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Author(s): Sridhar Balasubramanian, Kathy P. Prestridge, Gregory C. Orlicz and Balakumar J. Balasubramaniam

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Influence of Initial Conditions on Turbulence and Mixing in Richtmyer-Meshkov Flows in Presence of Re-shock[1]

Sridhar Balasubramanian, Katherine P. Prestridge, Gregory C. Orlicz and Balakumar J. Balasubramaniam

Extreme Fluids Team, Physics Division, Los Alamos National Laboratory
Los Alamos, NM, 87545, USA

sridharb@lanl.gov

The study of influence of initial conditions [amplitude (δ) and wavelength (λ) of perturbations] on variable-density flows stems from the the recent work done by *Dimonte et al. 2004* [1], *Miles et al. 2005* [2] and *Balakumar et al. 2008a* [3], where it was shown that both Richtmyer-Meshkov (R-M) and Rayleigh-Taylor (R-T) turbulent flows are not truly self-similar and have a strong initial conditions dependence on turbulence transport and mixing. However, so far most of the work on this topic has been numerical studies ([2], [4], [5], [6]) which suggest that for multi-mode systems, the emergence of a regime of self-similar instability growth independent of the initial conditions does not occur. Experimental evidence is needed to verify this theory. Thus, the present work focuses on conducting an experimental study at moderate Mach number (Ma=1.2) to understand the effects of multi-mode perturbations of the shocked interface on instability growth rate and mixing for R-M flows, which are important mechanisms in inertial confinement fusion reactions, supernovae, combustion and general fluid mixing processes. The ongoing 3-D numerical simulations using ILES will be used for validation of our experimental results.

The experiments to study R-M turbulence and mixing are carreid out at the Los Alamos Gas Shock Tube facility shown in Figure 1 and described in detail in *Balakumar et al. 2008b* [7]. A heavy gas curtain of SF_6, surrounded on both sides by ambient air, representing a light/heavy/light interface is flowed through a varicose nozzle (shown in Figure 1c). This initial interface is then accelerated by a Mach 1.2 shock, generated in the driver section. Simultaneous Particle Image Velocimetry (PIV) and Planar Laser Induced Fluorescence (PLIF) diagnostics are used to characterize the initial conditions and also image the evolving flow to measure instantaneous velocity and density fields. The evolving structures are re-shocked at various times using a moveable reflecting wall to study the initial condition effects on turbulence and mixing. Mean flow fields are averaged from an ensemble of experiments whose initial density fields correlate to within 97% of each other. From the mean field, the fluctuating quantities are determined, and the density self-correlations and density-velocity correlations are calculated.

In order to determine the effects of initial conditions on the mixing and turbulence in R-M flows, we performed experiments varying both the amplitudes and wavelengths present in the initial conditions. The wavenumbers ($n=2\pi/\lambda$) present in the initial conditions can be characterized using a power spectrum of the density field, which shows a changing distribution of modes over time for the singly-shocked gas curtain. Another metric that is important to study the effect of initial conditions is the dimensional length-scale, a, defined as

$$a = \kappa\delta, \quad where\, \kappa = \sqrt{\frac{\langle \nabla\rho\nabla\rho \rangle}{\langle \rho\rho \rangle}} \qquad (1)$$

In equation (1) κ is the zero crossing wavenumber, which is a measure of the frequency of density gradients at the centerline of the interface. A plot of power spectra of the density fields and the dimensional length-scale, a, is shown in Figure 2. From this figure there

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is an evidence of multi-modal distribution of wavenumbers at time $t \approx 230 \mu s$, indicating that re-shocking of morphologies after this time may lead to considerable mixing and transition to turbulence. We conducted re-shock experiments by varying the end wall position, thus altering the re-shock timing and the nature of the interface just before re-shock. The results of three different gas curtain experiments, with re-shock times of t=170 μs (a), 385μs (b) and 600 μs (c), are shown in Figure 3. As we re-shock the morphology at different times the value of the dimensional lengthscale, *a*, increases with each re-shock time. Figure 3 shows a clear variation in the appearance of the late-time turbulent structures of the density field after re-shock, with indication of transition to turbulence for cases (b) and (c) and no such transition for case (a), where the dominant wavelegth is still preserved. These results indicate that there may be a critical value of dimensional length-scale, *a*, for which R-M flows will transition to turbulence. The post processing statistics such as turbulent kinetic energy (k), Reynolds stresses (R_{ij}) and probability density functions of the fluctuating quantities at different times will be helpful to quantify the observable differences in the turbulence.

As a next step, we will conduct similar re-shock experiments by changing the configuration of the primary initial conditions using the alternating nozzle shown in Figure 4a, for which the initial wavelength is twice that of the varicose nozzle configuration ($\lambda_2=2\lambda_1$) while the amplitude, δ, is the same. A time series of the evolution of structures after first shock for the alternating nozzle configuration is shown in Figure 4b. The re-shock experiments will be conducted at two different times, t=170 μs and t=385μs and the results of these experiments will be compared with those of the varicose nozzle case. We believe that this study will help us better understand the predictability of the late-time flow, and dependence of the intial condition configuration, based on dimensional length-scale (*a*) parameter, on turbulence.

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Figure 1. (a) Schematic of the LANL Gas Shock Tube facility. (b) Illustration of the PIV and PLIF diagnostics to image the initial conditions and flow evolution. (c) Varicose nozzle with primary amplitude δ= 3mm and wavelength λ=3.6mm.

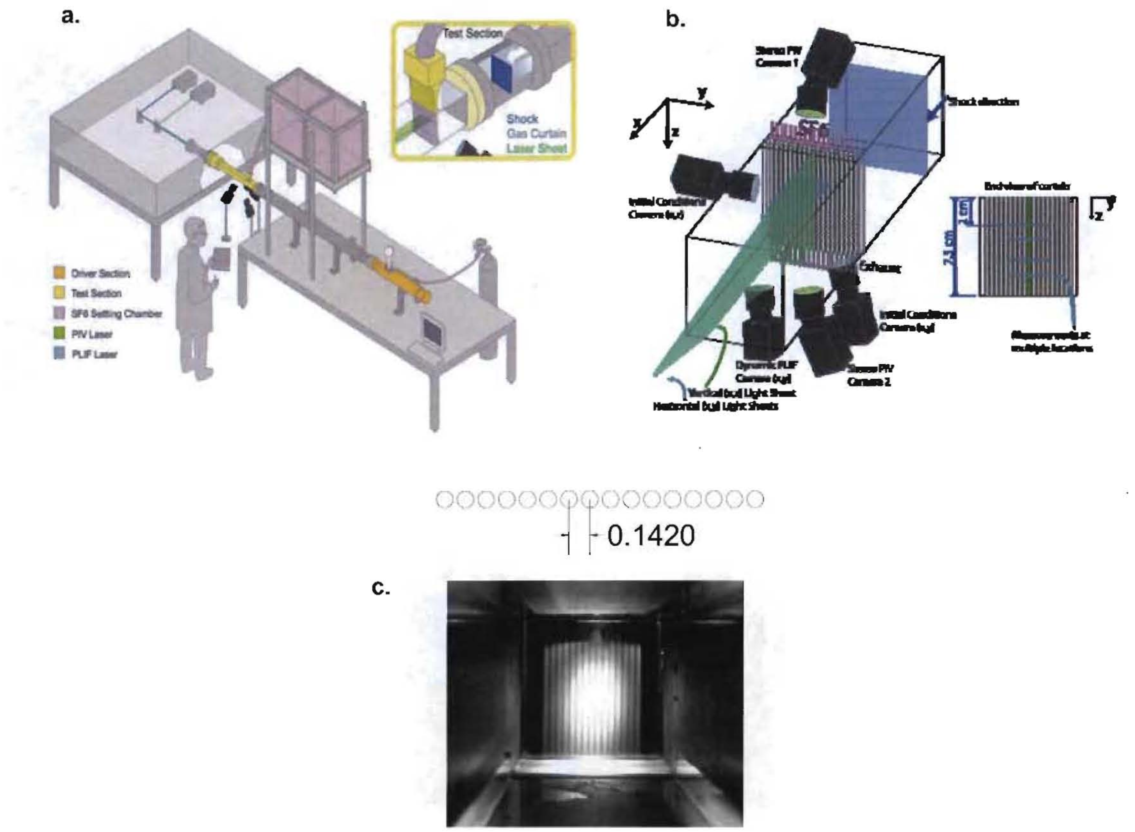


Figure 2. (left) Power Spectral Density plot of density fields and (right) A plot of dimensinal lengthscale ($a=\kappa\delta$) of developing structures after first shock.

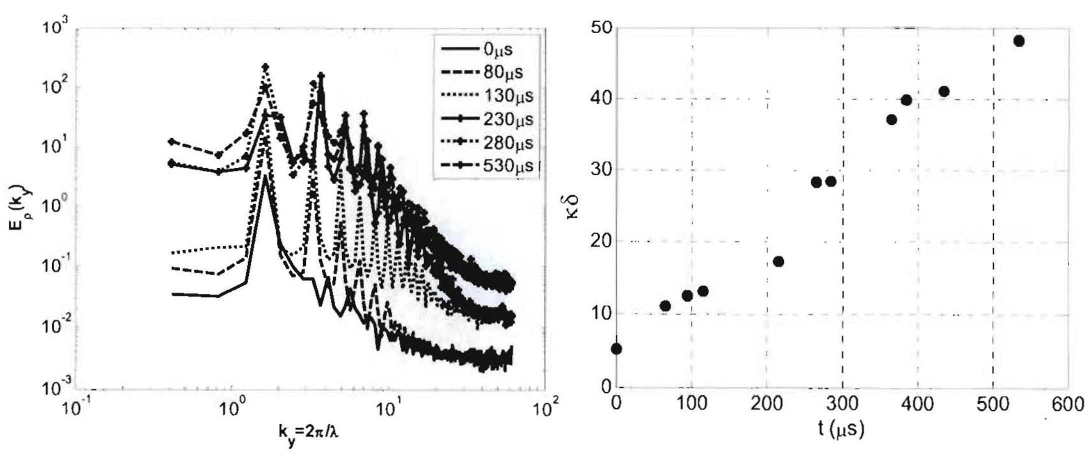


Figure 3. Instability grwoth at Mach 1.2 for three different re-shock times (a) - 170μs, (b) - 365μs and (c) - 600μs. The blue line indicates the re-shocked structures. White region indicates SF_6, and black region indicates air. Initial condition's correspond to time t=0 μs.

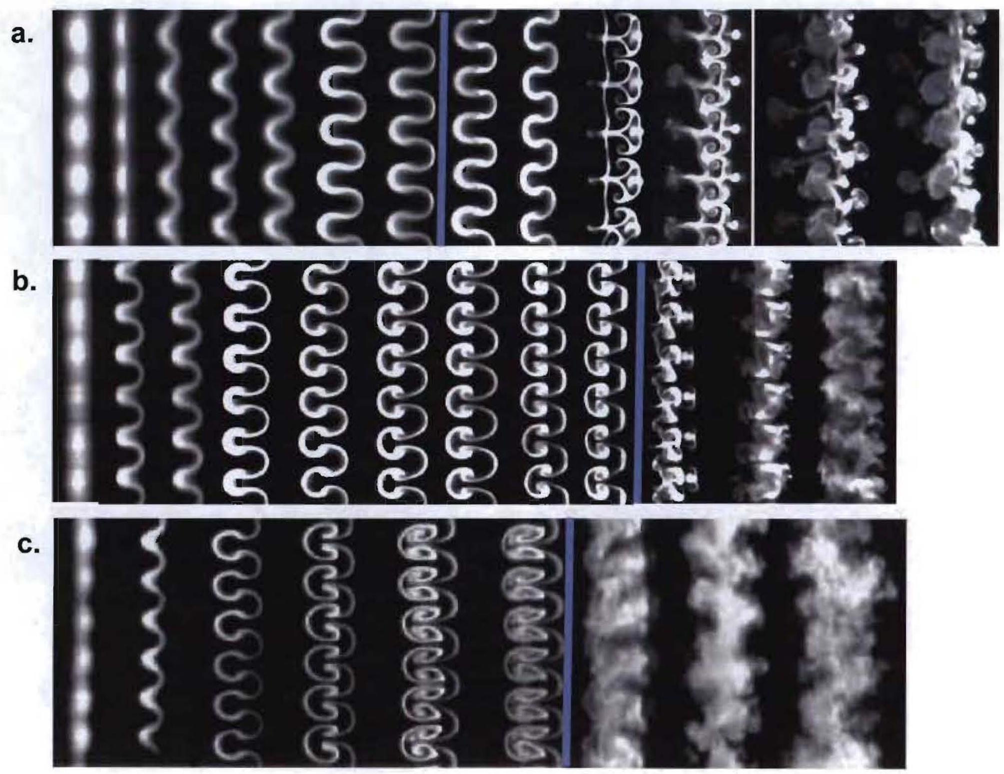
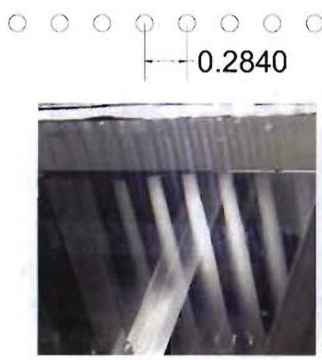
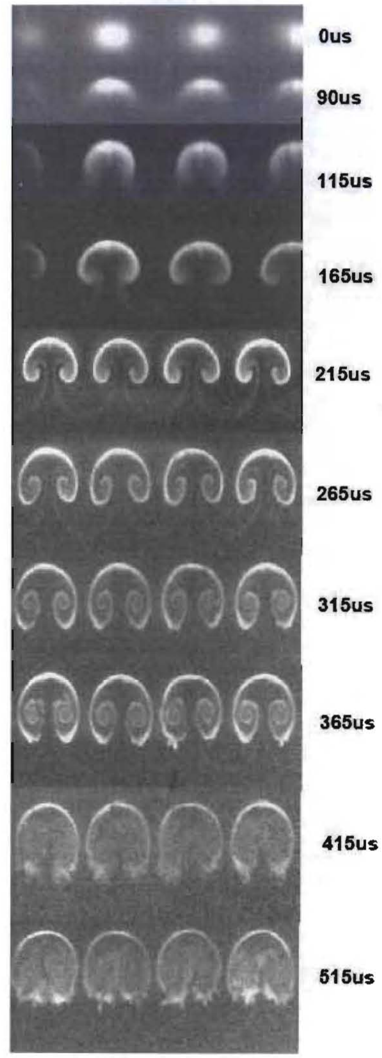


Figure 4. (a) - Alternating nozzle with primary amplitude δ= 3mm and wavelength λ=7.2mm.
(b) - Time evolution of R-M instability for the alternating nozzle configuration.



a.



b.