Study on Future Space Transportation System using Air-breathing Engines

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Abstract

The research and development of reusable space transportation systems are being tackled globally to reduce the cost of space transportation systems significantly. In this project, we will study the key technologies related to the practical application of a transport vehicle equipped with an air-breathing combined cycle engine, which is expected to achieve highly efficient reusability by using atmospheric air as an oxidant.

Reasons and benefits of using JAXA Supercomputer System

The following points are issues to consider when examining aircraft equipped with air-intake type combined cycle engines. 1) Aerodynamic characteristics that enable flight under various flow conditions, from subsonic speeds during takeoff to supersonic speeds. 2) The need for integrated design through the airframe and engine integration. 3) Accurate evaluation of thermal protection against aerodynamic heating. Therefore, three-dimensional Computational Fluid Dynamics (CFD) is an essential tool for designing these, and a supercomputer is required to run many CFD simulations efficiently.

Achievements of the Year

(1) We investigated the aircraft shapes that could be assumed for future air-breathing transport systems and analyzed them under various flight conditions. We performed aerodynamic analysis using FaSTAR's Euler analysis for more than 30 aircraft shapes under 162 conditions (6 Mach number conditions, 9 angle of attack conditions, and 3 sideslip angle conditions) per aircraft and evaluated the aerodynamic performance map. Figure 1 compares the lift and drag coefficients when the flow channel for the combined cycle engine is closed (close) and open (open), analyzed from Mach 0.3 to 6.0 and with an angle of attack from -10 deg to +20 deg. Comparing the drag coefficients, it was confirmed that the influence of opening and closing the flow channel increased as the

velocity increased.

(2) The purpose of the RD-1 hypersonic combustion flight test conducted in 2022 was to burn ethylene fuel in a vehicle flying at Mach 6 or so and to explore the combustion state under actual flight conditions. The test vehicle was launched into a ballistic flight trajectory by the S-520 small rocket, and the test was conducted when the Mach number was reached during the fall. In this case, it is essential to understand the flight conditions from the ADS (Air Data Sensing) System installed on the surface of the test vehicle. The use of pitot tubes in the hypersonic range is problematic from the perspective of aerodynamic heating. Therefore, in this study, we developed an algorithm to grasp the flight conditions using machine learning. Figure 2 shows an example of the aerodynamic analysis results used in this case.

(3) For aircraft equipped with air-breathing engines, regenerative cooling is being considered for cooling high-temperature parts, and there are also indications that the fuel may pass from the transcritical state to the supercritical state. Under these conditions, a strong nonlinearity in the change in thermal properties has been reported to often result in unstable flow patterns. Figure 3 shows an example of a two-dimensional cavity flow in which a hydrocarbon fuel is heated under transcritical conditions, and it has been confirmed that instability occurs in the analysis as well.

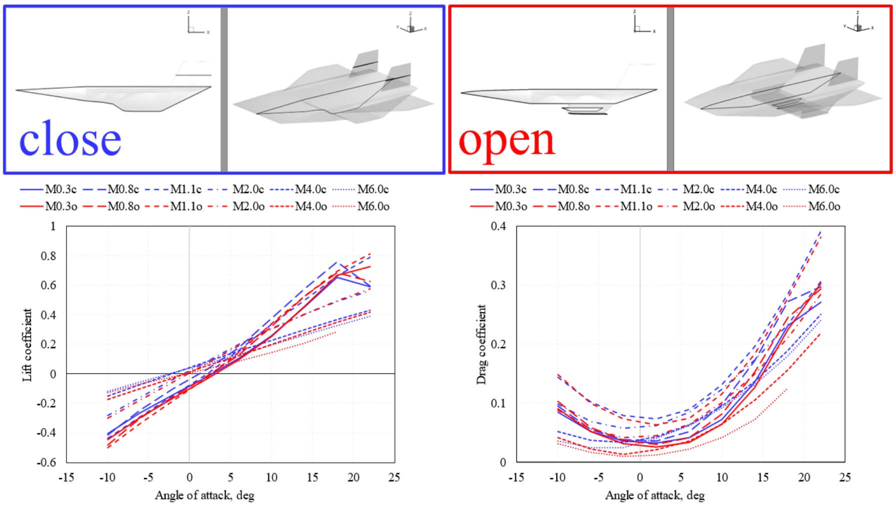

Fig. 1: Results of aerodynamic analysis of aircraft with a combined cycle engine: difference between when the air inlet is closed or open.

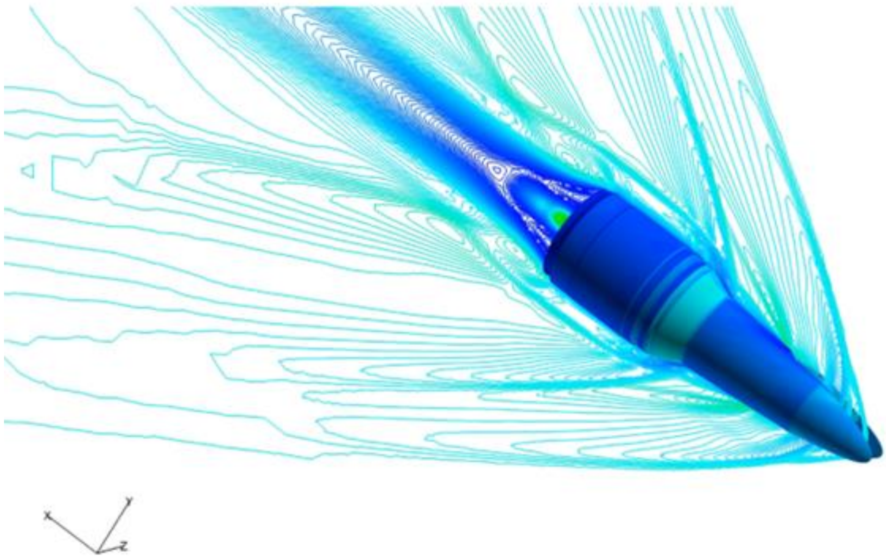

Fig. 2: Mach number distribution when the RD1 experimental model is descending.

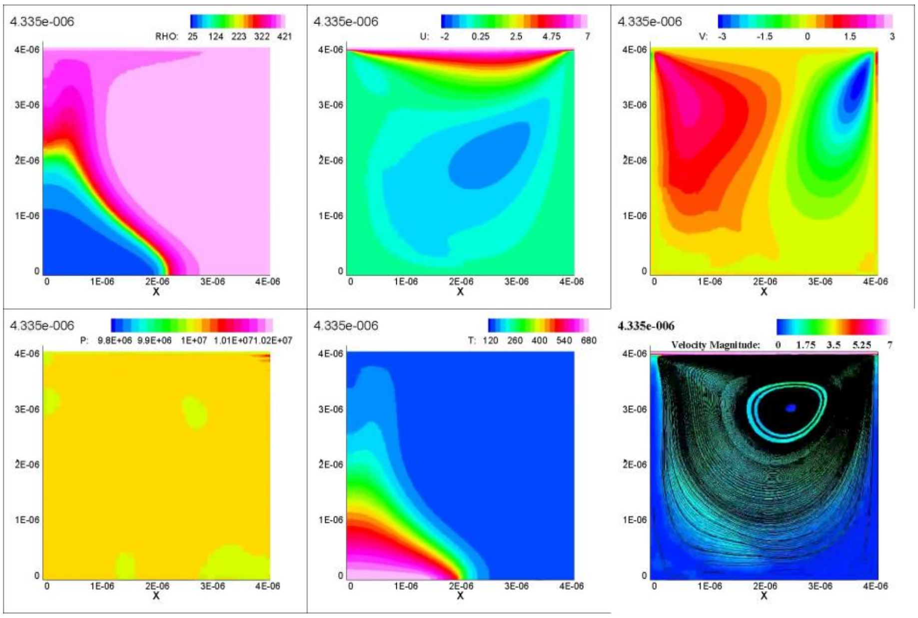

Fig. 3: Instability of two-dimensional heated wall cavity flow in supercritical methane (Video. Video is available on the web.)

Publications

- Non peer-reviewed papers

(1) Hasegawa, S. and Tani, K., "Comparison of Numerical Results with Aerodynamic Experimental Data for JAXA's Experimental Vehicle for Hypersonic Flights," AIAA Scitech 2025, AIAA 2025-1335, 2025.

(2) Takahashi, S., Takegoshi, M., Kato, K., Isono, T., Yatsuyanagi, S., Tomioka, S. and Kubosaki, K., "Numerical Analysis of Fuel Supply System of Scramjet Engine", AIAA Scitech 2025, AIAA 2025-0752, 2025

- Oral Presentations

(1) Hasegawa, S., "Research on Flight State Estimation Method Using ADS", 56th Fluid Mechanics Conference / 42nd Aerospace Numerical Simulation Technology Symposium, Kagoshima, July 2024.

(2) Takahashi, S., Takegoshi, M., Kato, K., Isono, T., Yatsuyanagi, S., Tomioka, S., Kubosaki, K., "Development of Transient Analysis Method for Fuel Feeding Line of Scramjet Engine", 56th Fluid Mechanics Conference / 42nd Aerospace Numerical Simulation Technology Symposium, Kagoshima, July 2024.

(3) Hasegawa, S., "Flight State Evaluation in Hypersonic Flight Experiments Using Statistical Machine Learning", Japan Society of Mechanical Engineers Annual Meeting, Ehime University, September 2024.

(4) Takahashi, S., Yatsuyanagi, S., Isono, T., Onodera, T., Takegoshi, M., Tomioka, S., "Numerical simulation of hydrocarbon flow near critical condition for prediction of flow instabilities", 38th Computational Fluid Dynamics symposium, 2024

(5) Kato, H., Sasaki, D., Takahashi, S., Takegoshi, M., "Fundamental Study on Aerodynamic Analysis toward Wide-Speed-Regime Spaceplane by FaSTAR",Northern Branch 2025 conference and the 6th symposium on reusable space transportation, 2025.

- Other

(Patent Pending) Susumu Hasegawa, Koichiro Tani: Patent Application 2024-210624, Method for Estimating Flight State Using ADS Using Machine Learning

Usage of JSS

- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	92 - 2496
Elapsed Time per Case	10 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 1.19

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	30,635,937.45	1.40
TOKI-ST	129,188.41	0.13
TOKI-GP	0.00	0.00
TOKI-XM	23.86	0.01
TOKI-LM	1,513.46	0.11
TOKI-TST	661.53	0.01
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	506.05	0.34
/data and /data2	82,114.79	0.39
/ssd	7,512.67	0.40

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage*2 (%)
J-SPACE	21.63	0.07

*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)	5,566.87	3.80

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