TOWARDS PRECISE PREDICTION OF FLOW PATTERS OF RESONATORS UNDER GRAZING FLOWS BY USING CARTESIAN-MESH CFD

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Abstract. Recently, the fan noise is increased along with the bypass ratio of the jet engine is increased. Then an acoustic liner is applied to engine nacelle to reduce that fan noise. However, the actual performance in flight is difficult to be predicted because the influence of flows to the sound absorption needs to be considered. In addition, the practical acoustic liner has a lot of resonators, which interact with each other and affect to the sound absorbing performance. In this study, computational results of the flowfields with multiple resonators were compared with results of the flowfield with only one resonator to investigate the effects of multiple resonators. Furthermore, this study analyzed the other models extended neck length to investigate the correlation of the shape of resonators and flowfield.

1 INTRODUCTION

The aircraft performance is needed to improve due to the demand of aircraft is increased. Especially, the improvement of flight performance and reduction of noise is needed. Then, CFD (Computational Fluid Dynamics) have a key role in solve those problem. CFD have been clarified the flowfield of aircrafts and jet engine and those results contribute to develop the technology. For example, the flowfield in the jet engine and wake of the jet is visualized by CFD. From those results, it is considered that to increase the bypass ratio is important to improve the fuel efficiency and reduce the jet noise. The bypass ratio has been increased. However, that causes increasing the fan noise and increasing the weight of the jet engine. Then,

various technology is used to solve those problem. For example, the acoustic liner is used to reduce the fan noise and new materials such as CFRP (Carbon Fiber Reinforced Plastic) are used to reduce weight.

This study focuses on the acoustic liner. The acoustic liner is a panel which is structured with the porous face sheet and a lot of resonators designed based on the Helmholtz resonance. However, the conventional acoustic liners are designed with semi-empirical approach. The approach is based with experimental results and experiences of engineers, thus the practical performances is difficult to be predicted because the influence of flows to the sound absorption is unclear. Therefore, the innovational approach is needed to clarify practical performances to improve. It is difficult to observe vortices around resonators in the experiment because the changes of the phenomenon of the resonator are too small. Then, CFD is a promising approach to investigate the flow phenomenon. In our past study, simple-shape model of the liner was analyzed to understand the fundamental characteristics [1].

As a previous study, Tam investigates the validity of CFD for visualization of the flowfield of acoustic liners through the aeroacoustics analysis with the two-dimensional Direct Numerical Simulation. In addition, the analysis shows the vortex shedding process transfers acoustic energy into kinetic energy associated with the rotational motion of the vortices. The energy is then dissipated into heat energy by molecular viscosity [2].

As mentioned above, researches for understanding the mechanism to improve performances of acoustic liners are attracted recently. Japan Aerospace Exploration Agency (JAXA) started "aFJR Project", and "aFJR" stands for Advanced Fan Jet Research [3]. Along with the increasing demand of aircrafts in the future, the next-generation jet engine which has a good environmental adaptability such as low-noise, the good fuel efficiency and low emission of CO_2 must be achieved. The project substantiates innovational technologies with some manufactures of the jet engine in Japan and some universities in Japan. This project aims to develop the lightweight and high-efficient jet engine through the research and develop the lightweight low pressure turbine and the lightweight and high-efficient acoustic liner. To develop the lightweight acoustic liner, acoustics research and fluid research are conducted through the experiment and computation. Various acoustic experiments are conducted to improve the sound absorption by changing the shape of resonator [4]. Furthermore, acoustic computation in the resonator is conducted to understand the mechanism of sound absorption through the visualization. On the other hand, the influence of grazing flows of acoustic liner is investigated by using experimental equipment of JAXA. The aim is to investigate an optimal method of an analysis considering flowfield and acoustics to realize elucidation phenomenon in flight, thus JAXA developed experimental facility of acoustic liner with their flow duct as shown in Fig. 1. The speaker is put on the upstream side and the downstream side. There are seven microphones which are not spaced equally on the upstream side and the downstream side. A test piece of an acoustic liner is attached horizontally. In the test, speakers output sound alternately and microphones measures transmittance and reflection. The sound absorption ratio is calculated with them. The maximum Mach number of this experimental equipment is 0.3 and the acoustic frequency range is from 200[Hz] to 2000[Hz]. Velocity profile is measured with the probe of dynamic pressure and static pressure. Figure 1 shows the whole overview of the flow duct and Fig. 2 shows the test piece of the acoustic liner. This facility enables to measure the sound absorption of various acoustic liners under the grazing flows.

This study investigates the influences of the number of resonators for flowfield through the

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comparison with the single-cell model which has only a resonator and multiple-cell models which have three resonators. The shape of those resonators is identical. In addition, this study analyses other models which is changed the length of neck to investigate the correlation of flowfield and the shape of resonator. In this study, block-structured Cartesian-mesh CFD is applied to predict the flows around resonators. Because the method has benefits to reduce numerical viscosity by the orthogonality of the mesh and employment of higher order accurate scheme. Thus, it is effective way to observe tiny phenomenon of complex-shape model.
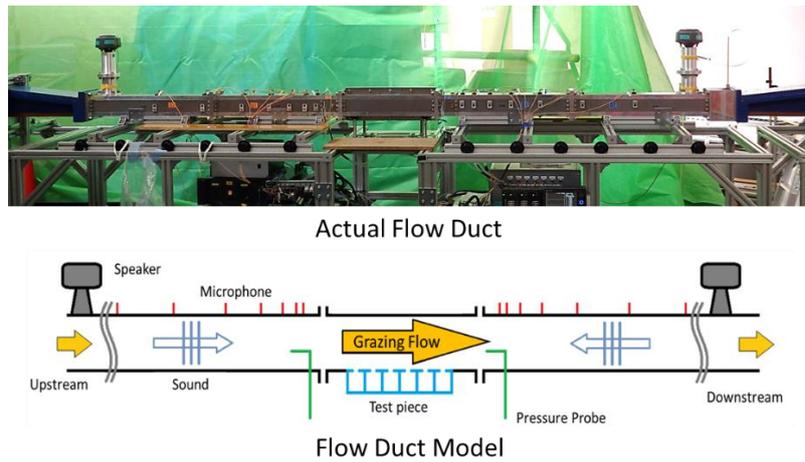
Fig. 1 Overview of The Flow Duct
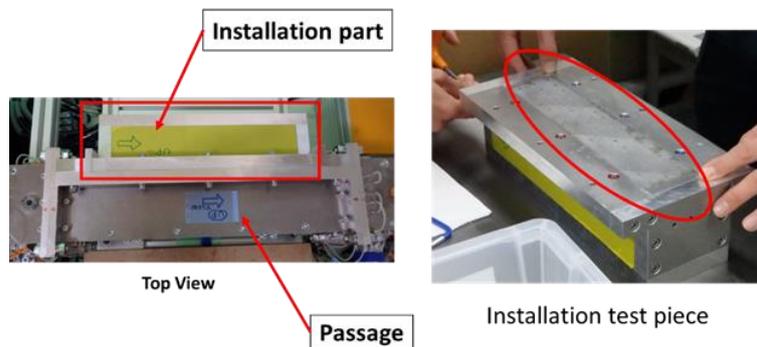
Fig. 2 Figure. 2 Test Piece of The Acoustic Liner

2 COMPUTATIONAL METHOD

2.1 Building Cube Method

This study adopts "Building-Cube Method (BCM)" which is based on the Cartesian mesh. This code employs compressible Navier-Stokes equations. BCM divides the computational domain with many blocks which is called "Cube" and shown in Fig. 3. Then, equally-spaced Cartesian meshes that is called "Cell" are filled in Cubes. The computational domain is composed of many Cubes with different size, but they have the same number of Cells regardless the Cube size. The method allocates many small-size Cubes near the model where physical

quantities change largely. Those dense mesh is distributed to the vicinity of the model to maintain the high spatial accuracy and to prevent the numerical vortex dissipation. BCM can generate mesh easy to complex models and can realize easily improvement the spatial accuracy because it is easy to exchange numerical information between adjacent meshes. Furthermore, BCM can calculate in each Cubes, so it can realize the large scale parallel computation. Each Cubes have overlap area of 3 Cells between adjacent Cubes to maintain the high numerical accuracy as shown in Fig. 4. However, if size of Cubes is different between adjacent Cubes, linear interpolation is conducted from small Cube to large Cube as shown in Fig.5. Cubes where physical quantities change sensitivity must be set equally to maintain the high spatial accuracy [5].

(a) Composition of Cube

(b) Composition of Cell
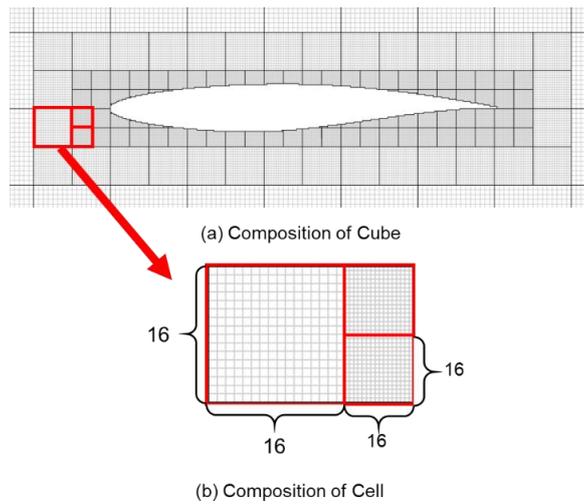
Fig. 3 Composition of Cubes and Cells in BCM
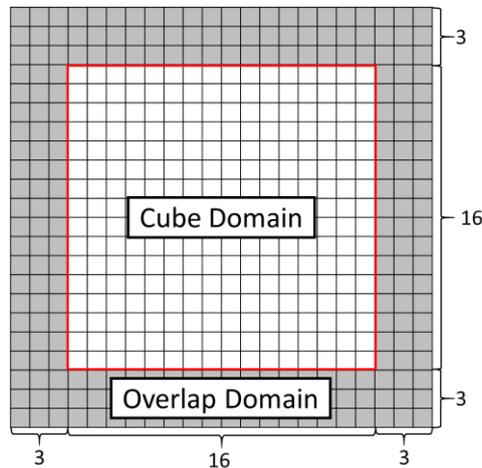
Fig. 4 Cells in Cube with Overlap Cells at each side
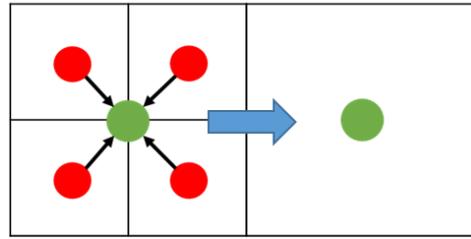
Fig. 5 Handling of Cubes Boundary

2.2 Model for Analysis

In this study, the single-cell model which has only a resonator and the multiple-cell model which has three resonators are analyzed. The shape of those resonators is identical. Figure 6 shows the single-cell model and Fig. 7 shows the multiple-cell model. In addition, the single-cell models changed the length of neck are analyzed. In this study, those models are called single-2.0 model which has the twice neck of single-cell model and single-5.0 model which has the 5.0 times neck of single-cell neck. Fig. 8 shows the resonator of single-5.0 model and Fig.9 shows the resonator of single-5.0 model. Table 1 shows the scale of each model. In addition, red lines mean the neck in each figures.

(a) Overview

(b) Resonator
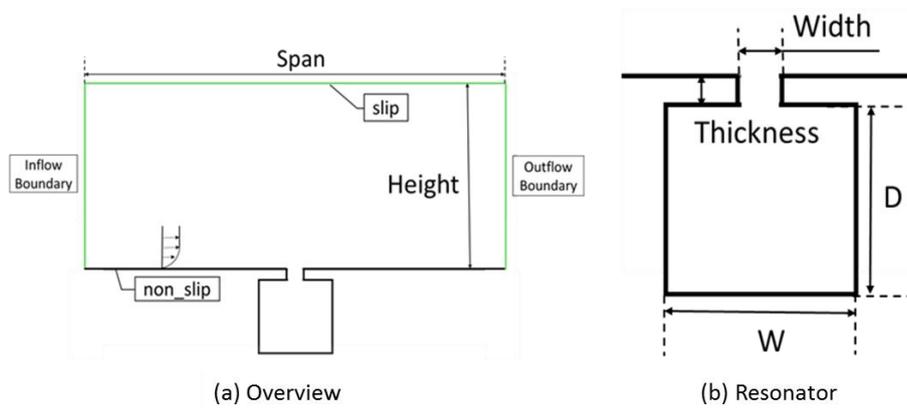
Fig. 6 Single-cell model
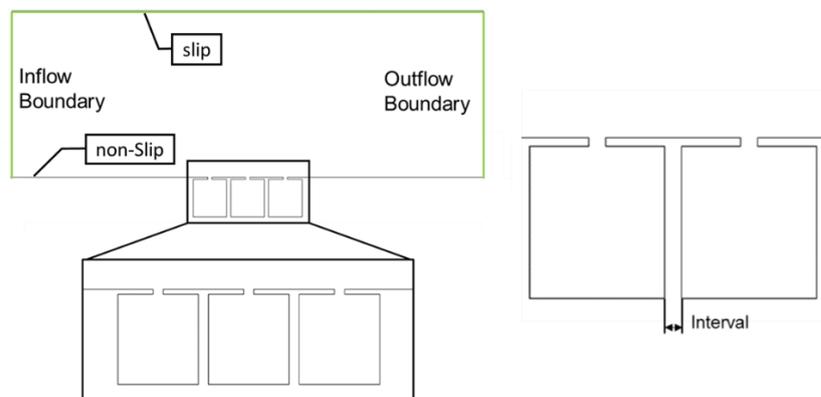
Fig. 7 Three-cell model

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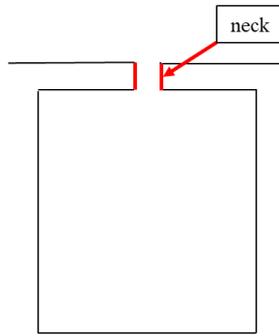
Fig. 8 Single-2.0 model
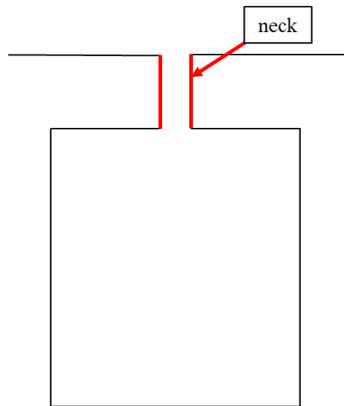
Fig. 9 Single-2.0 model

Table.1 The scale of models

	Single-Cell	Single-2.0	Single-5.0	Multiple-Cell
Passage Span	0.60[m]	0.60[m]	0.60[m]	0.714[m]
Pasage Height	0.254[m]	0.254[m]	0.254[m]	0.254[m]
Slit Width	6.35×10^{-3}[m]	6.35×10^{-3}[m]	6.35×10^{-3}[m]	6.35×10^{-3}[m]
Slit Thickness	3.18×10^{-3}[m]	6.36×10^{-3}[m]	1.59×10^{-2}[m]	3.18×10^{-3}[m]
Cavity Depth	5.745×10^{-2}[m]	5.745×10^{-2}[m]	5.745×10^{-2}[m]	5.745×10^{-2}[m]
Cavity Width	5.08×10^{-2}[m]	5.08×10^{-2}[m]	5.08×10^{-2}[m]	5.08×10^{-2}[m]
Interval				6.35×10^{-3}[m]

2.3 Boundary Condition

At the inflow boundary, the velocity of the incoming mean flow is 30[m/s] and Reynolds number is 13123 as scale length is 6.35×10-3[m] that is the width of opening of the resonator. The top wall is slip wall and the boundary layer on the wall is ignored. The boundary layer adjacent to the bottom wall is assumed to have a Blasius profile and the boundary layer thickness is 6.35×10-3[m]. Furthermore, both u-velocity which is x-dimensional velocity and v-velocity which is y-dimensional velocity are 0[m/s] in resonators as the initial condition. At the outflow boundary, the characteristic method to prevent divergence of computation at the

boundary. That solution is numerically calculated using Riemann invariants that is constant value along with characteristic curve in the method.

The full paper must be written in English within a printing box of 16cm x 21cm, centered in the page. The full paper including figures, tables and references must have a minimum length of 6 pages and must not exceed 12 pages. Maximum file size is 4 MB.

3   NUMERICAL RESULTS

3.1 Single-cell Model

Figure 10 shows streamlines of the overall averaged flowfield and averaged flowfield inside the resonator. From Fig. 10, the change of flowfield at the resonator does not affect to the passage. There is a circulated region with clockwise rotation at the opening of the resonator, and there is also a circulated region with counter-clockwise rotation in the resonator. A circulation at the opening is driven by the ambient flow and it takes flows into the resonator. A circulation inside the resonator is driven by the vortical flow at the opening.

Figure 11 shows the time history of contours of pressure coefficient. From Fig. 11, pressure in the resonator increases when flow goes into the resonator and then decreases when flow goes out to the passage. The changing pressure influences to the whole flowfield. The frequency of changing pressure is approximately 655[Hz]. In addition, the pressure fluctuation propagates to backward of the resonator. The influence of the pressure fluctuation is investigated through the comparison the changing pressure at A, B and C as shown in Fig. 12. Table 2 shows the pressure difference between the maximum pressure and minimum pressure. From Table 2, whereas the pressure at A is 58.64[Pa], it of C is 17.93[Pa]. In addition, the frequency of the pressure fluctuation at C is 653[Hz], although that frequency in resonator is 655[Hz]. Therefore, it is considered that self-noise due to the vortex released from the resonator propagates to backward. Then, the pressure decreases as the distance because those vortices are depressed by viscosity of the wall.

(a) Overview   (b) Resonator
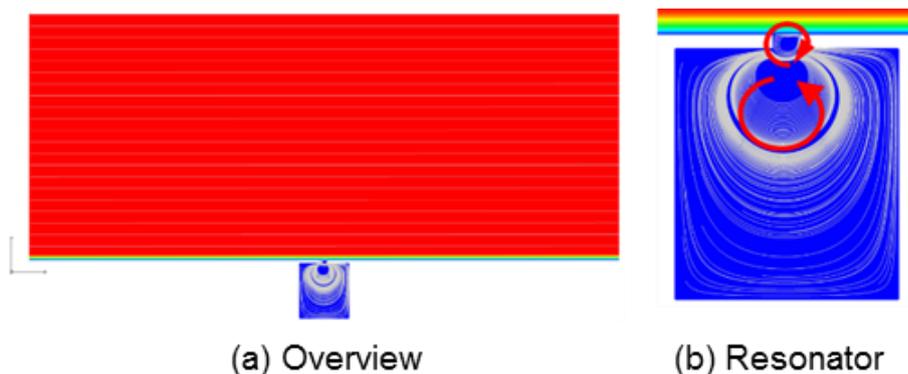
Fig. 10 The Streamline of The Whole Averaged Flowfield and Averaged Flowfield in Resonator

(a) t=0.0

(b) t=0.5T

(c) t=0.75T

(d) t=T

T: 1周期
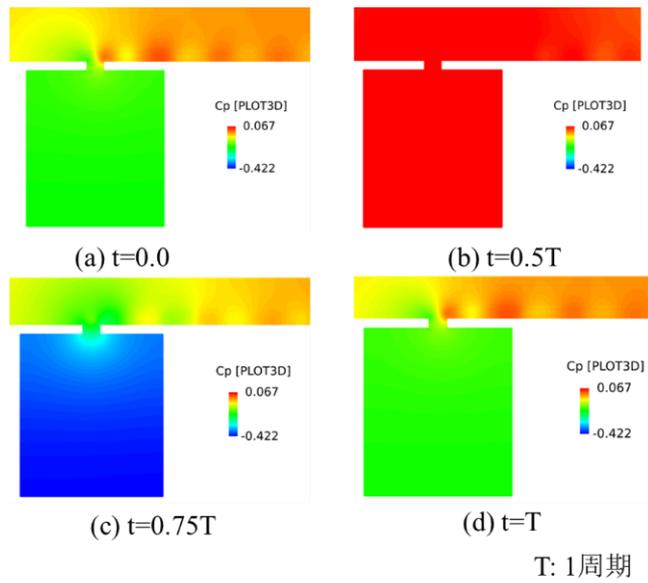
Fig.11 The Time History of Cp (Single-cell Model)
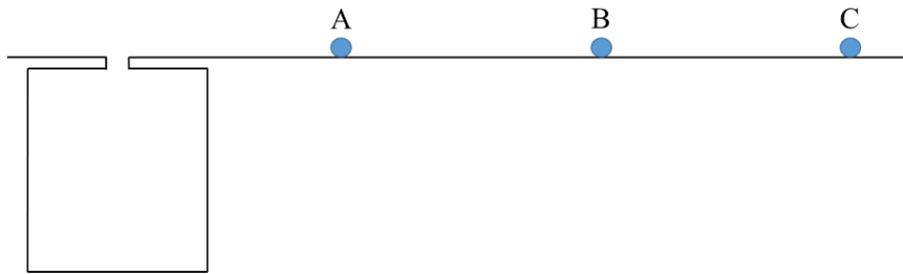
Fig. 12 Points for Calculation of Pressure

Table. 2 The Comparison of Pressure at Each Point (Single-cell Model)

	A	B	C
Pressure [Pa]	58.64	32.75	17.93

3.2 Single-2.0 Model and Single-5.0 Model

This section shows the result of the analysis of the single-2.0 model and the single-5.0 model. In the result of analysis of the Single-2.0 model, it is observed the periodical pressure fluctuation in the resonator. Theat frequency was approximately 608.7[Hz]. It means that the wave period become longer by getting longer the length of neck as expected. However, in the result of the single-5.0, there are not the pressure fluctuation in the resonator. Figure 13 shows the comparison with the averaged flowfield at the neck of Single-2.0 model and that of Single-5.0 model. From Fig.13, the neck of Single-2.0 model is filled by one vortex which circulates as clockwise. However, the neck of Single-5.0 model is filled by two vortices. The upper vortex circulates as the clockwise and other one circulates as anti-clockwise. The fluid near the wall of the passage is taken into the neck by the upper vortex and that fluid circulates in lower vortex. Then, that fluid is taken into upper vortrex and flows to the passage from the neck. Thus, the

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changes of the flowfield are completed only in the neck as the cavity flow and there are not the pressure fluctuation in the resonator.

(a) Single-2.0   (b) Single-5.0
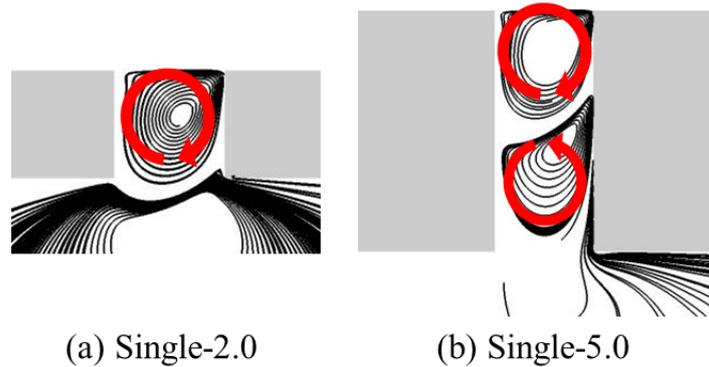
Fig. 13 The Averaged Flowfield of The Single-1.5 model and The Single-2.0 model

3.3 Multiple-cell Model

This section shows analyzed results of multiple-cell model which has three cells. Figure 14 shows instantaneous contour of Cross Flow Velocity of single-cell model and multiple-cell model. From Fig. 14, the development of vortices is encouraged by a repeat of flowing in and out to resonator. Figure 15 shows the comparison of boundary layer velocity profile on the wall at the passage. The boundary layer velocity profiles of multiple-cell model and the single-cell model at each side of inlet and outlet are plotted. From the figure, a low speed region in outlet side of multiple-cell model is larger than that of single-cell model. It means the energy loss becomes larger when the number of resonators is increased because the development of vortices is encouraged.

Figure 16 shows the time history of the pressure coefficient in resonator. The pressure of each resonator changes alternately as same as the single-cell model. However, the frequency of changing pressure is approximately 710[Hz] although the shapes of the resonators are identical as the resonator of single-cell model. Therefore, the interaction of resonators is expected to affect the pressure change of each resonator. Figure 17 shows the comparison of the change of pressure of each location that are same as Fig. 12. From Fig. 17, the shape of pressure fluctuation at A is awkward shape such as phase-shifted pressure fluctuation are overlapped. However, the pressure fluctuation of C is single-phase and that amplitude is the largest. However, the frequency of the pressure fluctuation at C is 689[Hz], although that frequency in resonators are approximately 710[Hz]. Thus, multiple vortexes are generated by the repeat of flowing in and out to resonators and the velocity of the propagation of vortexes is decelerated by viscosity of the wall. Then, those vortexes are merged and generate the pressure fluctuation which has the high amplitude.

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(a) Single-cell Model
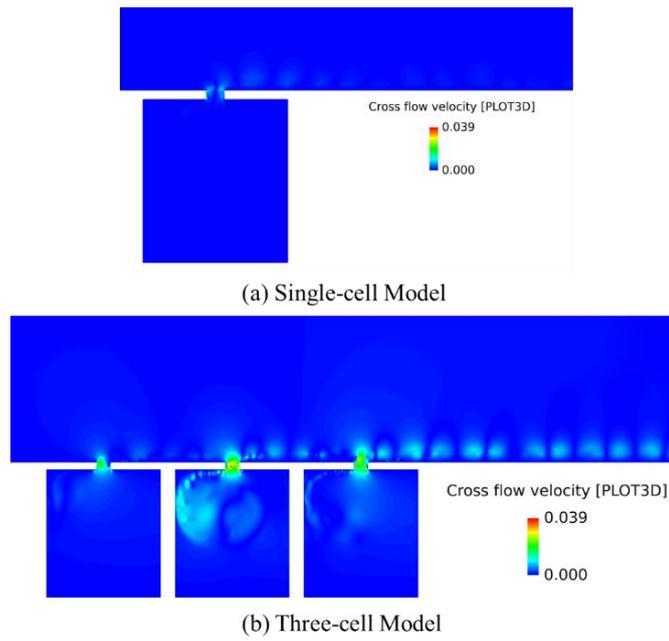
(b) Three-cell Model

Fig. 14 The Instantaneous Cross Flow Velocity
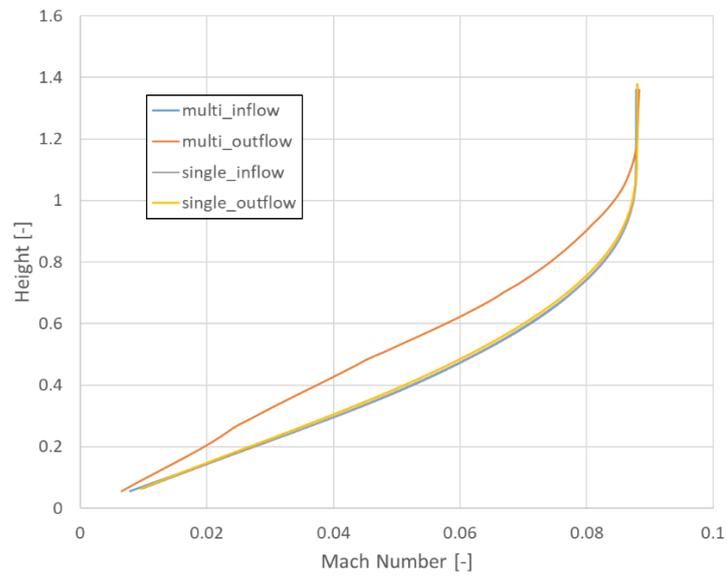
Fig. 15 The comparison of Boundary Layer Velocity Profile

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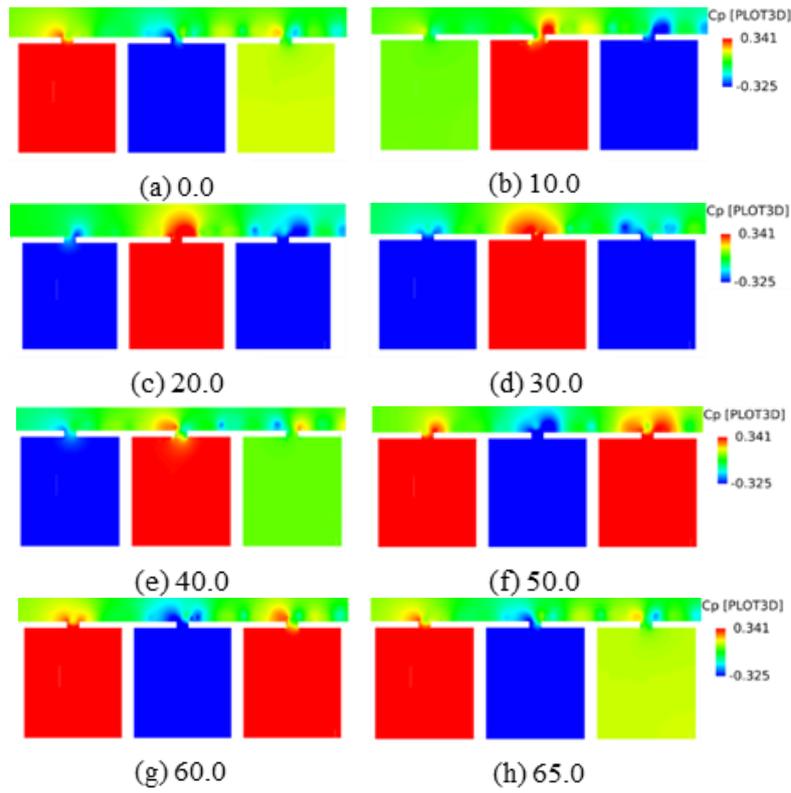
Fig. 16 The Time History of Cp (Three-cell Model)
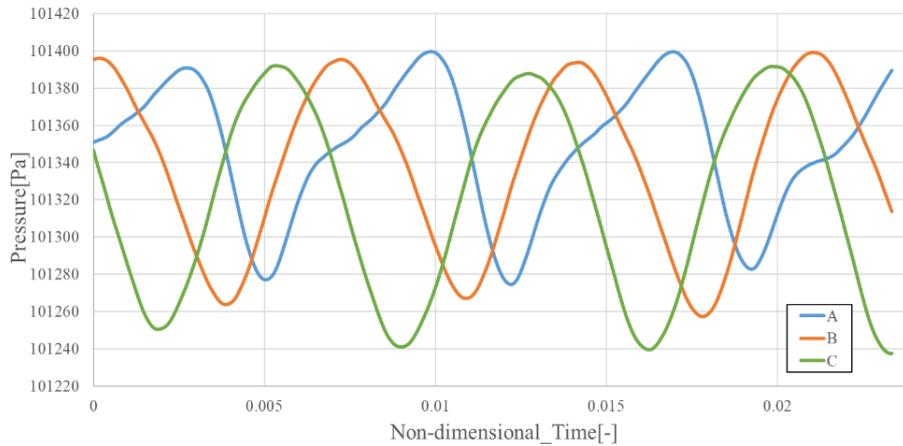
Fig. 17 The Comparison of pressure

Table. 3 The Comparison of Pressure at Each Points (Three-cell Model)

	A	B	C
Pressure [Pa]	125.04	132.37	149.70

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4   CONCLUSIONS

This study investigates the influences of the number of resonators for flowfield through the comparison with analyzed results of the single-cell model and the multiple-cell model. The development of vortexes is encouraged by multiple resonators and the energy loss becomes larger. In addition, the pressure fluctuation caused by vortices are merged and that amplitude becomes larger. In addition, from the result of analysis of flowfield of the single-2.0 model and single-5.0 model, the wave period becomes longer by getting longer the neck and there are not the pressure fluctuation in the resonator of the single-5.0 model because changes flowfield are completed only in the neck by two vortices. Influences of the shape of the resonator such as the single-5.0 model are needed to be investigated more. In addition, the developing the 3D-BCM is needed to investigate more practical flowfield and more complex model.

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