

# Performance of the fuel injector in supersonic combustor

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Enhancing the fuel-air mixing is critical for scramjet combustor performance. The performance of four different aerodynamic ramp injectors was reported in this paper. The experiments were conducted in a direct-connected scramjet test facility. The concentration profiles were obtained by gas sampling and chromatogram analysis. The pictures of the flow field were obtained by using laser scatter. It would be used to analyze the flow field generated by the aerodynamic ramp, then optimize the layout of the injectors. The results would offer some useful information for engine design.

## I. Introduction

SCRAMJET is the key technology for the hypersonic aircraft. Improving the fuel-air mixing is a critical and challenge for scramjet combustor performance because air travels through the combustor in a high velocity which makes the fuel stay in the combustor for only few milliseconds.

The methods of enhancing the fuel-air mixing can be divided into two kinds: passive and active. The passive methods operate through changing the structure of the flow fields, forming the vortices and so on. It includes physical ramp, aerodynamic ramp, cave in the wall, pylon, and so on. The active method is using active force to inspirit the flow field, such as impulse injection.

An aerodynamic ramp is actually an array of injectors. Compared with a physical ramp, it could provide certain advantageous flow features like streamwise vorticity and adequate fuel penetration of a physical ramp, while improving the fuel-air mixing, total pressure recovery and avoiding burning down the intrusive physical ramp. Fig.1 is a typical flow field of an aerodynamic ramp with 1-hole injector.

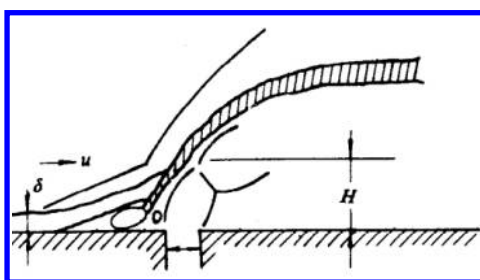


Fig.1 Sketch of 1-hole injector

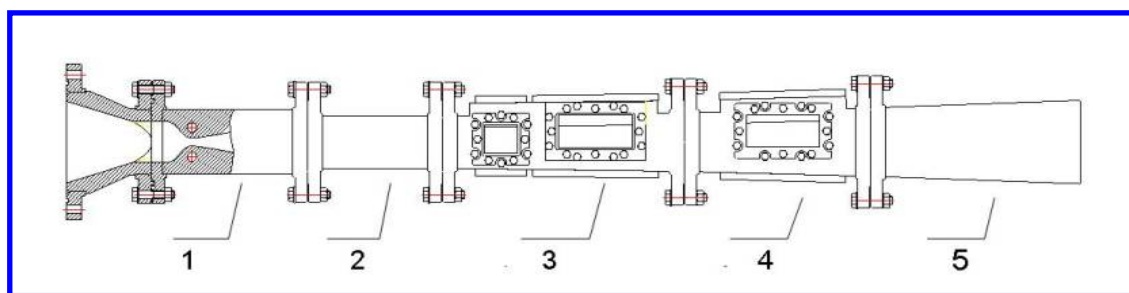
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## II. Test Facility

The effect of aerodynamic ramp on supersonic mixing was investigated in this paper. The experiments were conducted in the direct-connected scramjet test facility with Mach 3. The gas of carbon dioxide was injected through sonic nozzles into the main flow. The flow field was illustrated by laser scatter, and the concentration profiles were obtained by gas sampling and chromatogram analysis.

### 2-1 Direct-connected scramjet test facility

The direct-connected scramjet test facility was using the method of burning hydrogen and adding oxygen to create the main flow with high temperature and high pressure. The main flow was Mach 3 with total temperature 1000K and total pressure 2MPa. Fig.2 was the schematic of the facility where flow was from left to right. It consisted of supersonic nozzle, isolator, combustor 1 and combustor 2. The combustors had removable inserts on all four walls allowing optical access, installation of instrumentations and a wide parametric design margin for fuel injections.



1-Facility Nozzle 2-isolator 3-1<sup>st</sup> test section 4-2<sup>nd</sup> test section 5-Nozzle  
Fig.2 Direct-connected scramjet test facility

### 2-2 Aerodynamic ramp nozzle

The gas of carbon dioxide was injected from the wall in a sonic velocity into the main flow. Four different aerodynamic nozzles were designed and experimented. They all had the same effective diameter which was 2.4mm and their patterns were showed as follows:

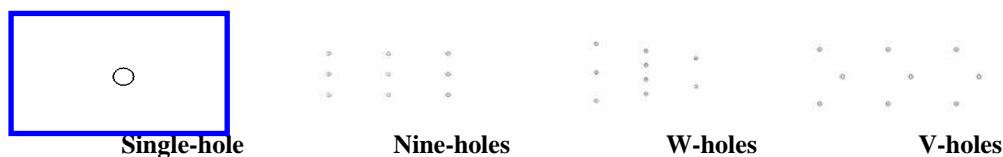


Fig 3 Scheme of different nozzles

### 2-3 Measurements

A sampling system was used to determine the concentration of carbon dioxide in the downstream of the flow field. The probe was on the symmetrical plane, and 70mm downstream from the CO<sub>2</sub> injection. There were four sampling points with the distance of 5, 10, 15, and 25mm from the wall respectively, showed in Fig 4. The effect of mixing would be evaluated from the CO<sub>2</sub> distribution. In addition, through adding particles to the injection flow and using the laser scatter, the clear picture would be got to reveal the mixing between the coming flow and injecting flow, which would be helpful to analyze the structure of the flow field.

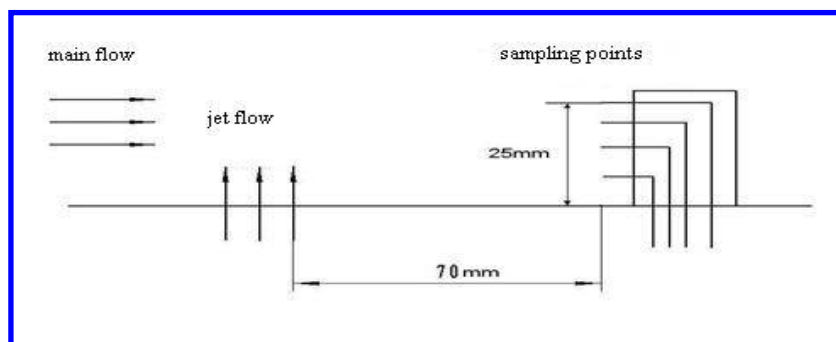


Fig 4 Scheme of the main flow and jet flow

### III. Results and Analysis

#### 3-1 Concentration analysis

The CO<sub>2</sub> distributions were obtained. Fig 5, Fig 6, Fig 7 and Fig 8 were the concentration distributions of four kinds of nozzles under two different pressures which were 2MPa and 3MPa. The distances between the wall and the four sampling points were 25mm, 15mm, 10mm and 5mm respectively. The datum showed in the picture were the relative concentration results, which were obtained from the original datum divided by the ideal concentration. The ideal concentration means the uniform value of the CO<sub>2</sub> to the global main flow. Thus the closer the datum to number 1, the better the mixing effect.

From the four pictures, we could get the results: the concentrations gotten by the four sampling points of the four kinds of nozzles were larger than the ideal concentration. So the concentrations of carbon dioxide in other places were lower than the ideal datum which showed the mixing between the injection flow and the main flow was not developed well. This was the exactly challenge for scramjet combustor.

From the four pictures, we could find that as the pressure increased from 2MPa to 3MPa, the relative concentration of all the four kinds of injection nozzle trended to be uniform, in which the difference between the peak and bottom value became smaller. The reason would be the increasing pressure made the jet momentum larger which would enhance the mixing of the injection flow and the main flow. However, the CO<sub>2</sub> profiles didn't change a lot, in which the relative concentrations of carbon dioxide were becoming larger as they were closed to the wall, and the largest concentration was at the place of about 10mm from the wall. Therefore, the effect of the jet pressure on mixing was limited, and it didn't change the flow pattern of the jet penetration

Fig 9 and Fig 10 were the comparing results of four kinds of nozzles under two pressures. Both the two figs showed that the relative concentrations of single-hole nozzle were more uniform than the other three kinds of nozzles, especially in the distance of 15mm to 5mm. That meant carbon dioxide coming from single-hole congregated in the axial direction and made better mixing due to the focus injection. However, the spanwise mixing should be measured further to evaluate the global effect.

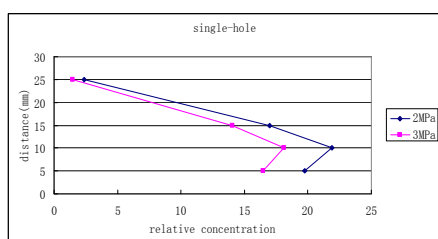


Fig 5 Relative concentrations of Single-hole

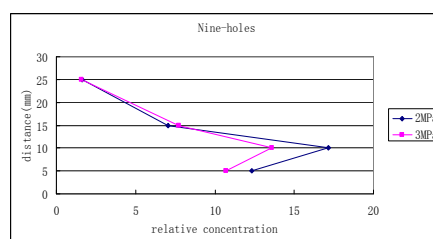
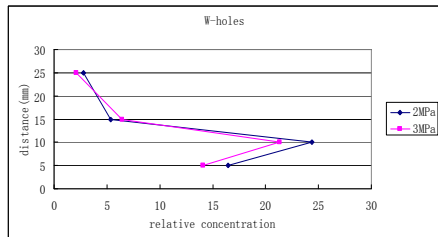
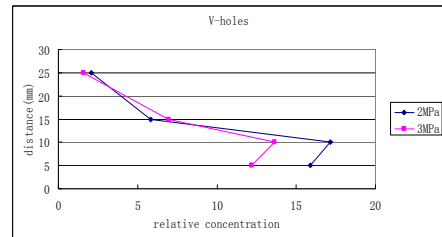


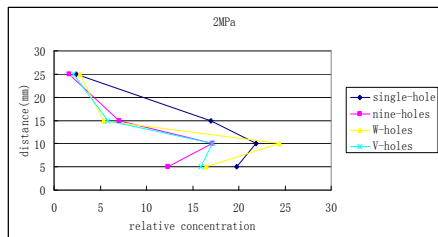
Fig 6 Relative concentrations of Nine-holes



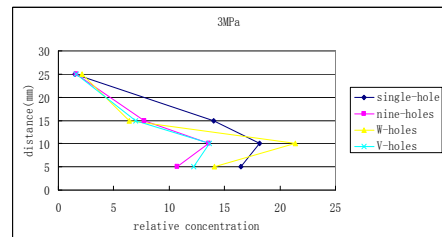
**Fig 7 Relative concentrations of W-holes**



**Fig 8 Relative concentrations of V-holes**



**Fig 9 Relative concentrations under 2MPa**



**Fig 10 Relative concentrations under 3MPa**

### 3-2 Scatter picture

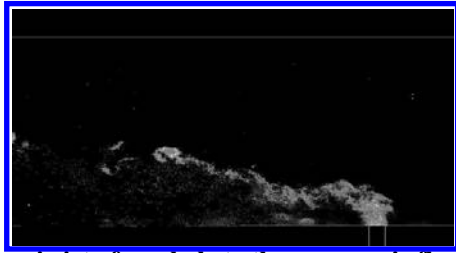
In order to get the flow structure, the laser scatter was used on the central symmetrical plane of the injection holes. Fig 11 were the scatter pictures: (A) was the subsonic jet of one hole into atmosphere; (B) was the sonic jet of one hole into atmosphere; (C) was the sonic jet of one hole to the supersonic main flow with Mach 3; (D) was the sonic jet of Nine-holes to the supersonic main flow. Fig.11 (A) shown the structure of large scale vortices which was the characteristic of the subsonic jet. Especially in the end of the jet, the structures of large scale vortices were very clear. Fig.11 (B) shown the structures of large scales disappeared for the sonic jet. The jet flow field was a cone type and the jet area augmented as the jet distance increased. Fig.11(C) was the sonic jet went into the supersonic main flow, that the cone type of jet flow field was destroyed by the supersonic main flow. The jet flow spread to the core of the main flow as it went to the downstream. During the process, some vortices were formed and they interacted with the shear layer which made the jet flow gradually mix with the main flow. Fig.11(D) was the flow field of the sonic jet of nine holes to the supersonic main flow. The picture was on the symmetrical plane through the central three holes. From Fig.11(D) we could find the effect of aerodynamic ramp clearly. Owing to the block effect of the former hole to the main flow, the latter hole had a stronger injection and deeper penetration than the former hole, which was exactly the character of the aerodynamic ramp. In addition, comparing (C) and (D), the penetrating depth of one hole was deeper than nine holes but particles dispersed better for nine holes. That meant the hole with bigger diameter had a bigger flow rate and had a deeper penetration. However, with the same effective diameter, nine holes had a better mixing.



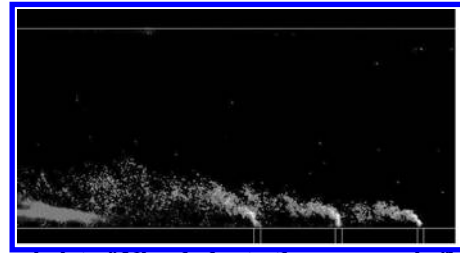
**A: subsonic free jet of one hole**



**B: sonic free jet of one hole**



C: sonic jet of one hole to the supersonic flow



D: sonic jet of Nine-holes to the supersonic flow

Fig 11 Scatter pictures

#### IV. Summary and Conclusion

The effect of aerodynamic ramp on supersonic mixing was investigated in the direct-connected scramjet test facility with Mach 3. The results were as follows:

- (1) As the jet pressure increased from 2MPa to 3MPa, the relative concentration of all the four kinds of injection nozzle trended to be uniform. This showed that the increasing pressure made the jet momentum larger which would enhance the mixing of the injection flow and the main flow.
- (2) The penetrations of the jet were limited. The concentrations of carbon dioxide were becoming larger as they were closed to the wall. The largest concentration occurred at the place of about 10mm from the wall.
- (3) The scatter pictures shown the interaction between the jet and main flow. The effect of the aerodynamic ramp was that the owing to the block effect of the former hole to the main flow, the latter hole had a stronger injection and deeper penetration than the former hole.

#### Acknowledgments

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