Numerical Simulation of Rocket Turbopumps

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Abstract

Turbopumps are still one of key components in liquid rocket engine development in terms of cost, time, and risks. Furthermore, a turbopump itself is a complex system consisting of sub-components such as pump, turbine, bearing, balance piston, sealing and so on. From numerical simulation technology point of view, there is no technology able to evaluate performance of an entire turbopump system in the world. And also, accuracy and fidelity of numerical simulation technology for sub-components are still poor and cannot be used to reduce the number of experiments. Therefore, experiments are indispensable to evalute feasibility of considered design in engine development.

In this study, numerical simulation technology of an entire turbopump system able to be applicable in engine design phase has been developed enhancing accuracy and fedelity. We are aiming at reducing cost and time for future engine development by making full use of our numerical simulation to reduce the number of experiments. And also, innovative design methodology for higher performance rocket turbopumps has been investigated by using our numerical simulations.

Ref. URL: https://stage.tksc.jaxa.jp/jedi/simul/index.html

Reasons and benefits of using JAXA Supercomputer System

In this study, JSS3 has been used because of the following reasons:

(1) To make it possible to perform large-scale numerical simulations with high accuracy and fidelity

(2) To produce a lot of computed results on time within limited short period of time under JAXA's rocket development

(3) To ensure information security about rocket-related technical information in JAXA's network only

Achievements of the Year

In the fiscal year 2023, we further deepen methodology to simulate unsteady phenomena that could potentially be a critical problem while designing turbopomps. Regarding turbines, since flutter appears to be a key issue for LE-9, a simulation of flutter based on a one-way fluid-structure coupling is validated against the flutter phenomena occurred during the development test series. Also, a two-way coupled fluid-structure simulation is attempted, and the methodology is verified against the hydrofoil flutter experiment. (Fig. 1)

For pumps, Large Eddy Simulation (LES) of unsteady flow in an inducer is conducted to achieve a better prediction of cavitation instability phenomena such as cavitaiton surge and rotating cavitation, which can cause a problem in a wide range of rocket engine operations. As a result of comparisons with experiments, it is confirmed that the simulation can accurately resolve backflow regions (Fig. 2), which can be a potential source to trigger cavitation instabilities. In addition, based on characteristic parameters of cavitation evaluated by numerical simulations, a novel model to accurately predict both onset and frequency of a cavitation surge is established.

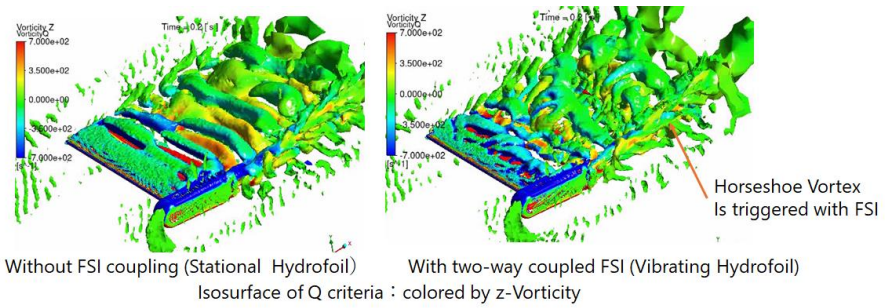

Fig. 1: Effects of two-way coupled fluid structure interaction (FSI) simulation to vortical structures.

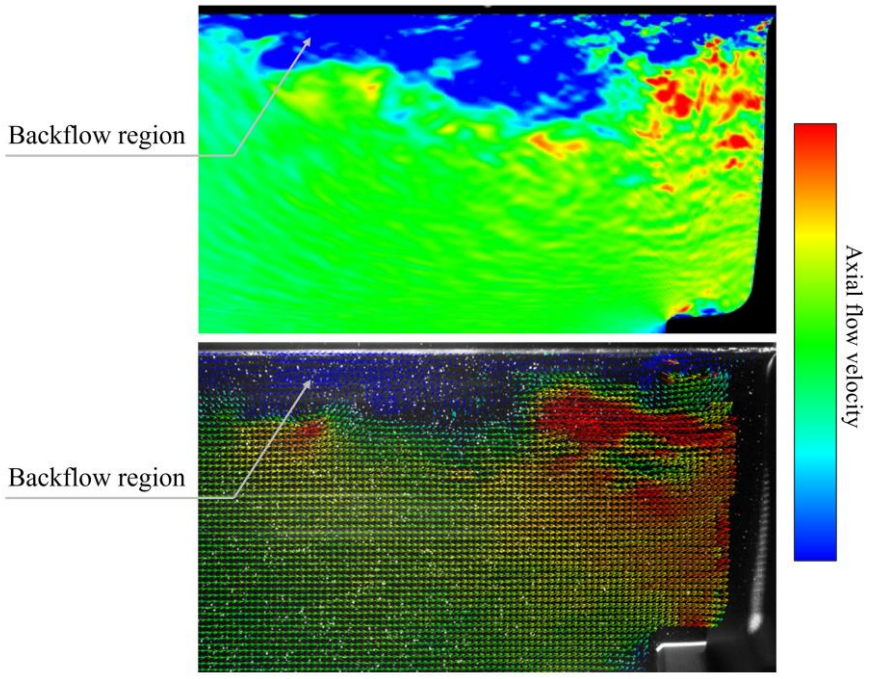

Fig. 2: Comparison of flow structure upstream an inducer from LES simulation and PIV measurement

Publications

- Peer-reviewed papers

Keita Yamamoto, Satoshi Ukai, Taro Fukuda, Satoshi Kawasaki, Hideyo Negishi "Establishment of Prediction Model for Cavitation Surge Frequency and Onset in an Inducer Considering Dynamic Characteristics of Cavitation Compliance and Mass Flow Gain Factor", 2023, ASME Journal of Fluids Engineering, Vol.145, DOI: https://doi.org/10.1115/1.4062377

- Invited Presentations

Keita Yamamoto, Establishment of prediction methods for cavitation phenomena in pumps and turbines, 2023, 50th anniversary workshop in Turbomachinery Society of Japan

Keita Yamamoto, Numerical approaches to simulate unsteady phenomena in rocket engine turbopumps, 2024, 490th social meeting of the Japan Society for Aeronautical and Space Sciences, Kansai Branch

- Oral Presentations

Keita Yamamoto, Satoshi Ukai, Mitsuru Shimagaki, Satoshi Kawasaki, Hideyo Negishi "Research Activities on Numerical and Experimental Studies of Cavitation Instabilities in the Rocket Engine Turbopump", 2023, Aerospace Europe Conference 2023 - 10th EUCASS - 9th CEAS

Keita Yamamoto, Satoshi Ukai, Ryo Nishimura, Takaaki Nigorikawa, Kazuyoshi Miyagawa, Hideyo Negishi "Numerical and experimental studies of inlet distortion in turbopump turbines", 2023, The 89th academic meeting of Turbomachinery Society of Japan

Satoshi Ukai, Keita Yamamoto, Hideyo Negishi "Current numerical technologies and future prospects of rocket engine turbines", 2023, The 89th academic meeting of Turbomachinery Society of Japan

Keita Yamamoto, Satoshi Ukai, Robson DosSantos, Tobias Traudt, Hideyo Negishi "Numerical simulations of the LUMEN turbine at nominal and throttling conditions", 2023, IGTC2023 Kyoto

S. Ukai, K. Yamamoto, H. Negishi, T. Irie and K. Miyagawa, "Two-Way Coupled FSI Simulation of Flat Plate Hydrofoil Flutter", 2023, IGTC2023 Kyoto

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	FLAT
Number of Processes	4800 - 20160
Elapsed Time per Case	300 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 1.40

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	36,683,013.09	1.66
TOKI-ST	258,732.75	0.28
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	11,865.02	0.90
TOKI-TST	3,519.39	0.06
TOKI-TGP	0.00	0.00
TOKI-TLM	21,760.10	61.03

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage[*2] (%)
/home	553.14	0.46
/data and /data2	191,497.52	1.18
/ssd	4,110.24	0.39

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	25.88	0.09

[*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)	1,863.39	0.84

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