ANALYSIS OF TRAILING EDGE TURBINE BLADE COOLING

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ABSTRACT

The gas turbine blade trailing edge play vital role in thermal analysis where flow behavior affects the entire region. The aerodynamics point of view a sharp and thin trailing edge required to lessen the profile losses. The conventional way is to discharge the lot of cooling air though a slot along the airfoil (blade cross-section) trailing edge. However, in scenario of internal cooling designs, coolant is not permissible to leave the channel except from the root section to avoid mixing of the gas in the main flow path with the coolant and loss of cooling medium. The challenge is to design an inner cooling channel, with the cooling medium entering and leaving the blade at root section that reduces metal temperatures to desired values with no increment in profile losses and at satisfactory cooling flow rate and pressure drop. Usually trailing edge blade has trailing edge slots where from the coolant leaves the blade and mixes with the main gas flow. The contemporary proposed a unique internal cooling channel design, which can cool the trailing edge without letting the coolant to mix with the gas flow. Therefore, it diminishes the thermal losses.

Keyword : - *Trailing edge1 , Internal cooling 2, Turbine blade3, and Aerothermal4*

Air extracted from the last stages of the compressor has been used as a cooling medium in gas turbines for years now. The extraction of air from the compressor results in a reduction in overall performance of the turbine. In combined cycle power plants, steam is available which can be used as the cooling medium replacing air. Steam has better thermal properties compared to air which makes it an attractive choice as a coolant. To show its supremacy on air, a comparison of the performance of both coolants has been made, where steam as well as air has been used as coolant in a two-pass smooth channel shown in Fig. 4-16 under similar thermal conditions.

Five different coolant flow rates were selected such that the Reynolds number at the inlet of the channel ranges from 20,000 to 100,000. The temperature and pressure at the inlet was the same for both air and steam resulting in the Prandtl number of steam equal to 0.94, while for air it was 0.68. As the thermal properties of air and steam are different at the same pressure and temperature, the velocity (and mass flow rate) at the inlet is different at the same Reynolds number such that under the selected conditions the velocity of air was found higher than that of steam at the inlet. Normalized temperature profiles at trailing edge corner are shown in Fig. 7-1 for all the cases

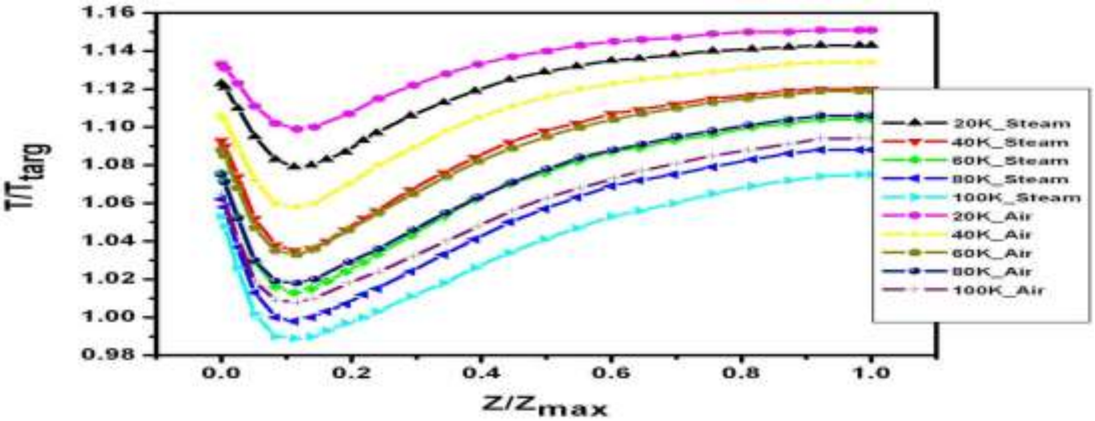

Figure 6.1: Normalized temperature profile at trailing edge corner for two-pass smooth channel atdifferent Reynolds number for air and steam.

One clear observation is that with the increase in flow rate, heat transfer increases and thus the temperature values drops for either of two coolants. Although the velocity at inlet was less when steam was used, the drop in temperature magnitude is more compared to air at the same Reynolds number. It is also worth to note that the temperature profile one gets at higher Reynolds number using air, is reproduced using steam at low Reynolds number. This shows that at similar thermal conditions, the required flow rate of steam is lower than that of air to achieve the same cooling. As an example, the temperature profile achieved by using air at Reynolds number = 80,000 was reproduced by using steam at Reynolds number = 60,000. Thus there is a reduction of 25% in required Reynolds number. This corresponds to a reduction of 45% in mass flow rate under given conditions.

6.1 Heat Transfer

Nine different two-pass trapezoidal channels are compared under the same thermal conditions. The purpose is to select the design that yields the lowest metal temperatures. The hottest region of the channel is the corner of the trailing edge called trailing edge corner in Fig. 4-16. The normalized temperatures on that corner are plotted for all of the nine cases and shown in Fig. 7-2. Point 0 is the edge point, where tip wall and the trailing edge meet. As for all cases, the inlet pass and the turn region are the same, the normalized temperature values are almost the same for all the cases at side wall attached to the turn region (Z/Zmax = 0 to 0.05). The effect of different heat transfer enhancement methods is more visible after this length. All ribbed channels except Case C, results in a notable reduction in the wall temperature. The temperatures are not only reduced but also approach a constant value along the length which is desired in reducing the thermal gradients in the metal. Surprisingly, neither of the finned channels with smooth bottom walls (Case F, G and H) leads to a reduction in metal temperatures. In fact, it can be observed that the bigger the fin is, the more ineffective it is at reducing the metal temperature. Another notable observation is that the channel with ribs at the trailing edge only (Case C) and smooth channel have similar results. This indicates that the ribs used at the trailing edge are not helping much in increasing heat transfer. On other hand, the ribs at the bottom wall are more helpful in reducing metal temperatures (or in other words increasing the heat transfer). Interestingly, providing ribs or a fin at the trailing edge has no significant effect, as these produce similar results as the channel with the ribs at bottom wall only.

For all channels, the normalized temperatures are more than the target value of T/Ttarg = 1 along the length. This means that none of the channel design is acceptable. Therefore further changesin the design are required to achieve the goal.

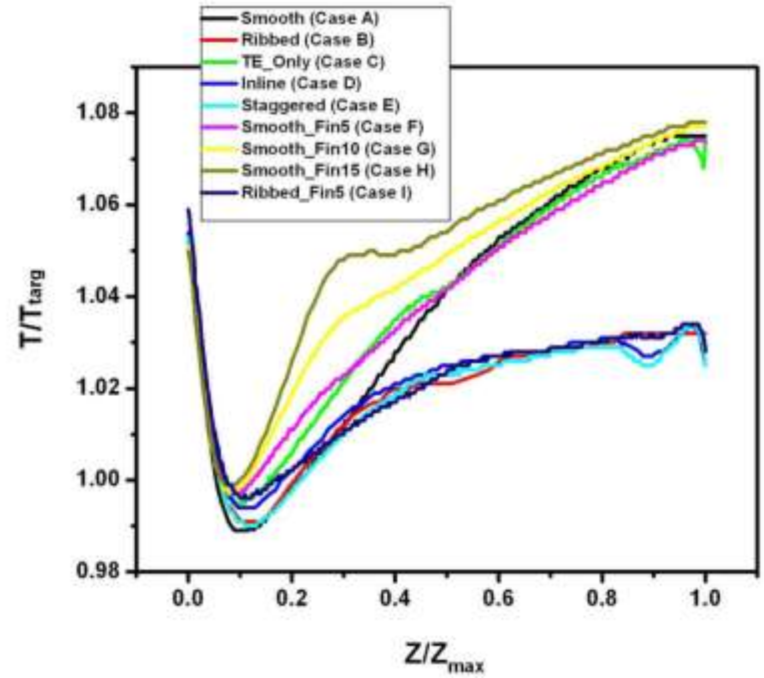

Figure 6.2: Temperature profiles at trailing edge corner for all cases.

6.2 Pressure Drop

Turbulators and other heat transfer enhancement methods may result in an increase in heat transfer and a reduction of the metal temperatures but they can increase the pressure drop. Thus it is very important to compare the pressure drop for these designs. Static pressure values were monitored at two points. Point 1 is at a distance of 14 mm from the tip wall to the inlet pass while point 2 is at a distance of 70 mm from the tip wall to the outlet pass. Equation 4.3 is used to calculate the friction factor f, where *l* is the length at the symmetry plane from one point of pressure measurement to the other point. Ac and Dh are the cross sectional area and hydraulic diameter respectively at station 1. The friction factor was normalized with fo, the reference friction factor for fully developed turbulent flow through a smooth channel, given by Eq. 4.4. Figure 7-3 presents the results for the friction factor ratio calculated in this way for all cases.

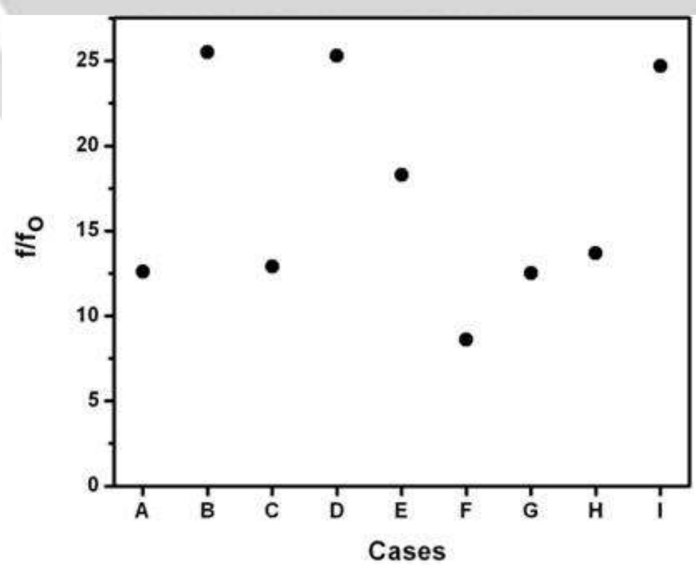

Figure 6.3: Pressure drop across different channels.

The lowest pressure drop is observed for Case F (smooth channel with small fin) but the heat transfer enhancement for this case is not significant. It was observed from Fig. 7-2 that the channels with ribs at the bottom wall result in a reduction in metal temperature. So comparing the pressure drop associated with those reveals that Case E (ribs in staggered arrangement) offers a small drop in pressure in comparison. Thus it is concluded, that for higher heat transfers with lower pressure drops, a channel with ribs at the bottom wall as well as at the trailing edge in staggered arrangement is suitable for further improvements.

6.3 Variation in Divider Wall

Its miles observed that for all cases, the normalized temperature values are above the target price of one, no longer most effective on the nook however also along the length of the trailing part corner. Therefore extra innovative designs are required to achieve the intention. For inner turbulent flows Nusselt quantity is described as

$$Nu \quad f(\mathrm{Re}, \mathrm{Pr}) \qquad \textbf{(7.3)}$$

These supportersandsuggest that for regular physical propoerties, warmness transfer increases with an increase in fluid pace. If the waft within the outlet skip is multiplied somehow, wall temperatures may be decreased. versions in the divider wall orientation have been tested that intention to boost up the waft inside the outlet bypass to lessen wall temperatures in this place wherein they're highest. on the left hand side in discern 6.3, a -pass smooth channel is proven which has a tapered divider wall at the same time as on right hand facet; a two-pass easy channel with a tilted divider wall is proven. inside the tapered case, the divider wall is altered such that the width of the inlet skip remains the equal and is regular alongside the duration as in the base case (Case A), however the outlet skip turns into a convergent channel. The maximum width of the divider wall is 4 mm, at the same time as it is zero.eight mm huge on the opposite quit. inside the other case, the divider wall is tilted with an attitude of 88° as a result making the inlet as well as the hole skip as converging channels. The maximum width at inlet is 5.86 mm while that at outlet the maximum width is 7.91 mm.

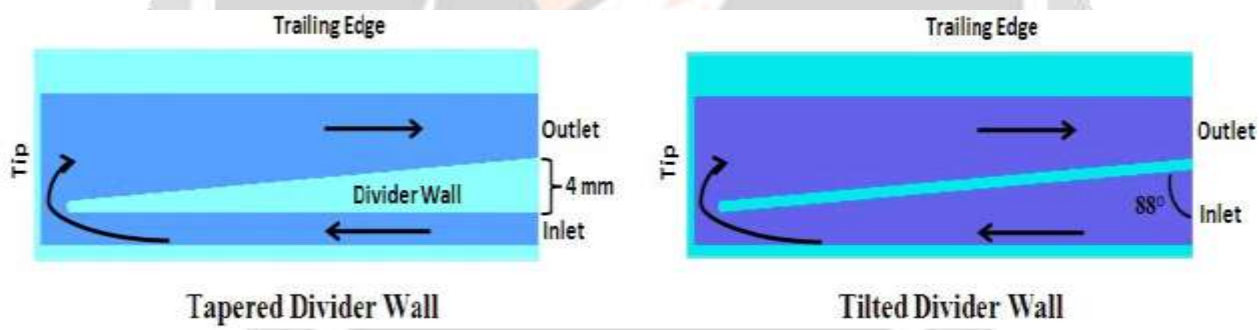

Figure 6.4: Two-pass smooth channel with tapered and tilted divider wall.

the rate magnitudes on the symmetry plane of these two cases are proven in Fig. 7-five. The Reynolds range, on the inlet is same for each channels therefore on the inlet of the tilted divider wall channel which has huge hydraulic diameter; the velocities are low in comparison to the ones at the inlet of the tapered divider wall channel with smaller hydraulic diameter. The converging channels outcomes in growth in velocities, as expected. For the channel with tilted divider wall, the float is extra elevated within the outlet pass because it follows an improved float from the converging inlet skip.

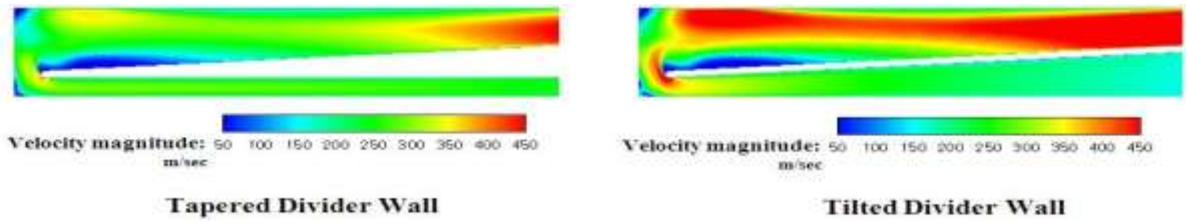

Figure 6.5: Velocity magnitudes at the symmetry plane of two-pass smooth channel with tapered andtilted divider wall.

The effect of this expanded go with the flow may be seen in Fig. 6.6, which offers the normalized temperature profile at trailing area corner for those cases and compares it with that of the clean channel (Case A). The glide situations at the turn region of a clean channel (Case A) and channel with tapered divider wall are similar consequently the temperature profiles for the 2 also are comparable to begin with. The multiplied glide in the outlet skip consequences in a drop in temperature. In case of the channel with tilted divider wall, the glide on the turn is greater expanded consequently it outcomes in a better temperature drop.

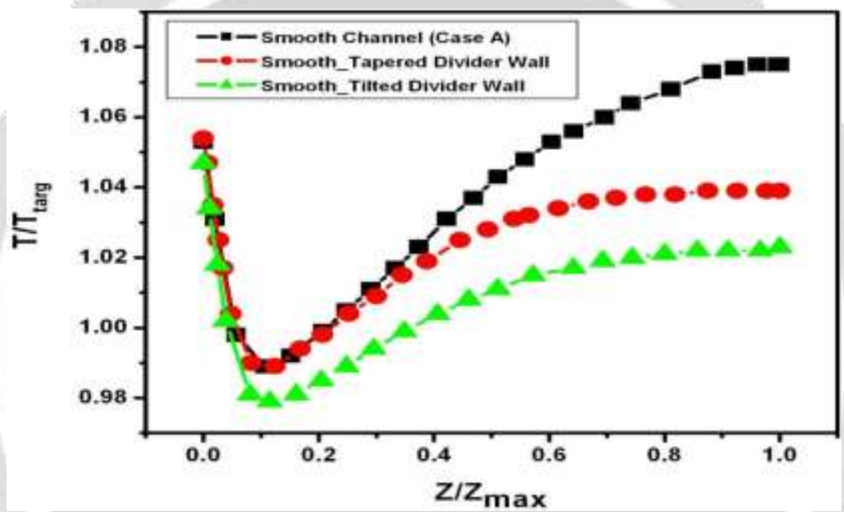

Figure 6.6: Temperature profile at trailing edge corner for a smooth channel and its two variations ofdivider wall.

Even though the clean channel with tilted divider wall facilitates in decreasing the temperature values significantly, still the values are above the target fee of 1. Consequently greater upgrades are wished in the layout. The first-rate choice is to introduce a staggered arrangement of ribs at the outlet skip of this tilted divider wall channel. The cause is that a staggered association of ribs gives the least pressure drop. Determine 6.7 figure the speed magnitudes on the symmetry aircraft of the sort of mixture. The elevated flow at the side of the ribbed triggered secondary flow is anticipated to enhance warmth transfer.

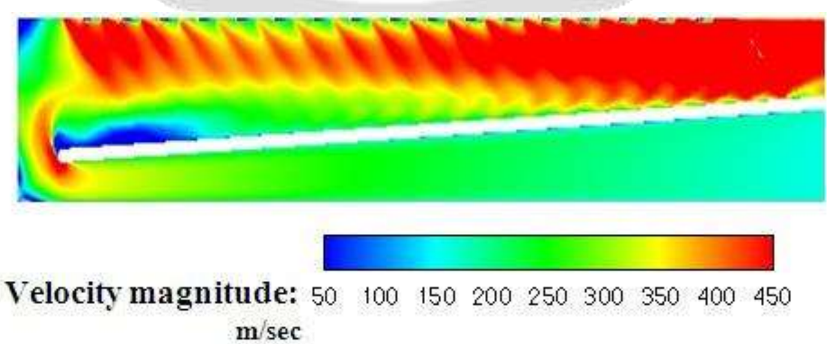

Figure 67: Velocity magnitudes at the symmetry plane of two -pass channel with staggered arrangementof ribs and tilted divider wall.

The end result of this mixture is shown in Fig. 6.8, which offers the normalized temperature

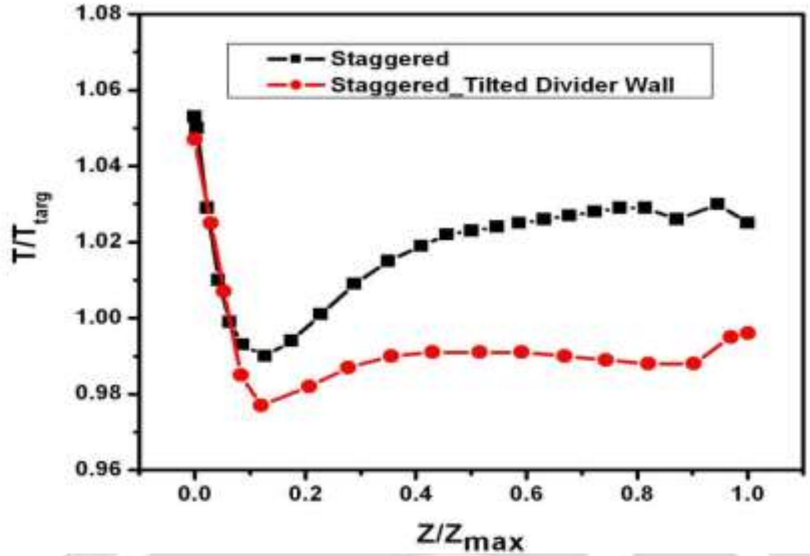

Figure 6.8: Temperature profile at trailing edge corner for a staggered ribbed channel and its variation of divider wall.

profile at trailing aspect nook of this channel and compares it with staggered ribbed channel (Case E). The new association is helpful in decreasing the wall temperature below the target value except on the initial duration of Z/Zmax = 0 to 0.08.It is crucial to look if different areas of the channel also are in an appropriate range or now not. Figure6.9 suggests the contours of the normalized temperature at one-of-a-kind walls of the channel. at the left hand aspect, the dimensions is similar to in the preceding figures. To get a clean photo, the dimensions is narrowed and is shown on the right hand side. it is discovered that besides for a small location inside the corner (in which the lowest wall, trailing aspect and tip meets) the temperature values are in appropriate variety.

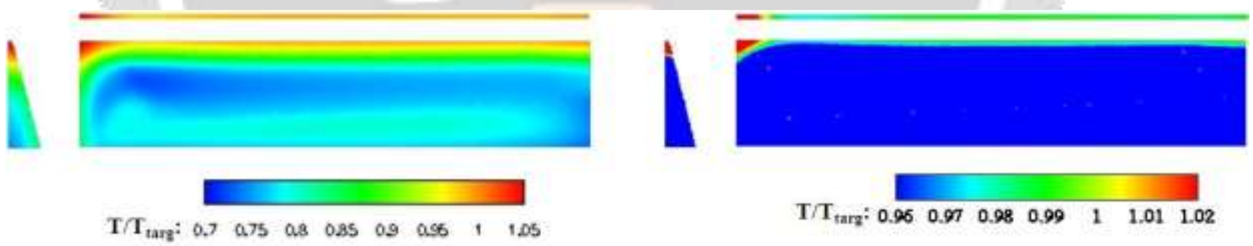

Figure 6.9: Normalized temperature contours at different walls of the channel with tilted divider walland staggered arrangement of ribs.

6.4 Impingement at Corner

Figure 6.8 and 6.9displays that a channel with tilted divider wall and staggered association of ribs in the outlet pass helps in lowering the temperature values appreciably to the goal cost in most of the regions of the trailing area. But nonetheless the nook of the channel isn't always inside the applicable temperature variety. Therefore extra aggressive method is needed to cool the nook. One such approach is to impinge the glide on that surface. Discern 6-10 shows the top view of three specific configurations which purpose to impinge the go with the flow on the corner, keeping the tilted divider wall since it has proved to be effective in lowering the wall temperatures. The cause is to peer the effect of the impingement at the corner only; therefore, those variations are made in the clean channel to reduce the complexity of the trouble. Case 1, is a easy channel with a tilted L-shaped divider wall wherein the attitude among the 2 legs is 60°. This L-shape enables direct the fluid to the corner. The maximum distance L1, of this divider wall from the tip is 5.22 mm even as the minimum distance L2, is 4.44 mm. The L-fashioned divider wall is truncated on the end such that its distance from the trailing edge I1, is 1.five mm whilst I2, is 2 mm. The purpose of this truncation is to permit the drift to diffuse frivolously in the outlet skip. Case 2 and Case 3 have the equal dimensions besides those distinct styles of openings inside the L-fashioned divider wall are brought. The reason is to do away with the low stress sector predicted in Case 1. The hole in Case 2 is tapered such that the most width of the outlet is 1.75 mm even as the minimum width is 0.77 mm. For Case three, an opening with consistent width of 0.7 mm is furnished. The give up of the divider wall before the hole is wedge shaped.

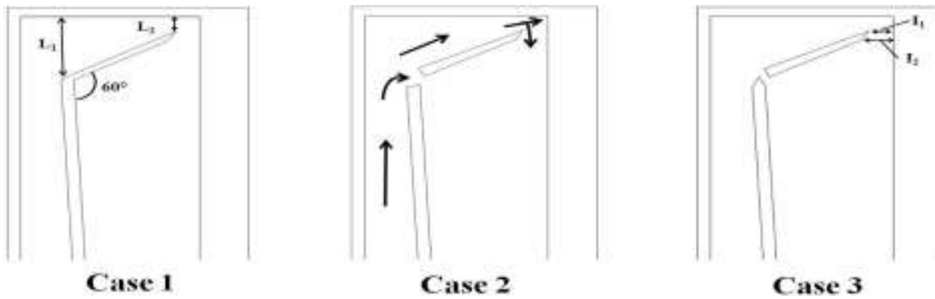

Figure 6.10: Top view of three different cases of impingement cooling of smooth channel.

The rate contours on the symmetry plane of those 3 cases is proven in discern 7-11. For Case 1, the fluid impinges on the nook with excessive velocity. It then paperwork a wall jet and continues to waft alongside the trailing edge inside the outlet skip. The excessive velocity area in the outlet skip that is connected to the divider wall is within the reverse route. This outcomes in a big recirculation area in rest of the opening bypass, consequently a high pressure drop is anticipated in this design. the hole gift within the divider wall, as in Case 2 and Case 3, facilitates in getting rid of this large wake. but by way of doing this, the mass glide is split and the velocity at the nook isn't always that excessive (compared to Case 1) which reduces the impinging effect on the nook. For Case 2, the flow thru the opening mixes greater lightly with the float at the outlet bypass as compared to Case three. This consequences in extra lightly dispensed velocity contours in the outlet bypass in Case 2.

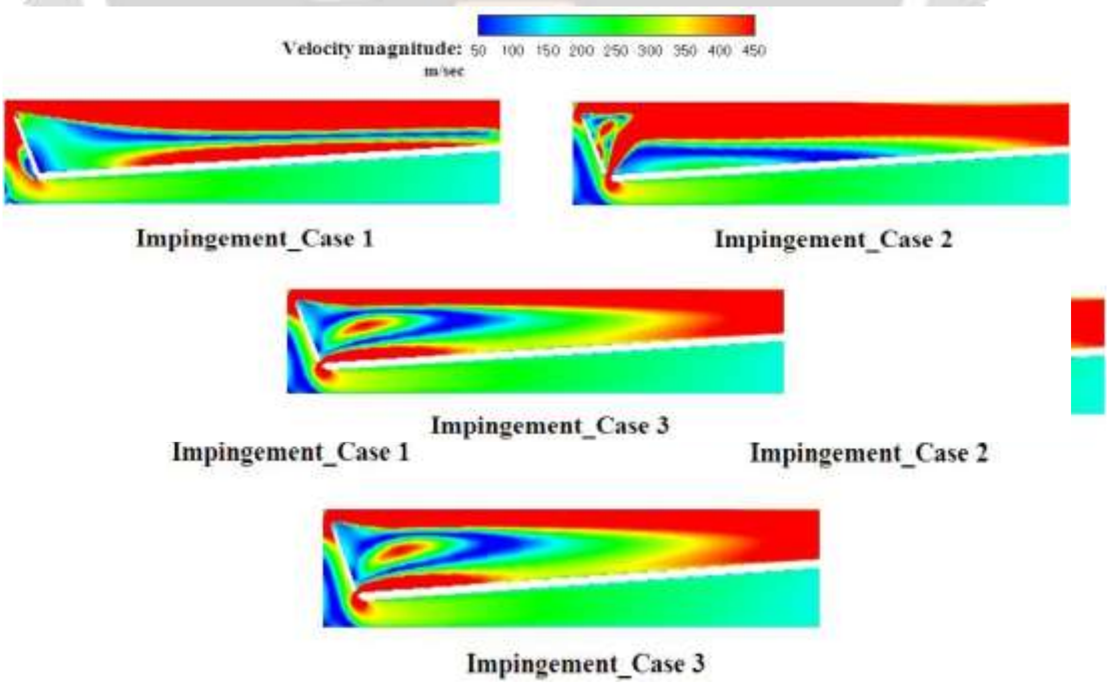

Figure 6.11: Contours of velocity magnitude at symmetry plane for three different cases of impingementcooling of smooth channel.

The effect of impingement on warmth switch at the nook of the channel is proven in Fig. 6-12 which offers the normalized temperature profiles at trailing area corner for the three impingement cases. The high impinging speed on the nook in Case 1 outcomes in a massive temperature drop. In fact not best the temperature values on the corner are under the goal value however additionally these are underneath it all alongside the duration of the channel. So this layout fulfills the layout target even without the usage of any heat switch augmentation gadgets like ribs and so forth. Case 2 and three also are supplying sufficient impingement and the normalized temperature values are under the goal price for most of the nook area in addition to most of the channel period.

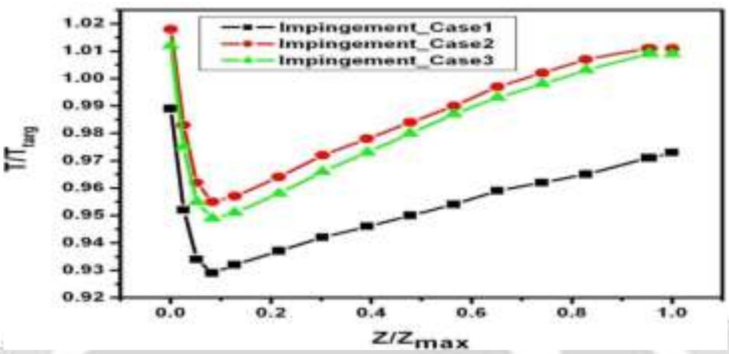

Figure 6.12: Normalized temperature profile at trailing edge corner for three cases of impingementcooling of smooth channel.

Figure 6.13 offers the normalized temperature contours at special walls for the instances defined in Fig. 6-10. As for trailing side corner, Case 1 is capable of producing sufficient warmth switch which reduces the wall temperature to below the target cost at every component. For Case 2 and three, a small a part of the nook and a small vicinity of the trailing part and bottom wall near the opening are above the goal price.

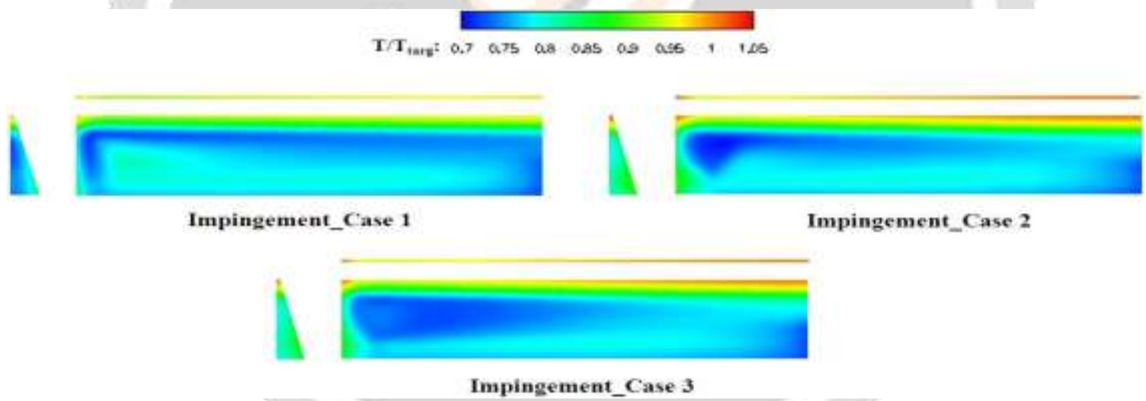

Figure 6-13: Contours of normalized temperature at different walls for three cases of impingementcooling of smooth channel.

From the above effects, Case 1 is the handiest channel design which completely satisfies the design target as a long way as warmness transfer is taken into consideration. However as discussed in advance, this design has a big recirculation location inside the outlet pass and that may motive a huge strain drop. Therefore, strain drop as described by means of Eq. 7.1 and seven.2 are calculated for the three channels. The normalized friction thing for those cases is given in table four.1.

Table 3: Normalized friction factor for three cases of impingement cooling of smooth channel.

Impingement Case	**$(f/fo)^{1/3}$**

Impingement Case 1	30.04
impingement Case 2	11.48
impingement Case 3	13.67

As anticipated, the strain drop in Case 1 is much better than the alternative cases. Though the identical channel is very effective in decreasing the wall temperatures to an appropriate range, its miles unacceptable due to its excessive drop in strain. Therefore, Case 2 which gives the least drop in stress should be altered such that the wall temperature at the trailing aspect reduces to the suitable range. A channel with staggered arrangement of ribs and a tilted divider wall fulfill this requirement as proven in Fig. 6.8 and 7.9. Consequently a fusion of the two ought to be a powerful manner to gain the target with the least stress drop. Figure 6.14 shows the rate magnitude on the symmetry aircraft of a channel having L-formed divider wall with a tapered establishing and staggered ribs in the outlet bypass. The fluid impinges at the nook and mixes with the fluid coming from the opening inside the divider wall. The ribs gift in the outlet bypass produce ribbed brought on secondary go with the flow and effects in the mixing of the fluid.

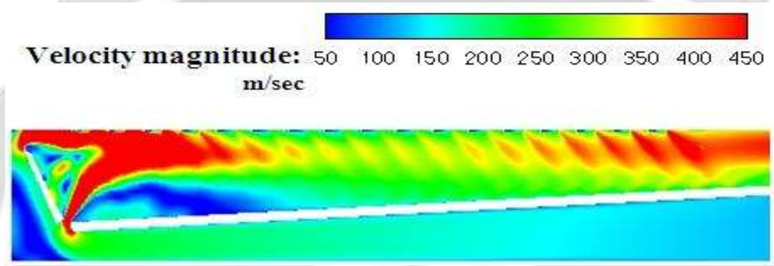

Figure 6.14: Velocity magnitude at the symmetry plane of a channel having L-shaped divider wall with atapered opening and staggered ribs in the outlet pass.

The blended impact of the ribs in the outlet bypass and the impingement in the corner alongside the tilted divider wall results in the required temperature drop. Figure6.15 compares the normalized temperature profile at trailing facet corner for the case with staggered arrangement of ribs and instantly divider wall, the case with staggered association of ribs and tilted divider wall and the case with staggered association of ribs and impingement in the corner. A tilted divider wall with impinging effect with staggered arrangement of ribs and a tapered commencing within the divider wall is the final association for the design target set for this observe. Handiest a small area of period Z/Zmax = 0 to 0.02 is above the goal price..

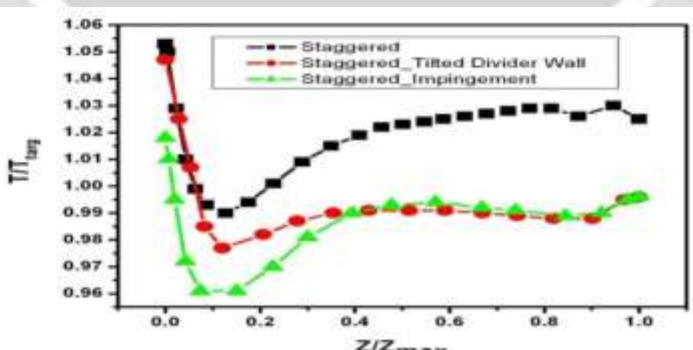

Figure 6.15: Normalized temperature profile at trailing edge corner for three different types of channelswith staggered arrangement of ribs.

Figure 6.6 presents the normalized temperature contours for extraordinary walls of the final designed channel. A narrower scale is used at the right hand side. A completely small location at the nook is above the target cost. Thus the layout target is correctly achieved in most of the vicinity by using this type of channel..

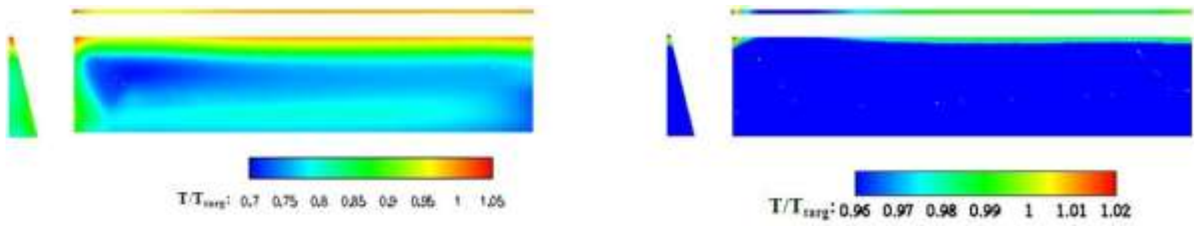

Figure 6-16: Contours of normalized temperature at different walls of the channel with staggeredarrangement of ribs and impingement in the corner.

6.5 Thermal Performance

The unique heat switch techniques used, typically bring about a growth in pressure drop. An optimized cooling channel is one which leads to most warmness transfer with minimum pressure drop. Thermal performance of various configurations of the channels is calculated the use of Eq. 5.2. The vicinity averaged Nusselt numbers are calculated for all inner walls of the channel (which are in touch with the fluid). Table 7-2 shows the thermal performance and pressure drop across the unique channels taken into consideration in this look at.

CONCLUSIONS

In the trailing edge turbine blade cooling various concepts were developed that are modification was made primarily to achieve the result. The most effective way to cool the trailing edge under set circumstances is to provide a staggered arrangement of ribs in a channel with L-shaped tapered divider wall with a converging notch in it. Nevertheless, the thermal performance of such a channel is low due to the increase in pressure drop. The channel with tilted divider wall and staggered array of ribs has better thermal performance but it has a comparatively larger area at the corner that is above the target value. Truncating the part which is on top of the desired value will increase the thickness of the trailing edge and can increase the aero thermal loss. Consequently, the best design of trailing edge, which uses internal cooling, is a tradeoff between heat transfer, pressure loss, and aero thermal loss.

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