Study on Future Space Transportation System using Air-breathing Engines

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Abstract

Recently, reusable rockets have been being studied to reduce the cost of space transportation systems significantly. However, in order to extend the structural lifetime, it is necessary to operate them with relatively low engine power, leading to a decrease in launch capability. Therefore, air-breathing engines such as scramjets and rocket/scram combined cycle engines are promising to compensate the drawback. By using air in the atmosphere as an oxidizer, it becomes highly efficient, and it can be expected to maintain and improve the launch capability even if it is reused. In this project, we will research and develop key technology for practical application of the engine.

Reasons for using JSS2

The following points are raised as problems of engine design by ground experiments. 1) There are limits to reproducing various airflow conditions from takeoff to hypervelocity range. 2) Measured data is limited and complicated three-dimensional flow structure inside the engine can not be well identified. 3) Since the time and cost are limited, it is not easy to change the engine flow path configuration. Therefore, it is indispensable to utilize 3D CFD as a design tool, and a supercomputer is required for performing numerous CFD works efficiently.

Achievements of the Year

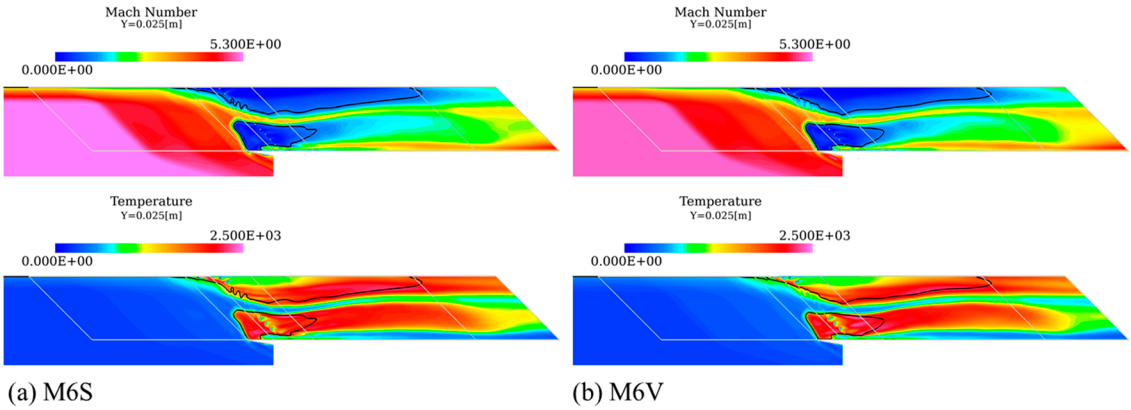
Subject 1: The air vitiation effect that thrust performance in air conditions including water vapor (M6V) was lower than that in dry air (M6S) was observed in the Mach 6 combustion tests for a hydrogen fueled scramjet engine at the Ramjet Engine Test Facility (RJTF). In order to investigate the cause, three-dimensional RANS analysis was carried out (Fig. 1).

Subject 2: RANS simulation corresponding to combustion tests of an ethylene-fueled scramjet combustor model was conducted by using a JAXA in-house solver LS-FLOW. For validation of the present CFD, the profiles of the combustion gas composition on the combustor exit plane predicted by the present CFD were compared with

experimental results measured by using a gas sampling rake probe. Influence of both the turbulent Schmidt number and the C2H4-Air combustion mechanism adopted for the present CFD on the numerical results were examined. The turbulent Schmidt number showed strong influence on the numerical results and the small value of 0.3 resulted in better agreement with the experiment than 0.89 for the present case, in which the combustor operated in a supersonic combustion mode. It was also shown that the combustion mechanisms adopted for the CFD did not show significant influence on the numerical results for the present case (Fig. 2).

Subject 3: A method to predict cooling capacity using pyrolysis of hydrocarbon fuel was constructed by CFD. Two-dimensional axisymmetric CFD was performed including a decomposition reaction tailored to heating experiments of dodecane in a circular tube. By devising the decomposition reaction model, it was possible to predict the endotherm with respect to the decomposition rate with good accuracy. However, it was found that there might be problems in handling physical property values, since the decomposition rate was predicted to be much lower than in experiments (Fig. 3).

Subject 4: As a tool to optimize the thrust performance of a dual-mode combustor according to the flight speed, we considered a performance prediction method using CFD with relatively low computational costs. The prospect of being able to predict by a RANS method was obtained by devising boundary conditions etc.. On the other hand, it was observed that the upstream extension of boundary layer separation was underpredicted (Fig. 4).



(a) M6S (b) M6V

Fig. 1: Comparison between results in M6S and M6V conditions: contour plots of Mach number (top) and temperatures (bottom).

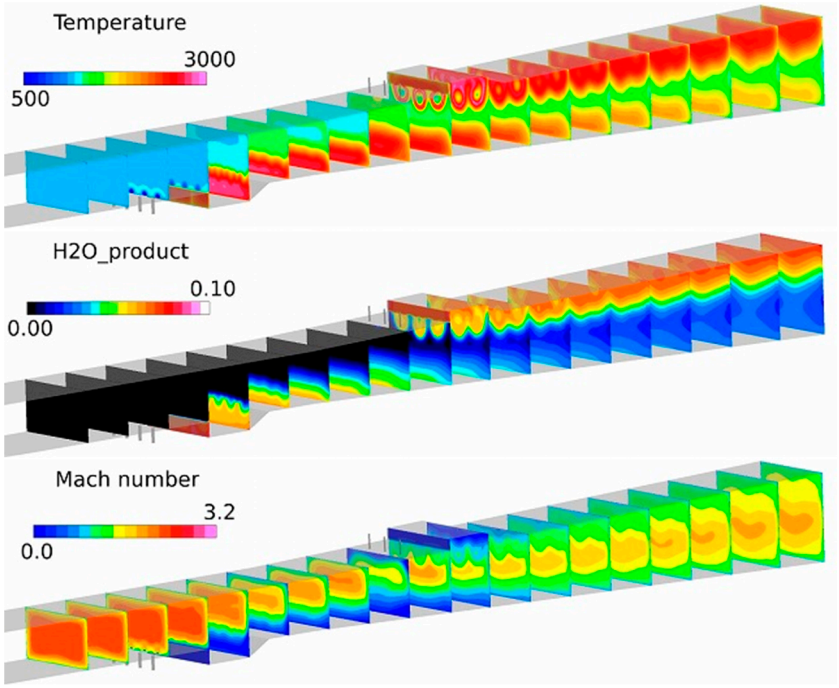


Fig. 2: Numerical results of a ethylene-fueled scramjet combustor flow-field; Static temperature (top), Mass fraction of H2O produced by combustion (middle), Mach number (bottom).

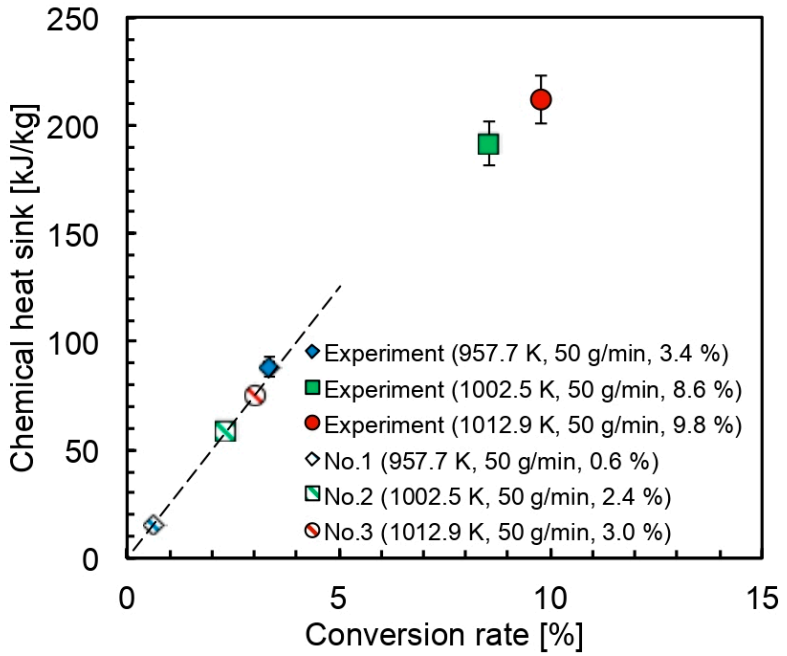


Fig. 3: Comparison between CFD and experiments in terms of correlation between conversion rate and endotherm.

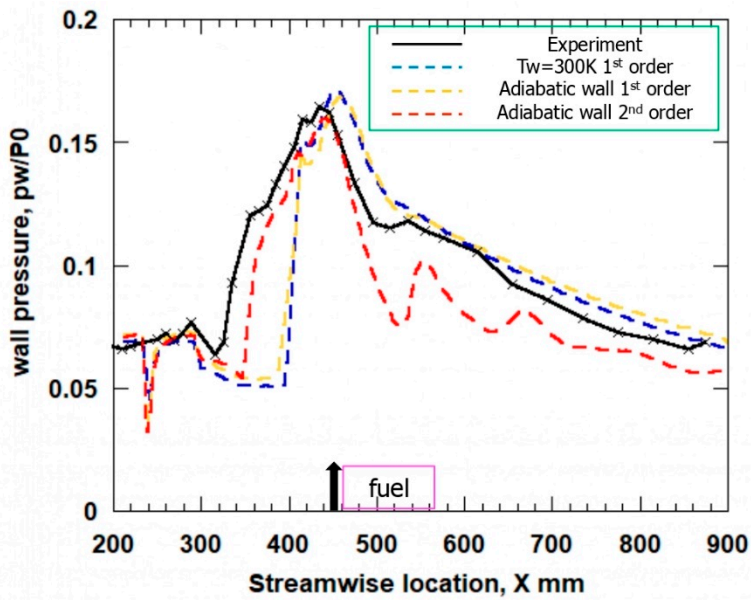


Fig. 4: Comparison between CFD and experiments in terms of wall pressure distributions.

Publications

- Non peer-reviewed papers

1) Kodera, M., Tomioka, S., "Investigation of Air Vitiation Effects on Scramjet Engine Performance," Proceedings of the 59th Conference on Aerospace Propulsion, 2019.

2) Takahashi, M., Nojima, K., Shimizu, T., Aono, J., Munakata, T., "Numerical Simulation of Ethylene-fueled Scramjet Combustor Flows by Using LS-FLOW Solver," Proceedings of the 50th Fluid Dynamics Symposium / The 36th Aerospace Numerical Simulation Symposium, 3C11, 2018.

3) Nishiguchi, H., Kodera, M., and Tomioka, S., "Performance Evaluation of a Dual-mole Combustor by the Three-dimensional RANS Simulation," Proceedings of the 2019 Annual Meeting, Northern Branch of the Japan Society for Aeronautical and Space Sciences, 2019.

4) Miyaura, T., Daimon, Y., Tomioka, S., "Study on Chemical Heat Sink of Liquid Hydrocarbon under Supercritical Condition," Proceedings of the 2018 Annual Meeting, The Japan Society of Mechanical Engineers, 2018.

- Oral Presentations

1) Kodera, M., Tomioka, S., "Investigation of Air Vitiation Effects on Scramjet Engine Performance," The 59th Conference on Aerospace Propulsion, 2019.

2) Takahashi, M., Nojima, K., Shimizu, T., Aono, J., Munakata, T., "Numerical Simulation of Ethylene-fueled Scramjet Combustor Flows by Using LS-FLOW Solver," The 50th Fluid Dynamics Symposium / The 36th Aerospace Numerical Simulation Symposium, 3C11, 2018.

3) Nishiguchi, H., Kodera, M., and Tomioka, S., "Performance Evaluation of a Dual-mole Combustor by the Three-dimensional RANS Simulation," The 2019 Annual Meeting, Northern Branch of the Japan Society for Aeronautical and Space Sciences, 2019.

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Usage of JSS2

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	640 - 1280
Elapsed Time per Case	400 Hour (s)

Resources Used

Fraction of Usage in Total Resources[*1] (%): 2.09

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage[*2] (%)
SORA-MA	19,067,821.96	2.33
SORA-PP	84,048.53	0.67
SORA-LM	674.69	0.31
SORA-TPP	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage*2 (%)
/home	158.64	0.16
/data	3,899.67	0.07
/ltmp	9,814.46	0.84

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage*2 (%)
J-SPACE	1.50	0.05

[*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.