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The axial fan noise simulation by the freewake method and acoustic analogy

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Abstract

In this paper, we performed the noise analysis for the large size axial fan with a duct. We acquired pressure fluctuation data by flow field analysis and with these data, noise prediction was implemented by the acoustic analogy. These data were compared with the measurement value. So, we verified this method for noise prediction.

1. Introduction

The axial fan is the device that has a very wide range of application and is used in the diverse fields, mainly HVAC device. Acoustic design of low noise fans has become imperative due to legal regulations and call for environment-friendly products.. But owing to the difficulty of analysis of fan noise and the complex interaction with surrounding devices, it has been pursued to lower fan noise by experimental approaching method until now. Recently, owing to the rapid advances of computers and computational fluid dynamics, the research for approaching this problem systematically with reducing tremendous time loss for experiment-basis design.

In the present work, for predicting noise of large size axial fans, acoustic analogy on the basis of anaylsis of potential flow is used. For the purpose of predict the aerodynamic noise of the interaction between blades and wake, the wake model which utilizes curved vortex filament is used to analyze flow with considering the effect of duct.. Using this result, Ffowcs William-Hawkings' acoustic analogy based on the Lighthill's equation was performed numerically in time domain.

2. Theory

2.1 Flow analysis

The free-wake generated by fan blades are depicted curved vortex. The curved vortex wake modeling with the curved elements is more convenient than conventional straight elements.

The curved vortex elements can simulate the wake of rotors with 1/10 of numbers of elements as required when using straight vortex elements. The calculation time requires only 38% of the calculation for equal accuracy.

The vortex filament is a singularity itself. So two types of curved vortex elements must be used by velocity calculation position.

First BCVE method is used when calculates the velocity induced at any point other than on the vortex itself. As seen in Fig.1 , BCVE can be modeled by using a parabolic curve. The velocity induced at a point in space is calculated by following equations.

$$\vec{q} = -\frac{1}{4\pi}\int_c \left[\frac{\Gamma \vec{r}_v \times d\vec{s}}{r_v^3}\right] \qquad (1)$$

$$\vec{r}_v \times d\vec{s} = -2\varepsilon z x_1 dx_1 \vec{i} + z dx_1 \vec{j} + (2\varepsilon x_1 x - \varepsilon x_1^2 - y) dx_1 \vec{k} \qquad (2)$$

Second method is used when calculates the velocity induced on the element itself. As seen in Fig. 1, SIVE passes through the three points. Velocity at point j can be calculated by Biot-Savart integration and it is possible to do the integration analytically as follows.

$$w_{SI} = -\frac{\Gamma}{4\pi R}\ln\left(\frac{4R}{d_c}\right) - \frac{\Gamma}{8\pi R}\ln\left[\tan\frac{\theta_1}{4}\tan\frac{\theta_2}{4}\right] \qquad (3)$$

The curved vortex elements defined by three points are interpolated through method shown in figure 2. The method is disadvantageous in that the gradient of the curvature between neighboring elements is snot continuous. The continuity can be imposed using higher order polynomials. Increasing the number of elements, however, is known to be advantageous when the accuracy of the solution with respect to the calculation time is considered.

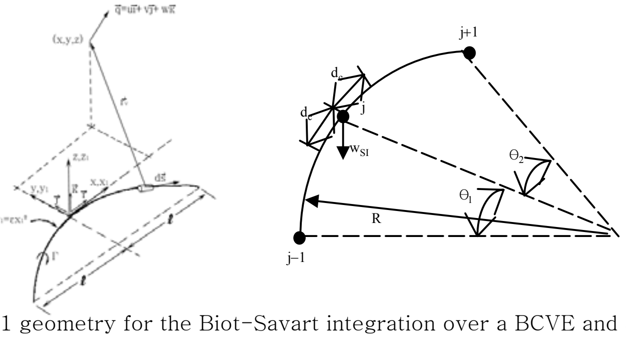

Fig. 1 geometry for the Biot-Savart integration over a BCVE and SIVE

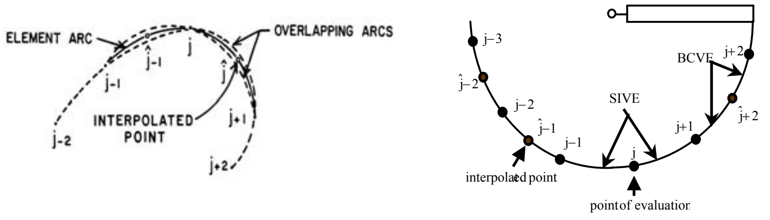

Fig. 2 connection method for curved vortex element

2.2 Time domain acoustic analogy

Ffowcs Williams and Hawkings formulated the equation for the manifestation of acoustic analogy proposed by Lighthill. The solution for the acoustic pressure can be obtained in the following form by using Green's function and coordinate transformation.

$$p'(\vec{x},t) = p'_T(\vec{x},t) + p'_L(\vec{x},t) \qquad (4)$$

$$4\pi p'_T(\vec{x},t) = \int_{f=0} \left[\frac{\rho_0 \dot{v}_n}{r(1-M_r)^2} \right]_{ret} dS + \int_{f=0} \left[\frac{\rho_0 v_n \left(r\dot{M}_i \hat{r}_i + c_0 M_r - c_0 M^2 \right)}{r^2(1-M_r)^3} \right]_{ret} dS \qquad (5)$$

$$4\pi p'_L(\vec{x},t) = \frac{1}{c_0} \int_{f=0} \left[\frac{\dot{l}_i \hat{r}_i}{r(1-M_r)^2} \right]_{ret} dS + \int_{f=0} \left[\frac{l_r - l_i M_i}{r^2(1-M_r)^2} \right]_{ret} dS + \frac{1}{c_0} \int_{f=0} \left[\frac{l_r \left(r\dot{M}_i \hat{r}_i + c_0 M_r - c_0 M^2 \right)}{r^2(1-M_r)^3} \right]_{ret} dS \qquad (6)$$

Here $p'_T(\vec{x},t)$, $p'_L(\vec{x},t)$ respectively denote the acoustic pressure due to thickness and loading, corresponding to the monopole and the dipole terms. Near-field and far-field terms are seen explicitly as $1/r^2, 1/r$ terms in the integrals, respectively.

3. Results

Fig. 3 Shows the fan and duct panel geometry for the flow field analysis. Duct has inlet cone and fan has 10 blades. This fan has 149 Hz First BPF and it is influenced main noise component until 3rd harmonics. So pressure fluctuation is calculated at 0.00125s time intervals for capturing 1st ~3rd harmonics exactly. To depict wake, free wake filaments are arranged 6 turns behind the fan.

For fan has unsteady flow field, pressure coefficient is calculated like this to apply the acoustic analogy to noise prediction.

$$C_p = 1 - \frac{Q^2}{v_{ref}^2} - \frac{2}{v_{ref}^2} \frac{\partial \Phi}{\partial t}$$

Fig. 4 shows curved vortex filaments that calculation ends. That depicts the real wake structure very well. It shows stream tube's contraction and expansion in the duct. Fig. 5 shows pressure fluctuation through azimuth angles. The figure shows only one blade but calculation considers 10 blades. The pressure fluctuation acquired in this way is used to noise prediction. The noise prediction results by time domain acoustic analogy are compared to measurement data in figure 6. The noise spectrum is measured at a distance 2m from the fan axis. In this figure, the numerical results about these discrete noises are predicted with sufficient accuracy.

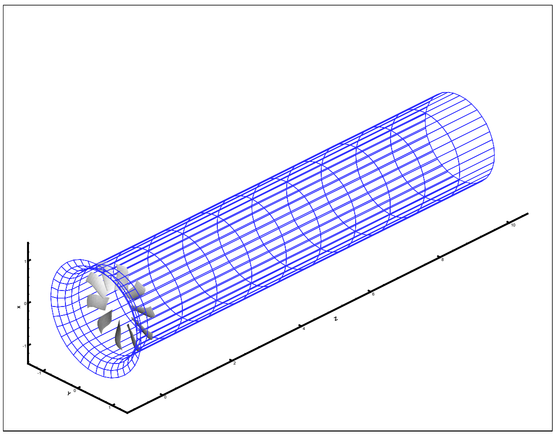

Fig.3 Fan and duct panel geometry

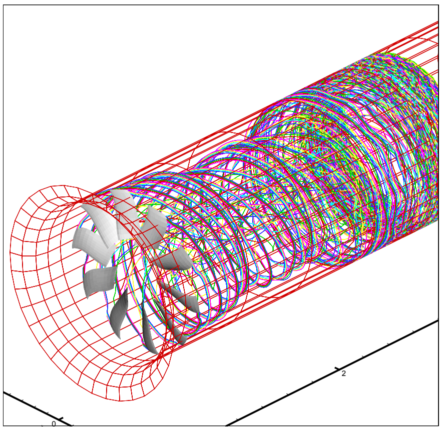

Fig.4 Free wake geometry

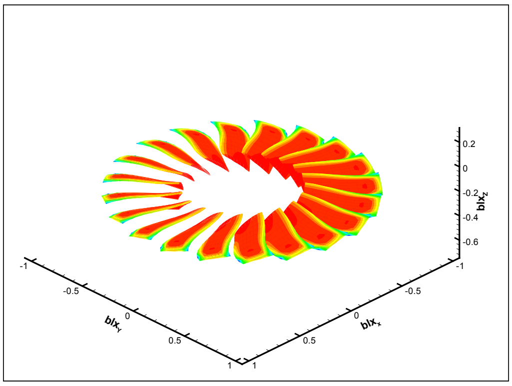

Fig.5 Cp distribution for noise calculation

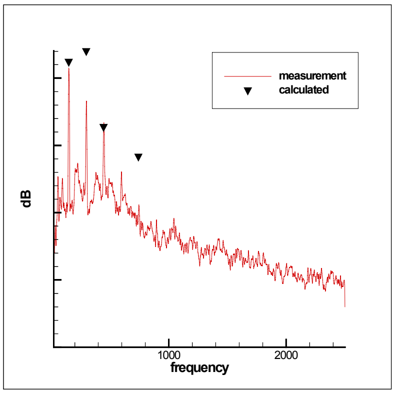

Fig.6 Noise spectrum-comparison calculation and measurement

4. Conclusion

In this paper, we simulated the discrete noise of the large size axial fan with duct. By the free wake method with the curved vortex filament, we could acquire pressure fluctuation in time domain. This method made a sufficiently exact solution, so numerical noise prediction by acoustic analogy could be implemented. Therefore the free wake-time domain acoustic analogy could predict the discrete noise component about the axial fan and it need less computation time, so we hope this method could be used to the low noise fan design.

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