Technical Comments

Comment on "Evaluation of Heat Transfer for Film-Cooled Turbine Components"

E. R. G. Eckert,* R. J. Goldstein,† and D. R. Pedersen‡
University of Minnesota, Minneapolis, Minn.

Nomenclature

c_n = hole spacing
c_{ps} = slot coolant specific heat
$c_{p\infty}$ = mainstream specific heat
d_n = hole diameter
$M = \rho_s u_s/\rho_\infty u_\infty$ = blowing rate parameter, same as G^* of Ref. 1
Re_s = slot Reynolds number
s = slot width
x = distance from injection point in flow direction
β = angle of injection
β' = injection parameter [see Eq. (2)]
ζ = effectiveness parameter [see Eq. (2)]
$\bar{\eta}$ = average film-cooling effectiveness [see Eq. (1)]
θ_{ad}^* = reciprocal of the average film-cooling effectiveness
μ_s = slot viscosity
μ_∞ = mainstream viscosity

Film-Cooling Effectiveness—Two-Dimensional Slot

The correlations of effectiveness data as presented by the authors[1] are strictly empirical requiring a separate equation for each injection angle. A single correlation of the data could be obtained using one of the models previously derived, e.g., Refs. 5 and 6.

As pointed out by the authors, the parameter θ_{ad}^* is the inverse of the average film-cooling effectiveness $\bar{\eta}$ where the bar indicates an average value (which must be used as the present experiments were performed using a wall with large thermal conductivity). Integrating the expressions for the effectiveness from Refs. 5 and 6 to obtain the average value over the plate results in

$$\bar{\eta} = 1/(1 + 0.182\, Re_s^{-0.2} M^{-0.8} (x/s)^{0.8}) \tag{1}$$

and

$$\bar{\eta} = 1.508/[1 + 0.183\zeta] \tag{2}$$

where

$$\zeta = (C_{p\infty}/C_{ps})\beta'(Re_s \mu_s/\mu_\infty)^{-0.2}(x/Ms)^{0.8}$$

and

$$\beta' = 1 + 1.5 \times 10^{-4}\, Re_s(\mu_s/\mu_\infty)\sin\beta$$

respectively. Data taken from figures of the Ref. 1 for both injection angles are given in Fig. 1 along with a line representing Eq. (2). The agreement of the experimental results with Eq. (2) is quite good and somewhat better than with Eq. (1).

Using the same parameter (ζ) as in Ref. 6, but adjusting the constants so that the best fit is obtained with the present

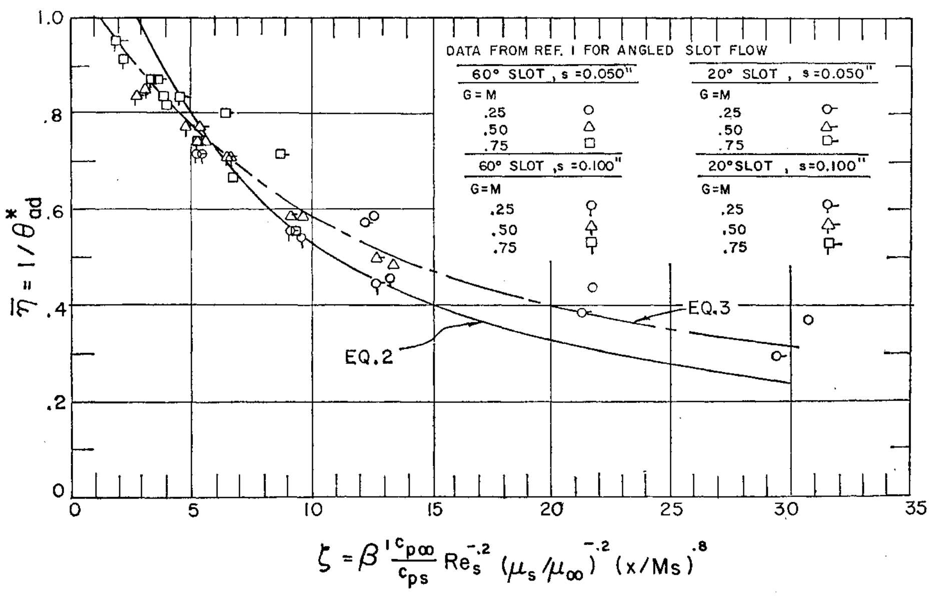

Fig. 1 Average film-cooling effectiveness for two-dimensional slot.

Received March 30, 1970.
* Professor and Director, Thermodynamics and Heat Transfer Laboratory. Fellow AIAA.
† Professor, Mechanical Engineering Department.
‡ Research Fellow, Mechanical Engineering Department.

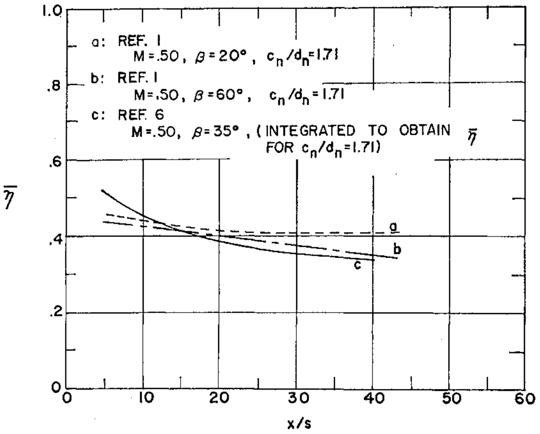

Fig. 2 Average film-cooling effectiveness for row of discrete holes.

experiments results in

$$\bar{\eta} = 1/(0.90 + 0.080\zeta) \tag{3}$$

which is shown in Fig. 1. The best fit to the data requiring that $\bar{\eta} \rightarrow 1$ as $x \rightarrow 0$ gives,

$$\bar{\eta} = 1/(1 + 0.065\zeta) \tag{4}$$

It should be noted that use of θ_{ad}^* rather than $\bar{\eta}$ as ordinate in Fig. 1 would make the scatter appear significantly reduced.

Heat Transfer—Two-Dimensional Slot

The parameter Φ_0 presented by the authors is the ratio of the average heat-transfer coefficient over a distance x/s with film injection to the average heat-transfer coefficient over the same distance without film injection. The experimental determination in Ref. 1 demonstrates again, in agreement with Ref. 2–4, that the normal heat-transfer coefficient from non-film-cooling results can be used except at high angles of injection. At first glance, the increase of heat transfer because of the film cooling for high angles of injection appears significant at the large blowing rate. However, the injected mass flow was apparently as high as 25% of the total free-stream mass flow. This additional mass could change the freestream Reynolds number by 25% resulting in approximately a 20% change in the freestream heat-transfer rate. This is also indicated by the significant increase in heat transfer even for the relatively long plates.

Film-Cooling Effectiveness—Row of Discrete Holes

The multiple hole data can be compared with Ref. 7 in which adiabatic wall temperatures were measured with coolant injection through a single hole. The assumption that the momentum equation is not coupled with the energy equation makes the solution of the energy equation linear and the effectiveness of several single holes with the required spacing can be obtained by superposition of single hole data. This concept was used by Malhotra and Cermak[8] for comparison of point source and line source mass diffusion data. Adding the effect of adjacent holes described by the effectiveness from Ref. 7, and averaging both longitudinally and transversely gives the average effectiveness for multiple hole data. The result of such a calculation is presented in Fig. 2 for $M = 0.5$, $\beta = 35°$, and for hole spacing of 1.71. Also presented are the curves from Ref. 1 for $M = 0.5$, $\beta = 20°$, and $\beta = 60°$, both for a hole spacing of 1.71. The agreement appears to be very good, indicating that the heat source model works well for injection through an arrangement of holes, at least at relatively small M.

References

[1] Metzger, D. E. and Fletcher, D. D., "Evaluation of Heat Transfer for Film-Cooled Turbine Components," *Journal of Aircraft*, Vol. 7, No. 6, Nov.-Dec., 1970, pp. 33–39.

[2] Hartnett, J. P., Birkebak, R. C., and Eckert, E. R. G., "Velocity Distributions, Temperature Distributions, Effectiveness and Heat Transfer for Air Injected Through a Tangential Slot into a Turbulent Boundary Layer," *Transactions of the ASME, Ser. C: Journal of Heat Transfer*, Vol. 83, 1961, pp. 283–306.

[3] Hartnett, J. P., Birkebak, R. C., and Eckert, E. R. G., "Velocity Distributions, Temperature Distributions, Effectiveness and Heat Transfer in Cooling of a Surface with a Pressure Gradient," *International Developments in Heat Transfer*, Pt. 4, 1961–62, American Society of Mechanical Engineers, pp. 682–689.

[4] Seban, R. A., "Heat Transfer and Effectiveness for a Turbulent Boundary Layer with Tangential Fluid Injection," *Transactions of the ASME, Ser. C: Journal of Heat Transfer*, Vol. 82, No. 4, 1960, pp. 303–312.

[5] Librizzi, J. and Cresci, R. C., "Transpiration Cooling of a Turbulent Boundary Layer in an Axisymmetrical Nozzle," *AIAA Journal*, Vol. 2, No. 4, April 1964, pp. 617–624.

[6] Goldstein, R. J. and Haji-Sheikh, A., "Prediction of Film Cooling Effectiveness," *ASME 1967 Semi-International Symposium*, Tokyo, Japan, 1967.

[7] Goldstein, R. J., Eckert, E. R. G., and Ramsey, J. W., "Film Cooling with Injection Through Holes: Adiabatic Wall Temperatures Downstream of a Circular Hole," *Transactions of the ASME, Ser. A: Journal of Engineering for Power*, Vol. 90, 1968, p. 384.

[8] Malhotra, R. C. and Cermak, J. E., "Mass Diffusion in Neutral and Unstable Stratified Boundary-Layer Flows," *International Journal of Heat Mass Transfer*, Vol. 7, 1964, pp. 169–186.

Erratum: "Prediction of Geometry of Sonic Boom Waves Incident on Arbitrarily Oriented Plane Walls"

Balusu M. Rao
Texas A & M University, College Station, Texas

and

Glen W. Zumwalt
Wichita State University, Wichita, Kansas

[J. Aircraft, 7, 256–260 (1970)]

In Eq. (2), the first parenthesis was misplaced. Eq. 2 should be $\Delta T_p = 2(T_g - T_p) = (2/V)(D_{gv} - D_{pv})$.

Received September 9, 1970.