HEAT TRANSFER NEAR TURBINE NOZZLE ENDWALL

Minking K. Chyu
Department of Mechanical Engineering
University of Pittsburgh
Pittsburgh, PA 15261, USA

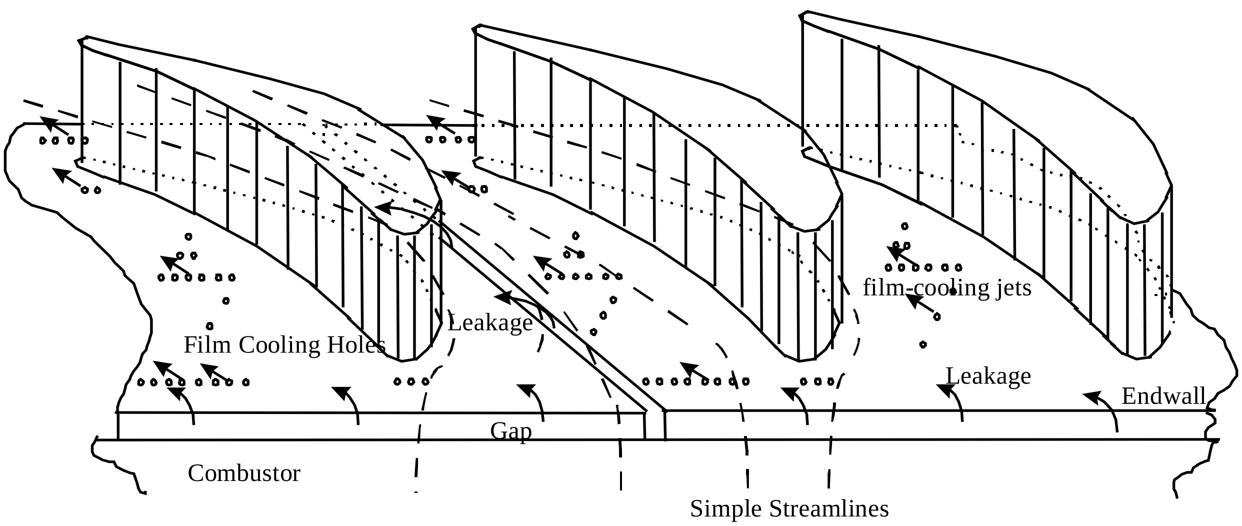
ABSTRACT

Endwall heat transfer is an important design consideration for modern gas turbines. The first stage nozzles or vanes of gas turbine are exposed to severe thermal load from the high temperature gas exiting the combustor. In an effort to increase the system performance and cycle efficiency, modern gas turbines are operated with high temperatures that are close to the metallurgical limits of constructing materials. To ensure component reliability, cooling is thus required for protection of the hot sections. In the past, thermal load on the turbine endwall was not alarmingly excessive, as combustor cooling and dilution air reduced the temperature of the flow adjacent to the endwall. Therefore, the focus of hot section control in gas turbines has been directed primarily to airfoils. Recently, modern combustor designs for low NO_x constraint have flattened the temperature profile at the turbine inlet and raised the level of thermal loading on the endwall. As a result, this has renewed the interest in endwall cooling. Cooling of the endwall is typically accomplished by film cooling. However, this approach poses considerable challenges because the secondary flows near the endwall tend to lift the coolant off the endwall surface and entrain the coolant into the core of hot gas flow. Secondary flows in a turbine passage bears several complex features which include horseshoe vortices and their evolution on the suction and pressure surfaces, passage vortices, gap leakage, and tip-clearance blow-by. Secondary flows become more dominant and complex for advanced turbines with low-aspect ratio and highly loaded airfoils. This paper reviews important aspects of heat transfer and recent advances in turbine endwall cooling.

Heat transfer characteristics over modeled cascade endwalls have been documented since the 1980's. Strongly influenced by the secondary flows aforementioned, heat transfer on the endwall surface is expected to be highly non-uniform and can only be resolved by localized data. Several local studies that used either traditional thermocouple measurement [1] or analogous mass transfer technique [2,3] have revealed detailed distributions of convective heat transfer coefficient over endwall surfaces under different thermal conditions. The values of local heat transfer coefficient vary substantially, by more than an order of magnitude, over the endwall. Aided by flow visualization, the heat convection patterns were found to be well correlated with the secondary flows in the near wall region. These results also help discovering several new flow features near the corners of endwall-airfoil junction.

While a significant amount of work pertaining to endwall heat transfer has been directed to the interaction of film cooling with secondary flows, one class of problem that is unique to endwall cooling is concerned with the flow leakage through the interfacial gap on the endwall. As turbine nozzles or rotors are usually assembled with a number of individual airfoils of singlet or doublet form. This type of assembly almost always produces a gap, formed in the

junction of different components to accommodate thermal expansion for different operating conditions. Usually no seal is implemented in the gap to separate the hot passage gas to the flow outside, so that a leakage flow through the gap can be induced radially, when the static pressure across the gap is different. Figure 1 shows the schematic of the gap leakage from the endwall with a doublet airfoil-assembly. Several recent studies [4-6] have been directed to exploring the effect of leakage on the endwall cooling and its interaction with the adjancent film cooling. One of the key features in the system is that the heat convection is likely driven by four different temperatures, which complicates the way of measuring cooling performance and heat transfer coefficient. Using both transient liquid crystal technique and laser-induced thermographic imaging method, Chyu et al. [4,5] reported that film cooling effectiveness is strongly affected by the presence of gap leakage. In addition, the amount of leakage and the interface geometry are two dominant factors of heat transfer characteristic over the endwall.



Another area has attracted significant attention recently is concerned with endwall contouring. Current turbine configurations permit implementing a considerable amount of contouring between the combustor exit cross section and turbine inlet cross section. The primary design issue here is to determine the optimal endwall contouring that minimizes horseshoe and passage vortices so that the cooling performance near the endwall region can be enhanced. In a series of studies combining experimental measurements with a guide nozzle simulator [7,8] and numerical simulation [9], the effects of coolant bled just ahead of contoured endwall have been investigated in great detail. The values of film effectiveness and the size of coolant coverage region depend on the mass flow ratio of the injectant and core flow. For very low bleed ratio, coolant is found to convect across the endwall surface and accumulate near the suction surface, resulting in poor thermal protection near the pressure side of the passage. As the coolant mass flow is increased, the influence of the coolant spreads to the entire endwall surface. When the injectant flow rate is sufficiently high, the pressure-side cooling becomes dominant and the suction-side corner is less protective, which is uncommon to traditional film cooling designs.

REFERENCES

1. Gaugler, R.E. and Russell, L.M., 1984, "Comparison of Visualized Turbine Endwall Secondary Flows and Measured Heat Transfer Patters," ASME J. Engineering for Gas Turbines and Power, Vol. 104, P. 715-722
2. Goldstein, R.J. and Spores, R.A., 1988, "Turbulent Transport on the Endwall in the Region Between Adjacent Turbine Blades," ASME J. Heat Transfer, Vol. 110, pp. 862-869.
3. Chen, P.H. and Goldstein, R.J., 1992, "Convective Transport Phenomena on the Suction Surface of a Turbine Blade Including the Influence of Secondary Flows Near the Endwall," J. Turbomarchinery, Vol. 114, pp. 776-787.
4. Yu, Y. and Chyu, M.K., 1996, "Influence of a Leaking Gap Downstream of the Injection Holes on Film Cooling Performance," *J. Turbomachinery*, *Trans. ASME*, Vol. 120, 1998, pp. 541-548.
5. Chyu, M.K. and Hsing, Y.C., 1996, "Use of Laser-Induced Fluorescence Thermal Imaging System for Film Cooling Heat Transfer Measurement," ASME 96-GT-430.
6. Lin, Y.-L., Shih, T. I-P., Chyu, M.K. and Bunker, R.S., 2000, "Effects of Gap Leakage on Fluid Flow in a Contoured Turbine Nozzle Guide Vane," ASME 2000-GT-555.
7. Burd, S.W. and Simon, T.W., 2000, "Effects of Slot Bleed Injection over a Contoured Endwall on Nozzle Guide Vane Cooling Performance: Part I – Flow Field Measurements," 2000-GT-199.
8. Burd, S.W., Satterness, C.J. and Simon, T.W., 2000, "Effects of Slot Bleed Injection over a Contoured Endwall on Nozzle Guide Vane Cooling Performance: Part II – Thermal Measurements," 2000-GT-200.
9. Shih, T. I-P., Lin, Y.-L. and Simon, T.W., 2000, "Control of Secondary Flows in a Turbine Nozzle Guide Vane by Endwall Contouring," 2000-GT-556.