NUMERICAL INVESTIGATION OF FILM COOLING FLOW INDUCED BY CYLINDRICAL AND SHAPED HOLES

Sylvain Barthet and Pascale Kulisa
Laboratoire de Mécanique des Fluides et d'Acoustique – UMR CNRS 5509
Ecole Centrale de Lyon – BP 163
69131 Ecully Cedex, France

The present study is the second line of a two part work realised in collaboration with SNECMA. The purpose is to investigate a new shaped hole film cooling in an experimental and numerical way. The first experimental part (not presented in this paper) is an investigation of film cooling phenomena around a shaped hole on a large scale turbine blade by measuring velocity field, heat transfer and film cooling effectiveness.

The second part is the subject of the paper. It is a numerical study of cylindrical and shaped hole film cooling on a flat wall.

We already know that shaping cooling hole provides a better effectiveness to protect the turbine blade from thermal diseases [1], [2]. The structure of the jet induced by shaped hole is quite different from that of a classical jet (cylindrical hole). Some new structures (anti-kidney vortices) may appear [3]. These differences can explain the performance of shaping.

This study is performed by using a multiblock, three-dimensionnal Navier-Stokes k-ε code developed by ONERA : CANARI [4]. The mesh used for the cylindrical hole calculation is presented in figure 1 and figure 2.

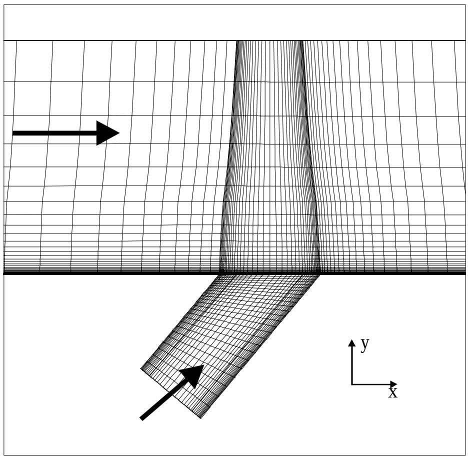

figure 1 : transverse view of the two-block mesh (cylindrical hole case).

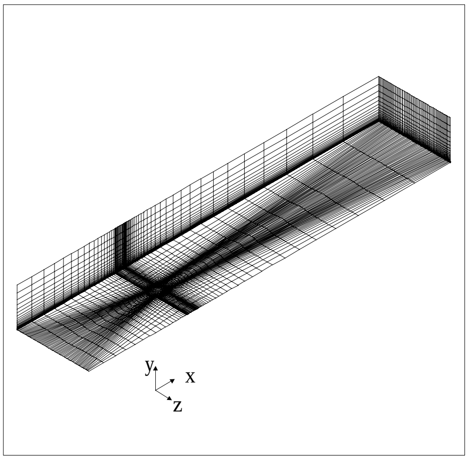

figure 2 : 3D view of the flat wall mesh (cylindrical hole case).

The aim of this study is to bring into light some additional details on the kinematic jet behaviour for the shaped hole film cooling case in order to complete experimental investigations.

In a second time, the two numerical simulations are compared to show up the difference between the two cases and to explain the better effectiveness of shaped hole film cooling.

Classical structures [5] such as horseshoe vortex and kidney vortices are shown up by plotting streamlines in some specific zones. We can see the development of two of these structures in figure 3 and figure 4. The detailed study demonstrates the influence of the location of these structures on the jet behaviour. The comparison of both cases reveals the impact of the form of the orifice on the velocity field and vortex motions.

More precisely, we focus our attention on kidney vortices which have a direct effect on the film cooling effectiveness [6].

Isomach plots give us a first idea of the flow behaviour, (figure 5 and figure 6). Especially in the vicinity of the jet we can see a separation region within the shaped tube, figure 5. This region will be discussed.

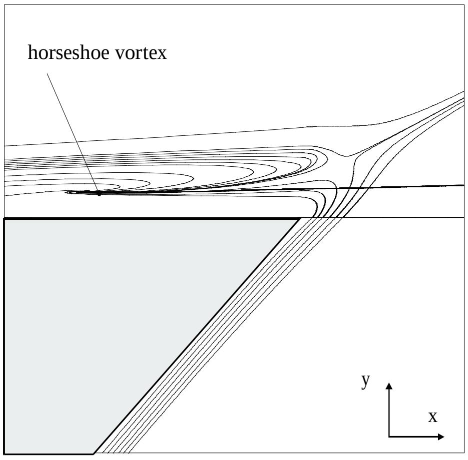

figure 3 : Horseshoe vortex near injection.

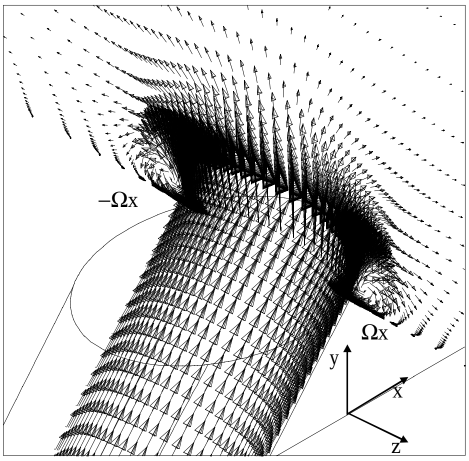

figure 4 : Development of one of the kidney vortices

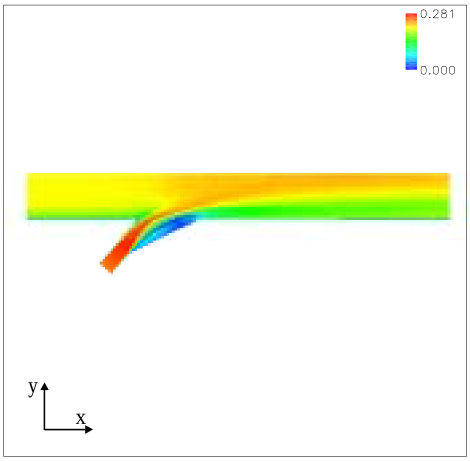

figure 5 : Isomach, shaped hole.

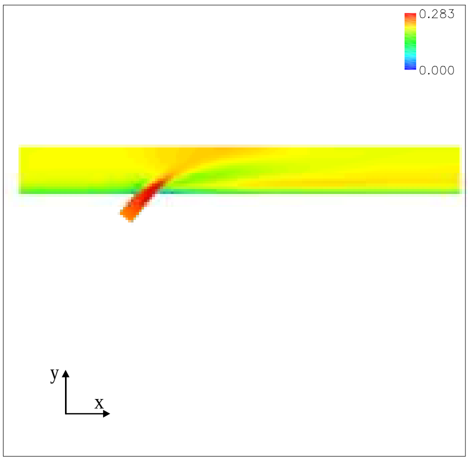

figure 6 : Isomach, cylindrical hole.

CONCLUSION

Two cases of film cooling geometry are computed : a "classical" cylindrical hole and an improved shaped hole. The results give us details of the jet structure. Their comparison gives a first explanation of the better effectiveness of shaping.

Now, we are computing the shaped hole film cooling on the turbine blade we used for the experimental investigations in order to compare numerical and experimental results.

REFERENCES

1. R.J. Goldstein, E.R.J. Eckert, Effects of hole geometry and density on 3D film cooling. *Int. J. of Heat Mass Transfer, Vol. 117, pp 595-607, 1973.*
2. J.P. Farmer, D.J. Seager, J.A. Liburdy, The effect of shaping inclined slots on film cooling effectiveness and heat transfer coefficient. *ASME Paper n°97-GT-339, 1997.*
3. B.A. Haven, M. Kurosaka, Kidney and anti-kidney vortices in crossflow jets. *J. Fluid Mech., vol. 352, pp 27-64, 1997.*
4. A. M. Vuillot, V. Couailler and N. Liamis, 3D turbomachinery Euler and Navier-Stokes calculation with multidomain cell-centered approach. *AIAA paper 93-2576, Monterey, California, 1993.*
5. J.L. Bousgarbies, L.E. Brizzi, E. Foucault, Vorticité au voisinage d'un jet circulaire débouchant perpendiculairement dans une couche limite ; cas des petits nombres de Reynolds. AUM, 10ème congrès français de mécanique, Paris, 1991.
6. B.A. Haven, M. Kurosaka, The effect of hole geometry on lift-off behavior of coolant jets. *AIAA Paper n°96-018, 1996.*

The simulations are performed on the "Institut de Développement et des Ressources en Informatique Scientifique" centre Necsx5 computer.