EXPERIMENTAL AND THEORETICAL STUDY OF HEATED COANDA JET

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Summary The results of the experimental and analytical study of the effect of temperature on circumfluenced wall and temperature gradient on the stability of the boundary layer along the curved wall (Coanda jet) are presented. Heating of the circumfluenced wall results in stabilizing the boundary layer which leads to a shift of the transition to turbulence. In the case of the Coanda jet this phenomenon is manifested by the shift of reattachment to higher values of the Reynolds number.

INTRODUCTION

The Coanda jet is defined as the wall jet along the curved wall. The flow of fluid along the curved wall is accompanied with the decrease of the pressure on the wall. The pressure on the wall drops below the surrounding pressure resulting in the attachment of the fluid flow to the wall. This phenomenon is best observed in two-dimensional or nearly two-dimensional flow. The laminar curved wall jet has the tendency to follow the circumfluenced wall only for small angles. The rapid increase of pressure along the wall occurs due to the influence of the curvature of the wall and the adverse pressure gradient in the direction of flow. It leads to flow separation for small values of the angle ϕ. On the other hand the turbulent flow has a strong tendency to remain attached to the circumfluenced wall up to $\phi=270^{o}$ as found in [2]. The magnitude of the angle of separation depends on the geometric configuration (especially, on the ratio of the radius of the wall to the width of the nozzle *R/b*) and on the magnitude of the Reynolds number $\mathrm{Re}=\frac{1}{\sqrt{2}}\frac{\mathrm{v}\sqrt{Rb}}{\nu}$; v is the velocity in the nozzle and ν is the kinematic viscosity corresponding to the temperature of the air flow in the nozzle.

There is no continuous increase of the angle of separation associated with the increase of velocity of the flow in the nozzle from the laminar flow up to the values corresponding to the fully developed turbulent flow. The flow is laminar for the low values of Re and the increase of the angle of separation with the increasing Re is very small. As the measurement of the turbulence intensity carried out by the HWA method shows that this change is associated with the transition of flow to turbulent regime. The further increase of the flow velocity leads to the gradual increase of the angle of separation. The angle of separation is not dependent on the magnitude of Re only for high values of Re [2].

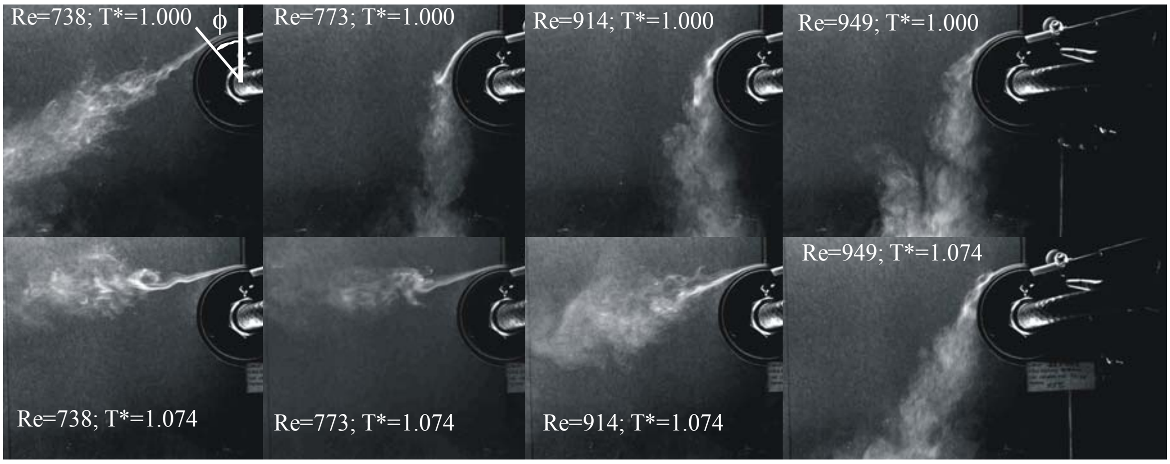

Fig. 1. Variation of the flow character with temperature. The upper pictures show the flow character at T*=1. The lower pictures show the flow character at T*=1.074. (R/b=8.16)

Most publications dealing with the Coanda jet are focused on the isothermal turbulent flow. There are only several publications investigating the problems of the flow along the heated/cooled wall [3]. The problems of the laminar flow along of the curved wall and the problems of the transition to turbulence are usually marginalized in the literature. The only exception known to the authors is the work by V. Tesař [4] where the effect of the temperature gradient on the character of the curved wall jet was observed.

The temperature change of the circumfluenced wall has a fundamental effect on the character of the flow and the transition to turbulence. This contribution brings new experimental results of the heated Coanda jet obtained using the smoke wire visualization method and the hot-wire anemometry (HWA). The analysis of the results based on the theory of the boundary layer stability has also been carried out.

RESULTS

The following conclusions can be formulated based on the smoke-wire visualization:

- At a certain value of the Reynolds number (Re_c) the reattachment of the separated flow occurs. For the isothermal case, the magnitude of Re_c depends on the slot width *b* and on the radius of curvature of the cylindrical surface *R*.
- The heating of the circumfluenced surface causes the increase of Re_c with increasing ratio $T^*=T_w/T_\infty$ (T_w is the temperature of the wall; T_∞ is the temperature of air flow that is not affected). This phenomenon is significant even for small values of T^* (see Fig. 2). The increase of Re_c with T^* is not linear – the rate of increase is reduced with increasing T^*.

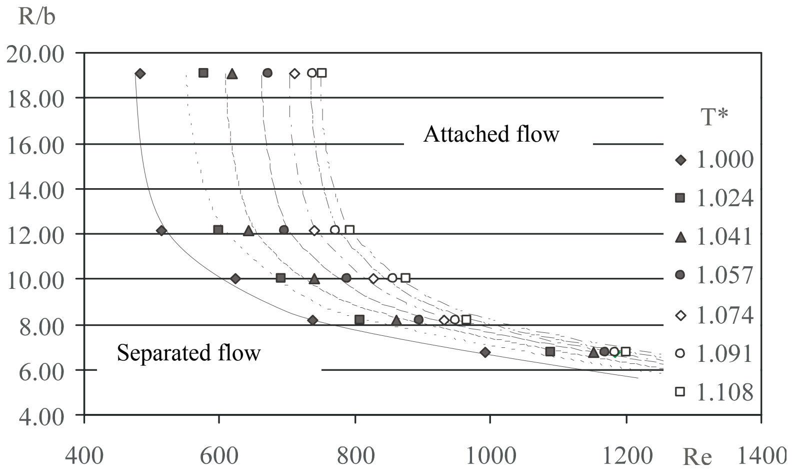

Fig. 2.The dependence of critical Reynolds numer $\mathrm{Re}_c = \dfrac{v\sqrt{Rb}}{\nu}$ on *R/b* ratio and on temperature ratio $T^* = T_w / T_\infty$

On the basis of the velocity and temperature profiles and the profiles of the turbulence intensity obtained from the HWA experiments it is possible to show that the separated flow is laminar until the separation point. The measured values of the turbulence intensity in the boundary layer do not exceed 5%. A significant increase of the turbulence intensity occurs near the separation point. For Re_c the attached flow has the character of the transitional turbulent flow. It was not possible to consider the turbulent flow as being completely developed with regard (due?) to the observed velocity range. The measured course of the intensity of velocity fluctuations in the streamwise direction shows a gradual increase of the turbulence intensity. Neither significant changes of the velocity profile, nor any significant profile changes of the turbulence intensity with the temperature gradient for the investigated ranges of the temperature gradient and the Reynolds numbers were observed.

Our theoretical analysis based on the similarity solution and the numerical simulation of the heated curved wall jet yields the following stability conditions:

1. The thermodynamic criterion [1] requires the following inequality to be fulfilled: : $\dfrac{\lambda}{T}\left(\dfrac{\partial T}{\partial y}\right)^2 + \mu\left(\dfrac{\partial v_x}{\partial y}\right)^2 + \mu v_x\left[\dfrac{d\ln\mu}{dT}\dfrac{\partial T}{\partial y}\dfrac{\partial v_x}{\partial y} + \dfrac{\partial^2 v_x}{\partial y^2}\right] \geq 0$. This criterion is responsible for the significant stabilization of the velocity profile for the heated curved wall jet. The convexity of the velocity profile $\partial^2 v_x / \partial y^2 < 0$ is compensated by the temperature gradient $\partial T / \partial y$. The stabilization effect increases with increasing T^* and decreases with increasing velocity.
2. The Rayleigh criterion requires that $\partial^2 v_x / \partial y^2 \neq 0$ is fulfilled in the boundary layer, i.e. the laminar velocity profile both for the non-heated and the heated cases of the curved wall jet is unstable.

CONCLUSION

The problem of the Coanda jet with the temperature gradient requires further theoretical, extensive experimental and numerical research. The principal advantage of the configuration with the temperature gradient is the distinguished position of the separation point of the boundary layer which coincides with the flow transition into turbulence. Both flow separation and flow transition into turbulence are phenomena which have not been satisfactorily described so far by any of the available complex theories.

References

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