Numerical fluid analysis of hypersonic aerodynamic heating during spacecraft re-entry.

Report Number: R23EACA63
Subject Category: JSS Inter-University Research
URL: https://www.jss.jaxa.jp/en/ar/e2023/23767/

Responsible Representative

Koyo Ando, Tokyo University of Science, Department of Mechanical and Aerospace Engineering

Contact Information

Koyo Ando(7523505@ed.tus.ac.jp)

Members

Koyo Ando, Daiki Asamitsu, Ko Ogasawara, Daiki Yoshikawa

Abstract

The aim of this research is to conduct aerothermal simulations around high-speed flying vehicles using particularly the analysis technique of "non-equilibrium chemical reaction flow." By doing so, more realistic simulation results can be obtained, enabling accurate prediction and evaluation of the performance and requirements of the vehicles. In actual high-speed flight, the flow around the reentry vehicle is subjected to high temperatures reaching tens of thousands of degrees due to the re-compression heating behind shock waves. This leads to phenomena such as dissociation of oxygen and nitrogen molecules in the air and ionization where electrons detach from atoms to form ions. Simulating such flows around the reentry vehicle requires incorporating chemical reaction equations for real gas effects like dissociation and ionization into the equations that typically handle ideal gases, necessitating numerical calculations that consider non-equilibrium chemical reaction flows.

Reasons and benefits of using JAXA Supercomputer System

Currently, for obtaining analytical values of the aerodynamic performance and thermal protection of upper-stage rockets and lifting bodies, extensive meshes for boundary layer resolution and high-precision calculation methods are computationally feasible using FaSTAR on the JAXA supercomputer.

Achievements of the Year

Prior to conducting thermal aerodynamic analysis in the hypersonic regime of lifting-body type reentry vehicles, research was conducted to visualize the flow field near the vehicle and estimate aerodynamic coefficients in the transonic regime.

Steady-state RANS analysis was performed using the JAXA analysis tool FaSTAR, employing the Spalart-Allmaras-noft2-R turbulence model. Fig.1 shows the values of the pitching moment coefficient obtained in this analysis. "Calculation" represents the pitching moment coefficient around a reference point based on previous studies, while "Calculation (ref)" represents the pitching moment coefficient around the assumed center of gravity of the entire vehicle with constant density. Both cases show a reversal of the slope of the pitching moment coefficient with respect to angle of attack, indicating aerodynamic instability. From the analysis of the flow field, it was determined that the cause of this is the flow separation at the nose section as observed in Fig.2. Additionally, it was found that a phenomenon similar to Vortex Lift is occurring from the flow near the vehicle, as shown in Fig.3.

Continuing, research will focus on the aerodynamic characteristics and aerodynamic heating of the lifting-body type reentry vehicle, particularly from the perspective of Mach number dependence and shape dependence.

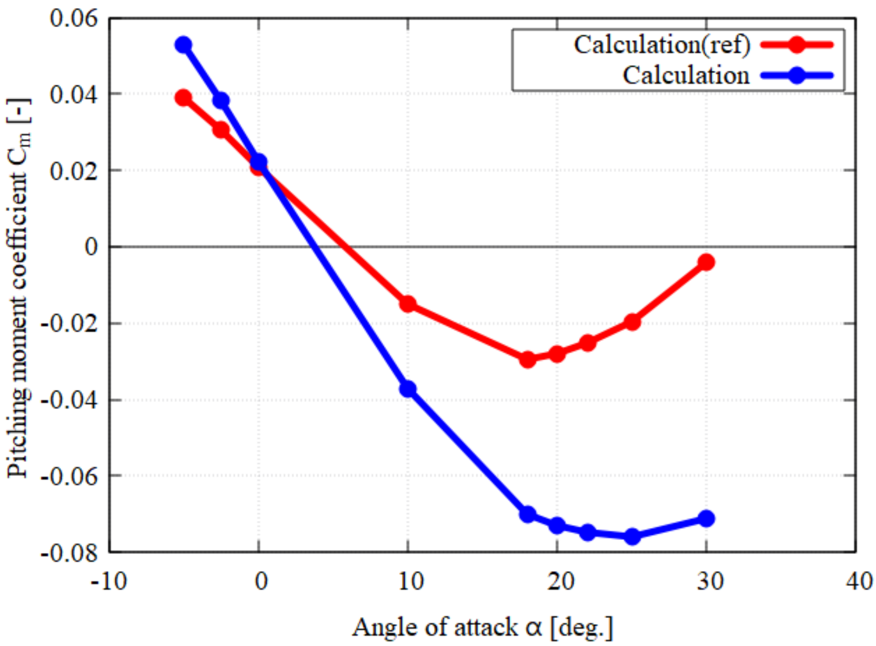

Fig. 1: Pitching moment coefficient with respect to angle of attack

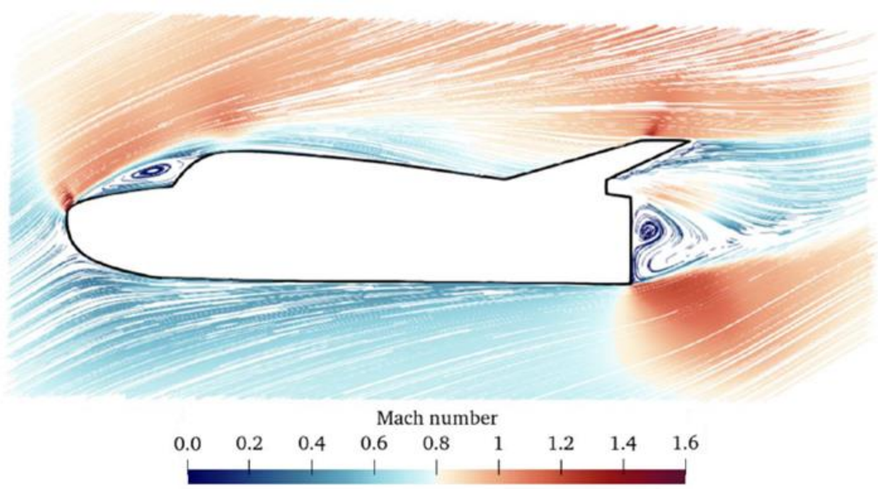

Fig. 2: Streamlines at the aircraft center section at an angle of attack alpha = 30 degrees.

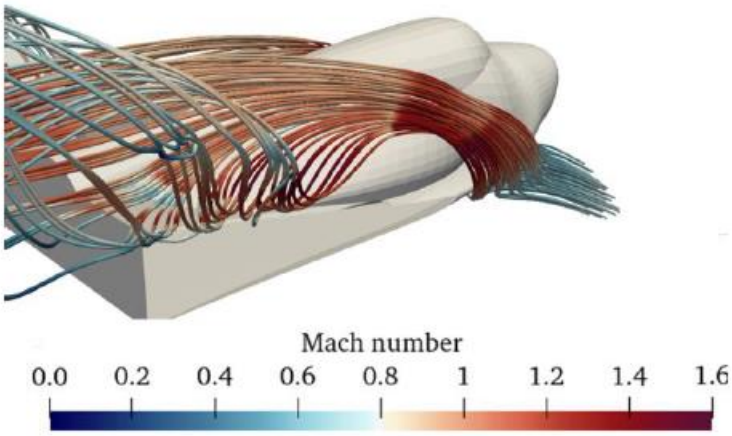

Fig. 3: Streamlines near the aircraft at an angle of attack alpha = 30 degrees.

- **Publications**

N/A

- **Usage of JSS**
- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	Automatic Parallelization
Number of Processes	50 - 240
Elapsed Time per Case	10 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	62,019.08	0.00
TOKI-ST	0.20	0.00
TOKI-GP	0.00	0.00
TOKI-XM	99.70	0.05
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	0.00	0.00
/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.