HiSST: 3rd International Conference on High-Speed Vehicle Science Technology

14 -19 April 2024, Busan, Korea

Observation of Hydrogen Combustion Characteristics in a Scramjet Combustor Based on Cavity Type

Geon Wook Yim[1], Hyoung Jin Lee[2]

Abstract

In a scramjet combustor, combustion characteristics were observed based on the L/D ratio of the cavity under equivalent equivalence ratio conditions. Combustion experiments were conducted at a Mach number of 2.0 and a pre-temperature of 1400 K inside the combustor. Hydrogen was used as the fuel, and the L/D ratios of the cavity were set at 7 and 12. The equivalence ratio was maintained at 0.4. The experimental results revealed a mode transition at L/D ratios of 7 and 12. At L/D 12, a mode transition occurred between cavity shear-layer stabilized combustion and cavity shear-layer/recirculation stabilized combustion. At L/D 7, a similar combustion mode transition occurred as at L/D 12, but the Jet-wake combustion mode also manifested. According to the experimental results, under the same equivalence ratio, L/D 12 exhibited more stable characteristics.

Keywords: *Scramjet, Cavity L/D, Combustion*

1. Introduction

In a scramjet combustor, since the flow remains supersonic, the residence time of the flow is extremely short. The role of flame-holder is important because fuel-air mixing and combustion must be completed quickly. Among these flame-holder, cavities are conveniently installed within the combustor and serve as low-velocity recirculation zones to sustain the flame. Cavities are classified as open or closed based on their L/D ratio, and at specific L/D values, they are categorized as transitional cavities[1]. Research on combustion characteristics in cavity-based combustors has led to the classification of combustion modes. Combustion modes are broadly classified into Cavity stabilized combustion and Jet-wake combustion, with further subcategories such as Cavity shear-layer stabilized combustion and cavity shear-layer/recirculation stabilized combustion under Cavity-stabilized combustion[2-5]. Most studies have been conducted with L/D ratios of 7 or below (open cavities), and research on combustion within closed cavities is limited. In this study, we designed cavities within a scramjet combustor with L/D ratios of 7 and 12 and conducted combustion experiments to observe combustion characteristics. Combustion experiments were conducted at a Mach number of 2.0 and a pre-temperature of 1400 K inside the combustor. Hydrogen was used as the fuel, and the L/D ratios of the cavity were set at 7 and 12. We compared the combustion characteristics observed in open and closed cavities by injecting hydrogen at the same equivalence ratio.

2. Experimental setup

The experiment was conducted using a blow-down type supersonic wind tunnel. In Fig.1, A 2D contour nozzle was employed to generate supersonic flow, followed by the placement of an isolator with a specific length at the nozzle's end, and subsequently connecting a two-dimensional combustor model. In this study, the experimental model was designed and produced as a block-type, enabling the replacement of a cavity with a different L/D ratio. During the experiment, the depth of the cavity

[1] INHA university*, Incheon Korea, ynte02@naver.com*
[2] INHA university*, Incheon Korea, hyounjin.lee@inha.ac.kr*

remained constant. The L/D was changed to 7 and 12 by adjusting the length. The ramp angle of the cavity was 20°. For the experimental data to observe the flow and flame characteristics in the combustor, images using general Schlieren visualization techniques, OH chemiluminescence, and pressure on the combustor wall were obtained.

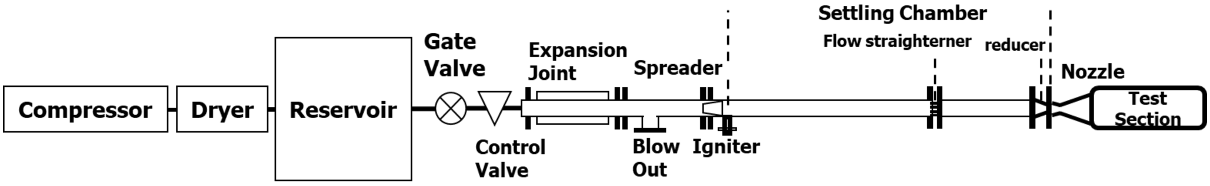

Fig. 1 Schematic of scramjet combustor test facility

3. Experimental result

At L/D 12, the Cavity shear-layer and cavity shear-layer/recirculation stabilized combustion modes were repeatedly observed during the test. In contrast, at L/D 7, three different combustion modes were observed during the test time. Similar to L/D 12, L/D 7 also exhibited the Cavity shear-layer and cavity shear-layer/recirculation stabilized combustion modes, intermittently accompanied by the Jet-wake combustion mode. Consequently, intermittent responses occurred at the pressure measurement point ahead of the injector. In Fig. 2, ① Jet-wake combustion occurs, leading to an increase in pressure at all points. In ②, the flame moves back rearward, transitioning into cavity shear-layer/recirculation combustion, causing a sharp decrease in pressure at P1 due to the flame's movement back. Subsequently, it transitions into cavity stabilized combustion mode.

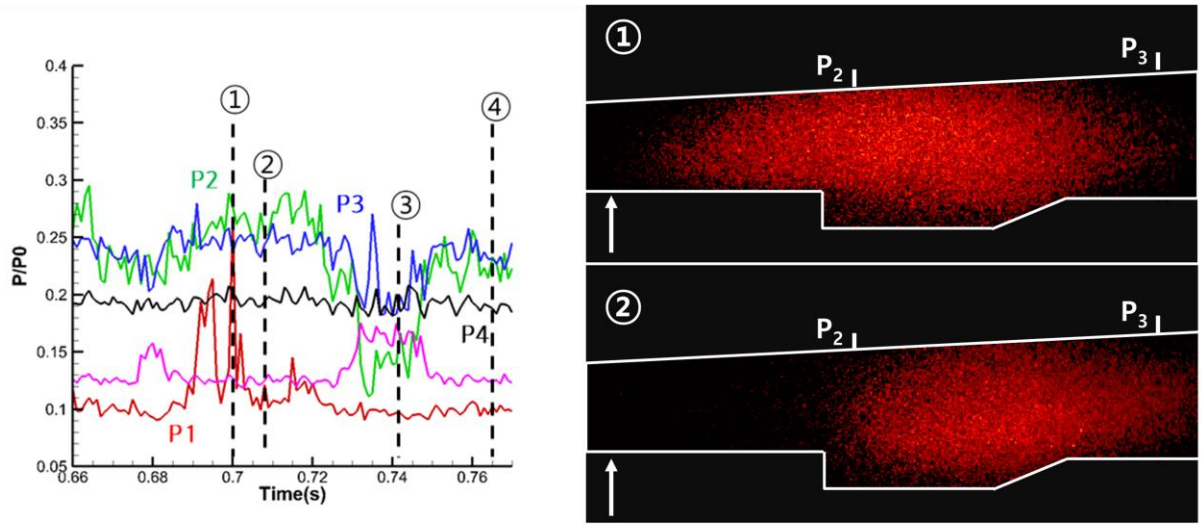

Fig. 2 Pressure & OH radical image with time (L/D = 7)

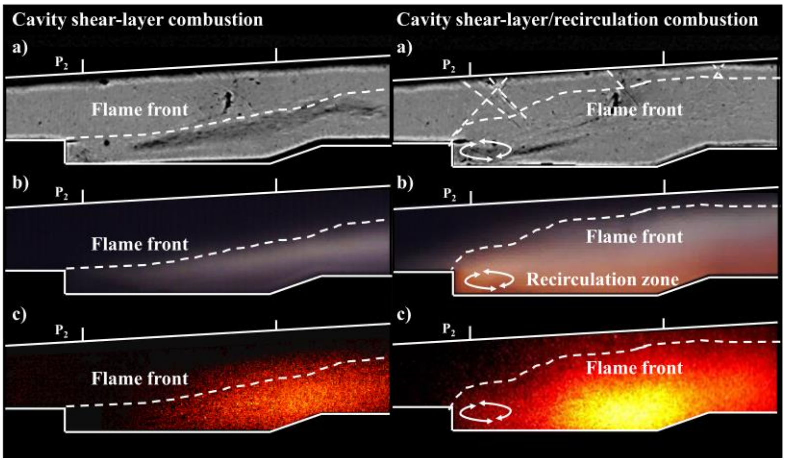

Fig. 3 Schlieren, direct and OH radical image with combustion mode (L/D = 12)

Fig. 3 shows the schlieren, direct OH radical images for each combustion mode at L/D 12. It can be seen that the shock wave is moved upstream and downstream of the combustor as the flame front moves.

4. Conclusion

Under an equivalence ratio of 0.4, we observed and compared the combustion characteristics of L/D 7 and 12. Despite having the same equivalence ratio, we observed distinct combustion characteristics between L/D 7 and 12. L/D 7 exhibited a greater transition between combustion modes, resulting in significant pressure fluctuations within the combustor. Therefore, under identical equivalence ratio conditions, L/D 12 demonstrated more stable combustion characteristics.

References

1. Palharini, R. C., Scanlon, T.J., White, C.: Chemically reacting hypersonic flows over 3D cavities: Flowfield structure characterisation. Computers and Fluids. 165, 173-187 (2018)
2. Wang, Y., Wang, Z., Sun, M., Wang, H.: Combustion stabilization modes in a hydrogen-fueled scramjet combustor at high stagnation temperature. Acta Astronautica. 152, 112-122 (2018)
3. Zhang, Y. X., Wang, Z. G., Sun, M. B., Yang, Y. X., Wang, H. B.: Hydrogen jet combustion in a scramjet combustor with the rearwall-expansion cavity. Acta Astronautica. 144, 181-192 (2018)
4. Micka DJ, Driscoll JF.: Combustion characteristics of a dualmode scramjet combustor with cavity flame-holder. Proc Combust Inst (2009). https://doi.org/10.1016/j.proci.2008.06.192.
5. Sun MB, Wang HB, Bai XS, et al.: Flame stabilization in a supersonic combustor with hydrogen injection upstream of cavity flameholders: experiments and simulations. Proc IMechE, Part G: J Aerospace Engineering. 225: 1351–1365 (2011)