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Development of high-efficiency axial flow fan using the FANDAS code

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Abstract

This study describes the FANDAS code and its application for high-efficiency axial fan development. Once fan design parameters are input, the FANDAS code constructs a 3-D blade shape model and predicts fan performance and noise level using the through-flow analysis method with pressure loss and noise models. The FANDAS code is also used to optimize fan design variables using the parametric studies on fan pressure, efficiency, and noise level. The optimized fan is manufactured and tested to verify the FANDAS predictions. The FANDAS predictions on the performance and the noise level of the optimized fan agree well with actual test results, within a small percentage of relative error. Furthermore, the present fan design optimization using the FANDAS code yields 10% efficiency improvement compared with the existing Korean market product.

Keywords: Axial flow fan, Performance, Efficiency, Noise, Through-flow analysis, Parametric study

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1. Introduction

Axial flow fans are widely used in low-pressure and high-flow capacity air handling systems such as air-conditioning, ventilating, and cooling equipment [1]. Because the internal flow field of an axial flow fan is three dimensional, unsteady, and viscous, it causes two typical flow effects, such as pressure loss and fluctuation, thereby reducing fan performance and generating excess noise (refer to Fig. 1). According to fan noise similarity law, the noise intensity of pressure fluctuation is proportional to fan pressure and flow capacity; therefore, fan noise characteristics are closely related to fan performance and efficiency [2]. Thus, fan designers for high-efficiency and low-noise applications have called for a design method, which can consider the effects of fan design variables on fan performance and noise level.

In this study, a computer program for fan design and prediction of performance and noise performance, the FANDAS code, is introduced and applied to actual fan design. At the first step of fan blade geometry design, the FANDAS code constructs a 3-D model of the curved blade shape using combined vortex design concepts. The second step is to predict fan performance using the through-flow analysis method with pressure and deviation models. Lastly, fan noise prediction is made by combining the through-flow and the performance analysis results with noise models for discrete frequency and broadband noise sources.

The FANDAS code is applied to actual air-conditioning fan design. Based on the parametric studies of fan pressure, efficiency, and noise level by the FANDAS code, the optimal values of fan design variables are determined for high efficiency and low noise. With the optimal fan design values, a new fan is manufactured and tested in a chamber-type facility. The fan test results are consistent with the FANDAS code predictions, demonstrating that the FANDAS design optimization can remarkably improve fan efficiency and reduce noise.

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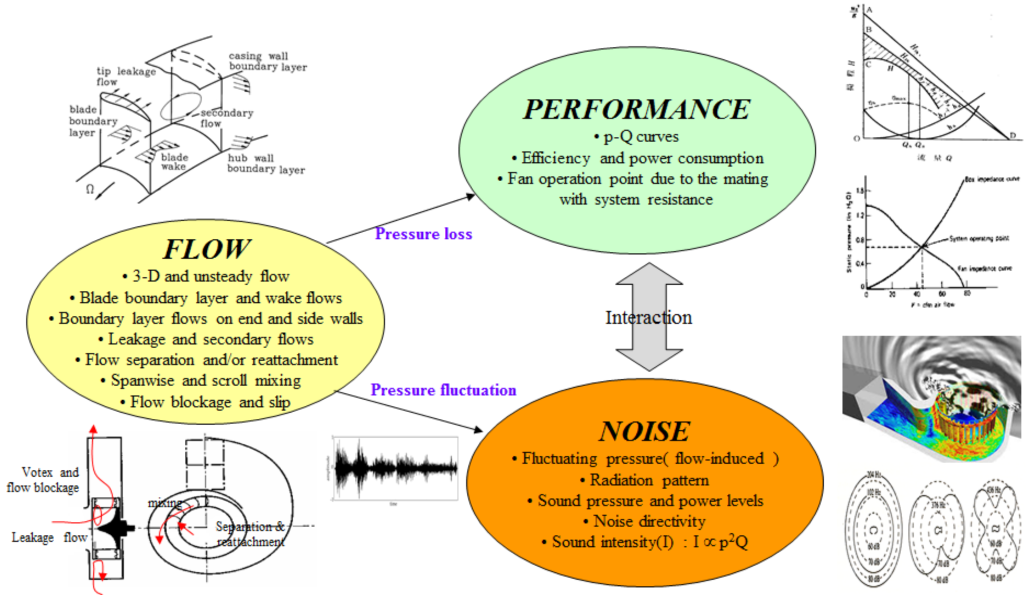


Fig.1 Interaction between fan flow, performance, and noise

2. Design, Performance, and Noise Prediction Methods of the FANDAS Code

2.1. Fan design method

While constructing the fan blade geometry, the FANDAS code first determines blade angle distribution along the blade span height using combined vortex concepts. After determining the blade angles at each blade section element, the FANDAS code constructs the camber lines and the blade thickness distributions for the blade elements and stacks the blade section elements along the blade span height [1].

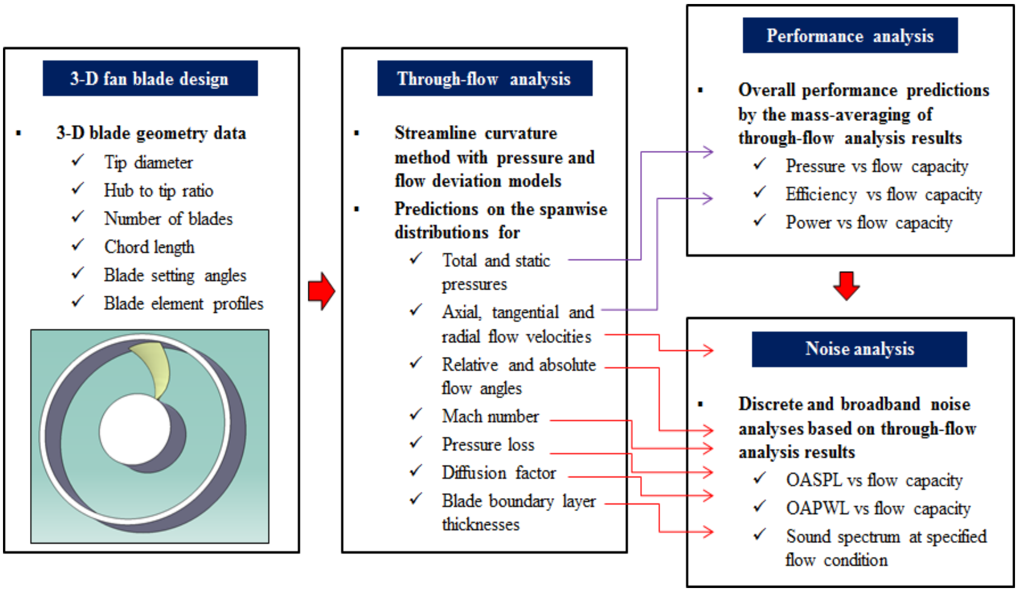


Fig. 2 Computation procedure of the FANDAS code

2.2. Fan performance and noise prediction methods

As shown in Fig. 2, after the fan blade geometry is determined, the FANDAS code analyzes steady-state and axisymmetric flow field using the through-flow modeling technique on pitch-averaged and hub-to-tip flow surface, wherein several streamlines are set along blade span. The through-flow method of the FANDAS code calculates the spanwise distributions of flow velocity, flow angle, and pressure at the fan blade outlet. Detailed solution procedure of the through-flow method is described in a study reported by Novak [3]. Through-flow analysis method generally requires flow deviation and pressure loss models, and the FANDAS code uses two empirical correlations for design and off-design points as flow deviation models [1,4].FANDAS categorizes total pressure loss into four components: blade profile, secondary flow, end-wall boundary layer, and tip clearance flow. Magnitudes of pressure loss are calculated using the corresponding empirical correlations [5,6,7].

After the through-flow analysis results are obtained for various flow conditions, overall fan performance parameters are computed using mass-averaging of the through-flow analysis results. The through-flow analysis and the performance prediction results are utilized to calculate fan noise levels using discrete frequency and broadband noise correlation models [8,9].

3. Design Optimization Results and Discussions

3.1 Parametric study results

The FANDAS code is applied to actual design of a new air-conditioning fan with the following design requirements:

-Static pressure: 30 mmAq
-Flow capacity: 200 m^3/min
-Efficiency: maximum
-Sound pressure level: <84 dBA @ 1 m

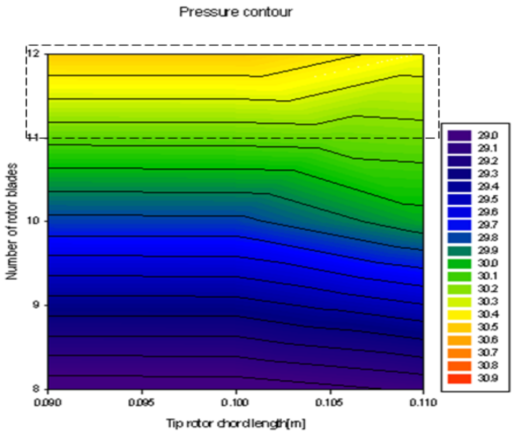
Table 1 summarizes the fan design specifications of this study. This study considers the rotor chord length and number of rotors as two free design variables to be optimized within 9–11 cm and 8–12, respectively.

Table 1 Fan design specifications and methods

RPM	1170	Stator chord	0.1 m
Tip diameter	0.63 m	No. of stators	11
Hub/tip ratio	0.44	Angle distribution	Free vortex
Rotor chord	**0.09–0.11 m**	Camber design	Circular arc
No. of rotors	**8–12**	Rotor airfoil	NACA65-010
Tip clearance	0.0025 m	Stator airfoil	Cambered plate

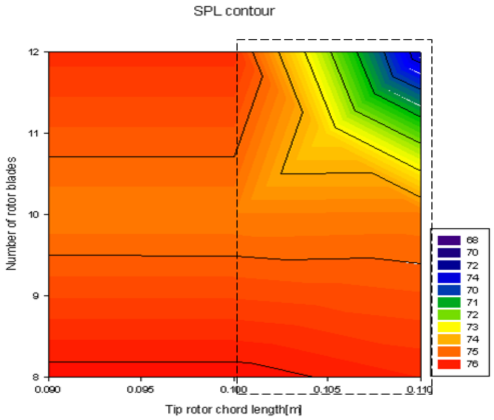
By changing the two design variables within the specified design ranges, the FANDAS code calculates the static pressure, efficiency, and overall noise level of the fan. The parametric study results are represented in Figs. 3–5.

Results shown in Fig. 3 reveal that the number of rotor blades should be >11 to meet the design requirements for fan static pressure (30 mmAq). The parametric study results in Fig. 4 show that rotor blade chord length should be >10 cm for a lower noise level. Considering the intersection of the results shown in Figs. 3–4, the number of rotor blades should be 11–12, with a chord length of 10–11 cm. The results on fan efficiency (Fig. 5) show that the highest fan efficiency of 78% is achieved when the rotor chord length is 10 cm and the number of rotor blades is 12. Therefore, this configuration was chosen to maximize the fan efficiency.



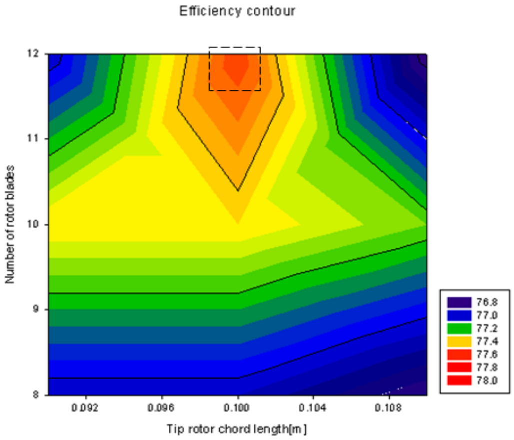
Pressure: 30 mmAq → No. of fan blades: 11～12

Fig. 3 Parametric study results of fan pressure



Low-noise fan design → Increasing fan blade chord length

Fig. 4 Parametric study results of fan noise level



Low-noise & high-efficiency fan design
→ Fan blade chord length: 10 cm , No. of fan blades: 12

Fig. 5 Parametric study results of fan efficiency

3.2 Design verification via measurements

The optimized rotor and stator blades are manufactured and assembled as shown in Fig. 6. The performance and noise tests for the optimized fan configuration are conducted in the chamber test facility at the Korean testing certification according to AMCA and ISO standards.

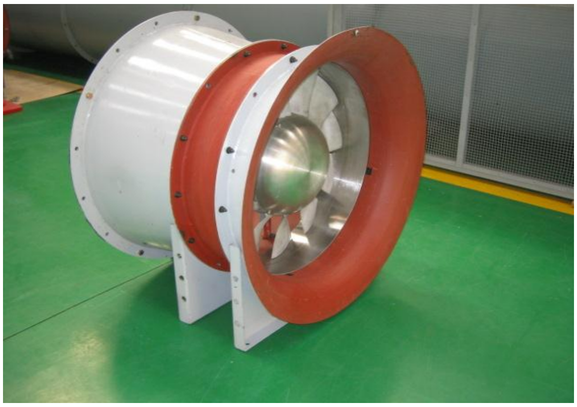


Fig. 6 Manufactured fan model (optimized)

Table 2 Performance and noise test results

Model	Evaluation method	Flow capacity [CMM]	Static pressure [mmAq]	Efficiency [%]	SPL [dBA]
Optimized fan model	FANDAS	200	32.36	78.20	78.09
	Test	200	36.00	75.00	79.00
Existing market product	Test	210	34.50	65.00	90.00

The test results from the optimized configuration agree well with the FANDAS predictions in Table 2, within a small percentage of relative error. These results verify that the FANDAS code is suitable as a design tool for an axial flow fan. Table 2 shows that optimization with FANDAS can improve fan efficiency by 10% and reduce noise level by 10 dB compared with the existing market product available in Korea.

4. Conclusions

This study presents the FANDAS code, a design method of axial flow fan coupled with fan performance and noise prediction models. The design code can be used for high-efficiency and low-noise fan design optimization. The FANDAS code is applied to the actual development of a new air-conditioning fan. The comparison results between the FANDAS and the test results show that the FANDAS code predicts fan performance and noise level within a few percentage of relative error and can be used as a design optimization tool, providing remarkable performance improvement and noise reduction. The future study using the FANDAS code will focus on combining the FANDAS code and several optimization algorithms to optimize fan design variables automatically.

Acknowledgements

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