EFFECTS OF INITIAL CONDITIONS AND MACH NUMBER IN THE EVOLUTION OF RICHTMYER-MESHKOV INSTABILITIES

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Abstract We present an experimental study of the effects of shock intensity and initial conditions on the evolution of Richtmyer-Meshkov Instabilities (RMI). This study is carried out in a vertical shock tube with a single interface of sulfur-hexafluoride and air. We use combined particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF) to obtain simultaneous measurements of velocity and density. These measurements enable us to determine single- and multi-point statistics of vector, scalar, and combined fields. We use these statistical descriptors to study the evolution of turbulence mixing in RMIs under different Mach numbers and initial conditions.

DESCRIPTION

A Richtmyer-Meshkov Instability (RMI) takes place when a shock wave interacts with the interface between two fluids of different density. Misalignments between the density gradient across the interface and the pressure gradient of the shock wave deposit baroclinic vorticity that amplifies initial perturbations in the interface. The interface evolves after this interaction starting with an initial linear growth of instabilities, followed by a non-linear growth, and given the appropriate conditions, transitioning to decaying turbulent mixing. The Mach number of the shock, the modal distribution of perturbations in the interface prior to shock interaction, and the density ratio are determining factors for the evolution of the RMI. Common examples of RMIs are supernova explosions, collapsing gas bubbles in liquids, supersonic and hypersonic combustion, interacting flame fronts and pressure waves, laser-matter interactions, and inertial confinement fusion (ICF). The effects of RMI-induced mixing are detrimental to energy conversion efficiency in ICF, but can be advantageous in combustion processes, and help understanding the way supernova explosions distribute matter in the universe. A deep understanding of the physical phenomena behind RMIs is critical, either to understand the consequences behind the natural events in which it is present, or to attempt to control its effects in technological applications.

After shocking two-mode varicose curtains of heavy gas with a large degree of separation of scales, Balasubramanian et al. [1] observed that the initial separation of scales remained apparent at late times, without transitioning to turbulent mixing prior to reshocking the growing instability. In contrast, Weber et al. [5] shocked a multi-scaled single-interface configuration and observed transition to turbulent mixing at late times without reshocking the interface. These contrasting observations suggest that the degree of separation of scales might be instrumental on transition to turbulent mixing prior to reshock. Using 2D simulations of RMIs, Tritschler et al. [4] observed that their broadband initial conditions (ICs) would give place to a classic turbulent cascading at late times of the evolution. Weber et al. [5] also observed this effect despite the fact that their ICs are significantly different than those of Tritschler et al. [4], giving support to the idea that broadband ICs will lead to classical cascading regardless of the particular details of the interface.

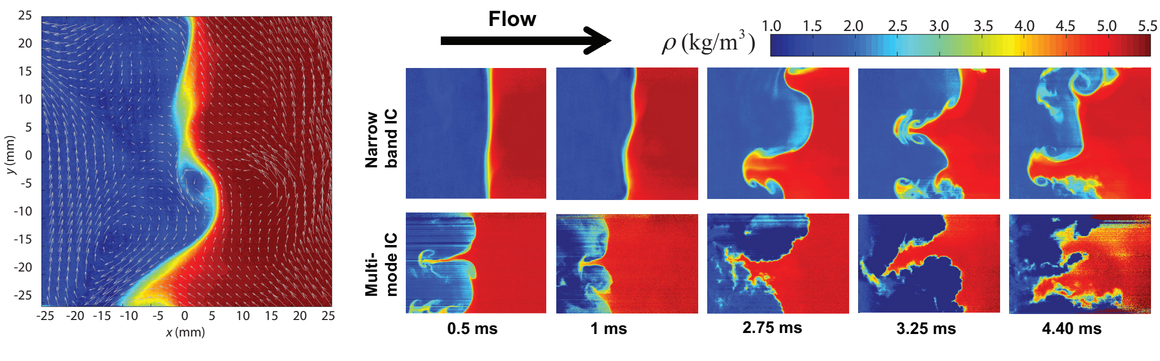

Figure 1. Left: Typical example of a simultaneous measurement of velocity (vector field) and density (contour map) at the initial conditions before shock. Right: Examples of the evolution of two initial conditions shocked at M=1.3. The top series is for a narrow-band initial condition and the bottom series is for a multi-mode initial condition. Each column represents a different stage of evolution after shock interaction. Only contour maps of density are shown for simplicity.

Experiments with single [2] and double interface [3] RMIs suggested that the Mach number would induce differences in the evolution of the interface due to variations in: the degree of compression of the initial conditions, the amount of vorticity deposited, and the refraction of the incident shock through the interface(s). These studies suggest that results for

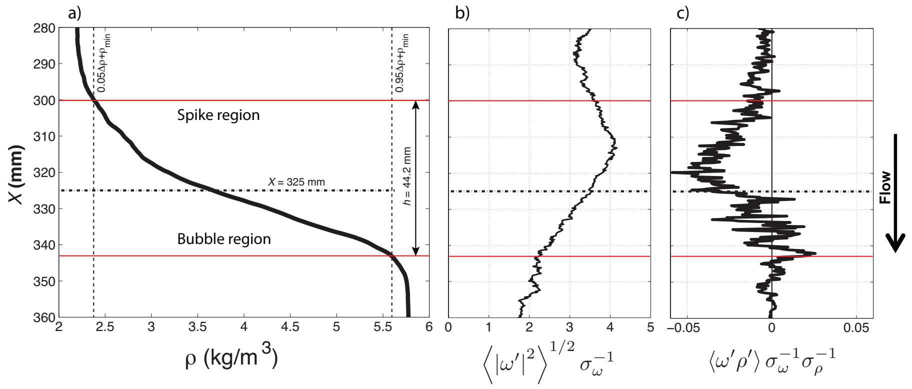

Figure 2. Some statistical descriptors for a multi-mode air-SF_6 interface shocked with a M=1.3 shock wave. The instantaneous realizations used to obtain these results were acquired around 3.25 ms after interface-shock interaction (see figure 1 for reference). All plots were calculated taking and ensemble average followed by a spanwise average of 100 instantaneous realizations of a) density fields, b) rms vorticity, and c) cross correlation of vorticity and density fluctuations. — average profile, — limits of the mixing region (5% to 95% rule), –·– position of center of mass of mixing region.

different Mach numbers can be made to collapse upon using the appropriate scaling (convective velocity and post-shock thickness), provided the initial conditions are consistent. Variations in the ICs lead to markedly different scalings [1].

In this work, a single-interface configuration is used to assess the effect of Mach number and ICs configuration on the development of RMIs. The facility used for this purpose is a vertical shock tube (VST) equipped with high resolution synchonized particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF). These diagnostics enable simultaneous measurements of velocity and density fields (see figure 1 for a typical example). The interface is generated by means of a transverse co-flow of air and sulfur-hexafluoride (SF_6) across the shock tube. This interface is perturbed by mechanical forcing and/or imposed differences in flow velocities. This VST exhibits high repeatability in generating initial conditions and shock strenght, enabling studies of mixing evolution with a full characterization of velocity and density fields. Single- and multipoint statistical descriptors for scalar, vectorial, and combined fields will be used for detailed assessments of turbulent mixing in RMIs.

Figure 1 presents a time-sequence generated with instantaneous realizations of velocity and density fields at different positions from the location of the ICs (only contour maps of density are shown for simplicity). These events were generated with the interaction of M=1.3 shock waves and two different ICs. The top row in figure 1 was generated with a narrow-band IC and the bottom row was generated with a multi-mode IC. Figure 2 presents some turbulence descriptors of the multi-mode IC case after the interface evolves for a time of 3.25 ms. These descriptors were calculated by ensemble averaging and then spanwise averaging one hundred instantaneous realizations acquired at $x = 325\,\mathrm{mm}$ from the initial position of the interface. The average density curve (figure 2a) shows an asymmetry between the upstream and downstream sides of the interface with reference to its center of mass. These regions are named spike and bubble regions respectively, according to the dominant events that take place in each one of them (see figure 1 for reference). Figure 2b shows the rms vorticity. The asymmetry in this curve suggests that enstrophy interactions are more important in the spike region than in the bubble region, suggesting that mixing is predominant in the light-fluid side. Figure 2c shows the cross-correlation of vorticity and density fluctuations. Its asymmetry suggests also that mixing is enhanced in the spike region. The obvious negative correlation indicates that entrainment of heavy fluid decreases rotation rate and that entrainment of light fluid increases the rotation rate, a result that follows from conservation of angular momentum.

References

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