Aerothermodynamic analysis for Atmospheric Entry Capsule

Report Number: R22EDU10300
Subject Category: Space and Astronautical Science
URL: https://www.jss.jaxa.jp/en/ar/e2022/20848/

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Abstract

In atmospheric entry capsules such as the Hayabusa sample return capsule, it is important to predict various fluid phenomena such as aerodynamic heating during the very high speed entry into the atmosphere. In this study, we are conducting thermoaerodynamic analysis of atmospheric entry capsules to understand various phenomena. Specifically, (1) prediction of the thermoaerodynamic environment of a deployable flexible aeroshell flight experimental capsule, (2) evaluation of the thermoaerodynamic environment of capsule models in expansion tube experiments, and (3) understanding of fluid phenomena related to MHD interaction effects are being conducted.

Reasons and benefits of using JAXA Supercomputer System

In order to properly analyze the flow around an atmospheric entry capsule in hypersonic flight, it is necessary to use a high-quality computational grid with an object-adaptive structure grid. Pointwise, which is available as ISV software, can not only generate a computational grid along an object surface, but can also flexibly adjust the computational grid, significantly reducing the time required to generate the grid. In particular, Pointwise's powerful smoothing functions produce high-quality computational grids even for deployable flexible aeroshell capsules with complex geometries. Therefore, we decided to use ISV software. The fluid analysis was performed on our own workstation using in-house code.

Achievements of the Year

For issue (1), a two-dimensional axisymmetric fluid analysis was performed to estimate the aerodynamic heating rate to simulate the thermal environment during the flight experiment of the deployable flexible aeroshell in 2021 (Figure 1). The estimated stagnation point heat flux is low (30-45% of the predicted value by empirical equation), but is reasonable considering the flight data of temperature sensors. We will continue modeling the thermal environment to reproduce the temperature data.

For issue (2), an expansion tube is an experimental device that can generate a high-speed, high-enthalpy flow

and can simulate an atmospheric entry flight environment. However, the duration of the flow is extremely short, and it is difficult to obtain sufficient information on the flow from experimental measurements. Therefore, we attempted to estimate the flow from both experimental measurements and fluid analysis (Figure 2). Specifically, we attempt to estimate the flow conditions that match the experimental visualization results within the expected range of flow parameters.

For issue (3), electromagnetic fluid analysis was conducted to investigate the effect of flow control technology using electromagnetic force. It was found that the shock wave shape can be significantly changed by applying electromagnetic force near the shoulder of a two-dimensional wedge shape (Figure 3). We will continue to study this situation and investigate whether it can be applied to flow control technology.

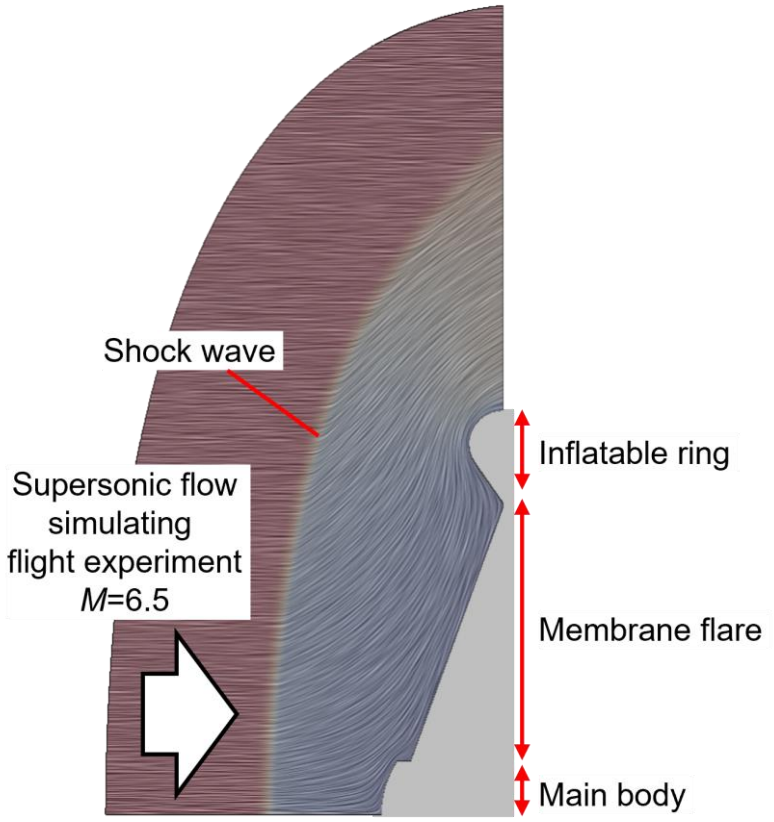

Fig. 1: CFD result of a deployable flexible aeroshell experimental capsule during atmospheric entry (velocity distribution and streamlines)

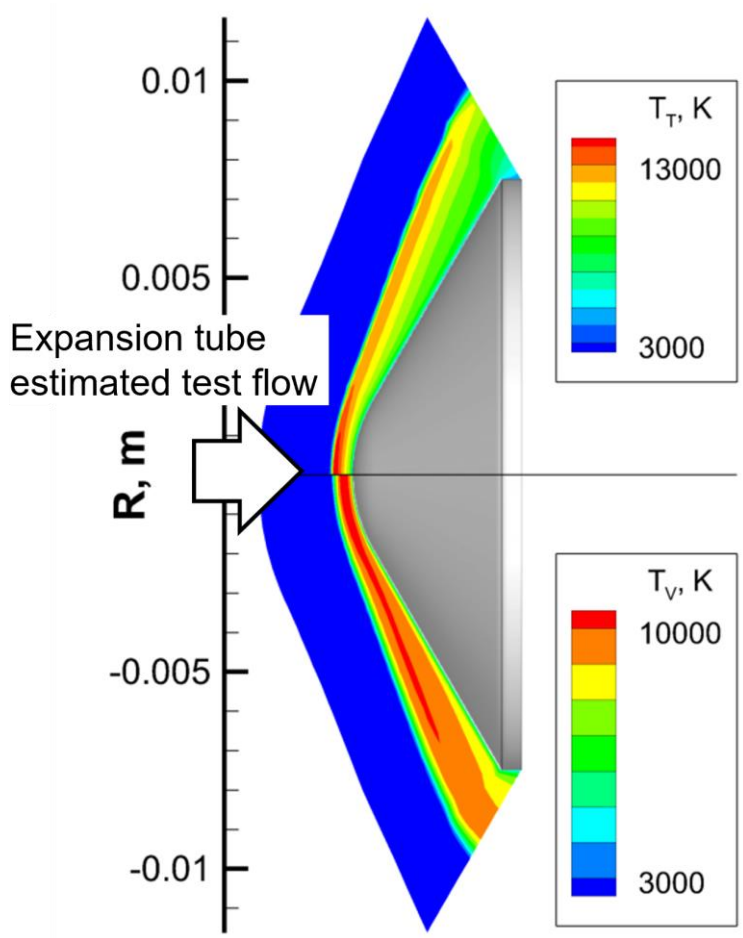

Fig. 2: CFD result of flow simulating an expansion tube for a Stardust-type experimental model (translational and vibrational temperature distributions)

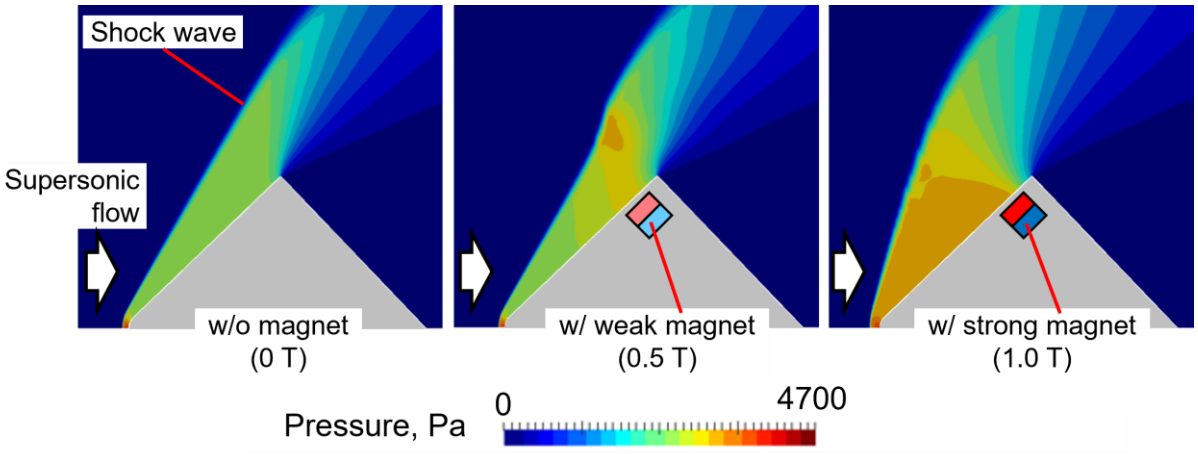

Fig. 3: MHD analysis results for 2D wedge shape (pressure distribution, left: no magnet, center: weak magnet, right: strong magnet)

Publications

- Oral Presentations

Ritsuki Sato, Osamu Imamura, Yasunori Nagata, Kazuhiko Yamada, MHD Fluid Analysis of Hypersonic Plasma Flow around Wedge Shape, Symposium on Shock Waves, 1B2-4, 2023.

- Poster Presentations

Souta Koyama, Tamami Kondo, Kohei Shimamura, Yasunori Nagata, Kazuhiko Yamada, Evaluation of Aerodynamic Heating of Re-entry Capsule for Deep Space Exploration with an Expansion Tube, 66th Space Sciences and Technology Conference, P095, 2022.

Usage of JSS

Computational Information

Process Parallelization Methods	N/A
Thread Parallelization Methods	N/A
Number of Processes	1
Elapsed Time per Case	1 Hour(s)

JSS3 Resources Used

Fraction of Usage in Total Resources[*1](%): 0.00

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	0.00	0.00
TOKI-ST	0.00	0.00
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	0.00	0.00
TOKI-TST	0.00	0.00
TOKI-TGP	0.00	0.00
TOKI-TLM	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage*2 (%)
/home	45.00	0.04
/data and /data2	450.00	0.00
/ssd	450.00	0.06

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage*2 (%)
J-SPACE	0.00	0.00

*1: Fraction of Usage in Total Resources: Weighted average of three resource types (Computing, File System, and Archiver).

*2: Fraction of Usage：Percentage of usage relative to each resource used in one year.

- **ISV Software Licenses Used**

ISV Software Licenses Resources		
	ISV Software Licenses Used (Hours)	Fraction of Usage*2 (%)
ISV Software Licenses (Total)	267.56	0.19

*2: Fraction of Usage：Percentage of usage relative to each resource used in one year.