Hydrogen Combustion Characteristics in Cavity-based Supersonic Combustor

Geon Wook Yim. Hyoung Jin Lee
Inha University
Incheon, Korea

1 Introduction

Recently, many countries have been making efforts to develop and operate hypersonic vehicles. The flow speed inside the supersonic combustor keeps supersonic. Since the residence time is very short, it is important to increase the effectiveness of fuel-air mixing and flame holding. For this purpose, various studies are being conducted, and it was considered that the cavity inside the combustor is one of the most realistic methods. Supersonic flow around a cavity strongly depends on the configuration of the cavity. Therefore, studies on the flow characteristics according to the configuration of the cavity were mainly performed. The effect of the length-to-diameter ratio (L/D) was conducted. According to the L/D of the cavity, Yakar and Hanson [1] called L/D <7 - 10 an open cavity in which the shear layer is attached to the rare wall of the cavity, and L/D > 10 - 13 the shear layer is attached to the bottom of the cavity. It is classified as a closed form. Wang[2] performed hydrogen injection in a single cavity and confirmed the existence of three combustion modes through direct light imaging, pressure measurements, and OH chemiluminescence. In this study, hydrogen was injected into the combustor to observe the hydrogen combustion characteristics according to the configuration of the cavity.

2 Experimental setup

The experiment was performed using a blow down type supersonic wind tunnel. The supersonic wind tunnel consists of a compressed air storage tank, on/off valve, pressure control valve, stagnation chamber, nozzle, test section, and diffuser. In this study, the test section corresponds to a combustor model. Fig. 1 shows the wind tunnel and combustor model used in the experiment. A 2D contour nozzle was used to generate supersonic flow, an isolator with a specific length was placed at the end of the nozzle, and then a two-dimensional combustor model was connected. From the nozzle to the combustor, tempered glass was used on both sides for internal visualization, and a cavity was applied to the lower part of the combustor model. In this study, the experimental model was designed and produced block type so that a cavity with a different shape can be replaced. The design Mach number of the supersonic nozzle was 2.0, and it was designed and produced with a length of 110 mm and a width of 30 mm. A height of 10 mm at the nozzle outlet. An isolator with a 100 mm length was placed downstream of the nozzle after the combustor was connected. The flow past the isolator is reduced to

Correspondence to: hyoungjin.lee@inha.ac.kr

Mach number 1.8 due to the influence of the boundary layer and then enters the combustor. The upper part of the combustor applied a diffusion angle of 3° considering the choking of the flow, and a cavity was applied to the lower part for mixing and flame holding. The cavity applied to the combustor was produced and used with L/D= 7 and 12 to observe the known open and closed characteristics. In addition, a model with a step of 1 mm in the L/D = 12 cavities backward was also produced. In the experiment, the depth of the cavity was fixed. The L/D was changed to 7 and 12 by adjusting the length. The ramp angle of the cavity was 20°.

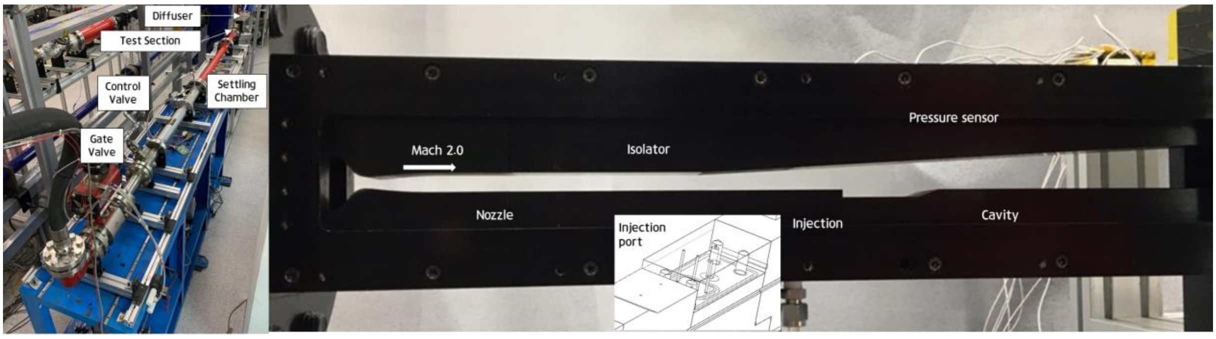

Figure 1: (Left) Vitiation air heater (right) scramjet combustor model[4].

3 Experimental measurement method

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. Schlieren images and OH chemiluminescence were obtained at 20,000 images per second using an ultra-high-speed camera. For pressure measurement, pressure sensors from Kulite and Sensys were used. The pressure in the stagnation chamber was measured using a pressure sensor from Sensys, which was set to replace the total pressure (P0) of the flow flowing into the combustor model because the ratio between the stagnation chamber and the nozzle throat was sufficiently large. The pressure was measured using the Kulite sensor on the upper surface of the combustor model.

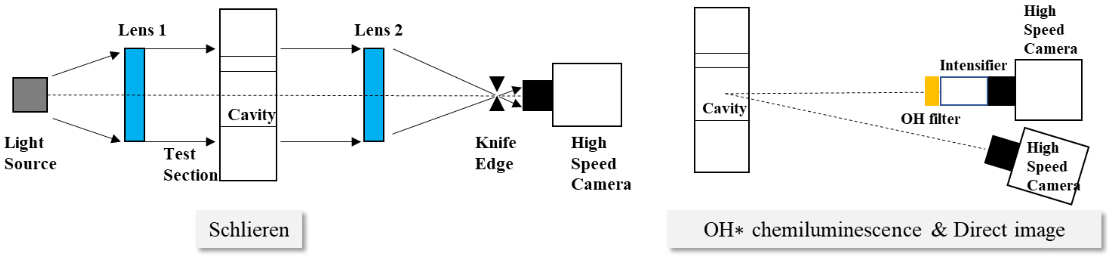

Figure 2: Visualization settings: schlieren, OH chemiluminescence & Direct image

4 Experimental Result

First, pressure measurement and visualization according to L/D were performed under non-injection conditions at a total temperature of 1350 K. Fig. 3 shows the results of schlieren visualization and pressure measurement. At L/D = 7 and 12, both showed the form of a closed cavity. In all cases, flow separation occurs at the pressure sensor P3 point, and the pressure rises. However, in models with steps, the pressure rise appears weaker than in other cases. Conversely, at point P4, the pressure decreases due to expansion in the case of the model without a step, but pressure rises again in the model with a step.

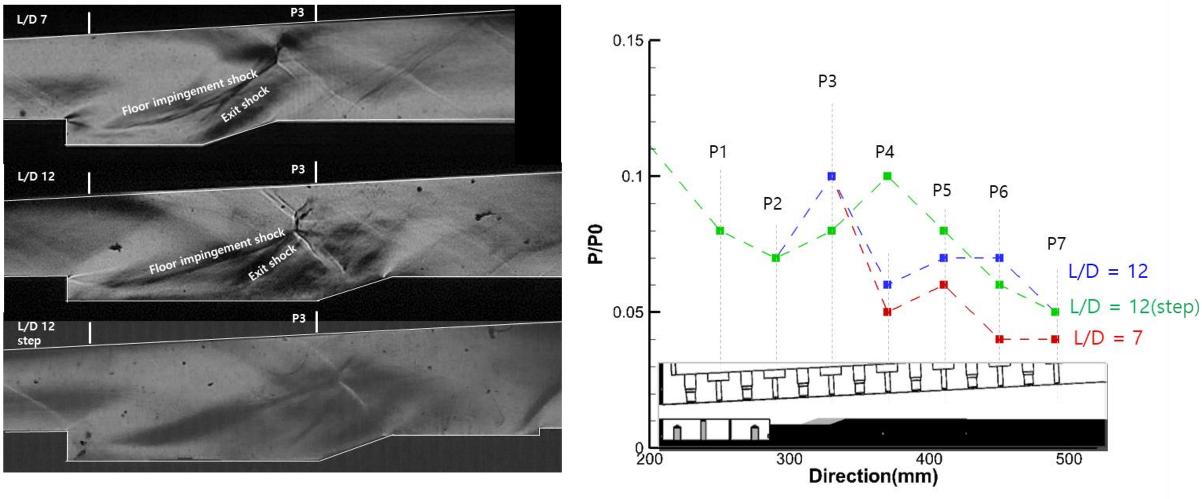

Figure 3: Flow visualization images (L/D=7,12,Step), Pressure data with x-direction [4].

Next, hydrogen was injected inside to observe combustion characteristics according to L/D. Experiments were conducted at L/D = 7 and 12 while increasing the hydrogen equivalence ratio from 0.29 to 0.54. As shown in Fig. 4, there was a pressure change due to injection, but ignition did not occur. A hydrogen injection experiment was also conducted on a model with a step difference. It was confirmed that ignition occurred inside the combustor under an equivalence ratio of 0.3. The flame vibrated during the test time, which can be verified by the pressure sensor results in Fig.4.

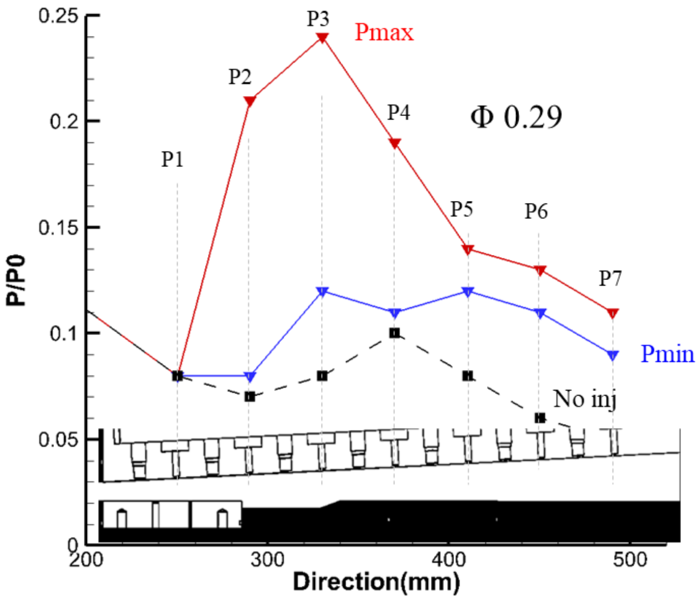

Figure 4: X-axis pressure data with combustion.

In the direct image results presented in Fig.5, the flame repeats ① ~ ④ during the test time, and the pressure value is the highest when the most flame is generated inside the cavity. The pressure value is the lowest when there is the least flame inside the cavity. Fig. 6 shows the OH chemiluminescence that resulted when the flame was initially generated. The initially injected hydrogen jet generates a flame, propagates into the cavity, and then settles inside the cavity. Afterward, it can be confirmed that the flame's intensity is weakened. This is because, after the flame is initially maintained inside the cavity by the jet, the separation of the boundary layer due to heat release interferes with the fuel transfer to the shear layer and the recirculation zone.

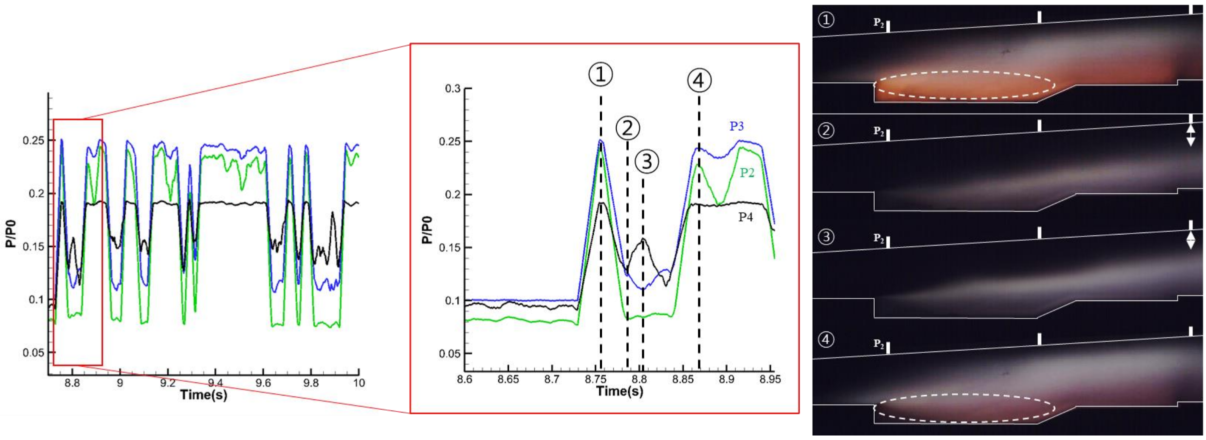

Figure 5: Pressure data with time & direct image.

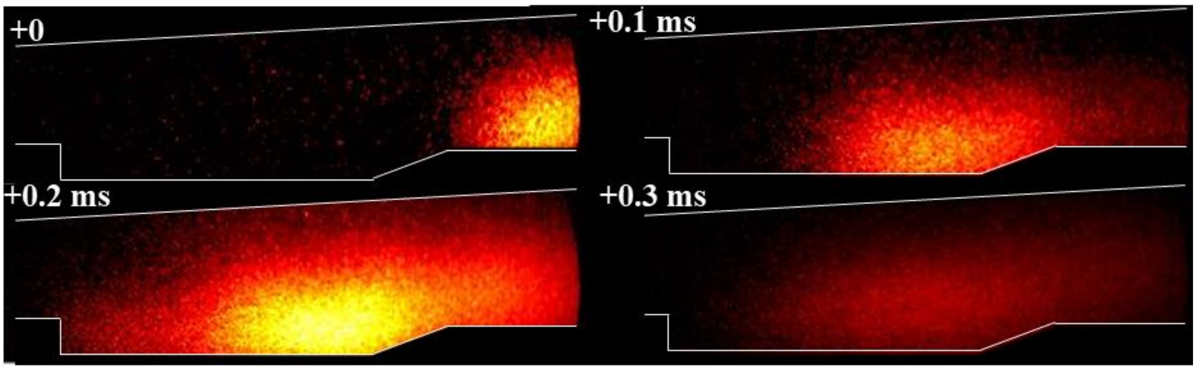

Figure 6: OH chemiluminescence image.

5. Acknowledgement

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References

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