Research for Future Transportation System (Research for Scramjet Engine Flow Path)

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Abstract

The purpose is to investigate the influence of the internal flow path on the engine performance by help of CFD in the viewpoint of aerodynamics about a scramjet engine as a reusable space propulsion engine, and to contribute to designing a scramjet engine.

In other words it is to compare the engine results with CFD in order to extract effective factors on improvement of the engine performance from a lot of experimental results of engine tests stored in Kakuda Space Center, and to make CFD simulation about a trial engine configuration which is proposed for engine performance improvement.

Ref. URL:
https://jaxa.repo.nii.ac.jp/?action=pages_view_main&active_action=repository_view_main_item_detail&item_id=9276&item_no=1&page_id=13&block_id=21 (予定)

Reasons and benefits of using JAXA Supercomputer System

In Kakuda Space Center, scramjet engine is being investigated, and a lot of engine performance tests have been made by using Ramjet Engine Test Facility (RJTF). It has been found in the tests that the difference of engine inner configuration produces large difference of thrust performance in the flight condition of Mach 6. CFD simulations are being carried out based on the plenty of engine test data stored in Kakuda Space Center about how the difference of engine inner configuration of main elements of the engine, inlet, isolator, strut and others influent on the engine performance, and CFD simulations on trial engine configuration not yet tested are also carried out.

Achievements of the Year

In order to compare to the result of engine configuration already tested in RJTF (Ramjet Engine Test Facility) located in Kakuda Space Center, a virtual engine test is being carried out about an improved engine configuration. The configuration has a boat-tail strut of which the tail is shortened and narrowed in order to improve the engine thrust performance, though it has the same basic dimension to the tested engine. Figure 1 shows the tested engine outline and the both configurations. Figure 2 shows the difference of engine inner quantity in the both engine configurations.

A commercial code ANSYS Fluent is applied to this calculation, and structured grid system is used. The minimum grid size is set by 0.1mm near the cowl leading edge. The calculation is done in the half of the engine model assuming mirror condition in the engine symmetric center plane. The number of grids at the maximum is 5.03×10^6. The limiter is the second order accuracy, space integral is AUSM+, time integral is explicit method, and turbulence model is k-omega model. For the combustion calculation, a model used here is the model of Fluent including Hydrogen-Oxygen reaction equation based on the Petersen and Hanson (1999). This time Finite Rate Chemistry Model is employed for the combustion calculation, and the reaction consists of 9 species and 20 elementary reactions.

Engine air flow condition for calculation is set at Mach 5.3 in the engine entrance, and total temperature is set at 1500K. RJTF nozzle exit boundary layer (57.9mm thickness / 99.9% of main stream velocity) is also set in the flows into the engine, which corresponds to the boundary layer on the air frame bottom surface.

The calculation is performed mainly on JAXA's present Supercomputer System the 3rd Generation, JSS3. It is used remotely from Kakuda Space Center.

1) Figure 3 is shown next, and the OH distribution in combustion flow is described. Fig.3 shows the OH distribution in the down stream of the strut in combustion condition. Fig.3a gives the 5/5-Height Strut configuration and Fig.3b gives the Boat-tail Strut configuration.

In the both configurations the high OH concentration areas are seen in the side of the top wall. This is the separation area occurring in the corner of the top wall and the side wall. The product of OH is also seen just in the downstream of cross point of the inclined cowl shock and the strut tail edge. It is clearer in the Boat-tail Strut configuration. Comparing to the 5/5-Height Strut configuration, red area is wider. The product of OH is rich, and the combustion is seen active. In fact the integral pressure thrusts calculated in combustion result are 715N in the 5/5-Height Strut configuration, and 825N in the Boat-tail strut configuration in the fuel flow rate of 48g/s, respectively, so the Boat -tail Strut configuration shows the higher performance. The difference of OH distribution supports the performance.

Anyway it is found that the cowl shock wave promotes the combustion reaction. The authors think that the cowl shock is not so disturbed and has influence much further into the downstream in the Boat-tail Strut configuration comparing to the 5/5-Height Strut configuration, so the combustion reaction is much more promoted.

In the Boat-tail Strut configuration, as reported the last year, the fuel equivalence ratio distribution is improved, and the performance is increased, and it is supported by the OH distribution difference. This configuration has superiority. 2) The air flow result based on the finer girds of Grid A (40×10^6 and the Grid B (10×10^6) are used for air condition in order to see the grid dependency. They are the eight times and two times as fine as the Grid C (5×10^6) employed in this research. The pressure distributions based on the grids are compared. Between the Grid A and Grid B the slight difference is found.

The disagreement between the grids is the section around the backward-facing step and the small path narrowed by the strut and the side wall. In the path the incidences and reflects of the shock waves and expansion waves repeat, and they are folding each other along the path to the downstream, where the separation and the recirculation zone behind the backward-facing step are included, so the flow field is too complicated to simulate exactly. In order to capture the situation accurately by CFD, another research is needed, and this is the problem to be solved in future.

Rather the finer girds the Grid C is found to be appropriate. In the air flow condition and the combustion condition the result obtained from Grid C agrees with the experimental results. The combustion calculation result is reported, and air flow condition results is also reported before. The result of Grid C is acceptable in calculation accuracy and is cost-effective in engineering aspect of grid points and calculation time.

The authors think that it is essential purpose to find sources of thrust in aerodynamics and combustion phenomena occurring in engines and to amplify them. Finding the sources contributes designing engines.

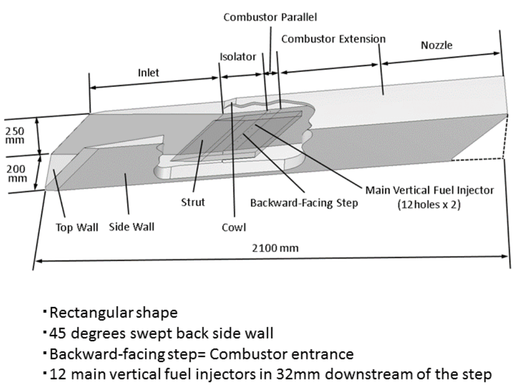


Fig. 1: Outline of scramjet engine tested. The engine is set upside-down on the test bed, and 5/5-hieght strut is equipped.

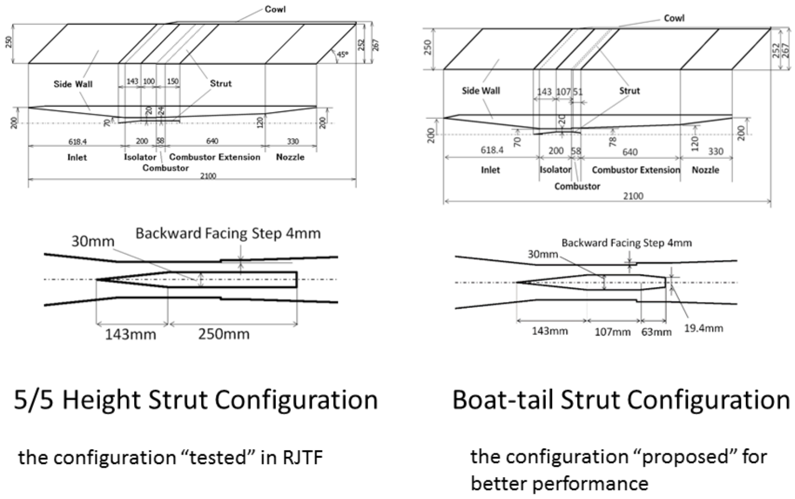
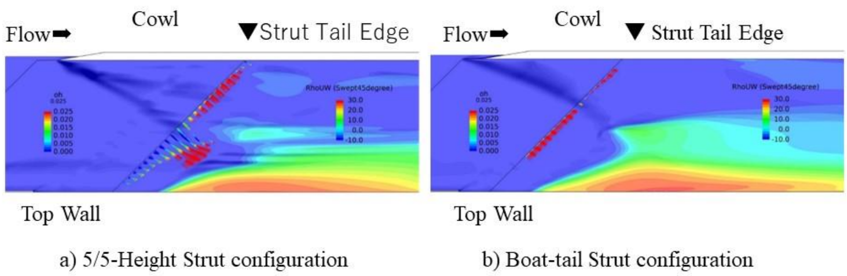


Fig. 2: Two types of strut for CFD comparison. a) 5/5H-Strut configuration is used in engine test, and b) the Boat-tail Strut configuration is an improved one designed as a virtual configuration. (unit:mm)



OH distributions in the strut wakes in the two engine configurations in the combustion condition. Note that each visualized cross section is the vertical cut in the middle of the flow path beside the strut.

Fig. 3: OH distribution in the down stream of the strut in combustion condition

Publications

- Non peer-reviewed papers

SATO Shigeru, FUKUI Masaaki, MUNAKATA Toshihiko, WATANABE Takahiro, TAKAHASHI Masaharu, and INOUE Taku
Trial for Performance Improvement of Scramjet Engine

-Better Fuel Equivalence Ratio Distribution by Modifying Strut Shape Proceedings of Fluid Dynamics Conference/Aerospace Numerical Simulation Symposium 2022 Morioka, JAXA Special Publication,JAXA-SP-22-007, Feb.,2023, JAXA (in Japanese).

- Oral Presentations

1)SATO Shigeru, FUKUI Masaaki, MUNAKATA Toshihiko, WATANABE Takahiro, TAKAHASHI Masaharu, and INOUE Taku,
Trial for Performance Improvement of Scramjet Engine
-Better Fuel Equivalence Ratio Distribution by Modifying Strut Shape,
Fluid Dynamics Conference/Aerospace Numerical Simulation Symposium 2022, Jun.-Jul., Morioka (in Japanese).

Usage of JSS

- **Computational Information**

Process Parallelization Methods	It depends on FLUENT
Thread Parallelization Methods	It depends on FLUENT
Number of Processes	4 - 36
Elapsed Time per Case	1680 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources*1(%): 0.08

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	0.00	0.00
TOKI-ST	208,947.47	0.21
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	648.65	0.04
TOKI-TST	0.24	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	53.55	0.05
/data and /data2	446.24	0.00
/ssd	100.95	0.01

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	0.27	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)	5,611.30	3.90

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