Physics and Modeling in Hypersonic and Transonic Flow toward Establishing Reentry Technology

Report Number: R23EACA53
Subject Category: JSS Inter-University Research
URL: https://www.jss.jaxa.jp/en/ar/e2023/23758/

Responsible Representative

Naofumi Ohnishi, Professor, Tohoku University

Contact Information

Yasuhito Okano, Tohoku University(yasuhito.okano.p4@dc.tohoku.ac.jp)

Members

Naofumi Ohnishi, Yasuhito Okano, Hiroki Sakamoto

Abstract

Critical issues for designing a reentry capsule are mainly the prediction of aerodynamic heating in hypersonic flows and dynamic instability in transonic flows. In hypersonic flows, the heating rate can be increased due to the transition from the laminar to turbulence at boundary layer. In transonic flows, the dynamic instability can be caused by the flow near the capsule side or capsule base. Both are computationally expensive because of the high Reynolds number and chemical reaction for prediction of the aerodynamic heating and longer time scale of the capsule motion than that of the fluid for prediction of dynamic instability. Although modeling is needed to overwhelm this problem, mechanisms of the physical phenomena are unknown in detail. In this study, numerical simulations are performed using the supercomputer to clarify the mechanism and conduct modeling. This year, we mainly used the supercomputer to perform numerical simulations of the dynamic instability at transonic flows.

Reasons and benefits of using JAXA Supercomputer System

Numerical simulations of the Navier-Stokes equation which is coupled with the pitch-direction equation of motion are conducted. Accurate numerical simulations are required to capture the turbulence behavior. In addition, the time scale of the reentry capsule motion is much longer than that of the fluid. Thus, the use of the supercomputer is necessary.

Achievements of the Year

This year, the dynamic instability of HRV-type capsules is investigated at Mach 1.2. The self-excited oscillation is observed at this flow condition in an experiment. The increase in the oscillation amplitude is confirmed even in our numerical simulation (Fig. 1). Thus, the same trend in the experiment is reproduced successfully. According to the analysis of the numerical simulation result, we found that the dynamic instability of the HRV-type capsule is caused by the hysteresis of the boundary layer separation on the capsule shoulder. Moreover, DMD analysis

revealed that the recirculation region on the capsule wake has a non-small influence on the dynamic instability. In future work, advanced analysis and numerical analysis of subsonic flow will be conducted.

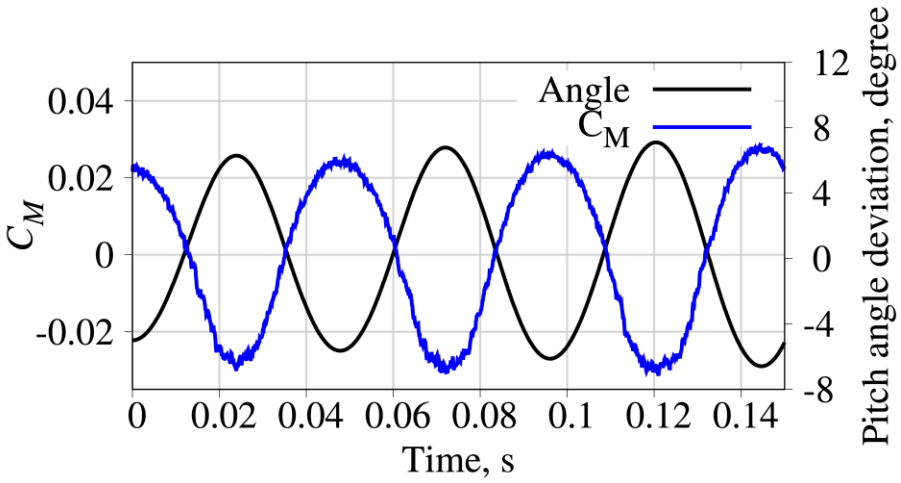

Fig. 1: Time-series pitch angle deviation and pitching moment coefficients

Publications

- Peer-reviewed papers

(1) Yasuhito Okano, Shintaro Sato, and Naofumi Ohnishi, Numerical study toward verification of analogy between hypersonic turbulent transition and directed percolation, Journal of Evolving Space Activities, Vol. 1, No. 56, 2023.

(2) Hiroki Sakamoto, Shintaro Sato, and Naofumi Ohnishi, Hypersonic boundary layer development on tube wall in long-distance propagation of shock wave, Journal of Evolving Space Activities, Vol. 1, No. 73, 2023.

- Oral Presentations

(1) Yasuhito Okano, Shintaro Sato, Naofumi Ohnishi, and Hiroki Nagai, Numerical Analysis of Free Oscillation of Reentry Capsule on Suppression of Dynamic Instability in Transonic Flow, 34th ISTS and 12th NSAT, 6, June, 2023.

(2) Hiroki Sakamoto, Shintaro Sato, and Naofumi Ohnishi, Hypersonic Boundary Layer Instability in Long-Distance Propagation of Shock Wave, The 34th International Symposium on Shock Waves, 16, July, 2023.

(3) Hiroki Sakamoto, Shintaro Sato, and Naofumi Ohnishi, Flow Instability in a Hypersonic Boundary Layer Behind a Propagating Shock Wave, 76th Annual Meeting of the Division of Fluid Dynamics, 19, November, 2023.

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	360 - 720
Elapsed Time per Case	360 Hour(s)

JSS3 Resources Used

Fraction of Usage in Total Resources[*1](%): 0.55

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	4,165.39	0.00
TOKI-ST	4,359,202.80	4.71
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	3,362.20	0.26
TOKI-TST	1,463.45	0.02
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	133,020.00	0.82
/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.