Computational study on prediction and reduction of aerodynamic noise from fans

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Turbomachinery is the machinery device in which the energy is delivered either to or from the fluid that is continuously moving due to the action of the moving blades. Performance and flow noise are the two major indices among the indices for evaluation of turbomachinery. In terms of energy transfer, researches on the performance of turbomachinery have been conducted since long time ago; and these researches for performance improvement are still ongoing currently. In addition, the flow noise produced by the turbomachinery came to the fore as the turbomachinery has been used in various fields and everyday life closely and frequently. Especially, consumers' demand on improvement in affective quality has been increased and the regulation on noise has been being reinforced due to damages and adverse effects caused by noise. Therefore, the development of high performance and low noise turbomachinery is highly required.

Meanwhile, the experimental methods have been used to develop low noise turbomachinery; however, the experimental methods solely are not sufficient to achieve such aim since measuring in small turbomachinery is challenging. Hence, prediction technique to which the numerical analysis method that yields complementary effects in combination with the experimental methods is applied is required.

This study was conducted with the aim of applying numerical analysis method for noise reduction in turbomachinery. Therefore, three-dimensional unsteady Navier-Stokes equation was solved to simulate the flow field. The turbulence models used to predict the flow field were SST $k-\omega$ model that provides outstanding simulation of separation and adverse pressure gradient in the boundary layer and LES

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model that presents the excellence in turbulence intensity modeling. The method used to predict the flow noise in this study was acoustic analogy that is one of the hybrid methods; and the acoustic analogy is the method analyzing unsteady state flow field by using Computational Fluid Dynamics (CFD) and predicting noise by using the information of unsteady state flow field obtained from the results of the analysis. To conduct acoustic analogy, Lowson equation that can be used to predict sound pressure for point force that are moving in a free field was calculated. Despite of the disadvantage that the influence of an object including scattering, diffraction, and reflection within the acoustic field is difficult to be considered, the method that directly reduces noise sources was able to be drawn since the location of the noise source was predicted.

In order to indicate the location of the noise source, “Aeroacoustic source strength, A_{st}” was defined and compared with the location of the noise source measured by the acoustic camera to which beamforming technology is applied; and they were agreed qualitatively well each other.

In this study, noise of a small axial flow fan with circular shroud, a small axial flow fan with square-type shroud installed in a rack mount server computer, and a small centrifugal fan used as a cooling fan in portable home electronics such as an ultrabook was predicted and compared with the measured noise. The tonal noise of BPF and of its harmonic frequencies was agreed well with the measured noise, and the broadband noise at low frequency range was also agreed well. Although the broadband noise at high frequency was somewhat different due to random broadband noise, the shapes for noise reduction were able to be drawn by predicting the location of the noise sources. Models suggested for noise reduction provided the result of noise reduction from the prediction and specific noise level was used to evaluate the noise reduction considering the changes in fan performance.

In case of the axial flow fan with circular shroud, the interaction between the rotating rotor blades and the flow separated from the inlet of the shroud was found to be the major cause of the noise through the analysis on the location of the noise sources and unsteady flow field. Consequently, reduction of the flow noise was predicted by correcting the shape of the shroud inlet.

In the small axial flow fan installed in the rack mount server computer, the tonal noise occurring by irregular clearance between the blade tip and the shroud due to the square-shaped shroud was well predicted. In addition, coherence analysis was conducted to identify the relationship between the surface pressure fluctuation due to

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the flow and the sound pressure predicted from the microphone. As a result, the correlation for each frequency was well presented.

For the centrifugal fan that is used as a cooling fan in home electronics such as a portable small ultrabook, the flow structure of the centrifugal fan was simulated by setting the condition to be analogous to the operating condition within the actual product. And then the reduction of the flow noise was predicted by correcting the tip of the impeller blades based on the location of the noise sources.

This study aimed to apply the method of numerical analysis to the noise reduction in turbomachinery. For this, unsteady flow field was analyzed, the result of noise prediction obtained from the flow filed information was compared and validated, and the location of the noise sources and the structure of the flow field causing the noise were understood; hence, the shape reducing the noise was able to be drawn.

In this study, the reduction of the flow noise was successfully achieved by adopting the method of numerical analysis solely and the flow noise of the fans that were improved for noise reduction was predicted to be reduced by 0.8 and 3.7 dB, respectively.