# Film Cooling Simulation and Control

Sumanta Acharya
Mechanical Engineering Department
Louisiana State University
Baton Rouge, LA 70803

In film cooling, the mixing between the injected coolant film and the hot crossflow controls the dispersion and effectiveness of the cooling process. The coolant flow is characterized by unsteady coherent structures, and the effect of these anisotropic structures along with small scale turbulence must be correctly modeled for accurate predictions. The most common method for modeling film cooling utilizes the time-averaged Reynolds-averaged Navier-Stokes (RANS) equations that incorporate a turbulence model. In this paper, RANS based approaches are first discussed and representative results shown.

One of the primary drawbacks of RANS is its inability to correctly predict the turbulent stresses and their anisotropy. Typically, vertical penetration of the coolant jet is higher than the measured values while the lateral stresses and the lateral spreading is under-predicted. This behavior is persistent even for complex models such as the Reynolds stress models indicating that the modeled stress equations do not have the right physics. Only ad-hoc corrections to represent the effects of anisotropy and to limit turbulence over-production or eddy viscosity (called realizable corrections) seem to improve the predictions. However, these corrections are based on empirical fitting designed to best match data, and can not be widely generalized.

As an exampled of RANS calculations, Fig. 1 shows centerline cooling effectiveness for film cooling resulting from a cylindrical inclined coolant hole. Several RANS predictions are compared with measurements, and indicate the variable nature of these predictions and lack of agreement with data.

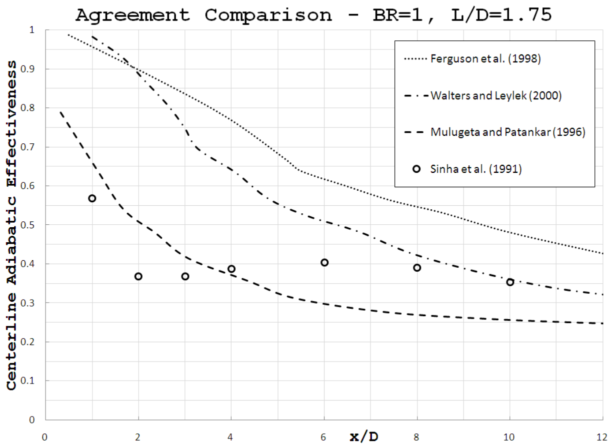

Figure 1: Centerline cooling effectiveness predictions with two-equation models (BR=1)

Since calculations based on the Reynolds-averaged equations do not adequately predict the turbulent statistics, it is argued that emerging approaches where the unsteady equations are solved directly provide increased quantitative prediction accuracy. Such approaches are termed Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) in the literature. It is shown that such approaches provide realistic solutions that agree with experimental visualizations, and that, first- and second-order statistics from these simulations agree well with measurements. These unsteady simulations enable: (1) a clearer understanding of the flow physics since spatial and temporal evolution of flow structures can be mapped, (2) utilization of DNS budgets to guide turbulence model development and (3) conduct numerical experiments for design, control and optimization. These issues are briefly discussed in this paper.

LES calculations of the centerline cooling effectiveness are presented in Fig. 2 for a BR of 0.5. As can be seen, these results are in excellent agreement with measured data. Detailed comparisons of the LES results with velocity, turbulence and cooling effectiveness will be presented in the full paper.

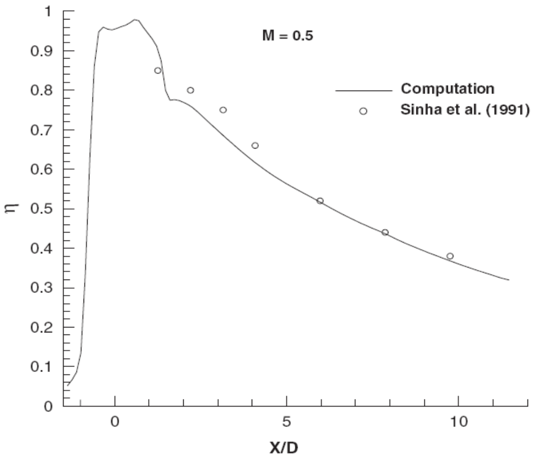

Figure 2: Film cooling effectiveness along the centerline of the computational domain for BR = 0.5 (Tyagi and Acharya, 2003).

While it is generally recognized that RANS calculations are the most cost-effective from a computational perspective, the improved predictions with LES and the availability of parallel computing at relatively low costs provide a reasonable justification for a greater usage of LES by the industrial community.

**References:**

Sinha, A.K., Bogard, D.G., Crawford, M.E., 1991, Film-Cooling Effectiveness Downstream of a Single Row of Holes with Variable Density Ratio, *ASME J. Turbomachinery*, **Vol. 113**, pp. 442-449

Tyagi, M., and Acharya, S., Large Eddy Simulation of an Inclined Film Cooling Jet, 2003, *ASME J. of Turbomachinery,* **Vol. 125**, pp. 734-742.