COMPARISON BETWEEN TWO MODELS OF COOLING SURFACES USING BLOWING

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This study is concerned with new cooling systems to protect walls subjected to an important thermal stress and can especially be applied to different components of turbines as combustion chamber or blades. Different ways are used to reduce walls temperature such as film cooling[1-3], impingement[4], ablation, etc. Nevertheless, these processes present disadvantages as an important requirement of coolant fluid or difficulties to obtain homogeneous cooling. An alternative possibility is blowing through a porous matrix. In this work, we numerically investigate the efficiency of cooling using blowing. A first model has been developed and validated for blowing on a flat porous plate[5]. To reproduce others geometrical configurations, which can be present in turbines, we investigate blowing through a porous circular cylinder.

In this paper, we present results using two different ways of modeling the blowing through porous elements at a Reynolds number of 3900, based on the cylinder diameter and the main flow properties. In contrast with others models where the fluid governing equations must be modified according to the injection rate[6-9], we developed a model where the physical phenomena due to blowing are directly taken into account. The first model (holes model) consist in considering the porous wall as a succession of adiabatic wall segments and holes. The hot turbulent main flow has a typical behavior of flow above a wall. The turbulence is modeled using a classical Reynolds Stress Model (RSM), while the injected cold fluid is supplied through the holes. The proportion of holes and wall segments is determined according to the wall porosity. The second model of blowing (sources model) consists in applying mass, momentum and heat sources at the first centroid above an impermeable adiabatic wall to account for the effect of the blowing. The two models are used for different injection rates, F, (defined as the ratio of the injected mass flow rate over the main one) and main flow temperatures. The results are compared to experimental works that we led in our subsonic heated wind tunnel[10].

Figure 1 exhibits the evolution of the thermal effectiveness ($\eta = (T_w-T_o)/(T_{inj}-T_o)$ with T_w, T_o and T_{inj} the surface, main flow and coolant temperature respectively) as a function of the angle (defined starting from the front stagnation point), with both models for a 2 % blowing rate and a 200 °C main flow temperature, whereas the injected fluid is at 38 °C. Even for the front stagnation point, the temperature is significantly reduced with blowing and the effectiveness is already around 70 %. For higher angles, it rises up to 95 % (beyond the separation point) before decreasing down to 85 %, due to recirculations. Furthermore, we can notice that the two models give similar results even if the effectiveness is weaker using the sources model, in particular for low angles. This gap is due to the difference in fluid mixing in the first cell between the two models. In the sources model, the mixing between the main and the secondary flow is completed in the first cell, whereas it is not the case with the holes model.

An example of the temperature profile along the normal direction is shown in figure 2 for an injection rate of 2 % at an angle of 65° using both models. When blowing is applied, an important increase in the boundary layer thickness occurs, reducing normal gradients to the wall and leading to an efficient wall protection against the hot main flow. This phenomenon is observed for all locations around the cylinder even beyond the boundary layer separation point. It can be noted that the profile curves for both models collapse, except close to the wall for the same reasons as the ones exposed above. Nevertheless, they give similar results, in terms of thermal boundary layer thickness in particular, and seem to be very well adapted to account for the cooling effects and to determine the important parameters of the study.

Finally, the thermal effectiveness is plotted in figure 3 for different injection rates and an angle of 65° using one of the two models (the sources model for this presentation) and experimental data. We can observe that the numerical model is in good agreement with the experimental results and allows to accurately determine the different temperatures. The wall temperature decrease is very important and no important injection rates are necessary to obtain a significant thermal protection. In fact, for a 1 % injection, the thermal effectiveness is close to 50 % and reaches 90 % for 4 % of blowing.

In conclusion, two models of cooling surfaces using blowing were developed. They both predict an important decrease of the wall temperature and an excellent efficiency of cooling. In the final paper, more details on the blowing models and numerical methods will be given. Others results concerning surfaces temperature and temperature profiles will be shown. Furthermore, the important reduction of the heat flux using blowing will be presented.

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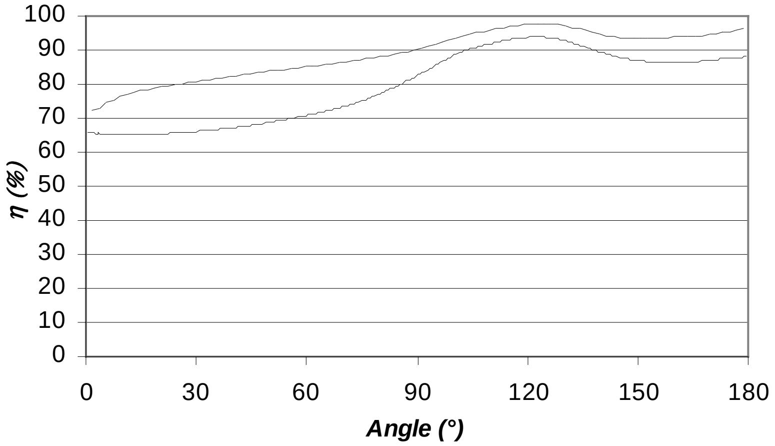

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Fig. 1 – Thermal protection effectiveness as a function of the angle. *Re* = 3900, *F* = 2 %. Solid line is the sources model, dashed line is the holes model.

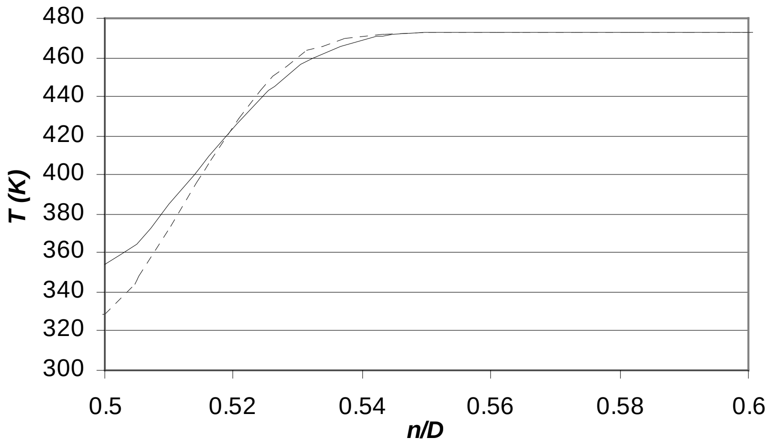

Fig. 2 – Temperature profile normal to the wall at an angle of 65°. *Re* = 3900, *F* = 2 %. Solid line is the sources model, dashed line is the holes model.

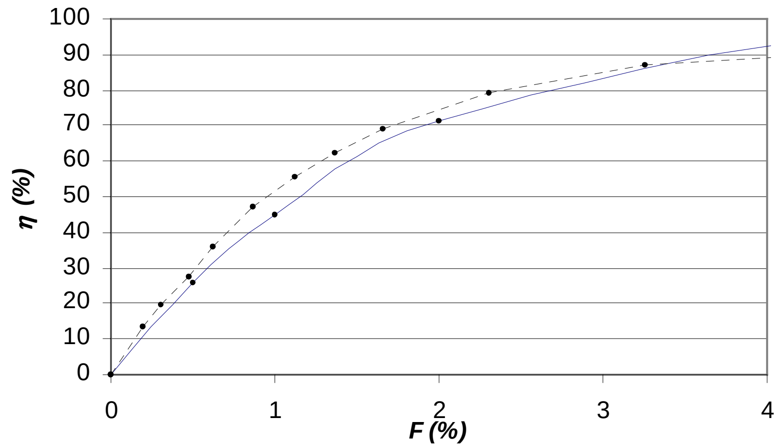

Fig. 3 – Thermal protection effectiveness as a function of blowing. Angle is 65°, *Re* = 3900. Solid line is the sources models, dashed line is experimental data.