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Evolution of Perturbations in Shocked Fluid Layers*

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Abstract. We present analytical and numerical studies of the RM instability in finite- thickness fluid layers for which experimental data has been recently available.

1 Introduction

We present analytical and numerical studies of the RM instability in finite-thickness fluid layers for which experimental data has been recently available.[1] They involve a layer (gas curtain) of SF_6 driven in a shock-tube, an A/B/A configuration for which we had derived an analytic expression[2]

$$\eta_1(\tau) = \eta_1(0) + \frac{\Delta v \Gamma^2}{\cos(\theta)} \left[\eta_1(0) - \sin(\theta)\eta_2(0)\right] \tau, \tag{1}$$

$$\eta_2(\tau) = \eta_2(0) + \frac{\Delta v \Gamma^2}{\cos(\theta)} \left[\eta_2(0) - \sin(\theta)\eta_1(0)\right] \tau. \tag{2}$$

Here τ stands for time and η_1 and η_2 refer to the first and second interface perturbations which are shocked in that order; i.e., interface 1 is the upstream side of layer B and interface 2 is its downstream side. The definitions of the other quantities are given in Ref. [2].

Three different patterns were observed in the experiments: "sinuous" (S for short), "upstream mushroom" (UM), and "downstream mushroom" (DM). S is found to result from varicose (V) initial conditions which, in our notation, can be described as $\eta_1(0) = -\eta_2(0)$. UM is found to result from $\eta_2(0) = 0$, and DM results from $\eta_1(0) = 0$.

Equations 1,2 were derived by applying Richtmyer's technique to a finite-thickness fluid layer. The *form* of Eq. 1,2 is enough to explain qualitatively the behavior described

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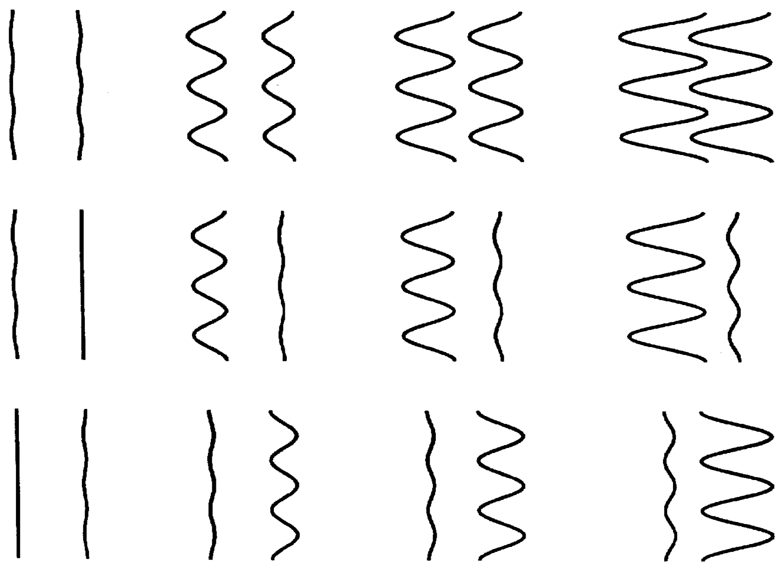

Figure 1: Evolution of S, UM, and DM in SF_6 gas curtains calculated from Equations 1,2.

above: When $\eta_1(0) = -\eta_2(0)$ (initially varicose or V) we have $\dot{\eta}_1 = \dot{\eta}_2$ for any value of $\sin(\theta)$ or Γ^2. This implies that the initial perturbations will evolve into an S pattern. When $\eta_2(0) = 0$ we have $\dot{\eta}_2 = \sin(\theta)\dot{\eta}_1$ which implies that as η_1 grows so will η_2 with the same sign, albeit slower. Similarly, when $\eta_1(0) = 0$ we have $\dot{\eta}_1 = \sin(\theta)\dot{\eta}_2$ which implies that as η_2 grows so will η_1, slower but again with the same sign. The last two cases describe the early stages of UM and DM respectively. In Fig. 1 we plot the above three cases using Eq. 1,2. Details can be found in Ref. [3].

We now turn to numerical simulations with Livermore's two-dimensional hydrocode CALE. A Mach 1.2 shock in air drives an SF_6 layer with density perturbations at one or both interfaces. To compare with the experimental results we show in Fig. 2 the initial configurations and the late time configurations for all three cases discussed above. The times for the late snapshots were chosen following Fig. 1 of Ref. [1], with which our Fig. 2 must be compared. Clearly, there is very good agreement with the experimental results.

We have not yet discussed a fourth and perhaps most natural and interesting case: $\eta_1(0) = \eta_2(0)$, i.e., an initially sinuous configuration. Just as Eq. 1,2 implied that $V \rightarrow S$, it also implies that $S \rightarrow V$, a conclusion which can again be deduced purely from the form of Eq. 1,2 because when $\eta_1(0) = \eta_2(0)$ we have $\dot{\eta}_1 = -\dot{\eta}_2$ for all θ and

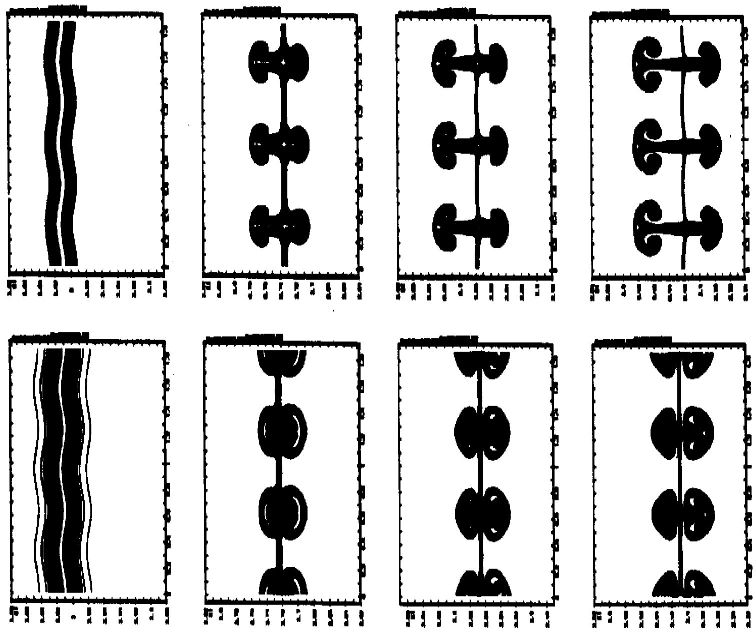

Figure 2: CALE calculations of the SF_6 gas curtain experiments reported in Ref. [1].

Γ^2. This is the one case where the growth rates have opposite sign.

Experiments with an initially sinuous configuration have not been performed. Our predictions for such experiments are shown in Fig. 3 for both an SF_6 and a Helium gas curtain. We see that opposite mushrooms (OM) develop for both gases. Note that the Helium case is shifted by $\lambda/2$ relative to the SF_6 case (the same happens with S, DM, and UM configurations) and indeed Equations 1,2 can be used to evolve the Helium case analytically and explain the shift of the pattern by $\lambda/2$ (See Ref. [3]).

In conclusion, Eq. 1,2 can be used to understand analytically, but not quantitatively, the evolution seen in the experiments and to predict new patterns associated with new initial configurations. Full code calculations are necessary to account for nonlinearity, compressibility, and density gradients, elements missing from Eq. 1,2. Our code calculations (Fig. 2) agree well with the experiments. A new pattern, OM, is predicted to evolve from initially sinuous SF_6 or Helium layers (Fig. 3). Code calculations for other configurations, including reshock, are given in Ref. [3]. We hope these predictions can be verified in future experiments.

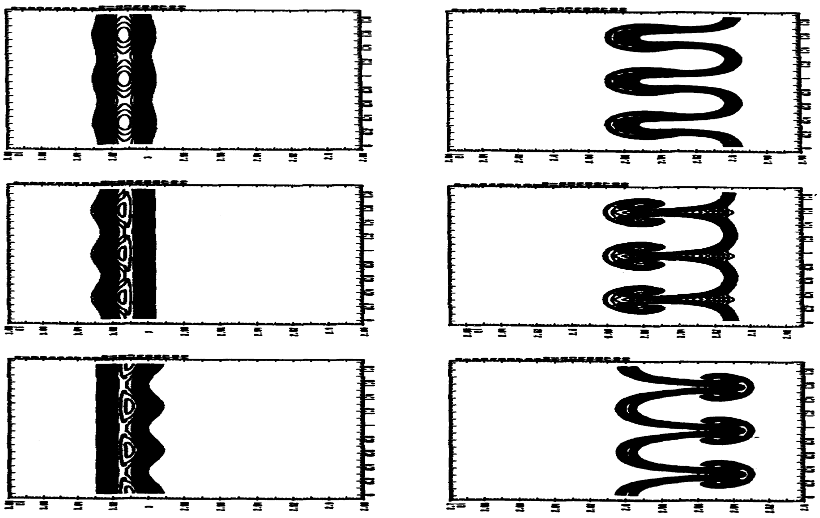

Figure 3: CALE predictions for the evolution of SF_6 (upper row) and helium (lower row) gas curtains into opposite mushrooms (OM).

References

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