Experimental Investigation of Shock-Interface Interactions

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Abstract

A DOUBLE – DIAPHRAGM shock tube is used to study the evolution of the interface between two gases. The thickening of the corresponding contact zone is measured during the two phases of its evolution, i.e., before and after its interaction with the reflected shock on the end wall of the tube. Recording the infrared emission of one of the gases (CO_2) monitors this evolution by quantitatively determining the thickening of the turbulent mixing zone before and after the interaction with the reflected shock wave. In the same way, the variation of a characteristic quantity (the product of the pressure vs the vibrational energy of CO_2) can be measured through this zone. The parameters most responsible for the thickening of the mixing zone are examined, that is, the intensity of the deceleration and the Atwood number of the gas combination.

Contents

Experimental Arrangement and Procedure

The experiments were performed in a double-diaphragm shock tube with two gas combinations, $H_2/CO_2/He$ and $H_2/CO_2/A$. The interface of CO_2/He or CO_2/A is of interest here. Hydrogen is used as the driving gas to easily obtain a large Mach number range in the CO_2 chamber. Carbon dioxide is used in the second chamber because of its important infrared radiation, the intensity of which is measured through the mixing zone during its expansion into the third chamber.[1] Rare gases are used in this third chamber to obtain a "regular reflection" of the incident shock wave on the end wall.[2] The gases (helium or argon) used result in different Atwood numbers and sound velocities, so the influence of these parameters on the behavior of the contact zone CO_2/He (or CO_2/A) can be analyzed.

The shock tube has a square cross section (8.5×8.5 cm^2). CO_2 and He (or A) are initially separated by a Mylar film (19 μm thick). The residual pressure is less than 10^{-3} Torr. The tube is carefully cleaned after each experiment. Calcium fluoride windows allow the measurement of the intensity of the i.r. emission coming from the asymmetric vibrational mode of CO_2 (wave length centered on 4.3 μm) by photovoltaic InSb detectors centered on 4.6 μm and cooled with liquid nitrogen. These detectors are calibrated with the same CO_2 radiation behind a shock wave of known strength. Thus, assuming vibrational equilibrium,[3] the quantity (pEv_3) of the CO_2 gas can be measured through the mixing region, p and Ev_3 respectively representing the pressure and the energy per unit mass of the asymmetric mode. In the conditions of the present experiments, the dissociation of CO_2 can be neglected. The velocity of incident and reflected shocks are deduced from traces given by the platinum heat-transfer gages placed along the tube.

For each experiment, a one-dimensional ideal wave diagram is computed by a classic method of characteristics assuming equilibrium and a start from the measured Mach number in chamber 2. (See Fig. 1.) The Mylar film is sufficiently thick so that a complete reflection of the incident shock in the CO_2 chamber is expected and corresponds to the experimental results. Furthermore, there is no detectable initial film curvature at the origin of a curvature at the front of the contact zone.

Experimental Results

The results of a typical experiment CO_2/He are represented on the records of Fig. 2, where S_1 and S_2 are the traces of the thermal gages and E_1 and E_2 those of i.r. detectors, each pair (E,S) being placed at the same abscissa along chamber 3. The passages of the incident i and reflected r shocks are clearly visible on traces S_1 and S_2 and the arrival of the contact fronts on traces E_1 and E_2. The incident mixing region can be observed on E_1 and the mixing region after its interaction with the reflected shock on E_2.

Thus, on E_1 (Fig. 2a), the rise time $1 \rightarrow 2$ (~ 40 μs) corresponds to the passage of the incident mixing zone CO_2/He. After a plateau $2 \rightarrow 3$ (~ 40 μs), the signal increases

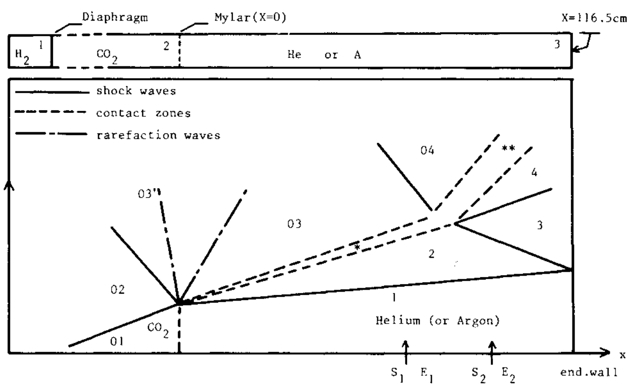

Fig. 1 Shock tube and (x,t) general diagram.

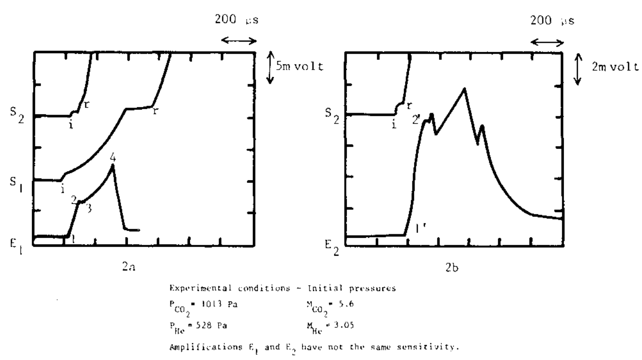

Fig. 2 Examples of oscillographic records.

Received Oct. 29, 1984; synoptic received Jan. 14, 1986. Full paper available from National Technical Information Service, Springfield, VA 22151, at the standard price (available upon request).

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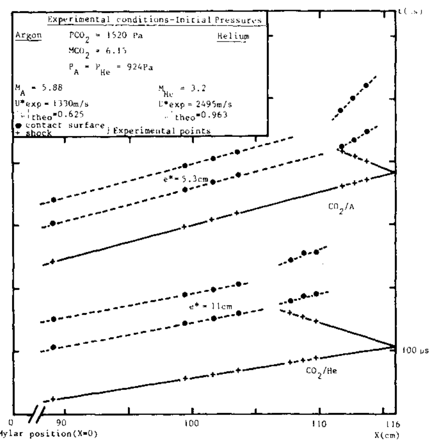

Fig. 3 *(x,t)* diagram and $(pEv_3)_{CO_2}$ evolution for CO_2/He and CO_2/A.

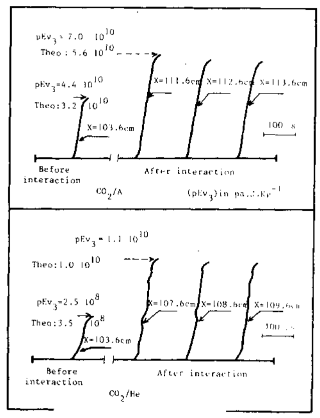

Fig. 4 Comparison between CO_2/He and CO_2/A contact zones.

again due to rarefaction waves arising when the film is destroyed. Then, point 4 indicates the arrival of the driver gas H_2 and point 5 the passage of the reflected shock. Infrared radiation coming from the film or residual impurities is negligible, as verified in blank testing. The velocity of the incident contact front U^*, measured at four abscissa along chamber 3 is practically constant for the considered cases.

The emission coming from the mixing zone CO_2/He, after its interaction with the reflected shock, is clearly visible on the trace E_2 (Fig. 2b: part $1' \rightarrow 2'$). The rise time is larger than before the interaction (~ 100 μs) and, thus, the relative thickening of the mixing zone is evident. Within the limit of the present experiments, the velocity of the contact front after the interaction can also be considered as constant.

For comparison, the experimental evolution of the CO_2/He and CO_2/A mixing zones is represented in Fig. 3 for the same conditions in the CO_2 chamber and the same initial pressure for He and A. Similarly, the corresponding evolution of the pEv_3 profiles of CO_2 across the mixing zones is represented in Fig. 4.

Discussion

As indicated above, the velocity of the incident contact front in the third chamber quickly becomes quasiconstant and the average thickness of the incident contact zone very slowly increases in each considered case (Fig. 3). However, the shape of the contact front itself changes along the tube (profiles of pEv_3, Fig. 3b), due to the growth in the turbulent instabilities within the mixing region.[4,5]

The growth rate of these instabilities depends on the Atwood number of the gas combination μ and the acceleration (or deceleration) rate of the interface.[6,7] Thus, in light of the present experiments, the following points can be noted. For the same initial conditions (see above), the lighter the driven gas is (He case), the faster the contact front velocity U^*, the larger the Atwood number, and the more important the diffusion. Thus, for the He case, one obtains a thick mixing region and large turbulent fluctuations, particularly at the contact front. The product μU^* is, in this case two to three times larger than in the CO_2/A case. For this case, the incident mixing zone is narrower and the shape of the contact front is more homogeneous (Fig. 4).

The thickening of the mixing region after the interaction with the reflected stock has been observed[8] previously. Furthermore, the present results indicate a quasilinear growth and a thickening that is much more important for CO_2/A than for CO_2/He, contrary to the incident mixing region. This is due to the fact that the deceleration is more pronounced in the CO_2/A case and thus becomes the predominant parameter. This deceleration comes from the existence of a "tailoring" shock Mach number not too far from the experimental conditions (~ 3). On the other hand, no tailoring exists for CO_2/He, so the interaction is weaker. This effect is also amplified by the fact that the incident contact zone CO_2/He is thicker than that of CO_2/A, which weakens the corresponding interaction with the reflected shock. However, the contact front remains more unstable for CO_2/He, as it was before the interaction (Fig. 4).

Conclusions

The present results show that the relatively thin incident contact region of CO_2/A thickens when decelerated by the reflected shock. On the other hand, the initially thick CO_2/He interface is weakly slowed by this shock and somewhat thickens, but remains more unstable and less homogeneous than the CO_2/A interface. A systematic study of the turbulent diffusion arising from successive cycles of acceleration and deceleration of a gaseous interface remains to be done. Furthermore, quantitative values of the mean parameter (pEv_3) of CO_2 gas have been obtained and need to be compared to a theoretical model. Experimentally, further direct measurements of the CO_2 concentration in the mixing regions as well as optical visualizations are planned.

Acknowledgment

This work was partially supported by the Centre d'Etudes Nucléaires de Limeil—Valenton.

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