

Experimental Study of Flame Acceleration and deflagration-to-detonation transition

Kong-Qian SUN, Yi-Ning ZHANG, Kun GUO
Beijing Power Engineer Institute, Beijing, China
Wei-Jun FAN
Beihang University, Beijing, China

1 Instructions

There are two kinds of flames in nature: the deflagration waves and the detonation waves. The flame speed of deflagration waves is 0.1-0.7m/s (laminar flame speed) or tens meters per second (turbulent flame speed). The detonation velocity can reach to thousands of meters per second. The deflagration can be transformed into detonation in the right condition, that called deflagration-to-detonation transition (DDT).

DDT problem has been studied for about one hundred years. The earlier work of Chapman and Wheeler[1] and Shchelkin[2] demonstrated that a flame initiated at the closed end of a duct can accelerate more rapidly toward the open end and if it passes through an array of turbulence-generating baffles. Bradley[3] proposed a methodology for determining whether a DDT might occur for flame propagation along a duct with baffles, of which the turbulent flame velocity was the key factor. Oran, Khokhlov and Gamezo[4~7] performed the numerical simulations of DDT and analyzed the shock-flame interactions, hotspots, and obstacles and boundary layers. Mayer[8] investigated the mechanism, speed and location of DDT for different enhancement techniques, including the effect of equivalence ratio. Farinaccio[9] studied the turbulent flow effects on DDT run-up distance.

In this study, flame acceleration and deflagration-to-detonation transitions are explored through equivalence ratios and obstacles in detail. Flame velocity is determined by the equivalence ratio. Six equivalence ratios of acetylene-air mixture are discussed corresponding to different styles of flames. The tube is closed at ignition end. Staggered obstacles are arranged to accelerate flames. The external flow fields can be captured by high-speed camera.

2 Experimental setup

A sketch of the experimental apparatus is shown in Fig. 1. The experiments are performed in a 2.2m long steel tube. The tube is composed of 50mm internal diameter pre-combustor and 100mm internal diameter main combustor. The expanding section connects pre-combustor and main combustor. The length of the pre-combustor and the expand section added is 0.5m. The test section of main combustor is 1.7m long. Several staggered obstacles of 25mm are distributed along the main combustor. The ignition end is closed and the other end is open. The time of arrival of shock front and the pressure

variations along the main combustor could be measured by pressure transducers embedded on the sidewall at six positions. Schlieren optical system is used to obtain external flow visualization. The diameter of parabolic mirror is 110mm. The diameter of external viewing field is about 100mm. High-speed digital imaging at rates up to 5000 frames-per-second (fps) was employed using IDT high-speed camera.

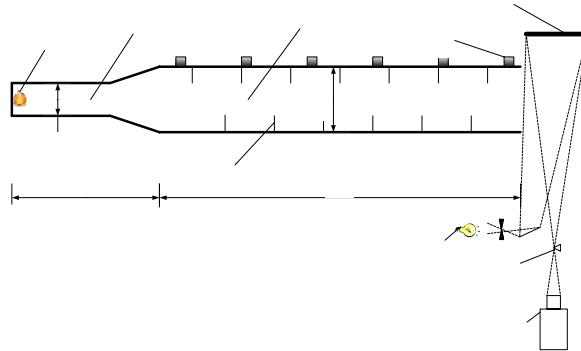


Figure 1. Sketch of experimental apparatus

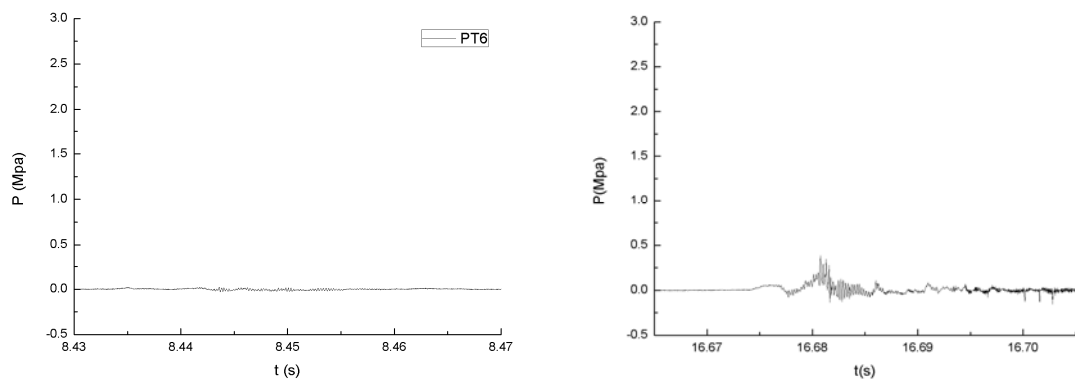
Six kinds of acetylene-air mixture were tested. Table 1 shows the experimental conditions. The unburned gases were mixed well before entering into pre-combustor, and sent to main combustor at a constant velocity. All the sections are initially evacuated to approximately 1atm.

Table 1: Experimental conditions

C ₂ H ₂ +air	Case 1	Case 2	Case3	Case 4	Case 5	Case 6
Equivalence ratio ϕ	<0.27	0.27	0.38	0.5	0.75	0.91

3 Results and discussion

For the case1, $\phi < 0.27$ and the ignition was failed in the experiment. All the values of relative pressures are zero, and not any flame is appeared in the external flow field. For the other cases, different flames were found in the external flow field, the pressure profiles are showed in Fig. 2 at PT6 (the sixth pressure transducer). Fig.3 shows the schlieren photographs of case2 to case5. For the case6, schlieren optical system was disturbed by the shake of detonation in the experiment and the photographs are not clear .



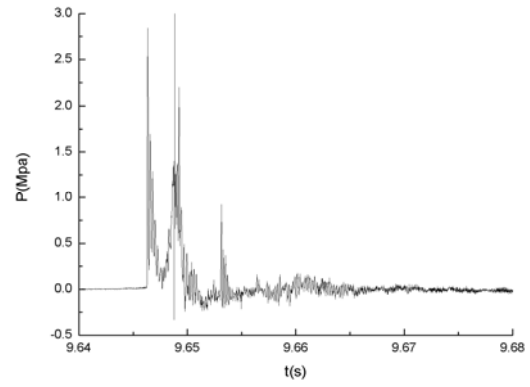
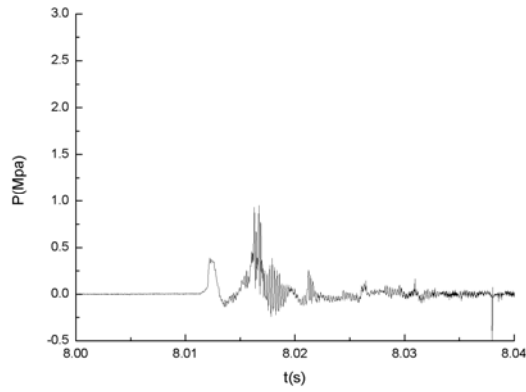
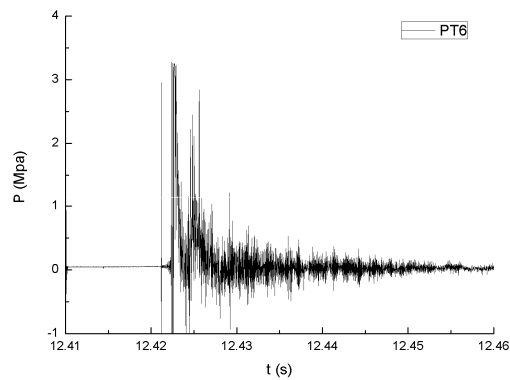
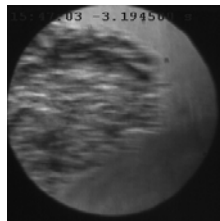
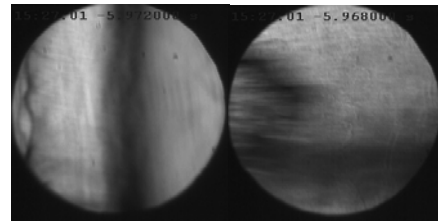
(a) $\phi = 0.27$ (b) $\phi = 0.38$ (c) $\phi = 0.5$ (b) $\phi = 0.75$ (e) $\phi = 0.91$

Figure 2 Pressure profiles for case2 to case6 at PT6

(a) $\phi = 0.27$ (b) $\phi = 0.38$

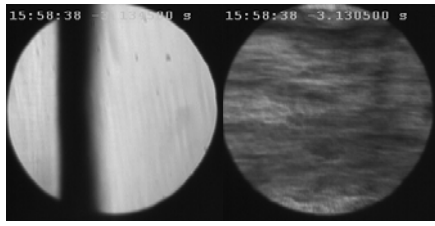
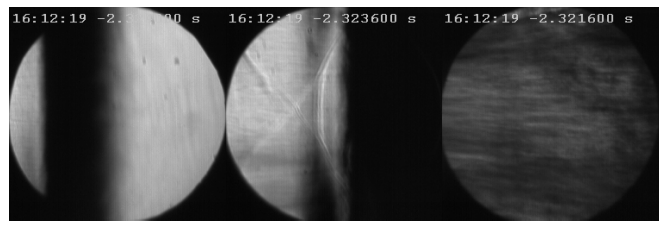
(c) $\phi = 0.5$ (d) $\phi = 0.75$

Figure 3 Schlieren photographs for case2 to case5. The number on right upper picture is the shooting end time. The left number is the interval before the shooting end time.

The pressure value of $\phi = 0.27$ at PT6 is nearly zero in Fig. 2a. and the turbulent flame is appeared in the external flow field (Fig.3a). It can be considered the general Iso-pressure combustion. The flame velocity can not calculate by the pressure profile.

For $\phi = 0.38$, there are two high-pressure regions in the pressure profile. The deflagration wave velocity is 362.5m/s between PT1and PT2, and low to 227 m/s between PT5 and PT6. The shock velocity between PT1and PT2 is created by small pre-combustor, but $\phi = 0.38$ is not enough to keep the shock. At the end of tube, the deflagration wave is composed of weak precursor compression wave and turbulent flame. For that the position of schlieren field-of-view is close to PT6 at the open end, the external flow field is closely related with PT6. Two high-pressure regions in Fig.2b and two typical photographs in Fig.3b are coroponding to precursor compression wave and turbulent flame.

For $\phi = 0.5$, the deflagration wave velocity is 381.8m/s between PT1and PT2, and up to 405 m/s between PT5 and PT6. The flame is kept steady by the equivalence ratio of 0.5 and obstacles. The deflagration wave is composed of precursor shock and turbulent flame at the end of tube. Two clear high-pressure regions in Fig.2c and two typical photographs in Fig.3c are coroponding to the shock and turbulent flame. The precursor shock is weakened with thickening wave front in external flow field, and the precursor shocks and flame are separated outside the tube.

For $\phi = 0.75$, the deflagration wave velocity is 401.1m/s between PT1and PT2, and up to 502 m/s between PT5 and PT6. The flame id strengthened by obstacles and compressed and accelerated by the precursor shock. This incident shock reaching the tube wall and obstacles create complicated reflect shocks. The reflect shocks strengthen the incident shock and flame wave at the same time. The flame pressure peak at PT6 has risen to 3.0Mpa in Fig.3d which can be considered as detonation flame pressure. The deflagration wave is composed of precursor shock and turbulent flame at the end of tube. Three typical photographs in Fig.3d are coroponding to shock, reflect shocks and turbulent flame.

For $\phi = 0.91$, the flame velocity is increased to 1720m/s between PT5 and PT6 . At the end of tube, precursor shock and turbulent flame are coupled (Fig.2e), and the detonation is performed. Fig.4 shows the whole process of DDT for $\phi = 0.91$.

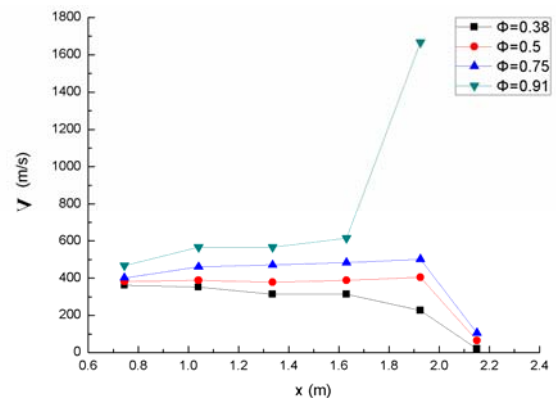
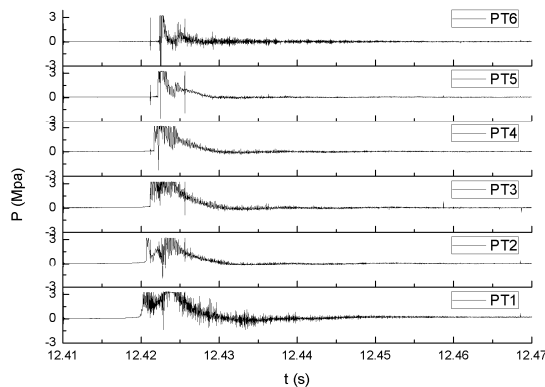


Figure 4. Pressure profiles $\phi = 0.91$

Figure 5. Velocities for different cases

From all the cases, it can be seen that the equivalence ratio and obstacles play the important roles in DDT. The flame velocity trend is showed in Fig.5 for different cases. The external field flame velocity is calculated by the photographs. We can see that flame velocity is decreased $\phi = 0.38$, almost steady for $\phi = 0.5$, and increased for $\phi = 0.75, 0.91$. For the enough equivalence ratio, the obstacles accelerate the flame to detonation.

4 Concluding remarks

In conclusion, an experimental study on the flame acceleration and deflagration-to-detonation transition of acetylene-air mixtures has been performed.

The flame acceleration process can be separated to five stages: turbulent flame, compression pressure waves and turbulent flame, precursor shock and turbulent flame, precursor shock and reflect shocks and turbulent flames, detonation.

The equivalence ratios and obstacles play the important roles in deflagration-to-detonation transition. The flame velocity is decreased $\phi = 0.38$, almost steady for $\phi = 0.5$. For the enough equivalence ratio, the obstacles enhance deflagration to detonation.

References

- [1] W.R. Chapman, R.N.V. Wheeler, J. Chem. Soc. London(1926) 2139–2147.
- [2] K.I. Shchelkin, Zh. Eksp. Teor. Fiz. 10 (1940) 823–827
- [3]. D. Bradley, M. Lawes, Kexin Liu Combustion and Flame 154 (2008) 96–108
- [4]. Oran, Elaine S Gamezo, Combustion and Flame, 2007, 148(1-2): 4-47
- [5]Khokhlov, A.M. and E.S. Oran. Combustion and Flame, 1999. 119(4): p. 400-416.
- [6]Gamezo, V.N., A.M. Khokhlov, and E.S. Oran, Proceedings of the Combustion Institute, 2002. 29(2): p. 2803-2808.
- [7] Gamezo, V.N., T. Ogawa, and E.S. Oran, Combustion and Flame, 2008. In Press, Corrected Proof.
- [8]Meyer T. R., Hoke J. L., and M. S. Brown, et al. 2002.AIAA 2002-3720
- [9] Farinaccio . R, Harris P.G. , and Stowe R.A. 2004.AIAA 2004-3917