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Study on the Effect of the Base Area to the Suction Performance in the Supersonic Ejector

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Abstract

JAXA has been studying the RBCC engine which combined the propulsion technologies including rockets and scramjet engines studied at Kakuda Space Center. At launch, the engine produces the power by specially designed rockets placed in a combustor and gains even more power with secondary combustion with induced air flow. This cycle is called an ejector-jet. The performance of the ejector-jet was crucial since the air was transport to the combustor and caused the pressure rise in the combustor. The configuration of the ejector exerted influence on the ejector performance. In this study, the effects of the base area was paid attention to design an RBCC engine with high performance. The ejectors with the base areas were designed and manufactured to clarify the effect of the base effects. Designing the base area was found to be important for the improvement of the suction performance.

Keywords: *Supersonic, Ejector, RBCC, Propulsion*

Nomenclature

P-Pressure

at-atmospere

th-throat

rkt-rocket

2 Experimental Apparatus and Procedures

The only propulsion system that enables space transportation is currently the rocket engine. The rocket engine can generate high thrust regardless of altitude of the vehicle. Because the rocket propulsion consumes a large amount of propellant (fuel and oxygen), its fuel efficiency is low. On the other hand, research and development of high-speed jet engines such as ramjets utilizing air in the atmosphere is under way. However, the thrust density is low and it can not operate at low speed from the principle. Currently, Kakuda Space Center of JAXA is conducting research on the combined cycle engine which combines high-speed jet engine and rocket engine as a future low -cost space transportation propulsion system [1]. To reduce transportation cost remarkably in the future, it is necessary to conduct research actively towards early realization. The combined cycle engine can realize a wide range operation from takeoff to arrival to space at excellent economical fuel performance by changing the operation mode such as ejector mode[2,3], ramjet mode, scramjet mode, and rocket mode in the single engine. A supersonic ejector is a simple device used to convert pressure energy into kinetic energy. The high-velocity jet entrains the secondary fluid. The two streams mix in the mixing tube, leading to pressure recovery. Since the theoretical analysis so far targeted the idealized situation, the effect of the base around the actual rocket nozzle exit was not included. The ejector suction performance was affected by mixing between the primary flow and the secondary flow and the base area around the rocket nozzle affected the mixing. It was necessary to clarify the influence of the base area on the suction performance. In this research, ejector models capable of changing the arrangement of the base area were manufactured, tested, and the effects of the base area were experimentally investigated.

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2 Experimental Apparatus and Procedures

2.1 Ejector Model

Fig.1 shows a side view of the ejector model. Primary flow was injected from the rocket nozzle. The Mach number at the nozzle exit was designed to be 3. The ramp angle of the secondary flow path was also designed to be 5 degree. The junction area of the primary flow and the secondary flow was the throat and had the minimum area. The flow path in the downstream direction of the junction was parallel. It was possible to change the area and the position of the base and the height of the secondary flow path by modifying the assembled parts of the ejector models as described below in detail.

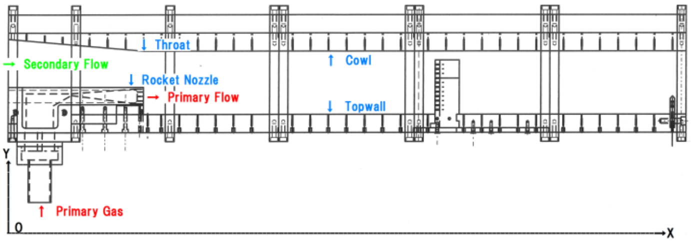

Fig.1 The schematics of the ejector model

2.2 Experimental Method

In the experiment, the ejector model was set up in the open atmospheric system and nitrogen gas which simulated rocket exhaust gas was supplied from six gas bottles. At the time of the test, the rocket gas was pressurized and adjusted in advance, and nitrogen was ejected from the rocket nozzle by opening the nitrogen valve. At that time, the pressure in the rocket chamber was measured. The wall pressure of the topwall and the cowl was also measured. Measurement device PSI® was used to measure the wall pressure of the topwall and the cowl, and the wave recorder was used for pressure measurement of the rocket chamber. Here, the pressure error was ± 0.5%. In case that the ratio of the atmospheric pressure Pat to the pressure Pth of the junction (throat) was 0.528, the secondary air was judged to be choked. When the air was choked, the Mach number of the secondary flow was 1 at the throat and the amount of the flow became maximum. In this study, the relationship between the base area and the suction performance was investigated by changing the ejector model configuration.

3 Experimental Results and Consideration

In this study, the effects of the base area around the rocket nozzle was investigated. Thereby the configurations of the ejectors were classified into three categories as shown in Fig.2. The dimension of the rocket nozzle end face (including the edge area) was 20 mm × 20 mm. The dimension of the nozzle end face except the edge area was 16 mm × 16 mm. In Fig.2, the configuration of no base area was defined as the type (A) and the configuration installed the base area on the side of the rocket was defined as the type (B), and the configuration installed the base area on side and bottom of the rocket was defined as the type (C).

In the graphs displayed below, the X-coordinate was the main flow direction. In the X-coordinate, the entrance of the ejector model was X=0, and the junction (throat) of the primary flow and the secondary flow was X=150mm. The configuration of downstream from X=150mm was the parallel rectangular duct and the X=800 mm was the end of the model which was open to the atmosphere. The wall on the primary flow side was called the topwall and the wall on the secondary flow side was called the cowl. The investigated results were described below.

Further research results were to be presented at the conference.

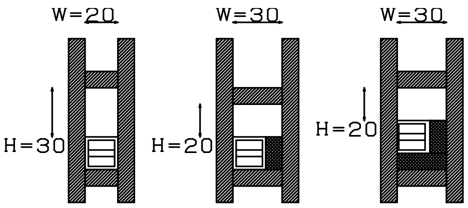

Fig.2 Three Configurations with different base layout

To examine the suction performance of the type (A) configuration, the rocket total pressure was set to the approximately constant value of 2.0MPa. Here, the height of the secondary flow path was H_{th}=30mm at the throat. Pressure distribution was depicted in Fig. 3 at the total rocket pressure P_{rkt}=2.0MPa. From the pressure distribution on the topwall, the pressure decreases from the entrance to the throat, and it did not reach the choke value at the throat. On the downstream from the junction, it was found that the pressure increased smoothly and the flow on the cowl side was subsonic. On the other hand, the pressure on the topwall decreased and the normarized pressure by the atmospheric pressure just downstream the rocket reached approximately 0.45, but thereafter the pressure rised and falled due to the effects of the oblique shock waves and the expansion waves and asymptotically approached to the atmospheric pressure. It was evident that the flow on the topwall side was supersonic from the pressure distribution on the topwall. Fig.4 showed the Schlieren photograph obtained by the experiments. As seen in Fig. 4, oblique shock waves and expansion waves were observed on the topwall side, nevertheless, oblique shock waves and expansion waves were not observed on the cowl side.

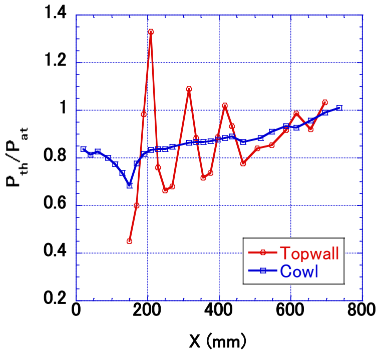

Fig.3 The pressure distribution

Fig.4 Schlieren photograph

Flow features were investigated by changing the height of the flow path of the secondary flow. Here, the cowl was moved so that the throat height was H_{th} = 20 mm, and the suction performance was examined under the condition of the rocket total pressure P_{rkt} = 2.0 MPa. Figure 5 showed the pressure distributions on the topwall and the cowl. It was found that pressure decreased from the entrance to the throat and in the throat flow reached the choke seen from the cowl pressure. Schlieren photograph was shown in Fig.6. As apparent from the Schlieren photograph, it could be seen that the expansion wave was generated from the shoulder at the end of the throat on the cowl side and the shoulder of the end of the secondary flow path, hence it was understood that the secondary flow was accelerated up to supersonic speed. As described above, when the height of the throat was narrowed, the secondary flow could choke, however the area of the secondary flow decreased.

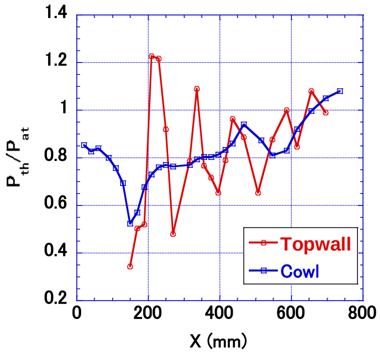

Fig.5 The pressure distribution

Fig.6 Schlieren photograph

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