EXPERIMENTS ON PERFORATED BLADES AS A MEANS OF INCREASING FAN STABILITY

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Abstract. *The diagram lift coefficient versus incidence angle indicates a landing for perforated plate airfoils. The simplest way to study the effect of this observation on fan aerodynamics is to construct a rotor with perforated blades. This paper presents some experimental results concerning the evolution of flow parameters of an axial fan with perforated blades. The tests indicate more flattened characteristics for the slotted blading as compared to the classical blading. This means that the slotted blades produce an increase in fan stability.*

Keywords. *perforated plates, airfoil, blades, axial fan*

1. Introduction

Permeable plates have many practical applications in industry – as flow control devices in particular. However, sophisticated solutions are not usually employed in the design of fan blades, because economic factors require simplicity of construction. Hence, the present paper focuses on the aerodynamic behavior of some simple perforated plate airfoils having different degrees of permeability.

The design of fans needs special attention. An important objective of the present investigation is to add to the existing body of knowledge concerning the aerodynamics of special blades used in turbomachines, by means of some experimental results obtained by testing a special fan with slotted blades.

The results indicate that slotted airfoils are capable withstanding a much wider range of angles of attack than conventional ones. Thus, the slotted blades of an axial fan have a better stability than the classical ones.

2. Experiments on permeable airfoils

Permeable airfoils may be made of special materials, but the use of perforated steel airfoils has the advantage that the geometry obtained is simple, easy to describe and easy to realize. Thus, unsophisticated description of the blades with different degrees of permeability may be done with accuracy.

The material for permeable blades is indicated to be a periodical medium. A uniform permeability means that the orifices must be identical and the arrangements of the orifices must have as many symmetry axes as possible. The symmetry axes of the blade must be symmetry axes for the orifices, too. Permeability is influenced by the diameter of the orifices and their position on the blade. A certain arrangement means a certain model, which is reproduced on the entire blade. Matei P. and Popescu Th. (1989) proposed as a model the rectangular triangle of equal legs. This geometric shape fits very well with the shape of the blade. Permeability μ is the ratio between the orifice surface and the total surface. The flat plate is the simplest type of airfoil and if it is thin, the influence of permeability may be noticed. Experiments were made on several flat plates of different permeabilities. All the perforated plates tested had the dimensions: chord c=120mm, length l=120mm, thickness t=2mm.

The tests were made at $\mathrm{Re} = 1.6 \cdot 10^5$. The first experiments used perforated plate airfoils with different coefficients of permeability: 0%, 5.1%, 9.8%, 16.2%, 20%, and 25.5% . The angles of attack had rates varying from 0^0 to 42^0. Permeability contributes a lot to the aerodynamic behavior, as easily can be deduced from Fig. (1) and Fig. (2). The sudden drop of the lift coefficient typical for the classical plate airfoil is replaced by a landing, for a lot of angles of attack. These observations introduce a new research topic: the utilization of perforated airfoils for fan blades that function at various angles of attack, corresponding to diverse operating regimes.

Matei P. et al (1992) continued the tests, in order to identify the optimum permeability coefficient. Some new arrangements were done for these experiments. The perforated airfoils were placed between two plates, one against the lateral side of the plate and the other at 5mm distance from the opposite side, for simulating the tip clearance gap. The permeability coefficients were: μ=0 ; μ=1.1% ; μ=2.2% ; μ=3.6% ; μ=5.1% ; μ=9.8% . The results are presented in Fig. (3) and Fig. (4).

The tests indicated that:

1. The size of the landing domain is proportional to permeability. For permeability coefficients greater then 3%, the landing domain is significant and increases with the increasing angle of attack.
2. The values of lift coefficients decrease when permeability increases.
3. The perforated plates with permeability coefficients 3.65% and 5.1% have the best aerodynamic behavior, because the landing domain exists and the values of the lift coefficients are satisfactory.

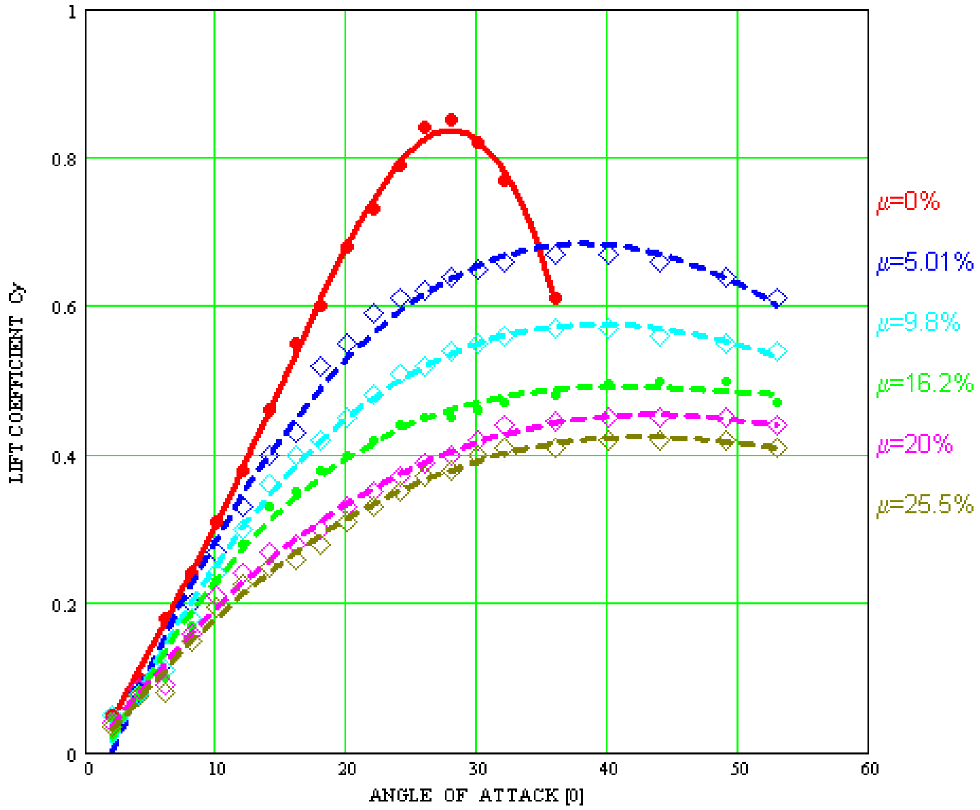


Figure 1. Lift coefficient versus angle of attack for unlimited perforated flat plate airfoils

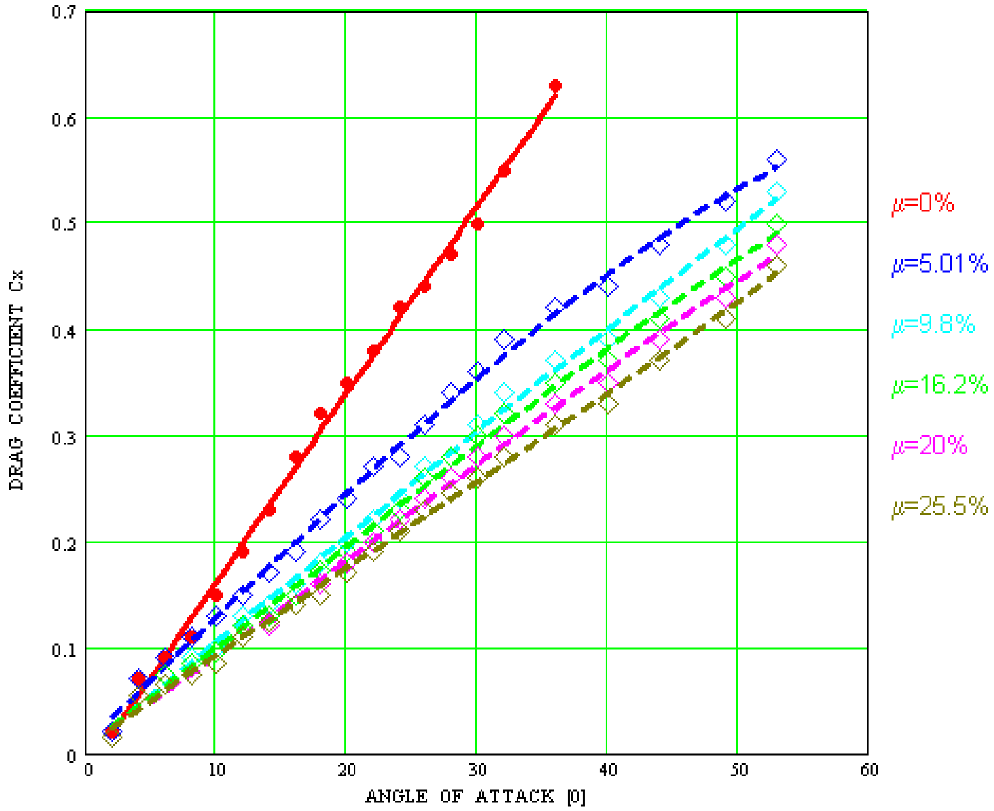


Figure 2. Drag coefficient versus angle of attack for unlimited perforated flat plate airfoils

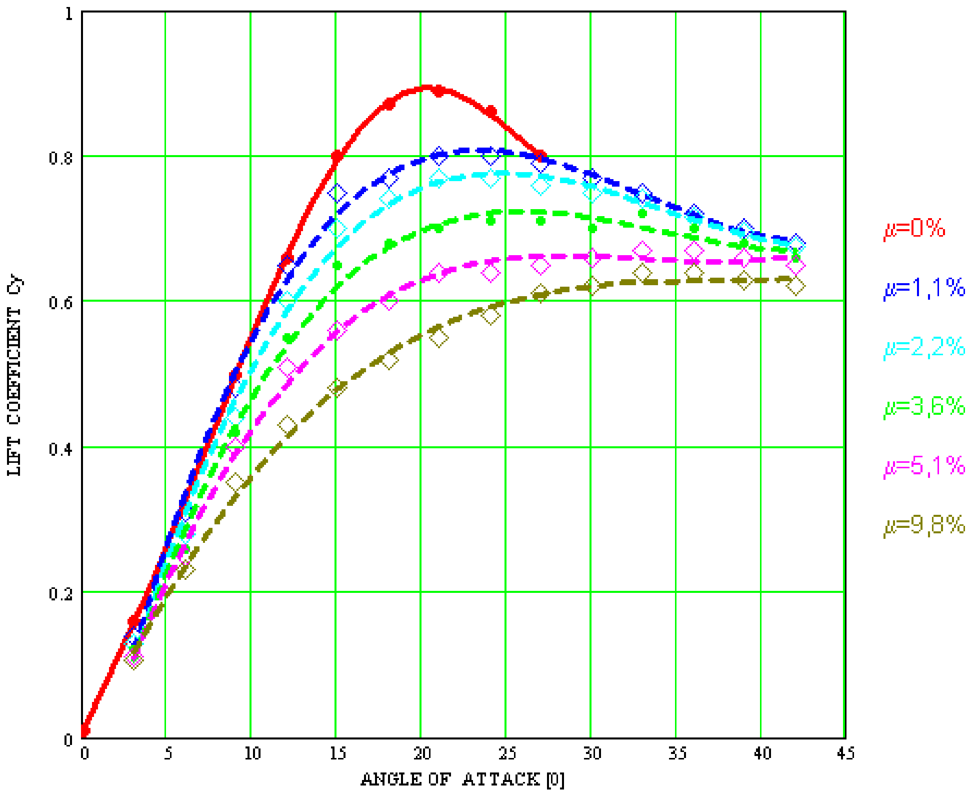


Figure 3. Lift coefficient versus angle of attack for limited perforated plate airfoils

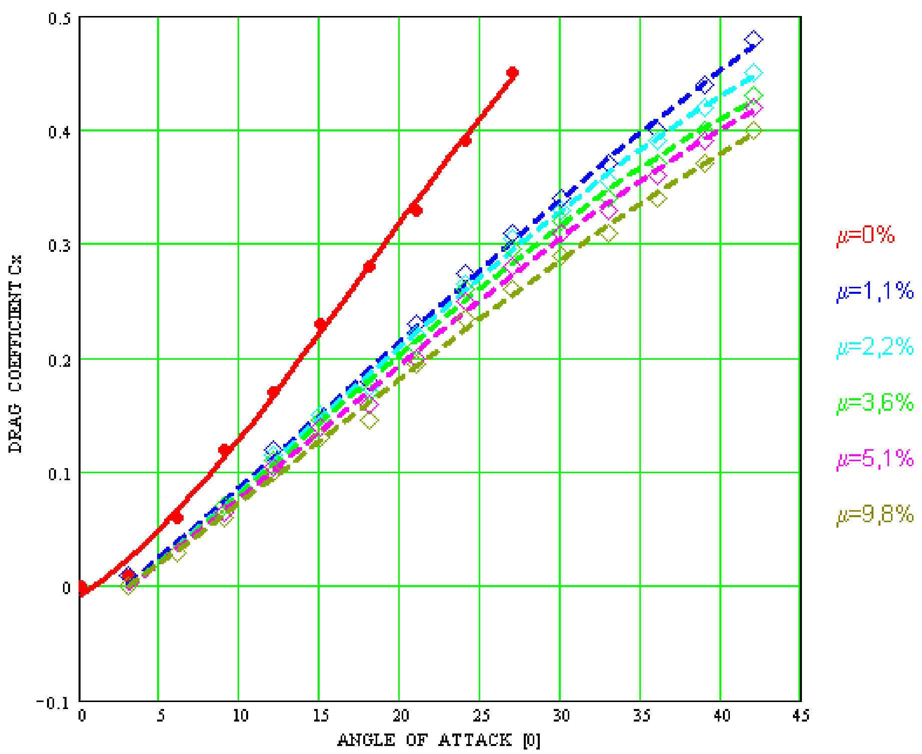


Figure 4. Drag coefficient versus angle of attack for limited perforated plate airfoils

3. Comparison between an axial fan with slotted blades and one with classical blades

The flow into the rotor of a fan may be idealized as the flow into a cascade of flat plate airfoils. It has been clearly established by Popescu D. (2002) that perforations have the ability of changing the aerodynamic behavior. This feature increases with the increasing angle of incidence. These observations may be important for fan design, but the literature concerning this issue is sparse and inconclusive. Popescu D. and Popescu Th. (2003) suggested that perforation is a possible technique for controlling the boundary layer.

The main aims of this comparative study is to establish the conditions to be respected by perforated blades in order for them to be recommendable for axial fans, if there are such conditions. Two fans identical in design, one of them with classical blades and the other with slotted blades, were tested. The chosen blades had a 4% circular-arc chordwise section, and the form was approximately rectangular. The test Reynolds number, based on blade chord, varies from $1.29 \cdot 10^6$ to $2.3 \cdot 10^6$.

Special experiments were performed in order to investigate in detail the aerodynamic parameters. A stand with two test sections, one upstream and one downstream was used. Claw tubes that were moved up and down the test sections, measured both the total pressure, and the deviation of the flow, and calibrated sharp-edged orifices mounted on the air duct measured the static pressures. To observe the modifications caused by permeability, the mass flow rates, noted "Qnp" for the classical rotor and "Qp" for the rotor with perforated blades had approximately equal rates.

The experiments showed that the flow has a deviation less than 1% with respect to the axial direction, in the test section upstream, noted section 1. Traverse measurements with the claw tube were conducted at 12 points that were placed 250mm in front of the leading edge of the cascade. Figure (5) presents the distribution of the total pressure in this section. Obviously, the curves for large radius values are modified, mainly because of the phenomena that occur near the duct wall. Generally, the blade loading may be considered satisfactory.

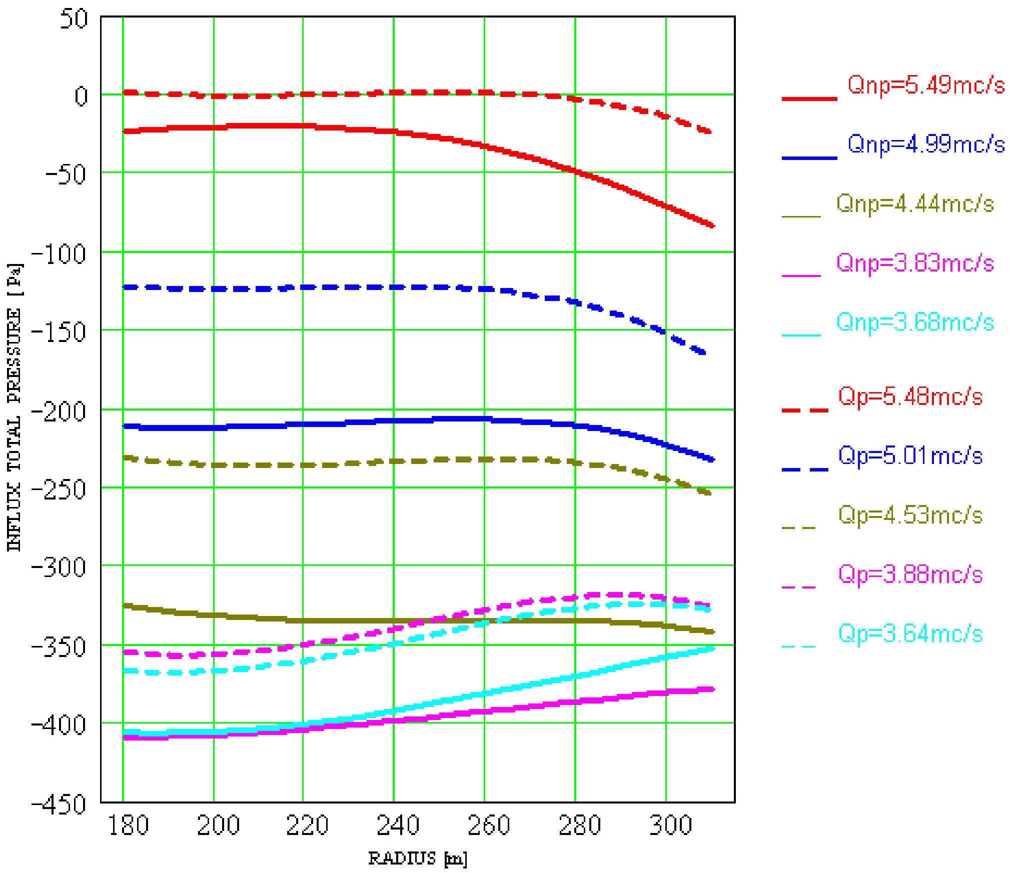


Figure 5. Distribution of total pressures upstream the leading edges of the blading.

Radial distribution of the pressures and deviations of the flow with respect to axial direction were measured in test section 2, placed 350mm downstream the trailing edges of the blades. Figure (6) evinces parabolic curves of total pressure distribution for the rotor with classical blades and even for the rotor with slotted blades. Both curves are more flattened at decreasing mass flow rates.

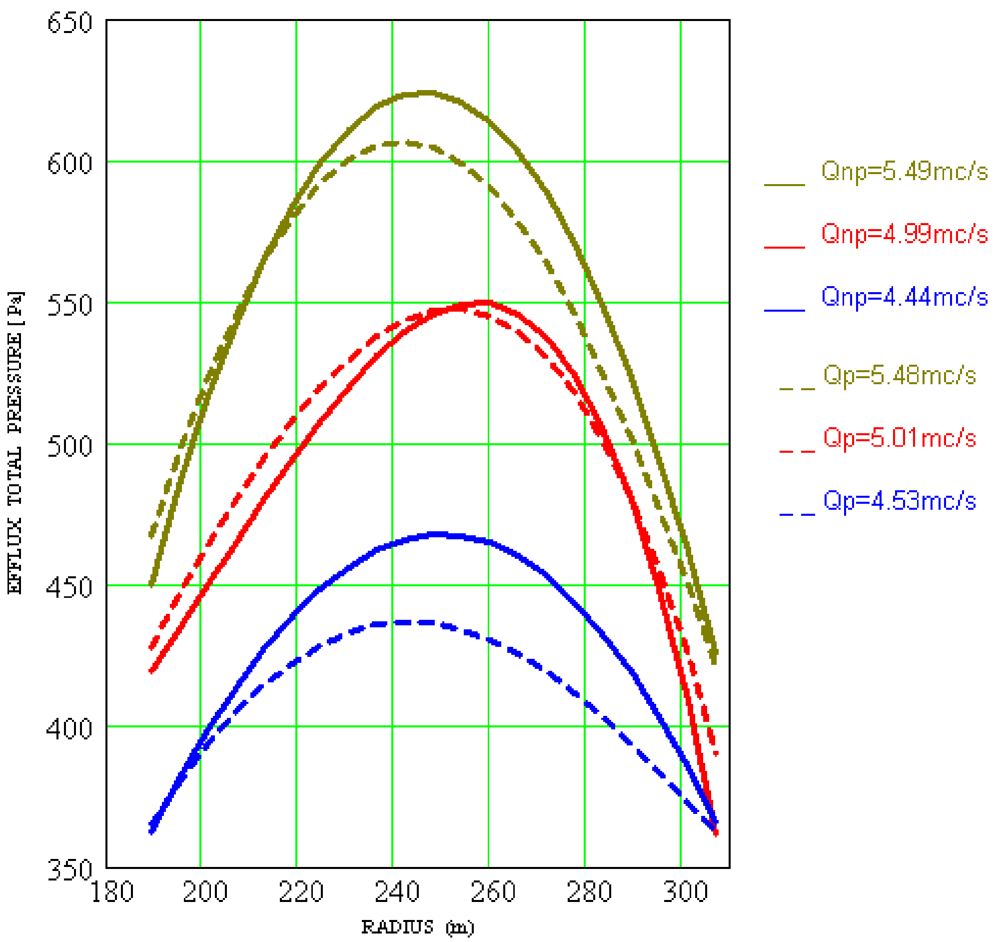
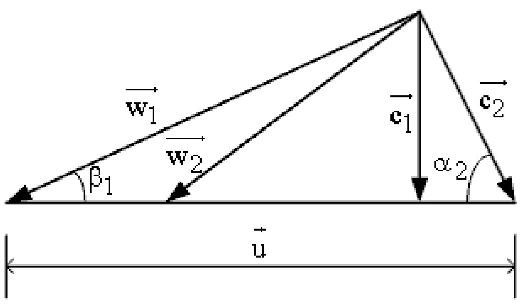


Figure 6. Distribution of total pressure downstream the trailing edges

The characteristics of the flow along the blades influence the fan performance, so significant differences between the fans can be observed in the evolution of swirl angles. It is important to know how permeability influences the angle α_2 between absolute velocity and tangential velocity (Fig. (7)).



$\vec{u}$ - tangential velocity

$\vec{w}_2$ - relative velocities

$\vec{c}_2$ - absolute velocities

Figure 7. Triangle of velocities

According to Fig. (8), the deviation of the flow in the hub region for perforated blading is greater and in the tip region smaller for than for classical blading. It has been acknowledged that the flow in a blade passage of a fan is influenced by various aerodynamic phenomena. Typical for these phenomena are the often separated flow near the suction surface - casing endwall interface, the influence of relative casing wall rotation, and blockage induced by the boundary layer that develops on the blade tip (Kordyban T., 1999; Kunz, R. et al,1993). This explains the aspect of the diagrams presented in Fig.8. Another observation is that the curves corresponding to the slotted blading are more flattened, especially in the hub regions, where we can be supposed that the boundary layer was not yet separated.

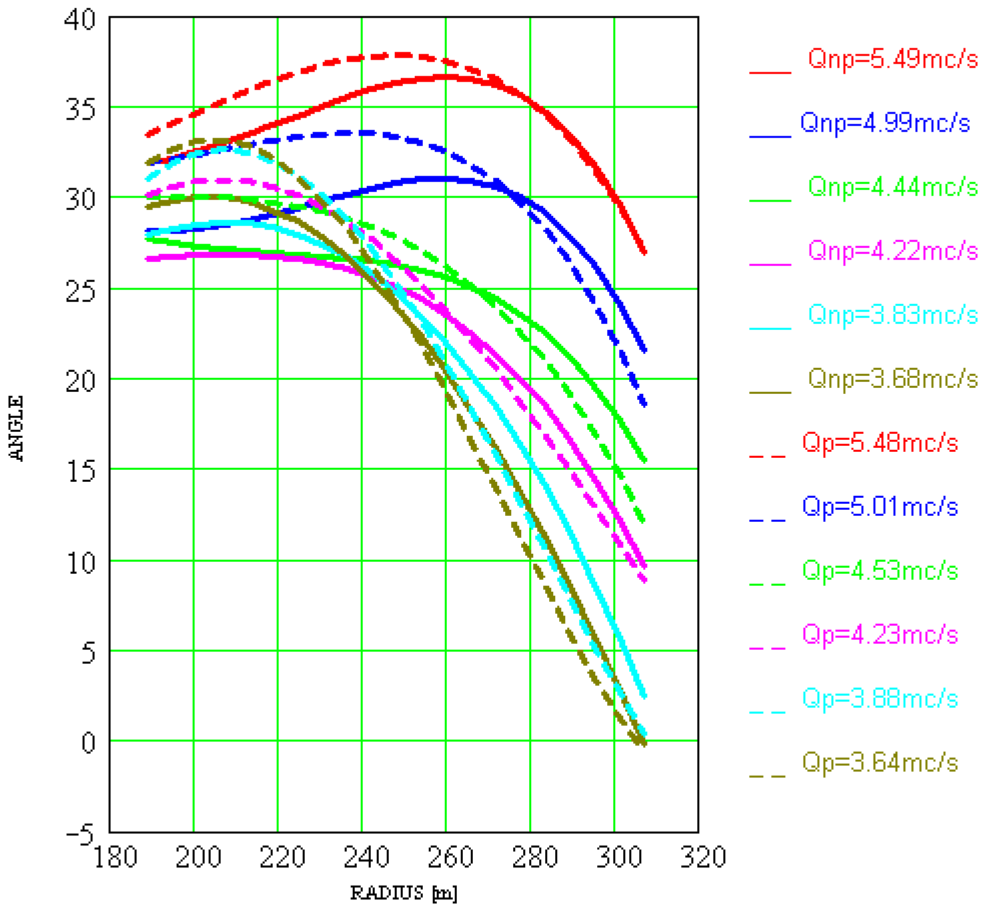


Figure 8. Distribution of angle α_2 in the efflux section

From the collected data presented in Fig. (9), the boundary layer separation occurs at $r = 245$, i.e. the middle span. The region between r=175mm, i.e. the hub radius, and the mid span, is adequate for extension analysis. The outlet parameter α_2 versus inlet parameter β_1 (angle between relative entry velocity and tangential velocity) was studied. Four calculations were made, including r=245mm. The graphs corresponding to perforated blading are more flattened especially for lower entry flow angles. These results can be explained by the aerodynamic perforated airfoil behavior. The absence of the lift stall observed in perforated airfoils leads to more uniform exit parameters from the rotor of the fan. This suggests the opportunity for studying another diagram: the total efflux pressure versus entry angle β_1.

Figure 10 shows that the total exit pressures measured for diverse radiuses vary slowly for the fan with slotted blades, as compared to the classical fan. The fan with perforated blades is more stable than the fan with classical blades; this results from smaller variation rates on diagram $\Delta p_t = f(\beta_1)$. Indeed, the total pressures obtained with the perforated blading are not so good, but this is a moderate price to pay when the fan functions at low flow rates. In this domain, the appearance of pump-back phenomena is most likely to occur. On the other hand, the decrease of angle β_1 means an increase of the attack angle, so that the total pressure increases with decreasing flow rate for both fans.

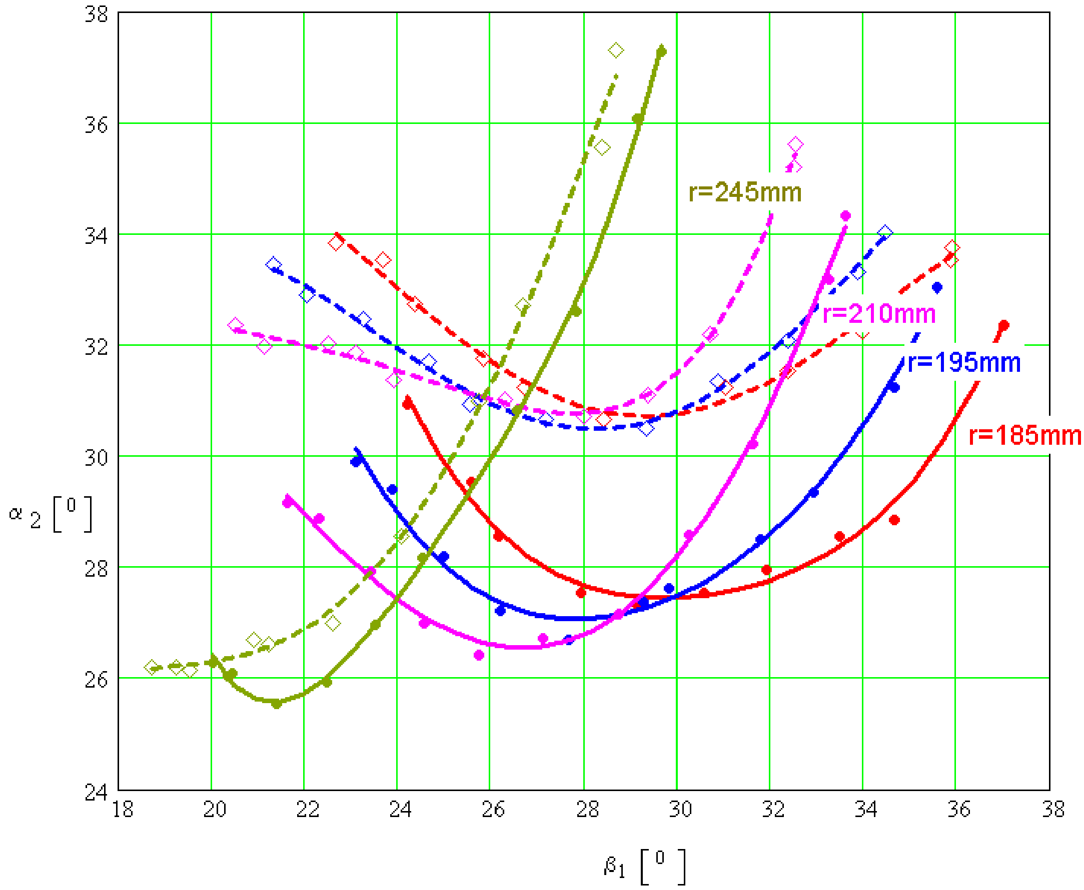


Figure 9. Efflux angle α_2 versus influx angle β_1 for perforated ( ) and classical ( ) fan bladings

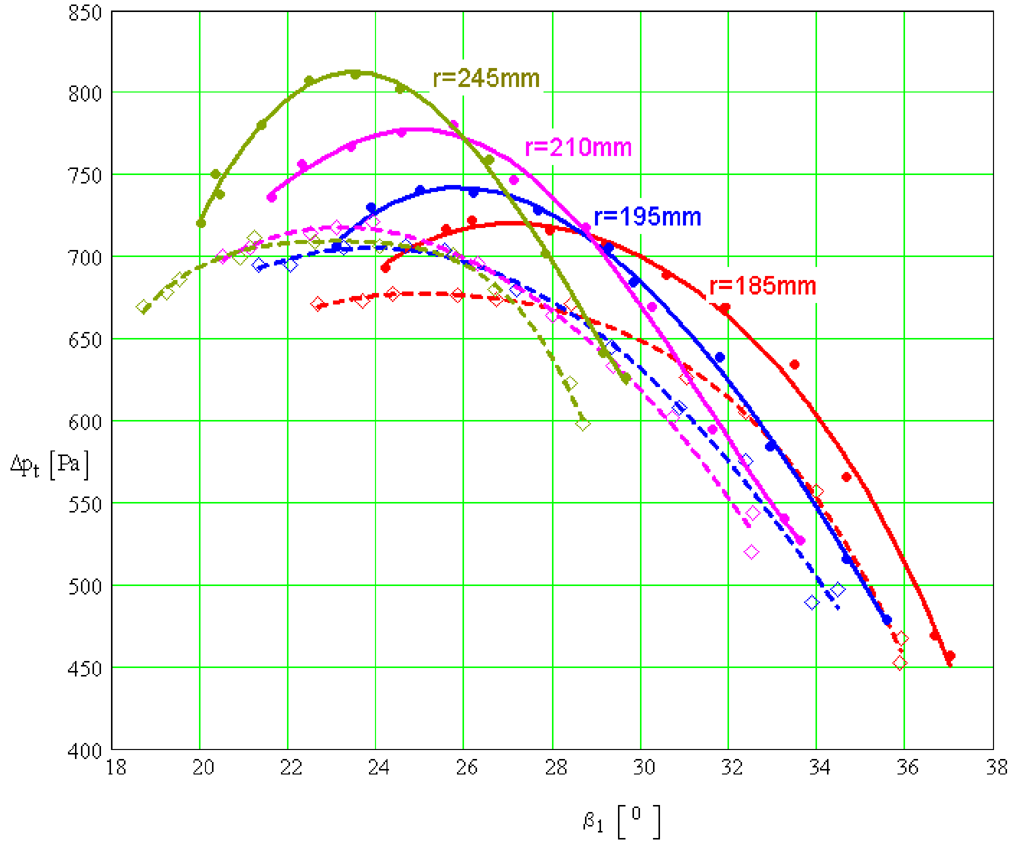


Figure 10. Total pressure Δp_t versus influx angle β_1 for perforated ( ) and classical ( ) fan bladings

4. Conclusions

The aerodynamic behavior of slotted plate airfoils reveals interesting results. Experimental data on perforated plates with permeability coefficient varying up to 25.5% allow us to determine porosity so as to yield satisfactory performances. These observations can be useful in axial fan design.

Detailed mechanisms of flow through an axial fan with perforated blades have been investigated, by means of measurements of influx - efflux total pressures and flows deviation downstream the blading, for different radii. The downstream parameters, such as angle α_2 between absolute and tangential velocity and total pressure Δp_t were studied with respect to an upstream parameter, angle β_1 between relative and tangential velocity. It appears that the fan with perforated blades has more flattened diagrams as compared to the fan with classical blades. Despite the fact that experiments on fans are limited to one single permeability coefficient, their results have revealed useful information. The modifications concerning the flow through the rotor are in accordance with the aerodynamic behavior of perforated plates. The stall lift of simple plate airfoils is replaced by a landing analogous with a landing for perforated blading characteristics.

Summarizing the above, the use of slotted blading instead of classical ones allows more uniform aerodynamic characteristics, especially in the hub region. Despite lower performances, the use of perforated blades is advisable outside the nominal domain, for low values of flow rates. Permeability produces a different boundary layer along the blades and this increases the stability of the fan.

5. References

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