Richtmyer-Meshkov Experiments
with
Rayleigh-Taylor-Generated Initial Conditions

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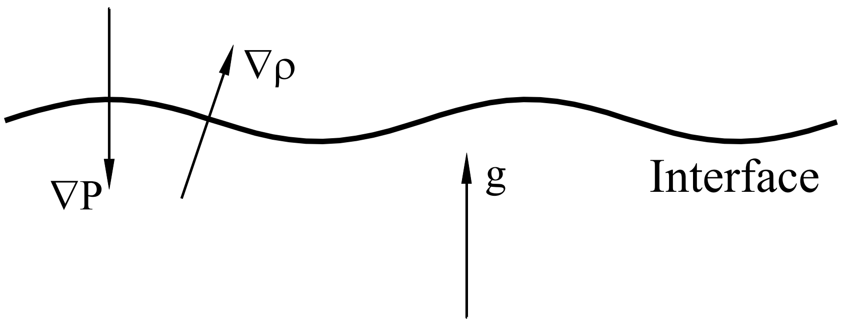
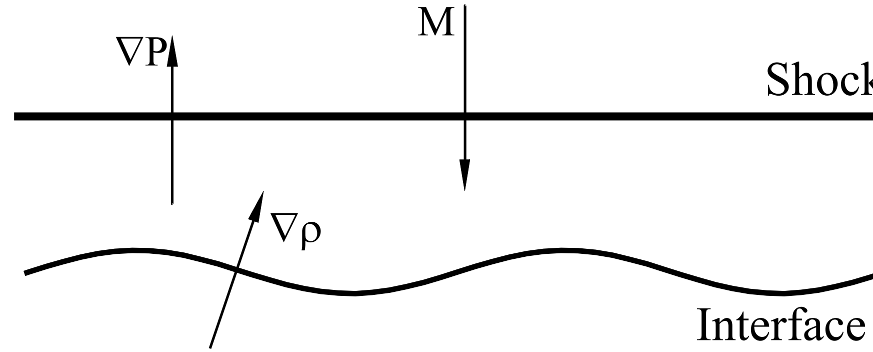
The R-T and R-M instabilities



Rayleigh-Taylor instability

- Constant acceleration of light fluid into heavy fluid



Richtmyer-Meshkov instability

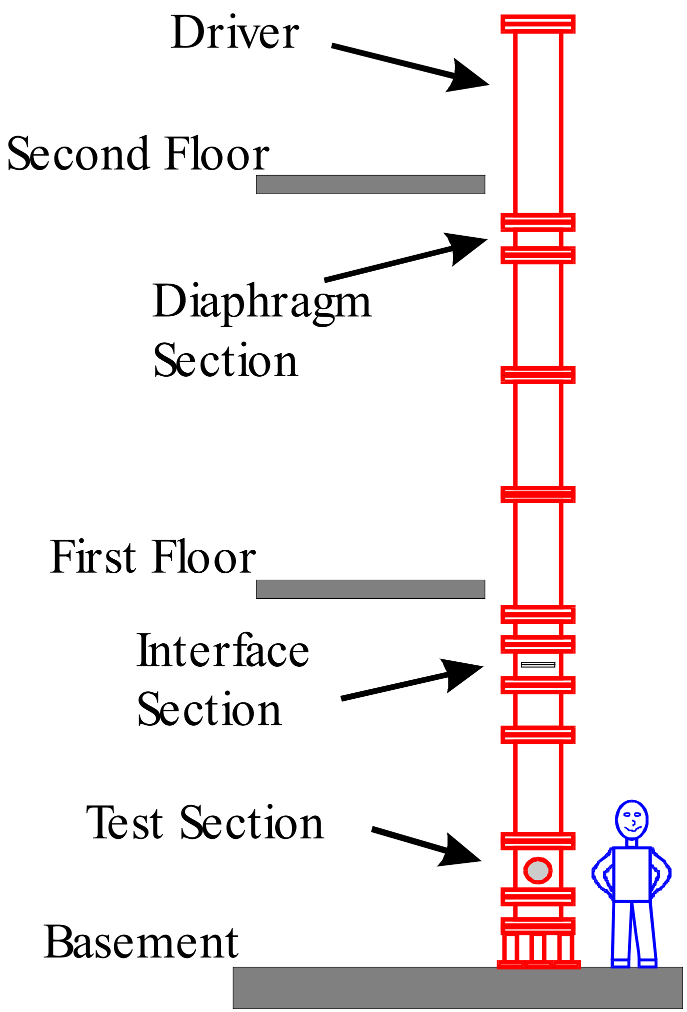
- Propagation of a shock across a density interface
- Instability exists independent of the direction of propagation of shock

- Occurrence of R-T and R-M instabilities
  - Inertial confinement fusion
  - Astrophysical phenomenon such as supernova

Motivation for the present research

- Experimental data during the nonlinear regime of growth
- Experimental data for strong incident shocks (M > 2)
- Issues concerning previous experimental investigations
  - Creation of membraneless interface with repeatable initial conditions

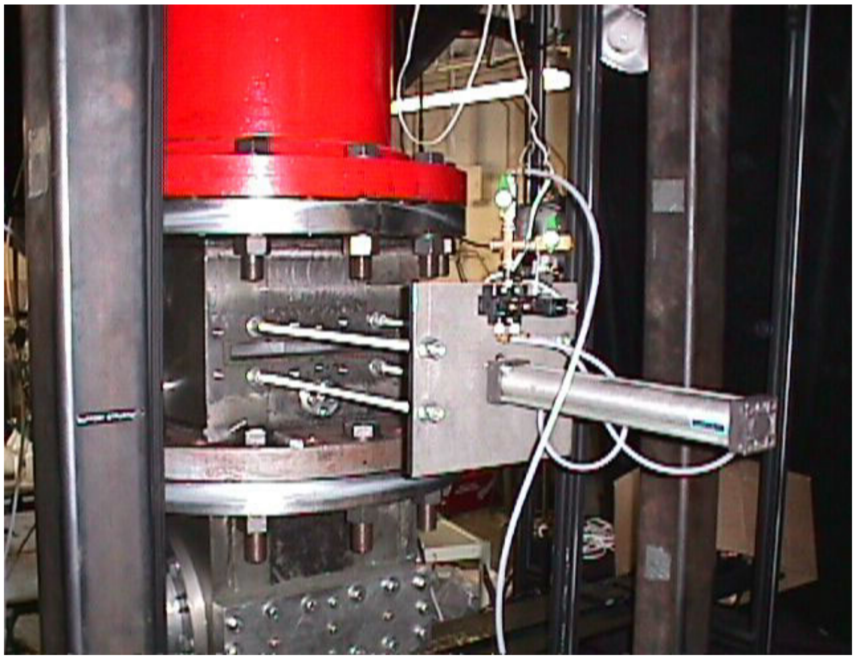
The Wisconsin shock tube



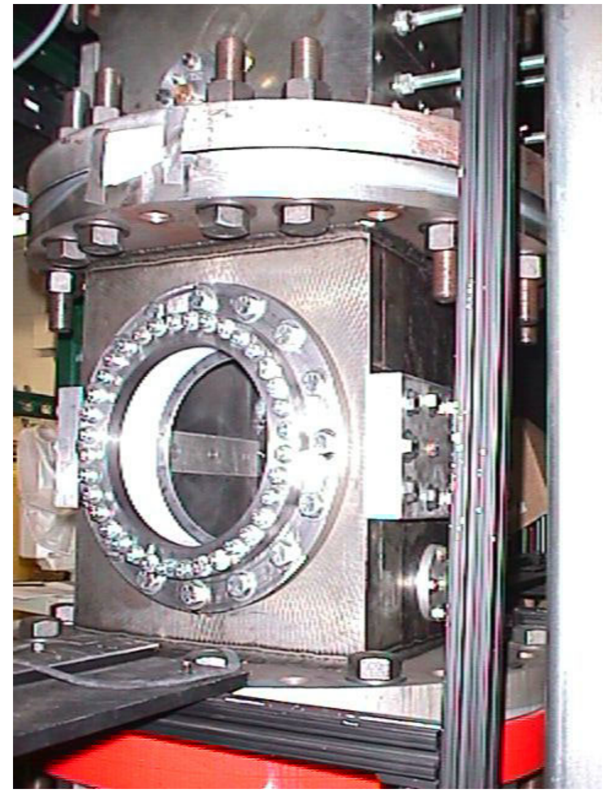
- Vertical
- Large internal cross-section (25 cm square)
- Total length 9.2 m, driver length 2 m
- Pressure load capability: 20 MPa
  - Mach 5 shock wave with driven gas initially at atmospheric pressure
- Modular driven section

Key components of the Wisconsin shock tube

Interface Section



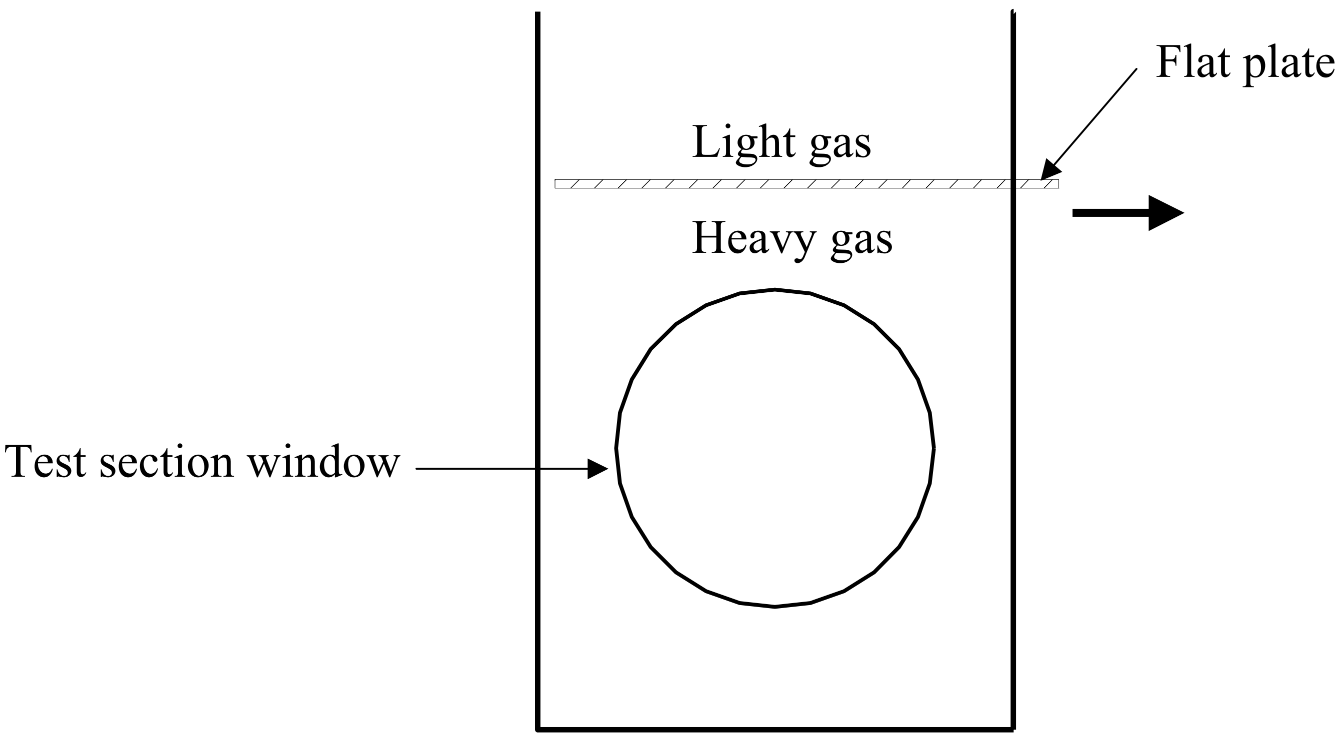
Test Section



- Interface section: Creation of an interface using retractable metal plate
- Test section: 24 cm diameter, 9 cm thick fused quartz window(s)

Creation of a membraneless interface

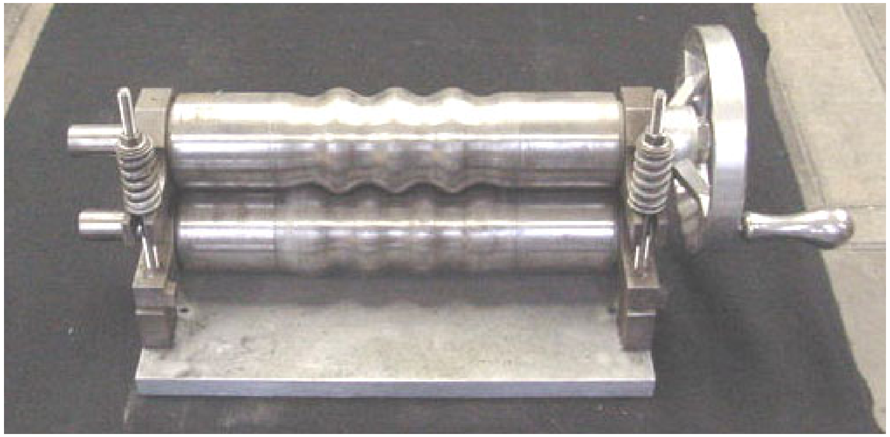
- Flat plate retraction technique in a vertical shock tube
  - Plate retraction normal to the line of sight



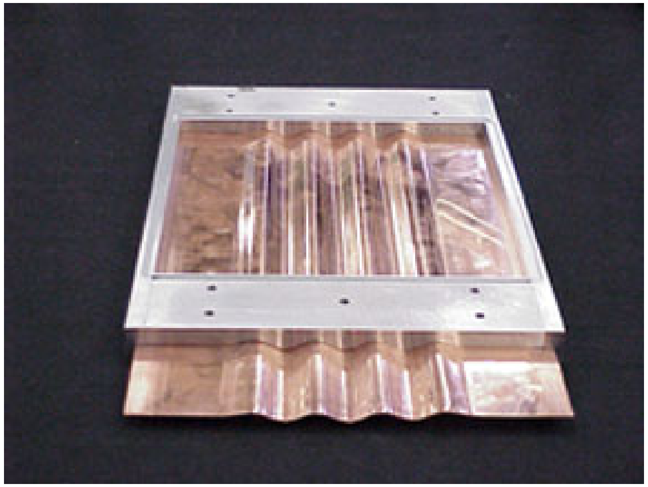
- Experiments show lack of repeatability in the formation of initial conditions

Modification of retractable plate technique

- Use of a retractable metal plate formed into a sinusoidal shape
- Copper plate, 0.6 mm thick
- Plastic deformation by rolling operation
- Sine wave parameters:
  - Amplitude (η) = 3.18 mm
  - Wavelength (λ) = 38.1 mm
  - $\eta/\lambda = 0.083$



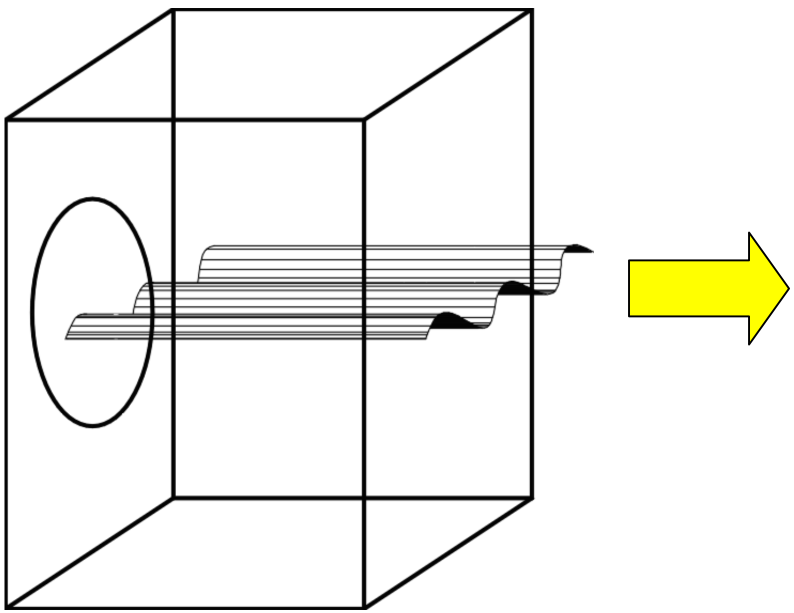
Rollers



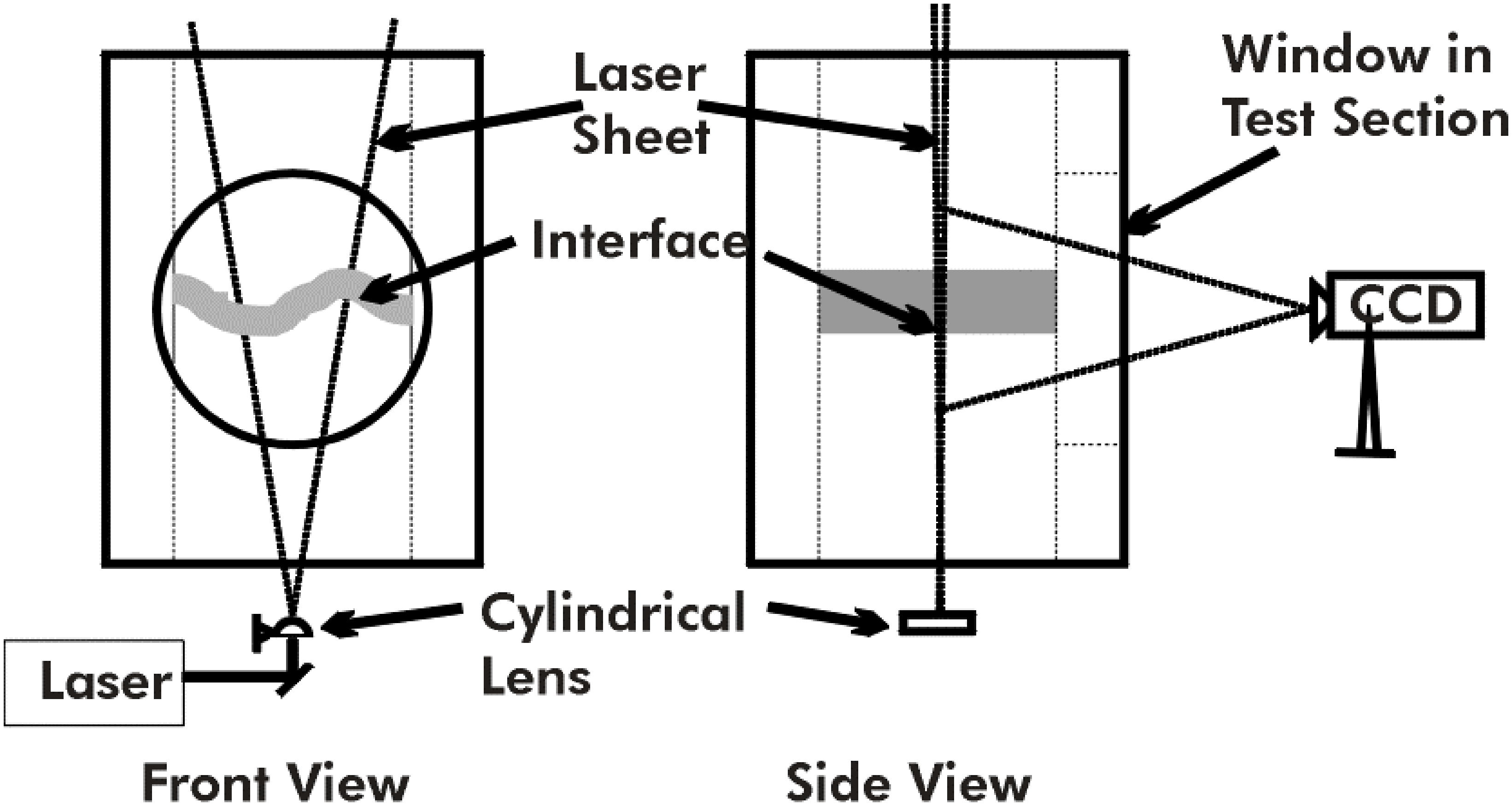
Formed plate

Characterization of initial conditions

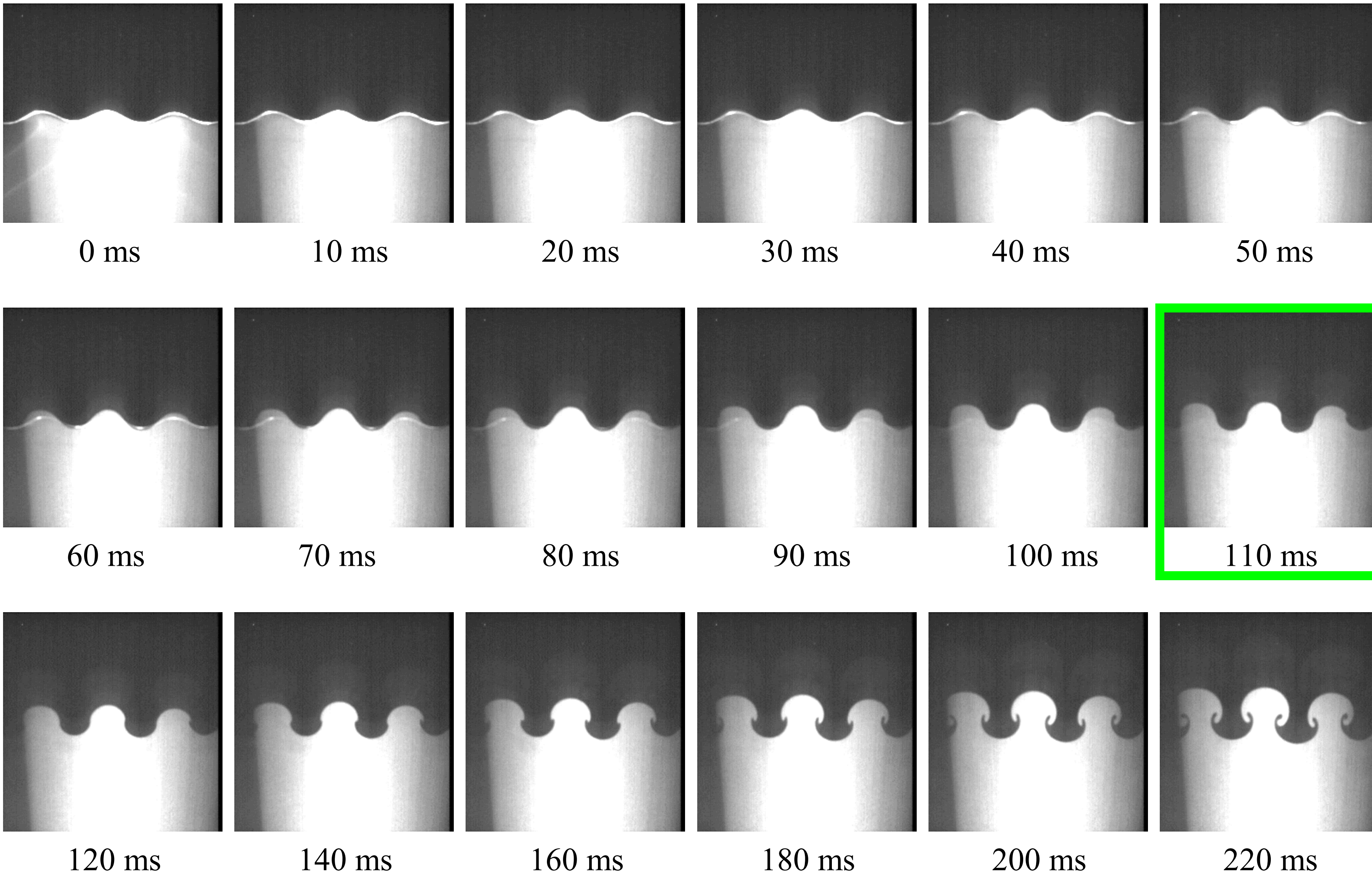
- CO_2-Air interface (Atwood number = 0.206)
- Plate retraction along the line of sight
- Planar Mie scattering visualization
- Ar^+ cw laser
- CCD camera: 256 x 256 pixel array, frame rate = 100 fps



Planar imaging setup

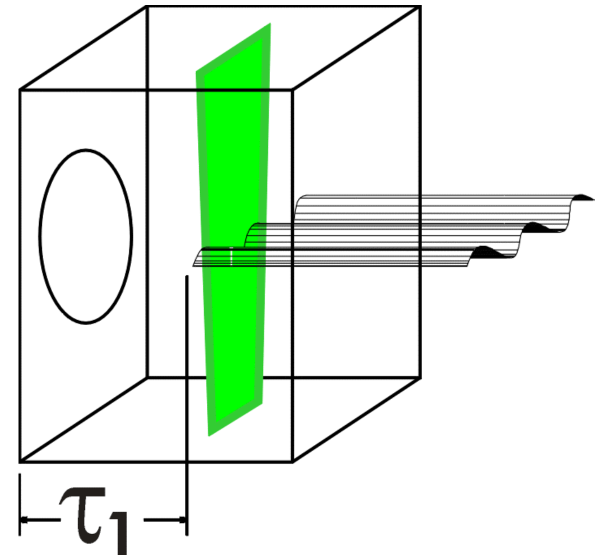


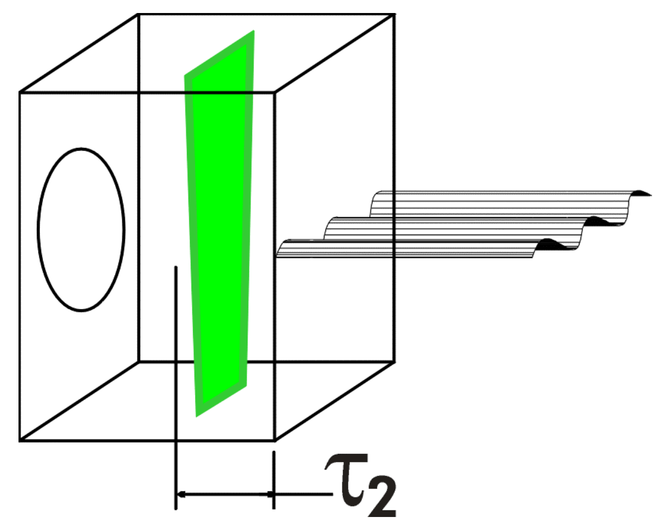
Rayleigh-Taylor instability visualization results



Design of R-M experiment

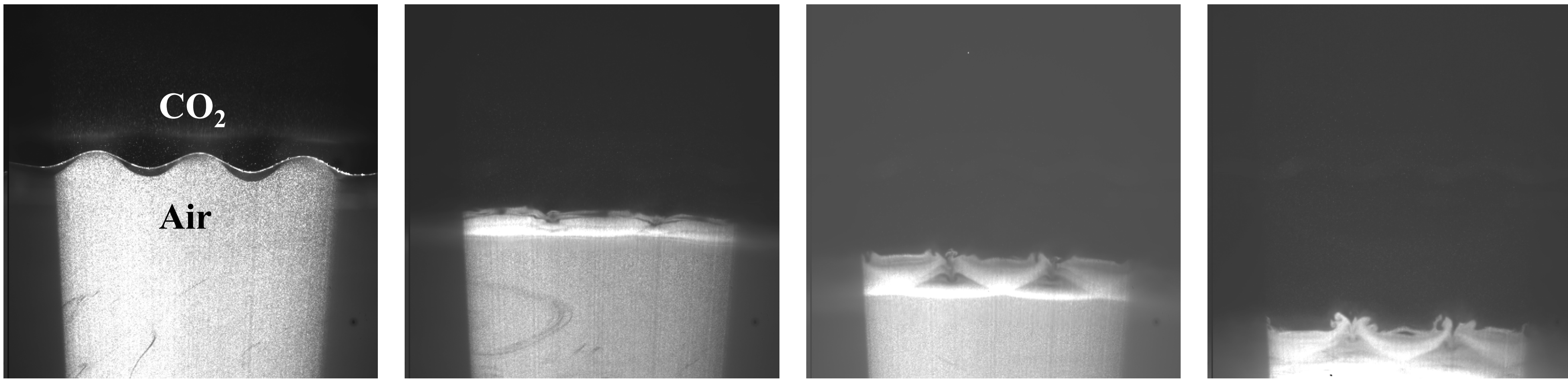
- $P_{initial}$ = 1 atm, $T_{initial}$ = 298 K
- Incident shock wave: M =3.06, in CO_2
- Post-shock Atwood number = 0.249
- Nd:YAG laser @ λ = 532 nm, 10 ns pulse
- Planar Mie scattering visualization
- CCD camera: 1024 x 1024 pixels, 16 bit/pixel
- Two-stage retraction (τ_1~ 250 ms, τ_2 ~ 80 ms)
- Initial conditions determined by the R-T instability





R-M instability visualization results

- Very early interaction of the shock wave with the sinusoidal interface
- Development of phase reversal



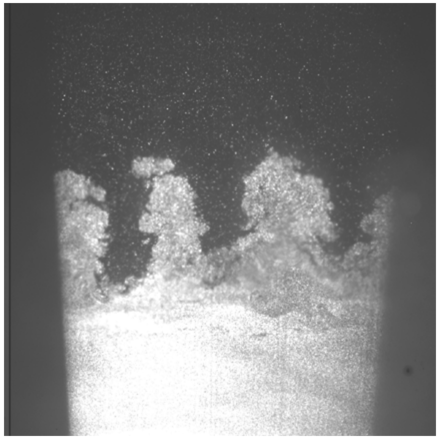
(a) (b) (c) (d)

- (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

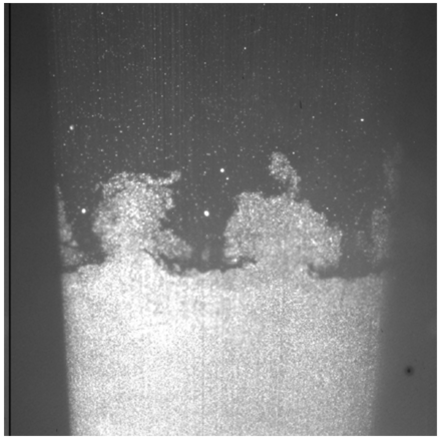
R-M instability visualization results (Cont'd)

- Initial condition: ~ 110 ms R-T old interface $(\eta_0/\lambda) = 0.232$

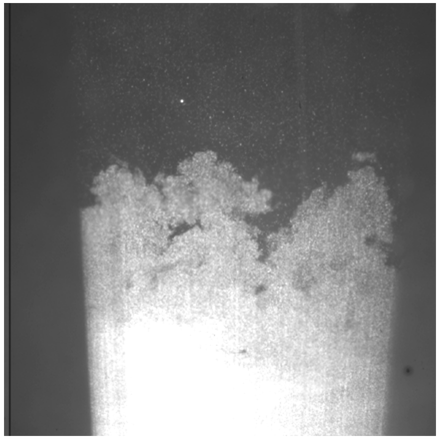
Single-mode, quasi two-dimensional



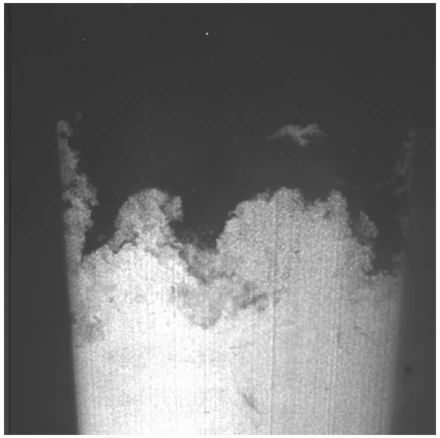
t = 646 μs



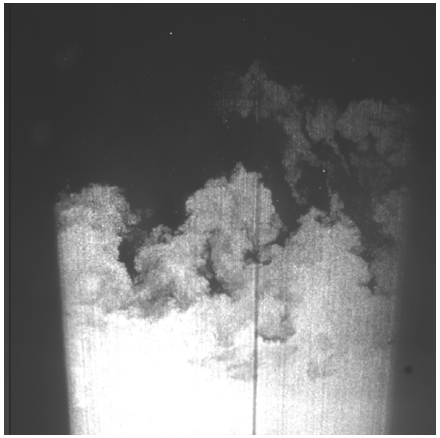
t = 1.08 ms



t = 1.37 ms



t = 1.80 ms



t = 2.10 ms

Nonlinear theories for R-M growth

- Zhang and Sohn theory : *Physics of Fluids 9(4): 1106-1124, 1997*

$$\left(\frac{d\eta}{dt}\right)_{total} = \frac{\left(\frac{d\eta}{dt}\right)_{lin}}{1+\left(\frac{d\eta}{dt}\right)_{lin}\eta_0^{'}k^2t+\max\{0,\eta_0^{'2}k^2-A^{'2}+1/2\}\left(\frac{d\eta}{dt}\right)_{lin}^2 k^2t^2}$$

where,

$$\left(\frac{d\eta}{dt}\right)_{total} = \text{Overall growth rate}$$

$$\left(\frac{d\eta}{dt}\right)_{lin} = \text{Growth rate in the linear regime}$$

$$\approx k[v]A^{'}\eta_0^{'}$$ where, $[v]$ is the velocity of the interface

$$A^{'} = \text{Post-shock Atwood number}$$

$$\eta_0^{'} = \text{Post-shock initial amplitude}$$

Nonlinear theories for R-M growth (Cont'd)

- Sadot *et al.* theory : *Physical Review Letters 80(8): 1654-1657, 1998*

$$\left(\frac{d\eta}{dt}\right) = \left(\frac{d\eta}{dt}\right)_{RM}\left(\frac{1+Bt}{1+Dt+Et^2}\right)$$

where,

$$\left(\frac{d\eta}{dt}\right)_{RM} = k[v]A'\eta_0'$$ where, $[v]$ is the velocity of the interface

$$B = \left(\frac{d\eta}{dt}\right)_{RM} k$$ for spike and bubble

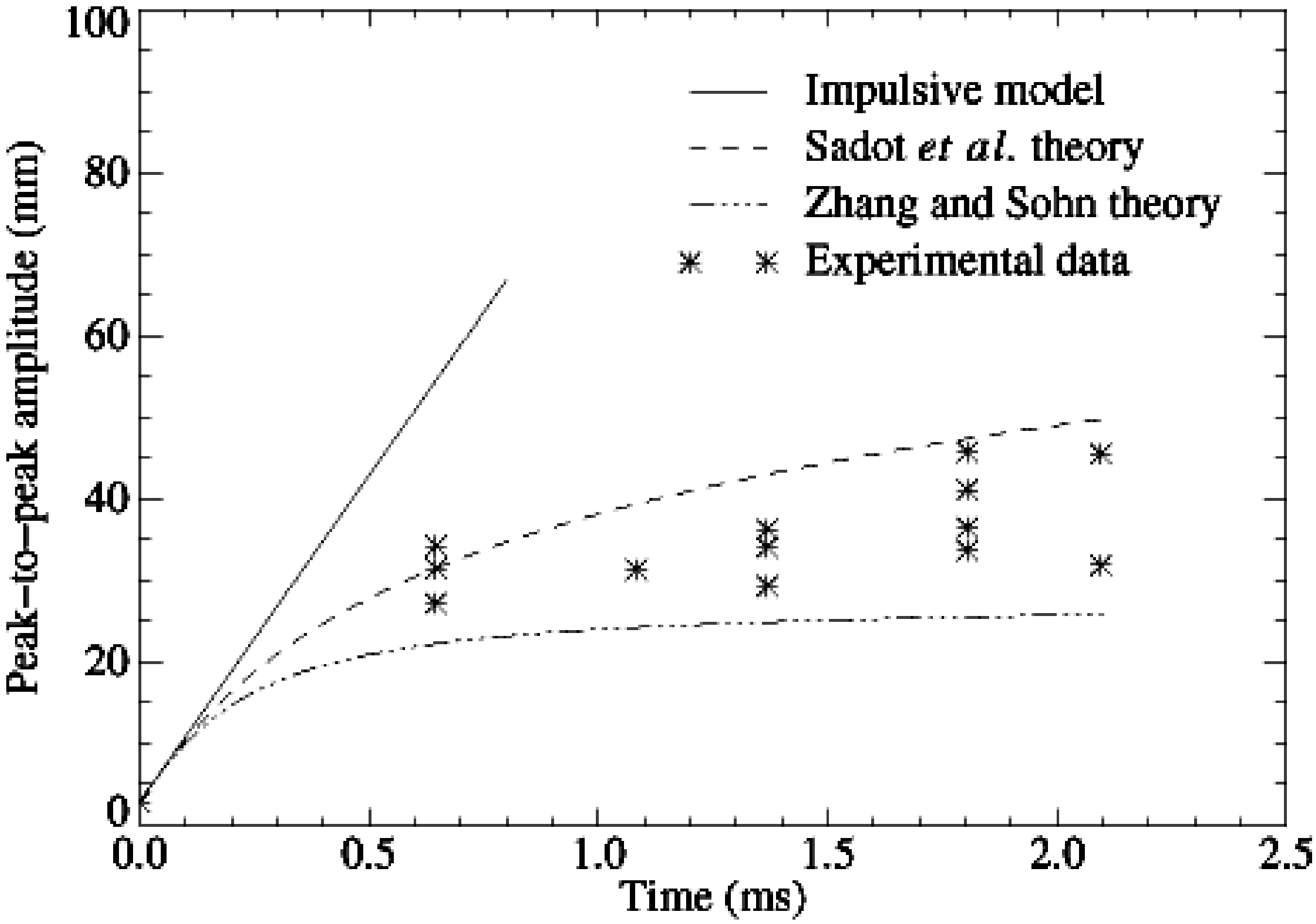
$$D = (1 \pm A')\left(\frac{d\eta}{dt}\right)_{RM} k$$ + sign for bubble and - for spike

$$E = \frac{(1 \pm A')}{(1 - A')}\frac{1}{2\pi C}\left(\frac{d\eta}{dt}\right)_{RM}^2 k^2 \quad \text{with} \quad C = \frac{1}{3\pi} \quad \text{for} \quad A' \geq 0.5$$

$$= \frac{1}{2\pi} \quad \text{for} \quad A' \to 0$$

Comparison of theoretical prediction with data

- Initial condition: ~ 110 ms R-T old interface



Conclusions

- Modification of plate retraction technique with the use of a metal plate formed into a sinusoidal shape

- A membraneless quasi two-dimensional single mode sinusoidal interface between two gases is formed by Rayleigh-Taylor instability

- R-M experiments are performed with R-T developed interface between CO_2 and air for a strong shock ($M = 3.06$)

- The instability growth is rapid in the initial stages following a phase inversion but is found to saturate at late times; an interaction of adjacent mushroom structures results in a mixing zone

- Comparison with prediction from nonlinear theories shows qualitative agreement
  - Sadot *et al*. theory overpredicts late time behavior
  - Zhang and Sohn theory underpredicts the behavior at all times