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Title: The tilted rocket rig: A test case for Los Alamos models

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The tilted rocket rig: A test case for Los Alamos models

Jon Reisner, Nick Dennisen, Bertrand Rollin, and Malcolm Andrews

- The tilted rig setup is a unique data source to test a given models ability to simulate Rayleigh Taylor (RT) and Kelvin Helmholtz (KH) instabilities
- Can be used to assess both implicit large eddy simulation (ILES) and Reynolds averaged Navier-Stokes (RANS) modeling approaches used in a common mix framework

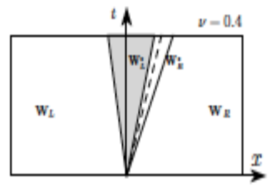
LANL Advanced Simulation and Computing (ASC) Codes

- LANL has 3 ASC codes, xRage, Flag, and Roxane
- Besides xRage using a total energy equation, the gas dynamic equation sets are similar---compressible Navier-Stokes with species energy/mass equations
- Results will be shown from xRage and Flag
- xRage uses a modified Godunov scheme
- Flag uses an ALE approach

Problems with Contacts?

Shock Tube Test: Le Blanc's Problem

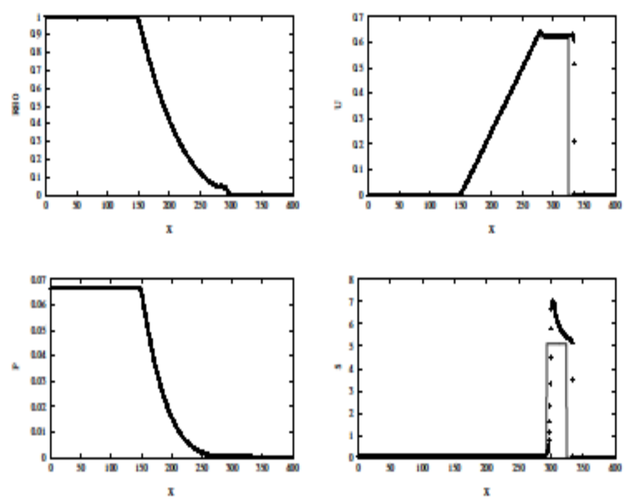
Left state	Right state
$\rho_l = 1$	$\rho_r = 0.001$
$u_l = 0$	$u_r = 0$
$p_l = 0.06667$	$p_r = 6.667e-10$
$\gamma_l = 1.667$	$\gamma_r = 1.667$

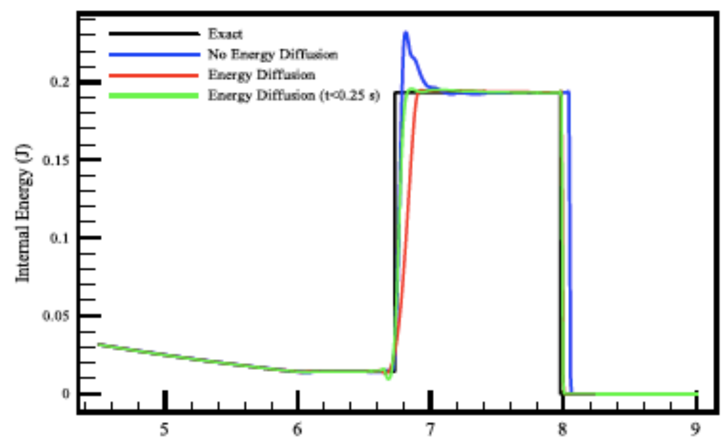


A variation on LeBlanc's shock-tube problem.

Scheme xrage::1d

Solver numrho6





Solution: Add artificial viscosity to energy equation?

Common Mix Framework

- *Goal:* Develop a consistent framework to test mix formulations across ASC codes
- *Methodology:* Start simple with a common BHR-II code base, validate and verify, add complexity if needed
- *Expected Results:* A framework that accurately represents mixing across a range of instabilities and is model independent…

What is BHR?

- BHR is a variable density turbulence model
- Formulated by assuming ensemble averaging
- Various formulations exist from simple BHR-II (TKE, L, a_i, and b) to complex multi-species approaches (a^k_i,b^k)

Why BHR-II to Comprise Common Mix Framework?

- Small number of tuning coefficients and numerical efficiency
- Ease of implementation across ASC codes
- Successful validation of the approach
- Numerical errors are relative small
- Future Capability: BHR-MS, BHR energy terms, matrix form of length scale S_{ij}, etc…

BHR-II
A Common Mix Framework Across ASC Models

$$\bar{\rho}\frac{DK}{Dt} = a_j\frac{\partial \bar{p}}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\frac{\mu_T}{\sigma_k}\frac{\partial K}{\partial x_j}\right) - R_{ij}\frac{\partial \tilde{u}_i}{\partial x_j} - C_k\bar{\rho}\frac{K^{3/2}}{L}$$ (turbulence kinetic energy)

$$\bar{\rho}\frac{DL}{Dt} = \frac{L}{K}\left[\left(\frac{3}{2} - C_4\right)a_j\frac{\partial \bar{p}}{\partial x_j} - \left(\frac{3}{2} - C_4\right) R_{ij}\frac{\partial \tilde{u}_i}{\partial x_j}\right] - C_3\bar{\rho}L\frac{\partial \tilde{u}_j}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\frac{\mu_T}{\sigma_L}\frac{\partial L}{\partial x_j}\right)$$

$$-\left(\frac{3}{2} - C_2\right)\bar{\rho}K^{1/2}$$ (turbulent length scale)

$$\bar{\rho}\frac{Da_i}{Dt} = b\frac{\partial \bar{p}}{\partial x_i} + \bar{\rho}\frac{\partial a_i a_j}{\partial x_j} - \bar{\rho}a_j\frac{\partial(\tilde{u}_i - a_i)}{\partial x_i} - \frac{R_{ij}}{\bar{\rho}}\frac{\partial \bar{\rho}}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\frac{\mu_T}{\sigma_a}\frac{\partial a_i}{\partial x_j}\right) - C_a\bar{\rho}a_i\frac{K^{1/2}}{L}$$

(density velocity correlation)

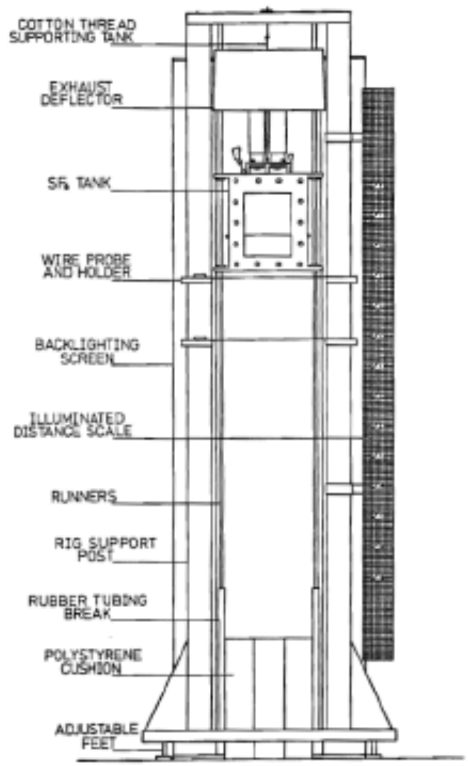
$$\bar{\rho}\frac{Db}{Dt} = 2\bar{\rho}a_j\frac{\partial b}{\partial x_j} - 2(b+1)a_j\frac{\partial \bar{\rho}}{\partial x_j} + \bar{\rho}^2\frac{\partial}{\partial x_j}\left(\frac{\mu_T}{\bar{\rho}^2\sigma_b}\frac{\partial b}{\partial x_j}\right) - C_b\bar{\rho}\frac{K^{1/2}}{L}b$$

(density self correlation)

A Common Mix Framework: Test Problems

- Tilted RT problem is being tested in xRage and Flag…appropriate for RT and KH instabilities
- Problem has helped in chasing out bugs and implementation issues
- Results compare reasonably well against DNS
- But a definite need exists for test problems that can verify mean and turbulent quantities under a wide range of conditions

Tilted Rocket Rig

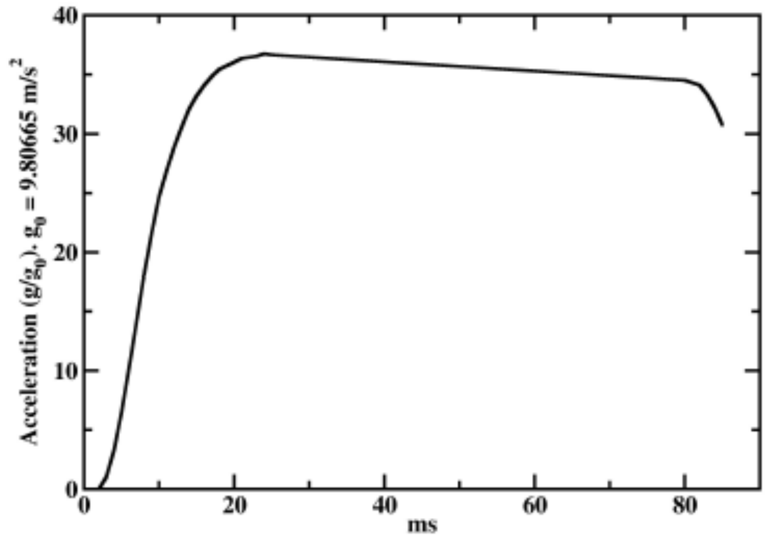


- Series of experiments from the UK AWE[1]
- Gravity is "flipped" via downward rocket motors
- Interested in case 110, low surface tension, significant interface tilt

t=55 ms

[1] Smeeton & Youngs, AWE Report No. O 35/87

Experimental Setup



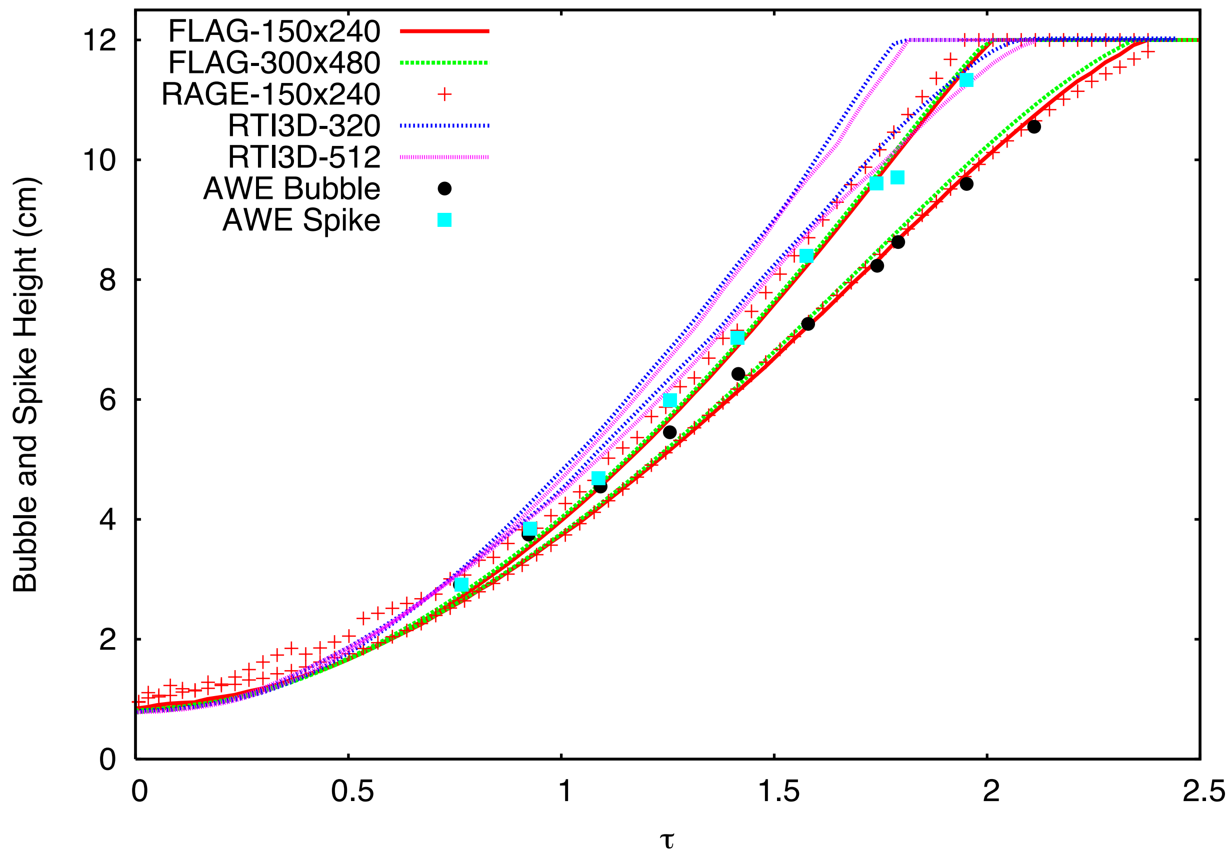
ρ_H	ρ_L	At	L_x	L_z
1.89	0.66	0.48	15	25

Table: Experimental parameters in units: cm, g, ms

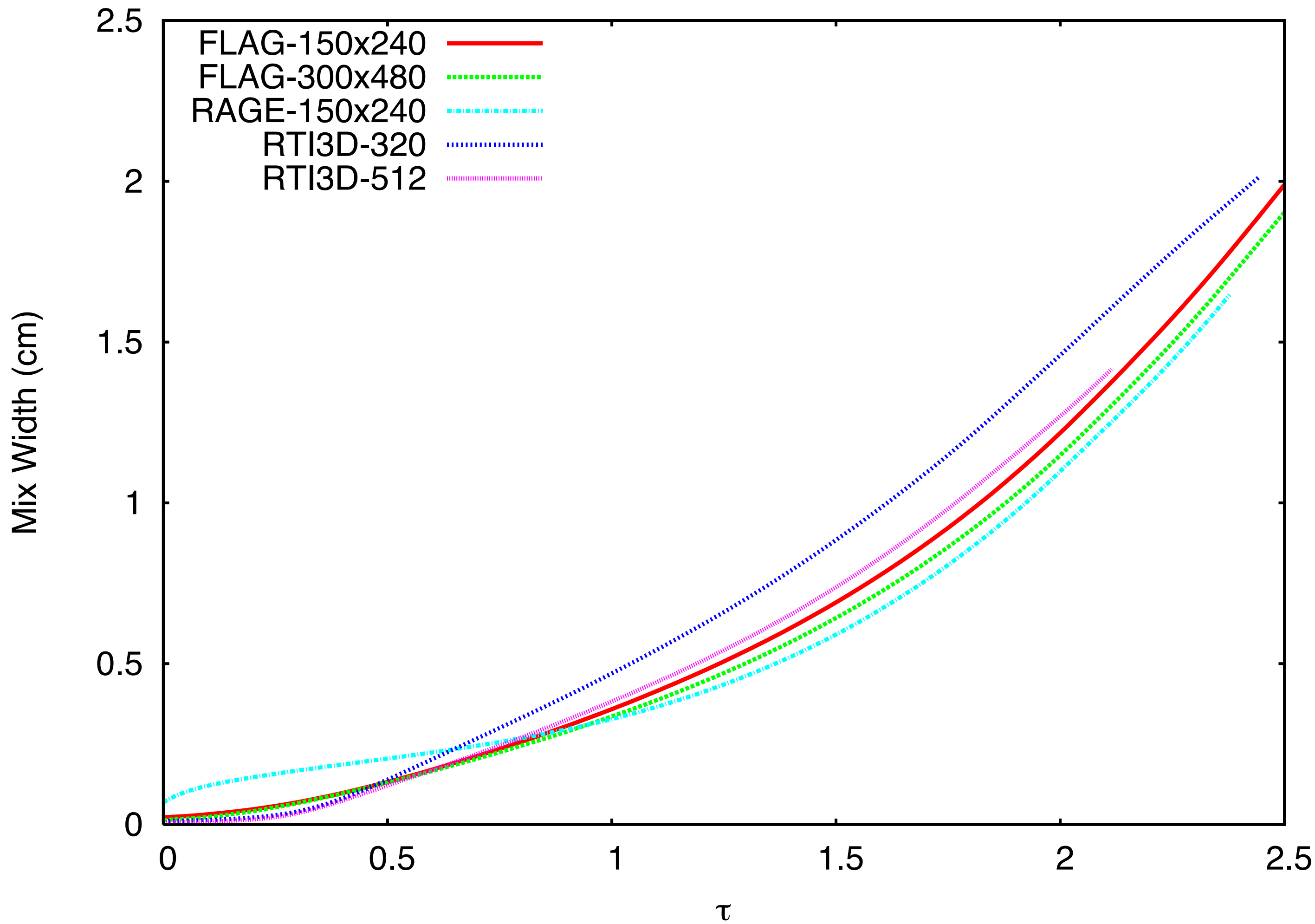
Model Setup

- Both xRage and Flag (complete remap-no artificial viscosity) used 150x240 grid points
- BHR-II was used in simulations and a gamma law gas EOS was used in the base simulations
- Flag used similar pressure/temperature to experiment; xRageinitially used much higher pressure/temperature
- Preliminary results suggest that xRage does not produce enough mixing

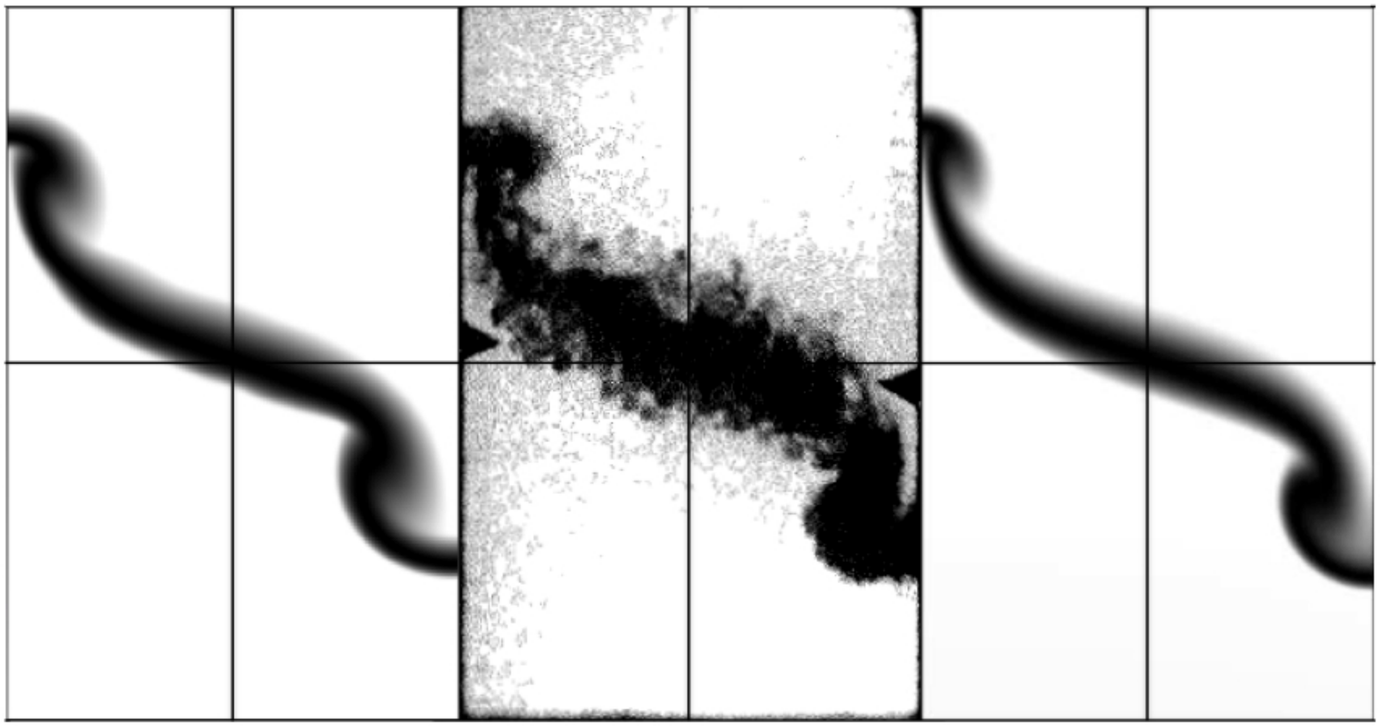
Bubble/Spike Growth Rates



Integrated Mixing Widths

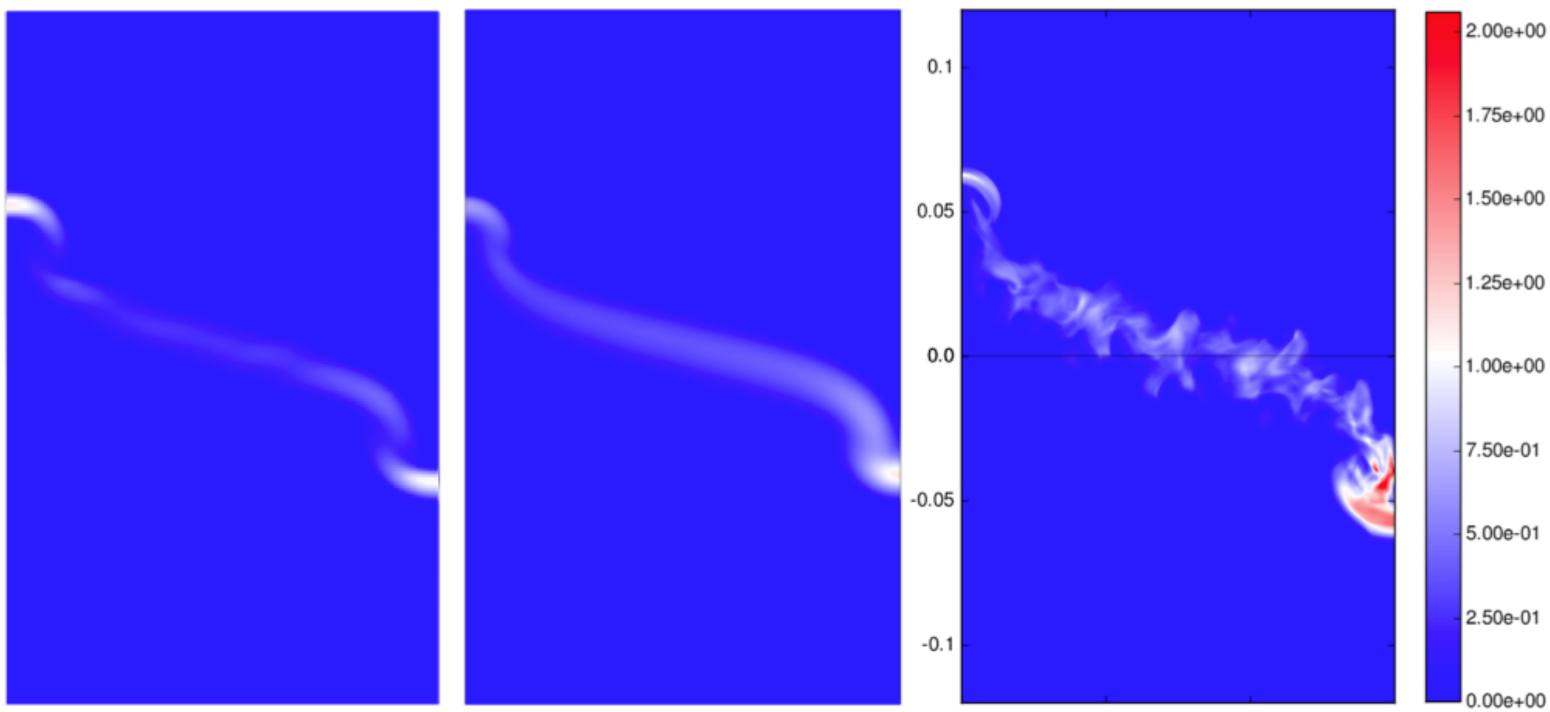


xRage, Experimental, and Flag results at t=55 ms (Mixing Parameter)



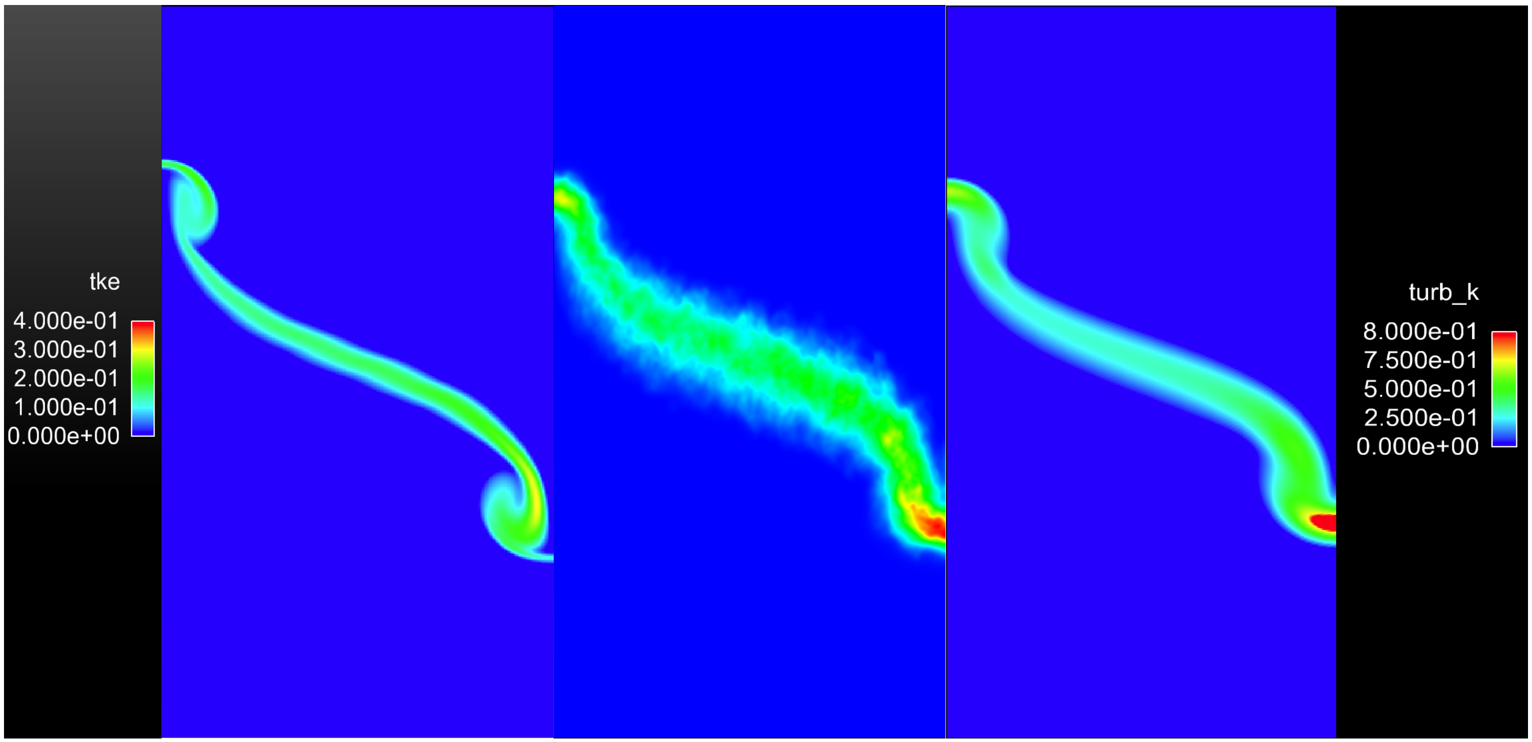
xRage Experimental Flag

xRage, Flag, and CFDNS TKE Results at t=45 ms
xRage is Symmetric (Why?)



xRage | Flag | CFDNS-Wei and Livescu

Same Findings for Different Tilted Rig Setup



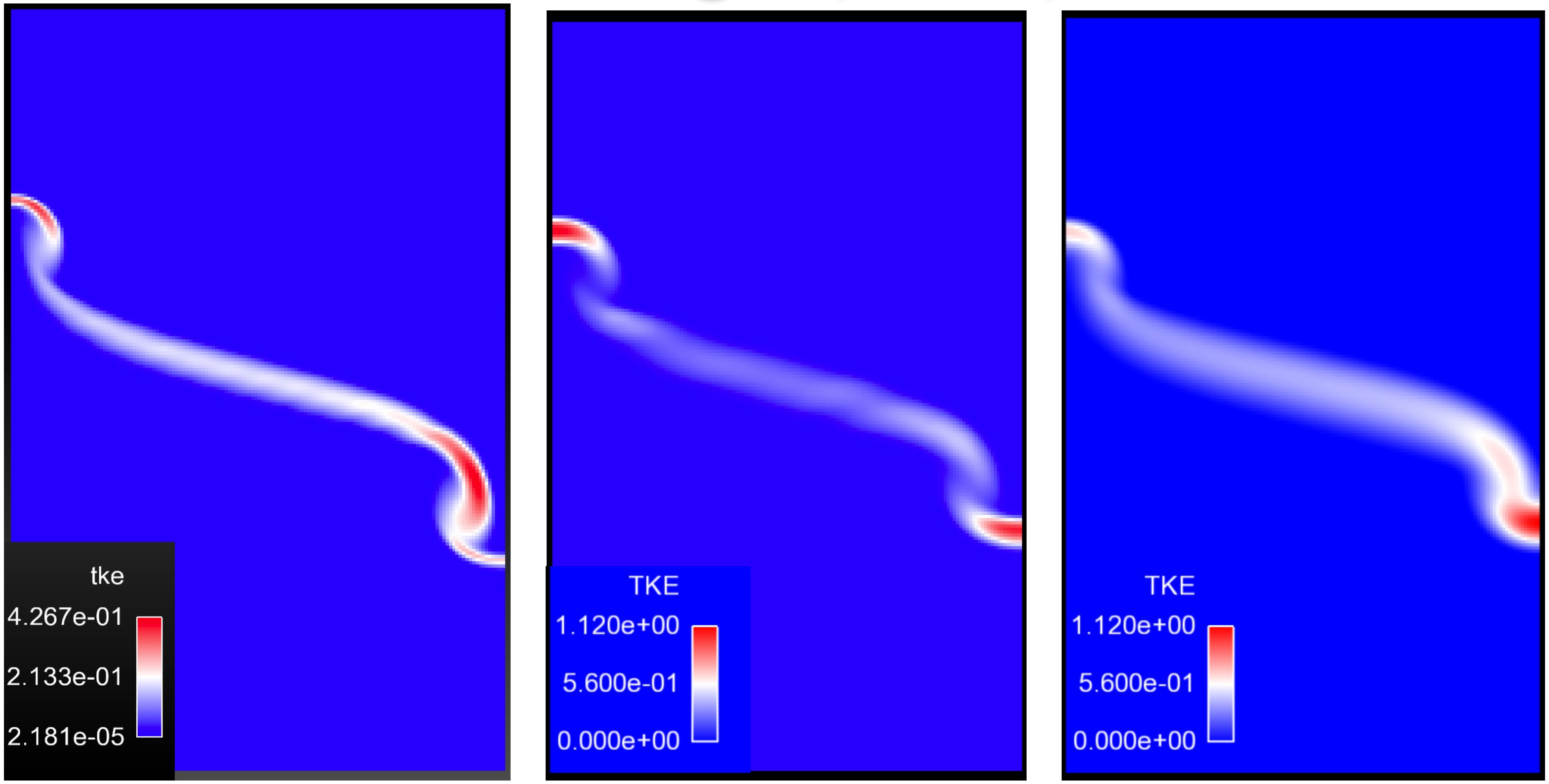
xRage + BHR mixing model (LEFT), averaged RTI3D (MIDDLE-Andrews) and FLAG + BHR mixing model (RIGHT)

Note the different scale only for the xRage figure

Why Differences Between Flag and xRage?

- xRages produces sharper features and less turbulent mixing
- BHR-II implementation issues/bugs?
- Differences in initial conditions?
- Numerical issues of base hydro solver… check using ILES

Impact of Initial Conditions in xRage (TKE)



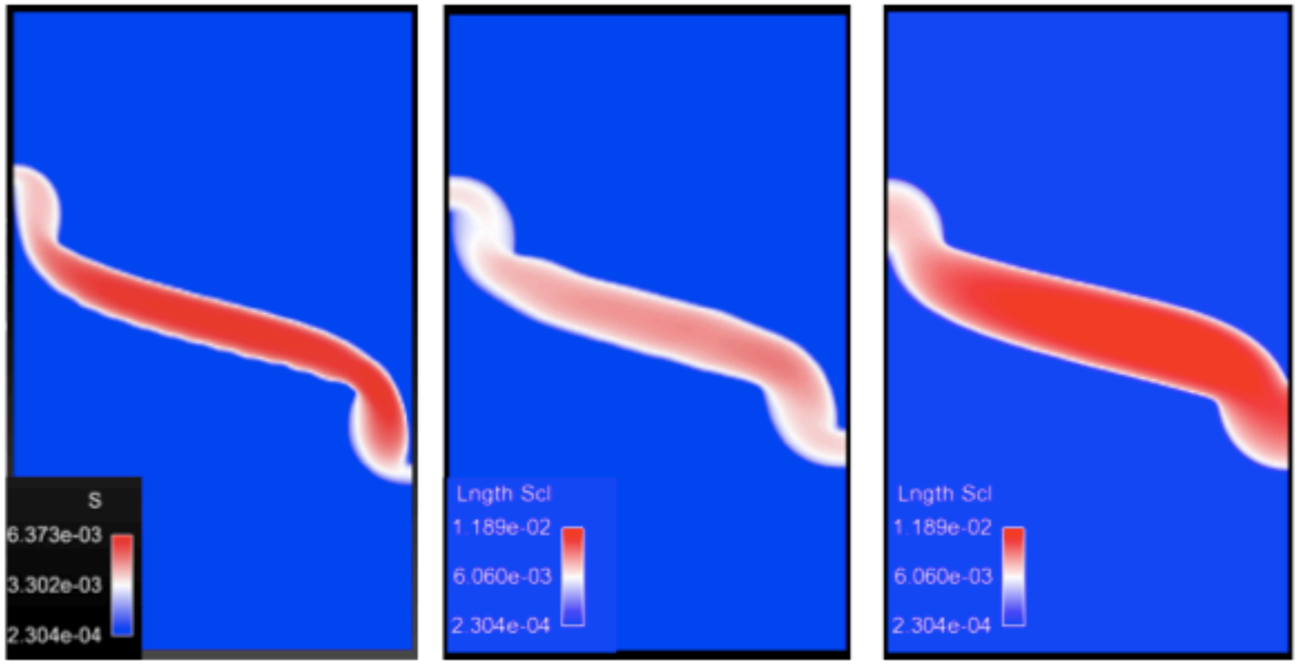
xRage with exact FLAG initial thermodynamics conditions, hydrobet =0 and BHR2.

xRage as thermodynamically initialized until now, hydrobet default value, and BHR2

FLAG and BHR2

Impact of Initial Conditions in xRage (Length Scale)

Turbulence Length Scale @ t = 45ms



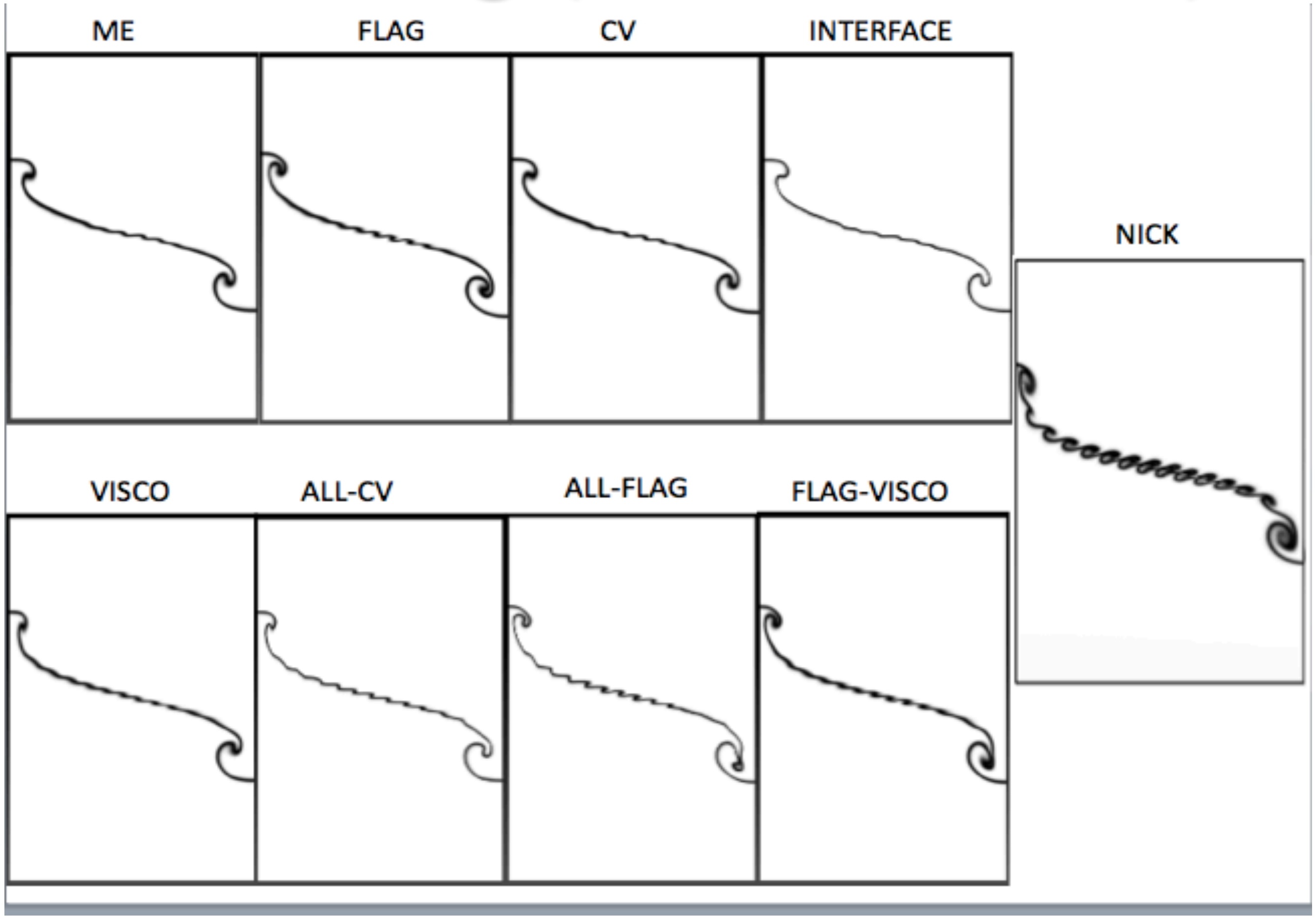
xRage with exact FLAG initial thermodynamics conditions, hydrobet =0 and BHR2.

xRage as thermodynamically initialized until now, hydrobet default value, and BHR2

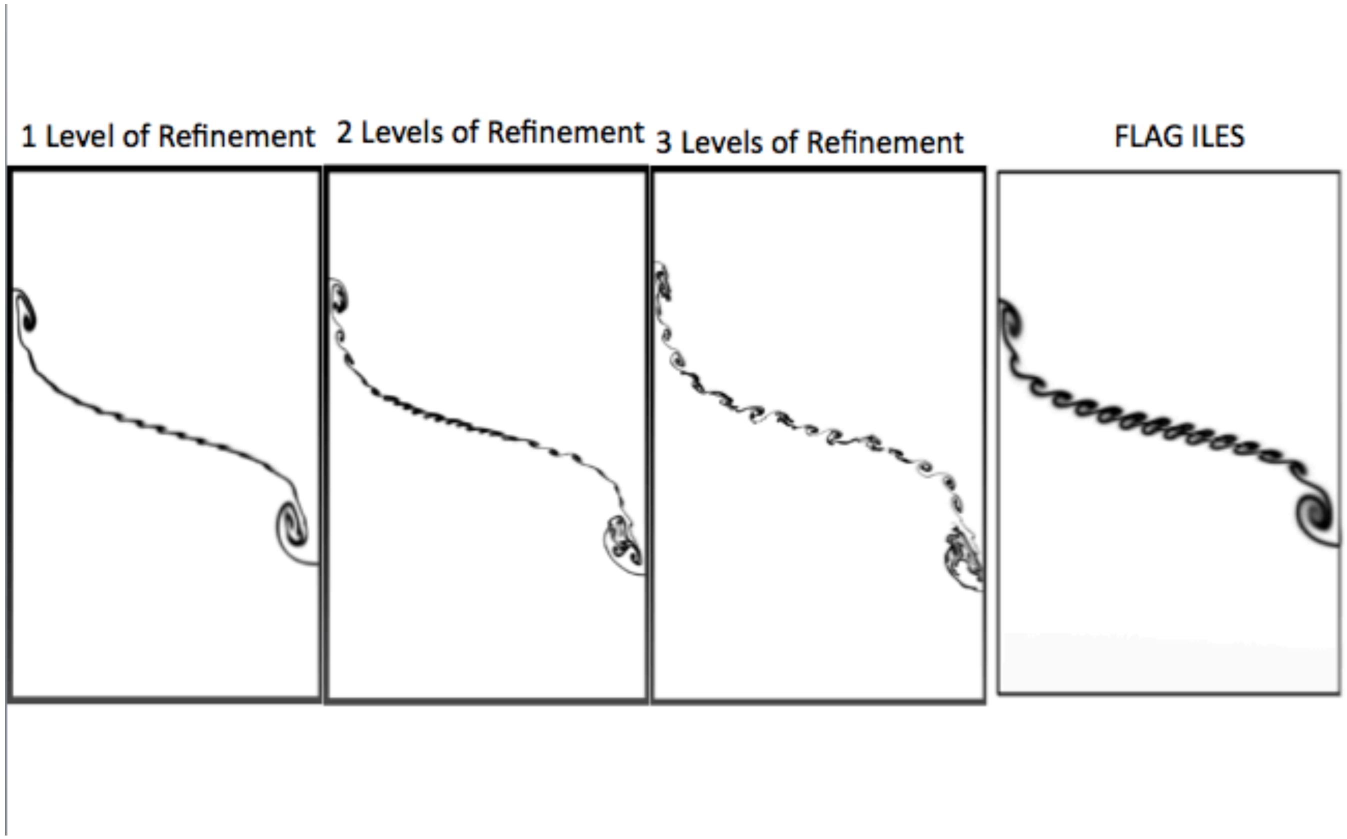
FLAG and BHR2

Use FLAG's scale for comparison

Various 2-D ILES xRage Results Versus Flag (Labeled NICK)

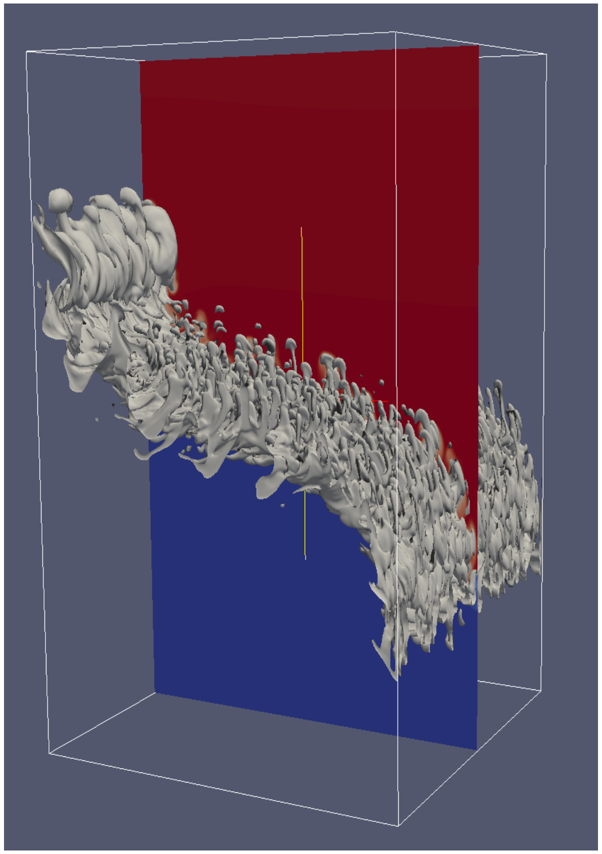


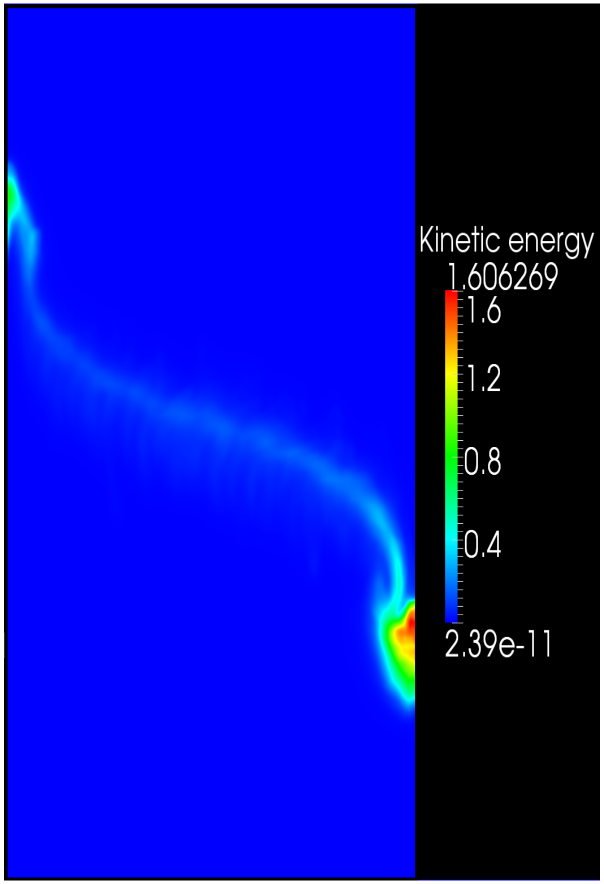
xRage (AMR) Versus Flag



3D-ILES xRage

Still Sharper than Flag but Larger Values of TKE





Overview/Questions Raised

- Differences between xRage and Flag appear to be the result of the underlying numerical scheme
- Will these differences increase/decrease for other problems, i.e., Richtmyer-Meshkov instability?
- Will Roxane produce results closer to xRage or Flag?