Numerical investigation of flow around intake and wing

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Abstract

The development of supersonic/hypersonic passenger airplanes has been accelerated in recent years to deal with the demand for faster intercontinental transport. Buzz is one of the most important problems in realizing air-breathing supersonic/hypersonic engines. This is the self-excited oscillation of the shock wave that occurs in supersonic/hypersonic intakes. This phenomenon induces the pressure oscillation inside the intake and can cause the structural damage to the engine. Therefore, estimating the pressure waveform of the buzz and designing the engine which is resistant to the buzz is necessary. Thus, in this study, the numerical simulations were conducted to clarify the buzz mechanism and construct the buzz pressure model.

Also, for substituting CFD for aircraft design and certification is expected to reduce costs. Accurate aerodynamic prediction of the flow field around high-lift devices remains difficult due to the occurrence of separation with unsteady flow. In this study, a combined RANS and WMLES method is applied to numerical analysis of the flow around a high-lift device. By clarifying the grid dependence while taking fluid phenomena into account, we aim to develop a technique that enables high-fidelity CFD to be performed with small computational resources.

Reasons and benefits of using JAXA Supercomputer System

The inner flow of the supersonic intake is so complex that the calculation cost is large. However, the execution of the unsteady simulations of the intake became possible by using JSS3. The flow field around high-lift devices is very complex and unsteady flow with large scale separation occurs. High-fidelity simulations of such flows require high computational power and the use of JAXA's supercomputer.

Achievements of the Year

The numerical simulations were conducted on the buzz occurring in the ramjet intake for High Mach Integrated Control Experiment (HIMICO). Figure 1 shows the static pressure waveform of the buzz upstream of the exit nozzle. A cycle of the buzz can be divided into the pressure increasing and decreasing period. During the pressure increasing period, the static pressure increases and the shock wave moves upstream inside the intake because the inflow rate exceeds the outflow rate. The CFD results indicate that the effects of the exit nozzle opening ratio on the static pressure and moving speed of the shock wave differ depending on whether the shock wave is moving upstream or downstream of the diffuser entrance. This suggests that the static pressure waveform during these two periods is determined by the theory of the moving shock wave, and the mass and energy conservation laws, respectively. By applying these theories, the buzz model to estimate the static pressure waveform during the pressure increasing period has been successfully constructed. To validate the model, it was applied to the buzz occurring in different freestream Mach numbers.

Unsteady CFD analysis of a 30P30N airfoil was performed using FaSTAR. WMLES was applied to the areas where high-fidelity simulations were required, and RANS was applied to the areas where high-fidelity simulations were not required to reduce the computational cost. As a result, the results were comparable to previous studies that applied WMLES to the entire analysis domain, using only about 60% of the number of grids. In addition, we were able to obtain an index for the generation of mesh when the RANS/WMLES hybrid method is applied to the numerical analysis of the flow around a high-lift device.

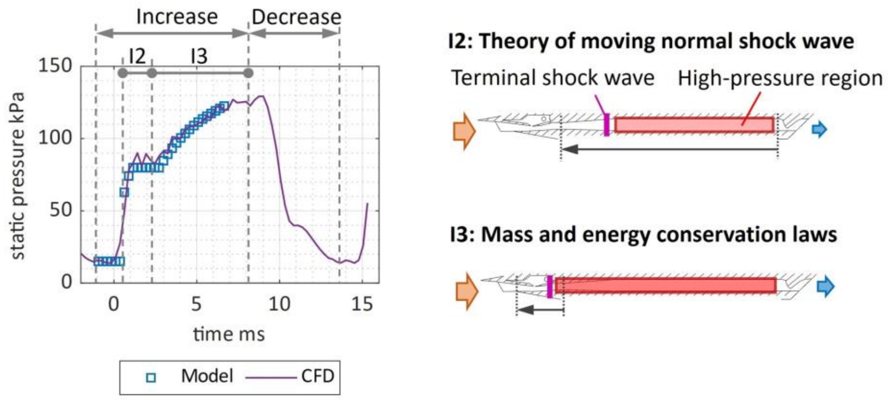

Fig. 1: Static pressure waveform of buzz upstream of exit nozzle, and schematic of pressure increasing period

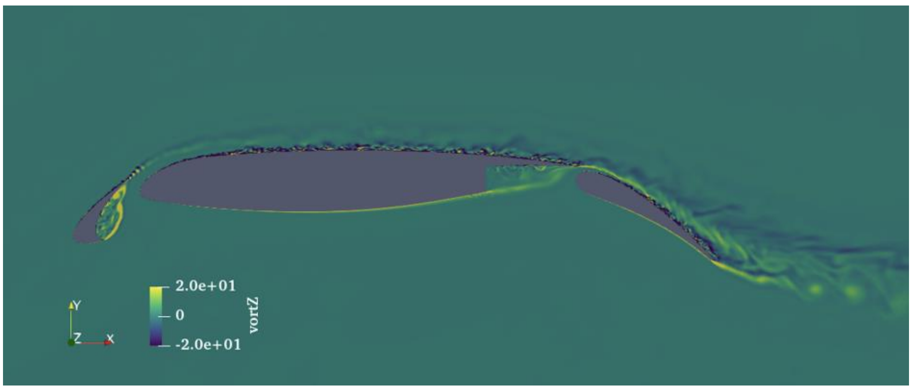

Fig. 2: Numerical analysis around 30P30N airfoil by RANS/WMLES hybrid method

Publications

- Oral Presentations

1) Fujii, M., Kuwabara, Y., Tanaka, R., Suzuki, A., Ariyoshi, S., Narita, T., Takamatsu, S., Sato, T., and Taguchi, H., "Considerations on Effects of Intake Throat Opening Ratio on Buzz Characteristics Based on Shock Wave Moving Mechanism," Space Transportation Symposium FY2023, STCP-2023-031, Kanagawa, Jan. 2024.

2) Fujii, M., Sato, T., Hashimoto, A., and Taguchi, H., "Estimation of Maximum Static Pressure based on Inner Flow Comparison in Supersonic Intake between Steady Operating State and Buzz," Symposium on Shock Waves in Japan, 1A3-1, Fukuoka, Mar. 2024.

3) Fujii, M., Sato, T., Taguchi, H., and Hashimoto, A., "Modeling and Consideration of Static Temperature Change in Ramjet Intake Buzz by Applying Law of Energy Conservation," The 63rd Conference on Aerospace Propulsion and Power, 1B02, Hokkaido, Mar. 2024.

- Poster Presentations

1) Fujii, M., Sato, T., Hashimoto, A., and Taguchi, H., "Pressure Model of Buzz Oscillation in a Ramjet Intake," Aerospace Europe Conference 2023, Joint 10th EUCASS - 9th CEAS Conference, Switzerland, Jul. 2023.

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Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	576 - 4608
Elapsed Time per Case	30 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.82

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	21,234,367.50	0.96
TOKI-ST	197,089.23	0.21
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	2,290.96	0.17
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	898.33	0.75
/data and /data2	55,776.67	0.34
/ssd	6,693.33	0.63

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	0.38	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)	2,497.82	1.13

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