Computational analysis of internal flow field in an aerospace propulsion engine using the building-cube method

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Responsible Representative

Shinichiro Ogawa, Osaka Metropolitan University, Department of Aerospace and Marine-system Engineering

Contact Information

Shinichiro Ogawa, Assistant Professor, Osaka Metropolitan University(shinichiro.ogawa@omu.ac.jkp)

Members

Shinichiro Ogawa, Loupmael Agulles, Daisuke Sasaki

Abstract

The utilization of computational fluid dynamics (CFD) for reducing development costs is increasing; however, conventional analysis solvers have traditionally employed structured or unstructured grids. Nevertheless, when using structured or unstructured grids, challenges such as difficulties in achieving higher-order spatial accuracy in the spatial scheme, high computational costs during large-scale calculations, and increased post-processing loads exist. Therefore, this study focuses on the Building-Cube Method (BCM), which can address these challenges. The BCM solver developed thus far lacks sufficient validation for internal flow fields within engines; hence, this study aims to clarify the accuracy of internal flow field analysis within engines. Additionally, improvements to the analysis solver tailored for internal flow fields within engines will be made to enable high-precision analysis.

This year, the research progressed under the following two objectives:

1. In the analysis targeting solid rocket motors, the validity of the wall jet model should be elucidated with a focus on star-shaped grain configurations.
2. In the analysis targeting scramjet engines, a model for fuel injection in supersonic flow will be constructed, and the validity of this model will be established.

Reasons and benefits of using JAXA Supercomputer System

In this study, to analyze the complex flow fields within an engine using three-dimensional numerical simulations, it is necessary to perform computationally intensive calculations. Therefore, we utilize the JAXA supercomputer, which enables the execution of large-scale calculations in a short time frame.

Achievements of the Year

The achievements for the fiscal year 2023 are as follows:

1. Solid Rocket Motor:

Numerical analysis of the internal flow field of a solid rocket motor with a star-shaped grain configuration (Fig. 1) was conducted. From the analysis results shown in Fig. 2, it was observed that airflow can be induced from the wall of the star-shaped grain. It was also evident that the wall jet conditions previously established can be applied to star-shaped grain configurations with different injection directions. Although a quantitative evaluation of the analysis accuracy was not achieved in the fiscal year 2023, efforts will continue in subsequent years to evaluate the accuracy of the analysis.

2. Scramjet Engine:

A model for fuel injection in supersonic flow was constructed and incorporated into the three-dimensional BCM solver. To validate the constructed fuel injection model, an analysis was performed using a model with fuel injection ports installed upstream of a cavity flame holder (Fig. 3). The analysis results reproduced fuel injection in supersonic flow, as shown in Fig. 4, and the model overestimates fuel injection compared to previous studies. In the coming fiscal years, efforts will focus on the reconstruction and revalidation of the fuel injection model.

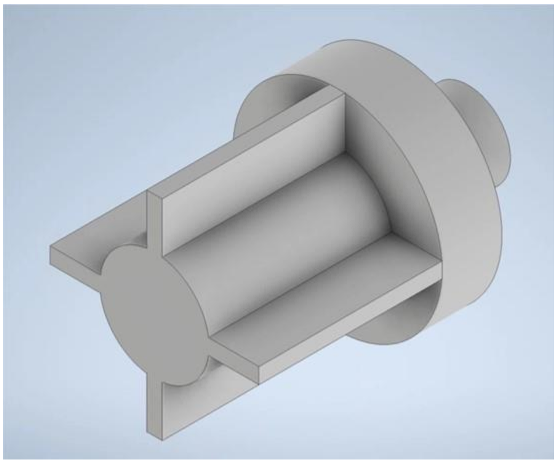

Fig. 1: Verification analysis model (solid rocket motor)

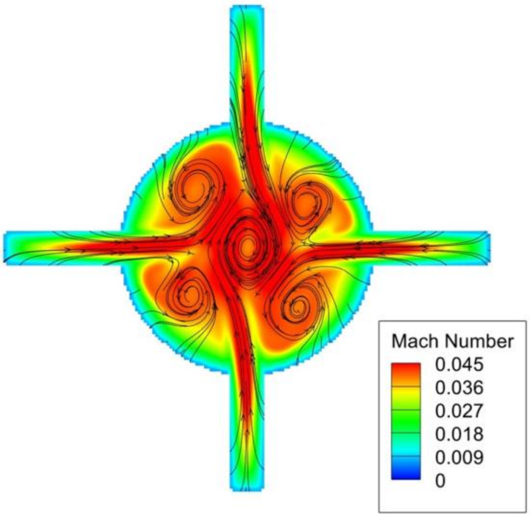

Fig. 2: Verification analysis results for star-shaped grain configuration (Mach number contour plot)

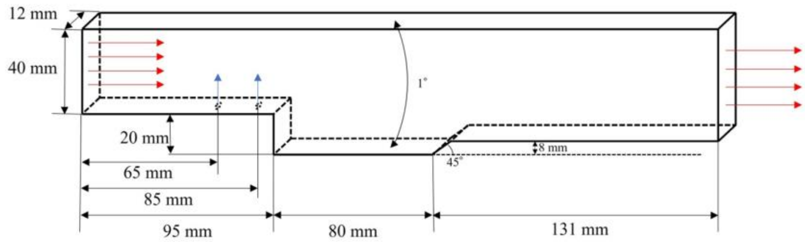

Fig. 3: Verification analysis model (scramjet engine)

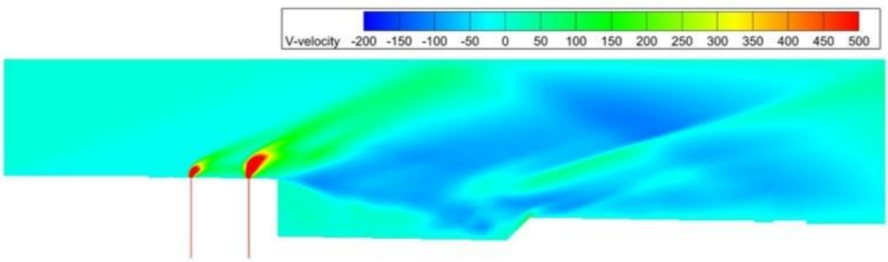

Fig. 4: Verification analysis results of fuel injection from upstream of cavity flame holder (Y-axis velocity distribution)

Publications

- Oral Presentations

[1] Shinichiro Ogawa, Daisuke Sasaki, Shoya Yoshinaga, "Effect of Burning Surface Regression on Internal Flow Field in Solid Rocket Motor," AIAA SciTech 2024 Forum, AIAA Paper 2024-0213, 2024.

[2] Shoya Yoshinaga, Keishiro Yoshida, Shinichiro Ogawa, Daisuke Sasaki, "Numerical Analysis of Flowfield from Star-Shaped Grains using Immersed Boundary Method," 36th Computational Mechanics Conference, 2023.

[3] Shinichiro Ogawa, Yuzen Sasaoka, Daisuke Sasaki, Shoya Yoshinaga, Keishiro Yoshida, "Numerical Analysis of Internal Flow in Laval Nozzle Using Building-Cube Method," 55th Fluid Dynamics Conference/41st Aerospace Numerical Simulation Symposium, 2023.

[4] Kentaro Miyata, Shinichiro Ogawa, Daisuke Sasaki, Koichi Mori, "Validation Analysis of Internal Flowfield Inside a Cavity in a Supersonic Flow using the Building-Cube Method," 55th Fluid Dynamics Conference/41st Aerospace Numerical Simulation Symposium, 2023.

[5] Shoya Yoshinaga, Daisuke Sasaki, Shinichiro Ogawa, "Investigation of Flowfield from Star-Shaped Grains using Building-Cube Method," The Japan Society of Mechanical Engineers Hokuriku-Shinetsu Branch 2023 Congruence Conference, 2023.

- Poster Presentations

[1] Kentaro Miyata, Shinichiro Ogawa, Daisuke Sasaki, Koichi Mori, "Development of Numerical Analysis Method for Cavity Flame-Holder in Supersonic Flow using Building-Cube Method," 20th International Conference on Flow Dynamics, 2023.

[2] Shoya Yoshinaga, Keishiro Yoshida, Shinichiro Ogawa, Daisuke Sasaki, "Numerical Analysis of Internal Flowfield in Star-Shaped Grains using Building-Cube Method," 20th International Conference on Flow Dynamics, 2023.

Usage of JSS

- **Computational Information**

Process Parallelization Methods	N/A
Thread Parallelization Methods	OpenMP
Number of Processes	1
Elapsed Time per Case	150 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources*1(%): 0.01

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	0.00	0.00
TOKI-ST	4,789.24	0.01
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	16,691.13	1.27
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	29,900.00	0.18
/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.