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

Pump simulation technology has been developed basd on Large Eddy Simulation (LES) in order to predict cavitation instability phenomena such as cavitaiton surge and rotating cavitation, which can cause a problem in a wide range of rocket engine operations. In this fiscal year, LES of a rocket inducer with a cavitation model was performed and showed a better capability to predict backward vortex cavitation against the conventional RANS simulations (Figure 1).

As for turbine simulation technology, a one-way fluid-structure interaction (FSI) method has been developed based on Unsteady Reynolds-Averaged Navier-Stokes (RANS) simulation to predict turbine flutter, which was identified one of technical issues to be solved in LE-9 engine development. In this fiscal year, a one-way FSI simulation was performed for a 1.5 stage axial compressor experiment conducted by Hannover university as a fundamental validation case. The computed result showed a reasonable agreement of the aerodynmaic damping characteristics, which are the important indicator to predict the onset of flutter, with the experimental data (Figures 2 and 3).

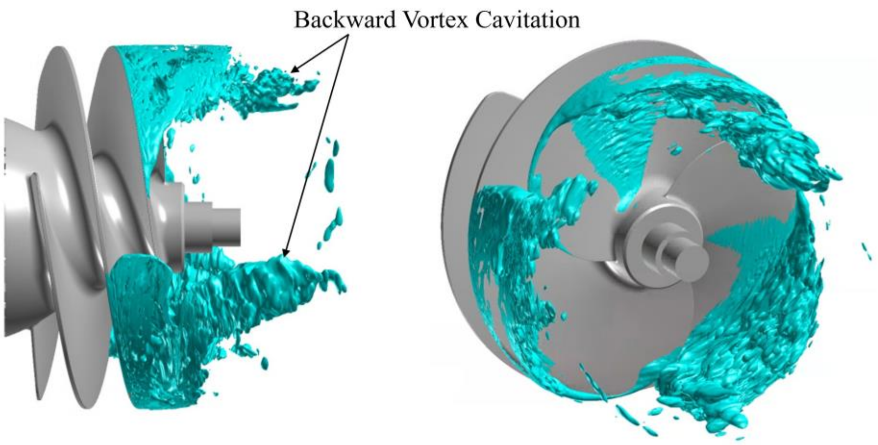

Fig. 1: Cavitation development by LES simulation

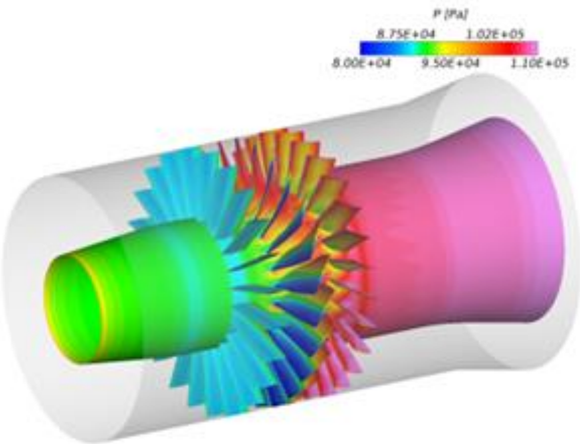

Fig. 2: Computed FSI simulation result of 1.5 stage axial compressor: Wall pressure distribution

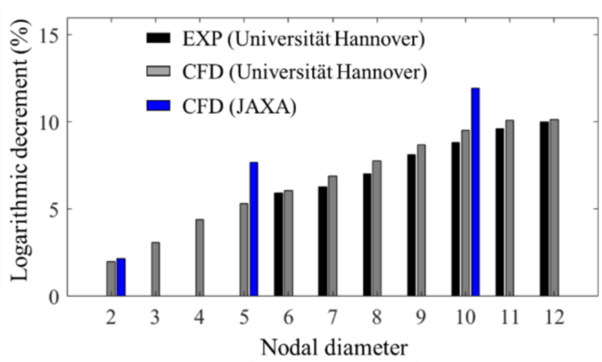

Fig. 3: Comparison of aerodynamic damping

Publications

- Non peer-reviewed papers

Keita Yamamoto, "Recent Activities to Establish a Prediction Method for Cavitation Surge in Rocket Engine Inducer," Turbomachinery, Vol. 53 No, 03, March 2025.

- Oral Presentations

1) Keita Yamamoto, Satoshi Ukai, Mitsuru Shimagaki, Satosh Kawasaki, Hideyo Negishi, "Flowfield Analysis of a Rocket Engine Inducer Using Unsteady PIV Measiurements," The 90th academic meeting of Turbomechinery Society of Japan, 17th May, 2024.

2) Keita Yamamoto, Satoshi Ukai, Mitsuru Shimagaki, Satosh Kawasaki, Hideyo Negishi, "PIV Measurements for Transient Flow Characteristics in a Rocket Engine Turbopump Inducer," ASME FEDSM2024 Fluids Engineering Division Summer Meeting, 15th-18th July, 2024.

3) Keita Yamamoto, Satoshi Ukai, Hideyo Negishi, Shinji Ohno, Junichi Kazawa, Maroldt Niklas, "The Aerodynamic Damping Evaluation of a 1.5 Stage Axial Compressor Using Unsteady RANS simulations," The 91st academic meeting of Turbomechinery Society of Japan, 17th September, 2024.

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](%): 2.43

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	64,815,405.41	2.97
TOKI-ST	221,935.52	0.23
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	12,106.46	0.87
TOKI-TST	864.04	0.02
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	636.37	0.43
/data and /data2	300,637.62	1.44
/ssd	4,735.29	0.25

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	56.63	0.19

[*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)	1,567.02	1.07

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