

LA-UR-14-25599

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

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Intended for: 2014 LANL Student Symposium, 2014-08-05 (Los Alamos, New Mexico, United States)

Issued: 2014-08-06 (rev.1)

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

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2014 Los Alamos Student Symposium

Outline

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- Turbulent Instabilities
- Motivation
- Problem Description

2 Numerical Methods

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- Simulation Parameters
- Results

4 Conclusion

- Conclusions
- Future Work

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

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

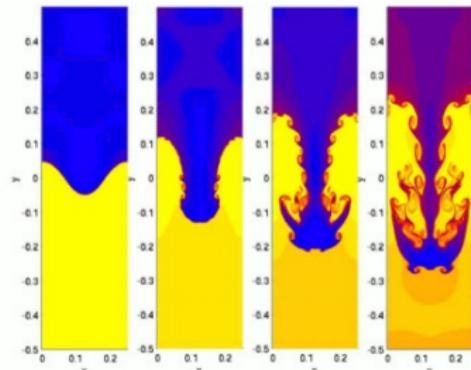


Figure: Evolution of the RT instability

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.

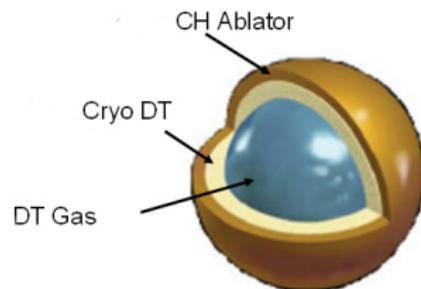


Figure: Simplified ICF Capsule

Source: J. Hager. Rayleigh-Taylor Experiments 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

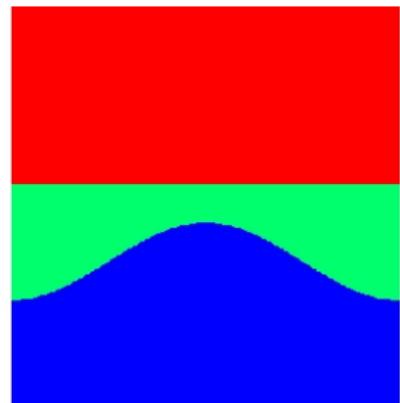


Figure: Initialization of Simulations

Compressible Euler Equations

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

Continuity

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

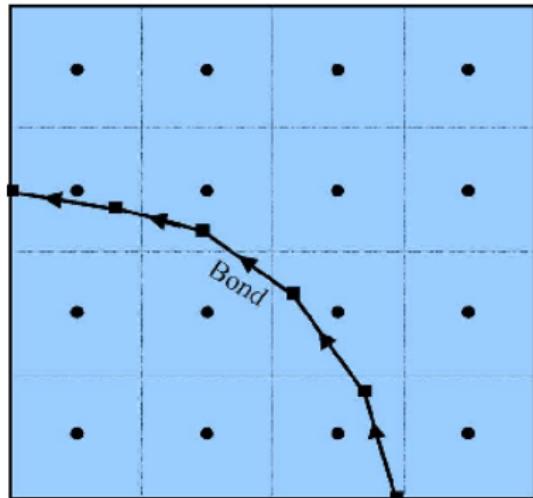
Momentum

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

Energy

FronTier

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



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

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

Courtesy: Dr. D. H. Sharp

Jeremy Melvin

Mixing Front Theoretical Model

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

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

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 λ
- 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

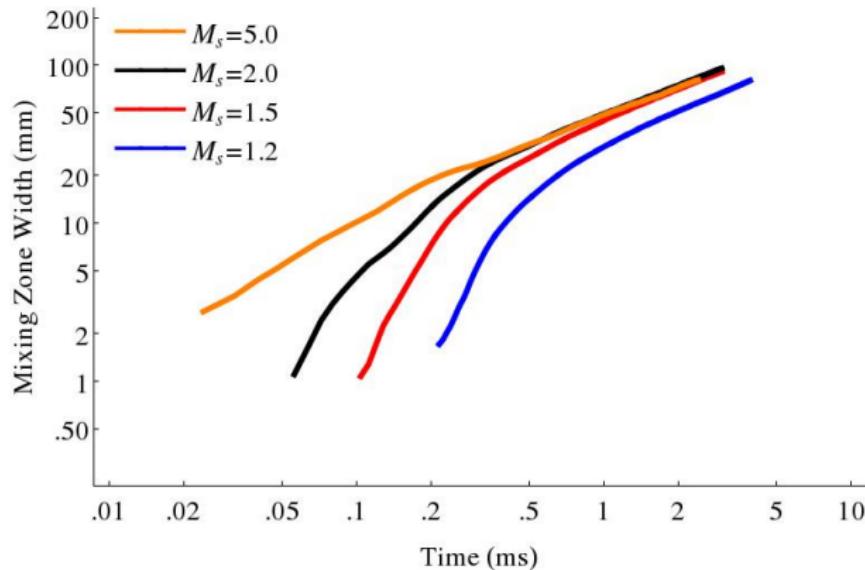


Figure: Growth vs. Time for a variation of Mach Numbers

Variation in pre-shock Atwood Number

$M_s = 1.5$, RM only simulations

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

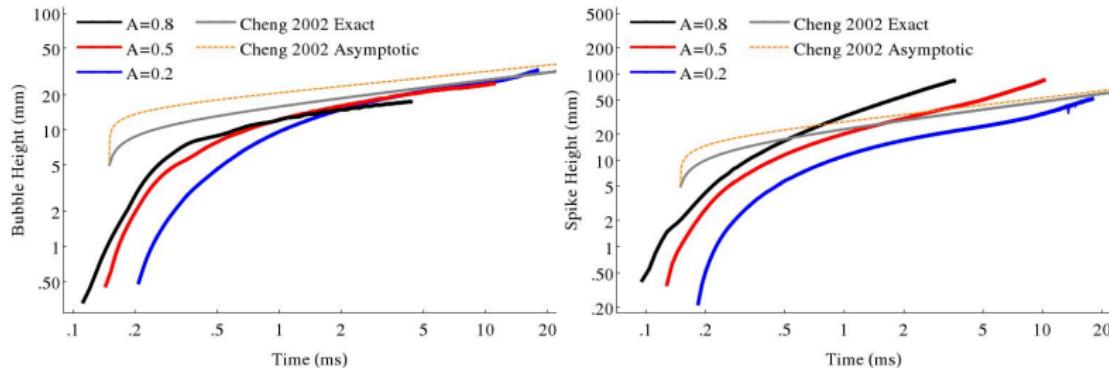


Figure: Growth vs. Time for a variation of Atwood Numbers, Left: Bubble, Right: Spike

RM and RT combined growth

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

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

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

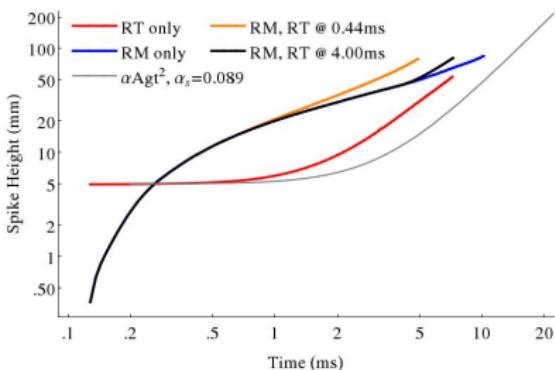
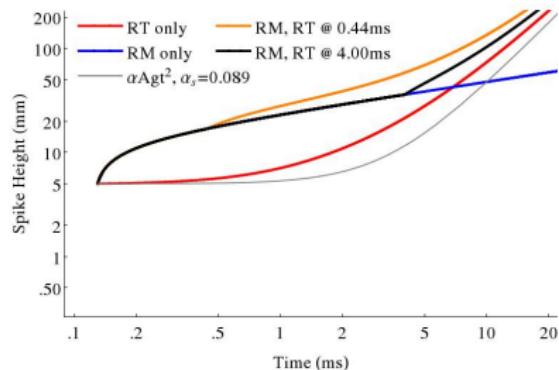


Figure: Growth rates for RM and RT combined, Left: Theory, Right: Simulations

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?