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Turbulent Mix Experiments

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Turbulent Mix Experiments

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MX_01

Objective of mix program is to quantify turbulent mix scaling laws

- Rayleigh-Taylor instability

$$h = \alpha A \left[\int \sqrt{g} dt \right]^2$$

- Richtmyer-Meshkov instability

$$h = \alpha_{RM} (U t)^\beta h_o^{1-\beta}$$

Used to test mix models and simulation codes

Basic understanding required to scale to applications

MX_03

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Investigate shock induced hydrodynamic (Richtmyer-Meshkov) instability at interface between two fluids at high compression

- Strong radiatively driven shocks

Shaped Nova pulse

Foam tamper

- Planar geometry for radiography

Face-on & side-on

- Seed perturbations at interface

Single mode

Multi-mode

Random

$$A = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} < 0$$

Test linear theory, full hydrodynamic simulations and models

RM_02

Configuration for Nova Richtmyer-Meshkov Experiments

Face-on
Streaked
Radiograph

Side-on
2D Gated
Radiograph

V (5 keV)
Backlighter

Side-on Streaked Radiograph

APS_04

CALE simulations (2D) reproduce measured growth of single mode

Agar tamper, high drive, $\lambda = 100 \mu\text{m}$, $\eta_0 = 10 \mu\text{m}$

Fourier analysis of face-on & side-on radiographs

APS_06

Growth rates from Nova and CALE agree for a variety of conditions

$\eta_0 < 0.15 \lambda$, growth rate proportional to $A k U \eta_0$ (impulsive models)

$\eta_0 > 0.15 \lambda$, growth rate limited to $15 \mu\text{m/ns}$ ($V_2 - U$)

RM_08

Experimental linear growth rates ($\eta_0 < 0.15 \lambda$)

agree with Meyer-Blewett model for $A < 0$

Meyer-Blewett model ($A < 0$)

$$\frac{d\eta}{dt} \sim A^* k U \frac{\eta_0 + \eta_0^*}{2}$$

Richtmyer model ($A > 0$)

$$\frac{d\eta}{dt} \sim A^* k U \eta_0^* > 0$$

$$\eta_0^* / \eta_0 \sim (1 - U/V_1) < 0$$

HIGH COMPRESSION (Mach > 3) required for models to obtain different sign of growth rate

RM_09

Perturbation spike cannot overtake transmitted shock without causing significant drag & nonlinearities

For perturbation spike to remain behind transmitted shock

$$U + d\eta/dt < V_2$$

Growth rate limit at large amplitude

$$A^* k U \eta_{\text{eff}}^* < V_2 - U$$

Affects experimental design on Nova

May be important for multiple shocks

RM_11

Figure 5: (a) Experimental configuration and (b) ablator

Figure 6: Side-on radiographs and x-ray transmission profiles

Figure 7: Side-on images and x-ray transmission profiles from 2D CALE simulation

Turbulent mix width obeys power law scaling
consistent with bubble merger or dynamic scale model

* Power law observed

$$h \sim (U \delta t)^\beta$$

$$\beta \sim 0.6 \pm 0.1$$

* Dynamic scale model

$$dh/dt \sim A k U h_o$$

$$\langle k h \rangle \sim \text{constant}$$

$$h \sim (A h_o U \delta t)^{0.5}$$

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- Test mix scaling laws

$$h = \alpha A \left[\int \sqrt{g} dt \right]^2$$

$$h = \alpha_{RM} (U t)^\beta h_0^{1-\beta}$$

- Linear electric motor (LEM)

Variable acceleration

Turbulent ($L > D \gg \lambda_{min}$)

Incompressible

- Optical diagnostics

LEM_02

Figure 10: Axial view of LEM (a) and close-up view of cell (b,c)

40908-09C1: Increasing g

40908-10C1: Decreasing g

40908-12C1: Constant g

40916-10C1: Impulsive g

Bubble penetration with constant acceleration

Bubble penetration proportional to displacement

$$h = \alpha A g t^2$$

$$\alpha \sim 0.06$$

ALE simulations yield

$$\alpha \sim 0.044$$

Bubble penetration with impulsive acceleration

$$A = 0.22 \quad g \sim 700 g_0 \quad Z_0 \sim 17 \text{ cm}$$

$$h \sim h_0 (Z/Z_0)^\beta$$

$$h_0 \sim 2 \alpha A Z_0$$

$$\alpha \sim 0.06$$

$$\beta \sim 0.5$$

Mix experiments test models and simulations

- Single wavelength RM experiments (Nova) find 2 regimes

$k\eta_0 < 1$: growth rate consistent with
Meyer-Blewett for $A < 0$

$$\frac{d\eta}{dt} \sim A^* k U \frac{\eta_0 + \eta_0^*}{2}$$

$k\eta_0 > 1$: growth rate approaches limiting value ($V_2 - U$)

- RM experiments (Nova) with 3D random perturbations find

$$h = \alpha_{RM} (U t)^\beta h_0^{1-\beta}$$

$$\beta \sim 0.6 \pm 0.1$$

- LEM for arbitrary acceleration profiles & detailed diagnosis

$$h \sim 0.06 A \left[\int \sqrt{g(t)} dt \right]^2$$

$$h \sim (U t)^{0.5}$$

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