Richtmyer-Meshkov Instability of a Membraneless, Sinusoidal Gas Interface

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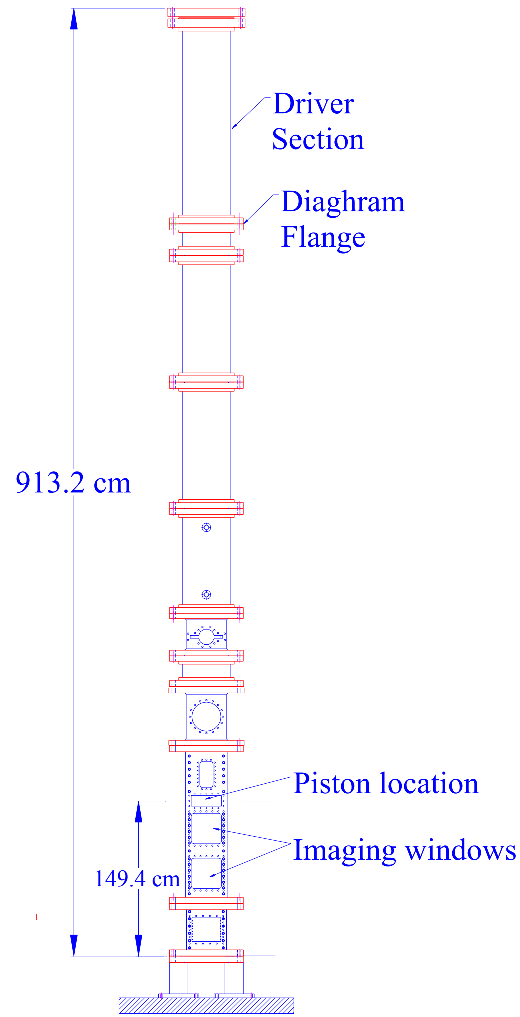
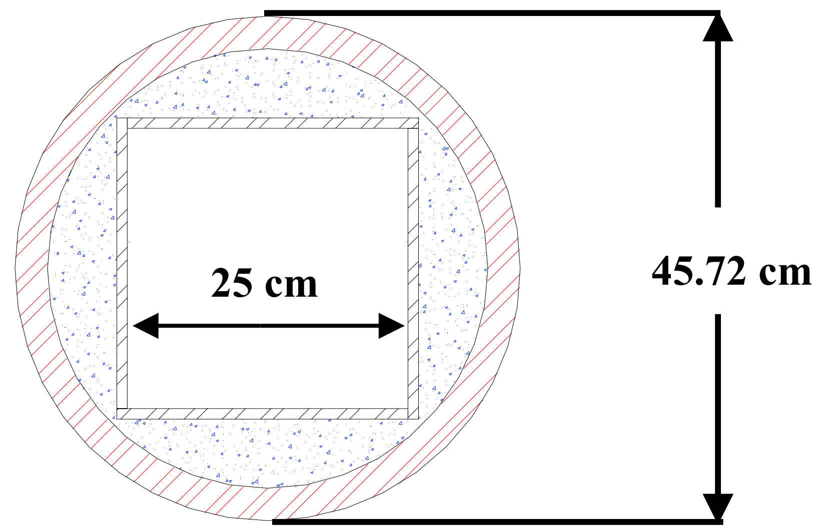
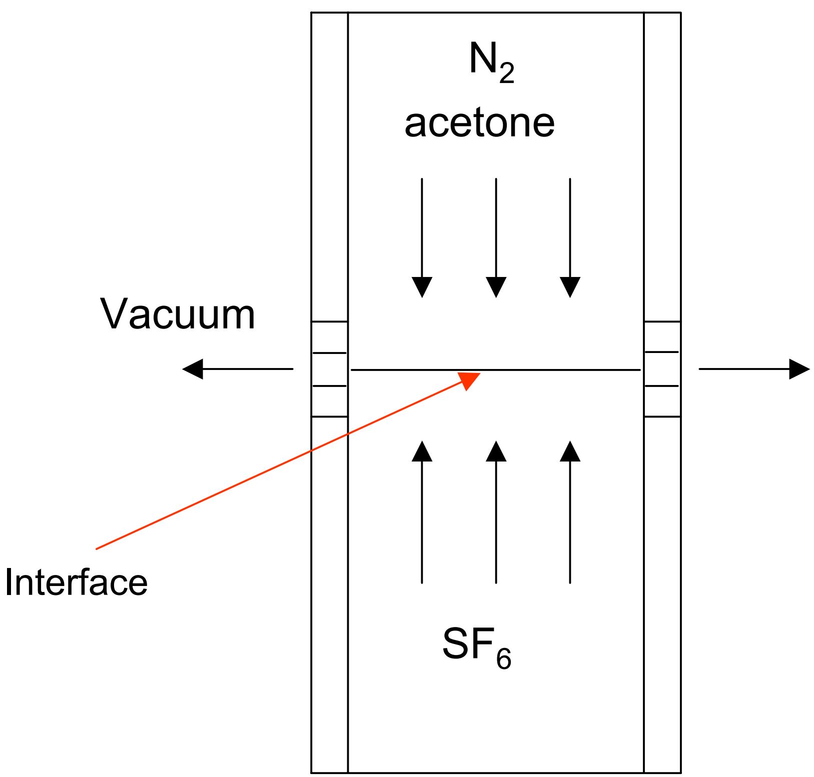
Wisconsin Shock Tube

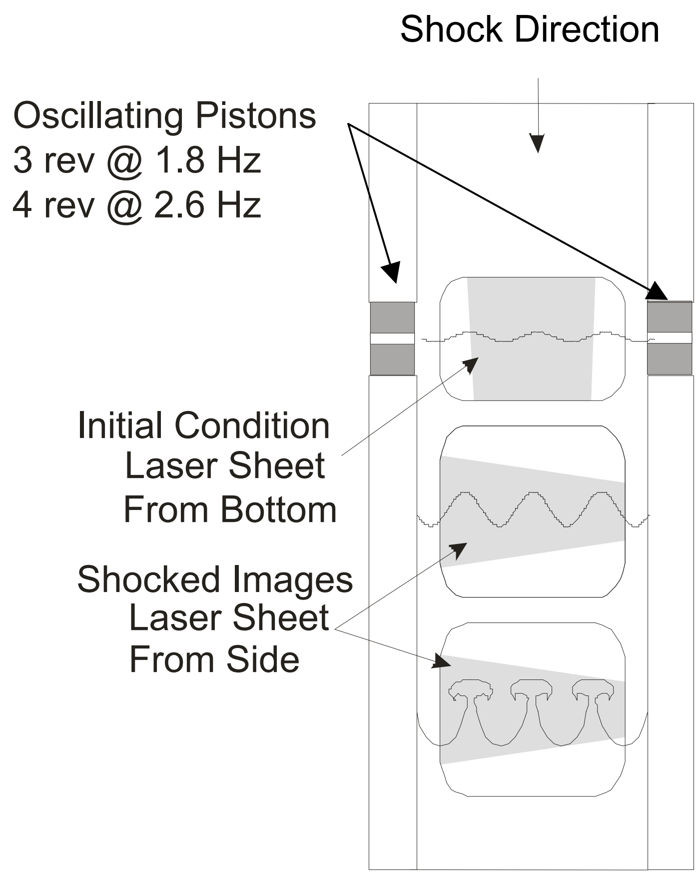


- Vertical
- Large internal cross-section (25 cm square)
- Total length 9.2 m, driver length 2 m
- Pressure load capability: 20 MPa
- Modular driven section

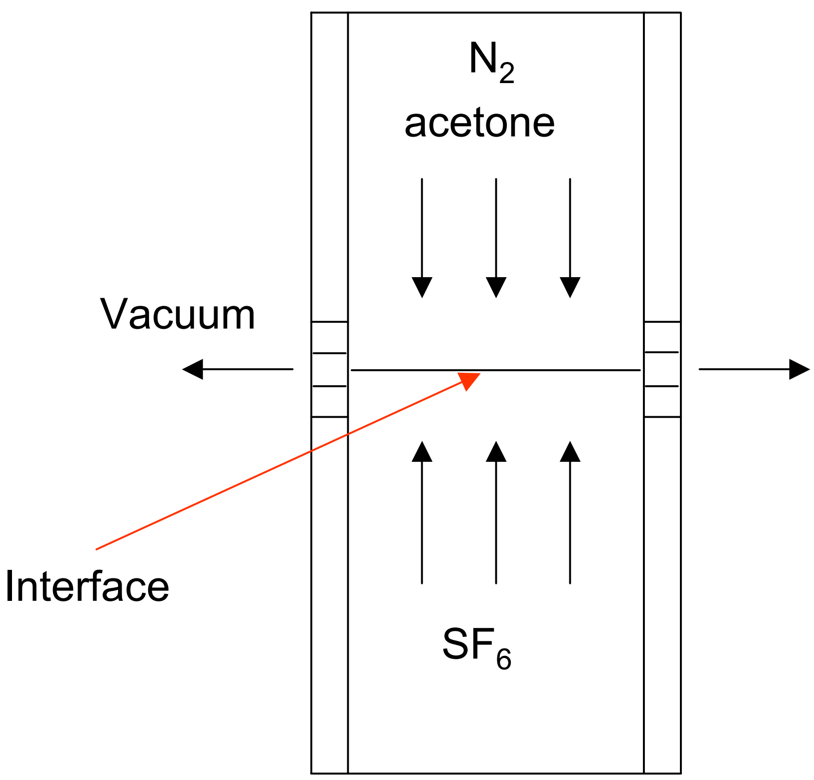


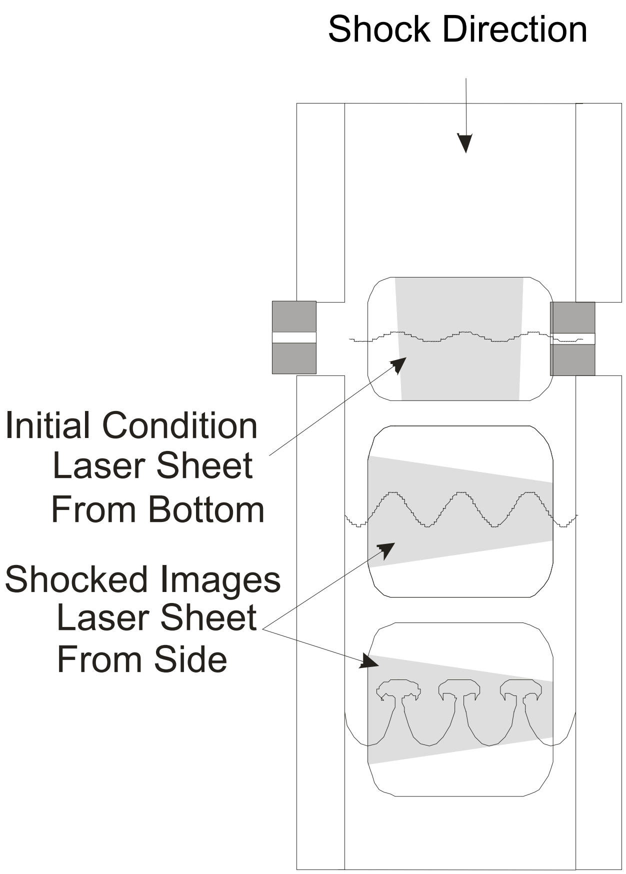
Experimental Setup



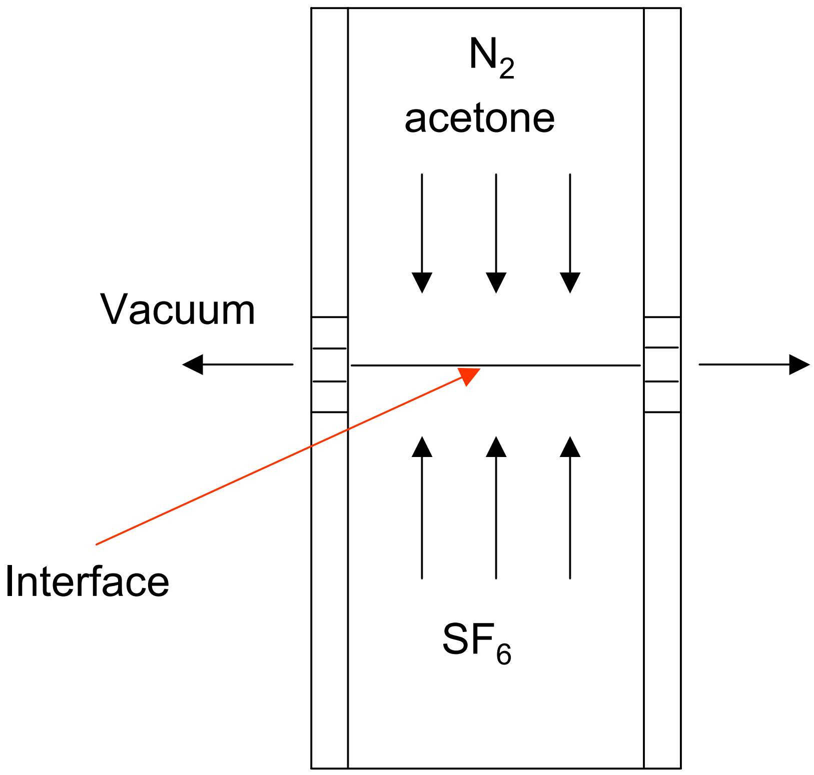


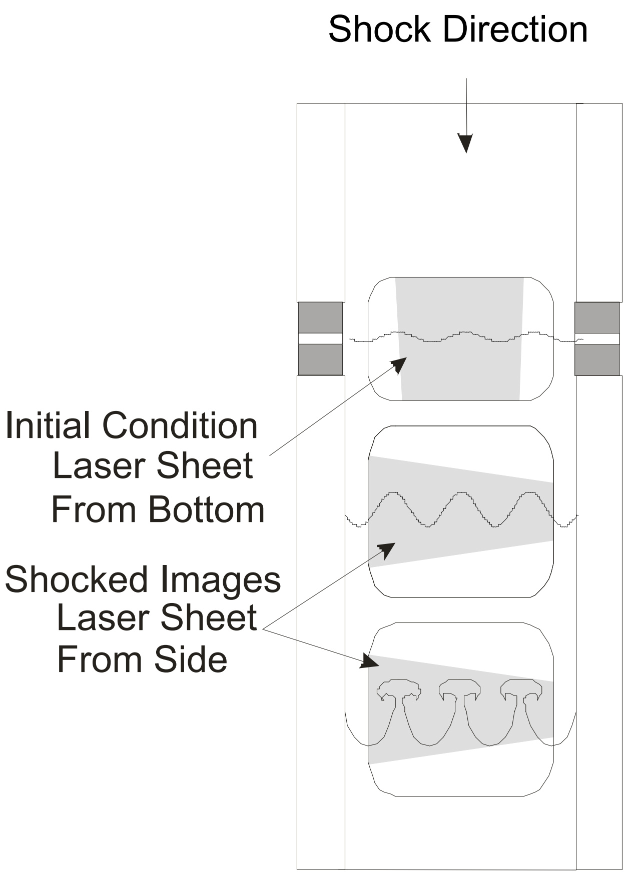
Experimental Setup



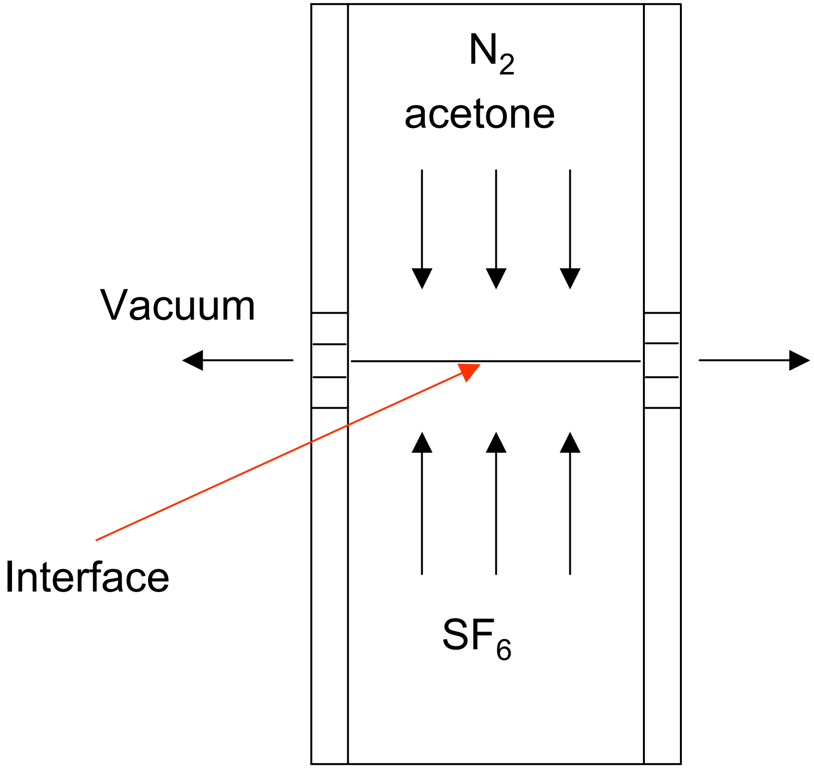


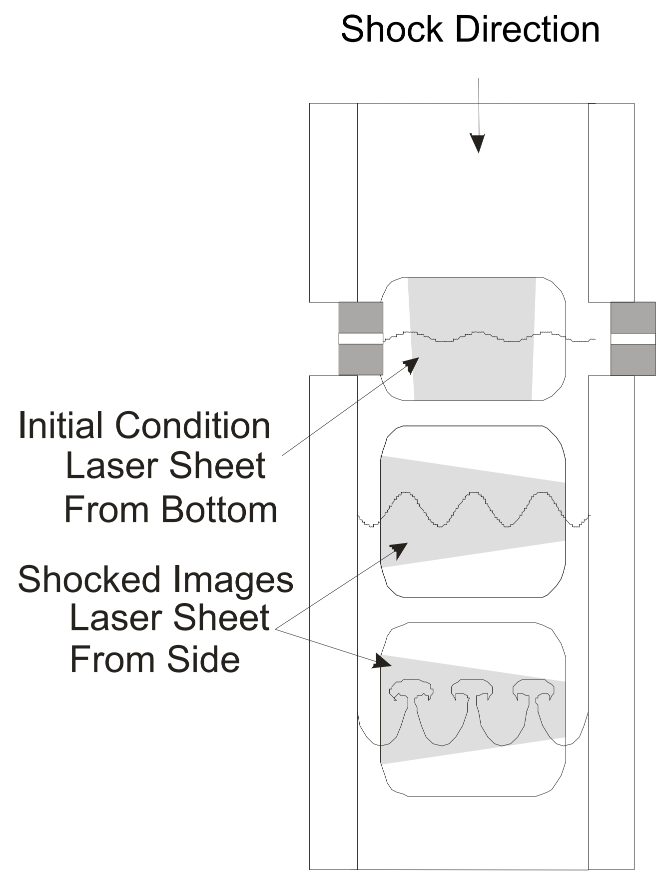
Experimental Setup



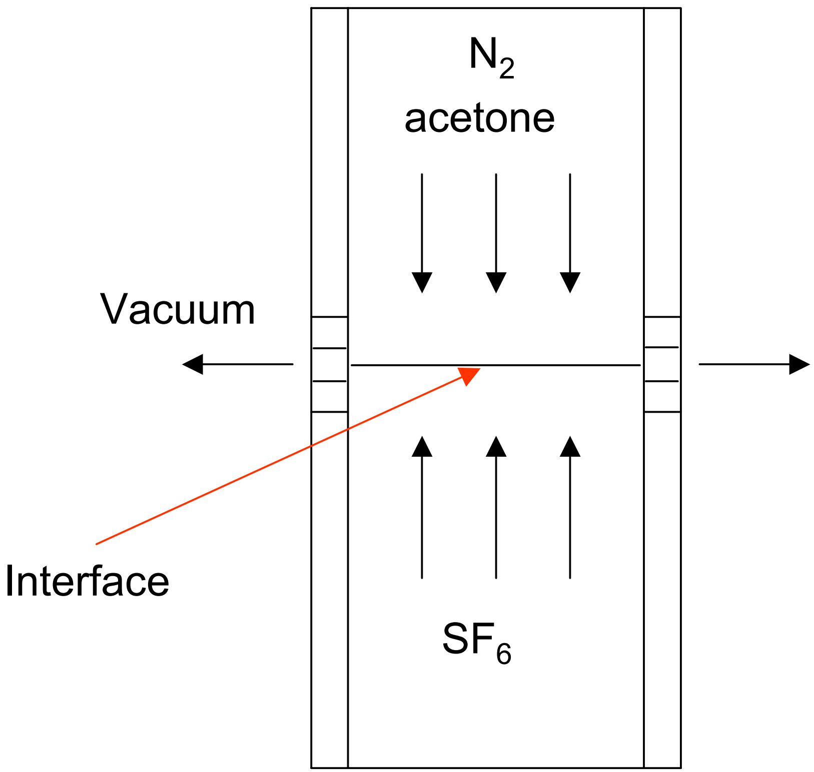


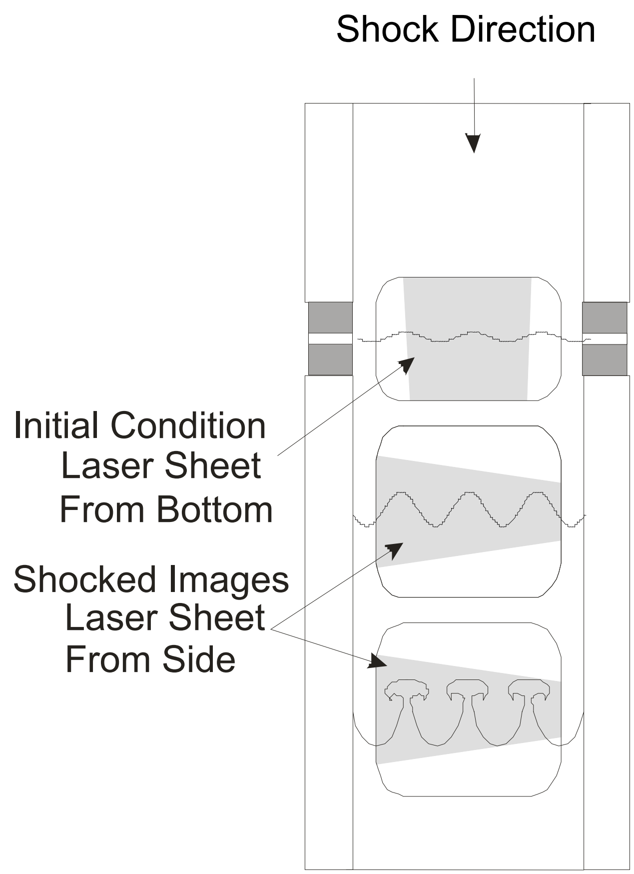
Experimental Setup





Experimental Setup



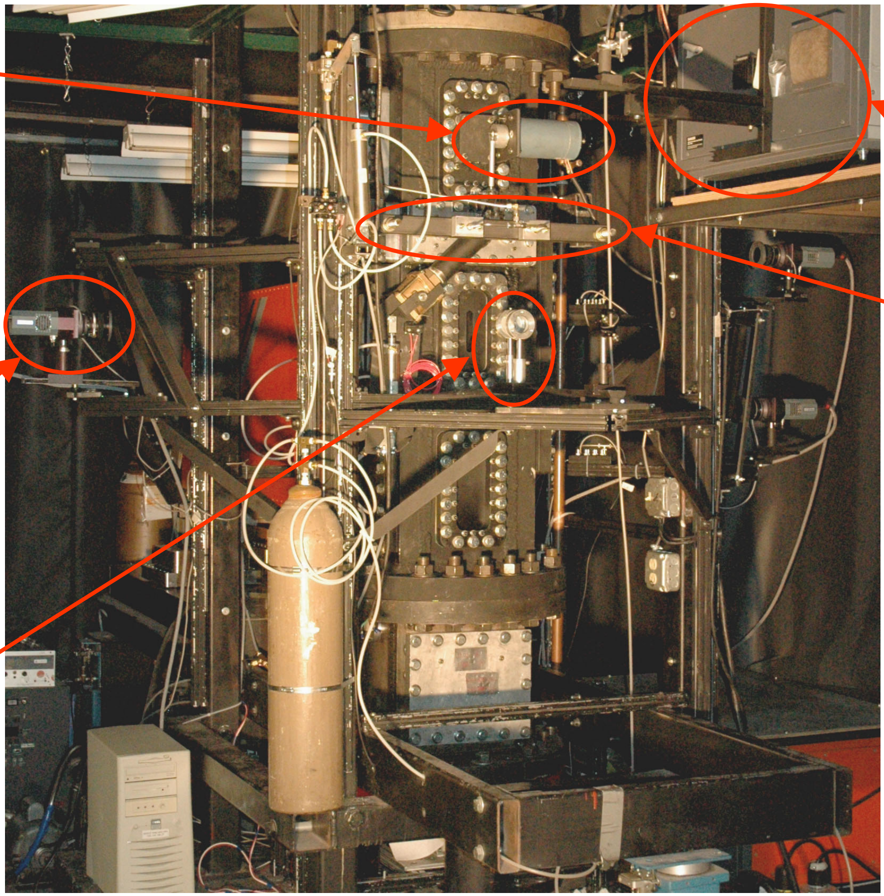


Experimental Setup

TEST SECTION

Stepper motor

Excimer Laser
λ = 248 nm
$E \approx$ 550 mJ



Piston

1024 x 1024
CCD Array

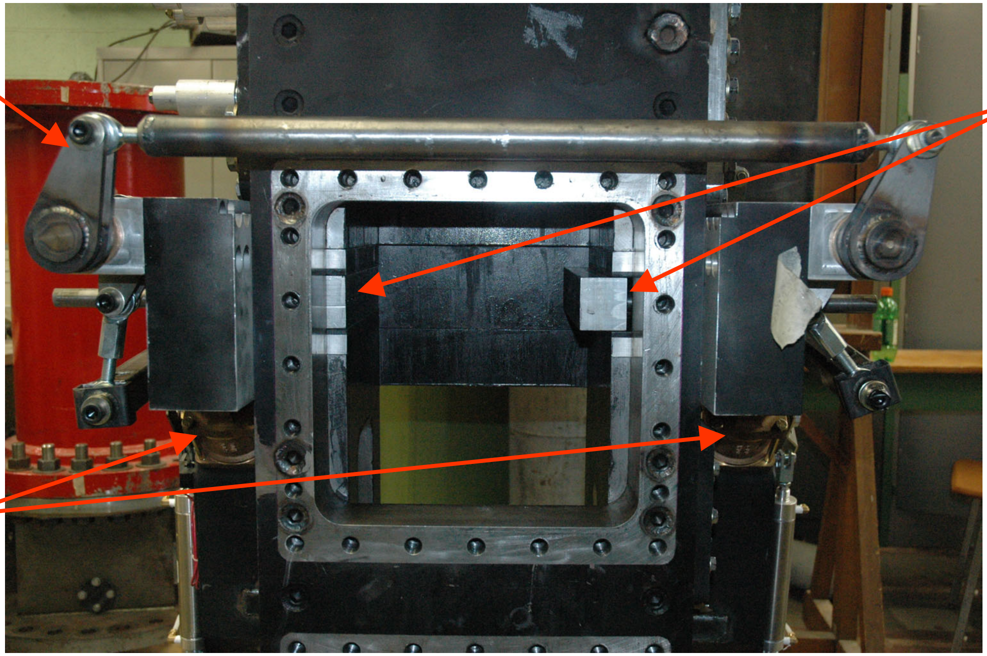
Laser sheet
forming optics

Experimental Setup

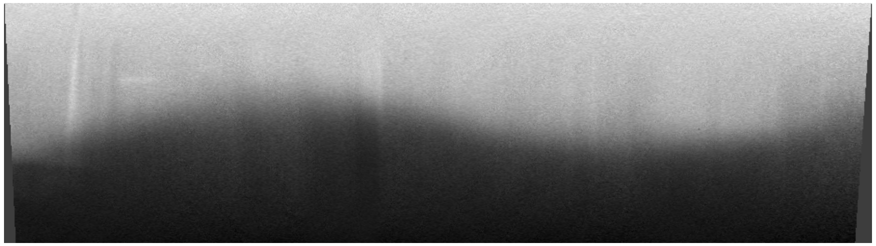
PISTON ASSEMBLY

Piston cam assembly

5.08 cm wide pistons



Back pressure exhaust ports



Initial Condition

1.9 Hz

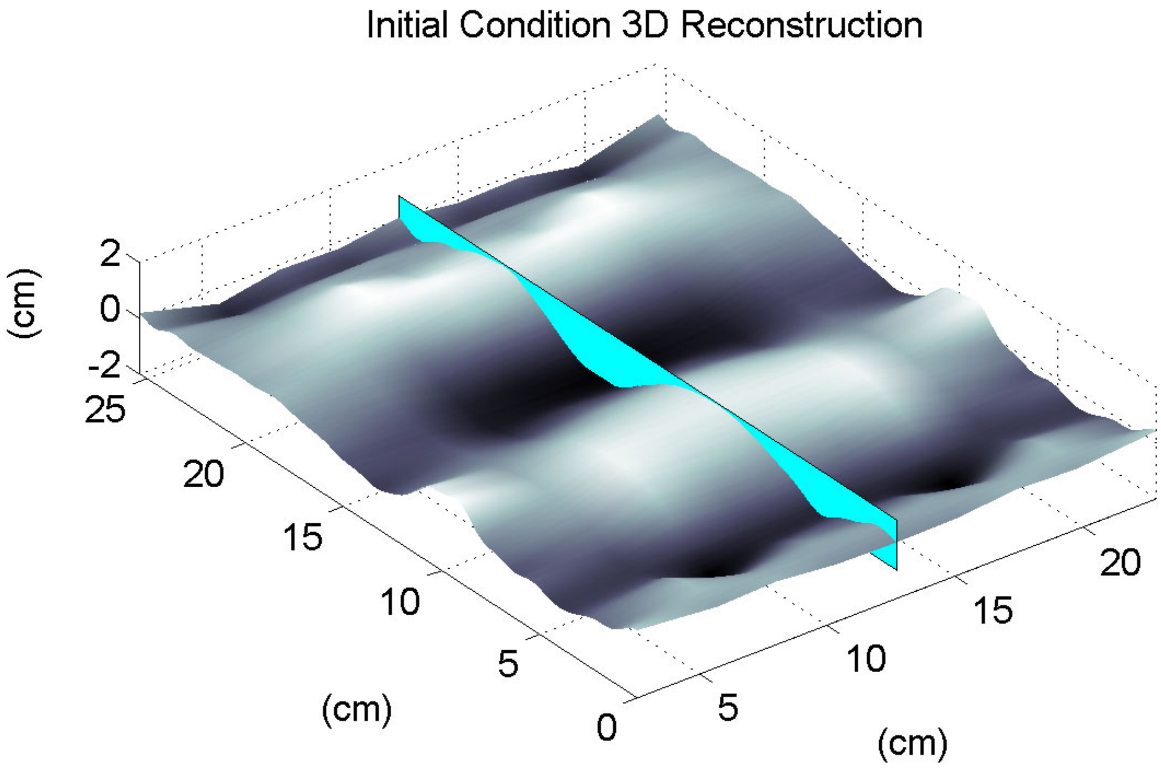


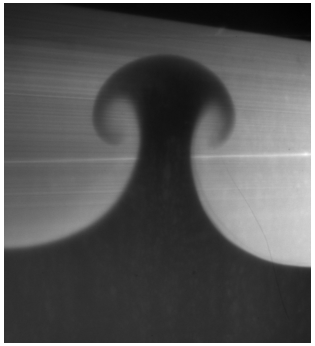
Image Analysis

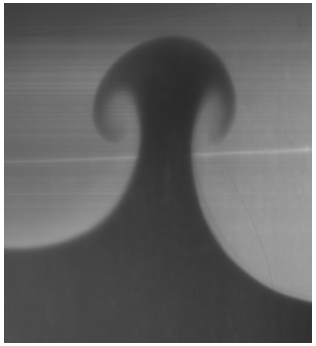
a) Raw image

b) Mapped image

c) Mapped image corrected using Beer's Law

d) Re-mapped corrected image


a


b


c


d

Computation Setup

2D hydrodynamic code – RAPTOR (LLNL)

a) solves the multi-fluid compressible Euler equations, with an ideal gas law equation of state

b) a shock-capturing scheme and higher-order Godunov solver is used to handle shock propagation accurately and suppress spurious oscillations

c) fixed (Eulerian) grid in 2-D Cartesian geometry, 512 grid points in the transverse dimension

d) two levels of adaptive mesh refinement (AMR) on the fluid interface

e) initial condition is characterized using a Fourier transform

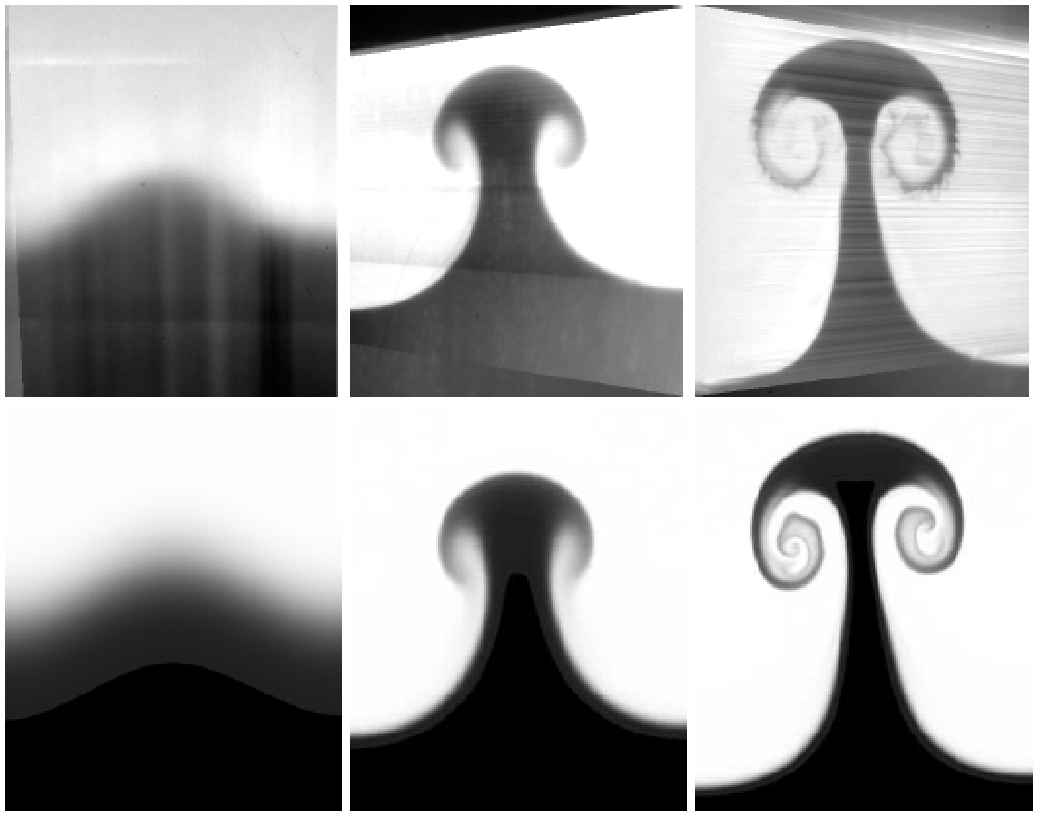
f) the interface is smeared vertically using a hyperbolic tangent distribution fitted to the diffusion characteristics of the experimental interface

Results

M = 1.3, 2.6 Hz driving frequency, λ= 90 mm, a_{0-} = 6.11 mm

Experiment

RAPTOR



t = 0 ms *t = 2.8 ms* *t = 5.3 ms*

Non – Dimensional Parameters

Method presented by Jacobs & Krivets, Physics of Fluids 17, 034105 (2005) paper

Non – dimensional amplitude = $ka - ka_0$

where k is the wave number, a_0 is the initial amplitude and a is the amplitude

Non – dimensional time = $k\dot{a}_0 t$

where $\dot{a}_0$ is the post shock growth rate, and t is time

In the analysis presented, the approximation $\dot{a}_0 \approx ka_0 A \Delta V$ is utilized,

where A is the post shock Atwood number and ΔV is the velocity change of the interface due to impulsive acceleration of the shock wave

$$A = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$$

Existing Analytical Models

1) Sadot et al., Phy Rev Lett Vol. 80 Number 8 (1998)

$$a(t) = [\frac{\dot{a}_0}{(4E - D^2)^{\frac{1}{2}}}(2 - \frac{BD}{E})] \times \tan^{-1}[\frac{2Et + D}{(4E - D^2)^{\frac{1}{2}}}] + \frac{\dot{a}_0 B}{2E}\ln(1 + Dt + Et^2) + K$$

2) Mikaelian, Physical Review E 67, 026319 (2003)

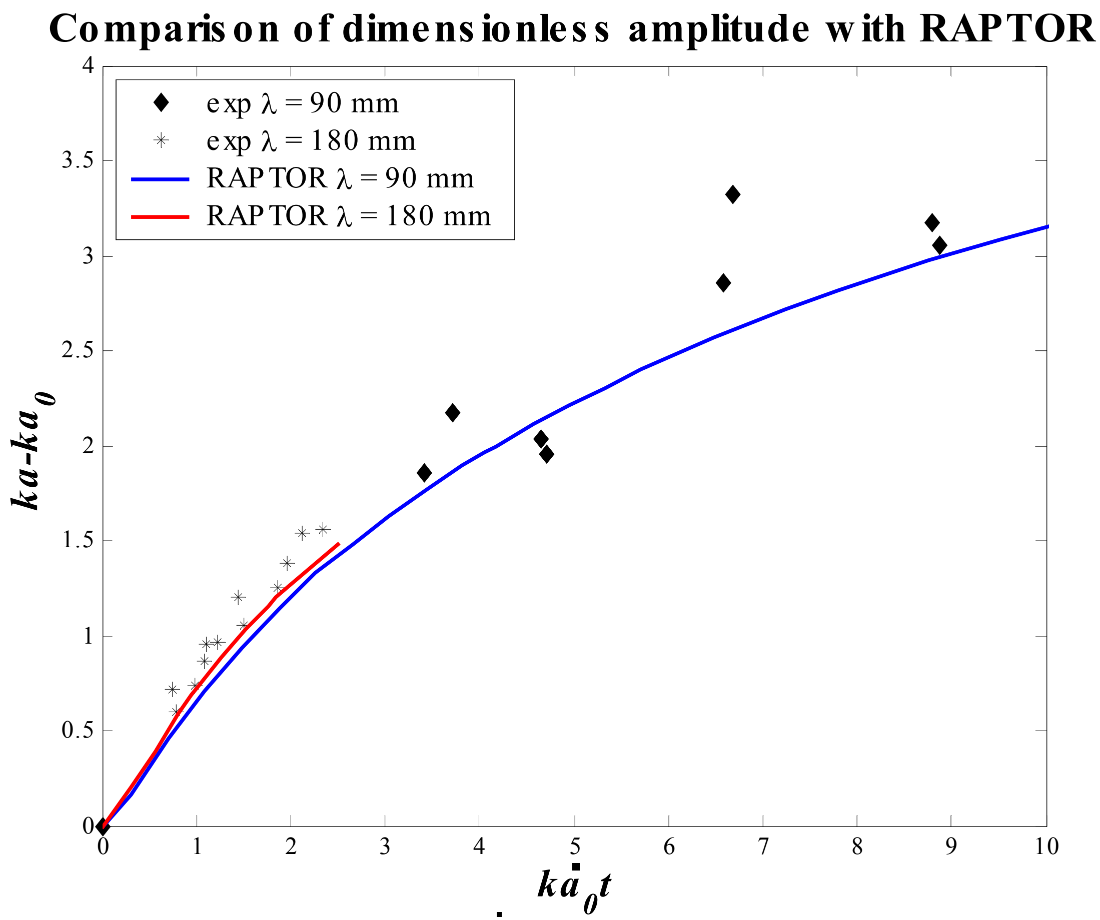
$$a(t) = a_0 + \frac{3 + A}{3(1 + A)k}\ln(1 + 3\dot{a}_0 kt\frac{1 + A}{3 + A})$$

3) Dimonte & Schneider, Physics of Fluids Vol. 12 Number 2 (2000)

$$a(t) = a_0 \tau_i^{\theta_i}$$ where $$\tau_i = \frac{V_{i0}(t - t_0)}{\theta_i a_0} + 1$$

Comparison

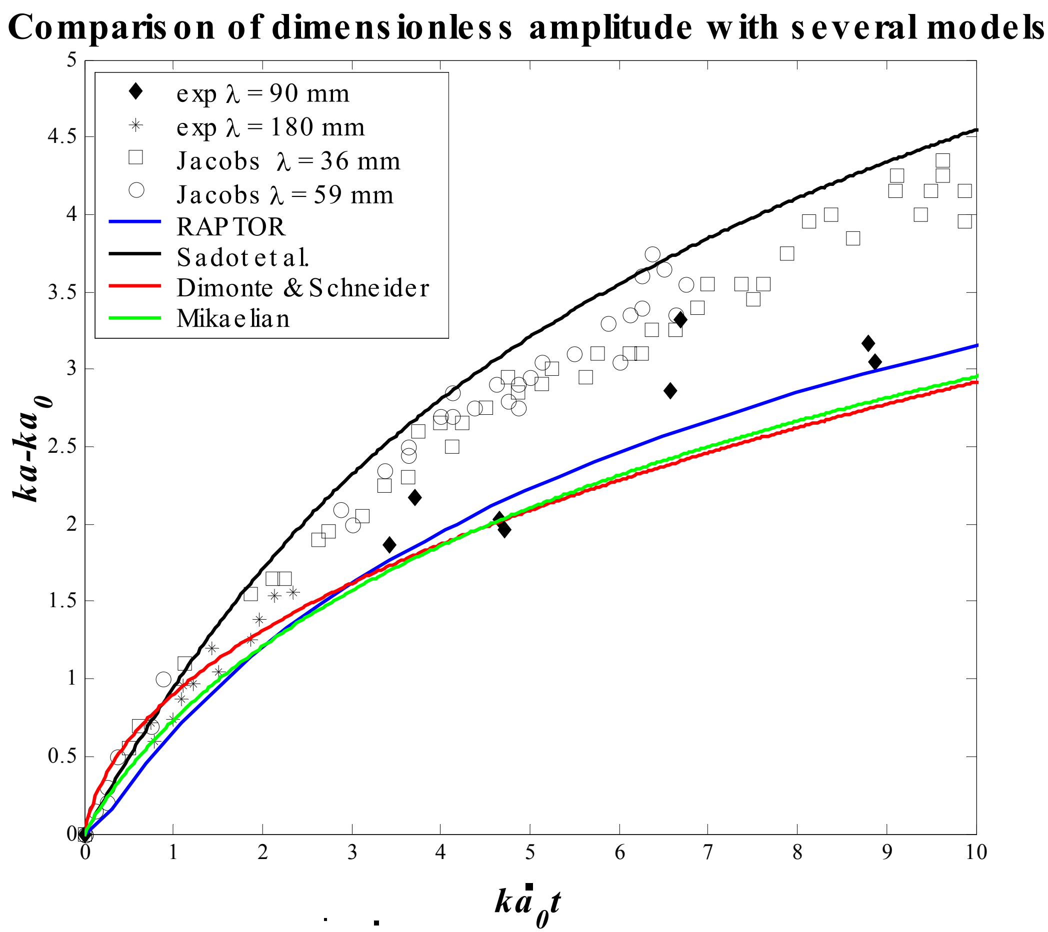
M =1.3



* *k* is the wave number of the dominant mode

Comparison

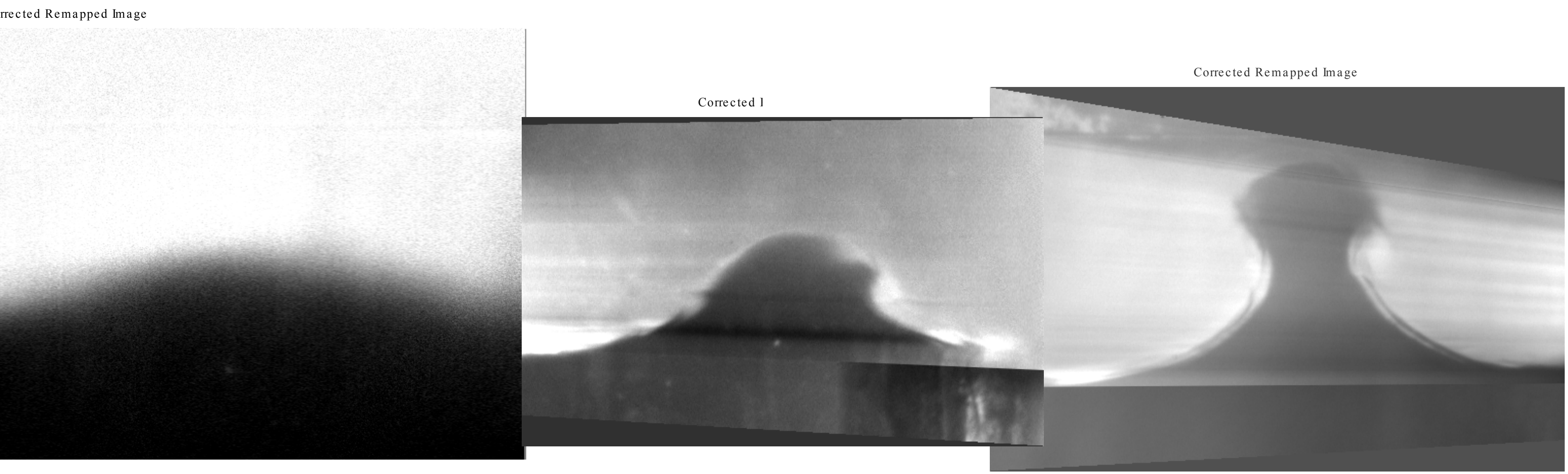
M =1.3



*Jacobs data taken from Figure 7 of J.W. Jacobs & V.V. Krivets Physics of Fluids 17, 034105 (2005) paper.

Preliminary Results

M = 2.13, 1.9 Hz, λ= 178 mm, a_{0-} = 7.24 mm



t = 0.00 ms

t = 0.77 ms

t = 1.42 ms

Conclusions

1. Conclusions:
   a. Piston setup creates a sinusoidal interface, and has been tested at high Mach numbers

   b. The Dimonte and Mikaelian models reliably predict the experimental growth rate at early and intermediate non-dimensional times

   c. RAPTOR correctly predicts the experimental growth rate and all of the geometrical features except the secondary instabilities

2. Future Work:

   a. Extensive high Mach number experiments

   b. Try different gas pairs (possibly $N_2 – CO_2$)

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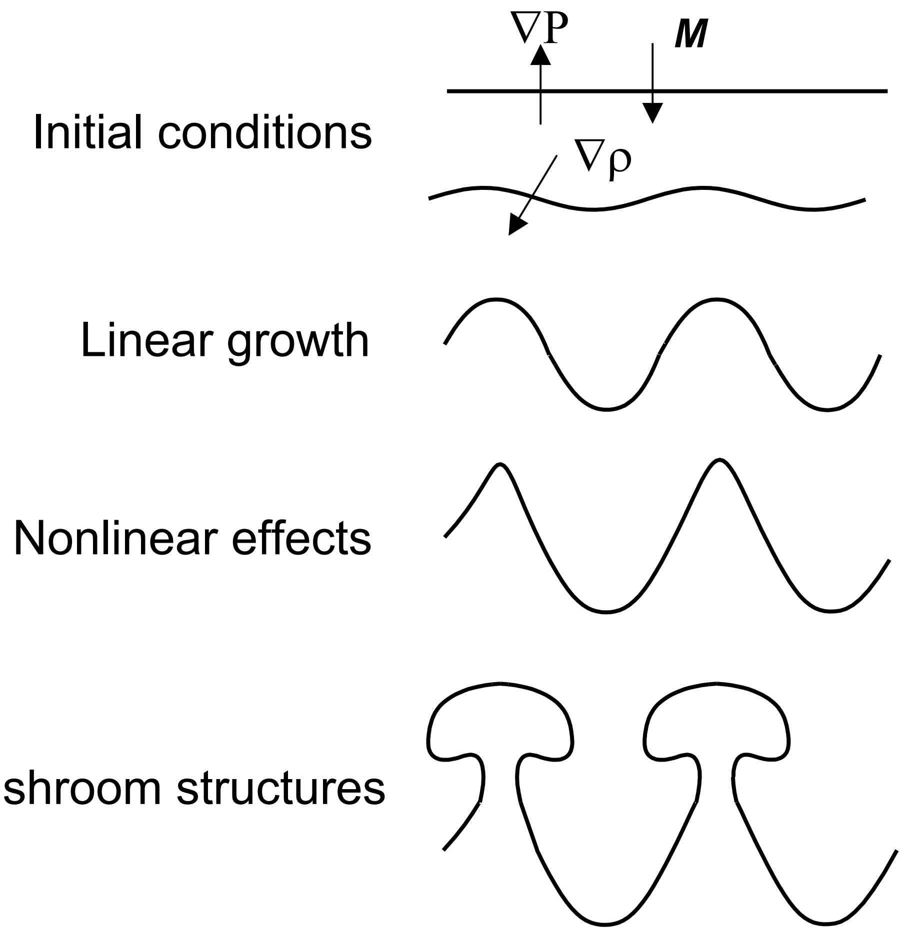
Richtmyer – Meshkov Instability

Defining Characteristics:
- Relative motion normal to the interface
- Baroclinic generation of vorticity at the interface

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



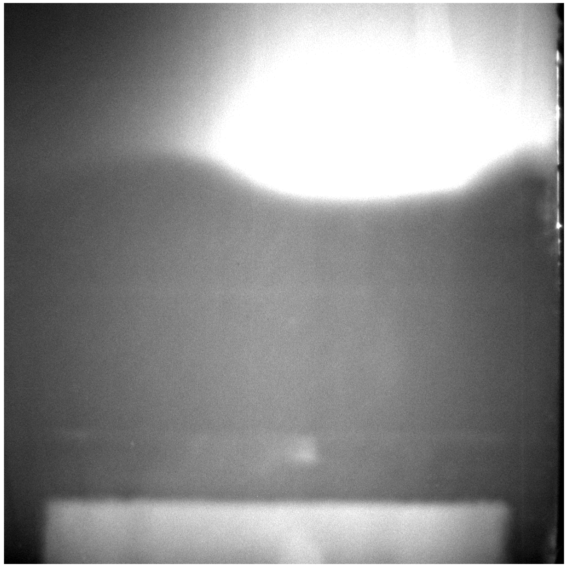
Motivation

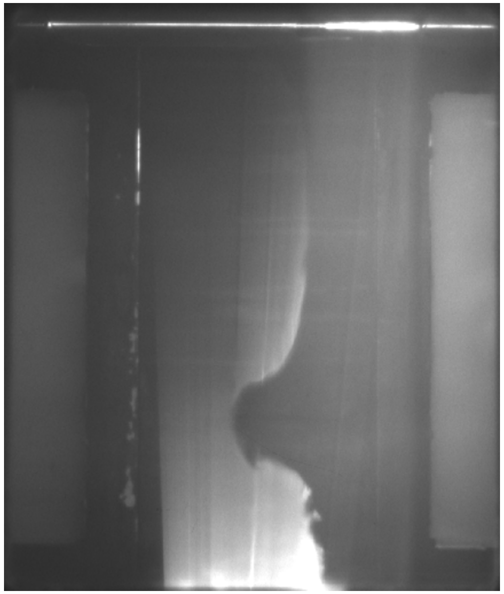
- Inertial fusion laser-driven experiments
  - small, spherical, solid shell filled with DT
  - laser-driven spherical shock wave implodes shell
  - Richtmyer-Meshkov instability affects the fluid mixing
  - very high energies, very small length scales, very short time scales

- In a shock tube
  - decouple the hydrodynamics from the plasma, radiation, and phase change physics
  - larger length scales, longer time scales than inertial fusion experiments

Results

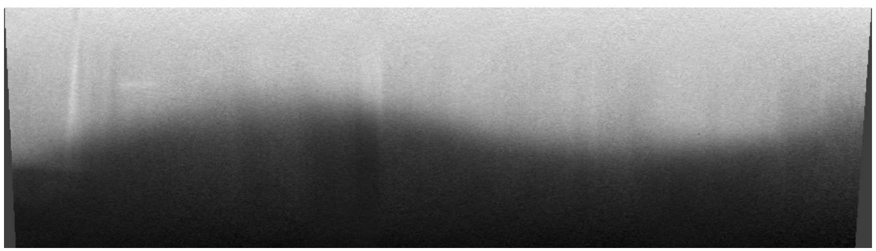
M = 2.04, 1.9 Hz driving frequency, λ= 180 mm





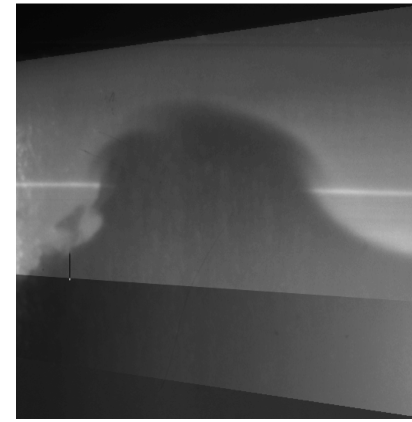
Results

M = 1.3, 1.9 Hz, λ= 180 mm, a_0 = 4.89 mm



t = 0 ms

t = 2.7 ms

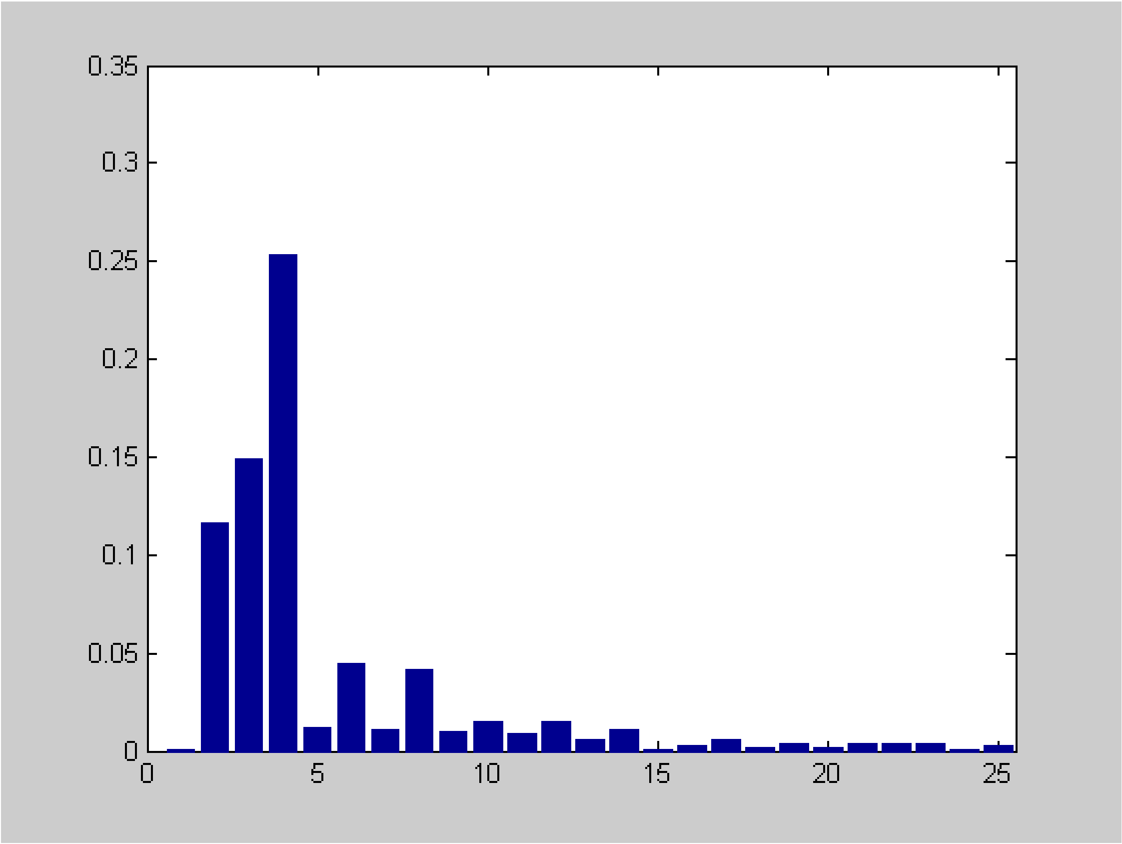


t = 5.2 ms

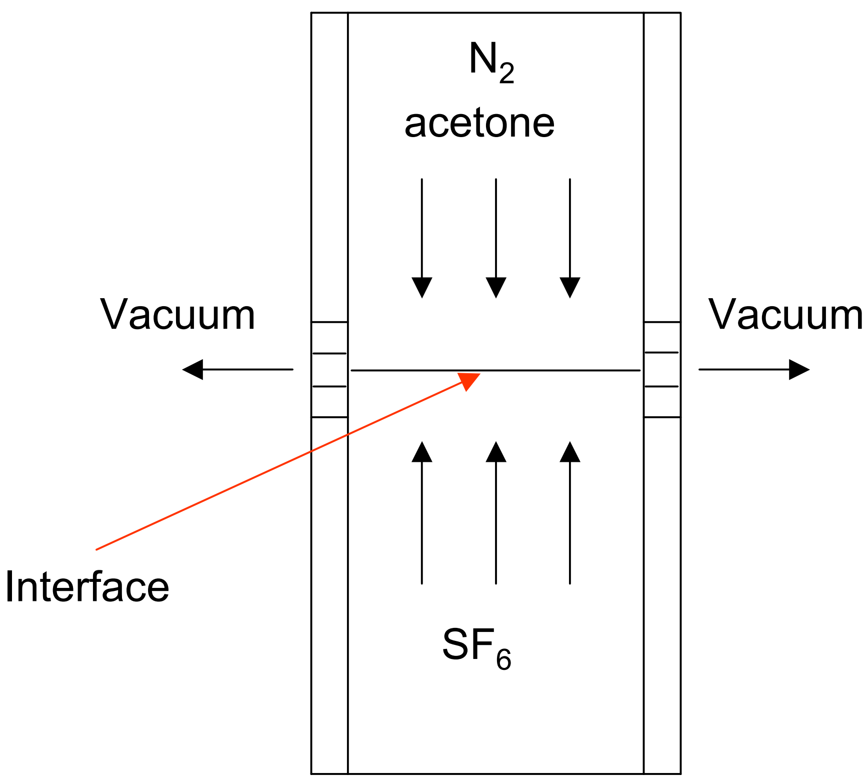
Results

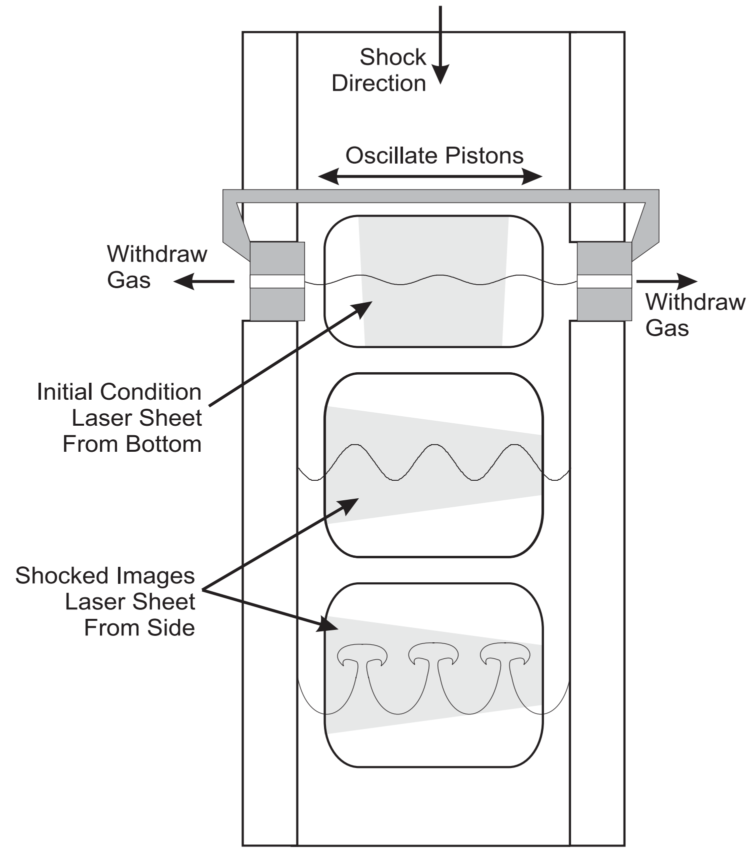
Mode amplitude (percent of total amplitude)

Test # 30, $\lambda \approx 180$ mm



Experimental Setup





Extra

Pistons – Aluminum, 5.08 x 25 cm
Light gas – Nitrogen seeded with acetone (30.8 lpm)
Heavy gas – Sulfur hexafluoride (SF_6) (9.3 lpm)
Pistons Driven: 1.9 Hz, 3 revolutions
2.6 Hz, 4 revolutions
Imaging: 1024 x 1024 CCD Andor cameras
Planar laser-induced fluorescence (PLIF)
Acetone concentration ≈ 11 %
Post shock Atwood number ≈ 0.68
Initial Mach # ≈ 1.3