Numerical Analysis of Internal Flow Field in an Aerospace Propulsion Using the Building-Cube Method

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Abstract

The Building-Cube Method (BCM), which is based on a Cartesian mesh and can easily handle the analysis of complex geometries, is useful to improve the computational performance. In this study, we develop a BCM solver for internal flow fields for a solid rocket motor and scramjet engine.

We investigated the following two objectives in this year. In the solid rocket motor, the propellant wall injection model using the immersed boundary method (IBM) is developed in this study. In addition, we investigated the vortex structure from the inhibitor to the nozzle. In the scramjet engine, the fuel injection condition from the fuel injector is developed in this study.

Reasons and benefits of using JAXA Supercomputer System

An internal flow of the solid rocket combustion chamber and scramjet engine is computed for three-dimensional fluid analysis using the Building-Cube Method, so that large-scale computational resources are needed. Therefore, a supercomputer with large-scale memory is needed. In addition, a fast calculation method using a supercomputer is needed.

Achievements of the Year

Solid Rocket Motor:

The propellant wall injection model using the immersed boundary method (IBM) is developed in this study. The basic algorithm of the present IBM is similar to that of Mittal et al. The numerical model of validation is an Ariane 5 solid rocket motor. The present computational data were compared with the experimental data. Figure 1 shows the computational grid and Mach number distributions. From the XZ cross section, the velocity vectors close to the injected wall surface show that the gas is perpendicularly injected to the propellant wall surface. From the axial velocity profiles shown in Fig. 2, the velocity profiles of the numerical simulation were in good agreement with the experimental data within the error range. Therefore, these results show that an improved correlation with the experimental results has been achieved using the propellant wall injection model using the IBM. Next, we investigated the structure of the vortex that appears from the inhibitor. As shown in Fig. 3, we clarify that the structure of the three-dimensional vortex appears from the inhibitor. These results could eventually lead to clarification of the pressure oscillation in the solid rocket motor combustor.

Scramjet Engine:

The fuel injection condition from the fuel injector is developed in this study. It was confirmed that the flow field involved with fuel injection can be solved with high accuracy. However, validation of this model is insufficient at this moment. In the next year, we should validate of this model.

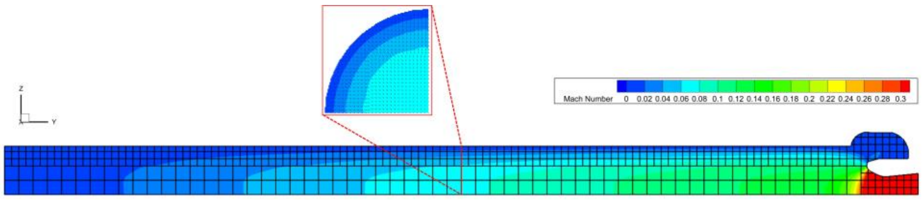

Fig. 1: Computational grids and Mach number distributions in the case of Ariane 5 solid rocket motor.

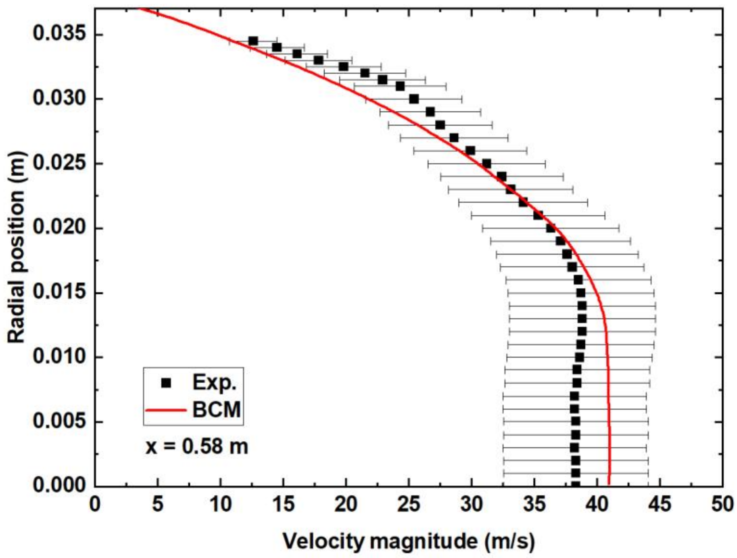

Fig. 2: Comparison of velocity profiles between experiments and numerical simulations at x = 0.580 m.

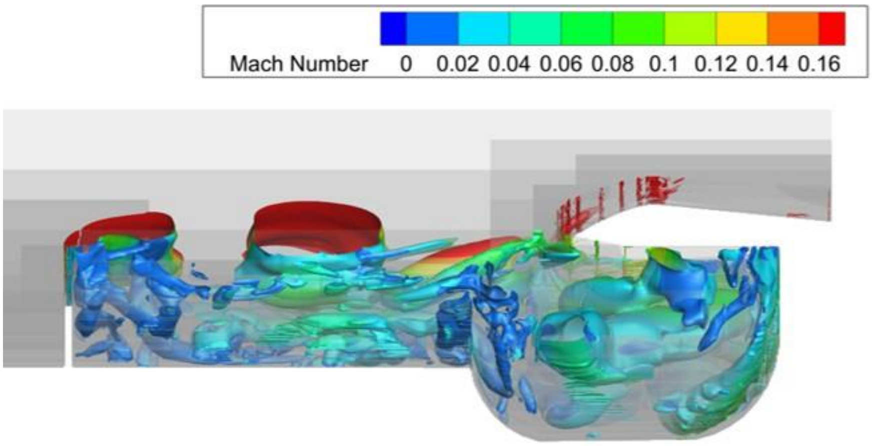

Fig. 3: Iso-surface of the Q-criterion near the nozzle cavity.

Publications

- Peer-reviewed papers

Shinichiro Ogawa, Kentaro Ouchi, and Daisuke Sasaki, "Three-dimensional Fluid Analysis of a Solid Rocket Motor with Nozzle Using Building-Cube Method," Aerospace Technology Japan, Vol. 22, 2023, pp. 1-10. (in Japanese)

- Oral Presentations

Shinichiro Ogawa, and Daisuke Sasaki, "Development of Wall Injection Model for Solid Rocket Motor Internal Flow by Block-Structure Cartesian Mesh," AIAA SciTech 2023, AIAA 2023-1131, 2023.

Shinichiro Ogawa, and Daisuke Sasaki, "Development of Wall Injection Model for Solid Rocket Motor Propellant using Immersed Boundary Method," 36th Computational Fluid Dynamics Symposium, B05-2, 2022. (in Japanese)

Shinichiro Ogawa, Kentaro Ouchi, and Daisuke Sasaki, "Development of Fluid Analysis Method Inside a Solid Rocket Motor with Cavity Using Building-Cube Method," 54th Fluid Dynamics Conference/40th Aerospace Numerical Simulation Technology Symposium, 1C02, 2022. (in Japanese)

- Poster Presentations

Kentaro Miyata, Shinichiro Ogawa, Koichi Mori, and Daisuke Sasaki, "Development of a BCM Solver for Internal Flow in Supersonic using the IB Method," 19th International Conference on Flow Dynamics, OS21-37, 2022.

Usage of JSS

- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	1 - 5
Elapsed Time per Case	150 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.06

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	0.00	0.00
TOKI-ST	64,160.79	0.06
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	170,369.77	11.42
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	13.33	0.01
/data and /data2	30,000.00	0.23
/ssd	133.33	0.02

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)	0.62	0.00

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