Tutorial handout of the ASME Turbo Expo 2020
Turbomachinery Technical Conference and Exposition
Turbo Expo 2020
June 22-26, 2020, London, England

GT2020-15888

A BASIC INTRODUCTION TO THE AERODYNAMIC DESIGN OF AXIAL FLOW INDUSTRIAL FANS

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OBJECTIVE

The legislation on energy efficiency already existing in many countries [2], and in the process to be implemented in many others (e.g., in the U.S. [3]), establishes limits that become more stringent from year to year also in the field of the industrial turbomachines. Accordingly, axial-flow fan manufacturers are working for a continuous improvement of the aerodynamic and acoustic design of their products. This tutorial of basics focuses on several aspects related to the aerodynamic design of axial-flow industrial fans with the aim to present an overview of the entire logical flow-chart of an industrial machine development. The special features of different fan types and the selection of the proper configuration of axial-flow fan, are followed by the presentation of aerodynamic design techniques applied to the design of a 800mm tube-axial fan. Finally, the typical issues related to real fans applications and how to adjust for them are considered.

TUTORIAL OUTLINE

Large industrial fans are applied in many processes: power generation, chemical industry, cement plant, steel and non-ferrous materials production, other productions (paper, glass, water oxygenation), industrial ventilation (mining, highway and metro tunnels, naval applications, turbogas ventilation) [3]. Largest units involve powers in the order of 1-10MW, and many of them use axial-flow machines to handle "clean" air (i.e., air with very limited content of dust, particles, condensed droplets…).

Given the widely different requirements, quantified by "ad hoc" performance parameters [4, 5], Axial-flow fans feature several configurations and arrangements ranging from single to multi-stage units, from free propellers to ducted fans, from tube-axial to vane-axial layouts [6].

The Cordier approach, which is widely used for many turbomachine types [7], was originally conceived for fans and hydraulic pumps [8] and aids the rational classification and the basic sizing of these machines in terms of the dimensionless specific speed and specific diameter parameters directly derived from the practical application of the fluid-dynamic similarity principles [9].

As per other turbomachine types, CFD tools are widely used to support the design of axial-flow fans. In particular, when either the preliminary design or the global aerodynamic performance assessment is concerned, RANS-CFD is now considered the standard tool. It supports most of the designer tasks by means of models featuring different extension of the fluid domain and different complexity of the underlying physical sub-models [10].

However, the core of industrial fan preliminary design, although aided by the fluid-dynamic simulation, still relies on in-depth knowledge of basic principles of axial-flow fan aerodynamics and designer experience. Accordingly, different practical approaches to basic sizing of the fan are available [11, 12, 13]. They permit the designer to obtain the meridional geometry of the fan as well as the spanwise distribution of the velocity triangles, once the vortex distribution (i.e., the blade loading concept) has been chosen. In the field of axial-flow industrial fans, free vortex, forced vortex or, more generally, arbitrary vortex distributions of the blade loading are not considered academic examples best suited to theoretical lesson for BSc students, but design solutions that must be properly applied to satisfy different performance requirements [3, 14, 15].

Especially when the hub-to-tip ratio becomes small, arbitrary vortex design rotors permit to obtain a good trade-off between compactness and efficiency [9] and, accordingly, they are frequently embedded into industrial fans. Ad hoc methods to design such rotors [16, 17, 18] may take advantages from blade sections specifically conceived for fans [19].

The optimization of either aerodynamic or acoustic performance suggests blade geometries embedding non radial staking line concepts. Methods to apply some of these concepts already in the preliminary design phase have been recently made available for the design of industrial fans [20, 21], whereas new researches are investigating of the possibility to obtain simple formulae able to preliminary check new designs for possible acoustic and vibrational issues [22].

After completion of the meridional geometry and blade design, experimental testing complying with the ISO standard [3] permits one to verify the aerodynamic global performance of new designs on small scale prototypes [23] also obtained by rapid prototyping techniques [24]. Careful attention must be payed to Scale and related Reynolds number effects [25, 26].

The design of industrial fans needs to cope with many issues arising from installation and application of the fan in the real operating environment. To illustrate the effect of installation on fan performance, the tutorial specifically considers the application of large diameter cooling fans. These so-called system effects include tip clearance [27], hub effects [28], inlet distortion and mutual interference between fans operating "in battery" arrangements [29].

Methods based on simplified CFD simulation techniques were suggested to deal with these issues [30]. The two methods considered are referred to as the pressure jump (PJM) and actuator disc methods (ADM). Although both methods have been applied successfully, they both exhibit shortcomings that have to be considered when evaluating the results obtained from the CFD models.

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