Numerical Simulation on Hypersonic Boundary Layer

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Abstract

A laminar-turbulent transition at the surface of a re-entry vehicle is an important issue for the design of a Thermal Protection System (TPS). Since the heat transfer coefficient in the turbulent boundary layer is several times higher than that in the laminar boundary layer, the location of the laminar-turbulent transition point is a crucial design parameter for the TPS. Currently, the transition process is not yet understood, and the actual design assumes a turbulent boundary layer along the entire flight path and allows excessive TPS weight. The objective of this project is to elucidate the transition process on the surface of the re-entry vehicle by numerical simulation on JSS3 and to obtain knowledge that will contribute to the weight reduction of the TPS.

Reasons and benefits of using JAXA Supercomputer System

Since the laminar-turbulent transition is closely related to the growth process of small disturbances in the airflow, its numerical simulation requires high spatio-temporal resolution. To achieve numerical simulations with high spatio-temporal resolution, it is essential to use a large amount of computational resources such as JSS3.

Achievements of the Year

A high-order accuracy numerical method has been developed for simulating disturbance growth and transition processes in high-temperature hypersonic flows (Fig. 1).

The effect of freestream disturbances on the disturbance growth process over a blunt body was evaluated. Fig. 2 shows developing two-dimensional waves, which was considered to be a Kelvin-Helmholtz (KH) instability, but it did not collapse and its effect on the wall heat flux was small (Fig. 3). Recent attempts include an evaluation of the wall roughness effects on the disturbance growth and a numerical analysis of the coupling of wall roughness-induced disturbances and freestream disturbances.

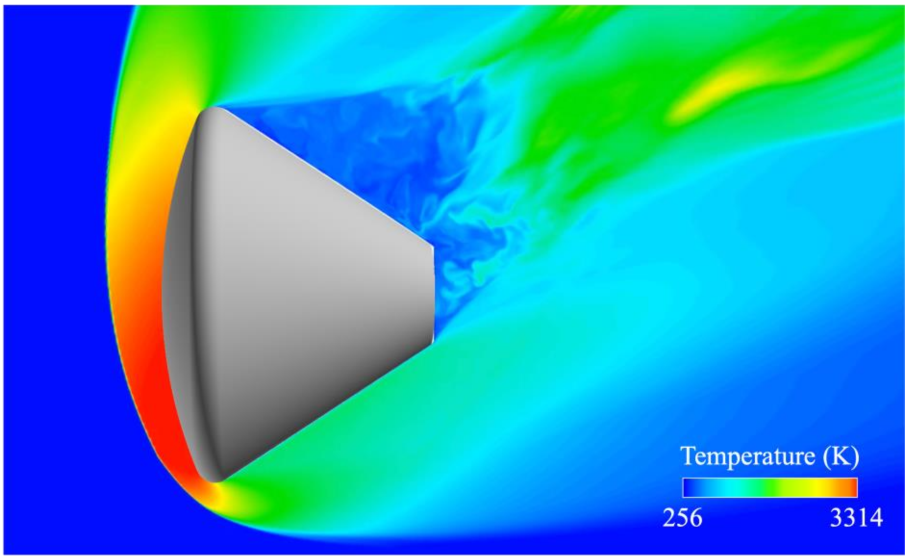

Fig. 1: High temperature hypersonic flow at Mach number 7.7 around the Apollo capsule

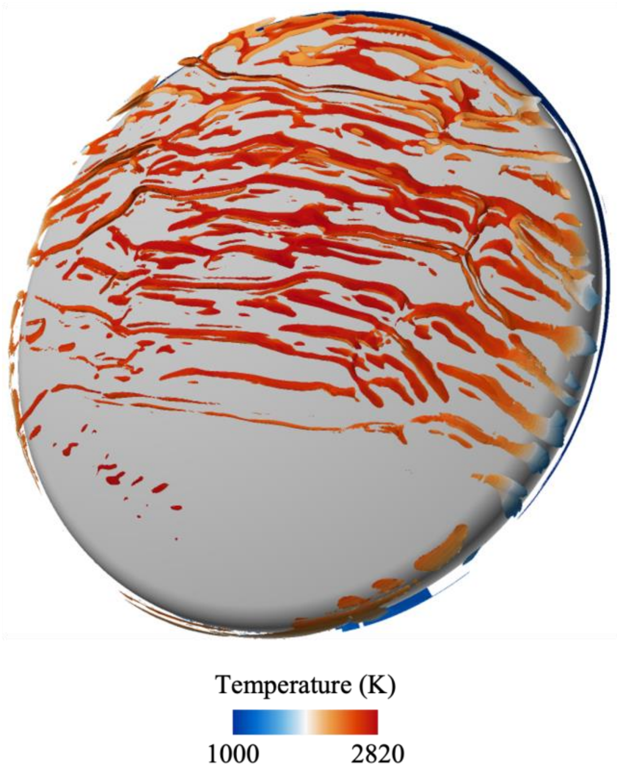

Fig. 2: Iso-surface of near-wall Q-criterion (Q =1e-4) colored by fluid temperature

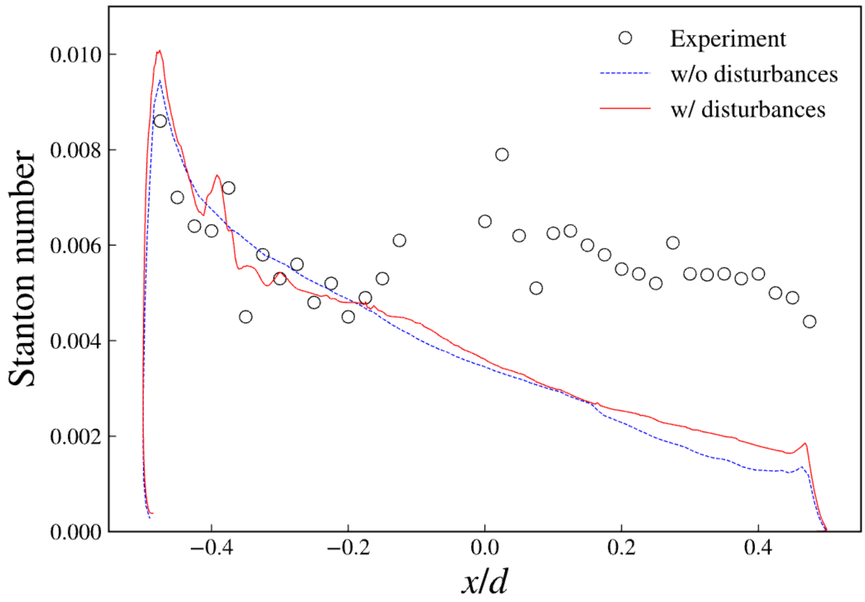

Fig. 3: Heat flux distributions on the heatshield side of the Apollo capsule model

Publications

- Oral Presentations

1) Shuto Yatsuyanagi, Hideyuki Tanno, "Flow characteristics of super-orbital expansion tube HEK-X," Symposium on Flight Mechanics and Astrodynamics, (2023).

2) Shuto Yatsuyanagi, Hideyuki Tanno, "Numerical Simulation of Boundary Layer Transition on Blunt Body," Symposium on Shock Waves in Japan, (2024).

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	912 - 3264
Elapsed Time per Case	72 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.65

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	17,699,196.03	0.80
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	0.00	0.00
/data and /data2	15,310.50	0.09
/ssd	0.00	0.00

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)	0.00	0.00

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