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DEVELOPMENT OF FAN PERFORMANCE, FLOW AND NOISE ANALYSIS SOFTWARE

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ABSTRACT
Numerical predictions of fan noise have not been studied extensively. This is due to the scattering effects of the fan casing, duct, etc and the difficulty in obtaining the aerodynamic acoustic source. So, we develop new numerical method to predict the fan noise and flow field. A vortex method is used to model the fan and to calculate the flow field. In order to obtain acoustic signal from the unsteady force fluctuation of the blades, we use an acoustic analogy. But the acoustic analogy can be applied only in the free field in general. In order to consider the solid boundary effect, the newly developed Kirchhoff-Helmholtz BEM (Boundary Element Method) is introduced. With the above-mentioned method we make new analysis tool, "FanNoise". In this program, we can calculates the flow field around the fan and predict the fan noise.

1 - INTRODUCTION
Noise of turbo-machines has often been cited as the most undesirable feature of life in the urban community. The noise of blower and fan consists of vibration-induced noise and flow-induced noise. In this paper only the flow-induced noise is considered. The flow-induced noise is a branch of "Aeroacoustics", which is concerned with sound generated by aerodynamic forces or motions originating in a flow field. Thus, in order to predict the noise source and its characteristics, exact information of flows is necessary. But still now, the predicting of the flow-induced noise is much difficulty because of the complexity of the flows. On the other hand, with the rapid development of computer hardware, the flow and the acoustic fields can be solved directly by using CAA (Computational AeroAcoustics) numerical technique. But it takes a lot of computational time, which cannot be applied to the real cases. In the early days, an acoustic analogy equation was developed, but such an equation has a shortage that cannot be applied when the rigid body is placed near the sound source [1]. So the sound field of ducted fan or centrifugal fan with casing is not completely analyzed yet. In this paper, a newly developed 'Kirchhoff-Helmholtz BEM' is used to calculate the radiated sound field of the ducted fan [2]. The acoustic source is calculated using the acoustic analogy. The force data is obtained from the unsteady flow field calculation [1,2].

2 - THE ALGORITHM OF THE PROGRAM
This program has three numerical steps to analyze the radiated sound field. The first step is about the analysis of the flow field. Other commercial software can replace this step. The important thing about this step is that the results should be unsteady force data. The second step is the calculation of the sound source at the Kirchhoff source surface. In this step, the signal in time domain is changed to the one in frequency domain. The last step is for the sound field. The newly developed Kirchhoff-Helmholtz BEM is used. The scattering and the other acoustic mechanism can be calculated by using the calculated Kirchhoff source.

3 - NUMERICAL METHOD

3.1 - An analysis of flow and performance of fan

The aeroacoustic source of the fan is generated from the fluctuations of forces on the blade. It is due to interactions between the flow passing through the impeller and structures of the casing. Therefore, calculations of unsteady forces on the blade are essential for the prediction of fan noise. In general, 2∼3 revolutions are enough to obtain converged or fluctuated solution for the performance calculation but about 10 revolutions for the noise calculation. To solve flow field around the impeller or rotor, Navier-Stokes equation should be solved. However, general CFD based methods have many difficulties in the case of rotating bodies and required so much computational time for the 10 revolutions. A grid-free vortex method is employed in this program to solve unsteady force of moving bodies fast and accurately without the field grid [1], [3].

3.2 - An analysis of aeroacoustic source of impeller

The acoustic field of the fan is generated by unsteady force fluctuation due to the interaction between structures and rotating impeller. For the tone noise dominant case, it is enough to predict the acoustic field from unsteady force fluctuation. In this program, the Kirchhoff surface is introduced around the impeller. This surface is fixed in the casing. All the acoustic information of rotating impeller is transferred to the Kirchhoff surface source. Acoustic analogy, especially Lowson's equation is used in the prediction of acoustic source [1,2].

3.3 - An analysis of acoustic field of fan

Many papers about acoustics in the free field have been published but there is no paper for the case of fan with casing or ducted fan. It is because that the noise source of the fan is related to the unsteady flow, and the method for solving acoustic radiation and scattering is not easy to implement. The Kirchhoff-Helmholtz BEM, developed by the authors, can handle the second problems. The Helmholtz integral equation with the Kirchhoff surface is shown as below [2].

$$\begin{aligned} C(P)\,\phi(P) = & \int_S \left[\phi(Q) \frac{\partial G}{\partial n}(P,Q) - \frac{\partial \phi}{\partial n} G(P,Q) \right] dS(Q) \\ & + \int_{Kirchhoff} \left[\phi(K) \frac{\partial G}{\partial n}(P,K) - \frac{\partial \phi}{\partial n} G(P,K) \right] ds(K) \end{aligned} \tag{1}$$

The advantage of this equation is that it can solve the scattered acoustic field of rotating acoustic sources like impeller or rotor through the fixed Kirchhoff surface.

4 - NUMERICAL CALCULATIONS

4.1 - An analysis of the fan

Results of the analysis are compared with the experimental data of Neise [4]. Figures 1 and 2 show the BEM mesh and the calculated acoustic field of the centrifugal fan. The surface grids of BEM are generated using the input data of program. Calculated acoustic contour is shown in figure 2. The standing waves generated in the interior region of the duct are also shown in the figure in addition to the scattered acoustic field in the exterior region of the duct.

Figure 3 shows the result of flow field analysis. This figure shows the unsteady vortex particle trajectories, head variation and blade force variation. Figure 4 shows the shape of axial fan used by Lohmann [3]. This fan has 3-blades, radius of 0.3025m, chord of 0.06m, hub twist-angle of 38deg, wing-tip twist-angle of 14deg and rotates in 2500rpm. 24 time steps are taken for one revolution. This figure shows the axial force variation converging to a certain value.

4.2 - The accuracy of the program

For the comparisons, previously studied fan is selected and analyzed. Figure 5 shows the calculated acoustic field of the centrifugal impeller with a wedge, which is used by Weidemann [5]. In the figure, the experiment (circle) and the calculated SPL (rectangle) are almost the same at the BPF and its higher harmonics. Figure 5 shows the results about centrifugal fan, which is used by Neise [4]. The scattering effect of the casing and duct is amplify the free field SPL. In the figure, the experiment (rectangle) and the calculation results (circle) are almost the same.

5 - CONCLUSION

Recently, fan noise prediction software, "FanNoise", is developed. This is designed for engineers requiring an accurate and efficient software tool, capable of direct simulation of flow field and scattered and radiated

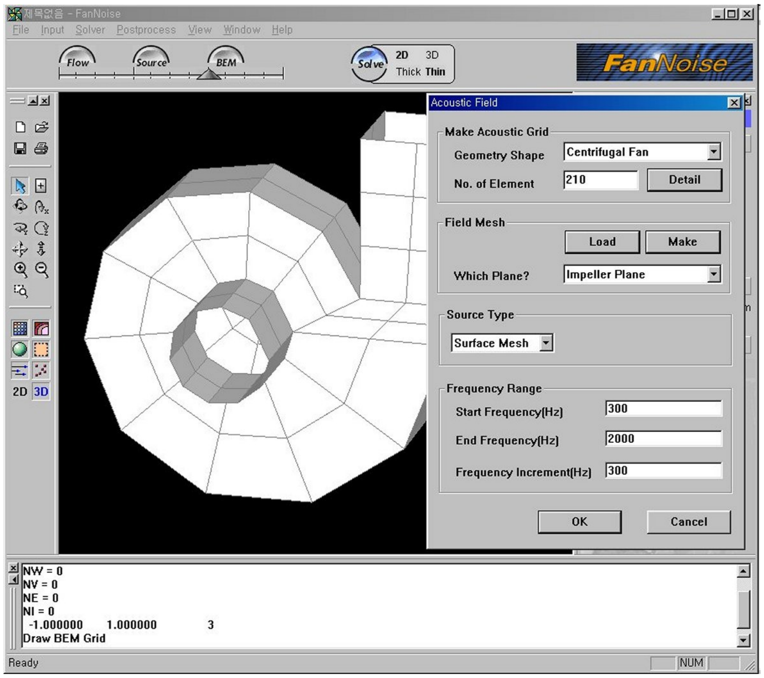


Figure 1: Centrifugal fan mesh for BEM.

acoustic field of a fan. By giving information about performance, flow and noise of axial and centrifugal fans, "FanNoise" will assist for the development of low noise fan

REFERENCES

1. **WanHo Jeon and Duck Joo Lee**, An analysis of the flow and aerodynamic acoustic sources of a centrifugal impeller, *Journal of Sound and Vibration*, Vol. 222(3), pp. 505-511, 1999

2. **WanHo Jeon and Duck Joo Lee**, An Analysis of the Flow and Sound Field of a Centrifugal Fan Located Near a Wedge, In *5th AIAA/CEAS Aeroacoustics Conference*, 1999

3. **Lohmann, D**, Prediction of Ducted Radiator Fan Aeroacoustics with a Lifting Surface Method, In *DGLR/AIAA 92-02-098*, 1992

4. **Neise, W**, Application of Similarity Laws to the Blade Passage Sound of Centrifugal Fans, *Journal of Sound and Vibration*, Vol. 43(1), pp. 61-75, 1975

5. **Weidemann J.**, *Analysis of the Relations Between Acoustic and Aerodynamic Parameters for a Series of Dimensionally Similar Centrifugal Fan Rotors*, NSAS TT F-18, 798, 1971

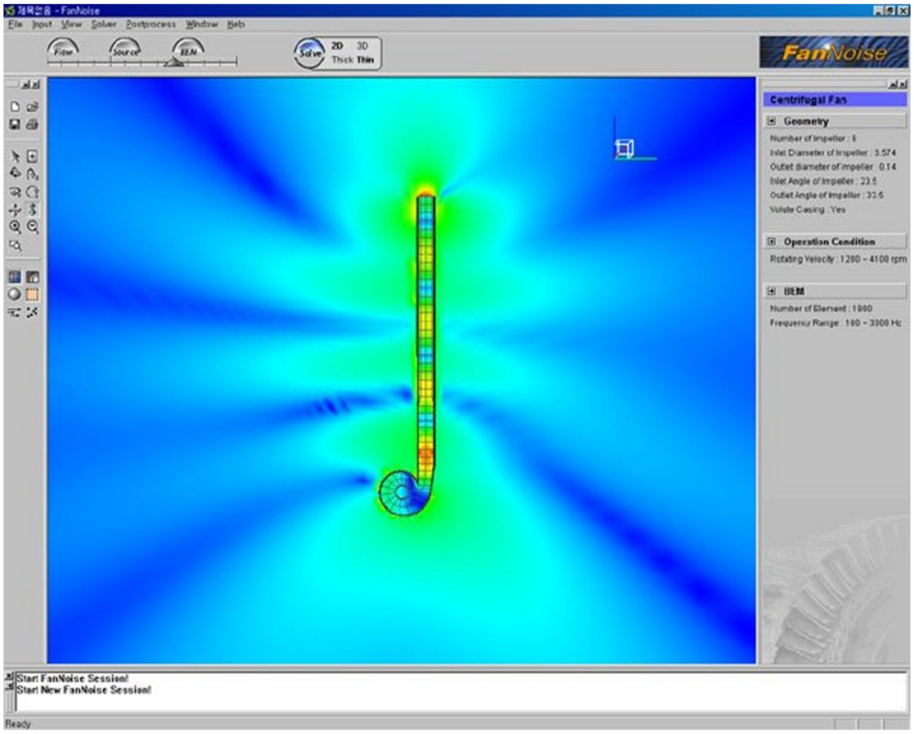


Figure 2: Calculated acoustic pressure contour.

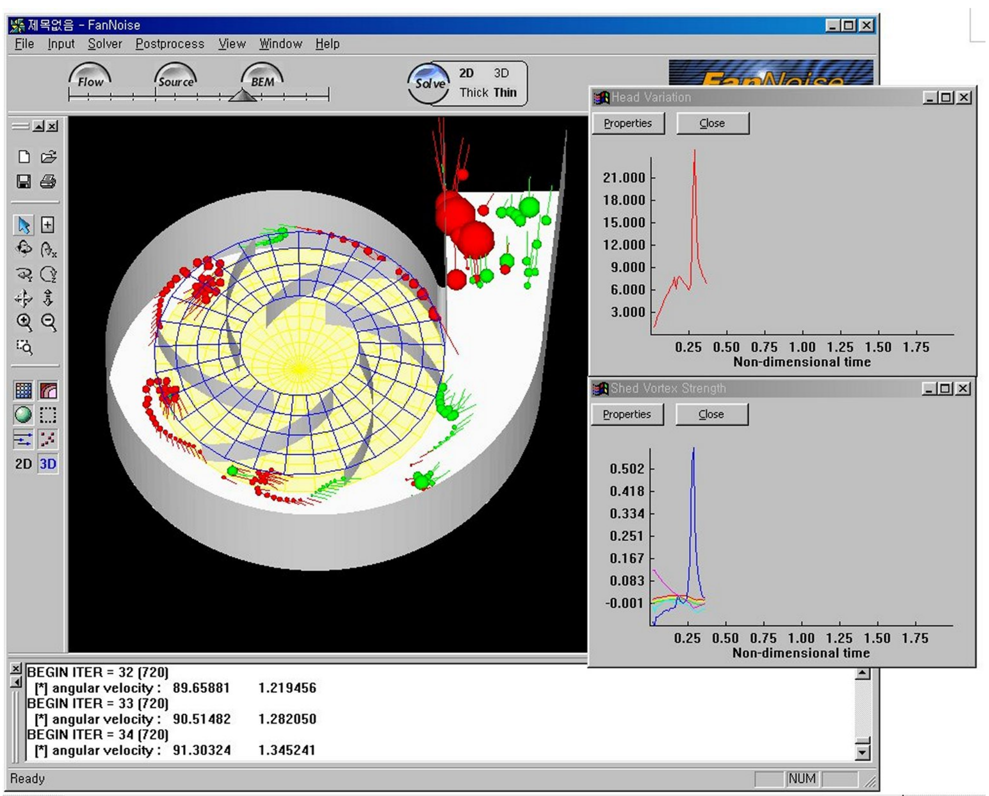


Figure 3: Calculated unsteady flow.

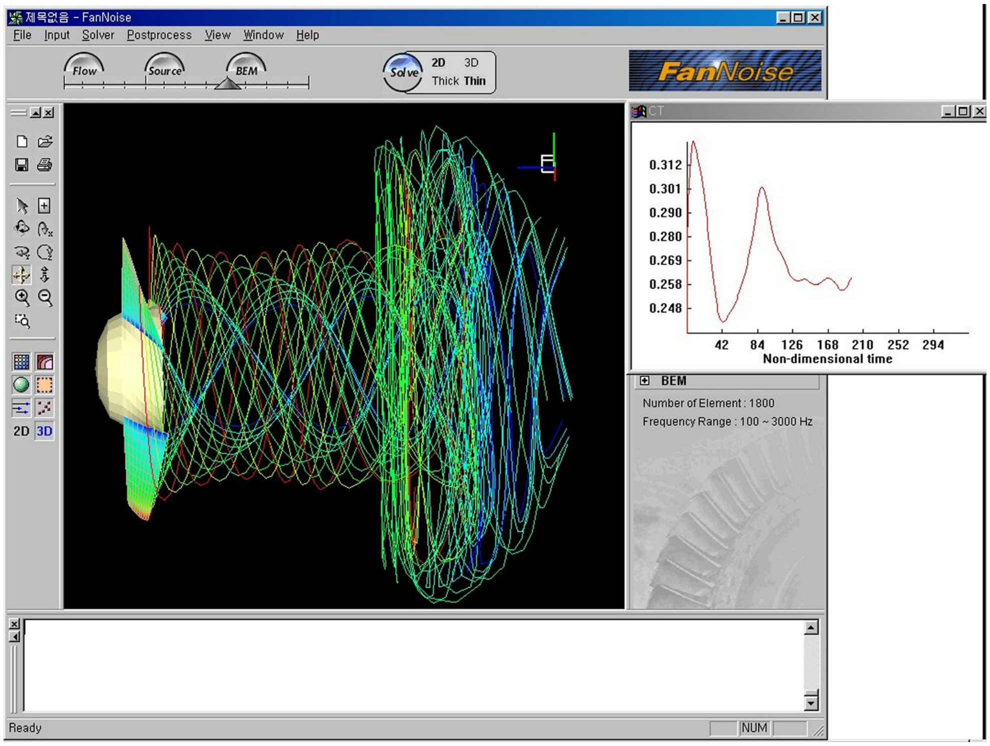
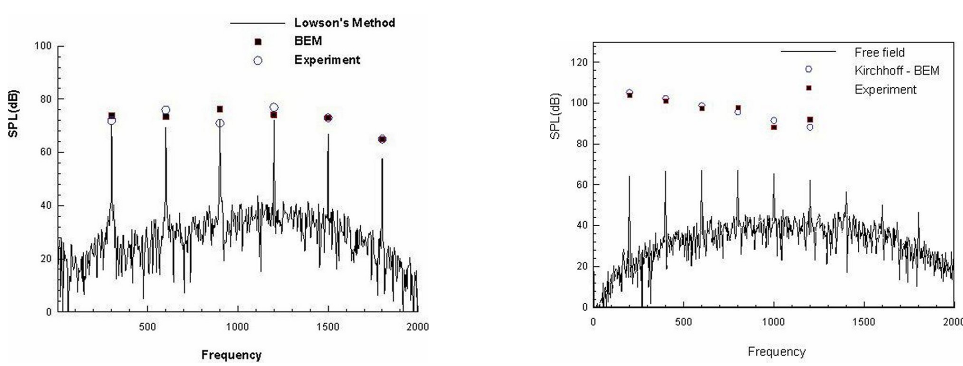


Figure 4: Calculation of the flow field of axial fan.



(a): Centrifugal impeller with wedge.

(b): Centrifugal fan with volute casing.

Figure 5: Comparison of the calculated and measured acoustic pressure.