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Title: Accounting for Initial Conditions in Models of Rayleigh-Taylor Turbulent Mixing

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Abstract Submitted
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On Accounting for Initial Conditions in Models of Rayleigh-Taylor Turbulent Mixing BERTRAND ROLLIN, MALCOLM ANDREWS, Los Alamos National Laboratory — For many fluid engineering applications, considering only the fully developed turbulence regime with a rough estimate for the turbulence model initial conditions is not sufficient. If we consider for example Inertial Confinement Fusion (ICF), the turbulence and turbulent mixing induced by the Rayleigh-Taylor (RT) instability are subject to initial condition (IC) effects during the time of interest. The degree of confidence in any prediction of the flow evolution in the turbulence regime is therefore open to question. To improve our predictive capability, we need to capture the evolution of the instability from the initial state until it is appropriate to use a turbulence model, in particular with the treatment of ICs that seed the instability. We present our approach for tracking the growth of the RT mixing layer evolution. We have constructed a modal model based on several existing descriptions for single mode and multimode RT mixing evolution. We also present how to extract profiles of turbulence variables that are used as initial conditions for a turbulence model. Finally, we discuss a metric for switching from our modal model to the turbulence model.

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Accounting for Initial Conditions in Models of Rayleigh-Taylor Turbulent Mixing

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LDRD: Turbulence by Design

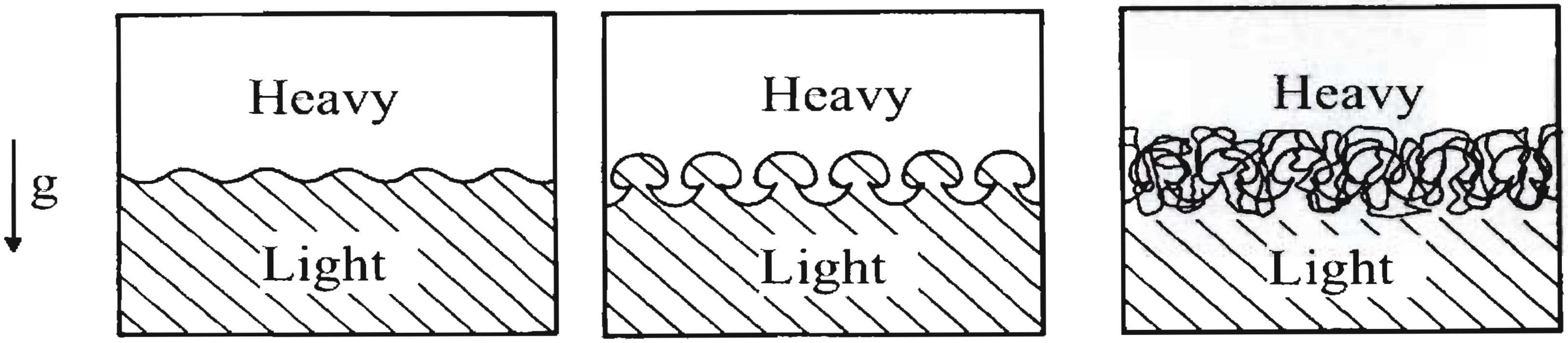
LA-UR 11-xxxx

APS DFD 2011

Baltimore, MD –November 2011

Rayleigh-Taylor Instability

Credit: M.J. Andrews



Exponential growth **Nonlinear growth** **Turbulent mixing**

Characteristic non-dimensional number: $A_T = \frac{\rho^h - \rho^l}{\rho^h + \rho^l}$

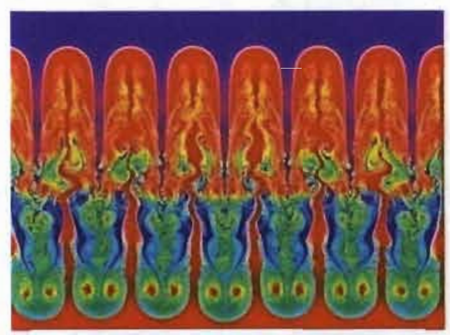
Interface is unstable if: $\nabla p \cdot \nabla \rho < 0$

M.J. Andrews, TAMU water channel experiment

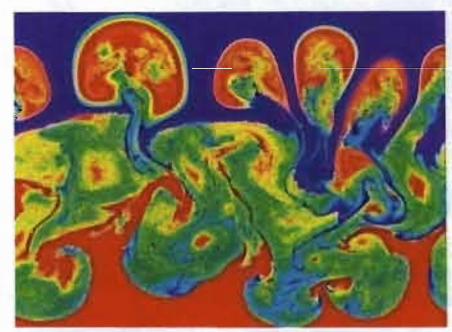
Long wavelength initial conditions

Short wavelength initial conditions

Credit: Hjelm & Ristorcelli



No IC noise



With IC noise

LA-UR 11-xxxxx

Importance of Initial Conditions for Turbulence "Design" and Prediction

Premise:

- Initial conditions could affect "late-time" turbulent transport and mixing effectiveness. Hence, a challenge for prediction, but also an opportunity for turbulence "design".

Objective:

- Provide a rational basis for setting up initial conditions in turbulence models.

A Modal Model for Multimode RT mixing layer Growth

A modal model for multimode RT built from the "fusion" between a potential flow model for single mode and a weakly nonlinear model:

For all k,

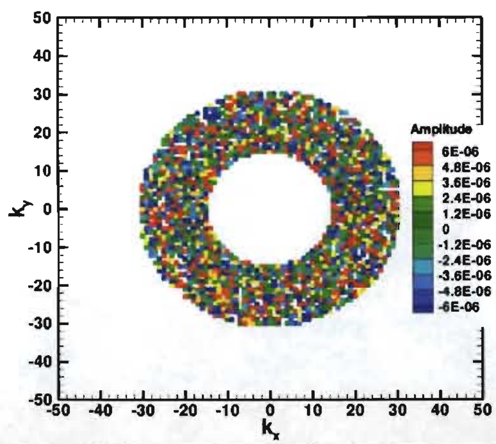
$$\begin{cases} \ddot{Z}_k = G(k) + A_T k \sum_m \left\{ \ddot{Z}_m Z_n \left(1 - \hat{m}\cdot\hat{k}\right) + \dot{Z}_m \dot{Z}_n \left(\frac{1}{2} - \hat{m}\cdot\hat{k} - \frac{1}{2}\hat{m}\cdot\hat{n}\right)\right\} & \text{Before k saturates} \\ \ddot{Z}_k = A_T k \sum_m \left\{ \ddot{Z}_m Z_n \left(1 - \hat{m}\cdot\hat{k}\right) + \dot{Z}_m \dot{Z}_n \left(\frac{1}{2} - \hat{m}\cdot\hat{k} - \frac{1}{2}\hat{m}\cdot\hat{n}\right)\right\} & \text{After k has saturated} \end{cases}$$

$$|m|,|n| < |k|$$

Saturation criterion given by Ikegawa & Nishihara (Phys. Rev. E **67** 026404, 2003)

$$G(k) = \frac{4(k - 8\eta_2)}{k^2 - 4A_T k\eta_2 - 32A_T\eta_2^2}\left(-\dot{Z}_k^2 k^2 \frac{(5A_T - 4)k^2 + 16(2A_T - 3)k\eta_2 + 64A_T\eta_2^2}{8(k - 8\eta_2)^2} - A_T g\eta_2\right) \qquad k = \sqrt{k_x^2 + k_y^2}$$

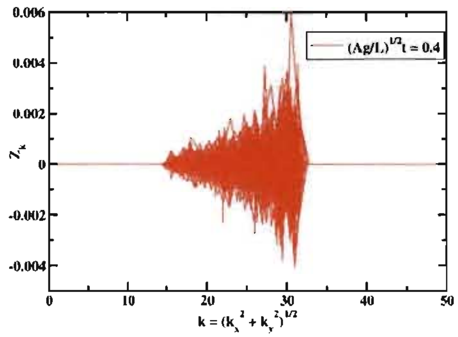
$$\eta_2 = -\frac{k}{8} + \left(\frac{k}{8} + \eta_2(0)\right)e^{-2k(\eta_0 - \eta_0(0))}$$

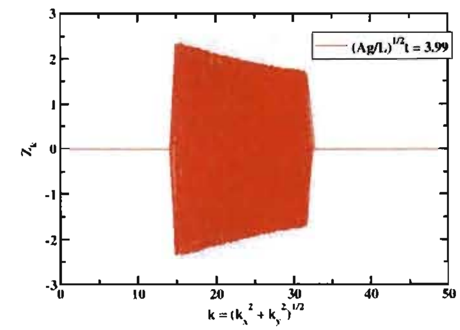


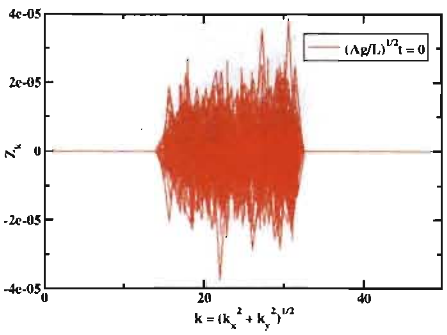
Initial perturbation in wave space

Modal Model Behavior

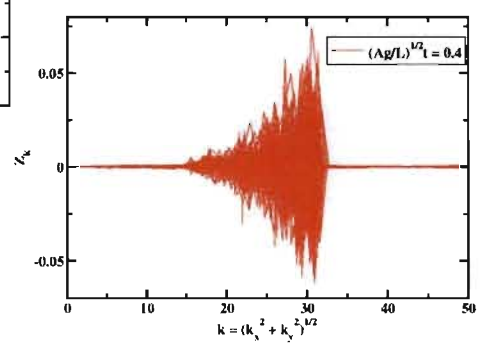
No Mode Coupling

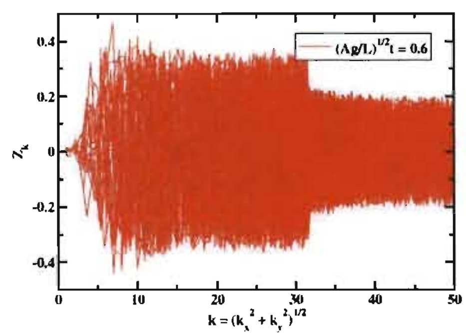


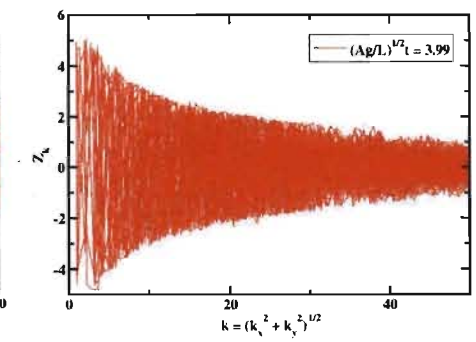




Mode Coupling

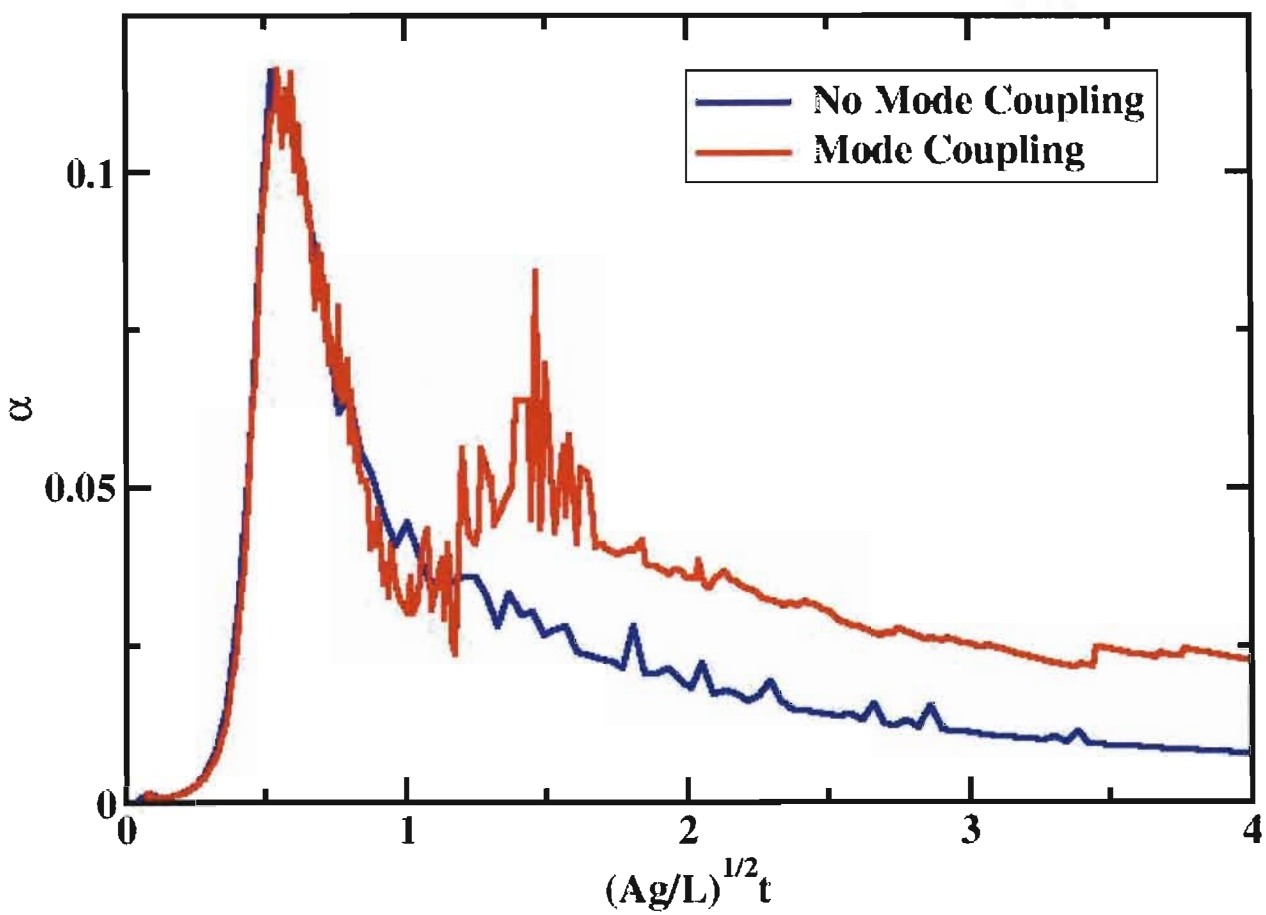






The mode coupling function allow generation of modes

Modal Model Behavior



Mode coupling is at the origin of self similarity

BHR Turbulence Model for RT Instability

Besnard-Harlow-Rauenzhan (BHR) turbulence model:

- **Single-point turbulent transport model**
- **Designed for variable density turbulence**

D. Besnard, F. H. Harlow, R. Rauenzhan, LA-10911-MS (1987)

Model Variables:

$$k = \frac{\langle \rho u''_k u''_k \rangle}{2\overline{\rho}} \qquad a_i = \frac{\overline{\rho' u_i'}}{\overline{\rho}} \qquad b = -\overline{\rho' v'} \qquad S = \frac{k^{3/2}}{\varepsilon} \qquad \nu_t = C_\mu k^{1/2} S$$

Governing equation for the variable S:

$$\partial_t S = \left(\frac{3}{2} - C_4\right) a_z g \frac{S}{k} + \frac{1}{\rho} \partial_z \left(\rho \frac{\nu_t}{\sigma_S} \partial_z S\right) - \left(\frac{3}{2} - C_2\right) k^{1/2}$$

BHR initiated with:

- **Profiles for:** $k \quad a_i \quad b \quad S$
- **Values for:** $C_4 \quad C_2 \quad C_\mu \quad \sigma_S \quad \ldots$

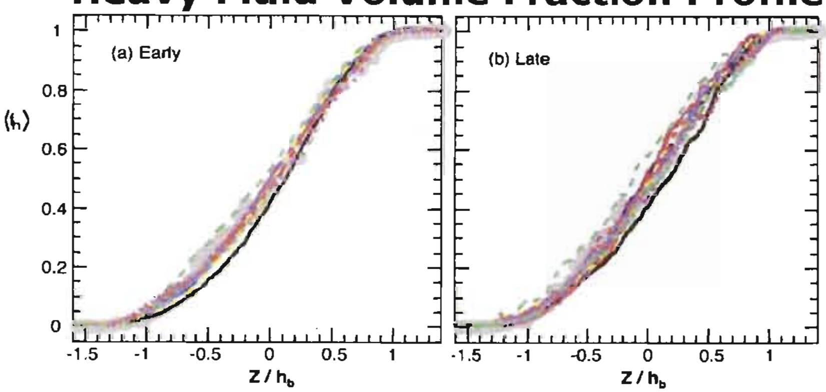
Two-Fluid Formulation for BHR Variables

$$\overline{\rho} = f_l \rho_l + f_h \rho_h \qquad \overline{\mathrm{u}} = f_l \mathrm{u}_l + f_h \mathrm{u}_h \qquad \overline{\rho}\tilde{\mathrm{u}} = \rho_l f_l \mathrm{u}_l + \rho_h f_h \mathrm{u}_h$$

$$a_i = \frac{\overline{\rho' u_i'}}{\overline{\rho}} \Longrightarrow a_z = C_{a_z} \frac{f_h f_l}{f_h \rho_h + f_l \rho_l} (\rho_h - \rho_l)(u_h + u_l)$$

We need an estimate for the mixture fraction profile to compute the two-fluid formulation of the turbulence quantity

Heavy Fluid Volume Fraction Profile



Dimonte *et al.*, Phys. of Fluids, **16** (2004)

$$\begin{cases} f_l = \dfrac{\rho - \rho_h}{\rho_l - \rho_h} \\ f_h = 1 - f_l \end{cases}$$

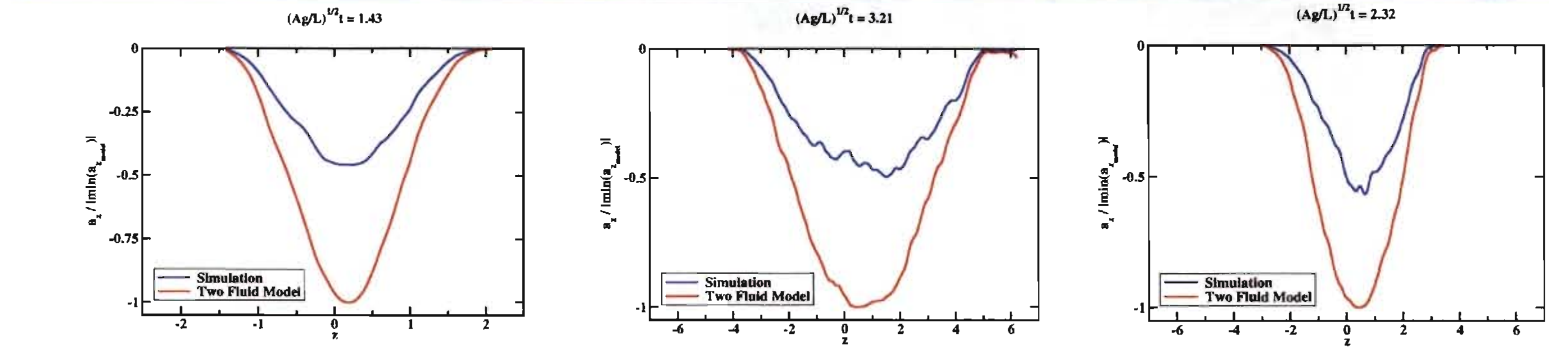
$$\begin{cases} f_h = 0 & if \quad z < -h_s \\ f_h = 0.5\dfrac{z + h_s}{h_s} & if \quad -h_s \le z < 0 \\ f_h = 0.5\dfrac{z}{h_b} + 0.5 & if \quad 0 \le z \le h_b \\ f_h = 1 & if \quad z > h_b \end{cases}$$

For a smooth mixture fraction description

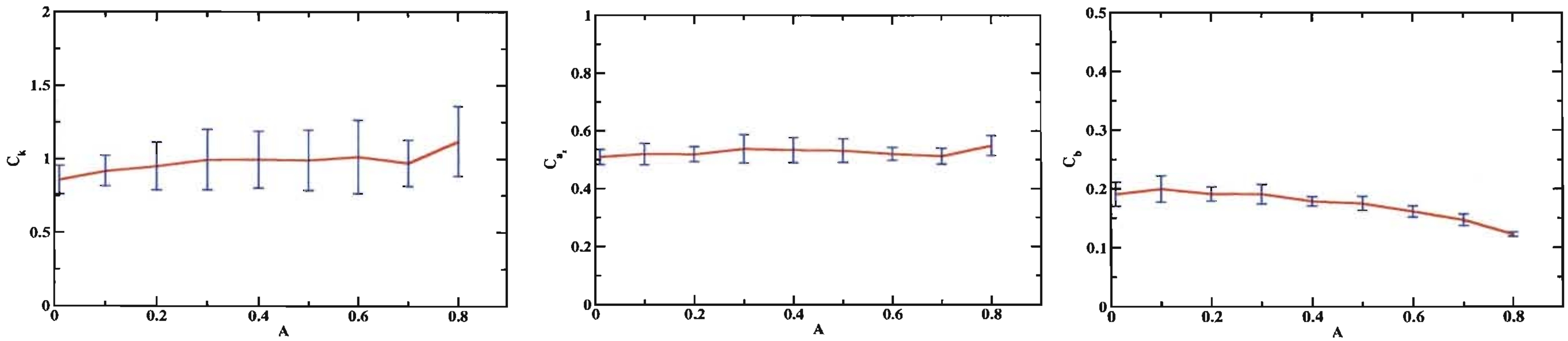
$$\tilde{f}_h(z) = \int_{h_s}^{h_b} (z - h_s)^{a-1} (h_b - z)^{b-1} dz$$

$$f_h(z) = \frac{\tilde{f}_h(z)}{\tilde{f}_h(h_b)}$$

Two Fluid Model Predictions and Coefficient



Two-fluid formulation produces reasonable profiles that need to be adjusted with correction coefficients



$C_k = 0.98$ $C_{a_z} = 0.53$ $C_b = 0.17$

Two fluid model correction coefficients could be considered independent from the Atwood number

Summary

- We constructed a modal model for multimode RT
- We use a two-fluid formulation for generating profiles of turbulence model variables in the self-similar regime
- We defined an approach to remove any guess from initializing a turbulence model for Rayleigh-Taylor turbulent mixing

- **Next steps:**
  - Improve our multimode model (larger Atwood, variable acceleration, RM etc...)
  - Define a metric for switching from our model to a turbulence model

- **Acknowledgements:**

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