EFFECT OF SURFACE ROUGHNESS ON MACH REFLECTION

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Summary The effects of surface roughness and transport properties have been compared experimentally to investigate non-self-similar Mach reflection phenomena. The surface roughness was given by pasting a piece of sand paper on the model surface. The results were compared with those for smooth surfaces. The effect of surface roughness turned out to be small compared with viscosity effect so that the effect of transport properties is proved to be dominant.

INTRODUCTION

It was first reported by Walenta [1] some twenty years ago that, under rarefied-gas conditions, the transition from regular to Mach reflection takes place during the incident shock propagation over a wedge. This non-self-similar phenomenon was first considered to be a phenomenon characteristic of extremely low-pressure, low-density atmosphere, because such dynamic transition phenomena have never been observed in ordinary atmospheric conditions. However, the authors observed a same kind of phenomenon even in atmospheric pressure for the first time [2], proving that such non-self-similar phenomenon is not restricted to low-pressure conditions.

The disruption of self-similarity suggests that a length scale has been introduced into the system. There are two candidate causes: viscosity and surface roughness. According to Henderson et al.'s numerical experiment [3], the condition on the solid boundary plays a key role in the phenomenon. The authors' experiment in Karlsruhe found different wave angles from those obtained in Saitama [4]. In the Karlsruhe experiment, the initial pressure p_1 of the driven section was below atmospheric pressure and ranges from 280 mmHg to 610 mmHg depending on shock Mach number M_i. In addition, the model surface roughness was estimated from 6 to 12 μm. In contrast, in the Saitama experiment, p_1 was atmospheric pressure and the surface roughness ranged from 1 to 2 μm. When the pressure is low, the effect of viscosity is enhanced, as seen by the definition of kinematic viscosity. Therefore, the results for both experiments are subject to mixed effects of viscosity and surface roughness. In this paper, we investigated the effect of surface roughness on the behavior of Mach reflection.

EXPERIMENT

Experimental Apparatus

We performed the experiments using a conventional shock tube in our institute. The working gas was air, and the driven section was set at room temperature and atmospheric pressure at each experiment run. The models were ordinary smooth wedges of 20º and 30º, over which a sheet of sandpaper was firmly pasted to keep it flat. We could select from two surface roughnesses by changing sandpaper (#60 and #240). This means the surface is not hydraulically smooth according to Ben-Dor et al [5]. In contrast, the surface roughness in past experiments [4] was 12 μm maximum, and the wedge surface was hydraulically smooth. The incident shock Mach number M_i was 1.10, 1.20, 1.30 and 1.40. However, only partial results are presented here due to page restrictions.

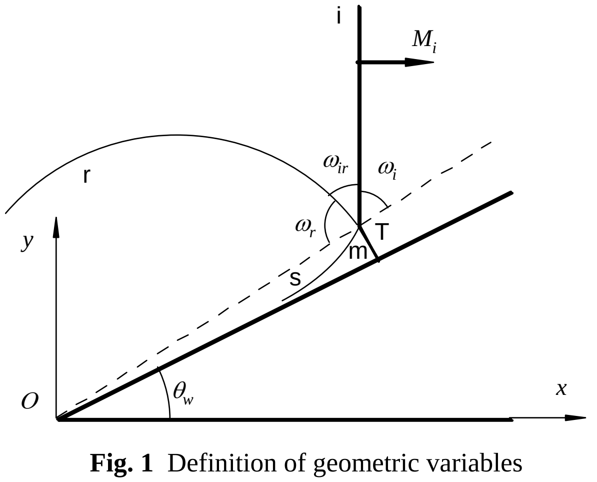

Fig. 1 Definition of geometric variables

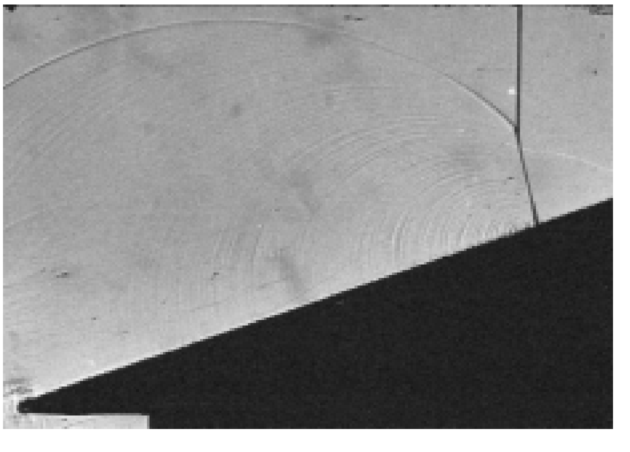

Fig. 2 Visualized reflection configuration

Measurement

The triple-point coordinate (x, y) and the angle ω_{ir} made by the incident and reflected shocks at the triple point were measured (see Fig. 1) directly from photographic negatives enlarged by a factor of about 50 using a profile projector (V-12, Nikon, Inc.). In measuring the triple-point location, the model corner ahead of the incident shock was taken as a reference point to avoid the influence of optical distortion behind the shock waves. The triple-point location was easily converted in the coordinate system with the leading edge taken as the origin *O*, and the incident shock propagation direction as the *x*-axis. The *y*-axis was defined upward normal to the *x*-axis. The maximum error involved in measuring the angle ω_{ir} is ±2.0º at an early stage of reflection (10 mm < x < 30 mm) where the radius of curvature of the reflected shock is small. However, the error is reduced within ±1.0º as the incident shock proceeds (x > 40 mm). The error was very large (around ±5º) for x < 5 mm.

RESULTS

Reflected wave configuration

Figure 2 shows a representative image of shock reflection over the wedge with surface roughness (M_i = 1.40, θ_w = 20º, #60, x = 64.19mm). A group of compression wavelets issues cylindrically from the wedge surface (see behind the foot of the Mach stem). The wavelets are more clearly observed when the surface roughness is larger, and their pattern is quite similar to the shock reflection over a multi-guttered wedge or a step-like wedge [6]. Although the data are omitted here, the triple-point trajectory proved to be almost independent of the surface roughness.

Variation of the angle between incident and reflected shocks

Figure 3 illustrates the variation of the angle ω_{ir} made by the incident and reflected shock waves at the triple point as the incident shock proceeds (M_i = 1.40). Angle ω_{ir} is large near the wedge tip but decreases and approaches an asymptotic value with the progress of the incident shock wave. The behavior of ω_{ir} shows that the Mach reflection is not self-similar. On the whole, angle ω_{ir} is smallest for smooth wedges. However, the difference is not clear for large x. Therefore, the effect of surface roughness on the wave angles is not strong.

The effect of viscosity can be taken into account by defining the dimensionless variable, $\zeta = \frac{\rho_1 u_r}{\mu_1} x$, where ρ_1 and μ_1 are the density and viscosity behind the incident shock, and u_r is the flow velocity there. With this transformation of space variable x, the difference of ω_{ir} obtained in Saitama and Karlsruhe diminishes as in Fig. 4 (M_i = 1.30). The difference is still large for M_i = 1.20 and 1.40. Possibly the error in angle measurement was larger than expected.

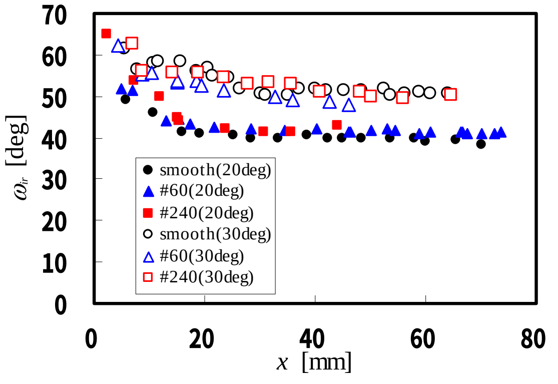

Fig. 3 The angle ω_{ir} between incident and reflected shocks

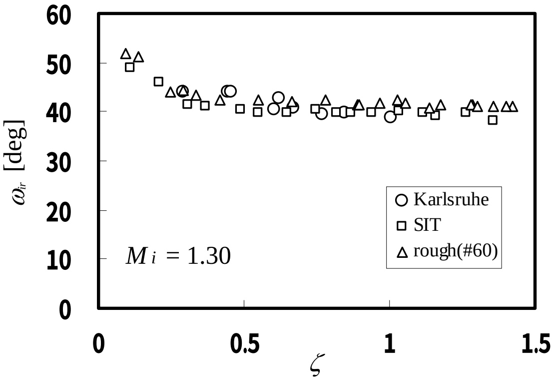

Fig. 4 The angle ω_{ir} in the dimensionless coordinate

CONCLUSIONS

The results show that the effect of surface roughness is not distinct with smooth (less than the surface roughness of about 10μm) wedges. This negative result leads to the conclusion that the effect of viscosity is dominant in non-self-similar phenomena of Mach reflection. Consequently, the difference in the two kinds of experiments [4] should be ascribed solely to viscosity.

References

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