PREDICTION OF PRESSURE LOSS AND HEAT TRANSFER IN INTERNAL BLADE COOLING PASSAGES

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ABSTRACT

Modern day demands for higher efficiencies in gas turbine engines require the gas turbine cycle to operate at higher pressure ratios and, of greatest significance to the turbine designer, at high turbine inlet temperatures. Turbine inlet temperatures can exceed the maximum blade metal alloy temperature by more than 500 degrees, so the blades can survive only with the use of effective cooling methods. Cooling reduces the mean temperature of the blade material and includes both external (film or transpiration cooling) and internal cooling techniques (convection or/and impingement cooling).

For both industrial and aero gas turbines, the ability of predicting the internal flow and associated heat transfer in blade cooling passages is essential if accurate blade metal temperature and then blade life time is to be calculated quickly. Note that a decrease of 25^{o}C can in some circumstances double the life of a high-pressure turbine blade. Also a better prediction capability would allow helping to minimize the amount of flow taken from the compressor to cool the turbine blades, reducing the thermodynamic penalties, thus improving the overall gas turbine cycle efficiency, which is a factor of reduction of emissions.

The convective heat transfer within the internal passages of a turbine blade is usually augmented with the use of ribs. The ribs are designed to introduce additional flow mixing, through secondary flow generation and turbulence enhancement, increasing heat transfer locally. The optimum design is achieved only with a balance of heat transfer and friction factor augmentation. For a more efficient and cost-effective ribbed channel design, there is an impending need for improvement and validation of numerical heat transfer predictions, namely near-wall turbulence models. Computational Fluid Dynamics (CFD) codes must be benchmarked with experimental data to monitor both flowfield, pressure and heat transfer predictions on both a quantitative and qualitative level. Novel improvements in turbulence modeling (V2F model [1,2,3,4,5]) have recently allowed a jump in the confidence that one can have in CFD in accurately predicting turbulent heat transfer.

The objective of our work has been to compute the turbulent flow, the pressure loss and thermal fields in a ribbed passage while the rib inclination is varied from 90^{o} to 33^{o} (Figure 1). To this end, the CFD-code Fluent [6], using unstructured hybrid high-quality 3D meshes (Centaur [7]), has been considered. Three turbulence models have been tested and compared against the recent pressure-loss and analogous mass-transfer (naphthalene sublimation technique) experimental data from Cho et al. [8]:

- Standard k-ε model with wall functions
- Standard k-ε model with the 2-layer near-wall approach
- V2F model

As far as pressure loss is concerned, a pretty good agreement is found for all the turbulence models (Figure 2). Only the use of wall functions at 90^{o} delivers inaccurate predictions. This is due to the fact

that it is almost impossible in this configuration to respect, in the same time, the lower distance-to-the wall limit of the first computational point near solid walls ($y^+>30$) and a sufficient meshing density of the ribs. However, only the V2F model is able to quantitatively predict the heat transfer levels (Figure 3). Both k-ε predictions are quantitatively inaccurate, and can also lead to bad qualitative assessments. Further quantities of interest, namely secondary flow patterns (although without any experimental data) and local heat transfer distribution along the ribbed wall, will also be presented in the final paper. A comparison with a correlation developed by Han and co-workers [9,10,11] will finally be performed.

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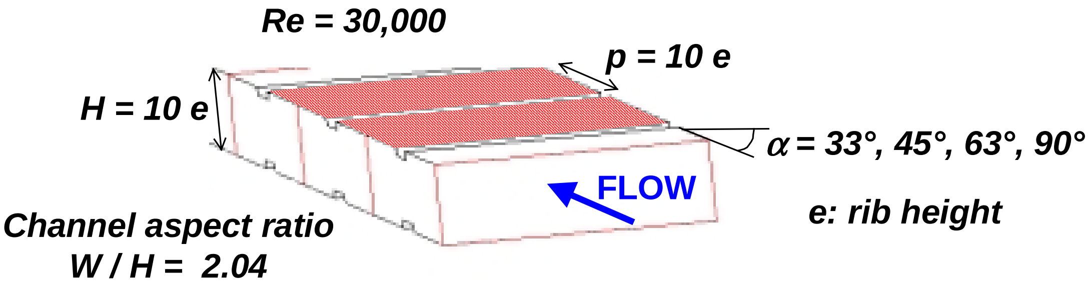

Figure 1 *Geometry of the ribbed channel considered*

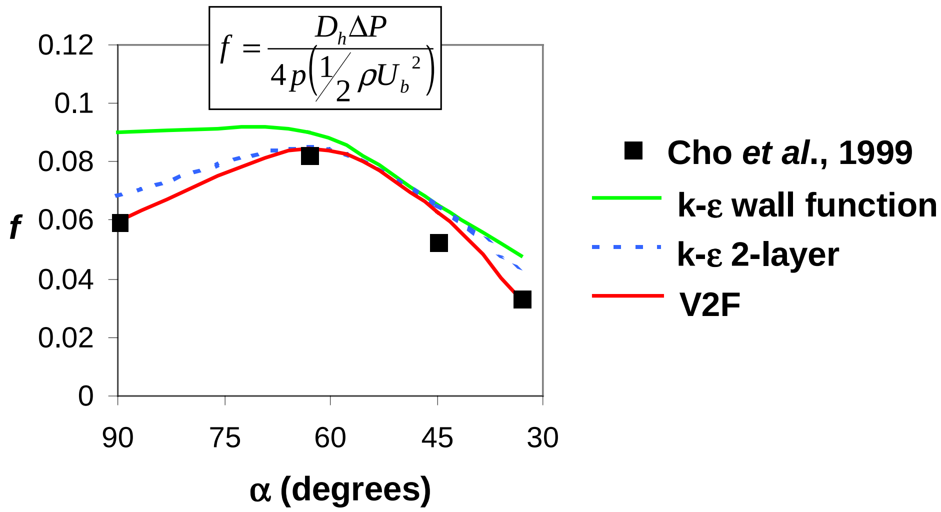

Figure 2 *Pressure loss (friction factor) across one rib module*

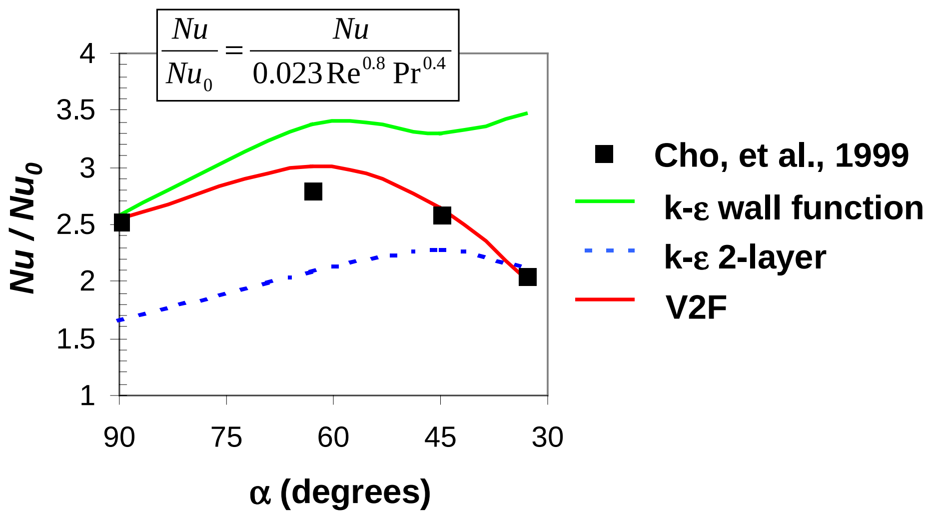

Figure 3 *Ribbed-wall averaged heat transfer enhancement*