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HEAT/MASS TRANSFER STUDIES IN CURVED CROSS-SECTION ROTATING CHANNELS

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ABSTRACT

Gas turbines are still one of the major thrust and power generators in the machine world. This paper presents the study of the heat/mass transfer through a radially outward internal cooling passage of a gas turbine blade with leading and trailing curved surface walls, using the naphthalene sublimation technique. While square and rectangular cross section channels have been studied extensively ([1], [2], [3], [4]), there is relatively little attention on channels with curved cross sections. There have been studies in bends and curved plates (ex. Chung. et. al [5], Arnal et. al [6]), which concentrate either on the flow over blade profiles or flow through a bend in the internal cooling passage. Laker et.al. [7] studied the flow through a circular duct, which gives an idea of the fluid flow through curved channels.

The experimental test rig for rotating mass transfer studies consists of a rotor with the test section on one end and counter balancing weight on the other. The test section consists of a single module of serpentine cooling channel whose internal sides are removable plates cast with naphthalene. Air flows at the required flow rate through the shaft of the rotor, through the test section and back out through the other end of the rotor to an exhaust. The Naphthalene surface of each of the test-section channel side is measured using a surface profilometer consisting of an LVDT and a computer-controlled traverse platform. The difference in height of the naphthalene surface before and after the test at preset coordinates on each plate surface gives the local amount of Naphthalene sublimated. From this, a Sherwood number (dimensionless mass transfer coefficient) is calculated. This Sherwood number can be converted into a Nusselt number through the mass-heat transfer analogy.

Figure 1 shows the different curved cross sections used during the experiments. The first section is defined as Section I for curved surfaces parallel to the blade profile and Section II for inwardly curved sections.

The experiments are done on walls with curvature 9.06 m^{-1} (0.23 $inch^{-1}$) and 15.11 m^{-1} (0.384 $inch^{-1}$) approximately, for Reynolds number of 10,000 and Rotation number in the range 0-0.07. The mass transfer data from the curved walled channels, is then compared to those from a smooth 4:1 rectangular duct with similar flow parameters. The local mass transfer data is analyzed mainly for the fully developed region and area-averaged to study the effect of Rotation number. The Sherwood number is normalized using the Mc Adams correlation for a smooth channel.

There are mainly two forces acting on the fluid flowing in a rotating channel. The centrifugal force, which tends to stabilize the flow in the channel and the Coriolis force, which induces secondary flows, and tends to destabilize the flow on the trailing wall (TW) of the inlet channel (flow directed radially outwards) and stabilize the flow on the leading wall (LW). The preliminary tests conducted on the 9.06 m^{-1} curvature sections (see Figure 2) showed the highest enhancement in mass transfer relative to the 4:1 flat-sided channel for the Section II channel at lower rotation numbers and a gradual decrease at higher Rotation numbers. The enhancement reduction is higher in the stabilized surface. Section I channel also shows a higher Sherwood number ratio than the corresponding 4:1 rectangular channel. This can be due to the small increase in surface area of the channel walls exposed to the coolant flow per unit volume of the channel, relative to that of a 4:1 rectangular channel. Or it might be due to the curvature effect of the walls on the mass transfer.

Observing the Sherwood number contour plots of Figure 3 on each side-surface of the inwardly curved channel it is noted that the destabilized wall (TW) displays a minimum near the center while the stabilized wall (LW) displays a minimum. This trend indicates that the usually single secondary flow pattern generated by rotation is split into two on either side of the central region which due to the restriction in crosssectional area is subject to lower velocities as the TW and LW boundary layers are connected. Higher velocities on either side due to reduced blockage lead to higher Coriolis forces, which give rise to the corresponding secondary flows. Further experiments are to be conducted in the higher curvature channels and for different Reynolds numbers in order to correctly qualify the effect of wall curvature on the mass/heat transfer results.

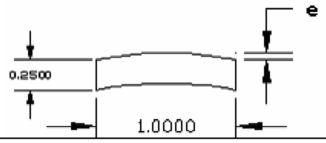
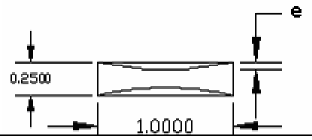
Section	Cross section
I or ((	
II or)(	

Figure 1: Cross-section of channels on which experiments are conducted.

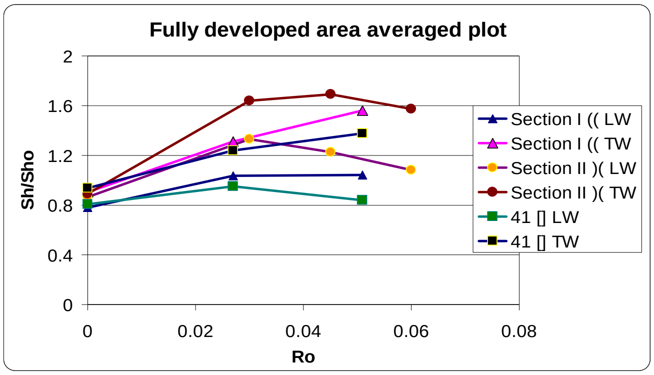


Figure 2: Fully developed area averaged plots for different sections.

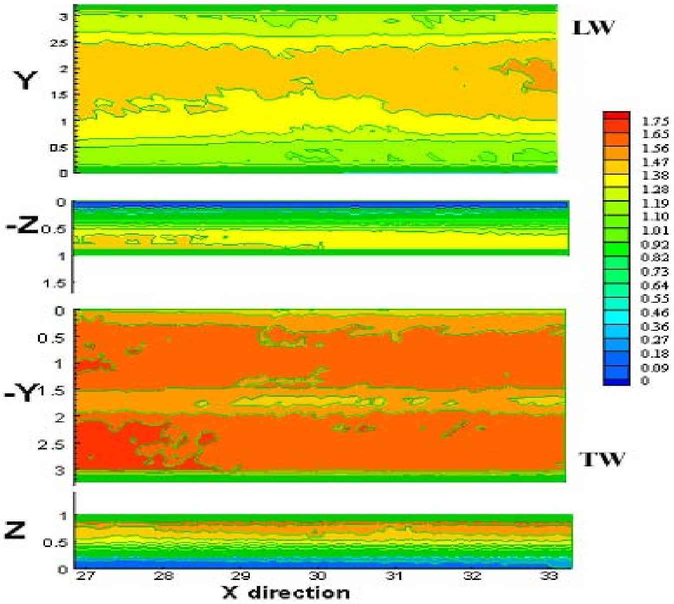


Figure 3: Contour plot of Section II Channel at Re=10,000 and Ro=0.027

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