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Shock–Accelerated Heavy Gas Layers*

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We describe experimental results and analyses of the shock-accelerated flow of a heavy gas layer embedded between lower-density gases. References [1, 3] contain detailed descriptions of the experimental results, the experimental techniques, and simple analytic models. A forthcoming publication [4] describes computer simulations that accurately describe the observed flows, and other computational work has been reported [5]. This report summarizes the experimental study.

The SF_6 layer forms a "gas curtain" with perturbed interfaces on both sides. As the planar shock wave accelerates the upstream air-SF_6 interface, interfacial perturbations grow because of the Richtmyer-Meshkov (RM) instability. Subsequently the downstream SF_6 air interface undergoes RM instability as it interacts with the transmitted shock wave. Thus, both upstream and downstream interfaces are RM unstable. However, this nonlinear fluid instability is more complex than the flow of a single interface or two decoupled interfaces undergoing Richtmyer-Meshkov instability. The observed complex flows involve the production, coupling and transport of vorticity in a system sensitive to initial conditions. The experiment observes the nonlinear growth of two nearby interfaces subjected to Richtmyer-Meshkov instability, where the interface dynamics are coupled. The resultant flow into one of three flow "families" is a distinct feature of thin-layer instability that is not observed in the instability of a single interface.

The interfacial perturbations grow, distort and interact. Nearly sinusoidal perturbations having a varicose profile are initially imposed on the interfaces. The three dynamic post-shock flow patterns are identified descriptively as: "upstream mushrooms," "sinuous", and "downstream mushrooms." An upstream mushroom pattern develops when the initial perturbations on the upstream side (i.e., the side first interacting with the

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shock wave) are larger than the perturbations on the downstream side. A sinuous pattern forms when the initial perturbations on the downstream side are about the same amplitude or slightly larger than upstream side. A downstream mushroom develops when the perturbation on the downstream side is much larger than the perturbation on the upstream side.

This experiment identifies phenomena that may occur during inertial confinement implosions. The thin fluid layer in these experiments is analogous to a molten shell of an inertial-confinement capsule. The ablative plasma is a lower-density fluid on one side of the layer and the fuel gas is a lower-density fluid on the other side. Thus, this experiment demonstrates fluid dynamics that may occur in such applications. In addition, this experiment is intended to provide benchmark data for validating computer codes intended to simulate highly distorted, impulsively driven flows, and recent work [4, 5] clearly demonstrates the value of these experimental results as a benchmark for code development. The experiments are also useful for engineering impulsively-driven interfaces at which inter-fluid mixing must be controlled.

The heavy gas layer is a "gas curtain" produced by a vertically flowing stream of SF_6 gas within the test section of a shock tube. A horizontal laser sheet illuminates a two-dimensional cross-section of the flow, and a cooled CCD camera captures two Rayleigh-scattering images of initial and post-shock flow profiles. Earlier work used a fluorescent tracer mixed with the SF_6 to image the 2D cross-section of the flow, and both sets of experiments observe the same flow patterns. The innovative combination of the gas curtain and laser sheet imaging enabled the experimental discovery of the three families of flow patterns. Attempts to detect these phenomena with conventional shadowgraphy were unsuccessful. Future work is intended to capture more than two images per event in order to measure the growth rates.

We can interpret the observations in terms of the baroclinic vorticity produced by the interaction of the planar shock wave with the perturbed interfaces. When the perturbation amplitude is greater on one side of the layer, more vorticity is generated on that side because it is generated at the interface where pressure and density gradients are most misaligned. The vorticity is preferentially deposited in the lighter fluid (air) because of the density dependence of baroclinic vorticity production. Mushrooms form on the side with the largest initial perturbation because the heavy fluid (SF6) is asymmetrically entrained into the side with the most vorticity. The flow is complicated by the wave dynamics of the shock wave traversing the heavy layer. A series of reverberating waves of successively decreasing strengths is generated within the heavy layer. Fluid simulations show the importance of these multiple waves and their interactions. These waves deform to the extent that they create transverse waves that run along the layer. The entrainment and roll-up suggests that interfacial mixing is greatest in the case of downstream mushrooms because the shear flow is greatest for this flow pattern.

In summary, these experiments show impulsively-driven flow instabilities that may occur in inertial confinement systems, and they provide a valuable benchmark for fluid simulations.

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