액체 램젯트 엔진 연소기내의 이차유동 특성

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Flow Characteristics of Secondary Recirculation Region in a Liquid Ramjet Combustor

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ABSTRACT

The flow characteristics of secondary recirculation region in a liquid fuel ramjet combustor are measured using PIV method. The model combustor has two rectangular inlets that form 90 degree angle each other. The tested angles of the air intakes were 30 , 45 and 60 . Three guide vanes are installed in each rectangular inlet to improve the flow stability. The experiments are performed in the water tunnel test with the same Reynolds number as the case of Mach 0.3 at the inlet. PIV software is developed to measure the characteristics ofthe flow field in the combustor. The accuracy of the developed PIV program is verified with rotating disk experiment and standard data. The experimental results show that the secondary recirculation flow occurred at the front junction of inlet main stream and combustorchamber. The size of secondary recirculation regions are increased with increasing air inlet angles. Since the performanceof combustor is very dependant on not only the main recirculation in the dome region but also the secondary recirculation flow in a junction region, the optimal angle of the air intakes should consider the both recirculation size as a frame holder.

1. Introduction

Advantages of the liquid ramjet engine are that it reduces the size and weight of a launching site and increases the flight distance due to a direct inhalation of air and an oxidizer from the atmosphere (Kubota and Kuwahara, 1996). Recent attention has focused on the integrated liquid ramjet engine whose combustor is utilized as a booster instead of using a subsidiary booster to achieve the required ram air. The objective of the combustor design of the liquid ramjet engine is to maintain stable and efficient combustion with (Eriksson et al., 1993; Ristori et al., 1999) a variation in the intake flow field according to various flight conditions. The combustion regime in the combustor can be categorized into the areas of stabilizing and propagating the flame. The design of the combustor is required to obtain the structure of stabilizing the

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flame, which is executed by forming the recirculation areas in the combustor. Usually the recirculation zone is mainly present in a dome area, but, secondary recirculation flows can appear at the front junction of inlet main stream and combustor chamber.

In this experiment, the secondary recirculation flow characteristics of the ramjet engine combustor were measured to determine the optimal configuration. In order to achieve this purpose, PIV measurement was performed to the complex flow field in the liquid ram jet combustor.

2. Experiment

In the present study, the test sections of the combustor as shown in Figure 1 are manufactured. Several configurations of the test sections of the combustor were manufactured to determine the optimum design of the liquid ramjet engine. Figure 1 shows the test sections with the two intakes of the rectangular duct forming a 90 degree angle with each other. The tested angles of the air intakes were 30 , 45 and 60 . Each of the test sections was changed to accommodate the sizes of the recirculation zones. Thus the characteristics of the flows corresponding to the various recirculation zones were examined. Additionally, 3-guiding vanes, 2mm thick, were installed at the intersection of the air intakes and the combustor to stabilize the fluid flow. The experiments were performed in a water tunnel test with the same Reynolds number as Mach 0.3 at the inlet.

PIV software was developed based on the correlation method (Adrian, 1988, 1991, 1997; Markus et al, 1998; Prasad et al., 1992; Westerweel et al., 1992). The verification of the PIV software was performed using two benchmarks. In the first benchmark particles were put on a circular and rotated with a constant velocity of rotation.

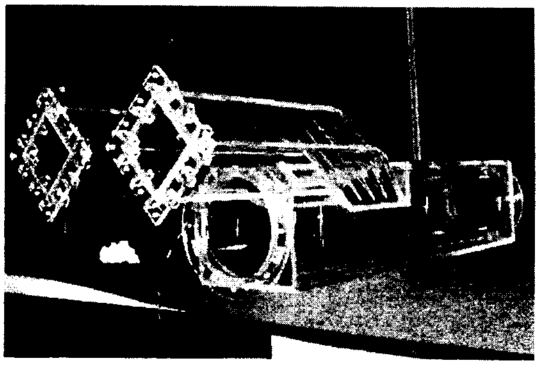


Fig. 1 Test sections

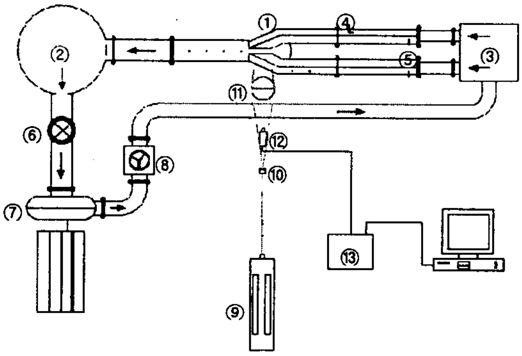


Fig. 2 Schematic diagram of experimental apparatus

Measurements of the particles' velocities through the PIV method are compared to the theoretical velocities. The standard data and image data of 2D wall shear flow obtained from the Japan Flow Visualization Association (Hu et al., 1998) were used as the second benchmark. The schematic of the experimental apparatus is shown in Figure 3. The fluid is introduced to the open tank from the closed tank by the pump. The flow control valve established between the closed tank and the pump plays a role in controlling the amount of flow, the closed tank reducing the oscillation in the pump. The fluid is introduced from the closed tank, through the test section and to the open tank. A duct, 700mm long, is set between the closed tank and the test section to obtain uniformity of the fluid. The by-pass valve and the manometer are set up at the positions of 5 and 4 to control the speed of flow and to measure the amount of flow, respectively. The measurements of pressure are performed at the two locations of the intake and the four locations of the combustor. A 200mJ dual head Nd-Yag laser is utilized as a light source of PIV system for the measurement of speed.

3. Discussions and result

The red box and lines in the Figure 3 shows the location of the measurements in the ramjet combustor by PIV. Each of the test sections can change the sizes of the recirculation zones. Since the secondary recirculation can occur in the junction of air intake and combustor body as red marked in Figure 3, the measurement planes were determined at the three offset distance from plane of symmetric line.

Figure 4 exhibits the calculated velocity vectors and contours of 45 intake angles with different distances from the symmetric section by CFD-ACE. Figure 4 (a) shows that main stream flows through the intakes into the combustor in the slanted direction. The velocity of upper region in the combustor is relatively small, thus forming the secondary recirculation zone as shown in figure 4 (b). It is observed that the direction of velocity moves to the low wall and to the upper wall at the locations of 80 mm away from the symmetric section.

Figure 5 shows the velocity vectors and enlarged recirculation vectors with different distances from the plane of symmetric section of the 60 degree inlet angle case. The contour shows the magnitude of speed near the secondary recirculation region.

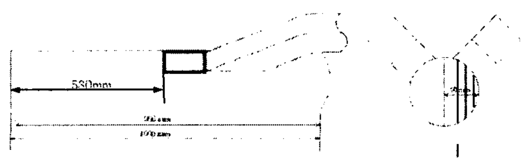
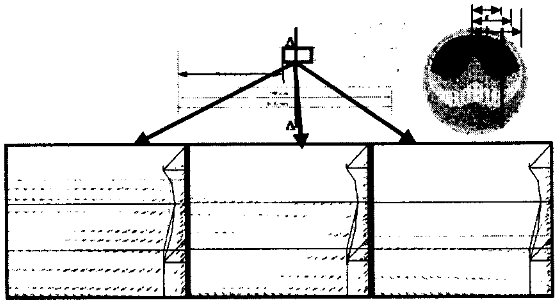


Fig. 3 PIV measured range and sections in a ramjet combustor



(a) 40mm (b) 60mm (c) 80mm

Fig. 4 Velocity vectors with different distances from the plane of symmetric section by CFD result

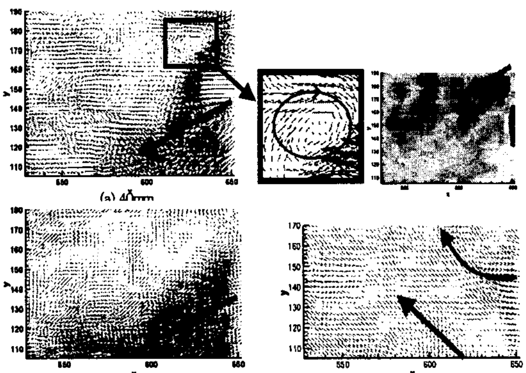


Fig. 5 Velocity vectors with different distances from the plane of symmetric section for a 60 degree inlet angle

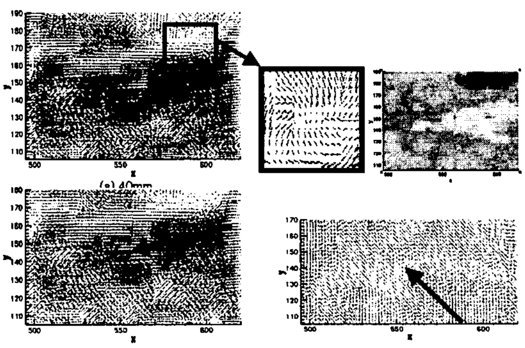


Fig. 6 Velocity vector with different distances from the plane of symmetric section for a 45 degree inlet angle

The contour shows the magnitude of speed near the secondary recirculation region. The arrows indicate the main flow directions of each measured cross sections. Figure 5 (a) and (b) shows apparent secondary recirculation vectors near the junction area. This secondary recirculation contributes the stability of combustion with the main recirculation in the dome area. In the case of the 45 degree inlet angle as shown in Figure 6, the secondary recirculation area was reduced even though the main flow direction was very similar. The measured results of a 30 degree inlet angle showed that the secondary recirculation region did not appear near the junction area. However, the total pressure loss was lower than that of the 60 degree inlet angle.

4. Conclusions

The secondary recirculation flow characteristics of the ramjet engine combustor were measured to determine the optimal configuration. To achieve this purpose, PIV measurement was performed to studythe complex flow field in the liquid ram jet combustor. The combustor has two rectangular inlets that form 90 degree each other, having intake angles of 30 degree. Three guide vanes are installed in each rectangular inlet and experiments are performed in the water tunnel test with the same Reynolds number as the case of Mach 0.3 at the inlet.

The experimental results show that the secondary recirculation flow occurred at the front junction of inlet main stream and combustor chamber. The size of secondary recirculation regions were increased with air inlet angles. Since performance of combustor is very dependant on not only the main recirculation in the dome region but also the secondary recirculation flow in a junction region, the optimal angle of the air intakes should consider the secondary recirculation size and total pressure loss.

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