THE VARIATION OF HEAT TRANSFER COEFFICIENT, ADIABATIC EFFECTIVENESS AND AERODYNAMIC LOSS WITH FILM COOLING HOLE SHAPE

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The use of film cooling to allow turbine entry temperatures well above the melting temperature of turbine components is well established and considerable research has been applied to optimise film cooling design. However, the cost of film cooling is reduced aerodynamic efficiency due to the interaction of coolant and mainstream flows. Thus the optimisation of design must include consideration of aerodynamic loss with any improvements in heat transfer and adiabatic effectiveness.

The heat transfer coefficient and adiabatic effectiveness of three conventional hole shapes – cylindrical, fan shaped holes and a slot - have been measured in a steady state, low speed facility. The aerodynamic loss due to each of the film cooling geometries has been measured using a boundary layer traverse and the film cooling results are considered in light of this data.

Heat transfer coefficient and adiabatic effectiveness

The heat transfer coefficient and adiabatic effectiveness are calculated by applying linear superposition[1]. By definition:

$h = \dfrac{q_c}{T_w - T_{aw}}$, $\eta = \dfrac{T_{aw} - T_m}{T_c - T_m}$ and dimensionless temperature $\theta = \dfrac{T_c - T_m}{T_w - T_m}$

By substitution and rearrangement, $\dfrac{q_c}{T_w - T_m} = h - h\eta\theta$ ·

Hence h and η at a particular point can be measured by varying q_c and θ and extracting the intercepts of a line through the points ($\theta, \dfrac{q_c}{T_w - T_m}$).

Aerodynamic Loss Measurement

Aerodynamic loss[2] is defined as 1-ε, where the aerodynamic efficiency,

ε, is defined: $\varepsilon = \dfrac{\{ActualKineticEnergy\}_{mixingplane}}{\{TheoreticalKineticEnergy\}_{available}}$.

The actual kinetic energy is calculated from the measurement of the velocity profile across the boundary layer, which is equated to a theoretical fully mixed out plane[3].

Discharge coefficient correction

Ideal momentum flux ratio, I_{ideal}, was used to correlate results where: $I = \dfrac{(\rho v^2)_c}{(\rho v^2)_m} = \dfrac{p_{oc} - p_c}{p_{om} - p_m}$.

Conclusions

The heat transfer coefficient and adiabatic effectiveness of the film cooling process have been measured and are considered in conjunction with the aerodynamic loss due to flow through the hole and mixing with mainstream air.

An automated data processing system has been developed to analyse a series of digital images and return contour maps of adiabatic effectiveness and heat transfer coefficient.

The film cooling performance of fan shaped holes is a significant improvement on cylindrical shaped holes, and it approaches slot performance due to spreading of the coolant over the surface to form a closed film a short distance downstream of the holes.

The penalty associated with fan shaped holes is large aerodynamic loss due to inefficient diffusion in the expanding section of the hole. The aerodynamic loss for all hole shapes increases with pressure difference ratio.

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