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Optimization of an axial fan for air cooled condensers

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Abstract

We report on the low noise optimization of an axial fan specifically designed for the cooling of CSP power plants. The duty point presents an uncommon combination of a load coefficient of 0.11, a flow coefficient of 0.23 and a static efficiency $\eta_{stat} > 0.6$. Calculated fan Reynolds number is equal to Re = 2.85 x 10^7. Here we present a process used to optimize and numerically verify the fan performance. The optimization of the blade was carried out with a Python code through a brute-force-search algorithm. Using this approach the chord and pitch distributions of the original blade are varied under geometrical constraints, generating a population of over 200000 different possible individuals. Each individual was then tested using an axisymmetric Python code. The software is based on a blade element axisymmetric principle whereby the rotor blade is divided into a number of streamlines. For each of these streamlines, relationships for velocity and pressure are derived from conservation laws for mass, tangential momentum and energy of incompressible flows. The final geometry was eventually chosen among the individuals with the maximum efficiency. The final design performance was then validated through with a CFD simulation. The simulation was carried out using a RANS approach, with the cubic k-ε low Reynolds turbulence closure of Lien et al. The numerical simulation was able to verify the air performance of the fan and was used to derive blade-to-blade distributions of design parameters such as flow deviation, velocity components, specific work and diffusion factor of the optimized blade. All the computations were performed in OpenFOAM, an open source C^{++}- based CFD library.

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Keywords: Axial flow fan; low-noise optimization; reduced-order simulations; OpenFOAM.

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Nomenclature

ch	chord length	[m]	Q	volume flow rate	[m^3/s]
ξ	pitch angle	[deg]	C_x	mean axial velocity	[m/s]
N_{ref}	number of reference sections	[-]	c_{ax}	axial velocity	[m/s]
K	number of nodes	[-]	U	rotation velocity	[m/s]
SPL	sound pressure level	[dB]	w	relative velocity	[m/s]
ψ	load coefficient	[-]	β	flow angle	[deg]
φ	flow coefficient	[-]	δ	deflection	[deg]
$\eta_{tot,stat}$	total static efficiency	[-]	W	specific work	[J/Kg]
$p_{tot,stat}$	total static pressure	[Pa]	CSP	concentrating solar power	[-]

1. Introduction

In regions where fresh water is not available, axial fans inside power plants can be used to force air into air-cooled condensers to provide fresh air. In particular, fans used in this kind of application are typically very large (with diameters > 7m) and slow (100÷200 rpm), providing a very small pressure rise (<250 Pa) at very high mass flow rates (>250 m^3/s). As these fans are typically working in large arrays of hundreds of devices, one key aspect in their design is related to noise emissions. For these fans it is possible to apply flow-control strategies to reduce noise related to tip-leakage-vortex, such as tip-endplates [1-3], or to control the wake such as leading edge bumps [4]. Another source of noise, typically related to trailing edge bluntness can be controlled by optimization of the twist and chord distributions of the blade [5]. To this aim here we present an optimization process based on an axial-symmetric Python code (AxLab) that applies the model described in [5] to compute trailing edge noise. The optimization process relies on brute force algorithm that explores all the possible combinations of pitch and chord spanwise distribution and generates a population of 200000 individuals to be tested with AxLab to verify their air performance and trailing edge noise with Fukano's model [5]. Finally CFD computations are used to verify the design point performance of the individual chosen among those with better performance. Then noise reduction was verified by post-processing the flow field and re-applying the model in [5] to numerical results.

2. Optimization

Numerical design optimization was used to minimize the trailing edge noise of a single stage axial fan. Two geometric variables were varied (chord and pitch distribution) in order to provide a wide database of optimized individuals, that can be used to search for solutions that can satisfy different geometrical constraints. Imposed constraints assured the same total pressure rise delivered from the baseline fan. A blade element model was used to evaluate the aerodynamic performance of the fan and trailing edge noise. One potential design was selected from the set of simulations and the comparison with the baseline blade showed that it is possible to obtain an individual that both can reduce noise generation and increase the total to total efficiency.

2.1. Methodology

A relevant noise source in the baseline fan is produced by the trailing edge, as with these large fans trailing edge bluntness in unavoidable to respect mechanical constraints. Trailing edge noise is caused by the vorticity shed from the trailing edge which produces local lift fluctuations. In the present study, a model for the trailing edge noise was combined with an aerodynamical model for rotor-only fans. For a given rotor geometry and fan operating conditions, the analysis tool provided the trailing edge noise and flow characteristics (e.g., velocity triangles, fan efficiency and pressure rise). Numerical model used for the generation of the database is implemented in AxLab, a tool for performance analysis of ducted axial fans. This software is based on a blade element axisymmetric principle. The rotor blade is divided into a number of streamlines. For each of these streamlines relations for velocity triangles and pressure are derived from incompressible conservation laws for mass, tangential momentum and energy. The complexity of 3D