Numerical study of mass streaming and heat transfer in thermoacoustic phenomena

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Abstract

When there is a flow path with a narrow diameter and temperature gradient in a gas-filled duct, acoustic vibration may occur thereby. This phenomenon is known as a thermoacoustic phenomenon, and the generated acoustic field may be accompanied by a unidirectional flow in the direction of the tube axis. While the magnitude of this flow is small compared to the vibration amplitude, it could give rise to a mass flow called acoustic mass streaming. Such acoustic mass flow influences the initially existing temperature distribution in the duct, causing convective heat transfer in addition to simple heat conduction and heat transport involved with acoustic vibrations. The heat transport phenomenon associated with this acoustic mass flow has a large effect on the heat transport characteristics of thermoacoustic devices, that is thermoacoustic prime mover, thermoacoustic refrigerator and so on. Therefore, in order to improve the performance of devices, it is inperative to clarify their characteristics. The goal of this study is to carry out numerical simulations using CFD to clarify the effects of thermoacoustic phenomena on acoustic mass flow and temperature distribution inside the duct, and ultimately on heat transport characteristics.

Reasons and benefits of using JAXA Supercomputer System

The numerical simulation in this study must be performed under an unsteady compressible flow environment, and especially the interaction between an unsteady acoustic field and heat transport is the key to this simulation. Therefore, although the mesh scale is relatively small, the simulation is necessarily highly accurate and long-time scale , minimum several seconds to tens of seconds on the heat transport time scale. In addition, building a database of analysis results requires a wide variety of calculation cases, resulting in a comprehensively large-scale and long-time simulation. In order to carry out simulations of this scale, it is essential to use a JAXA supercomputer that can run multiple simulations for long periods of time.

Achievements of the Year

To investigate how acoustic mass flow, Gedeon streaming, affects the heat transport properties of thermoacoustic devices, numerical fluid simulations were performed on a single-loop tube (Fig.1) with a thermoacoustic engine core which is composed of a regenerator sandwiched between two heat exchangers, and thermoacoustic phenomena were reproduced. In this numerical simulation, the acoustic impedance and the time-averaged flow velocity by Gedeon streaming was given as a boundary condition of the right end in the computational domain. The working fluids are 1 atm and 0.5 atm of air at room temperature, and the temperature difference between the two heat exchangers is 200K. While the acoustic mass streaming under this analysis of two pressure conditions, is in the opposite direction, due to this effect it was confirmed that the thermal buffer section adjacent to heat exchanger to room temperature changes significantly (Fig.2). Furthermore, it was investigated that the heat flow distribution within the engine core changes under the influence of acoustic mass streaming (Fig.3).

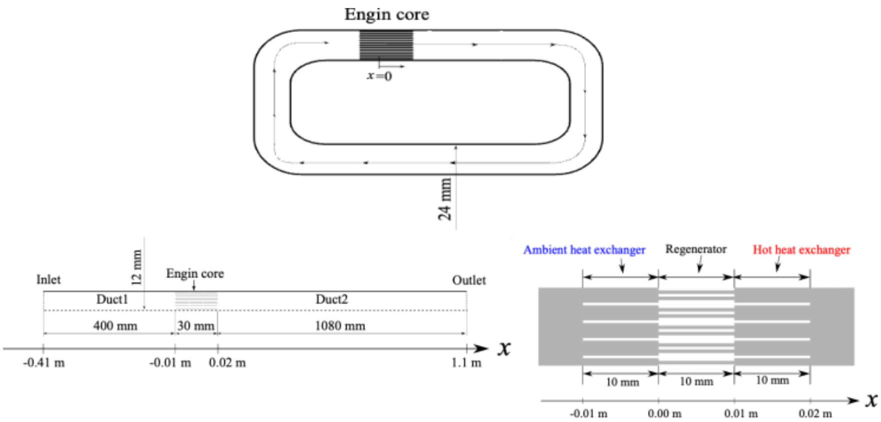

Fig. 1: Schematic diagram of thermoacoustic device (top) and computational model (bottom left: whole, bottom right: engine core)

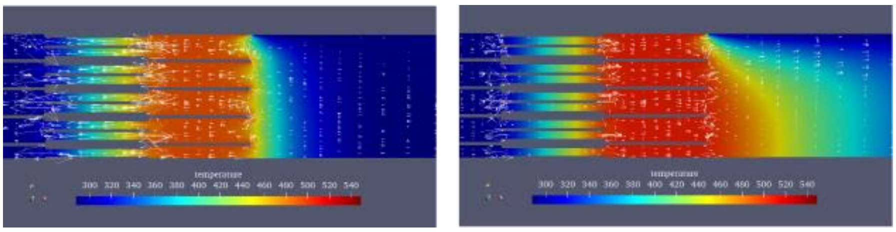

Fig. 2: Time-average temperature distribution near the engine core and high-temperature heat exchanger (left: 1 atm, right: 0.5 atm)

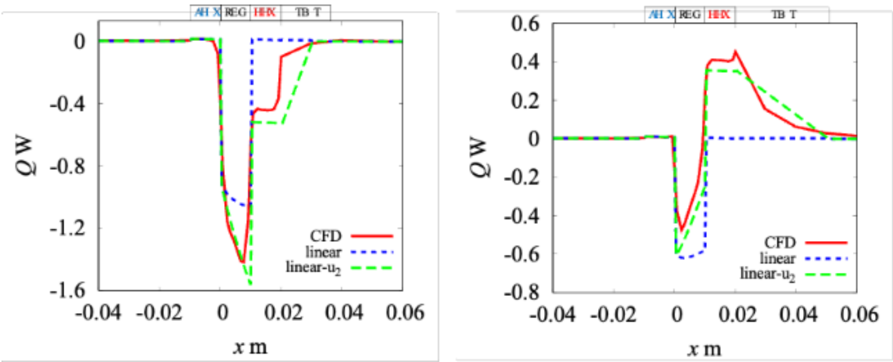

Fig. 3: Effect of Gedeon streaming on heat flow distribution near engine core (CFD: Gedeon streaming present, linear theory: Gedeon streaming absent, linear theory-u2: Gedeon flow velocity superposition)

Publications

N/A

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	1 - 7
Elapsed Time per Case	700 Hour(s)

JSS3 Resources Used

Fraction of Usage in Total Resources*1(%): 0.02

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	594,430.85	0.03
TOKI-ST	0.00	0.00
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	0.00	0.00
/data and /data2	0.00	0.00
/ssd	0.00	0.00

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	0.00	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)	0.00	0.00

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