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.

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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.

Fluid transport in the strut base flow is studied and is reported here. The strut base flow is important flow field on which mixing of air flow with fuel and fuel residence time depend, and its flow structure is influenced by the shock waves in the engine.

1) fluid transport in the two configurations in air flow: Figure 3 shows the fluid transport in the strut base flow in both configurations. Fig.3a gives the 5/5-Height Strut configuration, and Fig.3b gives the boat-tail strut configuration, being visualized from the side wall. The color indicates the mass flux, flow direction and velocity magnitude are given in vectors. The red means cowl direction, and the blue means the top wall respectively.

Comparing the both configurations, the Boat-tail Strut configuration is seen having larger fluid transport than the 5/5-Height Strut configuration. Being based on this, the fuel which is injected from the closer position to the top wall can be taken to the cowl side automatically owing to the fluid transport and is expected to contribute the fuel diffusion if the fuel rides streamline coming into the base flow.

2) fluid transport in the two configurations in combustion: Figure 4 shows enlarged situations in the both strut base flows in combustion. Those are the enlargement of strut base flow in the strut flow field which was reported before, and the visualization of the mass flux distributions in the strut base flows in the combustion in the view point of the engine side wall. Concentrating to the flow

running along the strut tail edge, values along this edge is given suffix xy. The suffix xy means combination of engine axis x line and the engine vertical y line, namely 45 degree direction paralleling to the strut tail edge.

At first the 5/5-Height Strut configuration in Fig.4a is to be observed. Mass flux ρu_{xy} is seen running to the cowl. In this 5/5-Height Strut configuration, In the top wall side under the line which the cowl shock wave is crossing, another large fluid transport is found towards to the top wall except the fluid transport towards to the cowl as well. It was not so clear in the air flow shown in Fiog.3. The fluid transport to the cowl side is an advance, but there is an inverse one against it, which seams to involve the fuel in the top wall side. The oblique shock wave from the cowl causes this difference.

Note that shock waves in the combustion is reported in the view point of difference from the air flow and of difference between the configurations, but the phenomena described above is found in the present enlarged new visualization of the strut base flow.

On the other hand, the whole of mass flux runs almost uniformly towards the cowl in the Boat-tail Strut configuration shown in Fig.4b. The authors think that this mass flux contributes the uniformity of the fuel diffusion. This configuration is better in the viewpoint of realizing uniform fuel distribution.

In the 5/5 Height Strut configuration, the strut has no contraction of tail and has a longer straight, rectangle tail. Therefore, flow in the engine has expansion and separation at the same time and the same place at the tail edge to occur larger drag and larger turbulence. The authors think that this causes the difference in the base flow structures to make the amount of fluid transport difference. (overlap of expansion and separation) Namely, though the large mass flux distribution is seen in the flow field, the inverse amount is also large, and the fluid transport is cancelled by subtraction.

Contrary in the Boat-tail Strut configuration/ the uniform fluid transport is seen along the tail edge from the top wall to the cowl, it is the effect that the enlarged recirculation region brings because the strut has a contraction of area at the tail before the tail edge, and the expansion leads the separation occurring in the downstream to make the strut base flow enlarged towards the downstream of the engine. (independence of expansion and separation) No large difference is seen before and after the crossing of the oblique shock from the cowl.

And also in comparison between the configurations, it is confirmed that the steep fuel distribution can be reduced in the Boat-tail Strut configuration, and it is suggested that a strut tail part shape can improve the fuel distribution. Consequently the explanation is can be denied that the concentration of fuel to the top wall close to the both side walls is caused by the swept-back side walls. "swept-back side wall theory"

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.

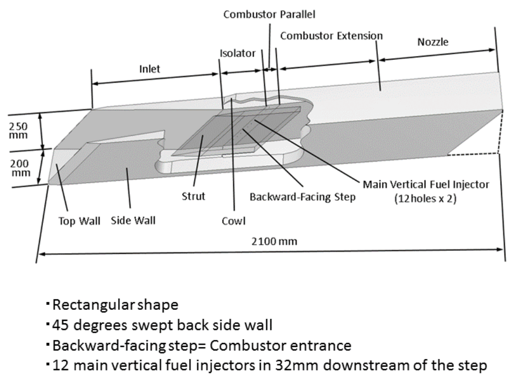

Fig. 1: Outline of scramjet engine tested. The engine is set upside-down on the test bed, and 5/5-hieght strut is equipped.

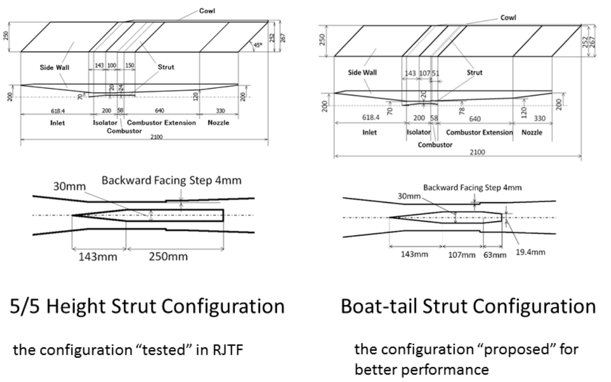

Fig. 2: Two types of strut for CFD comparison. a) 5/5H-Strut configuration is used in engine test, and b) the Boat-tail Strut configuration is an improved one designed as a virtual configuration. (unit:mm)

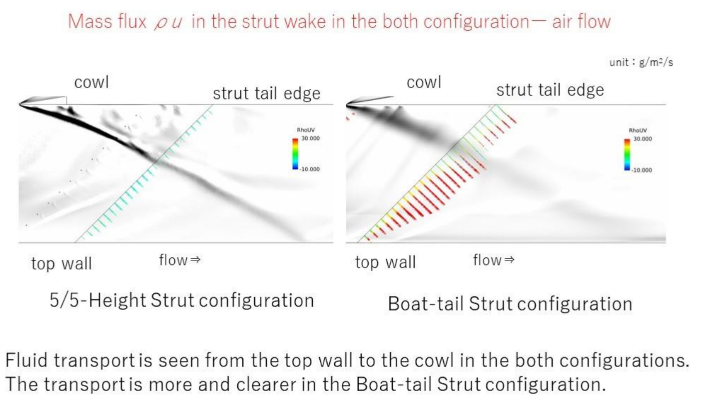

Fig. 3: Fluid transports in the strut wakes in the two engine configurations in the air flow condition.

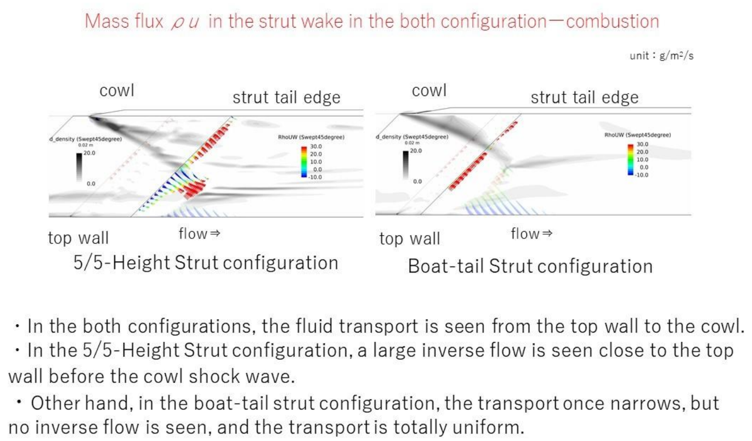

Fig. 4: Fluid transports in the strut wakes in the two engine configurations in the combustion condition.

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

– Flow Separation Domain Affecting Engine Performance Proceedings of Fluid Dynamics Conference/Aerospace Numerical Simulation Symposium 2021 Online,JAXA Special Publication,JAXA-SP-21-008,March 2022, 2022, JAXA(in Japanese).

- Oral Presentations

1)SATO Shigeru, FUKUI Masaaki, MUNAKATA Toshihiko, WATANABE Takahiro, TAKAHASHI Masaharu, and INOUE Taku,
Fluid Transport seen in the Wake of Strut in a Scramjet Engine
-Effect of Shock Wave-Strut System,
Symposium on Shock Waves in Japan, Mar 03-05 2021, on the Web(in Japanese).

2)SATO Shigeru, FUKUI Masaaki, MUNAKATA Toshihiko, WATANABE Takahiro, TAKAHASHI Masaharu, and INOUE Taku,
Trial for Performance Improvement of Scramjet Engine
– Flow Separation Domain Affecting Engine Performance, Fluid Dynamics Conference/Aerospace Numerical Simulation Symposium 2021 Online, Jun.30-Jul.02, on the Web(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	73,716.14	0.09
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	0.00	0.00
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	49.62	0.05
/data and /data2	469.00	0.01
/ssd	115.00	0.03

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2](%)
J-SPACE	1.17	0.01

[*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)	11,135.79	7.80

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