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LARGE EDDY SIMULATION OF INTERNAL COOLANT CROSS-FLOW EFFECTS ON FILM COOLING

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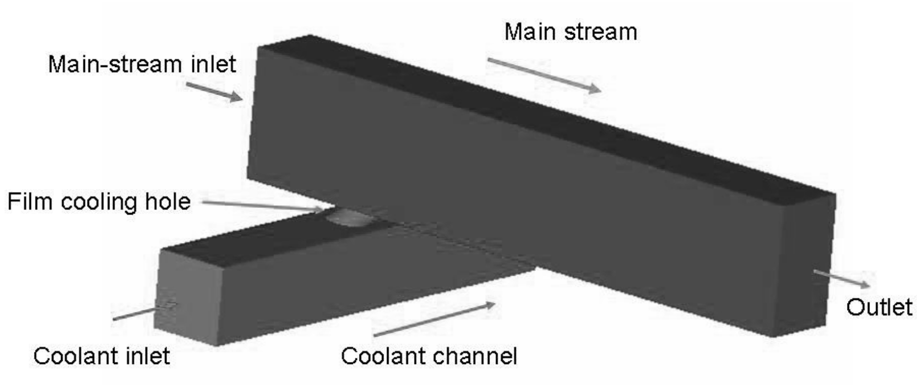
ABSTRACT

Film cooling is the introduction of a secondary fluid (coolant or injected fluid) at one or more discrete locations along a surface exposed to a high temperature environment to protect that surface not only in the immediate region of injection but also in the downstream region [Goldstein 1971]. Film cooling is widely used in gas turbines, in the blades, the combustion chamber walls and the nozzles. The literature on film cooling is very extensive, but most of these studies have been based on the plenum-coolant-feed film cooling model. Since this model simplifies the film cooling process, it does not give a comprehensive description of the flow in the internal coolant passage of the turbine blade which has large cross-flow velocities in the coolant supply channel. The effect of the internal coolant flow on the film cooling must be considered since some researches [e.g. Gritsch et al. 2003, Gritsch et al. 2004, Thole et al. 1997] had shown that the internal coolant conditions strongly affect the film cooling. However, there are few studies on the effect of the internal coolant cross-flow on the film cooling used the large-eddy simulation (LES) method.

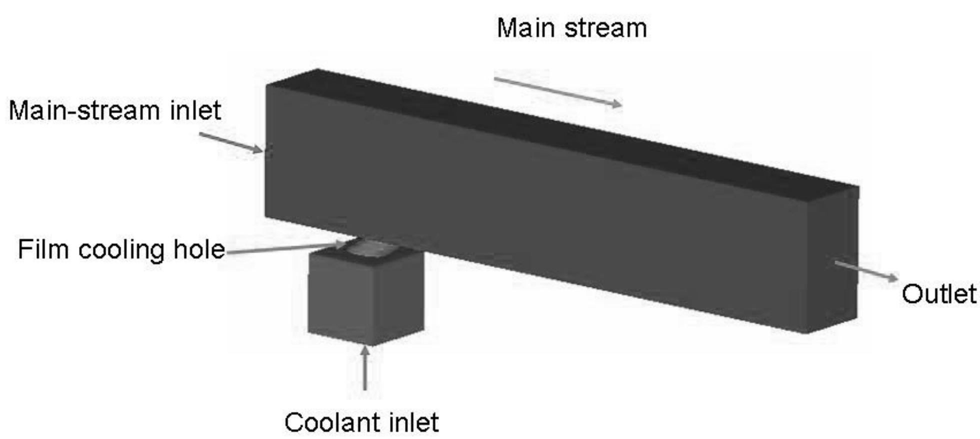
This paper analyzes the effect of the coolant cross-flow on the film cooling effectiveness using the large-eddy simulation (LES) turbulent flow model. The cross-flow-coolant model and the plenum-coolant-feed model are investigated for blowing ratio (M) of 0.5 and 1.0. The computational model, as well as the main boundary conditions, is similar to and extracted from the well-know study by Sinha et al. [1991]. A single film cooling hole is inclined at 35^o with respect to the mainstream direction with a lateral hole spacing of 3 hole diameters. The cooling hole has a length-to-diameter ratio L/D =1.75 with D of 12.7 mm. The inlet boundary conditions are listed in Table 1.

Table 1
Inlet Boundary Conditions

Nomenclature	Average Velocity (m/s)	Temperature (K)
Free stream	20	300
Cross-flow-coolant	7	150



(a) cross-flow-coolant model

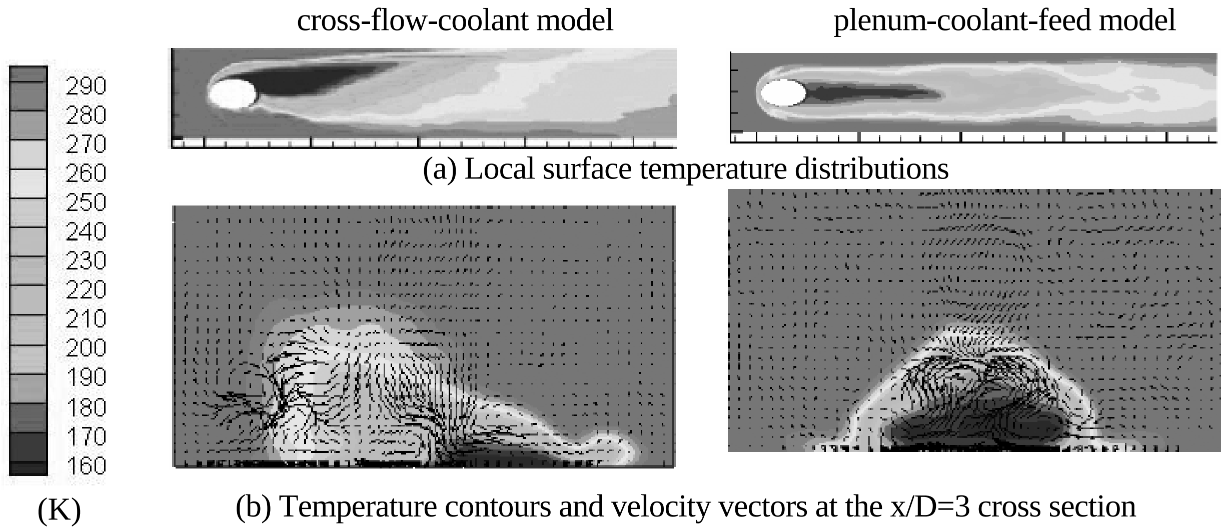


(b) plenum-coolant-feed model

Figure 1. Sketches of the physical models

The simulations show that the coolant cross-flow strongly affects the film cooling for the geometries shown in Figure 1. The cross-flow has a positive effect on the laterally averaged film cooling effectiveness. Film cooling with cross-flow generally has a higher effectiveness due to the delayed cooling jet detachment as well as the improved lateral coolant spreading and coverage as shown in Figure 2. Therefore, cross-flow at the entry to the film cooling hole should be taken into account when modeling film cooling of turbine blades. The results also indicate that the larger blowing ratio leads to poorer adhesion of jet stream and a lower film cooling effectiveness.

The LES model results are also compared with predictions using the SST k-ω model. The LES model accurately captures the instantaneous turbulent fluctuations which show that the turbulence field for the film cooling is not isotropic, so the RANS turbulence model must be modified to account for the non-isotropic effects.



(a) Local surface temperature distributions

(b) Temperature contours and velocity vectors at the x/D=3 cross section perpendicular to the mainstream direction

Figure 2. Influence of coolant-supply method on film cooling (M=0.5)

CONCLUSION

The present paper documents a numerical investigation to study the effect of the coolant cross-flow on the film cooling effectiveness. The large-eddy simulation (LES) turbulent flow model is used. Key conclusions can be drawn as follows:

(1) Film cooling with coolant crossflow generally performs higher effectiveness than plenum-coolant-feed model due to its delayed cooling jet detachment as well as improved coolant laterally spreading and coverage.

(2) Larger blowing ratio leads to poorer adhesion of jet stream and a lower film cooling effectiveness.

(3) The turbulence field for the film cooling is not isotropic, so the RANS turbulence model must be modified to account for the non-isotropic effects.

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