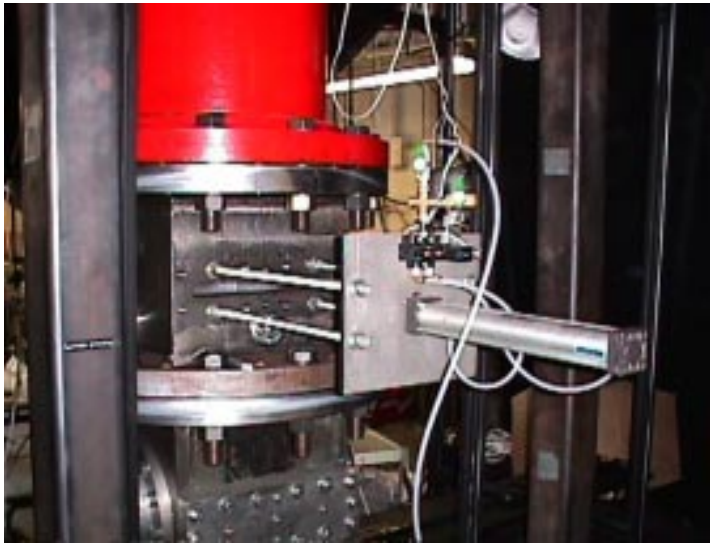




- Vertical Orientation
- Large Square Cross-Section (25 cm Square)
- Total Length 9.3 m, Driven Length 6.8 m
- Structural Capacity 20 M Pa
- Modular Construction
- Combustion Driver

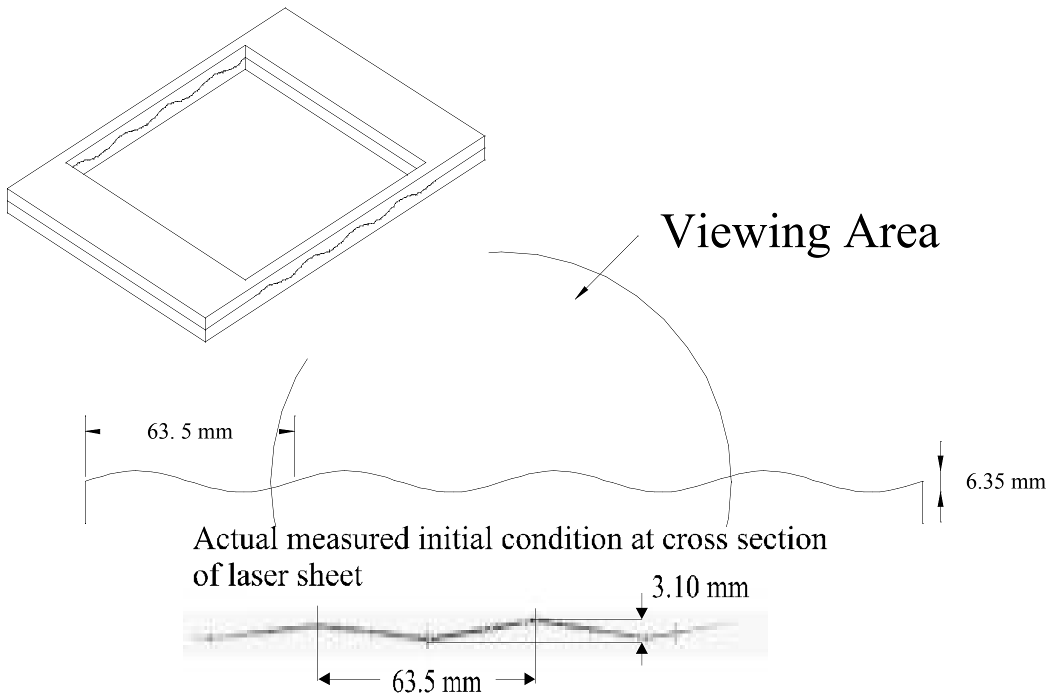
Key Components of Wisconsin Shock Tube





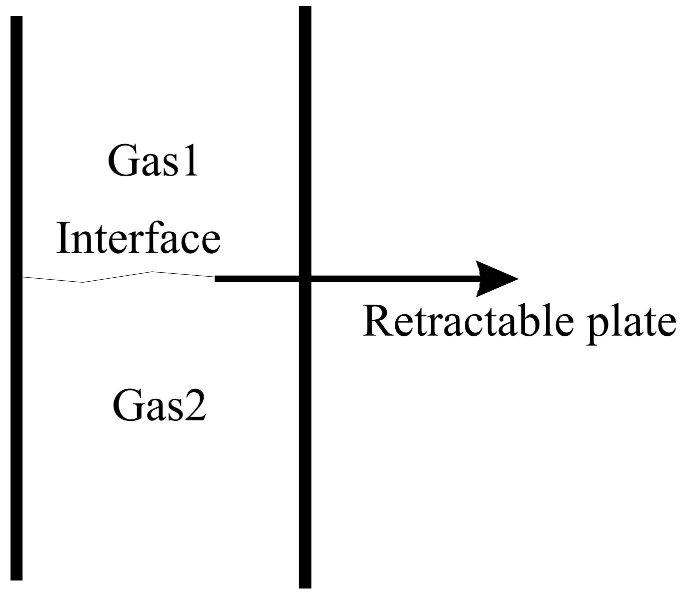
Formation of Initial Conditions

1. Discontinuous Interface



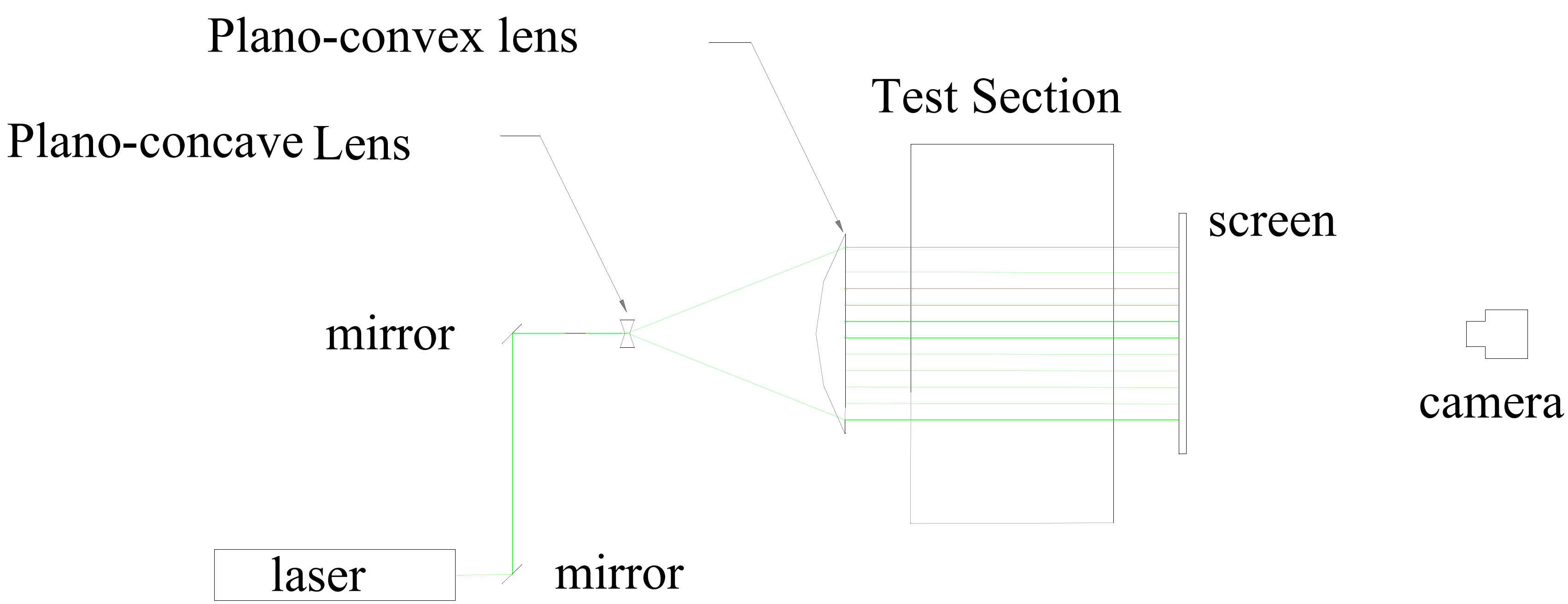
Nitrocellulose or Mylar membrane form the interface

2. Continuous Interface

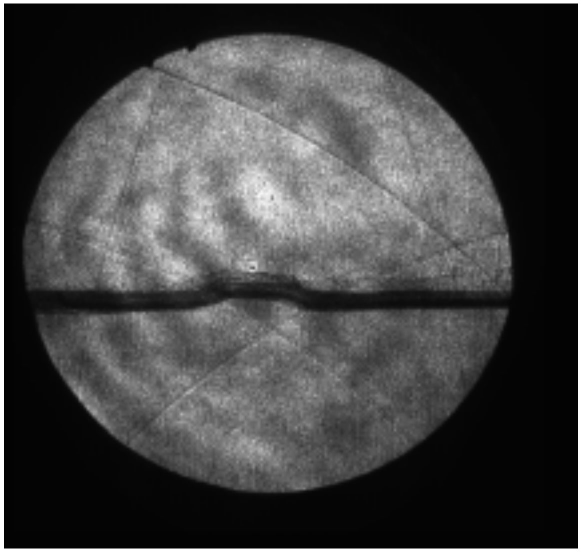


A diffuse interface created by plate retraction

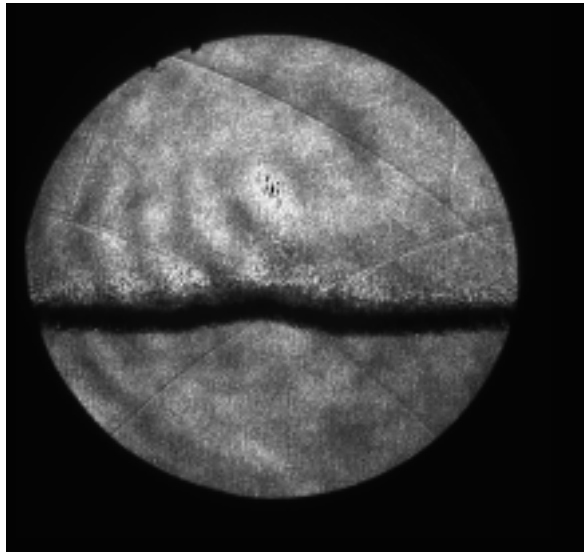
Shadowgraph Technique



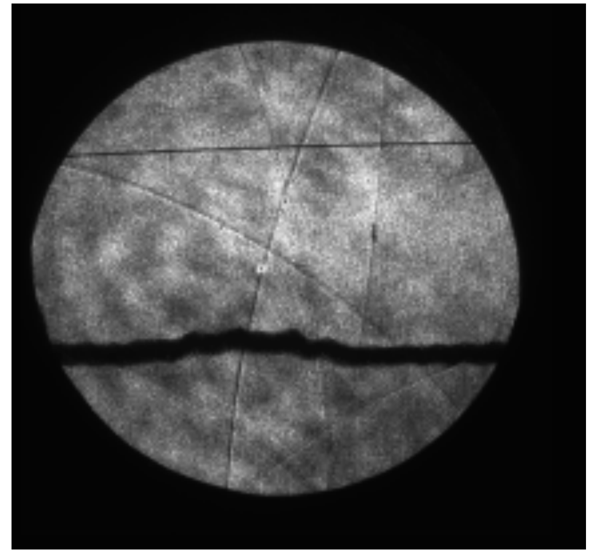
Similarity Between Flat Membranes



a



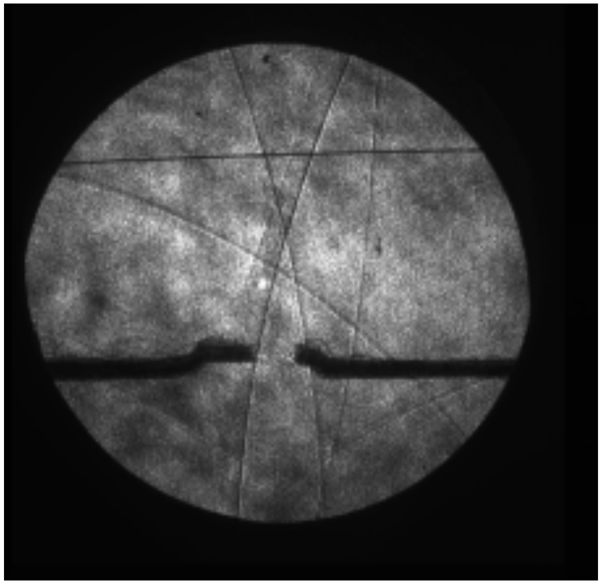
b



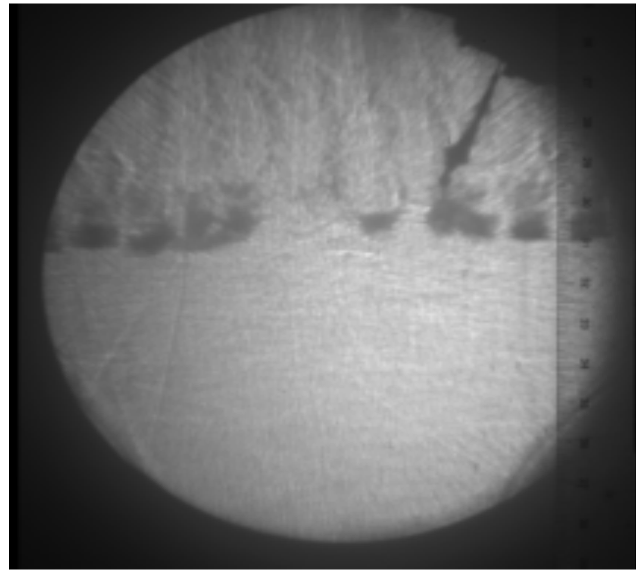
c

Shadowgraph pictures of a membranes separating two gases after acceleration by a Mach 1.93 shock wave. Membranes remain intact and travel with the interface. a) is a 0.5 µm thick nitrocellulose membrane between air and argon, 1.24 ms after initial shock acceleration b) is a 0.94 µm thick Mylar membrane separating air and argon 1.24 ms after initial shock acceleration c) is a 0.94 µm thick Mylar membrane between air and air 1.11 ms after initial shock acceleration . The small bump in the middle of the membrane is due to aerodynamic drag on the membrane.

Effects of Wires on the Membrane



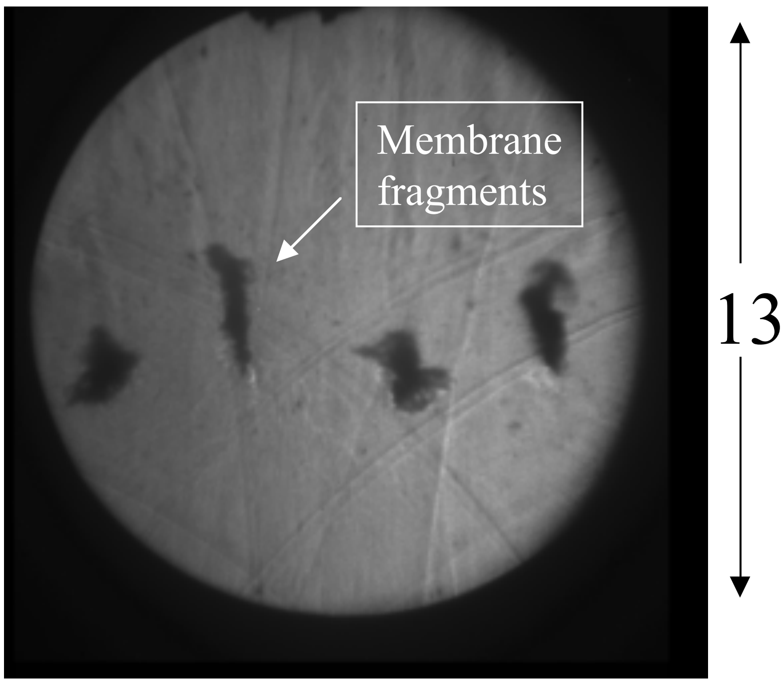
Nitrocellulose membrane 1.11 ms after acceleration by a Mach 1.93 shock wave. The membrane is cut by a single wire placed in the center of a frame supporting it forming two membrane fragments.



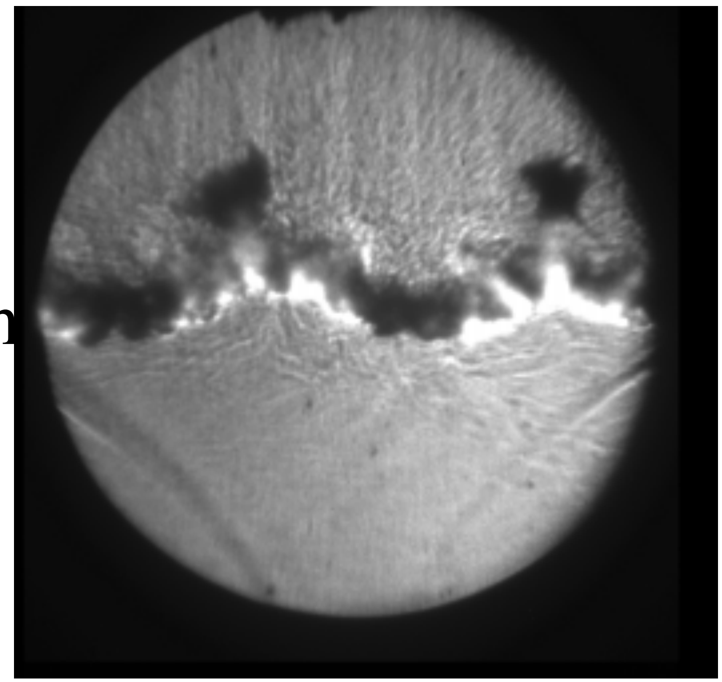
Nitrocellulose membrane 0.603 ms after acceleration by Mach 2.9 shock wave. The membrane is cut by 13 nylon wires spaced a distance of 1.27 cm apart. The wake from the particles can be seen at the top of the photograph.

Shadowgraph Images

Shadowgraph image of the membrane fragments accelerated by a Mach 2.02 shock wave for an N_2/N_2 "interface"

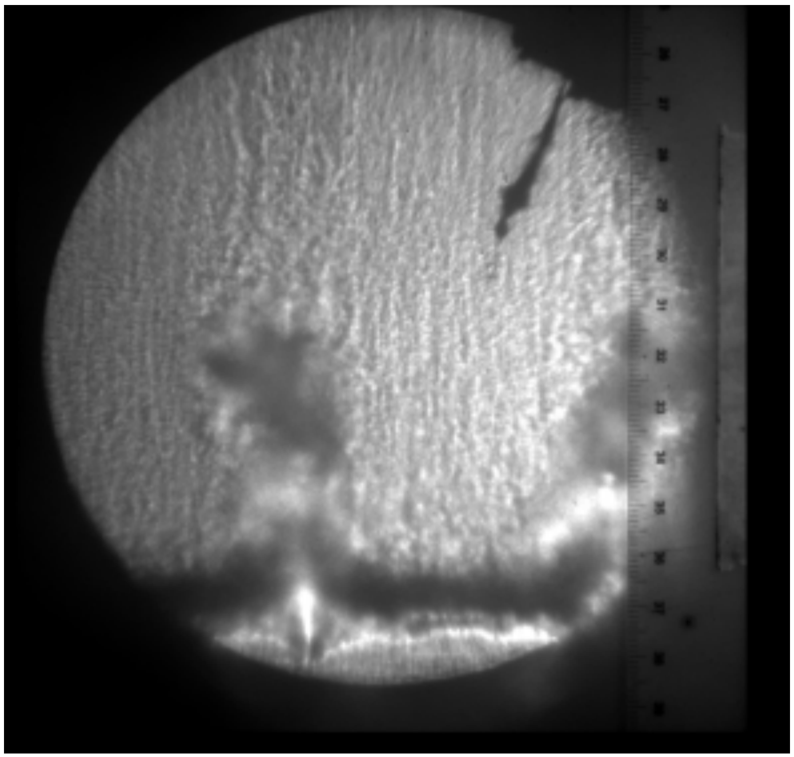


Shocked interface between air/CO_2, M = 2.02, Time = 1.134 ms after initial shock acceleration

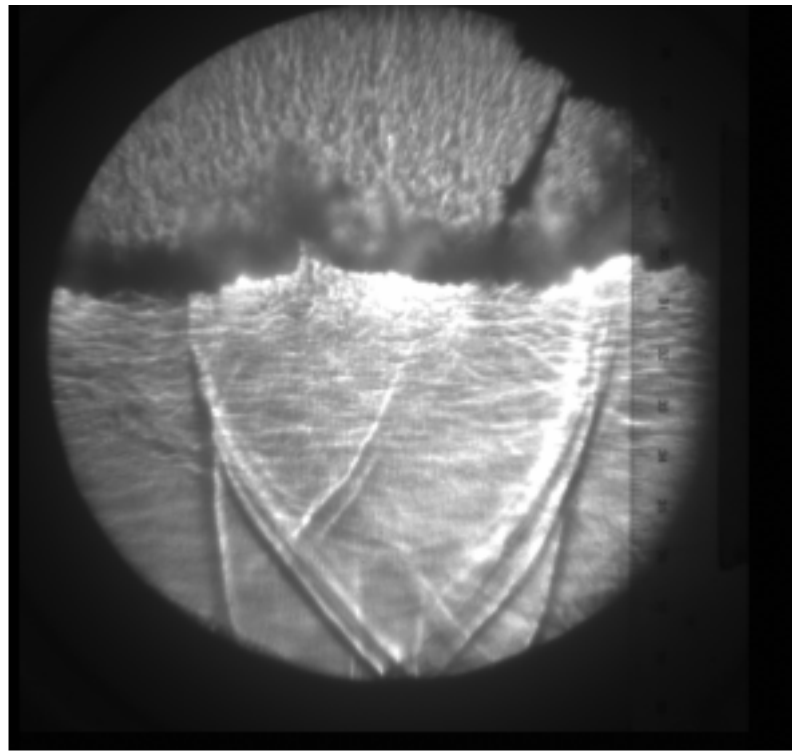


Shadowgraph Images

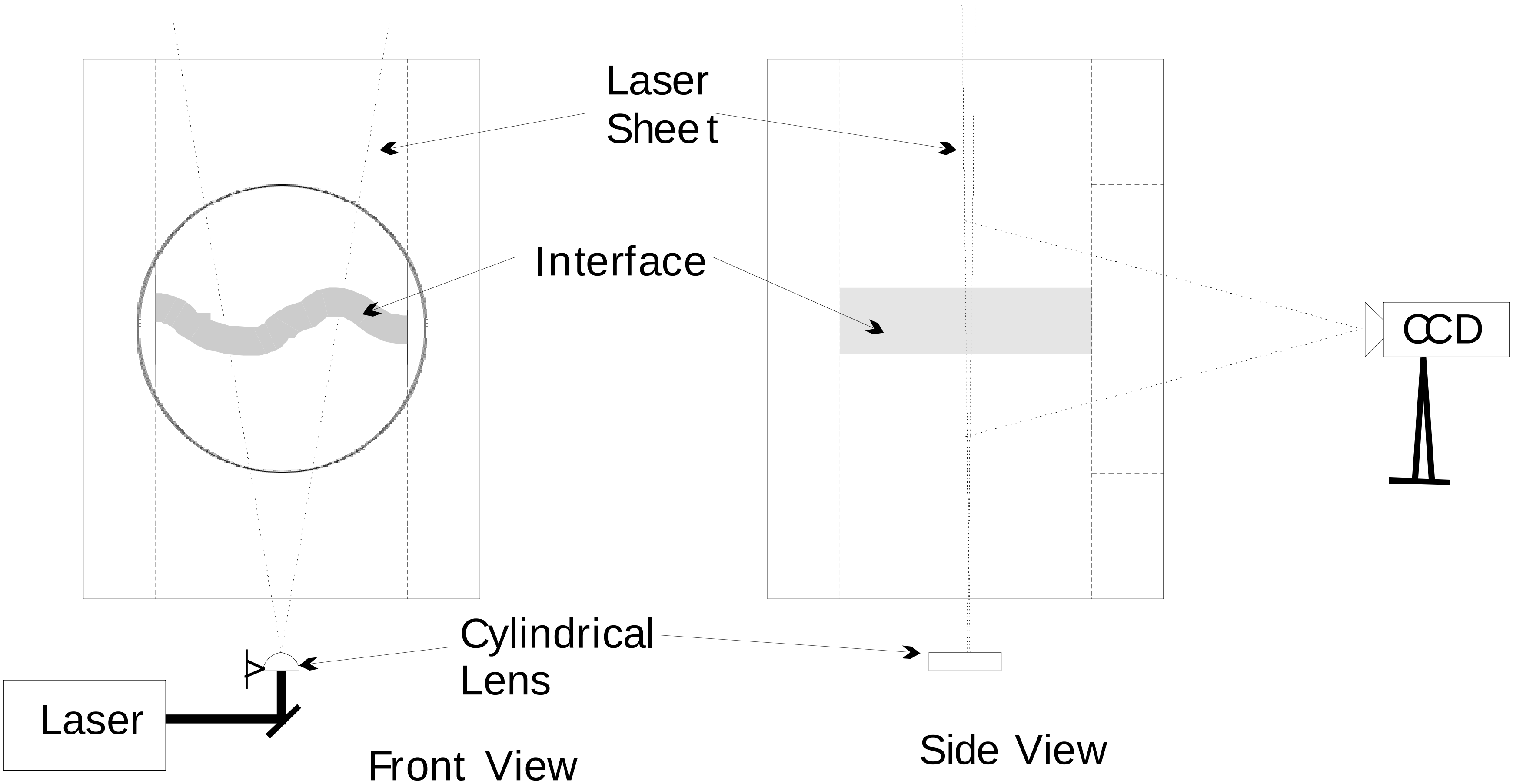
Shocked interface between He/CO_2, M = 1.90, Time = 0.859 ms after initial shock acceleration



Shocked interface between N_2/CO_2, M = 2.90, Time = 0.667 ms after initial shock acceleration



Planar Imaging Technique



Distortion of Intact Membrane

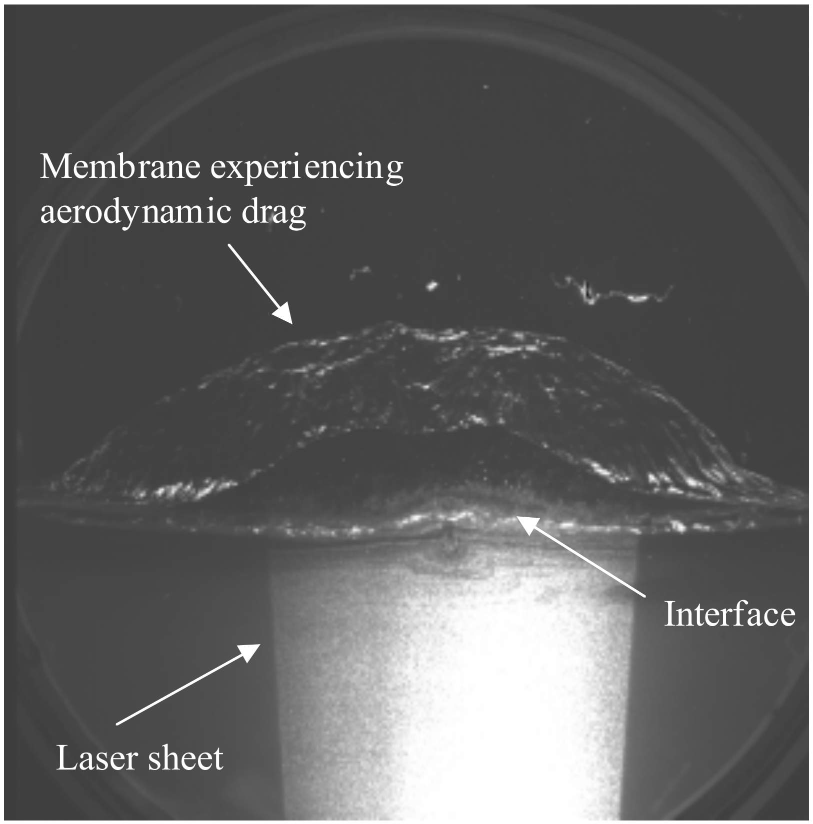


Image of a Mylar membrane separating N_2 and CO_2 1.109 ms after acceleration by a Mach 2.03 shock wave. The membrane was cut into two fragments and the larger of the two experiences a parachute effect due to aerodynamic drag. The distortion of the membrane is evident in the figure.

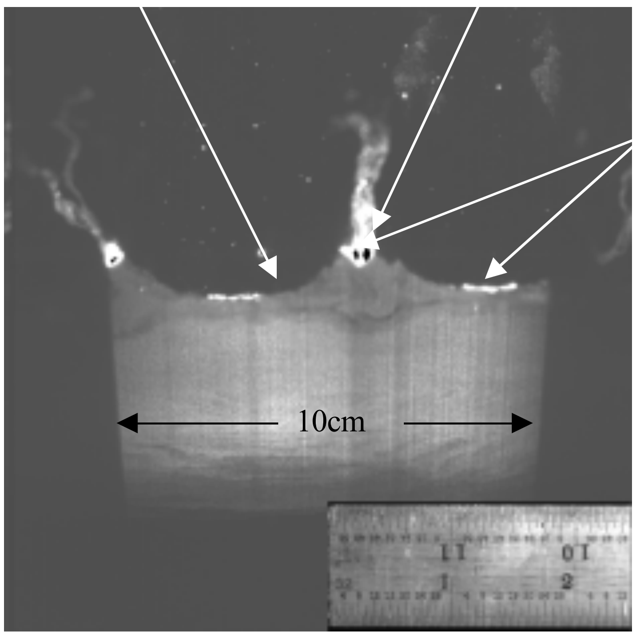
Planar Mie Scattering Images

Mie scattering image of a shocked helium/CO_2 interface, M = 2.03, Time after initial shock acceleration = 0.737 ms

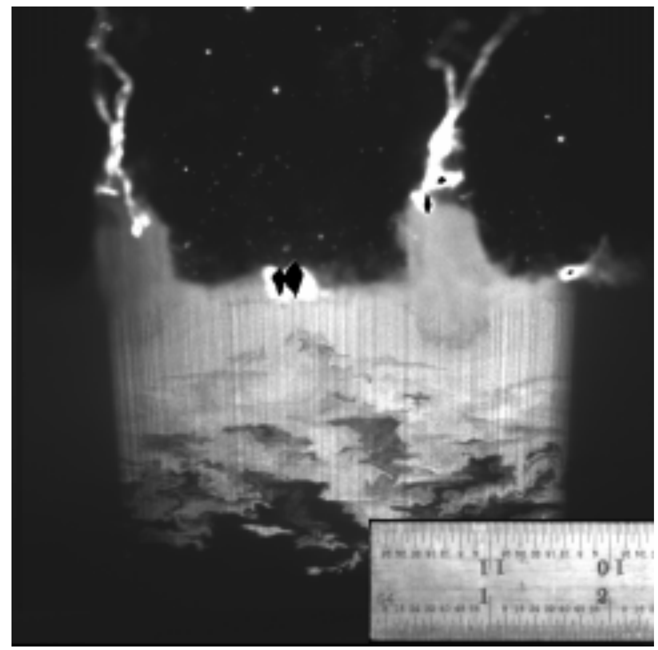
“Bubble” of helium into CO2

“Spike” of CO_2 into helium

Membrane fragments

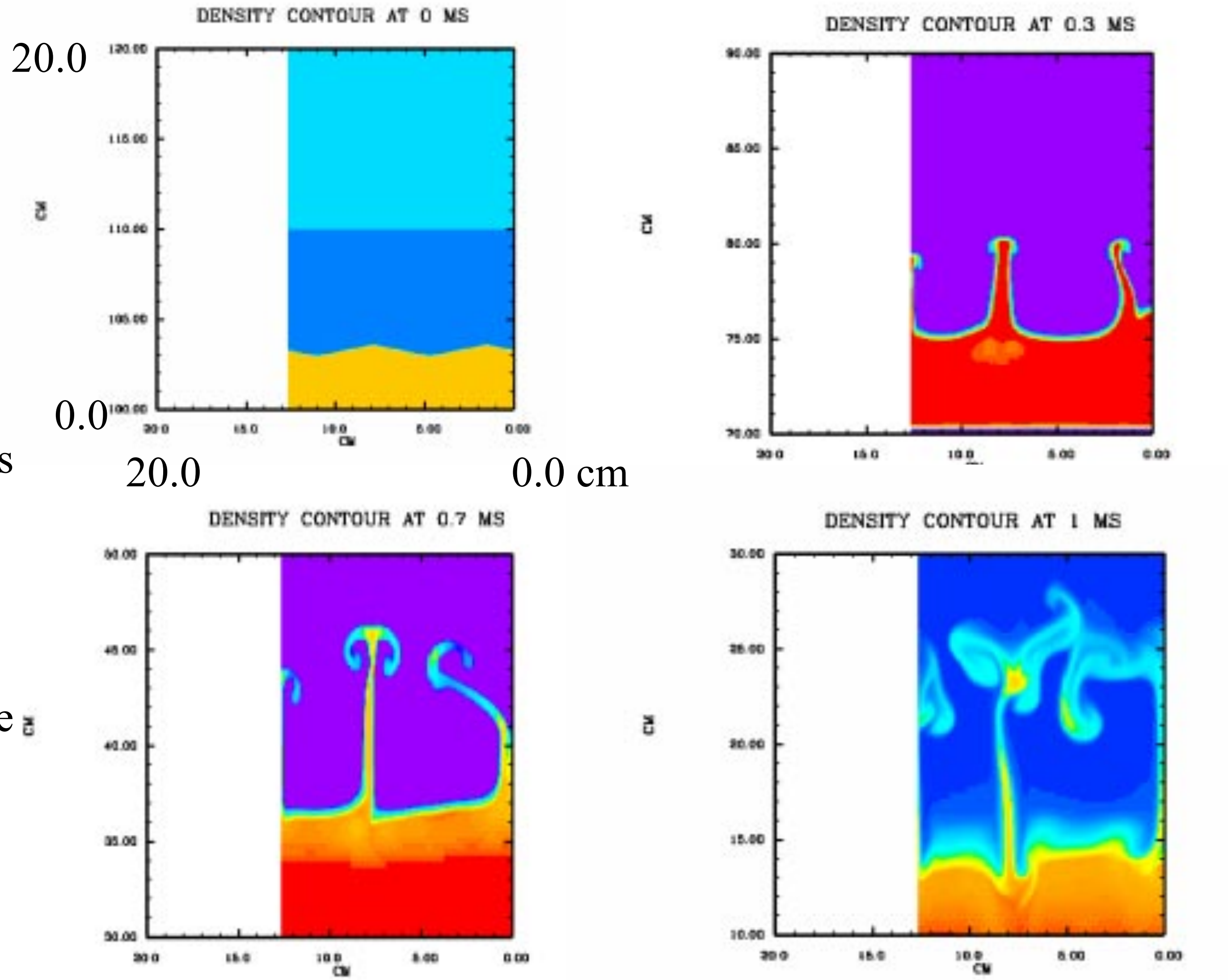


Mie scattering image of a shocked helium/CO_2 interface, M = 2.03, Time after initial shock acceleration = 1.23 ms

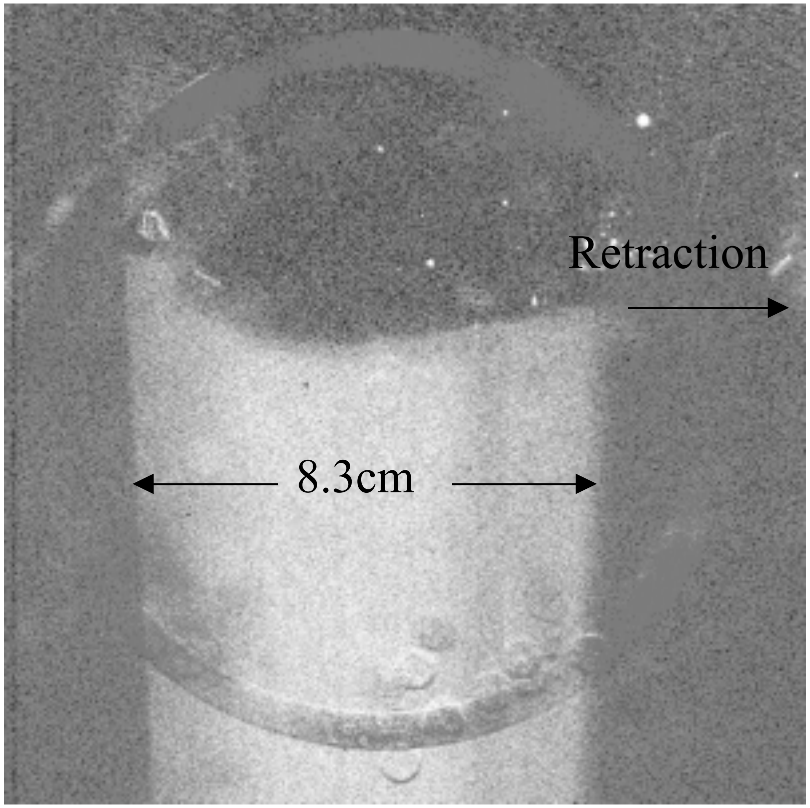


RAGE Simulation of UW Shock Tube Interface Experiment

- He/CO_2 1 atm. interface
- V_{shock}=2.1 km/s
- Up = 1218.2 m/s
- Level 5 RAGE calculation
- 100 cm interface transit length



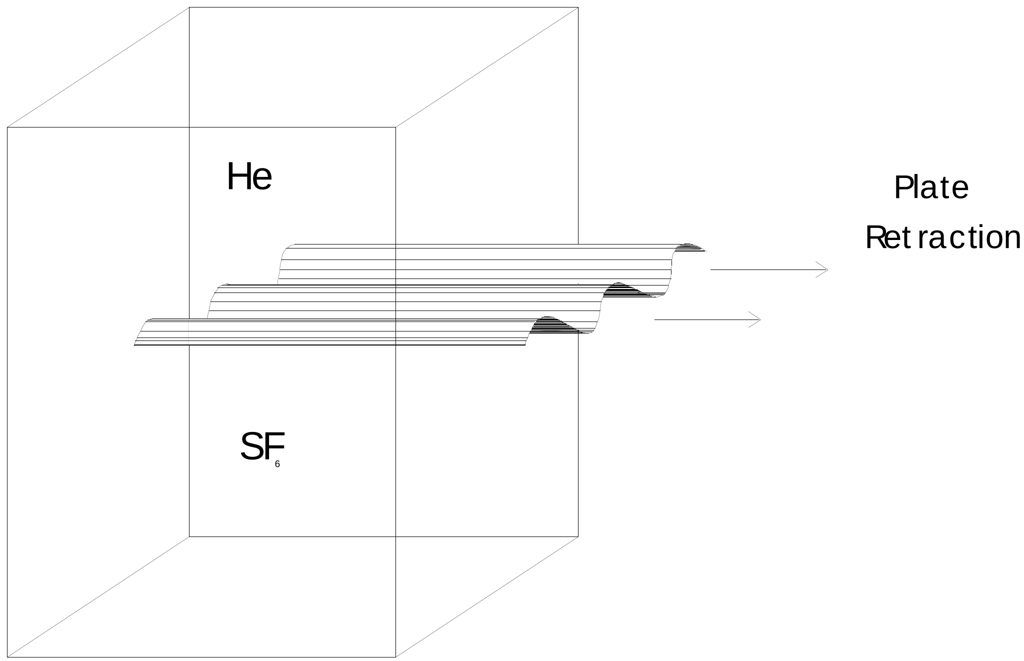
Planar Rayleigh Scattering Image of Continuous Interface



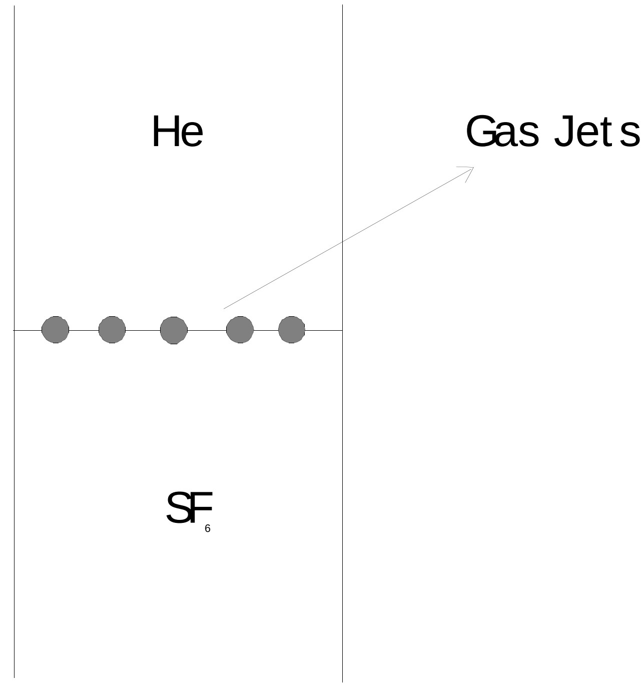
Shocked interface between He/CO_2, M = 2.03
Time after initial shock acceleration = 0.737 ms

The initial condition is a continuous interface formed by retraction of a thin S.S. plate. We are currently trying to image the initial condition.

Future Techniques to Form Interface



A



B

A. Retraction of a sinusoidal shaped thin plate to form a diffuse interface

B. Use of gas jets flowing across the width of the shock tube to provide initial perturbation

Summary

- A new, vertical, square shock tube has been fabricated to study the R-M instability in the non-linear regime. The facility is capable of withstanding strong shocks (M~5 into atmospheric air), studying reshocks and different types of interfaces.

- Preliminary results of the R-M instability have been demonstrated with shadowgraphy and planar imaging techniques such as Mie and Rayleigh scattering.

- Membranes have been found to severely affect the flow structure, especially in the non-linear regime.