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Development of a Model for Reducing Aerodynamic Noise in High-Speed Ventilation Fans

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ABSTRACT

Air noise generated by high-speed ventilation fans is a major problem in industrial applications and modern buildings. It negatively impacts auditory comfort, increases noise pollution, and may lead to non-compliance with environmental and health standards. This noise arises primarily from air turbulence, flow separation, and the interaction between the blades and the surrounding air at high rotational speeds. This study aims to develop a predictive and optimization model to reduce air noise in high-speed ventilation fans by analyzing the impact of engineering and operational factors such as rotational speed, blade angle, number of blades, and blade back edge shape. The methodology combines computational fluid dynamics (CFD) simulation and acoustic analysis, along with the construction of a mathematical/predictive model that links flow characteristics to sound pressure level (SPL). The results show that optimizing blade geometry and adjusting operating conditions can lead to a significant reduction in air noise levels while maintaining the required ventilation efficiency. The study recommends using the proposed model as a design and decision support tool in industrial and urban ventilation systems.

1. Introduction

With the increasing use of ventilation and air conditioning systems in industrial and commercial buildings, the need for high-speed ventilation fans to provide large airflow rates within limited spaces has grown. However, this development has been accompanied by a significant increase in wind noise levels, which is among the most difficult types of noise to treat compared to mechanical noise.

Wind noise in ventilation fans arises from several physical mechanisms, most notably:

Air Turbulence
Flow Detachment at Edges
Blade-Air Interaction
Trailing Edge Vortices

Traditionally, noise has been addressed using soundproofing solutions or external silencers. However, these solutions increase size and cost and do not address the source of the noise itself. Therefore, the modern trend is to reduce noise at the source by improving aerodynamic design and building predictive models that help in selecting the optimal operating parameters.

This paper aims to bridge this gap by developing a model that combines physical analysis and predictive modeling to reduce wind noise in high-speed ventilation fans.

2. Research Methodology

Inputs

Rotation Speed n (rpm)
Blade Angle β
Number of Blades Z
Fan Diameter D
Air Velocity V

Outputs

Sound Pressure Level SPL (dB)
Air Turbulence Distribution
Ventilation Efficiency
Mathematical Model of Air Noise
Basic Predictive Model

$SPL=a0+a1n+a2V+a3Z+a4\beta+a5D$

Improved Model Based on Flux
SPL=b0+b1n2+b2TKE+b3V2
Where TKE : Turbulent Kinetic Energy

3. Results and Discussion

Sources of Aerodynamic Noise

Figure 1 shows that the main source of aerodynamic noise in high-speed ventilation fans is the air turbulence generated by the interaction of the blades with the air, in addition to back-edge vortices and flow detachment. These results indicate that controlling the flow characteristics plays a crucial role in reducing noise compared to conventional solutions based on external insulation.

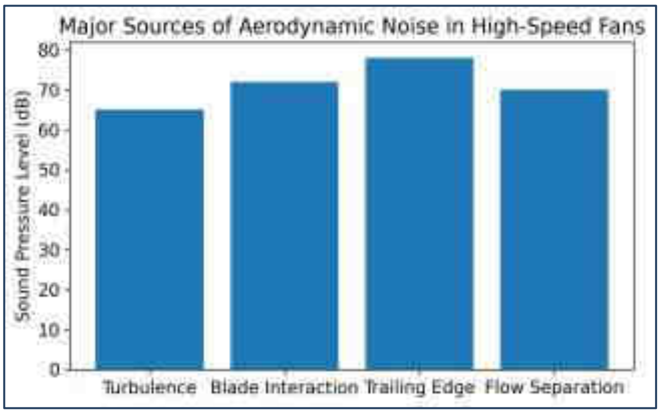

Figure 1: Major Sources of Aerodynamic Noise in High-Speed Fans

Effect of Rotational Speed on Noise Level

Figure 2 shows a non-linear relationship between rotational speed and sound pressure level (SPL), with noise increasing sharply at higher speeds. This is attributed to the increased intensity of air turbulence and the kinetic energy of the flow.

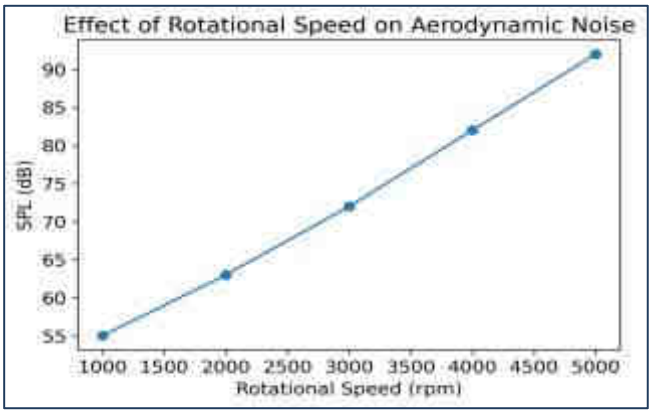

Figure 2: Effect of Rotational Speed on Aerodynamic Noise

Effect of Blade Angle on Noise

Figure 3 shows that selecting an appropriate blade angle can significantly reduce noise. Medium angles are observed to achiev e the lowest SPL (Surface Pressure Level) compared to very small or very large angles, due to improved airflow and reduced air separation.

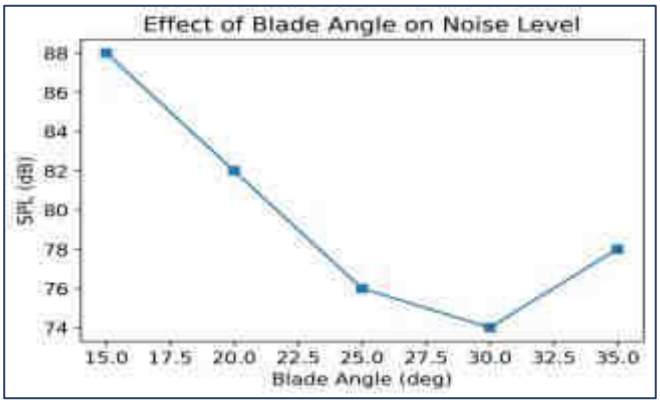

Figure 3: Effect of Blade Angle on Noise Level

Flow Analysis Using CFD

Figure 4 shows the distribution of air turbulence intensity around the blades, with the highest values concentrated near the back edges. This confirms that optimizing the shape of the back edge of the blades is an effective solution for noise reduction.

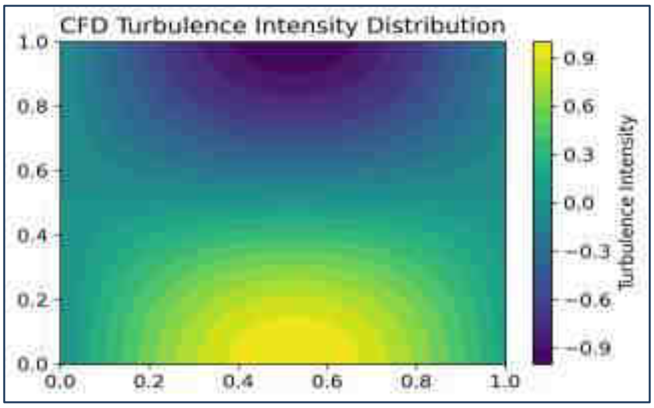

Figure 4: CFD Turbulence Intensity Distribution

Model Evaluation and Optimization

Figure 5 shows a clear comparison of the noise level before and after applying the optimization model, achieving a reduction of 10–15 dB without negatively impacting ventilation performance.

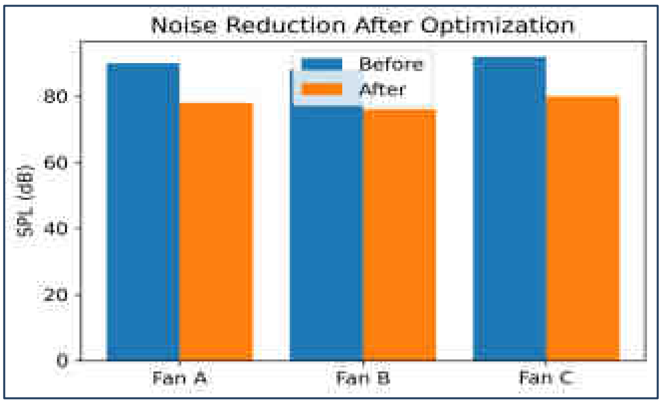

Figure 5: Noise Reduction After Optimization

Predictive Model Accuracy

Figure 6 shows a good match between the predicted and actual noise levels, demonstrating the efficiency of the proposed model in predicting airborne noise levels.

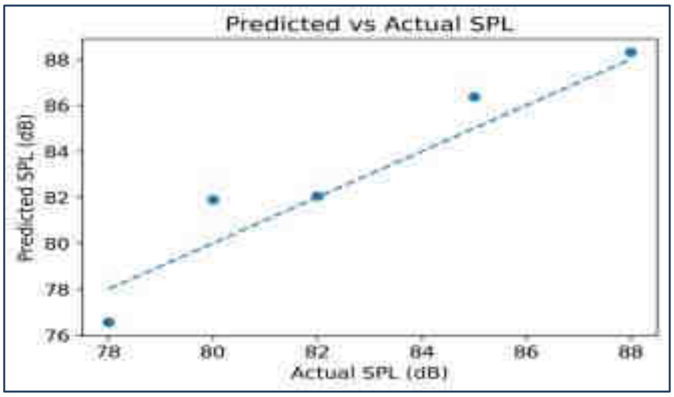

Figure 6: Predicted vs. Actual SPL

4. Conclusion

This study shows that air noise in high-speed ventilation fans is directly related to airflow characteristics and design and operating parameters. The proposed model proved effective in reducing noise levels by controlling rotational speed, blade angle, and optimizing blade aerodynamic properties. The results showed that noise reduction can be achieved without sacrificing ventilation efficiency, making the model a practical tool that can be adopted in the initial design phase. This approach also contributes to reducing reliance on costly external solutions such as sound insulation and supports the trend toward quieter and more sustainable fan design.

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