Richtmyer-Meshkov Parameter Study

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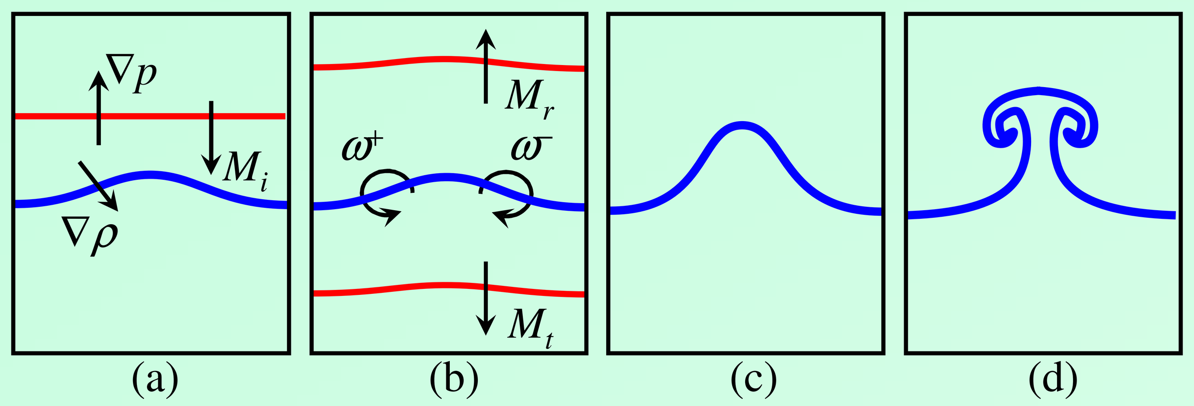
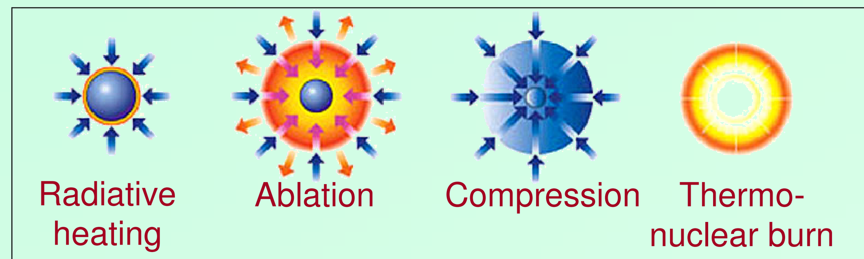
Background

The Richtmyer-Meshkov instability (RMI) arises when vorticity is deposited along an interface baroclinically ($(\nabla\rho\times\nabla p)/\rho^2 \neq 0$). The growth sequence is shown below. (a) The initial condition is a light gas over heavy gas with a perturbation on the interface. (b) The downward traveling shock wave (M_i) deposits opposite signed vorticity (ω) on either side of the perturbation forcing a linear amplitude growth and reflected (M_r) and transmitted (M_t) shock waves. (c) As the amplitude grows larger, the growth becomes nonlinear and (d) the spike becomes affected by the Kelvin-Helmholtz instability, where the sides of the spike roll-up into a mushroom-shaped structure.



This instability is important during the compression of an inertial fusion energy (IFE) target. Any perturbation on the layers between the ablator, the solid Deuterium-Tritium (DT) layer, and the DT gas layer will be amplified and result in conditions in the compressed core where yield is reduced or it fails to ignite.



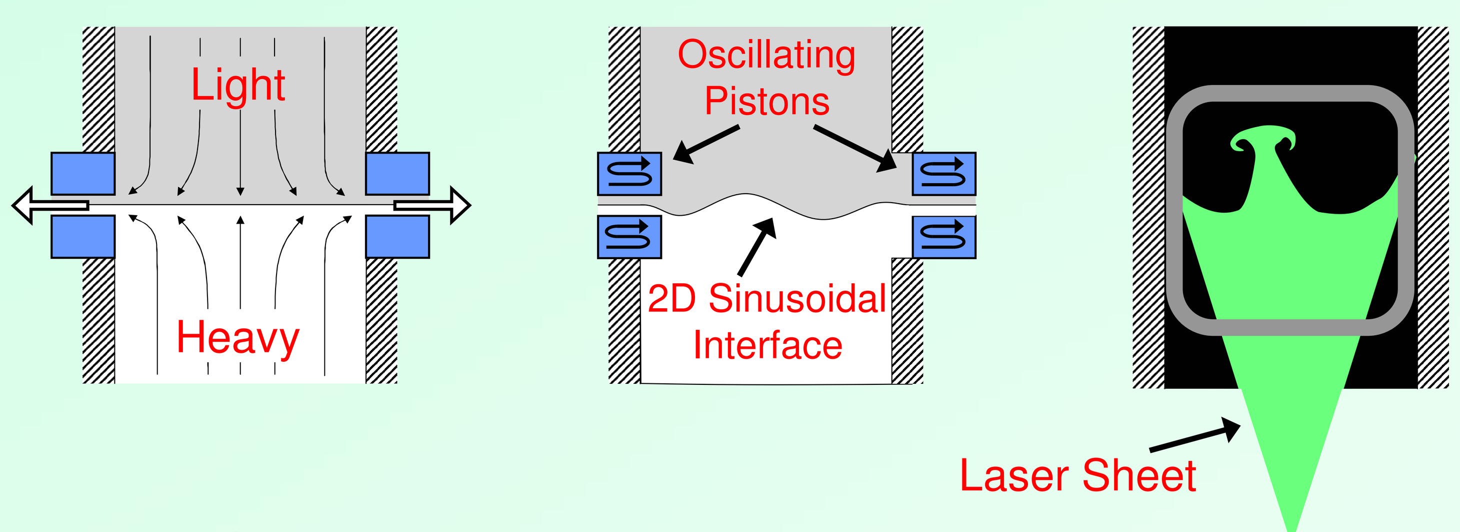
	IFE	Shock tube
L scale	10^{-6} m	10^{-2} m
t scale	10^{-9} s	10^{-6} s
ρ scale	10^3 kg/m^3	10^0 kg/m^3
M	~30	≤ 5
A	[-1,1]	[-1,1]

http://crystals.llnl.gov/new/icf1.html

Experimental Setup

Wisconsin Shock Tube Laboratory:

- 9.13 m vertical tube
- 20 MPa impulsive load capability
- 25.4× 25.4 cm square internal cross section
- Planar laser imaging
- Wall mounted pressure transducers



Interface Creation:

- Heavy and light gases flow to meet at a stagnation plane and exit through slots due to a pressure differential provided by a vacuum pump.
- Rectangular pistons oscillate to form a standing wave. The shock wave is timed to hit the desired interface shape.
- After the interface has traveled into one of the lower windows, a pulsed laser sheet illuminates the seeded gas.

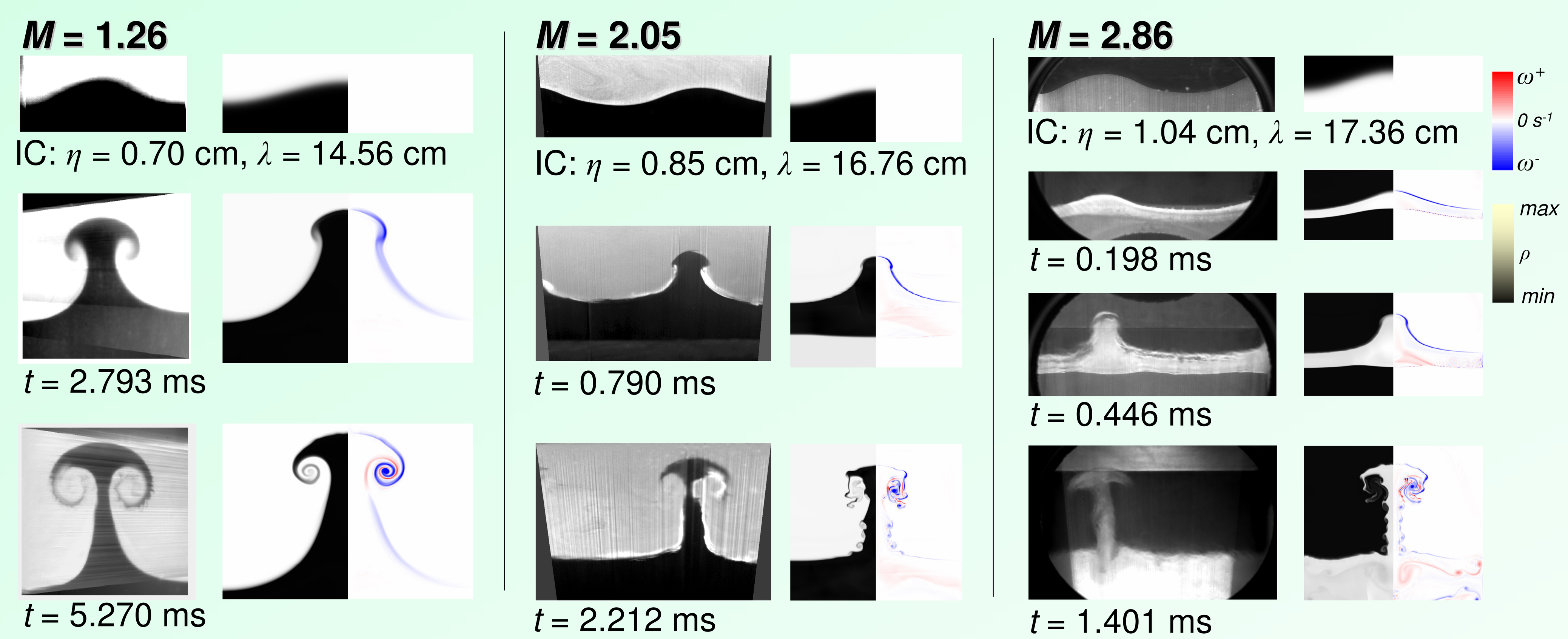
Introduction

An interfacial perturbation will grow in amplitude after acceleration by a shock wave. This instability, known as the Richtmyer-Meshkov instability, is studied in a shock tube by observing the growth of a near 2D, sinusoidal, membraneless interface separating a pair of gases. The results presented here span a range of Atwood numbers, 0.30<A<0.95, and shock wave strengths, 1.1<M<3. Numerical simulations of the experimental conditions are performed and compared with the experiments using the 2D hydrodynamics code *Raptor* (LLNL).

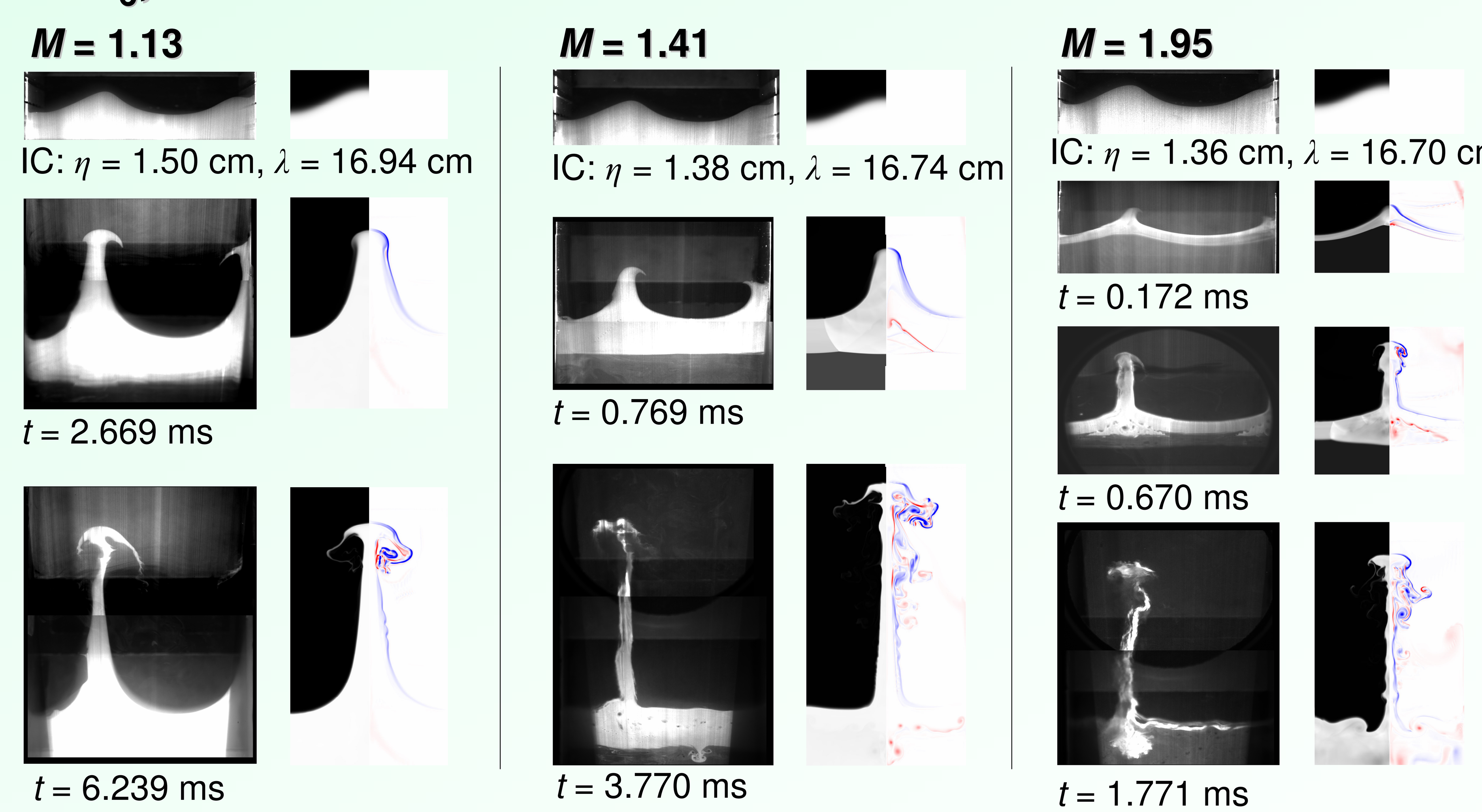
Visualization

Images from experiments (left) and simulations (right) of two Atwood numbers cases are shown below. The left half of the simulation image displays density (scale inverted as needed to match the seeded gas) and the right image displays vorticity.

N_2/SF_6, *A* = 0.68



He/SF_6, *A* = 0.95



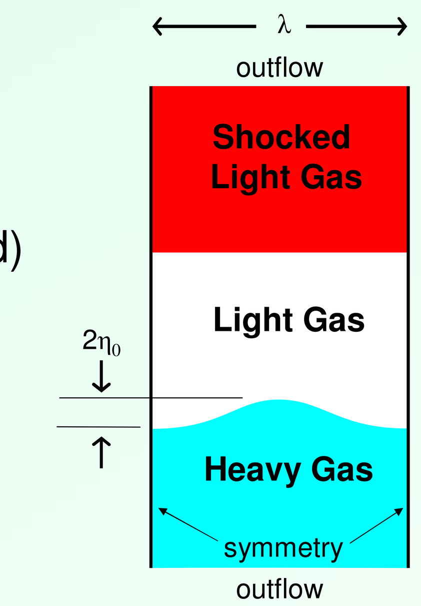
Simulation Setup

Simulation code: *Raptor* (LLNL):

- 2D compressible Euler equations; gamma-law EOS
- Higher-order Godunov solver (piecewise linear method)
- Adaptive mesh refinement (AMR): refine on $|\nabla\rho|$ and f
- VOF multifluid capturing

Setup:

- Single mode initial condition
- Hyperbolic tangent diffusion profile
- 2 levels (4x,4x) of AMR
- Finest-level resolution:
  512 cells/$\lambda \approx$ 512/16.7 cm → Δ = 326 μm



Dimensionless Scaling

- Richtmyer's impulsive growth model:

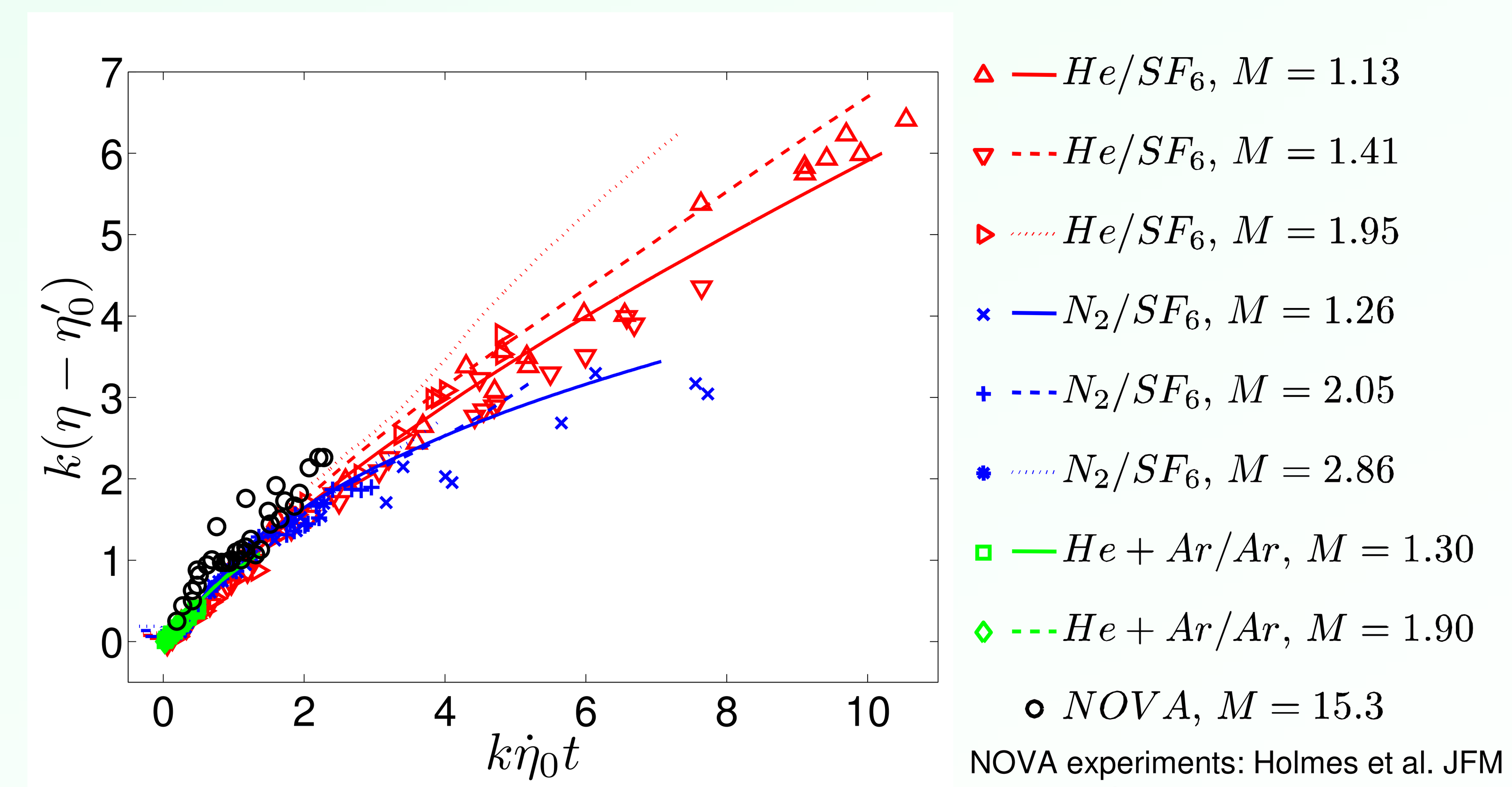
$$\dot{\eta}_{imp} = k\eta_0' A' \Delta V$$

- Scaling parameters proposed by Jacobs & Krivits (2005)
- Experiment scaled using simulation growth

$$\dot{\eta}_0 = \dot{\eta}_{imp}\left(\frac{\dot{\eta}_{avg}}{\dot{\eta}_{imp}}\right)_{simulation}$$

η	Perturbation amplitude
$k = 2\pi/\lambda$	Wave number
$A = \dfrac{(\rho_1-\rho_2)}{(\rho_1+\rho_2)}$	Atwood number
ΔV	Interface velocity

Primed quantities represent post-shocked values.



NOVA experiments: Holmes et al. JFM 1999 vol. 389 pp. 55-79
Scaled using $\dot{\eta}_0 = \dot{\eta}_{imp}$

Conclusions

- Scaling methodology works well for dimensionless time < 3.
- Laser driven NOVA experiments scale to early dimensionless time shock tube experiments.
- Macroscopic properties, such as perturbation amplitude, spike thickness, mushroom-structure, and bubble flatness are reproduced well by simulations.
- Compressibility effects evidenced by bubble flattening at high Mach number.

Acknowledgements

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