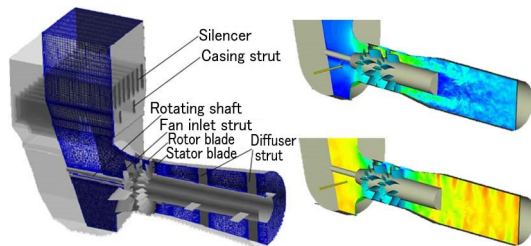


Aeroacoustic Analysis Using Large-scale Numerical Analysis to Realize Low Noise Product Design



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The noise design of power plants is one of the most important items from the perspective of environmental regulations. The main noise source in a plant is fluid equipment, so the prediction and reduction of flow-induced sound is important. Precise flow analysis and sound wave propagation analysis are necessary for the prediction of flow-induced sound. We are developing aeroacoustic analysis technology that utilizes the Lattice Boltzmann Method (LBM), which has been rapidly developed as a large-scale fluid analysis technique in recent years, and we are promoting the realization of low noise product design through the verification of the noise prediction accuracy of axial fans using this analysis technique.

1. Introduction

The noise design of power plants is one of the most important items from the perspective of environmental regulations. The main noise source in a plant is fluid equipment such as turbines, pumps, fans, etc., so the prediction and reduction of flow-induced sound generated by these products is important for the noise design of the entire plant. Meanwhile, the prediction of flow-induced sound requires precise flow analysis for the reproduction of turbulence, which is the noise source, and the propagation analysis of generated sound waves, so very large-scale analysis is required. We are developing aeroacoustic analysis technology that utilizes the Lattice Boltzmann Method (LBM), which has been rapidly developed as a large-scale fluid analysis technique in recent years. This paper presents the results of the accuracy verification of the noise prediction of axial fans used for power generation plants, which is one of the prediction examples, and describes future prospects

2. Large-scale aeroacoustic analysis using Lattice Boltzmann Method

In order to analyze the flow-induced sound of fluid equipment such as turbines, pumps, fans, etc., it is necessary to accurately analyze the disturbance of the fluid generated by the equipment and the generation and propagation of the sound waves. For this reason, it is necessary to accurately analyze the propagation of sound waves with respect to space and time. The Lattice Boltzmann Method (LBM) which has been developed in recent years has a very high efficiency in terms of large-scale analysis compared with the conventional method, and since the numerical viscosity is very small and the propagation of sound waves can be accurately analyzed, it is considered to be useful as a large-scale aeroacoustic analysis technique and is applied to the flow-induced sound prediction of various products.

The Lattice Boltzmann Method is a numerical calculation method that approximates a fluid called a lattice gas model with an aggregate of a large number of virtual particles having a finite number of velocities. It calculates the collision and translation of each particle by using the velocity distribution function of the particle and obtains a macroscopic flow field (flow velocity, pressure, etc.) from the velocity distribution function. The Lattice Boltzmann equation, which is a basic equation, is expressed as follows:

$$f_i(x + \Delta x, t + \Delta t) = f_i(x, t) - \frac{\Delta t}{\tau} [f_i(x, t) - f_i^{eq}(x, y)]$$

f_i is the velocity distribution function, τ is called the relaxation rate, and f_i^{eq} is the local equilibrium distribution function. By using this equation to calculate the collision and translation of the particles, we can calculate the flow field.

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For the analysis described in this paper, EXA PowerFLOW ver. 5.0c was used.¹ As the collision term model, a common BGK model was used and a VLES model was used as the turbulence model. The space 3-dimensional 19-speed model (D3Q19 model) presented in **Figure 1(a)** was used for the lattice gas model. Analysis was performed using an orthogonal grid as depicted in **Figure 1(b)**. Since the Lattice Boltzmann Method forms an analysis space with an orthogonal lattice, the advantage is that lattice generation is easy. The bounce-back conditions generally used in the Lattice Boltzmann Method are used for the object wall, and the velocity distribution function was obtained using the lattice point and the position of the wall.

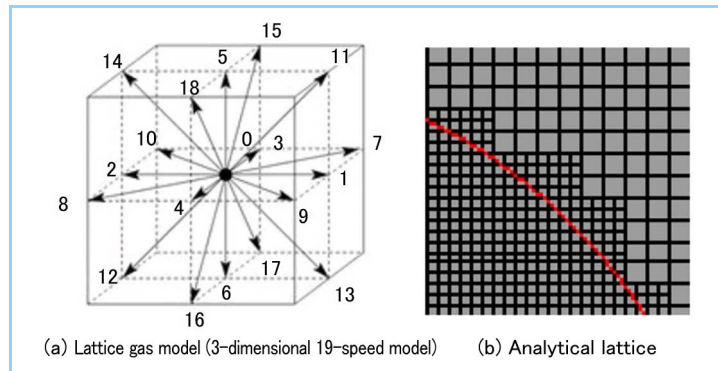


Figure 1 Lattice gas model and analysis lattice

3. Prediction of noise in axial fan duct

An axial fan is a piece of fluid equipment that generates noise within a power plant. Noise generated from an axial fan can be considered as blade rotation noise and interference noise from the struts. To take appropriate countermeasures against noise, it is necessary to accurately predict the noise that will be generated and properly implement quiet design such as the adoption of silencers. Therefore, noise in an axial fan duct was predicted by applying the developed analysis technique, and the prediction was compared with the results of actual equipment measurement to verify the validity of the analysis.

The analyzed axial fan had two-stage rotor blades and stator blades. Noise generated by an axial fan includes broadband noise caused by upstream turbulence and trailing vortex discharge and discrete frequency noise caused by rotor blade rotation noise and interference noise between the rotor blades and stator blades. The discrete frequency noise of a fan is generated with the blade passing frequency, which depends on the rotor blade rotating speed and the number of blades. For the prediction of broadband noise, it is necessary to capture fluctuations such as fine vortices, while for the prediction of discrete frequency noise, it is necessary to accurately simulate the interference between the pressure field generated by the rotor blades and an object. For this reason, the lattice spacing was made dense so that the vicinity of the rotor blade and the stationary blade could be analyzed with higher accuracy.

Figure 2 shows the analysis space and **Figure 3** presents the analysis grid. A space simulating the test duct upstream and downstream of the axial fan was reproduced and analyzed. **Table 1** shows the operation conditions of the fan, and **Table 2** gives the analysis conditions.

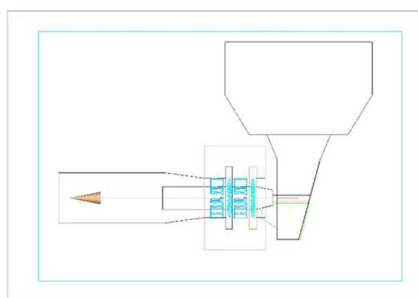


Figure 2 Analysis space

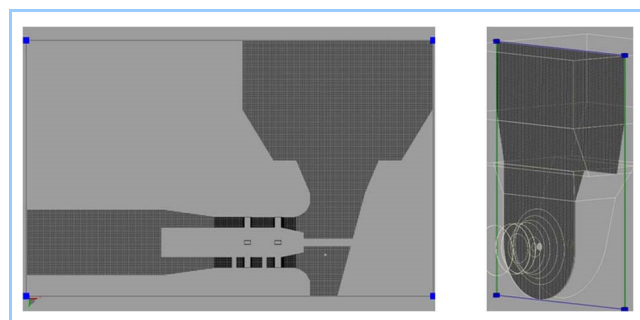


Figure 3 Analysis lattice

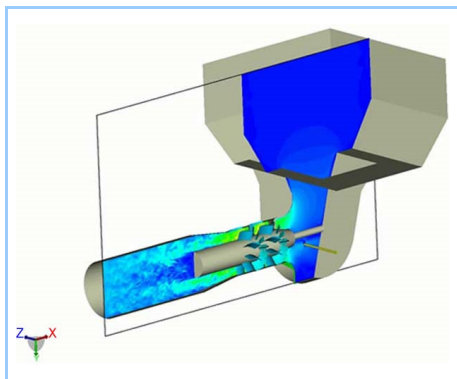
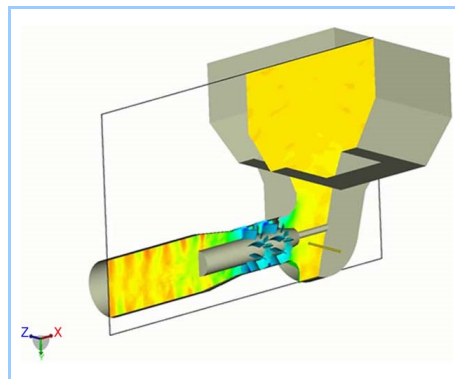
Table 1 Operation conditions

Item	Condition
Total pressure	100.7 kPa
Temperature	293 K
Rotor blade rotation speed	1765 rpm

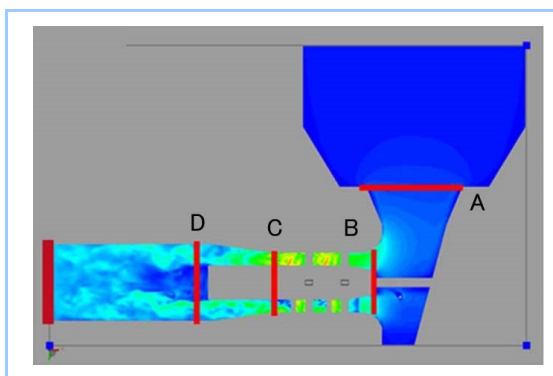
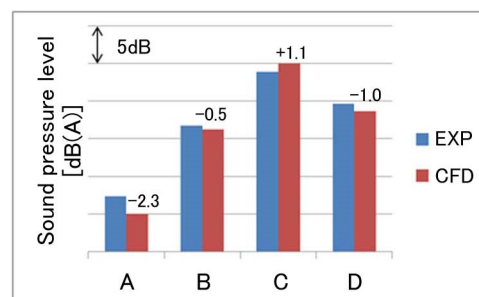
Table 2 Analysis conditions

Item	Condition
Analysis time period	10s
Time increment	13.26 μ s /timestep
Reynolds number	1.78 $\times 10^7$
Lattice size	Min 10mm, Max 20mm

Figure 4 and **Figure 5** show the flow fields obtained by the analysis. These figures represent the velocity and pressure distribution at any given moment. The velocity distribution in **Figure 4** indicates the structure of complex vortices emitted from the blade. It is considered that these complex vortices are one of the factors of broadband noise generation. Meanwhile, the pressure distribution in **Figure 5** indicates regular sound wave propagation to the upstream and downstream. Consequently, it can be considered that sound waves were generated by turbulence in the vicinity of the fan and the blade wake and then propagated.

**Figure 4 Flow field of axial fan (velocity distribution)****Figure 5 Flow field of axial fan (pressure distribution)**

In order to verify the validity of the noise prediction, the average OA value and the spectrum in the four cross sections A to D in **Figure 6** were obtained and compared with the actual measurement results. **Figure 7** is the OA value, and **Figure 8** gives the 1/3 octave band spectrum of each point. As can be seen in **Figure 7**, the prediction at each point in the duct could be performed accurately with a difference of 3 dB or less from the actual measurement results. The peaks appearing in the 500 Hz and 1 kHz bands of the spectrum in **Figure 8** are the primary and secondary peaks of the blade passing frequency, which are frequency components caused by rotor blade rotation noise and interference noise of the rotor blades and stator blades. The spectral shape also matches well, and the sound field in the duct is well reproduced. This makes it possible to accurately predict the noise spectrum at the silencer entrance located upstream and downstream, thus making proper quiet design possible.

**Figure 6 Cross-sectional evaluation positions****Figure 7 Comparison of noise OA value**

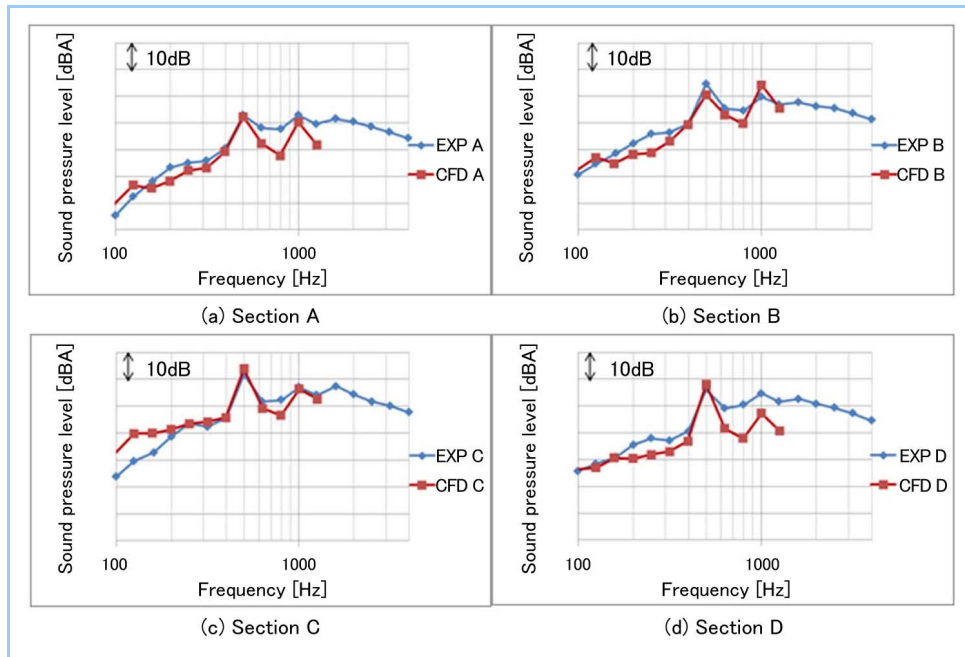


Figure 8 Noise spectrum of each evaluation section

4. Conclusion

We are working on the noise reduction of various equipment in order to improve the environmental friendliness of our products. This paper presented aeroacoustic analysis technology using large-scale analysis for the realization of quiet design of fluid equipment. This analysis technique is capable of accurately predicting the flow-induced sound and its propagation and is useful for studying measures to reduce noise. In this paper, the prediction accuracy verification results of the axial fan are presented as an example. We will continue to contribute to the reduction of the noise of our products by widely deploying this technology and considering appropriate measures for each piece of equipment.

References

1. Kotapati, R. et al., The Lattice-Boltzmann-VLES Method for Automotive Fluid Dynamics Simulation, a Review, SAE Technical Paper 2009-26-0057, 2009