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MASS/HEAT TRANSFER IN DIMPLED TURBINE-BLADE COOLANT PASSAGES

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ABSTRACT

To increase thermal efficiency, gas turbine blades are being designed to operate at increasingly higher inlet temperatures. This requires the development of more effective internal and external blade cooling strategies. Internal cooling is generally enhanced using rib-turbulators[1-3] that provide additional surface area for heat transfer, interrupt the development of the boundary layer, and increase turbulence levels.

In recent years, the concept of using indented (dimpled) surface has attracted attention due to the high heat transfer enhancement and lower pressure loss penalty associated with dimples. Russian investigators performed many of the early studies regarding the effect of dimples on heat transfer and flow structure[4-6]. Chyu, et al.[7] reported an experimental study with hemispherical and tear-drop shaped dimples. The dimples were imprinted on a heated plate with staggered arrays. Their results showed that everywhere on the dimpled surface the heat transfer coefficients were significantly higher than the values on smooth wall. Over a range of Reynolds numbers, the overall heat transfer rate is about 2.5 times smooth surfaces values, while the pressure loss is about only half of the values caused by rib turbulators. Similar observations have been made by Mahmood et al. [8-9] who have reported heat transfer enhancements of the order of 2-2.5 with dimples.

The above studies have been reported for stationary coolant channels. In the present study, we examine the effect of dimples in rotating coolant channels. The naphthalene sublimation method is employed in this study. Measurements were made in a two-pass rotating coolant channel facility. The test plates have hollow recesses into which naphthalene can be poured. The experiments themselves consist of measuring the naphthalene surface contour (with a profilometer) before and after the experiments, and converting the sublimation depth into a mass transfer rate or Sherwood number.

The present work focuses attention on mass/heat transfer measurements with imprinted arrays of circular dimples on the test plates. The coolant flow passage is 0.0254m square. The leading and trailing surfaces are dimpled, while the side walls are kept smooth. Measurements are made at a Reynolds number of 21,000 and for Rotation number of 0 and 0.2.

Figures 1 and 2 show the spanwise-averaged Sherwood number ratio along the leading, trailing and side walls of both the inlet and outlet duct. The measurements indicate that dimples enhance surface mass/heat transfer. This enhancement is stronger in the inlet duct (Figure 1) than in the outlet duct (Figure 2). As seen in Figure 1, peak mass/heat transfer occurs immediately downstream the dimples ($Sh/Sh_0=5$ in the inlet duct), while the minimum mass/heat transfer occurs in the dimple region itself ($Sh/Sh_0=2$ in the inlet duct). Higher mass/heat transfer is also observed along the lateral edges of the dimple. The location of the Sherwood number peaks (Figure 3) suggest the existence of streamwise vortical structures generated from the leading and lateral edges of the dimples.

In Figures 1 and 2, it can be seen that heat/mass transfer is higher along the trailing wall in the inlet duct and along the leading wall in the outlet duct. This represents the effect of Coriolis-induced secondary flows. These flows are seen not to alter the basic heat transfer distributions in the vicinity of the dimples.

The effect of dimple shapes was also investigated in the present work. Four types of dimple shapes (square, triangle, circle and tear-drop) were studied in a stationary channel, with the goal of determining the dimple geometry with the highest mass/heat transfer enhancement. Sherwood numbers are obtained both inside and around the dimples at a Reynolds number of 21,000., and are shown in Figures 4 and 5 for a circular and tear-shaped dimple. The area-averaged Sherwood number around the dimple increases from 30% for circular dimples to 53% for tear-shaped dimples.

FIGURES AND TABLES

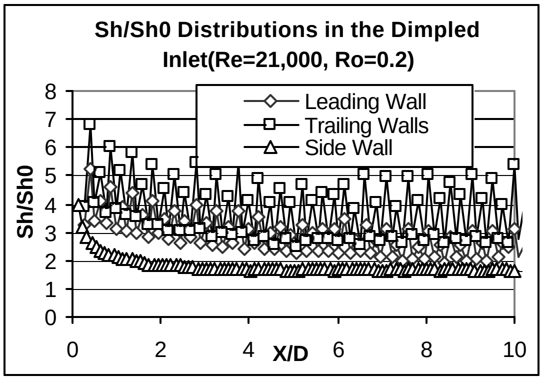

Fig.1 Spanwise Averaged Sh/Sh0 Distributions in Inlet

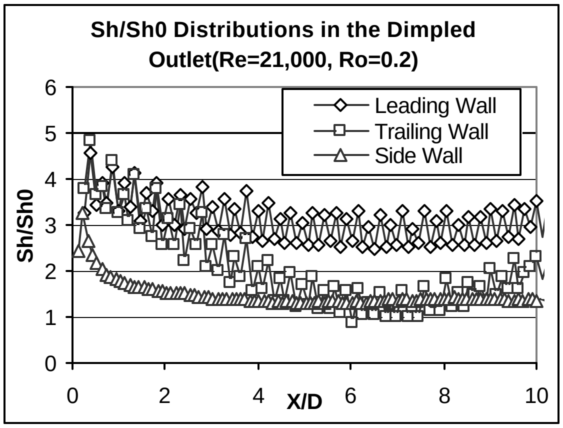

Fig.2: Streamwise Average Sh/Sh0 Distributions in Outlet

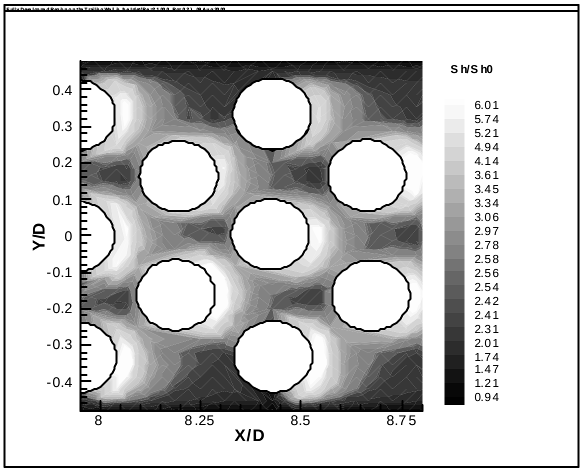

Fig.3 Sh/Sh0 Contours in the Fully Developed Region on Dimpled Walls (trailing wall in the inlet, Re=21,000 Ro=0.2)

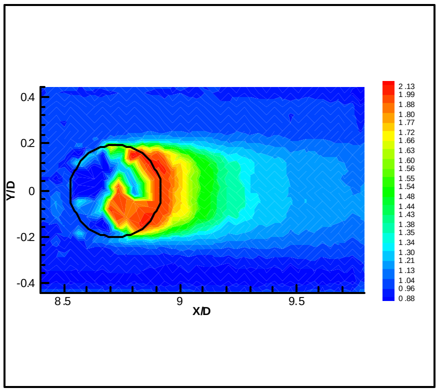

Fig. 4 Sherwood Number Contours around and inside Circular Dimples (Re = 21,000, Ro = 0)

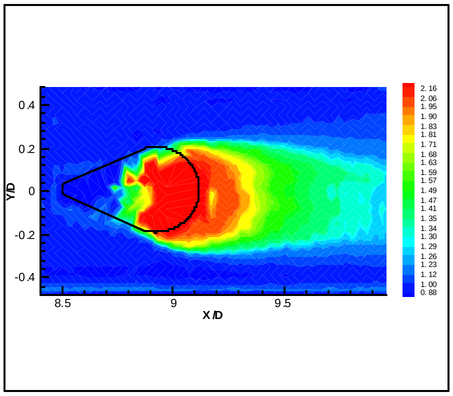

Fig. 5 Sherwood Number Contours around and inside tear-drop Dimples (Re = 21,000, Ro = 0)

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