FINITE ELEMENT ANALYSIS OF FLOWFIELD IN THE SINGLE HOLE FILM COOLING TECHNIQUE

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ABSTRACT

Film cooling technique is currently used in the gas turbine hot sections, such as the combustor wall and the turbine blades, to prevent those sections from failing at elevated temperatures. In the open slot film cooling technique, the coolant air flows from a slot into the mainstream and thus a layer of coolant air prevents the heat transfer between the hot gas mainstream and the wall. In this method, the flow field can be considered as two dimensional. But, in the single hole film cooling technique, as shown in Figure 1, coolant air flows from a hole into the mainstream and therefore the flow is naturally three dimensional. In this paper, the Navier-Stokes and the energy equations are solved on the flat plate by the Finite Element Method using brick elements. Algebraic equations are obtained by the use of the Petrov-Galerkin method. The pressure term is vanished from the momentum equations, by employing the Penalty method. The governing equations are transient and the flow is incompressible and turbulent. The model of turbulence in the near wall region is the wall function method, and in the fully turbulent region is the $k-e$ model. The system of the algebraic equations is solved by the Frontal method.

In the present work, a computer code is developed which is capable of solving the governing equations and hence modelling the flow geometry. The coolant injection angle, the blowing rate and the turbulence intensity are among the parameters which are studied. In order to examine the present computer code, the results are compared with the Blasius (exact) solution, for the laminar flow with Re = 6700, and also with the empirical $1/7^{th}$ power-law, for the turbulent flow with Re = 2×10^{6}. Figure 2 shows the good agreements for both the laminar and turbulent flow comparisons, where the normalized velocity profiles ($w/w_{infinity}$) versus the normalized vertical distance from the wall (x/L, where L is a characteristic length), are presented.

In the present paper, the optimum cooling performance is shown to be at a 35 degree angle of coolant injection, and the optimum blowing rate is 0.5. The film cooling effectiveness, at the above conditions, is directly compared with the experimental results of Goldstein et al.[1] , and a good agreement is demonstrated. This is illustrated in Figure 3, where this agreement is noticeable at downstream from injection (i.e., as z/D is increased). This is particularly true for the results on the injection hole axis (y/D = 0).

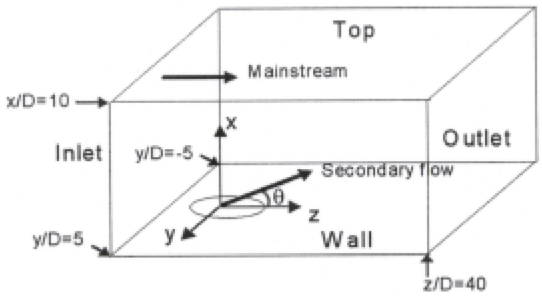

Fig.1 Overall computational domain.

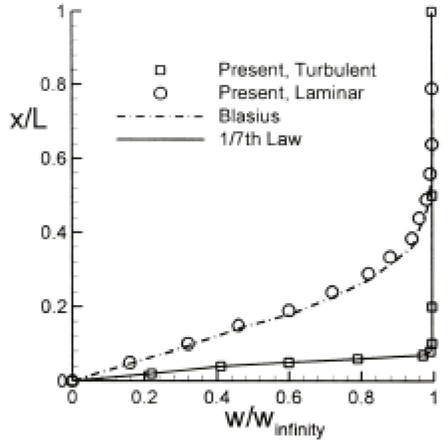

Fig.2 Comparisons of the present numerical results with those of Blasius (exact) solution and with the empirical $1/7^{th}$ power-law.

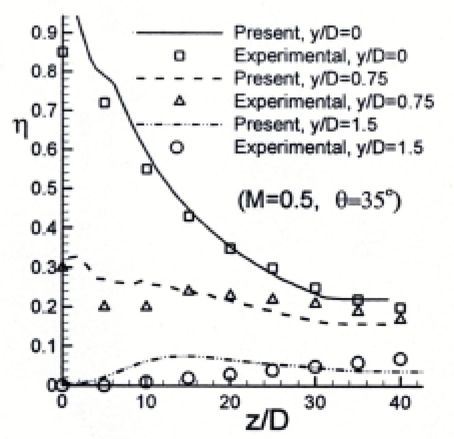

Fig.3 Comparisons of present cooling effectiveness data with experimental data of Goldstein et al.[1].

Reference

1. Goldstein, R.J., Eckert, E.R.G., and Ramsey, J.W., 1968, Film Cooling With Injection Through Holes: Adiabatic Wall Temperatures Downstream of a Circular Tube, Journal of Engineering for Power, Transactions of ASME, pp. 384-395.