Spectroscopic Analysis of Shock Layer Flows in a High Enthalpy Arcjet Facility

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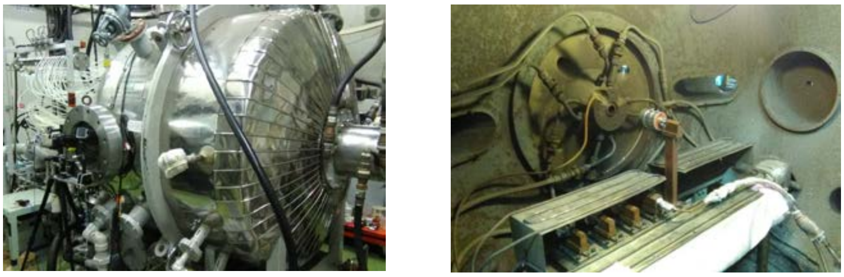
1. Introduction

When a space vehicle enter a planetary atmosphere, a strong shock wave is formed around the space vehicle, resulting in the severe aerodynamic heating. To protect the space vehicle from the heat load, a thermal protection system (TPS) is required. Arcjet facilities have been widely used for the heat tests of TPS in entry flight conditions. The performance of TPS is evaluated and updated through the heat tests. However, characteristics of test flows in an arcjet facility are not understood well because it is out of thermochemical equilibrium, degrading the accuracy of the heat tests. Experimental and numerical studies have been conducted to characterize the freestream and shock layer flows in arcjet facilities[1~3)]. These past studies are useful to understand the flow properties in an arcjet facility. However, the complete characterization of arcjet flows has not been yet possible. So, father studies of arcjet flows are required to characterize the test flows used for the heat tests of TPS in entry flight conditions. The present study investigates the shock layer flows generated in the arcjet facility at the Institute of Space and Astronautical and Science (ISAS) of Japan Aerospace Exploration Agency (JAXA)[4)]. Radiation from the shock layer flows around a blunt body is observed by emission spectroscopy and flow temperatures are evaluated by a spectrum fitting method.

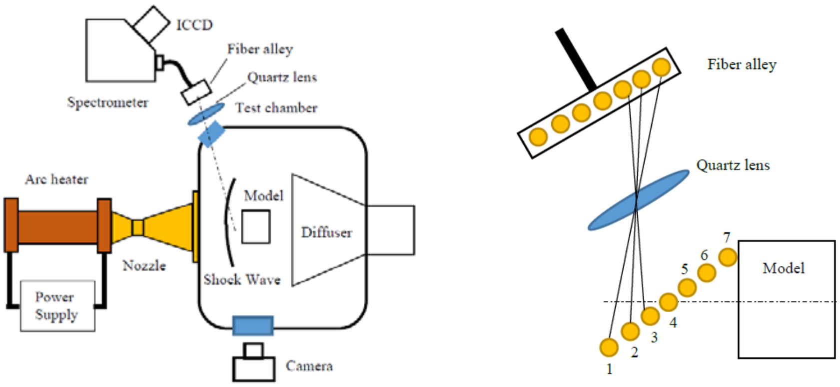
2. Experimental setup and test conditions

The shock layer flows around a blunt body are generated by a large scale arcjet facility at the ISAS of JAXA. The arcjet facility had been used to develop the TPS for HAYABUSA entry capsule. Figures 1 (a) and (b) show pictures of the arcjet facility. The facility mainly consists of a power supply, arc heater, gas supply system, test chamber and exhaust system. The maximum electrical power is 1MW. The arc heater of the facility is a segmented-constrictor type. The working gas is supplied into the constrictor part and heated by the arc discharge. Downstream from the constrictor part, the working gas is expanded through the convergent-divergent nozzle, generating a high enthalpy plasma flow in the test chamber. A shock layer flow is generated by positioning a blunt body with the diameter of 50 mm in the centerline of the plasma flow and the radiation from the shock layer flow is observed by spectroscopic measurements. Figures 2 (a) and (b) show schematics of the spectroscopic measurement system. The optical fibre alley enables us to obtain the multipoint spectra along the positions shown in Fig.2 (b) at a time. The arc heater is operated with a heater pressure of 0.5 MPa, an arc current of 450 A, and a voltage of 1500V, generating a plasma flow with the enthalpy of about 17 MJ/kg. Nitrogen is used as the working gas in this study.



(a) Overall of the facility (b) Test section

Fig. 1 Pitucures of the Arcjet Facility at the ISAS of JAXA



(a) Overview (b) Measurement positions

Fig. 2 Spectroscopic measurement system

3. Results and Discussion

Figure 3 shows a picture of the shock layer flow around a blunt body. It is found that the plasma flow is extremely bright near the model surface due to the generation of the shock layer. Based on the brightness of the plasma flow, the thickness of the shock layer is estimated to be about 5 mm from the model surface. Figure 4 shows a spatial profile of emission spectra measured at seven positions shown in Fig. 2(b). The intensity rapidly increases at position 4 which is about 5mm from the model surface, corresponding to the position of the shock wave. Figure 5 shows the measured spectrum in the shock layer. It is found that N_2^+ (1-) is predominant and many vibrational sequences can be identified in the measured spectrum. The vibrational sequence Δv=-1 of the N_2 (2+) is seen and merged with the vibrational sequence Δv=1 of the N_2^+(1-). To deduce the rotational and vibrational temperatures from the measured spectra, a spectrum fitting is performed in this study. Figure 6 shows a spectrum fitting result. The numerical spectrum is found to be in good agreement with the measured one. Figures 7 (a) and (b) show the spatial distribution of temperatures around the blunt body for N_2 and N_2^+, respectively. For N_2, the rotational temperature is much higher than the vibrational temperature in the freestream. Considering the characteristics of nozzle expanded flows, the rotational temperature is considered to be lower than the vibrational temperature. This is because the translational temperature decreases in the freestream followed by the decrease of the rotational temperature. On the other hand, the vibrational temperature is considered to be higher than the vibrational temperature because the relaxation between translation and vibrational is slower than that between translation and rotation. However, the present result shows the opposite tendency. The reason of the contradiction may be attributed to the fact that N_2(2+) is relatively weak and merged with N_2^+(1-) in the measured spectrum In the shock layer the temperature difference becomes smaller, showing the energy exchange between rotation and vibration modes proceeds. For N_2^+, the rotational temperature is much lower than the vibrational temperature in the freestream and shock layer. The rotational temperature is about 5250 K in the freestream and increases with approaching the model surface. On the other hand, the vibrational temperature is about 11750 K in the freestream and starts to increase in the shock layer due to the collision by electrons. The decrease of the vibrational temperature can be seen at position 7. This is considered to be fact that the vibrational relaxation process in the shock layer becomes faster than that in the freestream. The vibrational temperature is still higher than the rotational temperature, showing that the plasma is vibrational nonequilibrium in the shock layer.

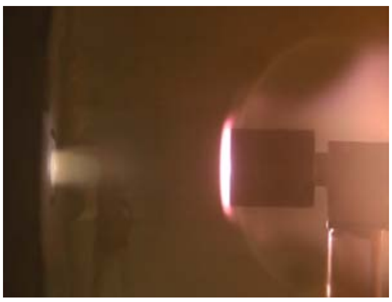


Fig. 3 Shock layer flow

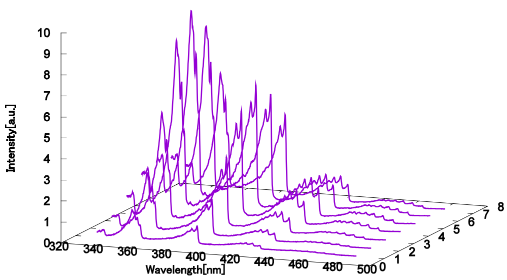


Fig. 4 Spatial profile of emission spectra

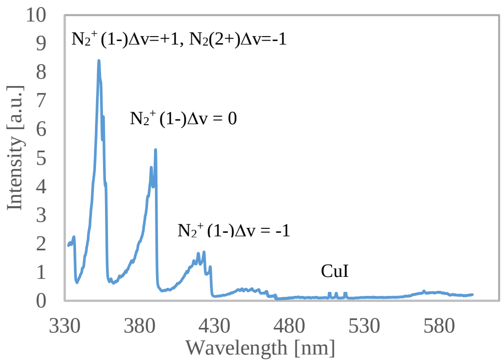


Fig. 5 Measured spectrum

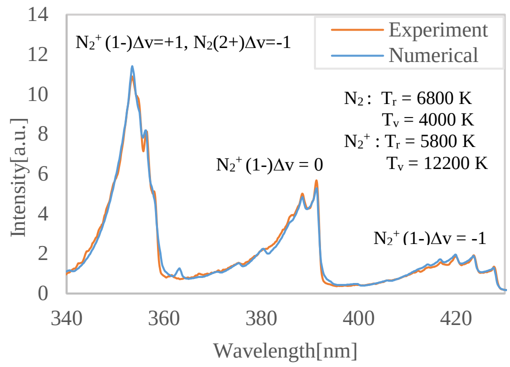
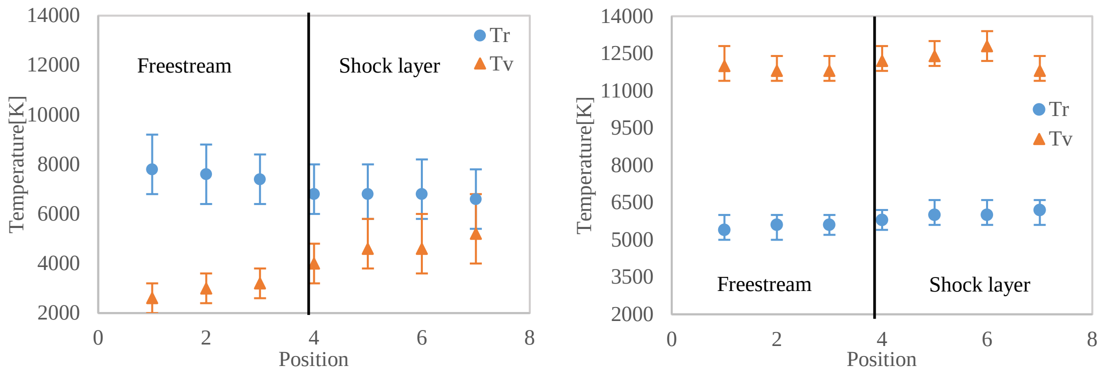


Fig. 6 Spectrum fitting result



(a) N_2 (b) N_2^+

Fig. 7 The spatial distribution of temperatures

4. Conclusions

In the present study, shock layer flows generated in the arcjet facility at the ISAS of JAXA were investigated by spectroscopic measurements. From the measured spectrum, N_2^+ is found to be the strongest radiator in the shock layer flow. Flow temperatures were evaluated by a spectrum fitting method. The different tendency is seen in the spatial distribution of the temperatures for N_2 and N_2^+. The temperature profile of N_2 disagree with the characteristics of nozzle expanded flows. The temperature profile of N_2^+ shows a reasonable trend in the freestream. In the shock layer, the increase of the rotational and vibrational temperatures can be seen. However, the vibrational temperature is still higher than the rotational temperature, showing the plasma is vibrational nonquilbirium in the shock layer.

5. References

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