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Experimental study of the three-dimensional flow field in cross-flow fans

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ABSTRACT

High-resolution PIV measurements of the flow field inside cross-flow fans have been performed in planes normal and parallel to the fan axis, both outside and inside the impeller. The well known difficulties in obtaining the optical access inside the impeller have been overcome by allowing the internal flow planes to be illuminated by the laser light sheet or shot by the CCD camera through the moving blade vanes. Measurements have been performed in two cross-flow fans having the same two-module impeller but casing geometries based on very different design concepts. PIV data in planes normal to the rotor axis show a strong correlation between vorticity distribution and turbulent shear stresses inside the eccentric vortex of each fan. Furthermore, they provide useful elements to explain the very different performance of the two fans evidenced by their characteristic curves. Measurements in planes parallel to the impeller axis show that wide three-dimensional recirculation structures develop near the casing end walls at the discharge of the fans. These mean flow structures are responsible for the backflow into the end portions of the impeller of part of the discharged fluid, which is then transported axially by the eccentric vortex towards the rotor central disc before being discharged once again outside the impeller. In the case of cross-flow fans including few rotor modules, the existence of significant axial velocity components inside the eccentric vortex can alter substantially the flow picture, common in the current literature, resulting from 2-D numerical models or measurements performed in a single transverse plane of the fan.

1. Introduction

Cross-flow fans (CFF) are used extensively in ventilation and air conditioning industry due to their compactness, shape, quiet operation, and ability to provide high pressure coefficients.

The CFF consists of a drum-like rotor with forward curved blades, placed in a casing that includes a rear wall (or volute), a vortex wall (or stabilizer) and two end walls (Fig. 1). The rotor is formed of modules, separated by discs, the length of which is usually equal to the impeller outer diameter. The flow rate delivered by the fan can be increased by simply extending the rotor lengthwise, i.e., by adopting a larger number of modules, without affecting the pressure rise. The rectangular geometry of the inlet and outlet sections, the easily scalable diameter to fit the available space and the adjustable length to meet the flow rate requirements for the specific application make the CFF an extremely versatile turbomachine.

In spite of their simple construction, the cross-flow fans are affected by a complicated internal flow. Unlike radial turbomachines, the main flow moves transversely across the impeller, passing the blading twice before being discharged. Furthermore, a steady eccentric vortex is formed that runs parallel to the rotor axis with the same rotation direction. As shown by Eck [1], this vortex and the associated through-flow develop also for the impeller rotating in an unbounded flow, i.e., without the casing, but in that case they tend to orbit about the rotor axis. The vortex wall is used just to lock the flow by stabilizing the position of the eccentric vortex on the discharge arc of the rotor.

The early studies of Eck [1], Porter and Markland [2], Murata and Nishihara [3,4], and the more recent contributions from Lazzaretto et al. [5], Toffolo et al. [6], and Toffolo [7], show that the casing design and the flow coefficient strongly influence the vortex dimension, position and strength, which in turn affect fan performance and acoustic emissions. In particular, the systematic and exhaustive experimental studies performed in [5] and [6] showed the effects of the most important geometric parameters on the fan performance and led the authors to establish the guidelines for the optimized design of the casing [8].

The complex flow field inside the cross-flow fans has been investigated by many authors. Early theoretical flow models based on the assumption of potential flow [9–11] showed limited predictive capabilities, mainly because the viscous effects play a leading role in determining the structure and strength of the eccentric vortex. Indeed, the steady vortex is fed with vorticity by the vortices shed from the impeller blades, while turbulent diffusion is responsible for the vorticity removal from the recirculating flow region, as shown by Tsurusaki et al. [12]. More recently, Computational Fluid

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