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CFD Prediction on Console Design for Film Cooling in Gas Turbine Engine

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Abstract: Development and testing of a new film cooling hole geometry, the converging slot-hole or console. Both the thermal and aerodynamic performance were measured, using the adiabatic effectiveness and heat transfer coefficient and aerodynamic loss respectively, to quantify performance. Comparative measurements were made, by testing conventional film cooling hole shapes in parallel with the console experiments. The CFD code, Fluent, was used to predict the performance of the initial design concept before it was manufactured. The concept of the console film cooling hole was first proposed by Oldfield and Lock (1998) and is the subject of a patent application. In this chapter the concepts behind the console design are outlined. The predicted performance of the console is explained with reference to the design features and the surface definition of the console generated using the CAD/CAM package CATIA.

Key words: Cooling hole geometry · Adiabatic effectiveness · Comparative measurements

INRODUCTION

The Converging Slot Hole or console film cooling hole geometry has been developed in response to the identified need for film cooling that provides a high and laterally uniform level of surface thermal protection without significantly augmenting aerodynamic loss over the surface or reducing the structural stability of the component. A slot film cooling geometry traditionally best met these heat transfer and aerodynamic requirements but did not provide the required structural stability. The console has been designed to offer the advantages of slot flow, whilst maintaining a structural strength similar to discrete holes [1].

The main features of the console are shown in Figure 1. The cross-section of the console changes from a near circular shape at inlet to a slot at exit. This change in cross section is produced by a convergence of the walls in side view (Figure 1a) and a divergence of the walls in plan view (Figure 1b), but the convergence is greater than the divergence so that there is a net decrease in cross-sectional area and the flow accelerates from inlet to outlet [2]. The reduction in cross-sectional area and increase in wetted perimeter for the console at the scale used for the low speed experiments (5 mm exit slot height) The minimum hole area (throat) and hence maximum flow velocity are at, or just before, the hole exit.

Console Design: The low levels of aerodynamic loss and accelerating flow are in contrast to conventional fan-shaped or expanded holes where the flow is diffused and slowed down in an attempt to spread the flow of coolant onto the surface with low momentum [3]. The separations in the fan-shaped hole, which reduce the aerodynamic efficiency, should be significantly reduced in the accelerating console flow. The low-turbulence exit flow from the console should lay a more stable layer of cooling air onto the external blade surface downstream of the exit and should reduce mixing of the coolant and the hot mainstream. Individual holes in a row of consoles are positioned such that adjacent holes meet just below the surface as shown [4] and a continuous slot is formed on the outside blade surface whilst the roughly triangular pedestals between holes maintain the strength of the blade. Although the inlet of the console will prevent the coolant film from being completely uniform as it would be for slot flow, by joining the hole exits below the blade surface, there will be a continuous film of coolant in the spanwise direction [5]. This is a significant improvement on discrete holes, for which the jets from adjacent holes only.

CFD Prediction in Console Design: The proficiency of the preliminary console design to achieve the design aims was tested using the CFD software package FLUENT and

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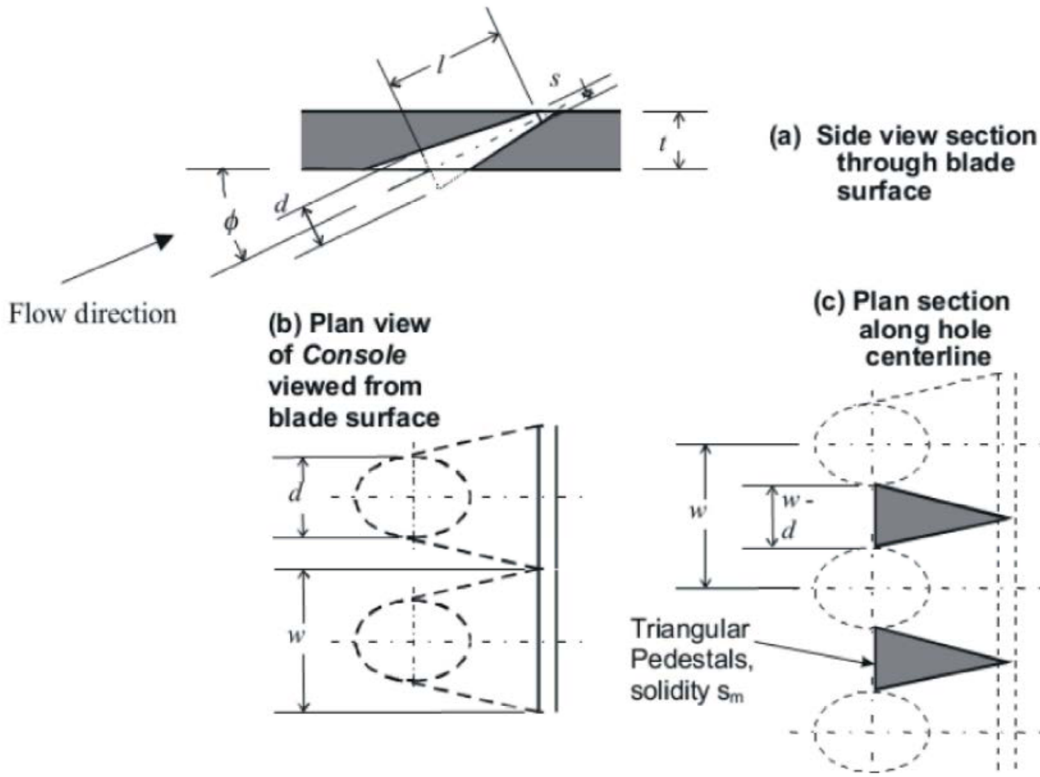
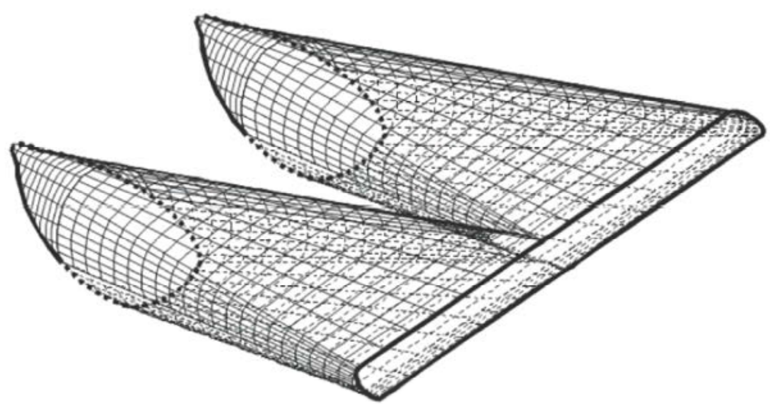
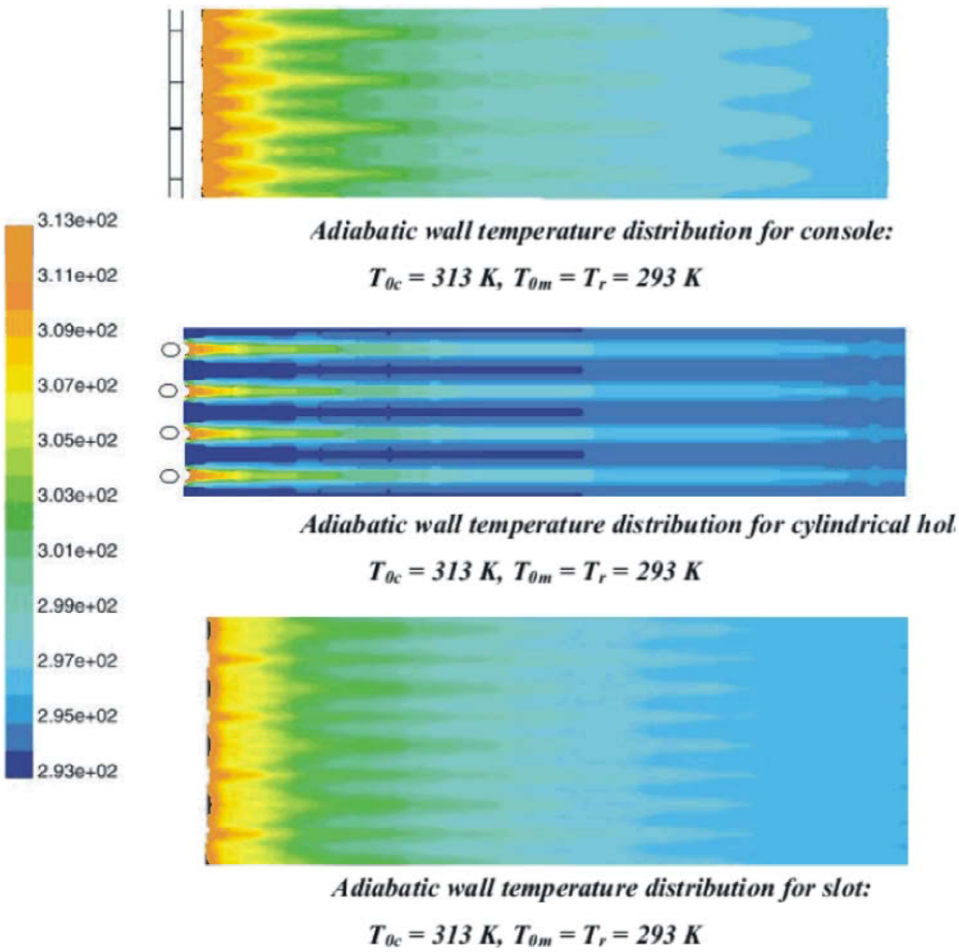


Fig. 1: Basic console configuration



Coolant temperature (K)	313
Mainstream temperature (K)	293
Plate Heat Flux (W/m^2)	0
Mainstream inlet total pressure (PaG) *	0
Mainstream outlet static pressure (PaG)	-309
Coolant inlet pressure (PaG)	60

compared with an analysis of slot and cylindrical film cooing holes. The data collected from the analysis provided an initial estimate of the adiabatic effectiveness and an indication of the likely flow patterns [6-12]. The adiabatic wall temperature downstream of the console is considerably more uniform than that shown for the cylindrical holes, although there is some structure to the flow for the console. The slot result also shows some three-dimensional streaks, even though the edges of the modeled area were set with a symmetry boundary condition.



CONCLUSION

The console film cooling hole design concept has been presented and the main features of the holes and the predicted effect that these will have on the film cooling heat transfer and aerodynamic performance have been discussed. The convergence of the hole should minimize the aerodynamic loss through the hole and the merging of the holes into a single slot at exit should improve the thermal protection of the surface and reduce the aerodynamic loss due to mixing.

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