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Review on Development Techniques of Small-Scale Axial Flow Fans

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ABSTRACT

This review presents a comprehensive state-of-the-art overview of recent studies devoted to optimizing the aerodynamic performance of small-scale axial flow fans by adjusting critical design parameters. Key focus areas include winglet configurations, blade geometry, casing treatments, and tip clearance, all of which directly impact efficiency, pressure development, and noise levels. The paper is organized into two main parts: the first explores how each parameter affects aerodynamic performance, while the second estimates the research methodologies used to model, simulate, and optimize the behavior. Emphasis is placed on computational approaches, including CFD, surrogate modeling, and multi-objective optimization. By integrating insights from design and methodological perspectives, this review identifies effective optimization strategies, evaluates trade-offs among techniques, and provides a solid foundation for guiding upcoming aerodynamic enhancements in axial fan systems.

1. Introduction

In recent decades, the pursuit of energy efficiency has become essential objective in the design and operation of mechanical systems. This rising emphasis is driven not only by tightening legal regulations but also by global concerns over the climate impact of energy consumption. Among the many devices under examination, axial flow fans stand out due to their widespread use across various applications and their considerable share of energy usage.

The progress in axial flow fan technology dates back to the early 19th century, with major advancements in design and efficiency achieved over time [1]. However, despite these developments, some fans still operate in a sub-optimal conditions, demonstrating a good opportunity to reduce energy consumption on a global scale by targeted performance improvements. In parallel, fan aerodynamic noise, primarily due to turbulence and non-uniform forces on the blades, has emerged as another critical research area that has attracted significant interest from scholars [2].

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Wide range of strategies have been explored recently to evaluate and enhance fan performance. As an example, flow control techniques have been employed to modify blade leading and trailing edges [3], investigate the impact of tip clearance, and evaluate the role of blade number on the fan behavior and efficiency [4]. Complementing these experimental techniques, numerical optimization using Computational Fluid Dynamics (CFD) has become an influential tool for refining design parameters. This is principally vital in compact fan systems, where elevated pressure can increase tip leakage and intensify vortex formation leading to energy losses. While experiments evaluations are able to reveal these effects, they are basically limited by setup complexity and cost. CFD, on the other hand, offers a cost-effective technique to powerfully visualize flow, analyze losses, and test design adjustments, making it indispensable for optimizing the fan performance. Addressing these challenges requires careful customization of blade geometry to suit the specific tip-to-shroud gap, reinforcing the importance of optimization in advancing axial fan performance.

Fans’ key performance parameters, like airflow rate and noise level, are essential to evaluate the axial flow fans, specifically when they are designed to deliver high flow rates at a minimized noise level. However, the assessment of the aerodynamic behavior around the fan blades is a complex phenomenon, making their design particularly challenging.

Due to the numerous interdependent design parameters that influence the fan’s overall performance, a comprehensive understanding of key design principles is central to develop effective and optimized systems. [5]. Among the design parameters that contribute significantly to the aerodynamic performance are blade shape and number, winglets, casing, and tip clearance. These factors collectively determine how efficiently the fan transforms mechanical energy into airflow. For instance, inappropriate blade angle design causes flow separation, while excessive tip clearance leads to vortex losses. Optimizing these parameters helps to achieve high efficiency with stable operation, and reduced aerodynamic losses.

This paper presents a state-of-the-art overview of research aimed at optimizing the aerodynamic performance of small size axial flow fans through the adjustment of critical design parameters, including winglets, blade geometry, casing, and tip clearance. The paper is structured into two main sections: the first deliberates the impact of the various design parameter on the aerodynamic performance while the second discusses the research approaches that have been employed to investigate and optimize these parameters. By combining insights from the parameters design and methodology perspectives, the review categorizes key optimization strategies, highlights effective modeling techniques in the literature, and provides a valuable reference for future research.

2. Axial Flow Fan Configuration Design

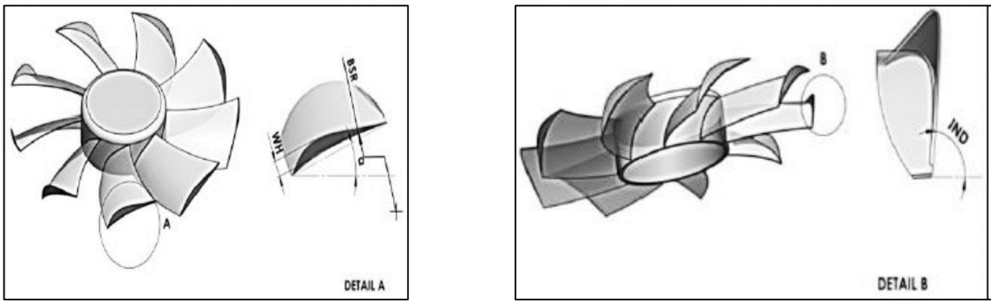
Blade design configuration is a central factor influencing the fans’ overall aerodynamic efficiency [5]. The geometry variations considerably impact pressure distribution, flow dynamics, and noise generation. Consequently, the precise optimization of these factors is essential for enhancing fan performance, reducing energy consumption, and meeting efficiency requirements in different commercial and industrial applications.

2.1 Winglets

The implementation of winglets in axial flow fans has gained attention as an important passive control approach. The blade tip extension and flow behavior alteration provided by winglets help to reduce the formation of leakage vortices, which not only enhance flow capacity and pressure rise but also improve overall efficiency. In this context, Diao, Ge [6] considered the impact of the tip winglet positions, three configurations, including two-sided (TSW), suction-side (SSW), and pressure-side (PSW) winglets, were examined and analyzed using different approaches. Rotational domain was divided into three regions (Z1, Z2, and Z3), with winglets placed in Z1 and Z2. All winglets were reported to effectively reduces tip leakage in Z1 and Z2 and stops its propagation in Z3, also TSW provided the highest pressure difference and blockage improvement. Generally, all investigated configurations exhibited performance enhancement in term of noise reduction.

In another study, Tutar and Cam [7] investigated the effects of winglet geometry on the performance on a specifically conceptual designed small axial flow fan. A double-step optimization technique, using a tip winglet and modifying the stagger angle, was performed using the CFD approach. The results showed improved efficiency when curved winglet is introduced. The achieved simulation results confirmed the efficiency of the adopted passive control approaches for enhancing the efficiency of the fan.

A research conducted by Abdulhussain [8] adopted a numerical simulation, validated with experiments, to investigate how specific geometric parameters affect the performance of a fan with curved winglet tips. The study investigated winglet tip bending angle, and different leading-edge twist angle, as illustrated in Fig 1. The results showed that each parameter having a distinct impact on the flow behavior.



(a) (b)

Fig. 1. Nine blades axial fan (a) front curvature angles of blade winglets; (b) side incidence angle at the blade tip [8]

Chan, Kil [9] suggested winglets at the blade tips of a large tip clearance axial-flow fan to mitigate performance losses. The original fan, fabricated without winglets, showed significantly lower flow rate and static pressure than anticipated, the analysis identified tip leakage and secondary vortex flows as the main contributors to the inefficiency. After modifying the blades with winglets, notable improvements in performance are recognized: the leakage and vortex flows were eliminated, and both flow capacity and static pressure increased by 300 CMH and 1.3 mm Aq, respectively.

The effect of winglets was also investigated in a study by Shivaramaiah, Nagpurwala[10] who reported that winglets help to achieve best performance. They act to enhance the pressure ratio and reduce wake losses, while lowering the stall margin as the trailing edge blockage increase. Within a similar research framework, Bizjan, Milavec [11] examined pressure and velocity fluctuations at the tip clearance region by comparing straight tip blades with blades featuring swept-back winglets. Using a novel experimental approach, the study highlighted important enhancement in energy conversion efficiency and reduction in the acoustic emission due to the application of tip winglets.

Zhang, Ji [12] proposed a novel combined blade tip and winglet design, shown in Fig 2, where blade–end wall blending is combined with winglet features. Conducted numerical analysis reported remarkable reduction in leakage flow and pressure difference at the tip, enhancing aerodynamic performance. Moreover, the design reduces the intensity of the vortex, developing lower operation noise levels.

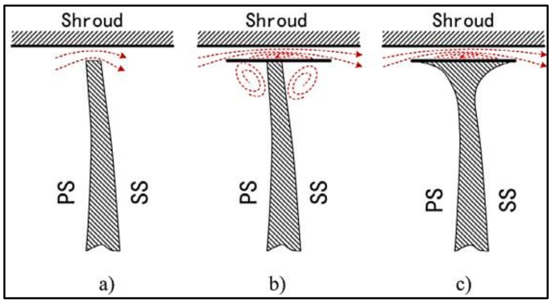


Fig. 2. Schematic illustrations of (a) The original blade, (b) The blade with winglet, and (c) The blended blade tip and winglet blade

Based on a hypothesis that winglets on the suction side of axial fan blades reduces efficiency losses by suppressing tip leakage flow, Jung and Joo [13] examined the tip clearance impact on the flow structure in fans equipped with winglets. Their findings, shown in Fig. 3, identified an optimal tip clearance, 30% of the chord length that achieves maximum efficiency.

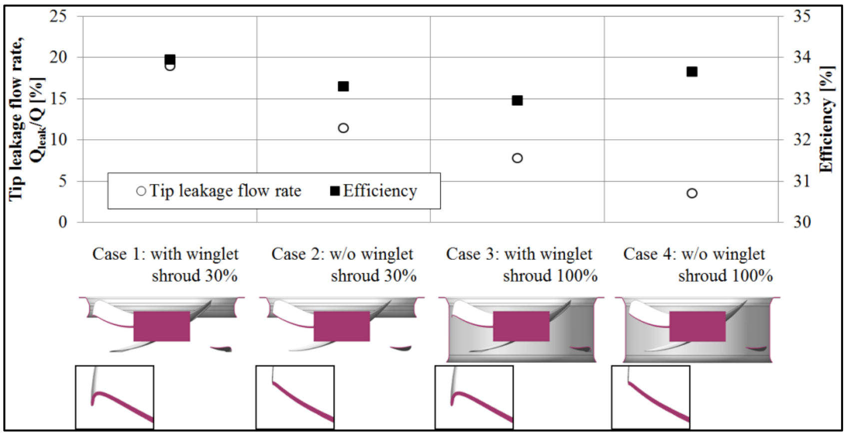


Fig. 3. Tip leakage flow and efficiency as influenced by winglet presence and shroud coverage [13]

Overall, winglets have garnered significant research attention due to their ability to reduce tip leakage flow, a major contributor to efficiency losses in axial flow fans. Optimizing winglet features, such as tip clearance, is important for maximizing aerodynamic performance and enhancing overall energy efficiency in fan designs.

2.2 Blade Count

Fan blade count has been proven to play a significant role in aerodynamic performance, directly affecting efficiency, structural load, and energy consumption. Fakhari and Mrad [14] highlighted that altering the number of fan blades can lead to up to a 9% increase in efficiency, while also impacting noise, energy consumption, and overall weight. Additionally, Rajabi, Rafee [15] investigated the effect of some design parameters including the blade number. Results, shown in Fig. 4, depicted 32% increase in outlet pressure when the blade count increased from 4 to 6, however the effect on the flow rate was limited. Further, the study reported that, at high flow rates, increasing the blade count does not meaningfully impact static pressure.

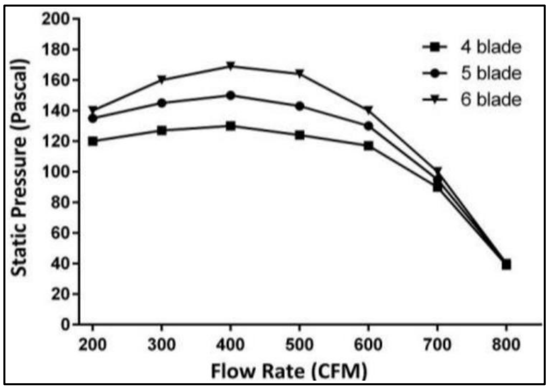


Fig. 4. Performance curves of fans with varying blade counts [15]

Another study by Corona Jr, Mesalhy [16]considered 5-fan configurations with different number of blades (2, 5, 7, 10, and 12). Results showed that the 5-blade fan had the best efficiency among the other fans. Moreover, although fans with a higher number of blades generally increase pressure generation, the study confirmed that this does not necessarily lead to improved performance. As a conclusion, the study highlighted that fan performance is maximized at an optimized blade count, beyond which additional blades lead to a reduced efficiency.

Aiming to optimize ducted fans, Adjei, Fan [17] considered two axial flow fans configurations with 10 and 12 blades. The optimization analysis revealed that the 12-blade design achieved a 1.32% efficiency gain compared to 1.05% efficiency improvement for the 10-blade configuration. The study also reported that the 12-blades fan was more influenced by hub thickness, sweep, and twist, though the 10-blades were affected by mid-to-tip core, sweep, and lean.

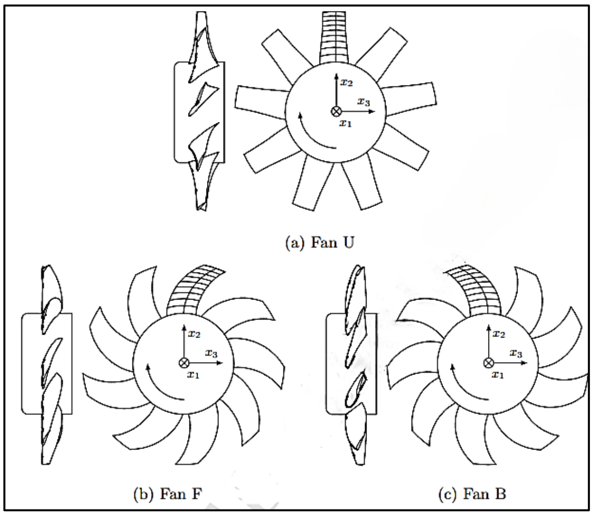
Blade count significantly impacts fan performance, affecting pressure, efficiency, and energy use. While increasing blade number acts to boost pressure, it often has limited effect on flow rate. A 5-blade fan demonstrated the best efficiency, proving that more blades don't always mean improved performance.

2.3 Blade Design

2.3.1 Blade blending

Another study by Liu, Xiong [18] considered the bending direction, blade number, and blade shape. The results revealed an optimal design comprising seven forward-bending blades at 9.5° tip angle, 58.0° root angle, and a streamlined low-curvature airfoil. Also, a 3.86% increase in air volume was achieved compared to the original fan at a similar energy consumption.

It is well established that blade skew impacts the aerodynamic performance, motivated by this fact, Krömer, Moreau [19] compared the performance of forward-, backward-, and unskewed blade designs shown in Fig. 5. The study found that the forward-skewed fan has the higher aerodynamic efficiency and minimum noise levels compared to the backward- and unskewed fans which demonstrated stronger noise and increased turbulent kinetic energy.



(a) Fan U

(b) Fan F

(c) Fan B

Fig. 5. Investigated axial fans: unskewed fan (a), forward-skewed fan (b) and backward-skewed fan (c) [19]

Aiming to examine the effect of blade leading edge serration, Bharanitharan and Senthilkumar [20] conducted a numerical analysis to evaluate the aerodynamic efficiency. Fig.6 presents the main findings where the serrated fan shows higher efficiency of 0.8 m^3/s compared to 0.6 m^3/s for the baseline fan. More generally, the results show that baseline fan is more efficient at low flow rates, while the serrated fan performs better at high flow rates.

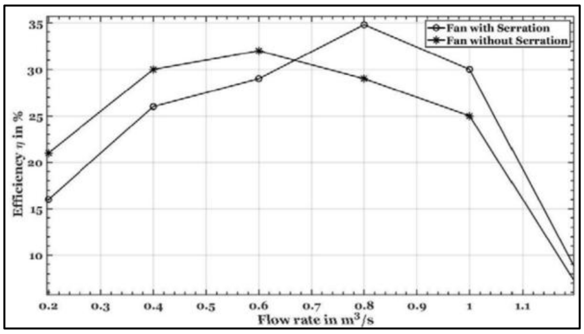


Fig. 6 Efficiency flow rate relationship [20]

Zhang, Yuan [21] considered the impact of trailing edge in four different impeller designs used in air-conditioner systems. Experimental and numerical approaches were used to evaluate the blade loading, vorticity, pressure distribution, and noise characteristics of the four designs. The study reported that optimized trailing edge could develop uniform velocity at the section surface and mitigate pressure fluctuations, leading to improved overall aerodynamic and acoustic performance.

Tan, Dong [22]examined impellers comprising bionic blade design that contains a wavy leading edge and seagull-inspired airfoil. The optimized design was proved to enhance the aerodynamic performance and increase the pressure efficiency by 2.28% compared to the original blade. This was combined minimized turbulence and suppressed backflows. Ding, Wang [23]introduced a new blade design based on the rational quadratic Bézier curves which were used to define the angle and bending of the blade. The results showed that optimized blade demonstrated increase in efficiency and pressure coefficient by 5.44% and 2.47%, respectively.

Obviously, simple blade designs, including forward-skewed and forward-bending blades, effectively increase efficiency and minimize noise with low complexity. Serrated edges improve high-flow performance but may negatively impact low-flow efficiency. More advanced designs, such as bionic blades, optimized trailing edges, and Bézier curve bending, offer greater aerodynamic and acoustic gains, though they are more complex and costly. Hence, simpler approaches are cost-effective, while advanced techniques provide better performance but require more resources, highlighting a trade-off between practicality and efficiency.

2.3.2 Tip gap and tip leakage

Tip gap is a significant design factor that impacts the aerodynamic performance, minimizing this leakage acts to suppress vortex formation, leading to aerodynamic performance enhancement. Aiming this issue, Li, Lu [24] proposed a dual numerical and experimental approaches to evaluate the impact of three bending factors, radial position, circumferential starting angle, and bending degree on the tip leakage. The study reported efficiency improvement and noise reduction due to bending. The optimal configuration, 90% radial position, 10° angle, 8% bend, was found to lower broadband noise by 0.54–2.68 dB(A) and improve the overall sound quality. The tip gap was also investigated by Moghadam, Meinke [25] who analyzed the tip vortex system under different tip gap sizes. The study outcomes confirmed that larger tip gaps maximize the strength of tip leakage and induced vortices, leading to reduced fan efficiency.

The tip gap and tip clearance were also considered by Chen, Zhang [26]who examined the effect of the axial width (L), front ring radius (R1), and rear ring radius (R2). The reported results confirmed an improvement in performance as the L and R1 increase, contrariwise, it reduces as the R2 increases. Lee, Park [27]considered the tip leakage vortex (TLV) in axial flow fan at 1000 rpm. A strong effect of incoming flow rate on the TLV evolution was reported, further, a breakup of the TLV occurs at peak efficiency and stall conditions. Further, the TLV center demonstrated a wandering motion that propagates downstream, growing the swept region. The study also reported big turbulence nearby the TLV center which is attributed to its interaction with the axial flow.

To minimize the leakage flow and enhance the aerodynamic performance, Pereira, Ravelet [28]suggested a novel technique comprises a hollow blade involves 16 air injection holes in the shroud, as illustrated in Fig. 7. At 1000 rpm and 800 L/min injection, the CFD analysis showed substantial improvements: 80% reduction in leakage, 53% in power, and 80% in torque, confirming the effectiveness of the technique.

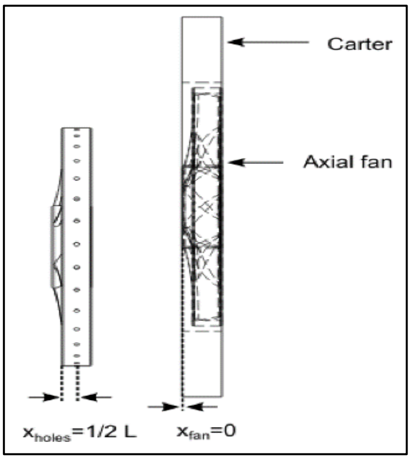


Fig. 7. On the left side, position of the injection holes, and on the right, location of the fan in the carter [28]

Overall, the studies highlighted that adjusting tip gap is crucial for improving the aerodynamic efficiency by suppressing tip leakage vortices. Easy techniques like blade bending offer practical efficiency advances and noise reduction, however, tip gap reduction is limited by manufacturing limitations. The innovative air injection approach offers significant performance improvements, however, it adds complexity and requires real-world testing. Generally, simpler techniques provide sound gains, but advanced control methods deliver greater benefits at higher complexity.

2.3.3 Casting, duct, and shroud

The main sources of noise in axial flow fans were identified as: blade-stator interaction, tip leakage flow, and surface boundary layers [29]. Unsteady tip leakage is the main reason behind pressure fluctuations which generate significant noise and aerodynamic losses. While smaller tip gaps reduce noise and enhance efficiency, they are constrained by some material and manufacturing limits. Alternative solutions include applying casing treatments. In this regard, Liu, Jiang [30] used open-cell metal foam casing where noise was reduced by 10 dBA. Conducted numerical analysis revealed that the used porous casing reduces leakage vortex due to reduction in flow momentum alteration across the blade. In the same context, Czwielong, Floss [31]investigated a micro perforated absorber duct design shown in Fig. 8. Results showed a noise reduction of up to 16 dB with no trade-off in pressure or efficiency, with a more noise minimizing as the fan moved downstream. Further, the investigation of various fan configurations confirmed the high effectiveness of the proposed duct, with inlet turbulence further enhancing its performance.

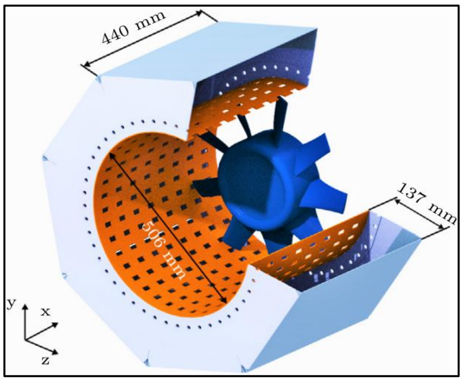


Fig. 8. Engineering design model of the micro perforated absorber duct [31]

Li, Wang [32] considered ducted propellers under axial and sloped flow conditions, numerous geometric parameters were observed throughout the study to identify their impact on performance. An important outcome of the study is the discovery that optimal thrust occurs when the propeller disk positioned at the midpoint of the duct, and the rear part of the duct expands outward by 5°.

The effect of shroud and its position relative to the fan is evaluated by Öztürk, Çetin [33] using numerical approach. Results revealed that setting the fan position at 56–60% projection into the shroud enhances the mass flow rate by 8% and improved flow uniformity. Moreover, decreasing the tip clearance to 6 mm improves the mass flow by 7%, though, further reduction is found to be counterproductive. The shroud's role in the aeroacoustics and aerodynamic performance of the fan is also considered by Huang, Xu [34]. The study reported big vortex structures in the shroud–impeller gap in addition to pressure fluctuations primarily at the shroud's mid or outlet regions. Additionally, the study reported that while the shroud has minor effect on far-field noise, its geometry impacts the location of maximum sound pressure. Köten [35]conducted a CFD-based optimization of a 16-blade axial fan, focusing on parameters including shroud angle and other key geometric features. The optimization resulted in a significant improvement in performance, with the flow rate increasing from 1.3 to 2.78 m³/s and static pressure decreasing from 87.79 to 54.59 Pa.

Casing, shroud, and duct modifications have been reported to significantly improve the aerodynamic performance of axial fans. Passive adjustments like porous foam and micro perforated ducts reduce noise effectively with not efficiency loss. On the other hand, geometric optimizations, like shroud positioning and duct shape enhance mass flow and thrust but need careful tuning.

3. Performance Analysis and Optimization Approaches

Analysis of axial flow fans generally integrates numerical simulations with experimental examinations, forming a comprehensive framework for analysis [36]. Numerical techniques like CFD provide detailed, cost- and time-efficient analysis for complex flow and design optimization, while experiments ensure accuracy required for validation. Though, fan design remains challenging due to the numerous interdependent parameters that are involved in the optimization [37]. Traditionally, trial-and-error and heuristics approaches were used in design and manufacturing [38]. The incorporation of CFD tools has improved this process by enabling a more versatile methodology, although it can be computationally intensive. Moreover, physics-based models offer another efficient design alternative. Add to that, the semi-empirical model which uses the blade element theory to discretizes the blade to compute flow and torque.

3.1 Modeling Techniques

Aiming to model the aerodynamic noise and unsteady flow of a low-speed axial cooling fan Mo and Choi [39] employed Large Eddy Simulation (LES) and the Flows-Williams and Hawking's (FW-H) method. The study reported that the simulation was able to captures detailed noise characteristics and velocity around the fan, showing good agreement with experimental data. Considering tip-clearance, and to determine tip leakage and its impact on noise generation, Luo, Chu [40] employed the SST and SAS models for the steady-state and transient analyses, respectively. This combination helps to balance between the computational cost and accuracy. The results showed that the flow field was successfully computed using second-order backward Euler time integration and blended second-order spatial discretization. Table 1 shows the validation and accuracy of the model in predicting the aerodynamic efficiency compared to the experimental results, ψt and εR the are the aerodynamic performance relative error, respectively.

Table 1. Comparison between numerical and experimental results of aerodynamic performance [40]

Parameter	Flow rate	Calculation	Experiment	ε_R
Ψ_t	0.126	0.232	0.251	7.57%
	0.151	0.225	0.240	6.25%
	0.176	0.201	0.211	4.74%
	0.201	0.188	0.193	2.59%
	0.226	0.168	0.172	2.33%
	0.250	0.141	0.144	2.08%
	0.276	0.110	0.113	2.65%

Using the LES, Park, Choi [41] performed analysis to find out how casing fence reduces the tip-leakage vortex. The study reported that the model was efficient in predicting the fan performance, confirming that the fence improves efficiency and lowers noise by weakening vortex strength. Jung and Joo [42]employed 3D analysis using the CFD solver to investigate stagnation pressure loss (Fig. 9), and efficiency. The analysis considered the changes in hub geometry and their effects on performance using the SST k-ω turbulence model for improved wall-boundary accuracy. Results showed that the CFD method accurately predicted the experimental data, with only a 1.5%p deviation.

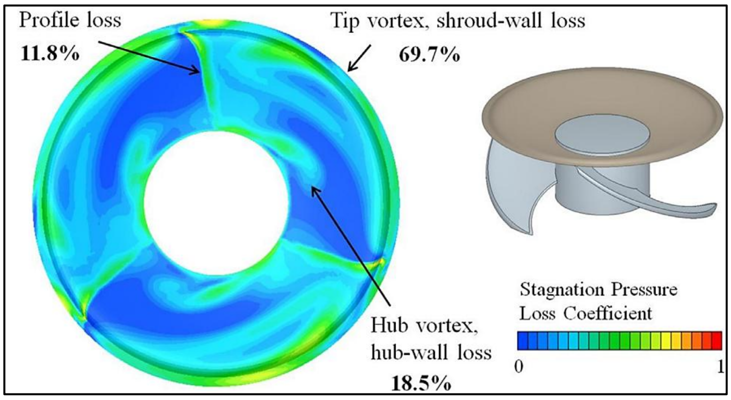


Fig. 9. Axial Fan Outlet Pressure Loss Distribution [42]

A 3D CFD simulations in Ansys-CFX was employed by Wu and Huang [43] to assess the fan performance with optimized blade designs. The outcomes confirmed the robustness of the developed model in optimizing the blade design under both design and off-design conditions. Yang, Zhou [44] developed hybrid surrogate model combining radial basis function and Kriging, aiming to optimize the blade tip design using a Bézier parameterization. NSGA-II was applied for multi-objective optimization, targeting flow rate and pressure efficiency. The model was able to successfully optimize the design, demonstrating a 1.78 m^3/min flow rate increase, and a 3% pressure efficiency enhancement.

Diverse modeling approaches have been presented aiming to analyze the performance, each presents trade-offs between accuracy and analysis cost. For instance, combined LES and FW-H approach provides high-fidelity predictions, however, it is computationally expensive. Contrariwise, the SST-SAS model offers a more practical balance with significantly lower resource demands. Moreover, CFD technique using SST k-ω and Ansys-CFX have proven reliable for performance evaluation, particularly when considering hub and blade design variations. Overall, while high-fidelity models offer comprehensive insights, hybrid and surrogate techniques provide time- and cost-effective alternatives for iterative design process.

3.2 Optimization Approaches

The numerous and interconnected design parameters of the axial flow fan make the design optimization complex task, demanding advanced techniques to attain desirable aerodynamic and aeroacoustics performance. Recently, surrogate-based optimization techniques, such as radial basis function (RBF) and Kriging models, are integrated with genetic algorithms for efficient exploration with minimum CFD runs [45]. Advanced hybrid techniques combining Expected Improvement with Kriging have also demonstrated strong promise in design [46]. Modern frameworks employ active subspaces, sparse polynomial chaos expansion, and Kriging to lessen model complexity while conserving the accuracy [47].

Ding, Wang [23] adopted a multi-objective optimization method linking Latin Hypercube Design (LHD), Computational Fluid Dynamics (CFD), and a Dendrite Net (DD) as a surrogate model to reduce computational cost. The DD model is trained on CFD to capture the relationship between design variables and performance metrics. The developed model is then combined with the Non-Dominated Sorting Genetic Algorithm II to efficiently search for optimal fan designs. Results showed that the developed approach enabled accurate and fast optimization of the performance with significantly reduced CFD evaluations. Gebert [48] used a multi-physics parametric optimization approach for designing a shrouded mixed-flow fan. By integrating structural deformation analysis into the design loop, the technique ensured more efficient and precise optimization compared to sequential approaches.

Li, Chen [49] developed 3D curvature control optimization technique by integrating Shell, Python, and Fortran scripts within a Linux framework. It comprises user-defined geometry, an optimization script, and the Dakota module, which manages the optimization using genetic algorithms. The technique considered optimizing camber line curvature to enhance the performance. Results confirmed the precision and efficiency of the technique in reducing radial secondary flow, shock losses, and delaying layer separation.

A recent study by Sun, Wu [50] employed genetic algorithms combined with artificial neural networks to optimize blade design parameters, including camber, chord length, stagger angle, and thickness to maximize efficiency. The technique enables efficient exploration, leading to improved efficiency. Results confirm a 7.43% efficiency improvement, highlighting the effectiveness of the technique for energy-saving applications.

Studies stress that advanced optimization techniques are vital due to its complexity of axial fan design. To minimize computational effort, surrogate models like Kriging and RBF are usually linked with genetic algorithms, facilitating exploration with minimal CFD runs. Moreover, hybrid approaches offer good balance between accuracy and cost. For example, using Dendrite Net with LHD and NSGA-II allows fast yet reliable optimization. In contrast, multi-physics methods which integrate structural impact ensure higher fidelity but are more computationally intensive. Script-based curvature control and neural network techniques enhance precision and aerodynamic efficiency, however, these require greater resources.

4. Comparative Summary of Reviewed Studies

To consolidate the key findings of this review, Table 2 delivers a summary of the most important and representative works reviewed throughout the paper. These studies encompass a variety of optimization strategies including geometric modifications, and advanced modeling approaches for small axial flow fans. The table highlights the key objectives, methods, and key outcomes of each study, offering a concise comparative reference for future designers. This aims to facilitate clearer insights into the limitations, progress, and promising directions

Table 2. Summary of main reviewed studies, highlighting the key methodology, focus, and significant findings of each contribution

References	Year	Research Method	Remarks	Results
Diao, Ge [6]	2023	Simulation and Experimental	The effects of two-sided winglets (TSW), drag winglets (SSW), and pressure winglets (PSW) were studied using different approaches	All winglets effectively reduced tip leakage in Z1 and Z2 and stopped its propagation in Z3, and overall, all studied configurations showed improved performance in terms of noise reduction

Table 2. Continue

References	Year	Research Method	Remarks	Results
Tutar and Kam [7]	2025	Simulation	Effect of airfoil geometry on propeller performance using a straight-tip airfoil and modified oscillation angle.	The results showed improved efficiency when using a curved wing.
Abdul Hussain [8]	2020	Simulation and Experimental	Study the effect of different aileron tip bend angle and leading edge twist angle.	The results showed that the wingtip bend angle and the twist angle have a distinct effect on the flow behavior.
Fakhry and Murad [14]	2024	Simulation and Experimental	Changing the number of fan blades	Increase in efficiency of up to 9%, while also affecting noise, energy consumption
Rafi Rajabi [15]	2017	Simulation	The effect of several design parameters, including the number of blades	The results showed a 32% increase in outlet pressure when the number of blades increased from 4 to 6, but the effect on flow rate was limited.
Adjei, [17]	2021	Simulation	Considered two axial flow fans configurations with 10 and 12 blades.	The optimization analysis revealed that the 12-blade design achieved a 1.32% efficiency gain compared to 1.05% efficiency improvement for the 10-blade configuration.
Liu, Xiong [18]	2021	Simulation	Study of the direction of the blades' bending, number of blades, and their shape was conducted	The results showed an optimal design consisting of seven forward-curved blades with a 9.5-degree tip angle, a 58.0-degree root angle, and a low-drag aerodynamic wing. This achieved a 3.86% increase in air volume compared to the original fan
Krömer, Moreau [19]	2018	Simulation	The performance of forward-tilted, backward-tilted, and non-tilted blade designs was studied	The results showed that the forward-tilted fan had higher aerodynamic efficiency and lower noise levels
Tan, Dong [22]	2023	Simulation and Experimental	Investigation of fans with a machined blade design featuring a wavy leading edge and a wingtip inspired by the shape of a gull	The improved design was shown to improve aerodynamic performance and increase pressure efficiency by 2.28% compared to the original blade.
Ding, Wang [23]	2022	Simulation and Experimental	A new blade design was studied based on rational quadratic Bézier curves, which were used to determine the blade angle and curvature.	The results showed that the improved blade exhibited increased efficiency and pressure coefficient by 5.44% and 2.47%, respectively.
Li, Lu [24]	2022	Simulation and Experimental	A dual numerical and experimental approach was used to evaluate the effect of three curvature parameters, radial position, circumferential starting angle, and curvature degree, on tip leakage	The study reported improved efficiency and reduced noise as a result of curvature. The optimal configuration—90% radial position, 10° angle, and 8% curvature—was found to reduce broadband noise by 0.54–2.68 dB

Table 2. Continue

References	Year	Research Method	Remarks	Results
Liu, Jiang [30]	2021	Simulation and Experimental	An open-cell metal foam casing	Reduced the noise level by 10 db. and reduced flow momentum change across the blade.
Öztürk, Çetin [33]	2019	Simulation	Using a numerical approach, it was found that adjusting the fan position to 56-60% of the shroud and reducing the tip clearance to 6 mm	Improves the mass flow rate by 8% and improves the mass flow by 7%; respectively
Köten [35]	2018	Simulation	Conducted a CFD-based optimization of a 16-blade axial fan, focusing on parameters including shroud angle and other key geometric features	Improvement in performance, with the flow rate increasing from 1.3 to 2.78 m^3/s and static pressure decreasing from 87.79 to 54.59 Pa

5. Conclusion

This review summarized recent advancements in optimizing axial flow fan performance by modifying key design parameters such as winglets, blade geometry, casing, and tip clearance. These elements were shown to significantly affect efficiency, noise, and flow behavior. Winglets efficiently reduce tip leakage, improving aerodynamic efficiency. More blade number is found to raise pressure, and improve the performance. Moreover, simple blade shapes improve flow and reduce noise, whereas advanced designs offer greater gains at higher cost. Although reducing tip gap boosts efficiency, it has some limitations; alternatively, air injection shows promising potential. Finally, well-designed casing and ducts has been proven to offer further flow enhancement and noise reduction.

The study also examined modeling and optimization methods, showing a shift from traditional experiments to advanced tools like CFD and surrogate models. While each technique involves trade-offs in accuracy and cost, hybrid methods offer a practical balance for efficient design. Studies reported that high-fidelity approaches like LES, and Fw-H provide detailed insights but are resource-intensive. Though, SS, SAS, and CFD with SST k-ω offer reliable efficient alternatives. Similarly, optimization techniques like Kriging and RBF combined with genetic algorithms enable effective design exploration with reduced CFD runs. By combining insights from both design and analysis perspectives, the review delivers a valuable reference for researchers and engineers working toward more efficient fan systems.

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REFERENCES

[1] Romik, D., I. Czajka, and A. Gołaś. “Numerical Study of the Effect of Selected Design Parameters on the Aerodynamic Noise of a Radial Fan.” Institute of Rock Mechanics Polish Academy of Sciences 18 (2016): 43–52.
[2] Engel, Z. Environmental Protection against Vibrations and Noise. Warsaw: PWN, 2001.
[3] Corsini, A., et al. “Aeroacoustic Assessment of Leading Edge Bumps in Industrial Fans.” In FAN 2015—International Conference on Fan Noise, Technology and Numerical Methods. Institution of Mechanical Engineers, 2015.

[4] Yadegari, M., et al. “Reducing the Aerodynamic Noise of the Axial Flow Fan with Perforated Surface.” Applied Acoustics 215 (2024): 109720.

[5] Ryu, S.-Y., et al. “Development of a Performance-Based Design Technique for an Axial-Flow Fan Unit Using Airfoil Cascades Based on the Blade Strip Theory.” Applied Sciences 14, no. 2 (2024): 804.

[6] Diao, L., et al. “Effect of Tip Winglet Position on Tip Flow and Noise of Axial Flow Fan.” Heliyon 9, no. 8 (2023).

[7] Tutar, M., and J. B. Cam. “Computational Design of an Energy-Efficient Small Axial-Flow Fan Using Staggered Blades with Winglets.” International Journal of Turbomachinery, Propulsion and Power 10, no. 1 (2025): 1.

[8] Abdulhussain, M. A. “Studying the Effect of Geometric Parameters of Axial Fan Twisted Blades Inside Different Cross-Sectional Ducts.” Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 65, no. 1 (2020): 140–158.

[9] Chan, L., et al. “The Performance Improvement of Axial Flow Fan with Large Tip Clearance by Using Winglet.” In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2018.

[10] Shivaramaiah, S., et al. “Effect of Rotor Tip Winglet on the Performance and Stability of a Transonic Axial Compressor.” In Gas Turbine India Conference. American Society of Mechanical Engineers, 2017.

[11] Bizjan, B., et al. “Energy Dissipation in the Blade Tip Region of an Axial Fan.” Journal of Sound and Vibration 382 (2016): 63–72.

[12] Zhang, C., et al. “Effect of Blended Blade Tip and Winglet on Aerodynamic and Aeroacoustic Performances of a Diagonal Fan.” Aerospace Science and Technology 98 (2020): 105688.

[13] Jung, J. H., and W.-G. Joo. “Effect of Tip Clearance, Winglets, and Shroud Height on the Tip Leakage in Axial Flow Fans.” International Journal of Refrigeration 93 (2018): 195–204.

[14] Fakhari, S. M., and H. Mrad. “Optimization of an Axial-Flow Mine Ventilation Fan Based on Effects of Design Parameters.” Results in Engineering 21 (2024): 101662.

[15] Rajabi, N., R. Rafee, and S. Frazam-Alipour. “Effect of Blade Design Parameters on Air Flow through an Axial Fan.” International Journal of Engineering 30, no. 10 (2017): 1583–1591.

[16] Corona Jr, J. J., et al. “The Best Efficiency Point of an Axial Fan at Low-Pressure Conditions.” Advances in Mechanical Engineering 13, no. 3 (2021): 16878140211001188.

[17] Adjei, R. A., et al. “Multidisciplinary Design Optimization for Performance Improvement of an Axial Flow Fan Using Free-Form Deformation.” Journal of Turbomachinery 143, no. 1 (2021): 011003.

[18] Liu, Z., Y. Xiong, and Y. Chen. “Simulation and Optimum Design of Small Fan for Animal House by CFD.” In Journal of Physics: Conference Series. IOP Publishing, 2021.

[19] Krömer, F. J., S. Moreau, and S. Becker. “Experimental Investigation of the Interplay between the Sound Field and the Flow Field in Skewed Low-Pressure Axial Fans.” Journal of Sound and Vibration 442 (2019): 220–236.

[20] Bharanitharan, K., and S. Senthilkumar. “Prediction of Aerodynamic Performance of Axial Fan with Leading Edge Serration Using Computation Fluid Dynamics.” In IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020.

[21] Zhang, W., et al. “The Influence of Axial-Flow Fan Trailing Edge Structure on Internal Flow.” Advances in Mechanical Engineering 10, no. 11 (2018): 1687814018811745.

[22] Tan, J., et al. “Coupling Bionic Design and Numerical Simulation of the Wavy Leading-Edge and Seagull Airfoil of Axial Flow Blade for Air-Conditioner.” Journal of Applied Fluid Mechanics 16, no. 7 (2023): 1316–1330.

[23] Ding, Y., et al. “Multi-Objective Optimization for the Radial Bending and Twisting Law of Axial Fan Blades.” Processes 10, no. 4 (2022): 753.

[24] Li, B., et al. “Effects of Outer Edge Bending on the Aerodynamic and Noise Characters of Axial Fan for Air Conditioners.” Processes 10, no. 4 (2022): 686.

[25] Moghadam, S. M. A., M. Meinke, and W. Schröder. “Analysis of Tip-Leakage Flow in an Axial Fan at Varying Tip-Gap Sizes and Operating Conditions.” Computers & Fluids 183 (2019): 107–129.

[26] Chen, L., et al. “Influence of Air-Guided Ring Structure on Performance of Axial-Flow Fan.” In Journal of Physics: Conference Series. IOP Publishing, 2024.

[27] Lee, H., K. Park, and H. Choi. “Experimental Investigation of Tip-Leakage Flow in an Axial Flow Fan at Various Flow Rates.” Journal of Mechanical Science and Technology 33 (2019): 1271–1278.

[28] Pereira, M., et al. “Improved Aerodynamics of a Hollow-Blade Axial Flow Fan by Controlling the Leakage Flow Rate by Air Injection at the Rotating Shroud.” Entropy 23, no. 7 (2021): 877.

[29] Moreau, S. “Turbomachinery Noise Predictions: Present and Future.” In Acoustics. MDPI, 2019.

[30] Liu, N., et al. “Effect of Porous Casing on Small Axial-Flow Fan Noise.” Applied Acoustics 175 (2021): 107808.

[31] Czwielong, F., et al. “Influence of a Micro-Perforated Duct Absorber on Sound Emission and Performance of Axial Fans.” Applied Acoustics 174 (2021): 107746.

[32] Li, Z., Q. Wang, and T. Wang. “Analysis of Axial-Flow and Tilt Aerodynamic Characteristics of Ducted Propellers.” Open Journal of Applied Sciences 15, no. 3 (2025): 700–714.

[33] Öztürk, İ., C. Çetin, and M. M. Yavuz. “Effect of Fan and Shroud Configurations on Underhood Flow Characteristics of an Agricultural Tractor.” Engineering Applications of Computational Fluid Mechanics 13, no. 1 (2019): 506–518.

[34] Huang, B., et al. “Numerical Investigation on the Aerodynamic and Aeroacoustic Characteristics in New Energy Vehicle Cooling Fan with Shroud.” Processes 12, no. 2 (2024): 333.

[35] Köten, H. “CFD Modeling and Multi-Objective Optimization of the Axial Fan Parameters.” Journal of Energy Systems 2, no. 4 (2018): 137–144.

[36] Yang, X., et al. “Numerical Simulation and Experimental Research on the Aerodynamic Performance of Large Marine Axial Flow Fan with a Perforated Blade.” Journal of Low Frequency Noise, Vibration and Active Control 37, no. 3 (2018): 410–421.

[37] Podgaietsky, G. L., M. L. de Oliveira, and C. J. Hermes. “Model-Based Efficiency Mapping and Parametric Analysis of Low-Pressure Axial Fans.” International Journal of Refrigeration 144 (2022): 136–144.

[38] Castegnaro, S. “An Aerodynamic Method to Design Low-Speed Axial Fans with Imposed Diameter and Rotor Speed.” 2017.

[39] Mo, J.-o., and J.-h. Choi. “Numerical Investigation of Unsteady Flow and Aerodynamic Noise Characteristics of an Automotive Axial Cooling Fan.” Applied Science 10, no. 16 (2020): 5432.

[40] Luo, B., W. Chu, and H. Zhang. “Tip Leakage Flow and Aeroacoustics Analysis of a Low-Speed Axial Fan.” Aerospace Science and Technology 98 (2020): 105700.

[41] Park, K., et al. “Effect of a Casing Fence on the Tip-Leakage Flow of an Axial Flow Fan.” International Journal of Heat and Fluid Flow 77 (2019): 157–170.

[42] Jung, J. H., and W.-G. Joo. “The Effect of the Entrance Hub Geometry on the Efficiency in an Axial Flow Fan.” International Journal of Refrigeration 101 (2019): 90–97.

[43] Wu, Y., and D. Huang. “Optimization Design of Axial Fan Blade.” Journal of the Chinese Institute of Engineers 42, no. 6 (2019): 473–478.

[44] Yang, K., et al. “Energy Efficiency Optimization Design of a Forward-Swept Axial Flow Fan for Heat Pump.” Frontiers in Energy Research 9 (2021): 700365.

[45] Zhou, S., et al. “Performance Optimization Design of Diagonal Flow Fan Based on Ensemble of Surrogates Model.” Applied Sciences 12, no. 19 (2022): 9732.

[46] Lagnoux, A., et al. “Expected Improvement Applied to an Industrial Context—Prediction of New Geometries Increasing the Efficiency of Fans.” arXiv preprint arXiv:2410.21830 (2024).

[47] Adjei, R. A., and C. Fan. “Multi-Objective Design Optimization of a Transonic Axial Fan Stage Using Sparse Active Subspaces.” Engineering Applications of Computational Fluid Mechanics 18, no. 1 (2024): 2325488.

[48] Gebert, D. “A Novel Axial Fan Concept Developed Using Parametric Optimization.” 2022.

[49] Li, J., et al. “Aerodynamic Design and Optimization of a High-Loaded Axial Fan Stage Using a Curvature Control Method.” Journal of Mechanical Science and Technology 33, no. 8 (2019): 3871–3883.

[50] Sun, T., et al. “Aerodynamic Performance and Flow Optimization of Axial Fan Based on the Neural Network and Genetic Algorithm.” Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 238, no. 7 (2024): 1129–1147.