This highlight refers to the PhD Thesis by Jie Wang (2021)

Design for high efficiency of low-pressure axial fans: use of blade sweep and vortex distribution

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Fans to drive air flow are a crucial element in many processes in industry, in the built environment, and in domestic applications, on a wide range of scales. Many applications are related to heating/cooling, e.g. in processing equipment, energy conversion plants, in (computer) data-centres, in individual computers, and in air conditioning systems. Fans are part of the "family" of rotating flow equipment. The flow is generated by a set of rotating elements, referred to as blades, of particular shape, and cross section. Fans are classified (see Figure 1) according to the direction of the generated flow relative to the axis of rotation of the blades (centrifugal versus axial), the pressure difference over the fan (low versus high), the structural integration, (free or ducted), and the blade characteristics such as length of the blades relative to the central hub, the orientation of the blades relative to the straight radius from hub to top, and the shape of the blades (sweep, dihedral).

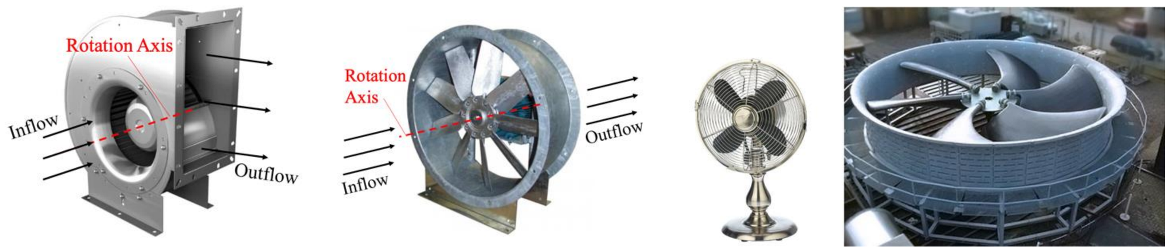

Figure 1: Examples of fans. From left to right: centrifugal fan, axial fan, free fan, ducted fan [1].

Increasingly strict requirements on energy losses in all processes are a strong driver for the continuous further optimization of fans, where at the same time minimizing the generated noise (environmental impact) is of increasing importance. Fan design is continuously progressing and for many cases quite adequate design criteria/rules exist using the main understanding of the various aspects of the rotating flow. However, nowadays an efficiency increase of only a few percent is already relevant, which may only be achieved by a better detailed understanding and control of the flow field locally in various regions, i.e. near the hub, or near the edges of the blade, like avoiding local backflow or flow separation, in relation to the (blade shape) design parameters.

In this research emphasis has been on the optimization of low pressure, low hub-to-tip ratio (HTR) cooling fans using Computational Fluid Dynamics (CFD) simulations by investigating the effects of sweep, dihedral and skew of the blades on the aerodynamic performance, and subsequently, to develop an optimal vortex distribution design method for high efficiency of such fans.

First the computational method was developed and its predictions were validated with results of experiments for a reference configuration of an axial fan with small HTR, see Figure 2. Secondly, extensive computations on configurations with varying blade orientation and shape were performed. Some characteristic results are shown in Figure 3.

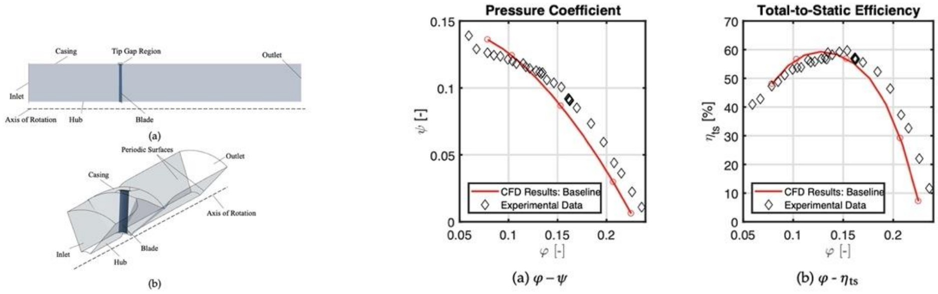

Figure 2: Computational domain in CFD (left) around fan blade, and validation result, of pressure coefficient (centre), and total to static efficiency (right), as a function of dimensionless parameter representative of volume flow.

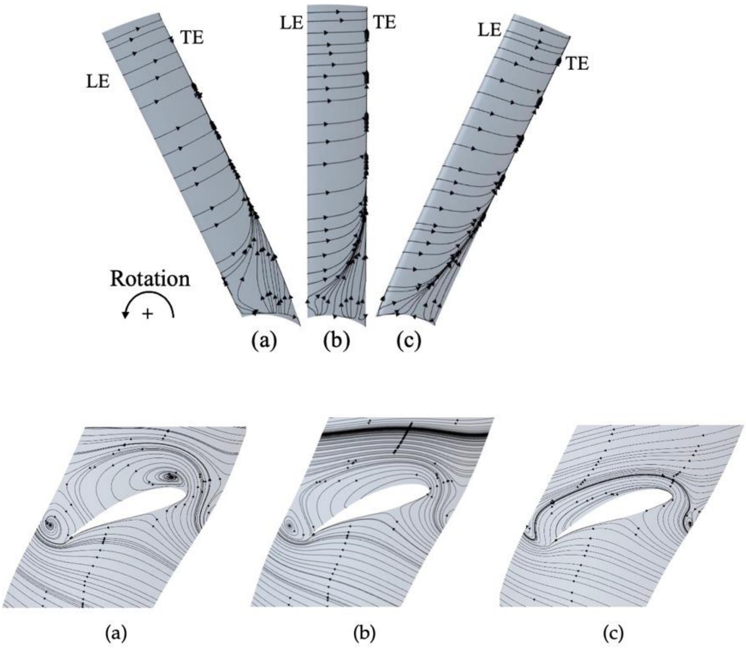

Figure 3: Top: Boundary Layer streamlines near the blade suction side surface. Bottom: velocity streamlines based on the relative velocity in the Blade-to-Blade plane at 2.5% spanwise (a) 25° Forward Sweep, (b) Baseline, and (c) 25° Backward Sweep. All for flow coefficient at Best Efficiency Point BEP. "LE" stands for Leading Edge, "TE" stands for Trailing Edge.

The CFD results have shown that forward sweep of blades can give improved aerodynamic performance, especially for the total-to-total efficiency. Effects of sweep, dihedral and skew in axial and circumferential directions (in forward and backward direction) on the aerodynamic performance of small HTR fans were also investigated, with a linear stacking line. The CFD results show that forward sweep and circumferential skew are beneficial for higher total-to-total efficiency and that higher total-to-static efficiency can be obtained by forward dihedral and axial skew. The backward shape variety generally gives detrimental aerodynamic effects. Forward sweep and circumferential skew shorten the radial migration path, but more flow separation is present near the hub. With forward dihedral and axial skew, the backflow region is reduced in radial size and axial extent, but a more significant hub corner stall region is found. The pressure reduction due to sweep and dihedral is more limited than what could be expected from wing aerodynamics.

Finally, the vortex distribution (polynomial in spanwise coordinate) and the HTR have been determined by maximizing the total-to-static efficiency of a baseline axial fan with small HTR. For free vortex designs, analytical expressions for the maximum total-to-static efficiency and the optimal HTR have been formulated. By combining the vortex distribution with a suitable choice for the spanwise lift coefficient distribution, fan blade designs have been established. The CFD results for these designs show that the free and the polynomial vortex distribution designs satisfy the desired pressure rise, with significantly improved total-to-static and total-to-total efficiency (maximum improvement by 3.9% and 4.6%, respectively). Flow field analyses show that no flow separation is present in the blade-to-blade plane, except near the hub region. For designs with small HTR, some backflow is present downstream of the rotor which affects the flow separation near the hub blade section.

Overall, the results presented in the PhD thesis contribute to better understanding of small HTR axial fan aerodynamics. The results can be applied to the design of low-pressure axial fans with higher efficiency.

Reference

Wang, J. (2021) Design for High Efficiency of Low-Pressure Axial Fans: Use of Blade Sweep and Vortex Distribution, PhD Thesis, University of Twente, Enschede, the Netherlands, ISBN 978-90-365-5299-8, DOI 10.3990/1.9789036552998