OPTIMIZATION OF V-SHAPED RIB TURBULATORS USING CFD

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Abstract - To achieve high thermal efficiency in a gas turbine engine, the turbine inlet gas temperature should be increased. However, the penalty is a high thermal load, which affects the durability of the turbine components. Therefore, improved cooling techniques such as film cooling and internal cooling are applied to turbine blades. Internal cooling is achieved by circulating low enthalpy air in multi-pass flow channels inside the blade structure. To increase the heat transfer of the internal cooling, the internal surfaces usually are roughened by angled ribs to trip the boundary layer and increase turbulence. A Computational Fluid Dynamics study was made to obtain heat transfer data for a single pass and two-pass rectangular channel (aspect ratio 2:1) with smooth and ribbed surfaces for two channel orientations. The V-shaped ribs are placed on the leading and trailing surfaces. Seven Different arrangements of 45 deg V-shaped ribs are studied. The Reynolds numbers for study are selected as 5000 and 40000 and the rib height to hydraulic diameter ratio is 0.094, the rib pitch-to-height ratio is 10, and the inlet coolant-to-wall density ratio is maintained around 0.115 for every test. The CFD studies are carried out fort parallel 45 deg V-shaped rib arrangements and produce better heat transfer augmentation than inverted 45 deg V-shaped ribs and crossed 45 deg V-shaped ribs to determine the better heat transfer and augmentation of the flow. CFD is used to predict the bulk temperature inside the duct passage from which heat transfer coefficient is arrived. Nusselt number comparison between the various arrangements gives the insight for the enhanced heat transfer.

Index terms - CFD, RIBS ,Reynold's Number, Duct passage, Nusselts Number, Gas Turbine

I. INTRODUCTION

Gas turbines play a vital role in today's world and as the demand of power increases, the thermal efficiency and power output of the engine should be optimized. One method of increasing both the power output and thermal efficiency is to increase the inlet temperature of the hot gases through the internal passages. The main three components of a gas turbine engine are compressor, combustor and turbine. In advanced gas turbines, the turbine inlet temperature of the gases is as high as 1700° C – 2000° C. These temperatures exceed the melting point of the turbine components. Therefore it is very important to cool the turbine components so that they can withstand these extreme temperatures. With current cooling techniques the temperature is decreased to almost 1000° C, so that they can withstand this extreme environment.There are several techniques such as jet impingement, film cooling, rib turbulators, shaped internal cooling passages, dimple cooling etc, to cool a modern gas turbine blade. The jet impingement is used to cool the leading edge, pin fin cooling at the trailing edge and rib turbulators are used cool the internal passages. The present study focuses on the internal cooling turbine blades using rib turbulators or turbulence promoters.

II. LITERATURE REVIEW

Han, J. C., et.al. (1992) performed experiments on various channels now with angled ribs. The ribs were oriented at angles 30, 45, 60 and 90. The effect of rib orientation on the thermal performance is the main objective of the study. It is concluded that the angled ribs have higher heat transfer performance than the orthogonal ribs. The friction and heat transfer correlations are derived from their study. Iacovides, H. (1998) performed the computation work on the ribbed rectangular passages.

In his study both stationary and rotating rectangular passages were considered. The computation work was based on the orthogonal square ribs. The work mainly concentrated on the effect of turbulence model on the channel performance. A differential stress model was developed and it proved to yield better results than the standard k-e model. Bonhoff, B., et.al. (1999) performed an experimental and numerical study in coolant channels with 45 degree ribs. A stationary square channel is used in the study. Experimental results and the numerical results are obtained by using a Reynolds stress model. The results compared well. A cyclic boundary condition was used for the numerical study. Velocity and heat transfer distributions were recorded.

III. METHODOLOGY

Rib Design Parameters: Attaching rib turbulators to a flow passage is an effective means of enhancing heat transfer. Rib turbulators are effectively used in serpentine cooling air channels for the internal cooling of turbine blades. The present investigation involves the numerical analysis of heat transfer characteristics of a rectangular channel roughened with plain, square ribs of in the flow direction on one of the wall from figure below.

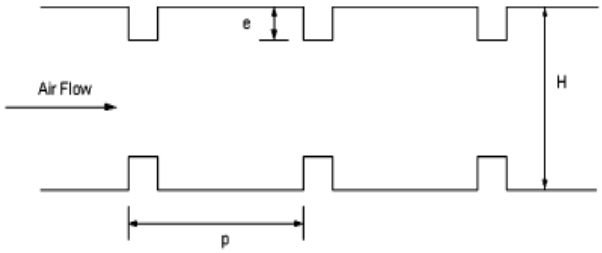


Figure Rib Turbulators cross sections

Parameters	Symbol	Range of Values
Channel Aspect Ratio	W/H	2
Rib height to Hydraulic diameter ratio	e/D	0.094
Rib Width to Rib height ratio	w/e	2
Rib Spacing	P/e	10
Reynolds Number	Re	5000,15000,40000

Table Dimensional Parameters

Dimensions Derived:-

W = Width of Rectangular Channel = 25.4 mm, Height of Rectangular Channel = 12.7 mm.

D = Hydraulic Diameter of the channel = 16.933 mm.

Rib Height (e) = 1.1938 mm.

w = Width of rib = 2.3876 mm

IV. METHODOLOGY

V-Shaped Ribs geometry is simplified by considering the eight ribs on the bottom surface of duct. Inlet and Outlet are placed at a distance equal to pitch.

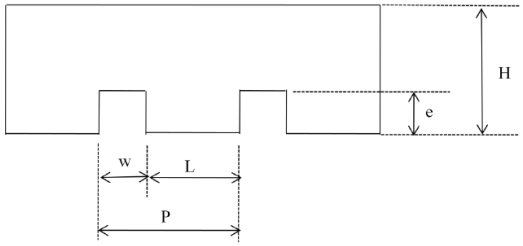


Figure : Rib Arrangement along flow direction

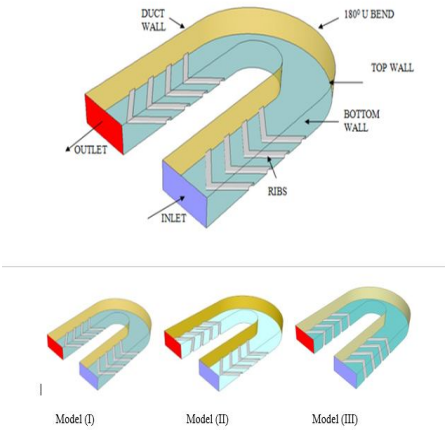


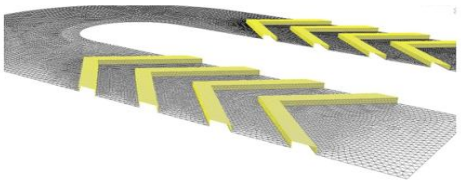
Figure- CAD model of V-Shapped Rib arrangement and Channel

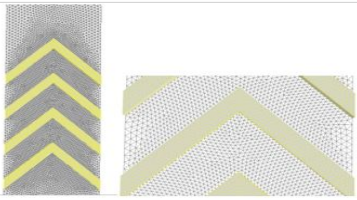
Model (I) shows the Rib Arrangement in straight manner on both passes

Model (II) shows the Rib Arrangement Straight in first pass and Inverted arrangement in second pass

Model (III) shows the Rib Arrangement inverted manner in both passes.

MESH





Tetrahedral mesh elements are used and the total mesh size of 0.43 Million is used to capture the Ribs near wall and rectangular flow channel efficiently.

Boundary Condition

Table : Boundary Conditions for CFD Analysis

	Boundary Condition Type	Parameter Defined
INLET	Velocity Inlet	Velocity in m/s Inlet Temperature
OUTLET	Pressure Outlet	0
Ribs	Wall	Copper Wall with Heat Flux - Coupled
Bottom Wall	Wall	Aluminium
Top Wall	Wall	Aluminium
Duct Wall	Wall	Aluminium
Turbulence Model	-	K-Epsilon - Standard
Upwind Scheme	-	First Order Upwind

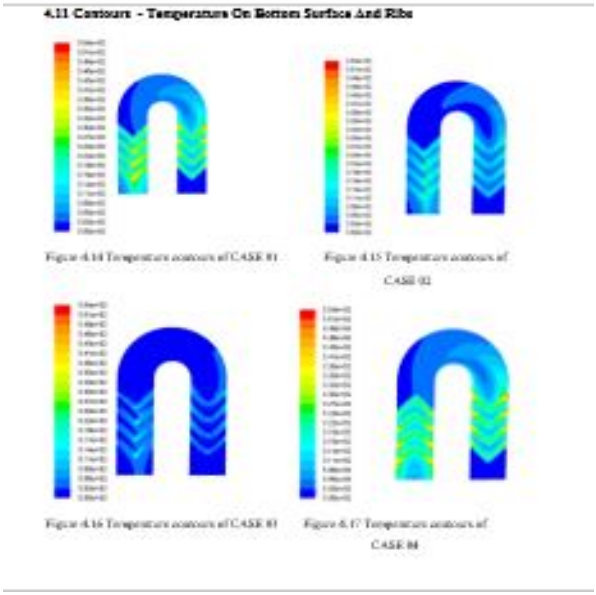
Boundary Condition Set up is followed as shown in Table above. Velocity is calculated for different Reynolds number accordingly and defined as inlet. Ribs are of Copper material which is coupled and all other wall is considered as Aluminium. Fluid properties are discussed in chapter 3 and incompressible ideal gas is considered as fluid material. K-Epsilon Standard Algorithm is used for the solution of the problem and first order upwind scheme is chosen due to convergence issues with other models. Rib Wall temperature is known and is

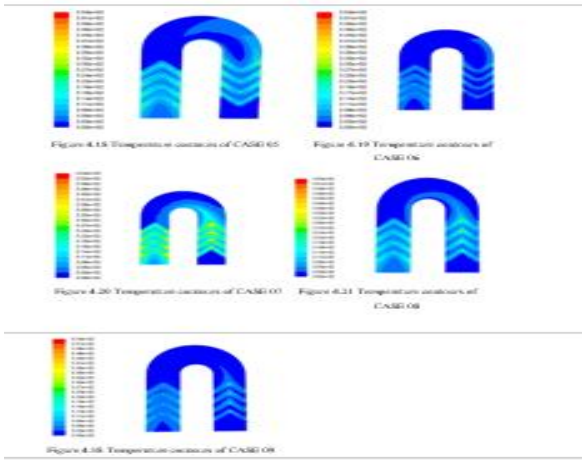
about 360 K. And Air inlet temperature is atmospheric 300K at 101322 Pa.

V. RESULTS AND DISCUSSIONS

	Model Type	Reynolds Number Re	Velocity inlet m/s	Inlet Temperature K	Ribs Wall Temeprature K
Case 1	Model I	5000	3.79	300	360
Case 2	Model I	15000	11.34	300	360
Case 3	Model I	40000	30.25	300	360
Case 4	Model II	5000	3.79	300	360
Case 5	Model II	15000	11.34	300	360
Case 6	Model II	40000	30.25	300	360
Case 7	Model III	5000	3.79	300	360
Case 8	Model III	15000	11.34	300	360
Case 9	Model III	40000	30.25	300	360

Three models arrangements are studied with respect to range of Reynolds numbers. Ribs wall temperature is around 360 K and the inlet air temperature is around 300 K. The analysis is carried out for above cases, heat transfer coefficient and Nusselt Numbers are determined and comparison and results are tabulated below.





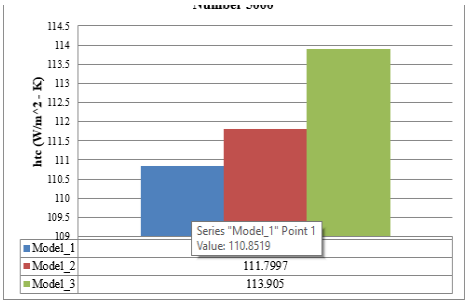


Fig HTC Comparison with respect to model Reynolds Number 5000

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From the above figure it is evident that the Model 3 predicts higher Heat Transfer Coefficient for Reynolds Number 5000. So the Rib Arrangements in model 3 is suggested for lower Reynolds Number 5000

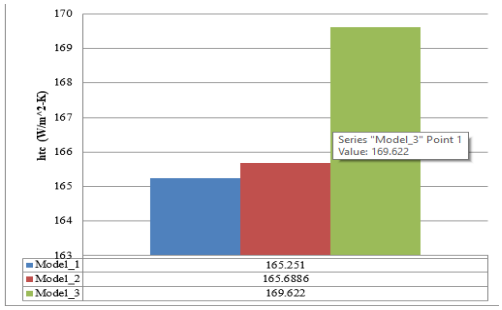


Fig HTC Comparison with respect to model Reynolds Number 15000

From the above figure it is evident that the Model 3 predicts higher Heat Transfer Coefficient for Reynolds Number 15000. So the Rib Arrangements in model 3 is suggested for Reynolds Number 15000

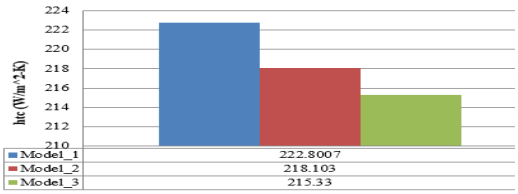


Fig HTC Comparison with respect to model Reynolds Number 40000

From the above figure it is evident that the Model 1 predicts higher Heat Transfer Coefficient for Reynolds Number 40000. So the Rib Arrangements in model 1 is suggested for Higher Reynolds Number around 40000

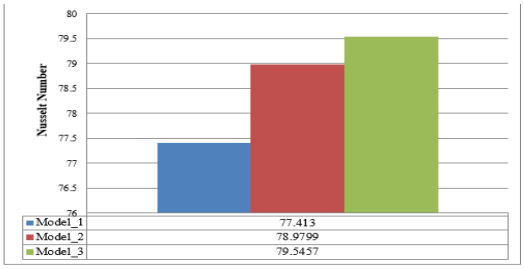


Fig Nusselt Number Comparison with respect to model at Reynolds Number 5000.

From the above figure it is evident that the Model 3 predicts higher Nusselt Number for Reynolds Number 5000. So the Rib Arrangements in model 3 is suggested for lower Reynolds Number 5000.

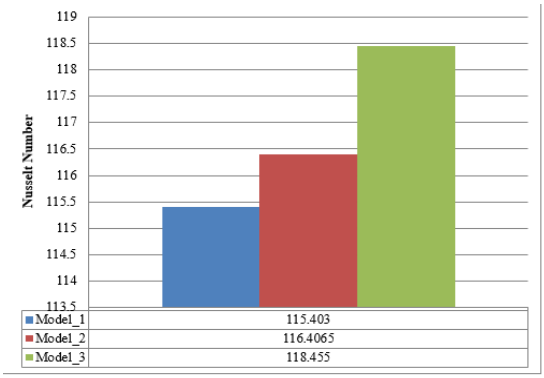


Fig Nusselt Number Comparison with respect to model at Reynolds Number 15000.

From the above figure it is evident that the Model 3 predicts higher Nusselt Number for Reynolds Number 15000. So the Rib Arrangements in model 3 is suggested for Reynolds Number 15000

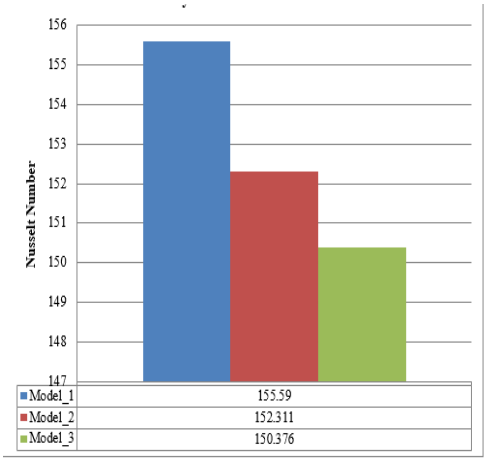


Fig Nusselt Number Comparison with respect to model at Reynolds Number 40000.

From the above figure it is evident that the Model 1 predicts higher Nusselt Number for Reynolds Number 40000. So the Rib Arrangements in model 1 is suggested for lower Reynolds Number 40000.

	Model Type	Reynolds Number Re	Velocity inlet m/s	Heat Transfer Rate Through Ribs W	Heat Transfer Coefficient W/m^2-K	Nusselt Number
Case 1	Model I	5000	3.79	8.93	110.85	77.43
Case 2	Model I	15000	11.34	13.629	165.251	115.4
Case 3	Model I	40000	30.25	17.402	222.80	155.59
Case 4	Model II	5000	3.79	9.033	108.79	75.97
Case 5	Model II	15000	11.34	13.746	166.689	116.41
Case 6	Model II	40000	30.25	17.847	218.10	152.311
Case 7	Model III	5000	3.79	9.4113	113.905	79.546
Case 8	Model III	15000	11.34	13.978	169.62	118.45
Case 9	Model III	40000	30.25	17.621	218.33	150.375

CONCLUSION

From results, we can determine

- Model 3 with Inverted Rib Arrangement is best suited for flows with comparatively Low Reynolds Number 5000.
- Model 3 Proves to perform with same effect, and it is recommended for Reynolds Number around 15000
- Model 1 with Straight Rib Arrangements are best suitable for flows with high Reynolds Number around 40000
- Model 2 Performance is not efficient in comparison with other two models
- Henceforth it can be concluded that for Reynolds Number of range 5000 – 15000 Model three yields higher Heat Transfer Coefficient and High Nusselt Number which concludes as best suitable arrangement. Whereas for Reynolds Number of 40000 Model 1 performs better in comparison with Model 1.

Future Work

CFD can be a useful tool for studying different configurations with rib arrangements. It gives intricate details in flow field, near wall flow behavior. Thus providing a scope for W shaped rib arrangement studies and exploring with wedge, triangular, blunt type ribs arrangement with different angle of orientation 45^0, 65^0 ,90^0 and with varying flow velocities.

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