Active control of the leakage flow by air injection into the rotational shroud or the fixed carter of an axial fan composed of hollow blades

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1 Introduction

In recent years, more and more investigations on turbomachinery deal with the control by tip injection. In fact, this type control could improve different aspects of the device which could not be enhanced by the geometry. By using injection upstream of the rotor, Weigl et al. [1] succeeded to stabilize rotating stall and surge in a transonic compressor which provided an enlargement of the operating range. Rhee et al. [2] increased the lift of a hydrofoil by injection control. Eberlinc et al. [3, 4, 5] experimentally rose of approximatively 6% the pressure of an axial fan composed of hollow blades. This gain was due to a free jet at the trailing edge of the blades. In fact, the free jet increased the velocity and consequently reduced the adverse pressure gradient in the boundary layer. Wang and Zhao [6] experimentally and numerically investigated a transonic turbine cascade with different trailing edge ejection. As Eberlinc et al., the authors successfully reduced the vortex at the trailing edge of the blades.
This paper focuses on the injection used to reduce the phenomenon of leakage flow occurring at the blade tip. This flow driven by the pressure difference between the pressure side and suction side is responsible for important energy dissipations.That is why many authors have sought to reduce this phenomenon. Neuhaus and Neise [7] attempted to reduce the leakage flow of an axial fan by applying active flow control in the tip region of the impeller. They injected air in the opposite direction of the flow by slit nozzles flush mounted in the inner casing wall. By this process, the authors succeeded to shift the stall point towards lower flow rates and to enlarge by 62% the usable range of the fan characteristic. They also increased the pressure of 28% and the efficiency by about 10%. Hamik and Willinger [8] analytically and numerically investigated the concept patented by Auxier [9] in 1995. The idea is to connect the blade leading edge to the blade tip by an internal channel. Due to the pressure difference, a jet is injected to the tip gap and blocks the leakage flow. With an injection mass flow rate of 0.5% of the mass flow, they predicted a performance improvement which is independent of the tip gap width. Hu et al. [10] applied the concept proposed by Auxier to an axial fan and

experimentally investigated the interaction between the tip leakage flow and the tip injection flow by a 2D-PIV. As expected, the authors observed a reduction of the leakage flow. However, the tip injection generated a flow phenomenon similar to Karman vortex street in the wake which exacerbate the complexity and non-stationarity of the flow.
In this study, active control by air injection in the tip clearance gap of an axial fan is experimentally investigated. A new methodology was developed to build hollow fan in which an internal flow could occur. The internal flow, generated by the compressed air system of the laboratory, exited the fan at the tip clearance in purpose to reduce the leakage flow. The results of this control by air injection are presented in this paper.

2 Experimental setup

The figure 1 represents the hollow fan (a) and the fan drive system (b). The fan used in this study was developed for automotive engine cooling system application. [**?**]. It was built in plastic material by a rotomolding process in order to make it hollow. The fan has six blades with a hub-to-tip radius ratio ($R_{\text{int}}/R_{\text{max}}$) equal to 0.337 and a the tip radius (R_{max}) equal to 179 mm. A specific drive system was built at the DynFluid laboratory of Arts et Métiers ParisTech in order to connect the compressed air system to the hollow fan. The internal flow generated by the compressed air exits at the fan periphery by 57 tip holes (figure 1 a). The internal flow circulation is represented from the compressed air system to the fan tip clearance by green arrows on figure 1 (b).

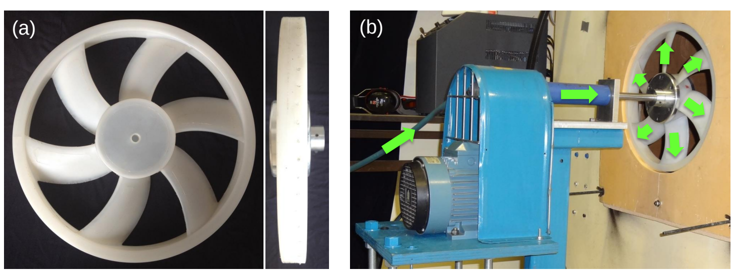

Figure 1: The hollow fan (a) and the fan drive system (b)

3 Results

Only the aerodynamic characteristic is represented in this extended abstract. The figure 2 shows the results obtained at three rotation speeds 1020, 1560, 2000 rpm for two configurations with and without air injection. The injection control was realized with an internal flow equal to 13.3% of the external volume flow. Each curve is the result of five measurement points. The air injection induced an increase in pressure difference regardless of the rotation speed. As the injection was realized in the purpose of controlling the leakage flow, the pressure increase is assumed to be a consequence of the secondary flow reduction. For $\phi = 0.065$, the increase varies from 18% to 25%

depending of the rotation speed, whereas at higher flow rate of about 0.1, it varies from 41% to 98%. These results could be explained by a better control of the leakage flow at $\phi = 0.065$ than at 0.1 as this phenomenon intensifies at higher flow rate [7].

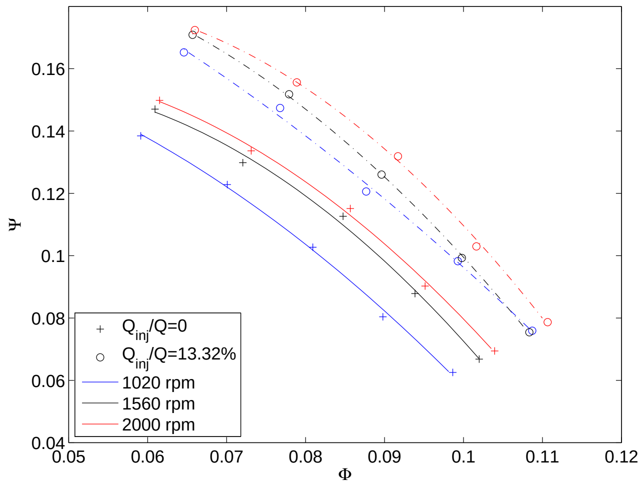

Figure 2: Comparison of aerodynamic characteristic of the axial fan for the case with and without internal flow and for 3 rotation speeds: 1020, 1560 and 2000 rpm

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