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Title: Evolution of Rayleigh-Taylor growth after an initial Richtmyer-Meshkov instability

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Evolution of Rayleigh-Taylor growth after an initial Richtmyer-Meshkov instability

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Outline

Rayleigh-Taylor (RT) Instability

- Two fluids of different densities separated by an interface
- Light fluid pushing on the heavy fluid
- Characterized by bubbles and spikes
- Leads to chaotic mixing of the fluids

$$\nabla p \cdot \nabla \rho < 0$$

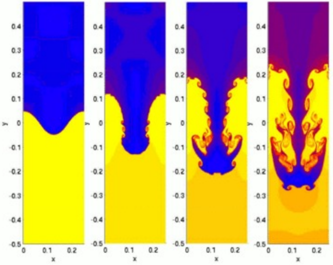

Figure: Evolution of the RT instability

Source: Wikipedia.org

Richtmyer-Meshkov (RM) Instability

- Similar setup to RT Instability
- Impulsive acceleration (shock wave)
- Bubbles and Spikes
- Leads to chaotic mixing of the fluids

$$\nabla p \cdot \nabla \rho \neq 0$$

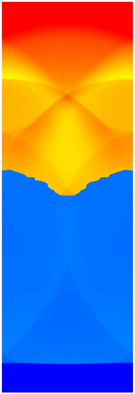

Figure: RM instability early stages

Motivation

- Inertial Confinement Fusion
  - Multiple layers of different fluids
  - Many shocks and stages of acceleration
  - Validation of Simulations by Experiments
- Astrophysical Phenomena, Climate, Supersonic Combustion, etc.

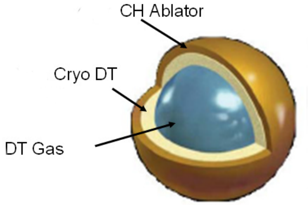

Figure: Simplified ICF Capsule

Source: J. Hager. Rayleigh-Taylor Experiements in Materials and Conditions Relevant to Inertial Confinement Fusion. PhD Thesis. University of Rochester (2011).

Problem Description

- Single mode perturbation
- Pass a shock wave across it
- At some point turn on a constant gravity

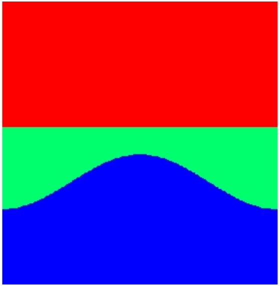

Figure: Initialization of Simulations

Compressible Euler Equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v_i}{\partial x_i} = 0 \qquad \text{Continuity}$$

$$\frac{\partial \rho v_j}{\partial t} + \frac{\partial(\rho v_i v_j + p\delta_{ij})}{\partial x_i} = 0 \qquad \text{Momentum}$$

$$\frac{\partial E}{\partial t} + \frac{\partial(E + p)v_i}{\partial x_i} = 0 \qquad \text{Energy}$$

FronTier

- All simulations use Stony Brook **FronTier** code

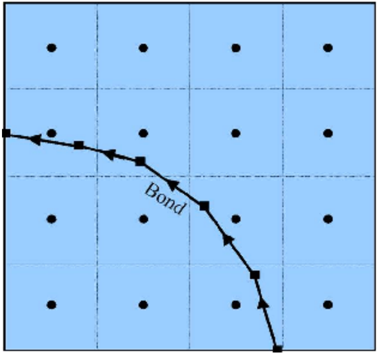

Figure: 1D tracked curve representing interface in 2D grid

- 2D Eulerian Hydro
- Lagrangian tracked interfaces
- Front Propagation via Riemann solver
- Interior Update using like component data

Courtesy: Dr. D. H. Sharp

Mixing Front Theoretical Model

- B. Cheng et al. Phys. Rev. E **66**, 036312 (2002)
- Based on buoyancy drag considerations

$$(\rho + k\rho')\frac{d|V|}{dt} = (\rho - \rho')g(t) - \frac{C\rho' V^2}{|Z|} \qquad (1)$$

ρ = density of penetrating fluid

ρ' = density of ambient fluid

$g(t)$ = gravity

C = drag coefficient

Z = height of mixing zone edge

k = added mass coefficient

Mixing Front Theoretical Model

- Set $k = 1$, Let $A = \left|\frac{\rho - \rho'}{\rho + \rho'}\right|$ be the atwood number
- Let $|V'| =$
  - $|V|/\sqrt{Ag|Z|}$ for RT
  - $|V|/\sqrt{A|Z|}$ for RM
- Let $dt' =$
  - $dt\sqrt{Ag/|Z|}$ for RT
  - $dt\sqrt{A/|Z|}$ for RM
- Substitute scaled variables into (1) and solve the resulting ODEs
  - Gives you $|Z| = Z(|Z_0|, |V_0|, t_0, t)$

Simulation Parameters

- Single mode sinusoidal perturbation Amplitude $= 0.1\lambda$
- Vary the initial (preshock) Atwood number A_{ps}
  1. $A_{ps} \approx 0.2$
  2. $A_{ps} \approx 0.5$
  3. $A_{ps} \approx 0.8$
- Vary the Mach number of the shock M_s
  1. $M_s = 1.2$
  2. $M_s = 1.5$
  3. $M_s = 2.0$
  4. $M_s = 5.0$

Variation in shock Mach number

$A_{ps} = 0.8$, RM only simulations

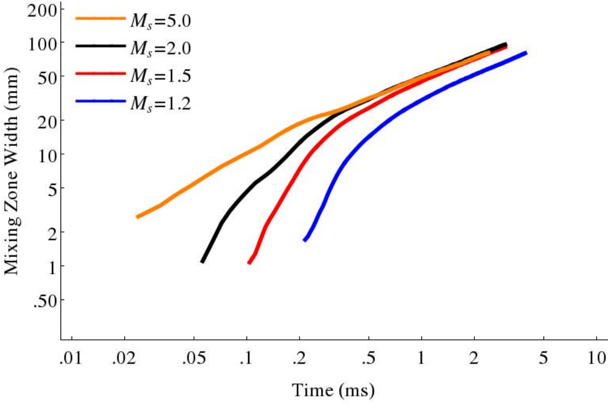

Figure: Growth vs. Time for a variation of Mach Numbers

Variation in pre-shock Atwood Number

$M_s = 1.5$, RM only simulations

Theory: $V_0 = M_s, Z_0 = 5, t_0 = .15, \alpha_b = 0.06$

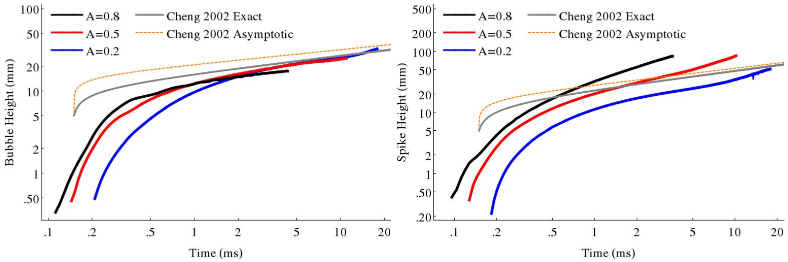

Figure: Growth vs. Time for a variation of Atwood Numbers, Left: Bubble, Right: Spike

RM and RT combined growth

$A_{ps} = 0.5, M_s = 1.5$

RM Theory: $V_0 = M_s, Z_0 = 5, t_0 = .13, \alpha_b = 0.06$

RT Theory: $V_0 = 1, Z_0 = 5, t_0 = .13, \alpha_b = 0.06$

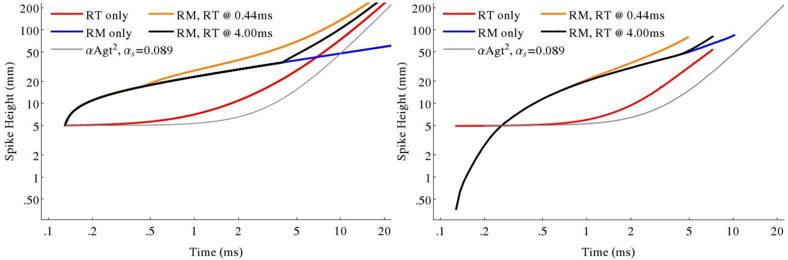

Figure: Growth rates for RM and RT combined, Left: Theory, Right: Simulations

Conclusions

- RT vs RM then RT has a significant growth discrepancy at early time
- Theory may not be ideal for ICF regime
- Asymptotic RT growth is insensitive to the initial RM conditions
- ICF RT growth rates have the potential to have a dependency on the RM seeding

Future Work

- Investigate in a more ICF like regime
  - Spherical Geometry
  - Multiple shocks of varying strengths
  - Stronger acceleration
  - Radiation effects
- Simulations with and without front tracking
  - Impact of numerical diffusion
  - Change in growth rates

Thank you

THANK YOU!

QUESTIONS?