

Simultaneous 50kHz Schlieren and OH-PLIF Measurements of Shock-Induced Combustion in High-Mach-Number Flows

Yiyun Du^{1,2}, Lang Wang¹, Rongqin Luo^{1,2}, Jinkun Xiong^{1,2}, Xiaoyuan Zhang¹, Lianjie Yue^{1,2}, and Qili Liu^{1,2,*}

1: Institute of Mechanics, Chinese Academy of Sciences, China

2: School of Engineering Science, University of Chinese Academy of Sciences

* Corresponding author: qililiu@imech.ac.cn

Keywords: OH-PLIF, Shock-Induced Combustion, High-Mach-Number

ABSTRACT

This study investigates shock-induced combustion within a scramjet combustor under a Mach 8 inflow condition. Direct-connect combustion experiments were conducted in a detonation-driven shock wind tunnel, with hydrogen injected into the combustor via struts. A wedge was employed to generate an oblique shock wave to induce combustion. Simultaneous high-speed schlieren and PLIF (Planar Laser-Induced Fluorescence) were utilized to resolve the flame structure and the underlying physical mechanisms of shock/shock and shock/boundary layer interactions. For OH-PLIF measurements, a self-developed high-repetition-rate burst-mode ultraviolet laser system was employed. This system features an intra-burst frequency of 50 kHz, a burst duration of 20 ms, and a temporal sequence of 1000 sub-pulses. It exhibits a power stability better than 0.79% over one hour, an intra-burst pulse energy uniformity of less than 0.86%, and supports continuous tuning over the wavelength range of 280 nm to 287 nm. These capabilities enabled OH-PLIF measurements under high-Mach-number (Mach 8) inflow conditions with a wind tunnel effective operating time of approximately 9.5 ms, achieving an acquisition frequency of 50 kHz. This provided critical insights for resolving the unsteady flame characteristics at high Mach numbers. In addition, pressure transducers mounted on the lower wall of the combustor provided time-resolved pressure data to complement the optical diagnostics. Experimental results reveal the unsteady characteristics of non-ideal detonation combustion within the combustor. It is observed that fuel combustion initiates within the high-temperature boundary layers, generating a separation shock wave. This separation shock wave subsequently interacts with the oblique shock wave from the wedge, leading to Mach reflection and promoting upstream flame propagation. The pressure data corroborate the optical observations, showing sequential pressure rises from the downstream to the upstream sections as the high-pressure region moves forward. Furthermore, the results indicate that the combustor length for shock-induced combustion ramjets should not be excessively long. An overly extended combustor allows the shock wave to continuously compress the incoming flow, significantly shortening the ignition delay distance of the fuel. Consequently, the fuel tends to auto-ignite within the boundary layer, which disrupts the stability of the intended shock-induced combustion mode and may lead to undesirable upstream flame propagation and potential engine unstart. Therefore, optimal combustor length is critical to balancing sufficient compression for ignition and avoiding adverse boundary-layer auto-ignition. Overall, this study provides insights into the transient dynamics of non-ideal detonation and offers practical guidance for the design of robust shock-induced combustion engines.

1. Introduction

As the representative configuration of hypersonic air-breathing propulsion systems, scramjet engines encounter a pronounced thrust deficiency at elevated flight Mach numbers (Ferri, 1964; Rubins & Bauer, 1994). This challenge necessitates the development of combustion strategies characterized by high efficiency and low aerodynamic resistance. Shock-induced combustion refers to the rapid combustion that occurs when a combustible gas mixture reaches its auto-ignition temperature upon being compressed by a shock wave. This mode of combustion offers advantages such as rapid heat release rate and high thermal cycle efficiency, which can shorten the combustor length, reduce frictional drag within the combustor, and decrease engine weight (Kailasanath, 2000; Wolański, 2013), has emerged as a viable approach and has been implemented in combustor designs. The application of shock-induced combustion to engine propulsion has led to the development of three configurations: the pulse detonation engine (PDE) (Kasahara et al., 2009; Starikovskiy & Aleksandrov, 2013), the rotating detonation engine (RDE) (Lu & Braun, 2014; Rankin et al., 2017), and the oblique detonation engine (ODE) (Veraar et al., 2009; Zhang et al., 2022). Among these, the oblique detonation engine has attracted attention due to its simple structure and its ability to provide a sustained thrust.

Most studies on shock-induced combustion are based on assumptions of two-dimensional, inviscid, premixed fuel conditions in an open space (Miao et al., 2018; Teng et al., 2014; Wang et al., 2015). However, actual oblique detonation engines involve issues such as fuel mixing, pre-ignition suppression, and shock/shock as well as shock/boundary layer interactions. Due to the stringent grid resolution requirements for simulating shock-induced combustion, it is challenging to perform numerical simulations of a full-scale, three-dimensional combustor of a shock-induced combustion ramjet. Therefore, direct-connect combustion experiments are necessary to investigate the combustor of a shock-induced combustion ramjet.

Owing to the extreme inflow velocity characteristic of high-Mach-number engines, the flow residence time within the combustor is limited to milliseconds only. Capturing the transient dynamics of such flows thus necessitates diagnostic techniques with high temporal resolution, such as laser-based measurements. PLIF (Planar Laser-Induced Fluorescence) is an optical measurement technique with high spatial and temporal resolution, used for combustion diagnostics and fluid mechanics' research. The OH radical is a key intermediate species in the combustion reaction chain of hydrocarbon fuels (including hydrogen) and exists primarily in the high-temperature burned gas region and the flame front. Therefore, by exciting naturally occurring OH radicals in the flame with a laser and detecting their fluorescence signal, the location, morphology, and intensity of the high-temperature reaction zone can be determined. OH-PLIF is

commonly used to identify the flame front position, the morphology of the high-temperature reaction zone, and whether the flame is stable. OH-PLIF has been applied by many studies to supersonic combustors (Fulton et al., 2016; Fureby et al., 2015; Li et al., 2017; Tian et al., 2016). However, for high-Mach-number direct-connect combustion experiments, the effective operating time of the wind tunnel is short, on the order of several milliseconds. To capture high-frequency OH-PLIF images, a laser source with a short pulse-to-pulse interval is required. In addition, due to the low static temperature and static pressure of the high-Mach-number incoming flow, increasing the pulse energy of the laser source is required to achieve a higher signal-to-noise ratio and hence image quality. Besides, in shock-induced combustion ramjets, the flame structure and heat release distribution are closely coupled with shock/shock and shock/boundary layer interactions. Therefore, it is necessary to develop simultaneous high-speed schlieren and PLIF measurement techniques, employing schlieren visualization to reveal the flow field structure and shock wave distribution, and PLIF to characterize the combustion distribution and flame structure. In this study, direct-connect combustion experiments are conducted in a detonation-driven shock tunnel. A self-developed tunable ultraviolet laser with an intra-burst frequency of 50 kHz and a burst duration of 20 ms was employed for laser-induced fluorescence measurements. By employing synchronized schlieren imaging and planar laser-induced fluorescence (PLIF), which helps resolve the flame structure with high spatiotemporal resolution, revealing key mechanisms of flame stabilization and combustion dynamics in the shock-induced combustion flowfield.

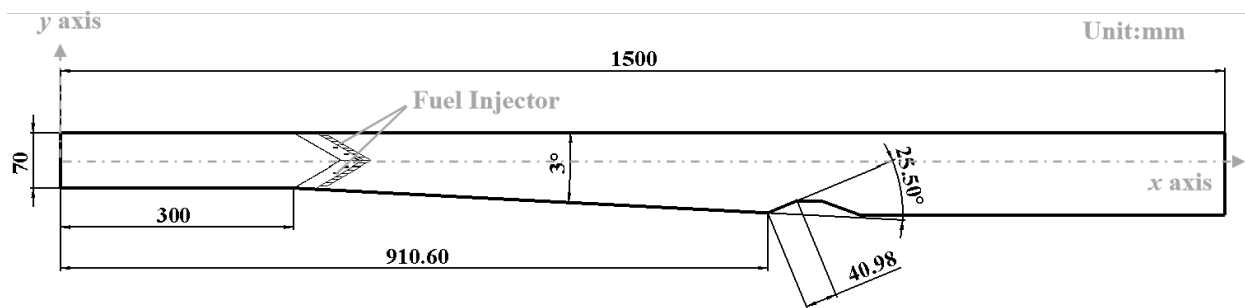
2. Experimental Setup

This study employs the JF-24 detonation-driven high-enthalpy shock tunnel developed in Institute of Mechanics, Chinese Academy of Sciences. The tunnel comprises a shock tube, a Laval nozzle, a test section, and a vacuum chamber. The 23-meter-long shock tube consists of three distinct sections separated by diaphragms: a relief section, a driver section, and a driven section. Utilizing reverse detonation-driven technology, the tunnel generates shock waves to compress air stored in the driven section, achieving high-pressure and high-enthalpy conditions required for flight simulations. The compressed air is subsequently accelerated to supersonic velocities through the Laval nozzle, forming the inflow for the test section. A vacuum chamber connected to the test section outlet maintains low backpressure conditions during wind tunnel operation. In this study, a scramjet model is designed for a nominal flight condition of Mach 8, with a total temperature of 2,900 K and a total pressure of 15 MPa as shown in Table 1. The high-enthalpy, shock-compressed air is accelerated through a Mach 5.4 Laval nozzle to generate the combustor inflow conditions.

Table 1 Computed flow conditions of the high-enthalpy air freestream

Flow conditions	Values
Stagnation temperature (K)	2900
Stagnation pressure (MPa)	15
Mach number	8

Figure. 1 presents the configuration of the direct-connect test section in the detonation-driven shock tunnel. The direct-connect combustor model with a constant-area isolator is coupled to the JF-24 nozzle exit. The combustor features a rectangular cross-section with a horizontal upper wall. The lower wall is composed of a 300-mm constant-area isolator, followed by a 610-mm section with a 3° divergence, a wedge with a 25.5° inward compression angle, and a subsequent horizontal segment. The wedge is employed to generate an oblique shock wave for combustion induction. Optical access windows are installed on both sides of the test section for high-speed optical diagnostics. The laser sheet for planar laser-induced fluorescence is formed by an optical path conversion system above the combustor and is injected transversely into the high-speed flow. Gaseous hydrogen at room temperature is used as the fuel in the experiment.

**Figure. 1** Dimensions of combustor model.

For optical diagnostics, schlieren photography was employed to resolve the shock structure, while PLIF was simultaneously used to characterize the combustion distribution and flame structure. The OH-PLIF measurements were performed using a inhouse-developed, high-repetition-rate, burst-mode tunable ultraviolet laser system. A schematic of this system is presented in **Error! Unknown switch argument.**, where it can be seen that the system consists of a home-built Diode-pumped solid-state (DPSS) laser and a customized dye laser (LIOPSTAR-HQ+PDA). The DPSS laser features a master oscillator power amplifier (MOPA) configuration and integrates five key modules: a seed laser source, a burst train generation unit, a beam control unit, a power amplification unit, and a harmonic generation unit. A Spectra Physics Explorer-1064 laser acts as the seed source, producing 1064 nm pulses with a pulse energy of 26 μJ , a duration of 8.57 ns, and

a repetition rate of 50 kHz. Through local gain amplification, the burst train generation unit modulates these seed pulses at a specific repetition rate to form a burst train sequence. Following this, the beam control and power amplification units operate in concert to amplify the μJ -level pulses progressively to the mJ level. Finally, the harmonic generation unit converts the 1064 nm laser to 532 nm via frequency-doubling, and this output is used to pump the dye laser. The dye laser itself comprises four modules: an oscillator stage, an amplification stage, a frequency-doubling module, and a Pellin–Broca prism spectral splitting module. The complete laser system generates bursts with an intra-burst frequency of 50 kHz and a burst duration of 20 ms, each burst containing 1000 sub-pulses. The system demonstrates a power stability better than 0.79% over one hour, and an intra-burst pulse energy uniformity (i.e., pulse-to-pulse stability) of less than 0.86%. Moreover, the laser is continuously tunable across the wavelength range from 280 nm to 287 nm. The successful development of this high-repetition-rate, burst-mode ultraviolet laser provides crucial hardware support for high-speed laser-induced fluorescence diagnostics and is expected to enable quantitative measurements of vibrational temperature and species concentrations in high-enthalpy non-equilibrium flows.

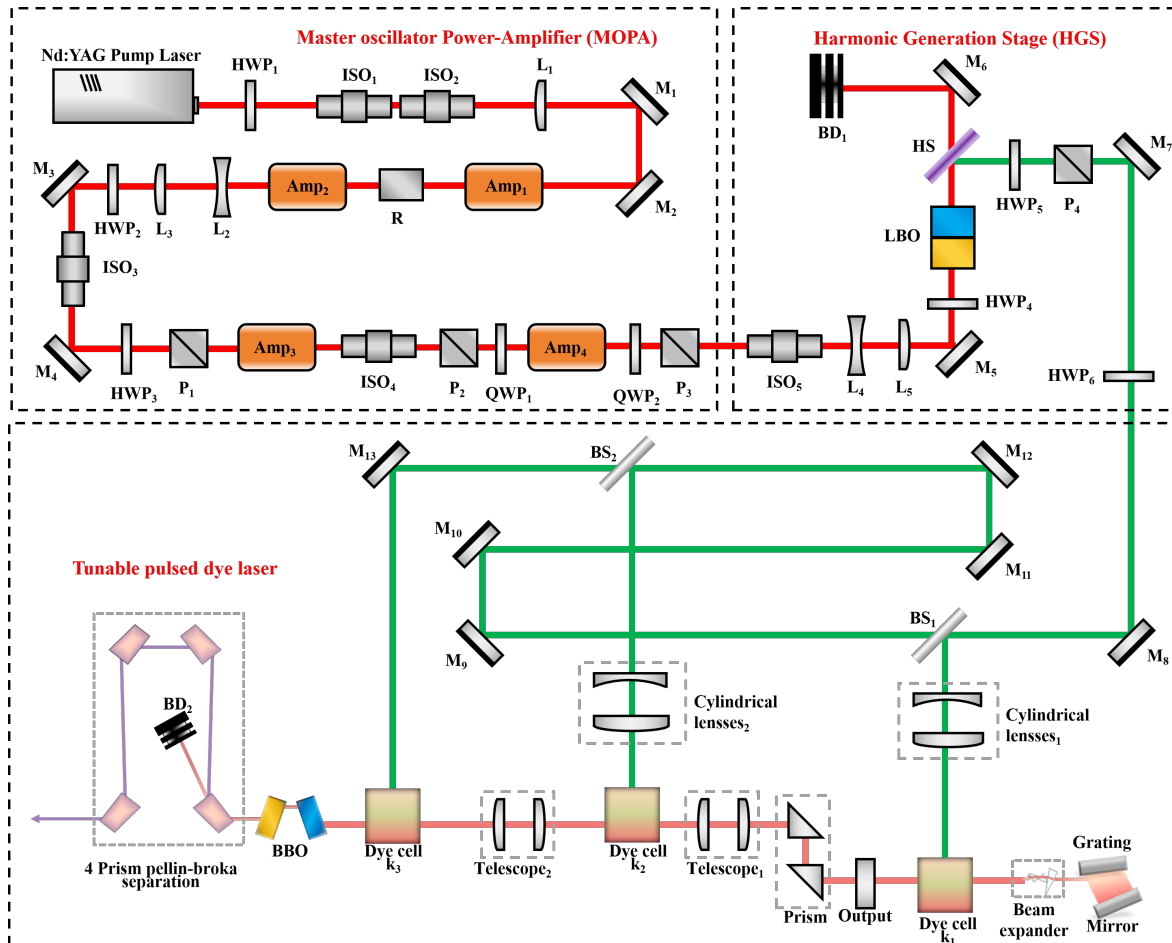
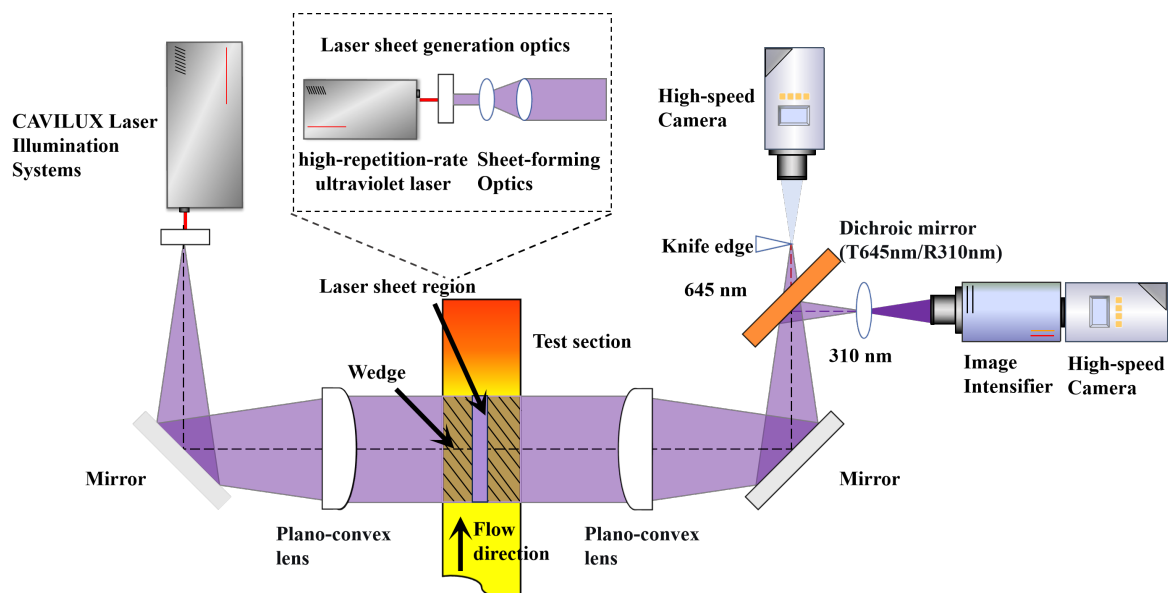


Figure. 2 Optical configuration of a high-repetition-rate, pulse-train ultraviolet laser

The schematic diagram of the optical path is shown in Figure. 3: A pulsed Nd: YAG laser, frequency-doubled to 532 nm, pumps a high-repetition-rate dye laser, whose output is wavelength-tuned to 283 nm. This beam is then formed into a laser sheet by a sheet-forming lens assembly and introduced into the flowfield through the optical window on the upper wall of the combustor, perpendicular to the mainstream direction. For schlieren measurements, a high-frequency laser source (CAVILUX Laser Illumination Systems) emits a laser beam at a wavelength of 640 nm. The beam first passes through a plano-convex lens (made of Corning 7980) for collimation, and is then introduced into the combustor through a side-wall optical window. After traversing the test section, both the schlieren signal and the OH-PLIF fluorescence signal exit the combustor, are reflected by a mirror, and subsequently pass through a plano-convex lens (also Corning 7980) for beam conditioning. The combined beam then impinges on a dichroic mirror. The dichroic mirror exhibits 99% reflectivity in the 300–400 nm range and 95% transmittance in the 440–1100 nm range. For OH-PLIF, the excitation targets the $P_1(1)$ line of the $A^2\Sigma^+ - X^2\Pi(1,0)$ electronic transition band at a wavelength of 282.254 nm (tuning near 283 nm, with fluorescence near 310 nm). The resulting OH fluorescence signal is reflected by the dichroic mirror and collected by an intensified charge-coupled device (ICCD) camera. An optical bandpass filter (Asahi, 310 ± 5 nm) is mounted in front of the camera lens to mitigate interference from flame radiation and other stray light. Meanwhile, the schlieren signal (640 nm) is transmitted through the dichroic mirror, passes through a knife edge, and forms schlieren images on another high-speed camera. The temporal resolution of this laser diagnostic system reaches 50 kHz.

**Figure. 3** Schematic of the overall arrangement.

3. Results and Discussion

The transient process of unsteady combustion and upstream flame propagation is captured by the pressure evolution. Pressure contour plots in the x - t plane and the time histories of the free stream, fuel injection pressure, and ignition TTL (Transistor-Transistor Logic) signal are shown in Figure. 4. At approximately $t = 20$ ms, the wind tunnel sends an ignition signal. The shock tunnel generates high-temperature and high-pressure gas through hydrogen-oxygen detonation, which is then accelerated via a nozzle. Following the ignition TTL signal, the solenoid valve controlling fuel injection is triggered. At around $t = 28$ ms, the fuel injection pressure reaches the preset value corresponding to an equivalence ratio of 1.0. Simultaneously, the total pressure measurement point at the upstream of the combustor registers a jump, indicating that the incoming flow has arrived upstream of the combustor. After the total pressure jumps, it takes approximately 0.5 ms to reach a steady state, which lasts for about 9.5 ms. Thus, the effective test time for each run is 9.5 ms. In the pressure x - t contour plot, after the incoming flow reaches the combustor, the highest pressure is observed at the measurement point located at approximately $x = 910$ mm behind the wedge, indicating the formation of an oblique shock wave. This oblique shock wave reflects off the combustor wall, creating a high-pressure region at the measurement point near $x = 1200$ mm. From approximately $t = 29$ ms to $t = 34$ ms, an unsteady combustion process can be observed within the combustor, during which the high-pressure region at the downstream end of the combustor progressively moves upstream and eventually stabilizes at around $x = 700$ mm.

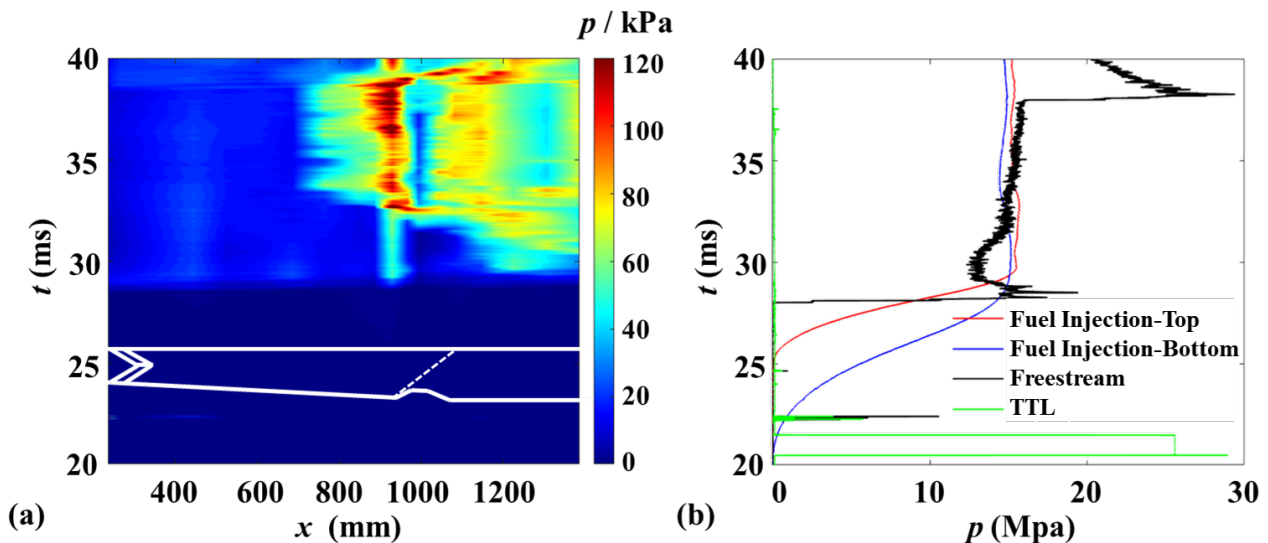


Figure. 4 (a) Pressure contour in x - t plane (b) Pressure histories of freestream, fuel injection and TTL.

As shown in Figure. 5, simultaneously schlieren and PLIF images were captured at the wedge location, with an acquisition frequency of 50 kHz. The moment when the incoming flow arrives at the wedge is taken as the time zero ($t = 0$ ms). The images record the unsteady combustion process during the effective test time from $t = 0$ ms to $t = 9$ ms. From $t = 0$ ms to $t = 2$ ms, the oblique shock wave at the wedge remains stable. At $t = 3$ ms, combustion gases propagating upstream from the downstream of the combustor, accompanied by a separation shock wave, interact with the oblique shock wave at the wedge. This interaction causes the oblique shock wave at the wedge to become detached and propagate forward continuously. The process of oblique shock detachment occurs within 1 ms, from $t = 3$ ms to $t = 4$ ms. Along with the detachment of the oblique shock wave, the combustible mixture inside the combustor undergoes combustion, and the OH distribution fills the entire imaging field of view.

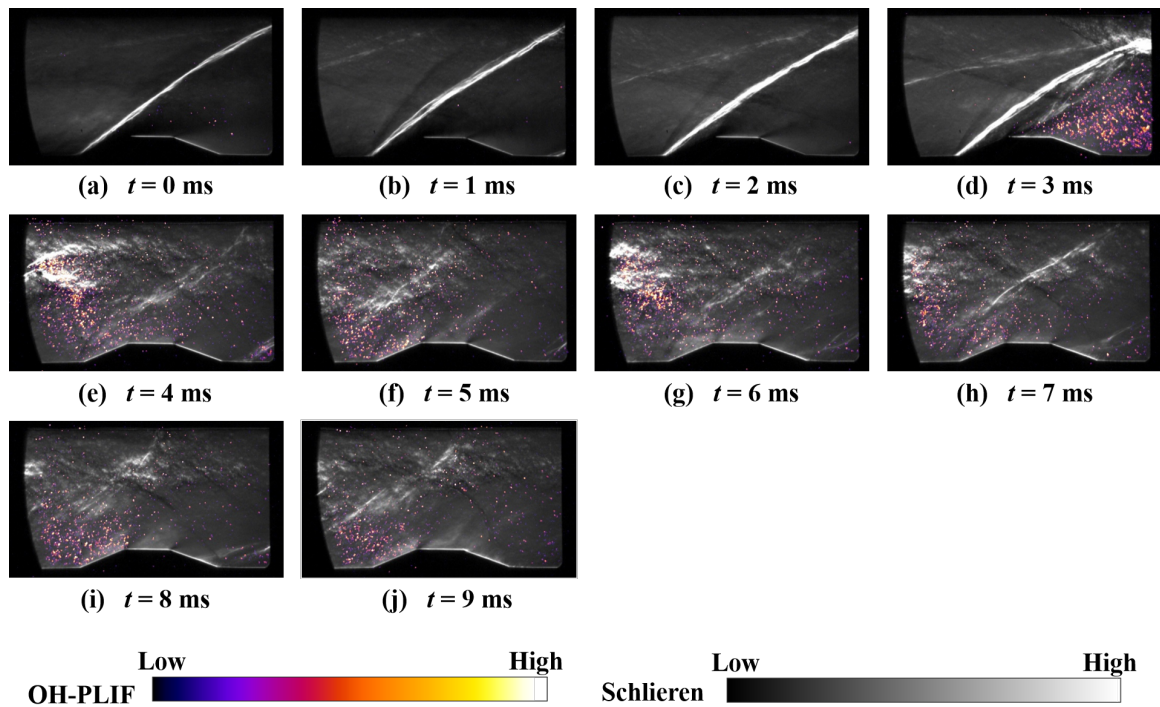


Figure. 5 Simultaneously captured schlieren and PLIF images from $t = 0$ ms to $t = 9$ ms

The pressure sensor data acquired from the lower wall of the combustor also reflect the unsteady combustion process within the combustor. Sensor data from six pressure measurement points, P1 to P6, are presented in Figure. 6. At approximately $t = 28.5$ ms, the pressure at P1–P6 begins to rise, indicating the arrival of the incoming flow in the combustor. At around $t = 29.5$ ms, the pressure at point P6 is the first to jump, followed by a continuous increase in pressure at P5. At approximately $t = 31.5$ ms, the pressure at P4 rises rapidly, indicating that the high-pressure region

downstream of the combustor has reached the location of P4, which is consistent with the schlieren imaging results. Subsequently, the pressure at P3 also rises sharply, indicating the continued upstream movement of the high-pressure region. At about $t = 32.5$ ms, the pressure at P2 increases rapidly, indicating that the oblique shock wave has become detached. The detachment process occurs within 1 ms. At approximately $t = 33$ ms, the pressure at P1 begins to rise and then decreases continuously, indicating that the detached shock wave oscillates in the vicinity of this measurement point and eventually stabilizes near this location.

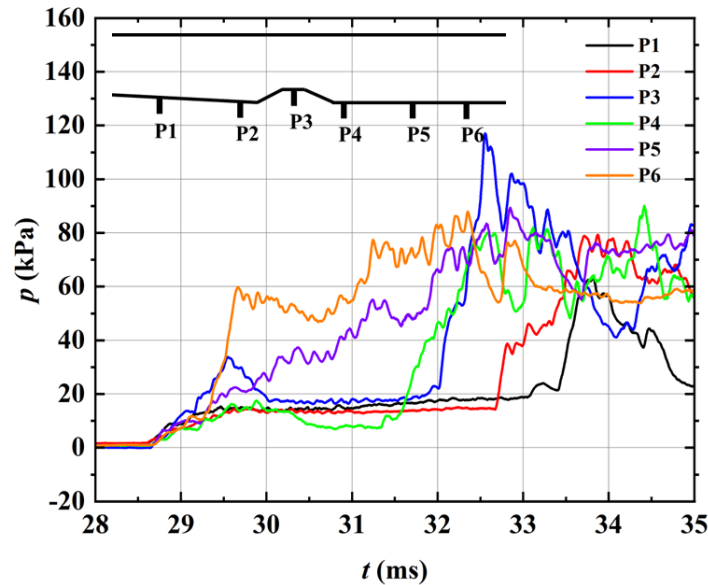


Figure. 6 Time-variant surface pressure at P1-P6

To investigate the evolution of the detached shock wave downstream of the combustor, simultaneously captured schlieren and PLIF images from $t = 2.24$ ms to $t = 2.46$ ms, with an interval of 0.02 ms between images, are illustrated in Figure. 7. At $t = 2.24$ ms, no OH signal is observed behind the oblique shock wave at the wedge, indicating that under this Mach 8 condition, the static temperature and static pressure of the incoming flow are low. Consequently, the static temperature and pressure behind the oblique shock wave are insufficient to induce fuel combustion. However, a separation shock wave originates from the downstream of the combustor and propagates continuously upstream, accompanied by an OH signal. This indicates that the separation shock wave results from the combustion of fuel in the downstream boundary layer of the combustor. Although the static temperature and static pressure of the incoming flow are low, the fuel experiences increasing temperature and pressure as it reaches the downstream region of the combustor, due to the compressive effects of the compression shock waves generated by the wedge, as well as its reflected shock waves. As a result, the ignition delay time of hydrogen is progressively shortened, ultimately leading to hydrogen combustion within the downstream

boundary layer of the combustor. The heat release from combustion reduces the gas flow velocity near the boundary layer, inducing flow separation and consequently generating the separation shock wave. Additionally, because the local incoming flow velocity decreases, the flame continuously moves upstream.

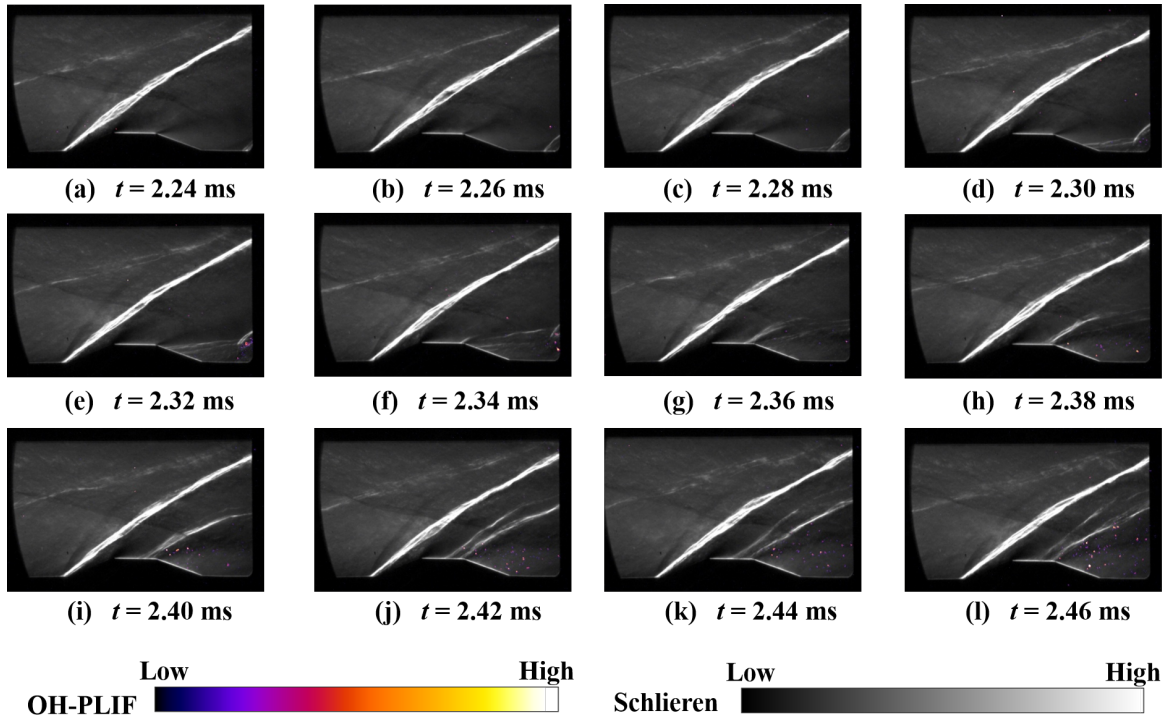


Figure. 7 Simultaneously captured schlieren and PLIF images from $t = 2.24$ ms to $t = 2.46$ ms

A representative sequence of the detached shock wave generation at the upper combustor wall is observed, driven by the interaction between the upstream-propagating separation shock and the wedge-induced oblique shock. Simultaneously captured schlieren and PLIF images from $t = 2.96$ ms to $t = 3.18$ ms, illustrating the generation process of the detached shock wave at the upper wall of the combustor, are presented in Figure. 8. As the separation shock wave generated downstream of the combustor intersects with the oblique shock wave at the wedge, the increased shock wave strength induces flow separation at the reflection point of the oblique shock wave on the upper wall of the combustor, thereby generating a separation shock wave. The flow separation reduces the local gas flow velocity, making the flow residence time longer than the hydrogen ignition delay time. This allows the fuel to combust within the separated region of the boundary layer. The heat released by combustion further expands the area of the separation zone and enhances the strength of the separation shock wave. The two oblique shock waves, from the lower and upper walls of the combustor, interact with each other and continue to propagate upstream under the effect of combustion heat release.

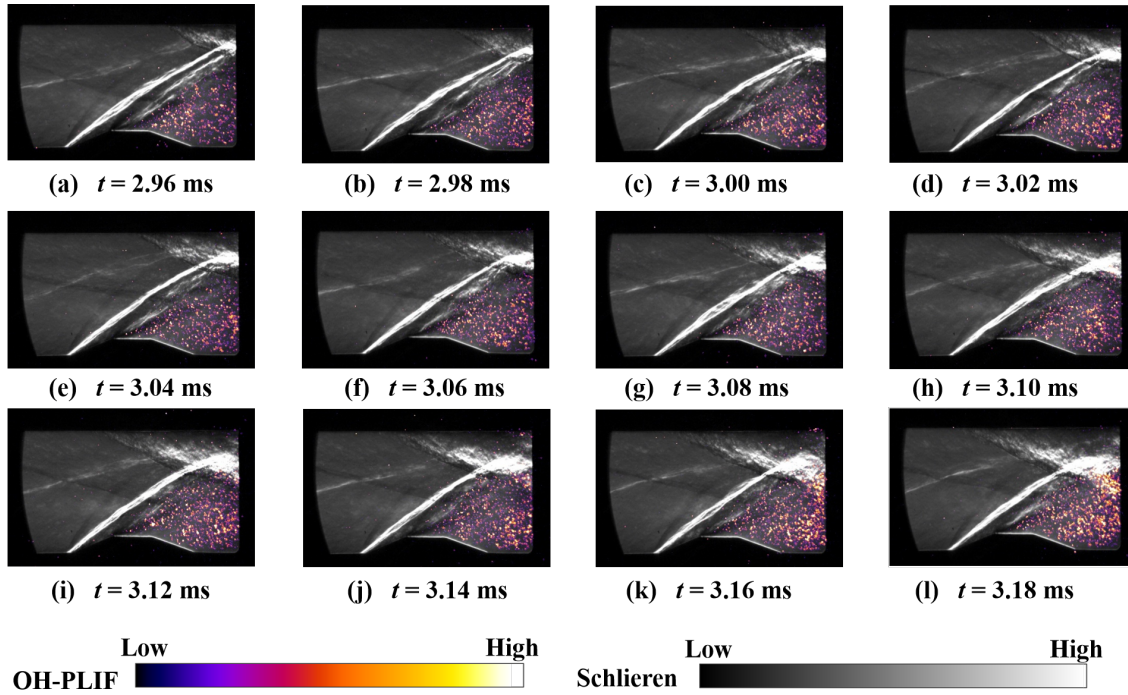


Figure. 8 Simultaneously captured schlieren and PLIF images from $t = 2.96$ ms to $t = 3.18$ ms

The interaction between the two oblique shock waves evolves into Mach reflection, followed by upstream propagation and eventual stabilization of the Mach stem within the combustor. Simultaneously captured schlieren and PLIF images from $t = 3.30$ ms to $t = 3.53$ ms are displayed in Figure. 9. The two oblique shock waves, from the lower and upper walls, interact with each other, resulting in Mach reflection and the formation of a Mach stem. Since the flow behind the Mach stem is subsonic, hydrogen combustion becomes more intense in this region, driving the Mach stem to propagate continuously upstream. Figure. 10 shows simultaneously captured schlieren and PLIF images from $t = 3.58$ ms to $t = 3.80$ ms. As the Mach stem moves upstream, the oblique shock wave at the wedge eventually becomes detached and continues to propagate upstream. When the flame speed matches the local flow velocity, the Mach stem ceases its upstream movement and stabilizes inside the combustor.

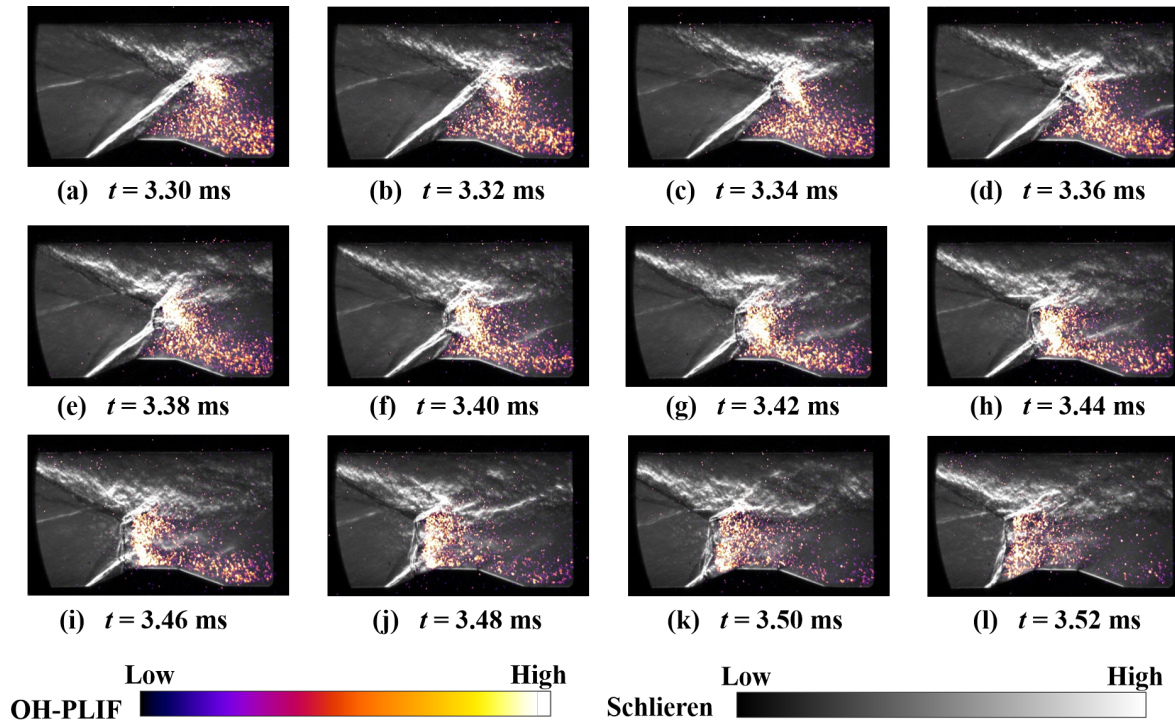


Figure. 9 Simultaneously captured schlieren and PLIF images from $t = 3.30$ ms to $t = 3.52$ ms

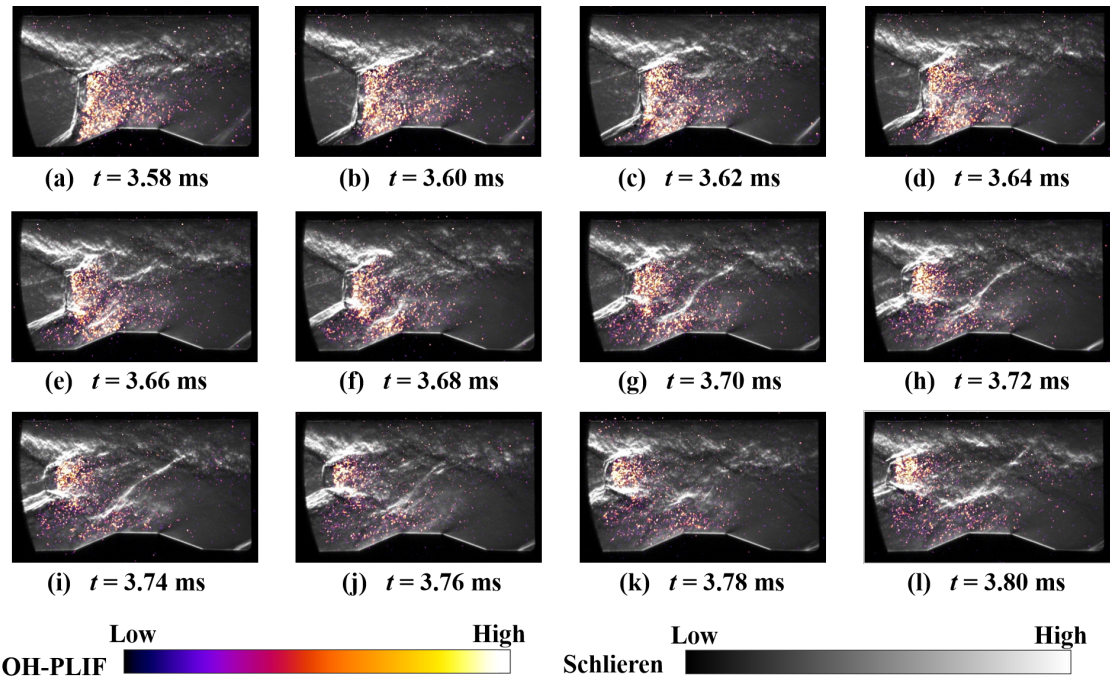


Figure. 10 Simultaneously captured schlieren and PLIF images from $t = 3.58$ ms to $t = 3.80$ ms

Under Mach 8 inflow conditions, the total temperature and total pressure of the incoming flow are 2900 K and 15 MPa, respectively. After being accelerated by a nozzle with an exit Mach number of 5.4, the static temperature and static pressure of the incoming flow are insufficient to induce shock-

wave-induced combustion directly via the oblique shock wave generated by the wedge. However, shock wave compression increases the static temperature and static pressure of the incoming flow, thereby shortening the ignition delay time of the fuel. Consequently, the fuel eventually combusts within the high-temperature boundary layer in the downstream region of the combustor. This combustion generates a separation shock wave that propagates upstream and finally stabilizes inside the combustor. These observations indicate that even under relatively low Mach number inflow conditions where direct shock-induced combustion is not achievable, if the combustor length is sufficiently long, the fuel will undergo auto-ignition due to shock wave compression, with the oblique shock wave playing an enhancing role in combustion. Furthermore, to achieve genuine shock-induced combustion, the combustor length must be carefully designed; otherwise, combustion occurring within the high-temperature boundary layer downstream of the oblique shock wave may compromise the stability of the upstream shock-induced combustion.

4. Conclusions

This study investigated the unsteady flame structure and flow-field characteristics of shock-induced combustion through direct-connect experiments at Mach 8 flight conditions. Simultaneous schlieren and PLIF imaging method was employed to capture the instantaneous unsteady flow phenomena. For scramjet engines operating at such high Mach numbers, the short ignition delay time of hydrogen fuel promotes auto-ignition readily under shock compression. The resulting flame distribution exhibits a strong, coupled interaction with the shock waves. Combustion relies on the compression provided by the shock wave and, in turn, influences the shock structure itself, exhibiting unsteady dynamic behaviors. This interaction highlights the critical importance of high-repetition-rate laser diagnostics in the development of high-Mach-number engines.

References

- Ferri, A. (1964). Review of Problems in Application of Supersonic Combustion. *The Journal of the Royal Aeronautical Society*, 68(645), 575-597. <https://doi.org/10.1017/S0368393100080391>
- Fulton, J. A., Edwards, J. R., Cutler, A., McDaniel, J., & Goyne, C. (2016). Turbulence/chemistry interactions in a ramp-stabilized supersonic hydrogen-air diffusion flame. *Combustion and Flame*, 174, 152-165. <https://doi.org/10.1016/j.combustflame.2016.09.017>
- Fureby, C., Nordin-Bates, K., Petterson, K., Bresson, A., & Sabelnikov, V. (2015). A computational study of supersonic combustion in strut injector and hypermixer flow fields. *Proceedings of the Combustion Institute*, 35, 2127-2135. <https://doi.org/10.1016/j.proci.2014.06.113>

- Kailasanath, K. (2000). Review of Propulsion Applications of Detonation Waves. *AIAA Journal*, 38(9), 1698-1708. <https://doi.org/10.2514/2.1156>
- Kasahara, J., Hasegawa, A., Nemoto, T., Yamaguchi, H., Yajima, T., & Kojima, T. (2009). Performance Validation of a Single-Tube Pulse Detonation Rocket System. *Journal of Propulsion and Power*, 25(1), 173-180. <https://doi.org/10.2514/1.37924>
- Li, X. P., Liu, W. D., Pan, Y., Yang, L. C., An, B., & Zhu, J. J. (2017). Characterization of kerosene distribution around the ignition cavity in a scramjet combustor. *Acta Astronautica*, 134, 11-16. <https://doi.org/10.1016/j.actaastro.2017.01.037>
- Lu, F. K., & Braun, E. M. (2014). Rotating Detonation Wave Propulsion: Experimental Challenges, Modeling, and Engine Concepts. *Journal of Propulsion and Power*, 30(5), 1125-1142. <https://doi.org/10.2514/1.B34802>
- Miao, S., Zhou, J., Liu, S., & Cai, X. (2018). Formation mechanisms and characteristics of transition patterns in oblique detonations. *Acta Astronautica*, 142, 121-129. <https://doi.org/10.1016/j.actaastro.2017.10.035>
- Rankin, B. A., Fotia, M. L., Naples, A. G., Stevens, C. A., Hoke, J. L., Kaemming, T. A., Theuerkauf, S. W., & Schauer, F. R. (2017). Overview of Performance, Application, and Analysis of Rotating Detonation Engine Technologies. *Journal of Propulsion and Power*, 33(1), 131-143. <https://doi.org/10.2514/1.B36303>
- Rubins, P. M., & Bauer, R. C. (1994). Review of shock-induced supersonic combustion research and hypersonic applications. *Journal of Propulsion and Power*, 10(5), 593-601. <https://doi.org/10.2514/3.23768>
- Starikovskiy, A., & Aleksandrov, N. (2013). Plasma-assisted ignition and combustion [Review]. *Progress in Energy and Combustion Science*, 39(1), 61-110. <https://doi.org/10.1016/j.pecs.2012.05.003>
- Teng, H., Zhang, Y., & Jiang, Z. (2014). Numerical investigation on the induction zone structure of the oblique detonation waves. *Computers & Fluids*, 95, 127-131. <https://doi.org/10.1016/j.compfluid.2014.03.001>
- Tian, Y., Yang, S. H., Le, J. L., Su, T., Yue, M., Zhong, F. Y., & Tian, X. Q. (2016). Investigation of combustion and flame stabilization modes in a hydrogen fueled scramjet combustor. *International Journal of Hydrogen Energy*, 41(42), 19218-19230. <https://doi.org/10.1016/j.ijhydene.2016.07.219>
- Veraar, R., Mayer, A., Verreault, J., Stowe, R., Farinaccio, R., & Harris, P. (2009). *Proof-of-Principle Experiment of a Shock-Induced Combustion Ramjet* 16th AIAA/DLR/DGLR International Space Planes and Hypersonic Systems and Technologies Conference,
- Wang, T., Zhang, Y., Teng, H., Jiang, Z., & Ng, H. D. (2015). Numerical study of oblique detonation wave initiation in a stoichiometric hydrogen-air mixture. *Physics of Fluids*, 27(9). <https://doi.org/10.1063/1.4930986>
- Wolański, P. (2013). Detonative propulsion. *Proceedings of the Combustion Institute*, 34(1), 125-158. <https://doi.org/10.1016/j.proci.2012.10.005>
- Zhang, Z. J., Wen, C. Y., Yuan, C. K., Liu, Y. F., Han, G. L., Wang, C., & Jiang, Z. L. (2022). An experimental study of formation of stabilized oblique detonation waves in a combustor. *Combustion and Flame*, 237, 5, Article 111868. <https://doi.org/10.1016/j.combustflame.2021.111868>