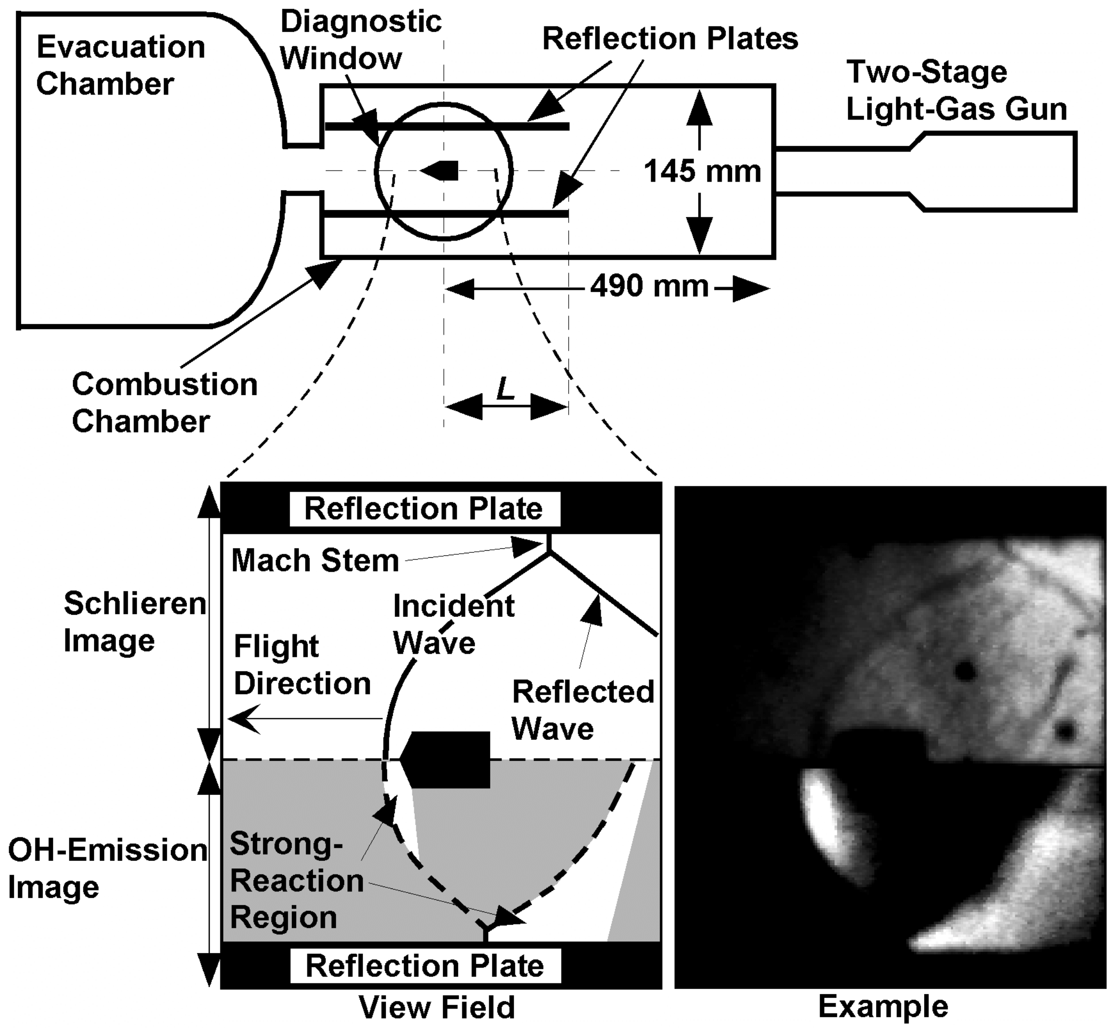
Generation of Detonation Waves by Reflection of Hypersonic Oblique Shock Waves

T. Endo, H. Kuroda, T. Ohkubo, J. Kasahara, and T. Fujiwara
Nagoya University, Chikusa-ku, Nagoya, 464-8603, Japan

We carried out experiments on ignition of oblique detonation waves by reflection of hypersonic oblique shock waves. This is one of the most important issues in hypersonic propulsion applications, for example, the ram accelerators[(1)]. Experimental arrangement and conditions are shown in Fig. 1. A projectile was accelerated by the two-stage light-gas gun, and fired into the combustion chamber, which was initially filled with stoichiometric hydrogen-oxygen premixed gas. In the combustion chamber, we installed a pair of flat reflection plates, between which the projectile flew. A bow shock wave, generated around the hypersonic projectile, impinged on the reflection plates and was reflected. Flowfield between the reflection plates was optically diagnosed through the diagnostic window. As optical diagnostics, we adopted a schlieren method and an OH-emission imaging method. For time-resolving imaging, we used a high-speed multi-frame camera. In the experiments, we varied projectile nose angle θ_n, initial gas pressure P_0, and length of the reflection plates L as governing parameters.

A typical image is also shown in Fig. 1. The upper half of the image shows the schlieren image, where density discontinuities, namely inert shock waves or detonation waves, are shown by black curves. The bow shock wave generated by the projectile impinged on the reflection plate. In this case, Mach reflection is recognized. The lower half of the image shows the OH-emission image, where strong-reaction regions are shown by white regions. Along the incident bow shock wave, the strong chemical reaction occurred only in the vicinity of the projectile, whereas almost no reaction occurred near the triple point. That is, the incident wave was almost an inert oblique shock wave. On the other hand, the reflected wave and the Mach stem were accompanied with strong chemical reaction; namely, they were both detonation waves. It should be noted that the Mach stem was overdriven because the projectile speed was higher than the Chapman-Jouguet detonation speed and the shock angle of the Mach stem was almost normal.

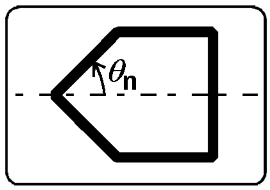
In the experiments, we investigated dependence of the shock-reflection configurations and the ignition conditions on the projectile nose angle θ_n and the initial gas pressure P_0. The projectile nose angle θ_n mainly governed the angle of the incident shock wave. The initial gas pressure P_0 mainly governed the induction time for the exothermic reaction. Three types of wave-reflection configurations were observed, which are shown in Fig. 2. The first type, shown in Fig. 2(a), was the Mach reflection where the reflected wave and the Mach stem were both detonation waves whereas the incident wave was almost an inert shock wave. The second type, shown in Fig. 2(b), was the regular reflection where the reflected wave was a detonation wave whereas the incident wave was almost an inert shock wave. In these two types, the OH emission from the incident shock wave was very weak compared with the reflected wave. Oblique detonation waves were successfully ignited by reflection of the hypersonic oblique shock waves in these two cases. The third type, shown in Fig. 2(c), was the regular reflection



Experimental Conditions

Projectile

Shape	Cone-Nosed Cylinder	
Diameter	10 mm	
Mass	0.73 g	
Velocity	3.41 km/s (±6%)	
Nose Angle	θ_n=30° - 75°	



Gas

Mixture	$2H_2+O_2$	Temperature	300 K
Pressure	P_0=0.20 - 0.33 atm		

Reflection Plate

Width	50 mm	Separation	40 mm
Length	L=0 - 280 mm		

Diagnostics

Camera Exposure Time 1 μs

Interference Filter for OH-Emission Imaging

λ_{peak}=306.1 nm, $\Delta\lambda_{FWHM}$=9.0 nm, T_{peak}=58.4%

Figure 1 Experimental arrangement and conditions

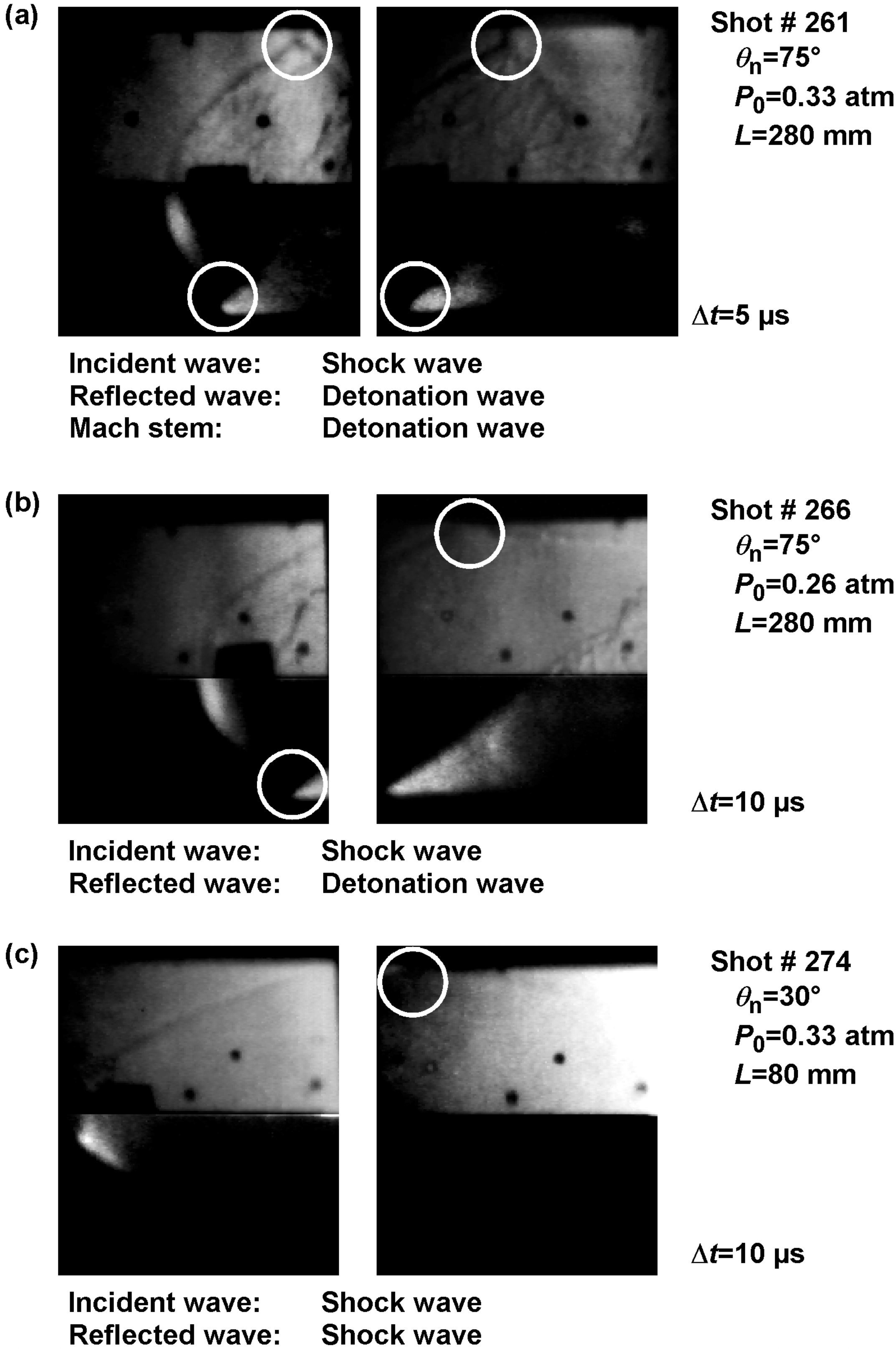


Figure 2 Observed wave-reflection configurations
(a) Mach reflection. (b) Regular reflection. (c) No ignition.

where both the incident and reflected waves were inert shock waves, that is, no ignition was observed in this case. The observed wave-reflection configurations are summarized in Fig. 3. In Fig. 3, the right upper region corresponds to the region where an oblique detonation wave is directly initiated by the bow shock (detonation) wave even without the reflection plates. All of the observed wave-reflection configurations were in steady state, which was confirmed by varying the reflection-plate length from zero to 280 mm.

The experimental results were analyzed mainly with the shock and detonation polars[2]. It has been suggested that the quantity of the heat release at the detonation-wave front depends strongly on the wave-reflection configurations.

References

(1) A. Hertzberg, A. P. Bruckner, and D. W. Bogdanoff, *Ram Accelerator: A New Chemical Method for Accelerating Projectiles to Ultrahigh Velocities*, AIAA J. **26**, 195 (1988).

(2) J. M. Powers and K. A. Gonthier, *Reaction zone structure for strong, weak overdriven, and weak underdriven oblique detonations*, Phys. Fluids A **4**, 2082 (1992).

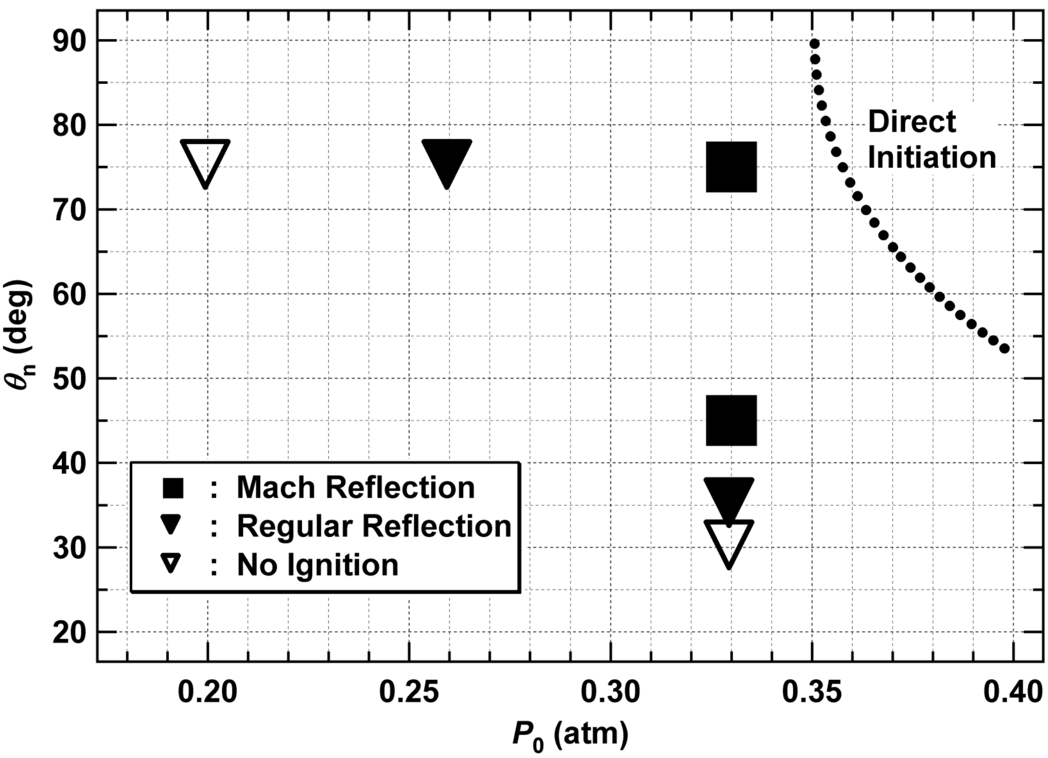


Figure 3 Summary of the observed wave-reflection configurations