Steadiness of Oblique Detonation Waves around Spherical Projectiles

Akane Uemichi[1], Sinpei Kato[1], Jiro Kasahara[1], and Akiko Matsuo[2]

[1]Department of Engineering Mechanics and Energy,
University of Tsukuba, 305-8573, Ibaraki, Japan

[2]Department of Mechanical Engineering,
Keio University, 223-8522, Kanagawa, Japan

1 Introduction

We have experimentally studied self-sustained oblique detonation waves around hyper velocity projectiles as a part of the application of an oblique detonation wave engine. In previous papers [1-4], we used optical observation to clarify the fluid-dynamic structure of self-sustained oblique detonation waves stabilized around cone-nosed projectiles and the criticality for detonation waves.

Higgins [5] and Higgins and Bruckner [6] studied the criticality of detonation initiation by projectiles using pressure history inside a tube. Lee [7] proposed a theory for initiation criticality by using a cylindrical, strong blast-wave analogy. Many other researchers have studied the oblique detonation phenomena in their reports [8-14]. In the present paper, we discuss the steadiness of the oblique detonation waves around the projectile by using a high speed camera.

2 Experimental set up and conditions

The experimental set up is composed of four elements: (1) a two-stage light-gas gun to launch a hyper velocity projectile, (2) a combustion chamber which is filled with containing a detonable gas, (3) shadowgraph visualization system, and (4) an evacuation chamber for releasing the projectile and burned gas. The schematic diagram of the experimental arrangement (top view) is shown in Fig. 1. We have used a high speed camera (HPV-1, SHIMADZU) in order to observe of an oblique detonation wave. The inter-frame time of this camera is 1 μs with a spatial resolution of 312 × 260 pixels. The camera was trigged by a He-Ne laser cutting signal. For visualization of an oblique detonation wave, shadowgraph was used. Table 1 shows each experimental condition. A projectile diameter is 4.76 mm. Acetylene-oxygen-krypton mixture ($2C_2H_2+5O_2+20.5Kr$) was used as detonable gas. The initial pressures p_0 and temperatures T_0 of detonable gas were shown in Table 1.

3 Results and discussion

The oblique detonation structure around hypersonic projectiles is defined as Fig. 2 [2]. Figure 3 shows multi-flame photograph of the stabilized oblique detonation (Shot No. 1).

Correspondence to: acane-u129@edu.esys.tsukuba.ac.jp

Projectile velocities V_p are 1.5 and 2.3 km/s. The detonation wave propagating velocity V_W is defined as $V_W=V_p\sin\theta_W$, where θ_w is detonation wave angle. Figure 4 shows that V_W is 1.17±0.23 km/s. The experimental error of the wave velocities V_W were 10 %. The C-J detonation velocity by calculated chemical equilibrium computation, V_{CJ}, is 1.23 km/s.

The stabilized detonation wave was observed in all the experimental conditions as shown in Table 1. In the three experimental conditions, the quasi C-J detonation waves (Fig. 2) were observed. The quasi C-J detonation wave partly propagates at lower speed than the C-J detonation wave due to strong interaction of the rarefaction-wave generated from the spherically-curved surface projectile.

By these experiments, we confined the steadiness of this oblique detonation structure [2] proposed by the multi-flame pictures as shown in Fig. 2.

Then, we digitized the location of oblique detonation wave fronts. For Figure 5, the x-axis and y-axis show the traveling direction of projectiles and the normal direction of traveling projectiles.

Table 1: Condition of experiment

Shot No.	p_0, kPa	T_0, K	$\bar{V}_p$, km/s	θ_W, deg.	V_W, km/s
1	63.0±0.05	277.6±5.0	1.50±0.18	33.9	1.24±0.15
2	63.3±0.05	284.7±2.5	2.26±0.27	60.5	1.11±0.13
3	60.2±0.05	284.0±2.5	2.29±0.27	62.0	1.07±0.13

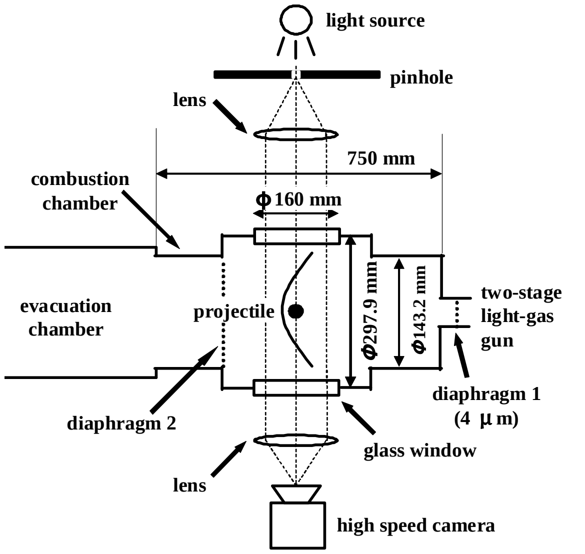

Figure 1 The schematic diagram of the experimental arrangement (top view).

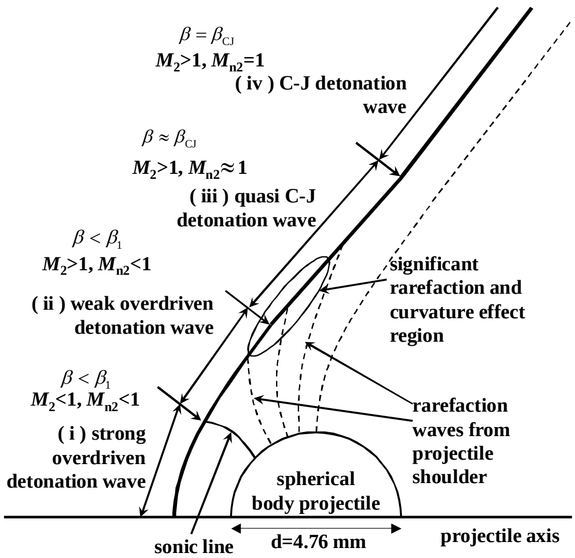

Figure 2 The oblique detonation wave structure around spherical projectiles.

References

[1] Kasahara J, Arai T, Chiba S, Takazawa K, Tanahashi Y, Matsuo A. (2002). Criticality for stabilized oblique detonation wave around spherical bodies in acetylene/oxygen/krypton mixture. Proceeding of Combustion Institute. 29: 2817.

[2] Kasahara J, Fujiwara T, Endo T, Arai T. (2001). Chapman-Jouguet oblique detonation structure around hypersonic projectile. AIAA Journal. 39: 1553.

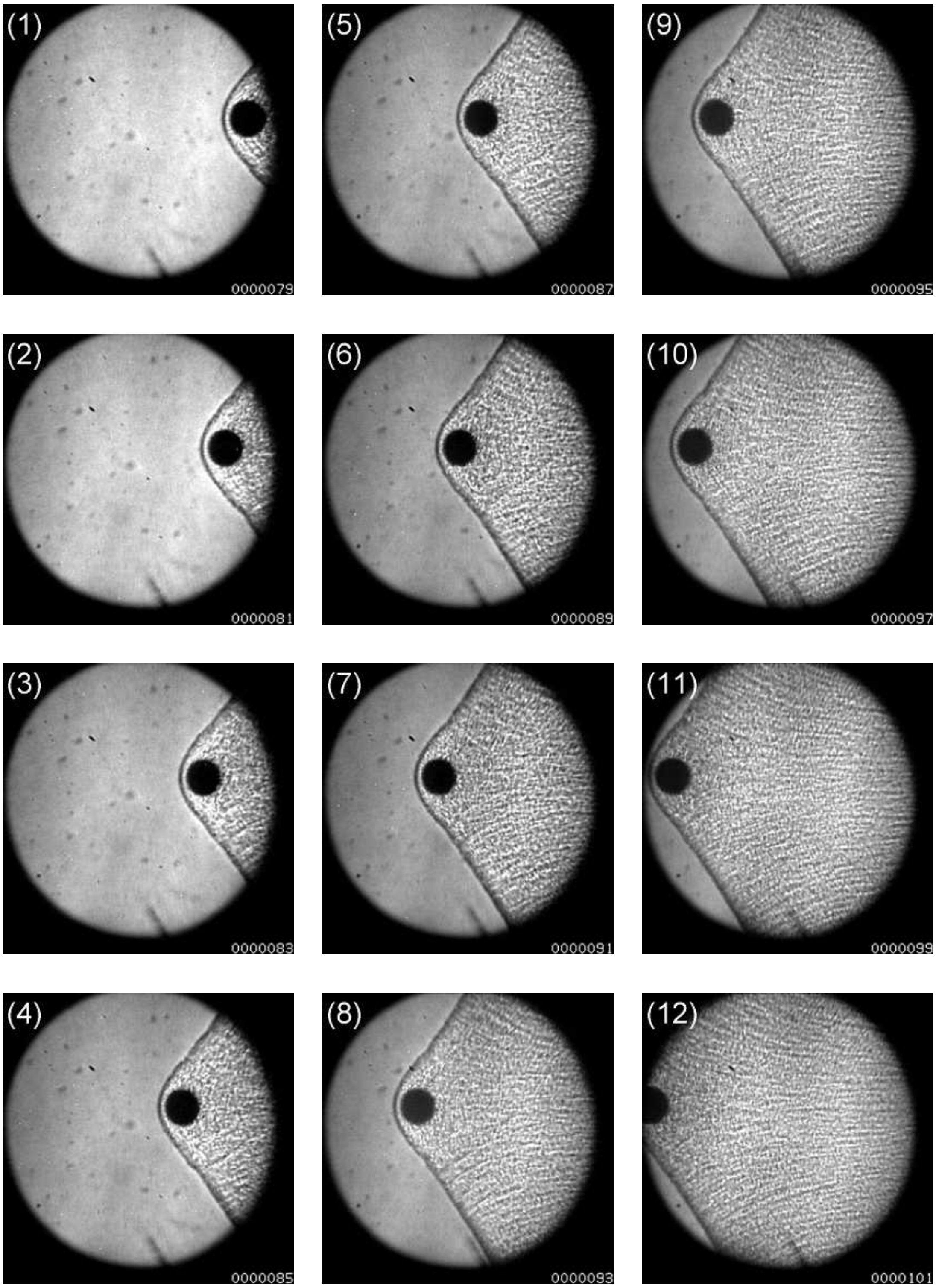

Figure 3 Multi-flame picture of the oblique detonation wave around the spherical projectile. (Shot No.1, p_0=63.0 ± 0.05 kPa: $2C_2H_2$+$5O_2$+20.5Kr, T_0=277.6 ± 5.0 K, V_p=1.50 ± 0.12 km/s, d=4.76 mm).

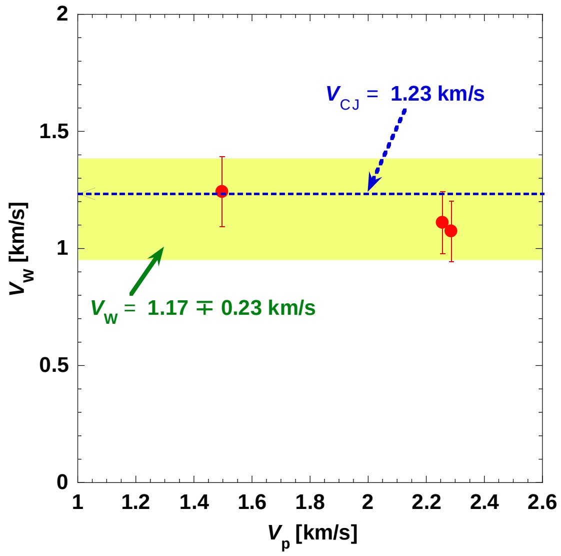

Figure 4 The detonation wave velocity and the projectile velocity

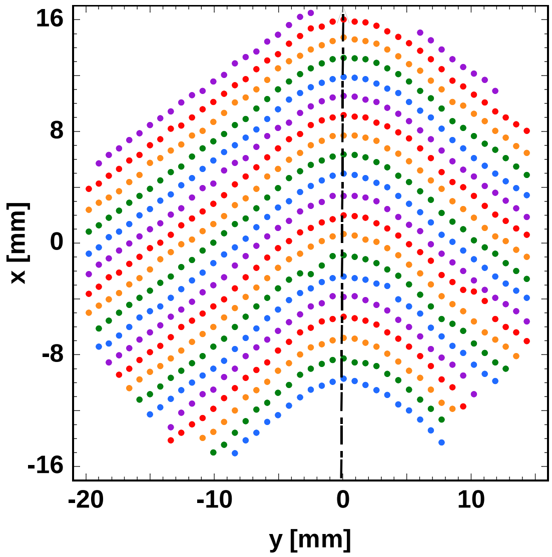

Figure 5 The digitized x-y location of the oblique detonation wave front (Shot No.1)

[3] Matsuo A, Fuii K. (1998). Prediction method of unsteady combustion around hypresonic projectiles in stoichiometric hydrogen-air. AIAA Journal. 36: 1834.

[4] Matsuo A, Fujii K. (1996). Detailed mechanism of the unsteady combustion around hypersonic projectiles. AIAA Journal. 34: 2082.

[5] Higgins AJ. (1997). The effect of confinement on detonation initiation by blunt projectiles. AIAA paper. 97: 3179.

[6] Higgins AJ, Bruckner AP. (1996). Experimental investigation of detonation initiation by hypervelocity blunt projectiles. AIAA paper 96-0342.

[7] Lee JHS. (1997). Initiation of detonation by hypervelocity projectile. Advances in Combustion Science: In Honor of Ya. B. Zel'dvich. 173: 293.

[8] Lehr HF. (1972). Experiments on shock-induced combustion. Astronautica Acta. 17: 589.

[9] Debordes D, Hamada L, Guerraud C. (1995). Supersonic H_2-air combustion behind oblique shock waves. Shock Waves. 4: 339.

[10] Li C, Kailiasanath K, Oran ES. (1994). Detonation Structure behind oblique shocks. Phisics of Fluid. 6: 1600.

[11] Kaneshige MJ, Shepherd JE. (1996). Oblique detonation stabilized on a hypervelocity projectile. Proceedings of the Twenty-Sixth Symposium (International) on Combustion. 26: 3015.

[12] Kailasanath K. (1999). Applications of detonation to propulsion: a review. AIAA paper 99-1067.

[13] Hertzberg A, Bruckner AP, Bogdanoff DW. (1988). Ram accelerator: a new chemical method for accelerating projectiles to ultrahigh velocities. AIAA Journal. 26: 195.

[14] Powers JM. (1994). Oblique detonations: theory and propulsion applications. Combustion in High-Speed Flows (ISBN 978-0792328063).