ON THE EVOLUTION OF A HEAVY-GAS CYLINDER ACCELERATED BY A CYLINDRICAL CONVERGING SHOCK WAVE: EFFECT OF INITIAL CONDITIONS

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Summary An experimental study of a heavy-gas cylinder accelerated by cylindrical converging shock waves and the reshock is presented here. The cylindrical converging shock waves are generated in an ordinary horizontal shock tube based on shock dynamics theory. The gas cylinder is positioned within the converging part with different distances from the gas cylinder axis to the center of convergence. The sequence of cross-sectional views of the gas cylinder captured in a single run for each case indicates that the evolution of the gas cylinder is highly dependent on the initial conditions.

INTRODUCTION

In study of the Richtmyer-Meshkov (RM) instability [1, 2], much attention has been paid to the RM flows induced by converging shock waves due to their potential applications in shock-wave lithotripsy, inertial confinement fusion, turbulent mixing in scramjet and collapse in supernova. One of experimental challenges is to produce a converging shock wave in laboratory situations [3, 4]. Recently, a simple but effective technique for generating cylindrical converging shock waves was proposed based on shock dynamics theory [5] and first experimental results with respect to a heavy-gas cylinder were reported [6]. The present experimental study is a continuation of our previous work [6] and the influence of initial conditions on the RM instability characteristic of the heavy-gas cylinder is assessed.

EXPERIMENTAL METHOD AND RESULTS

Fig. 1 presents the schematic of the experimental setup and details of initial conditions. The test section consists of a straight wall and a curved wall manufactured accurately by the linear cutting technique with a well-designed profile, which can directly convert an incident planar shock wave into a cylindrical one [5]. The controllable parameters involve the incident planar shock Mach number M_0, the converging angle θ_0 and the shock tube height h. A heavy-gas cylinder well mixed with tracer flows under gravity into the test section through a single, round nozzle of diameter D_0 mounted along the bisectrix of the converging angle on the top wall and is sucked mildly through a plenum on the bottom wall by a vacuum pump. The gas cylinder is positioned within the converging part with the distance from the gas cylinder axis to the center of convergence of L_0. The flow is monitored by a high-speed video camera (FASTCAM SA5, Photron Limited) under illumination of a laser sheet with thickness of less than 1 mm created by a high-power continuous laser (SDL-532-15000T, 15 W output power, 532 nm wavelength, Shanghai Dream Lasers technology Co. Ltd.). The sequence of images obtained in a single shot clearly exhibits the development of the gas cylinder accelerated by the cylindrical converging shock wave and the reshock.

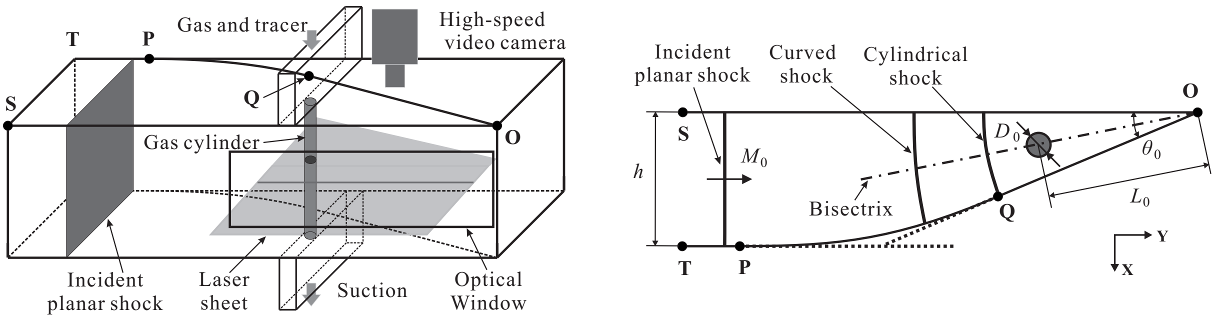

Figure 1. Schematic of the experimental setup (left) and details of initial conditions (right). M_0, the incident planar shock Mach number; θ_0, the converging angle; h, the shock tube height; D_0, the diameter of the gas cylinder; L_0, the distance from the gas cylinder axis to the center of convergence.

The initial conditions cover the shape of the test section (e.g. M_0, θ_0 and h), the feature of the gas cylinder (e.g. D_0 and L_0) and the category of the gas (e.g. SF_6, krypton, argon and others). For present work we mainly focus on the influence of L_0 and more studies are the scope of our next work. In experiments, the horizontal 95 mm×95 mm square cross section shock tube described in detail in Si *et al.* [6] with M_0=1.2, θ_0=15° and h=95 mm is adopted. In this way the radius of the converging part R_Q=143.9 mm and the Mach number M_Q=1.29 at point Q can be obtained theoretically. SF_6 mixed with glycol droplets flows through the nozzle of diameter D_0=5 mm, resulting in the gas cylinder steadily. Two different values of L_0 are used, i.e. L_0=93.3 mm and L_0=115.5 mm, respectively. Fig. 2 shows the sequences of cross-sectional views of the SF_6 cylinder accelerated by the cylindrical converging shock and the reshock for both cases. It can be easily

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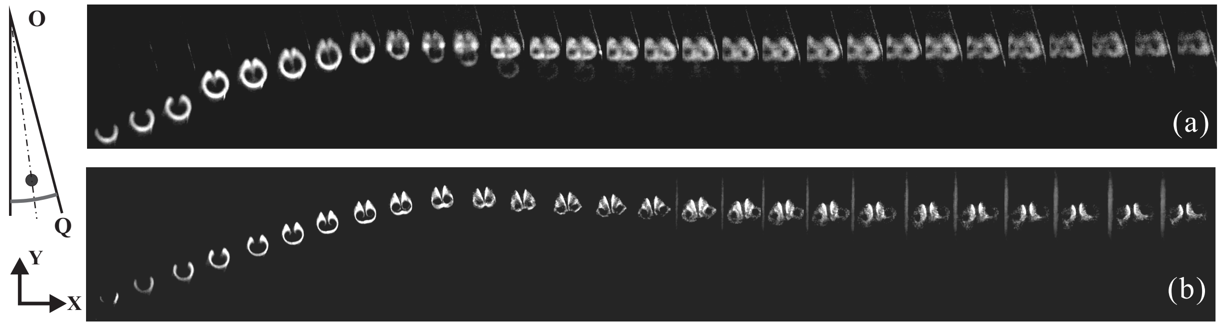

Figure 2. Influence of L_0 on the evolution of SF_6 cylinder accelerated by the cylindrical converging shock and the reshock. (a) L_0=93.3 mm, the frame rate is 40,000 fps and the shutter is 1/253,000 s; (b) L_0=115.5 mm, the frame rate is 35,000 fps and the shutter is 1/153,000 s. The initial position of the SF_6 cylinder is sketched on the left.

seen that the phenomena are different from those in the single planar shock cases studied previously [7, 8] and also a little different from our previous study for L_0=181.6 mm [6], which is much larger than those in the present work. Note that the initial conditions are confirmed prior to each run and the initial shape of the interfaces is not presented because of relatively narrow light sheet in order to gain an acceptable scattering light intensity when the flow field is illuminated.
In experiments, the incident cylindrical shock wave impacts with the SF_6 cylinder and then reflects back. The evolving interface is confronted to the reflected shock, resulting in distinct flow structures, as shown in Fig. 2. For L_0=93.3 mm, the cylindrical shock Mach number is about 1.35 when the shock arrives at the position of the SF_6 cylinder. At the beginning, the SF_6 cylinder is distorted and develops into a crescent shape quickly. As time proceeds, the bottom interface forms an arch and a counter-rotating vortex pair is formed due to the vorticity initially deposited on the boundary of the gas cylinder. Then the evolving interface interacts with the reflected shock and suddenly stops moving onwards. The top vortex pair rolls up more slowly and a new vortex pair with opposite rotating directions is generated due to the deposition of additional vorticity. Later on, the bottom interface grows in size and gradually diffuses, and the second vortex pair develops and becomes mixing with the ambient air. For L_0=115.5 mm, the cylindrical shock Mach number is about 1.32 when the shock impacts with the SF_6 cylinder. Before the arrival of reflected shock, the evolution of the gas cylinder is similar to that described above. When the evolving interface undergoes the reshock, the development of gas cylinder becomes distinct. In this situation the vortex pair gathers most of the interface mass at its top boundaries and continues rotating with the same directions. The bottom arcuate interface becomes flat and then breaks up into two parts, moving together with the vortex pair. At late times, the vortex pair diffuses gradually due to the mixing of two gases.

CONCLUSIONS

The interaction of a SF_6 cylinder with cylindrical converging shock waves and the reshock was investigated experimentally in a horizontal shock tube. The distance from the gas cylinder axis to the center of convergence was changed to assess the influence of initial conditions on the evolution of the gas cylinder. The evolutions of the SF_6 cylinder accelerated by converging shock waves and the reshock were captured using a high-speed video camera combined with a high-power continuous laser and different phenomena were obtained. More improved experiments and quantitative analysis considering all initial conditions are needed in the future in order to understand the mechanism of the RM instability induced by converging shock waves and the reshock.

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