Numerical investigation of the supersonic intake and wings

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Abstract

Development of supersonic/hypersonic passenger airplanes has been accelerated in recent years to deal with the demand for faster intercontinental transports due to the acceleration of global business development. A 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 pressure oscillation inside the intake and can cause 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, numerical simulations were conducted to clarify the buzz mechanism and construct the buzz pressure waveform model. Develepment of CFD method for high-lift device flow is also conducted. 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 lattice 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 buzz is an unsteady phenomenon characterized by an movement of shock waves and separation, and the calculation cost is large. The use of JSS3 enabled the reproduction of the phenomenon with various freestream conditions. 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 buzz is an unsteady phenomenon (Fig. 1) accompanied by an imbalance between the intake's inflow and outflow flow rates, so predicting the intake outflow rate is crucial to construct buzz models. Therefore, the time change of the density and total temperature distributions, which are closely related to the mass flow rate, were investigated. The results indicated that the density and total temperature distributions change significantly and rapidly due to the rapid movement of the terminal shock wave during the period I2. In contrast, during the I3, it was found that the total temperature distribution is strongly influenced by the convection. Based on these results, a model was developed to predict the physical quantities upstream of the exit nozzle and the outflow rate by utilizing theoretical formulas for a moving normal shock wave. The constructed model was then integrated into the previously developed buzz model, and it was confirmed to be able to predict the buzz static pressure waveform quantitatively and reasonably well (Fig. 2). For the analysis of the flow around high-lift devices, CFD simulations were conducted using the FaSTAR solver with a RANS/WMLES hybrid approach applied to the 30P30N airfoil. WMLES was applied to regions requiring high-fidelity simulation, while RANS was used in other regions to reduce computational cost. By carefully configuring the placement of the RANS and WMLES regions, we explored the setup that yields the most physically accurate results. Detailed examinations of the flow field visualization (Fig. 3) and surface pressure coefficient distribution (Fig. 4) revealed that placing the RANS region on the suction side of the wing provides physically reasonable results.

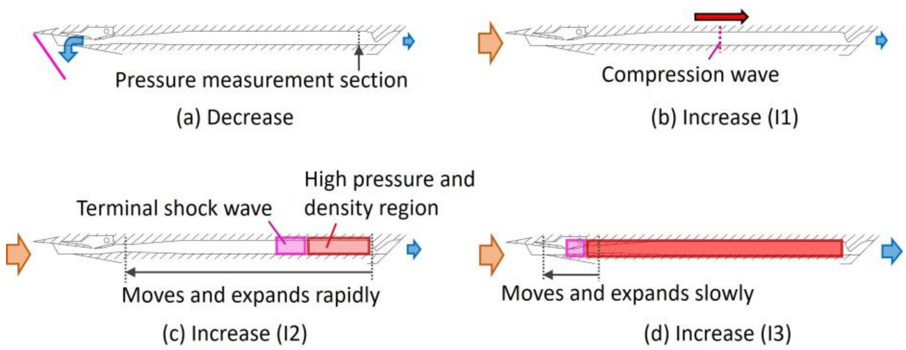

Fig. 1: Schematic of intake buzz

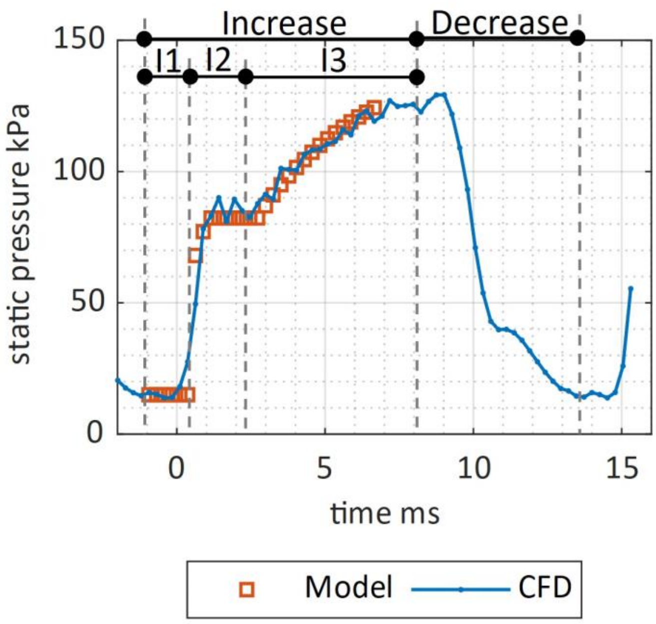

Fig. 2: Output of buzz static pressure waveform model (Measurement section of CFD result is represented in Fig. 1(a))

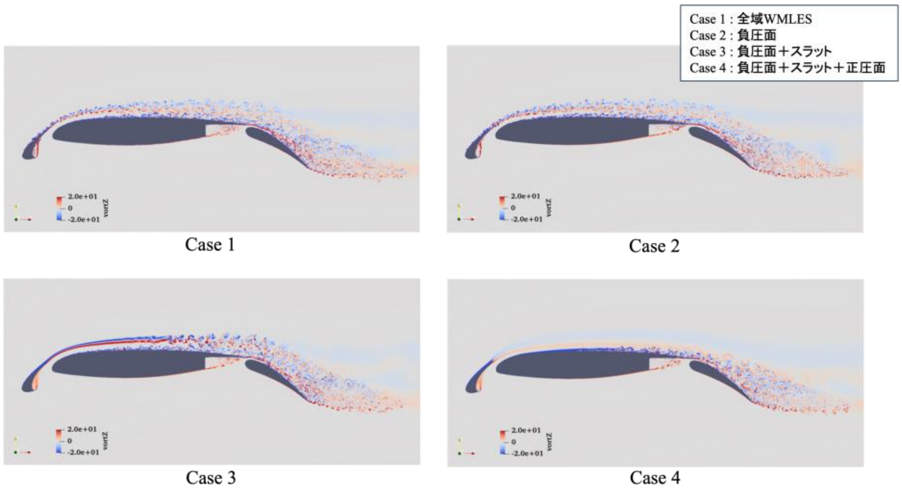

Fig. 3: Visualization of span-wise vorticity over 30P30N airfoil

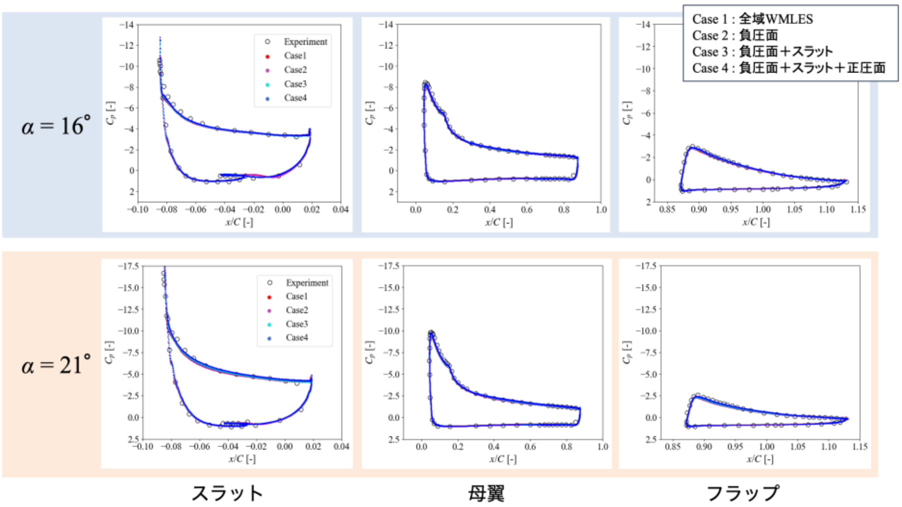

Fig. 4: Surface pressure distribution

Publications

- Peer-reviewed papers

1) Fujii, M., Sato, T., and Taguchi, H., Investigation of Intake Buzz Focusing on Shock Wave Movement and Inflow/Outflow Balance, Journal of Propulsion and Power, accepted.

- Oral Presentations

1) Fujii, M., Sato, T., Hashimoto, A., and Taguchi, H., Mechanism Investigation of Density Distribution Change during Buzz in Ramjet Intake, 2024 AIAA AVIATION, AIAA 2024-3917, Las Vegas, Jul. 2024.

2) Uchida, K., Kojima, Y., Aoyama, T., RANS/WMLES Hybrid Simulation of Flow around High-Lift Devices, 38 th CFD symposium, Tokyo, 2024.

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	96 - 4608
Elapsed Time per Case	96 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.70

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	17,819,534.40	0.82
TOKI-ST	92,465.33	0.09
TOKI-GP	0.00	0.00
TOKI-XM	2,260.43	1.10
TOKI-LM	12,419.94	0.90
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	775.83	0.52
/data and /data2	48,121.67	0.23
/ssd	5,438.33	0.29

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)	4,401.10	3.01

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