A New Combination Facility for Testing Refraction, Diffraction and Interaction of Shock Waves*

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Abstract In this paper, a new facility is introduced, which is the combination of a shock tunnel and a shock tube. Experiments on refraction of a moving shock at a slip-surface, diffraction of a moving shock around a corner under the condition of a uniform flow ahead of the shock, and interaction of a moving shock with a bow shock attached to a testing model were conducted in the combinated facility and some new phenomena were observed.

Keywords: shock tube, shock tunnel, shock refraction, shock diffraction, shock interaction.

1 Introduction

When a moving shock propagates through a nonuniform medium or over a nonuniform wall boundary, there will occur reflections, diffractions, and refractions of shocks and at the same time the strength, orientation and the shape of the shock will be changed. The reflection of a shock on a solid wall[1], the refraction of a shock at an interface between different media[2-5] and the diffraction of a shock around a convex corner[6-8] have already been studied in detail. However, almost all of the early researches focused on shocks without flow ahead. Here we extend the study to the case where the gases ahead of shocks are not quiescent. This is a new area of shock dynamics.

In the experiments on reflection, diffraction and refraction of a moving shock in a moving flow, a facility that can provide a uniform flow field and a moving shock is necessary. As is known, a moving shock can be easily produced by using a common shock tube, and a steady supersonic flow field also can be easily obtained in a conventional supersonic wind tunnel. But it is difficult to obtain them simultaneously in a test section of a facility. Several facilities[9-11] were set up, but they all have some disadvantages. In this paper, a new type of combinated facility is presented. The combinated facility, consisting of a shock tube with a rectangular cross-section and a shock tunnel with a rectangular cross-sectional nozzle, can provide a supersonic flow field and a moving shock in its test section simultaneously, which enable us to study the phenomena of refraction, diffraction and interaction of shocks under the condition

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of moving gases ahead of shocks.

2 Experimental Facility and Its Principle

As shown in Fig. 1, the combinated facility was made up of a small reflected shock tunnel with a contoured nozzle, 50 mm × 60 mm ($M=5$) in exit cross-sectional area, and a 147 mm × 60 mm rectangular cross-sectional shock tube. The latter is connected to the test section of the former at an angle of 50°, with their top and bottom walls keeping coincident. The schlieren system was arranged to pass the light beam vertically through the test section.

The operation process is as follows. After the diaphragm in the shock tunnel is burst, a moving shock is formed in the driven section of the shock tunnel (we call it the first shock). When the first shock arrives at where the transducer is located, the transducer sends out a voltage signal to a high voltage discharge system (see Fig. 1). The high voltage capacitors discharge through an explosion wire attached to the mylar diaphragm in the shock tube making the diaphragm collapse. At this time, another moving shock is formed in the shock tube (we call it the second shock). The first shock starts the nozzle and sets up a supersonic flow field in the test section of the shock tunnel, forming a slip-surface (see Fig. 2) before the second shock enters the test section.

Let it be pointed out that the initial pressure in the driven section of the shock tube (as well as the test section of the shock tunnel and the vacuum tank) should be carefully controlled in order to obtain a satisfactory slip-surface.

Three experiments, which can hardly be performed in conventional facilities, were conducted in the combinated facility. The first was on the refraction of a moving shock at a slip-surface. Fig. 3 shows that when the second shock enters the supersonic flow in the test section of the shock tunnel, it will pass through the slip-surface, so that the refraction of the moving shock at the slip-surface takes place in the vicinity of point P.

The second experiment was on the diffraction of a moving shock around a convex corner of a supersonic flow ahead of the shock. After the second shock is refracted at the slip-surface, a transmitted shock (PQO in Fig. 3) enters the supersonic flow field in the tunnel and there occurs the diffraction of the shock around the convex corner O.

The third experiment was on the interaction of a moving shock with a bow shock. When the test model m was mounted in the test section of the tunnel, a bow shock formed on the model in the supersonic flow. The transmitted shock PQ in Fig. 3 collides with the bow shock, making the moving shock interact with the bow shock.

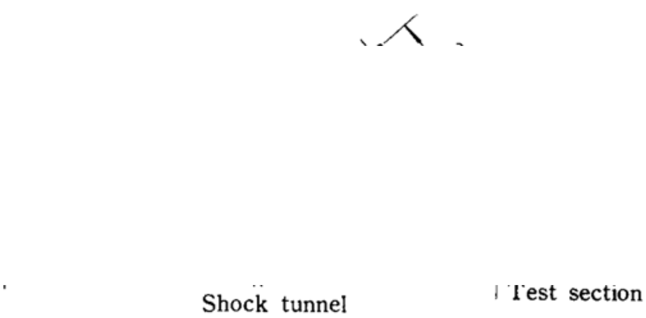

Fig. 1. The combinated facility made up of a shock tunnel and a shock tube.

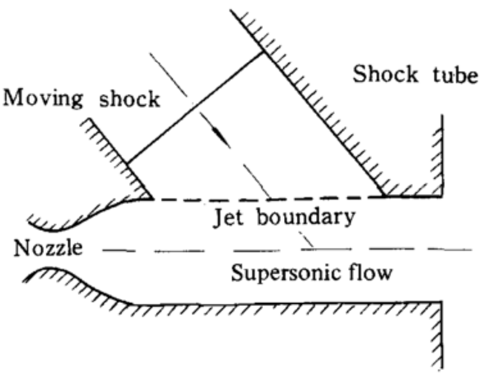

Fig. 2. The testing section.

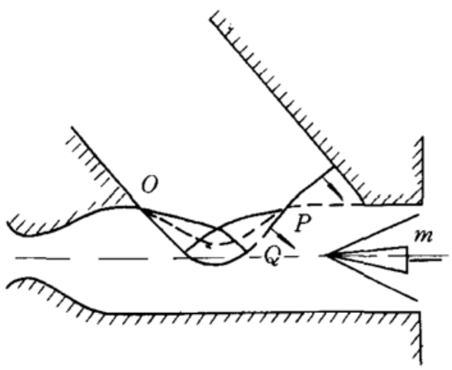

Fig. 3. Principle of the experiments.

3 Experimental Results

Testing gas in the experiments: nitrogen. The Mach number of the first shock (M_{s1}): about 1.6 and the Mach number (M_{s2}) of the second shock ranged 2.5—4.6.

3.1 *Refraction of a Moving Shock at a Slip-Surface*

Refraction of a shock at a gas interface can be classified into three types according to the behaviour of the shock and the gas in each region. The first type is the refraction of a moving shock at an interface of quiescent gases. Jahn[2] and Abdel-Fattah and Henderson[3-5] have made detailed experimental investigation on this type of refraction. The second is the refraction of a stationary shock at a slip-surface, which has already been explained in many text books of gasdynamics. The third one is the refraction of a moving shock at a slip-surface.

Figure 4 is three typical photos taken in the experiments, which belong to the refraction of a moving shock at a slip-surface. When the moving shock is strong enough, the behaviour of the refraction is similar to that of a moving shock at a "fast-slow" quiescent gas interface (the so-called "fast-slow" means that the shock propagates from a region with high sound speed to a region with low sound speed). The transmitted shock bends backward as shown in Fig. 4(a). When the moving shock

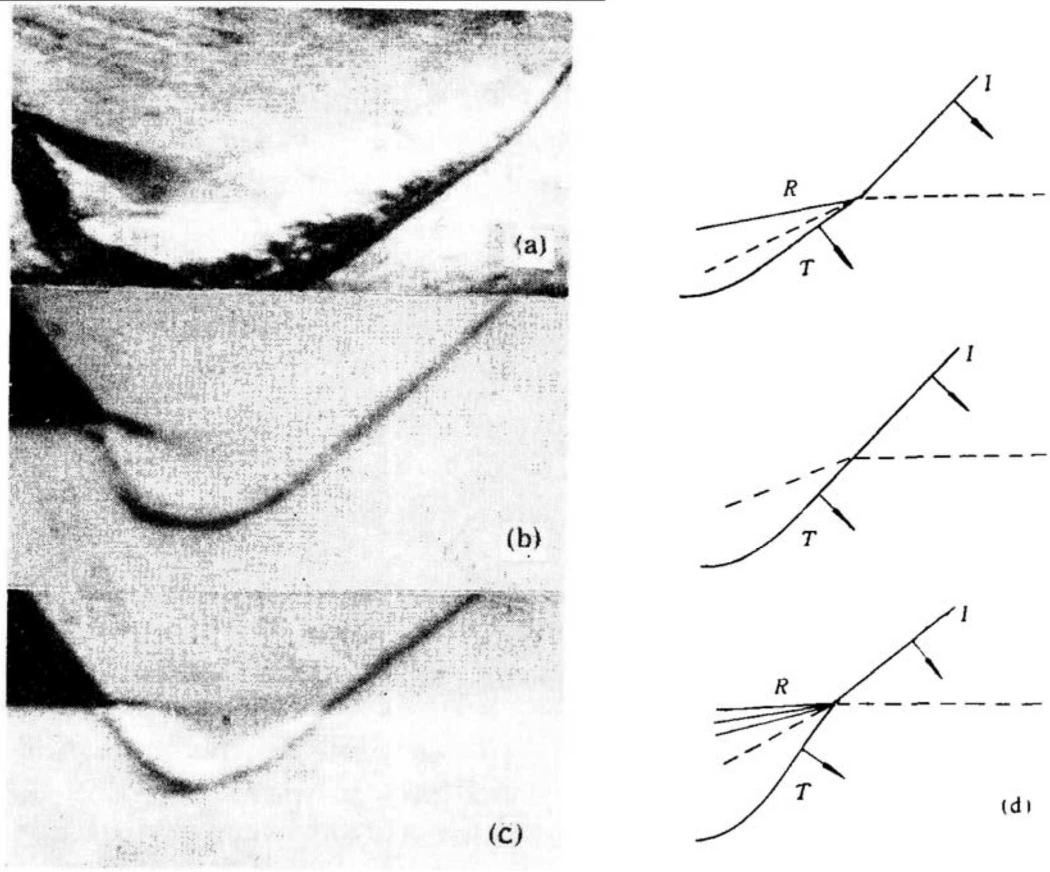

Fig. 4. Experimental results on the refraction of moving shocks on the slip-surface. I, Incident shock; T, transmitted shock; R, reflected shock. (a) $M_{s1}=1.52$, $M_{s2}=4.51$, (b) $M_{s1}=1.59$, $M_{s2}=4.10$, (c) $M_{s1}=1.59$, $M_{s2}=2.78$.

is weaker, the transmitted shock bends forward (Fig. 4(c)). This is similar to the refraction of a shock at a "slow-fast" quiescent gas interface opposite to the "fast-slow".

It should be noted that for the refraction of a moving shock at a quiescent gas interface, the "fast-slow" or "slow-fast" refraction depends only on the properties of the gases on the two sides of the interface. But, in the present case, it depends not only on the parameters on each side of the slip-surface, but also on the shock itself. Although in Fig. 4(a) and 4(c) the same is the condition of slip-surface (the speed of sound in the region ahead of the incident shock is higher than that ahead of the transmitted shock), different flow patterns are observed for different moving shock strengths. This is one of the main differences between the refractions at a slip-surface and at a quiescent gas interface.

Another important result in the experiments is that under a given condition of the slip-surface, there exists a shock strength. With this strength, the shock passes straight through the slip-surface without changing its direction (the shock strength is changed) as shown in Fig. 4(b). It seems that there is no interaction between the moving shock and the slip-surface at all. Such "no-refraction" is a phenomenon unknown before.

3.2 *Diffraction of a Moving Shock in the Case of a Flow Ahead of the Shock*

The occurrence of the diffraction of the transmitted shock around the corner can be seen from Fig. 4. This type of diffraction is different from that of quiescent gas. Fig. 5(a) is a photo taken when the shock tunnel ceased working. It is the diffraction of a moving shock around the convex corner *O* in the case of quiescent gas ahead of shock. Comparing the results in Figs. 4 and 5(a), we can find two differences between the two cases (for comparison, Fig. 4 and Fig. 5(a) are overlapped and drawn in Fig. 5(b)).

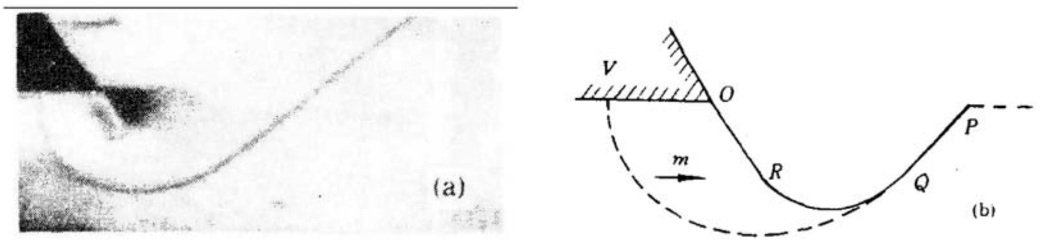

Fig. 5. Comparison between diffraction of shocks in the case of quiescent gases and moving gases ahead of the shocks.

The diffracted shock in the quiescent gas propagates along the wall (dashed line in Fig. 5(b)). But for the diffracted shock in a supersonic flow, there are two possibilities: one is that the diffracted shock may propagate along the wall surface; the other is that a part of the diffracted shock may become steady, oblique, attaching to the corner (line *OR* in Fig. 5(b)).

The strength of the diffracted shock in the quiescent gas is gradually reduced along the shock surface from the first disturbed point *Q* to the wall surface (dashed line *QV* in Fig. 5(b)). But for the diffraction in a supersonic flow, the shock near the corner may be stronger than the undisturbed one. The shape and strength of the diffracted shock in the two cases can be calculated according to the geometric shock dynamics[12].

3.3 *Interaction Between a Moving Shock and a Bow Shock*

It is difficult to simulate the "shock-shock interaction" phenomenon in ground facilities. During the 1960s, some experiments were conducted. However, there were some shortcomings in these experiments. Han *et al.*[11] developed an electrically controlled double driver shock tunnel and performed experiments on shock-shock interaction by the method of wave interaction in the facility. However, this type of facility applied only to the interaction of a weak moving shock with a bow shock. Our combinated facility can be used to test the interaction of a strong moving shock with a bow shock at a large interaction angle.

Figure 6 (a) is the experimental results of interaction of moving shock with bow shock. In the experiments, since the uniform region between the moving shock and the slip-surface was very narrow and the effective time for the interaction was very short, the test model was small in size. An improvement is needed.

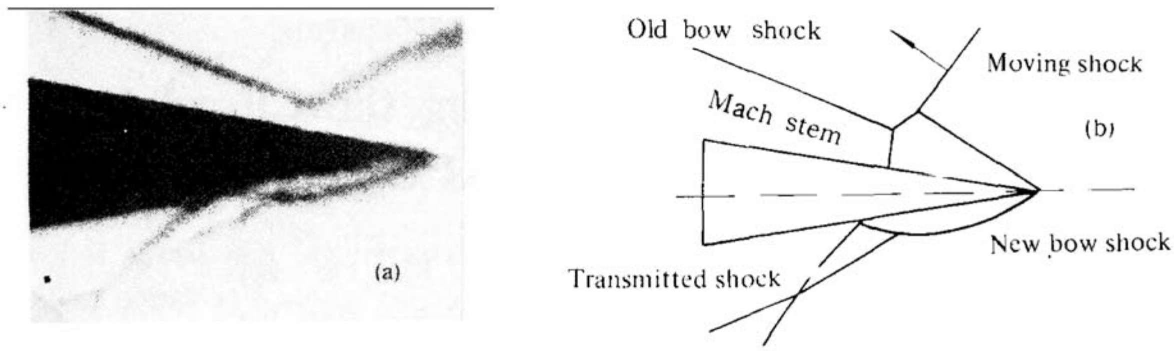

Fig. 6. Experimental results of interaction of moving shock with bow shock.

4 Conclusions

For the first time we developed a combinated facility of a reflected shock tunnel and a shock tube and with it conducted the experiments on the refraction, diffraction and interaction of shocks moving into a supersonic flow field.

The experimental results show that the behaviour of the refraction depends not only on the parameters on the two sides of the slip-surface, but also on the strength of shock itself. Under a given condition of the slip-surface, there is a shock strength with which the shock passes straight through the slip-surface without changing its direction.

The diffraction of shock moving in a supersonic flow field around a convex corner differs from that of shocks in the quiescent gas in strength and shape.

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