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Experimental Investigation of Pressure Drop in Stationary Square Channel with 90° Ribs

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Abstract – The influence of attached ribs on wall of square duct and the pressure drop has been experimentally investigated in this study. The combined effects of geometrical parameters of ribs on friction factor are reported for the Reynolds number based on the duct hydraulic diameter in the range of 5000-25000. The geometrical parameters of ribs are systematically varied in this study were the pitch to rib height ratio (p/e), rib height to duct hydraulic diameter ratio (e/Dh), Results are reported for 0.2 ≤ e/Dh ≤ 0.4, 6 ≤ p/e ≤ 12, in duct having aspect ratio AR = 1. For attached ribs the friction factor attain maxima corresponding to pitch ratio (P/e) value of 10 experimental result reveals that the friction factor is increasing with increasing e/Dh.

Keywords: Flow through channel; Pressure drop; friction factor; attached ribs.

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1. INTRODUCTION

The turbine inlet temperature of modern gas turbine engines has been increased to achieve higher thermal efficiency. However, the increased inlet temperature can result in material failure of the turbine system due to the higher heat transfer and induced thermal stresses. In order to overcome the potential problem from the high temperature environment and prevent failure of turbine components, effective blade cooling is essential. Blade cooling is performed by film cooling at the external surface of the turbine blade and also by internal forced-convection cooling which uses winding flow passages inside the turbine blade. Internal cooling passages that are mostly modeled as square or rectangular channels with various aspect ratios.

Several methods are used to increase the heat transfer coefficient inside the channels. The passive method of heat transfer enhancement is based on two main strategies: disturbing the thermal boundary layer and using bulk fluid mixing. Destruction and restarting of the boundary layer in presence of roughness elements causes an increase in heat transfer by producing a boundary layer that is thinner on average than the uninterrupted boundary layer. Vortices in the flow can enhance heat transfer through bulk fluid mixing which reduces temperature gradients in the core flow concentrating thermal gradients in the near wall region. Such mixing can be effected using ribs, vertex generators, dimples, or surface bumps. But the increase in heat transfer is also accompanied by increase in pressure drop.

2. LITERATURE REVIEW:

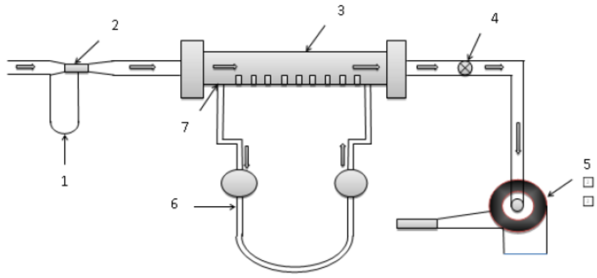
Rib-turbulators are often cast on both walls of the internal cooling passages that are mostly modelled as square or rectangular channels with various aspect ratios. Cooling enhancements induced by the ribs are fairly straightforward for stationary airfoils which are due to the additional secondary flow from the ribs, but become much more complicated in rotating blade channels due to the effects of rotation, coolant velocity, and buoyancy which may result in strong secondary flows and even local flow reversal.

V.S. Hans *et al.* [**1**] conducted experimental investigations of heat and fluid flow in a rectangular duct with multiple V-ribs on one broad wall subjected to uniform heat flux and found an increase Nusselt number and friction factor. They also developed the correlations for Nusselt number and friction factor in terms of roughness geometry and flow parameters

V. Sri Harsha *et al*. [**2**] studied the effect of rib height to the hydraulic diameter ratio on the local heat transfer distributions in a double wall ribbed square channel with 90^0 continuous attached and 60° V-broken ribs .The effect of detachment of ribs in case of broken ribs on the heat transfer characteristics is also presented. They observed that the heat transfer augmentations in the channel with 90^0 continuous attached ribs increase with increase in the rib height to hydraulic diameter ratio (e/D) but only at the cost of the pressure drop across the test section. The enhancements caused by 60° V-broken ribs are higher than those of 90° continuous attached ribs and also result in lower pressure drops. **Pongjet Promvonge** [**3**] conducted experiments to assess turbulent forced convection heat transfer and friction loss behaviours for air flow through a channel fitted with multiple 60° V-baffle turbulator. The experimental results show that the V-baffle provides the drastic increase in Nusselt number, friction factor and thermal enhancement factor values over the smooth wall channel due to better flow mixing from the formation of secondary flows induced by vortex flows generated by the V-baffle. Substantial increase in Nusselt number and friction factor values are found for the rise in blockage ratio and for the decrease in pitch ratio values **Teerapat Chompookham *et al.*** [**4**] study the effect of combined wedge ribs and winglet type vortex generators (WVGs) on heat transfer and friction loss behaviours for turbulent air flow through a constant heat flux channel. Wedge ribs (right angle ribs) create reverse flow in the channel whereas winglet type vortex generators (WVGs) generate longitudinal vortex flows through the tested section. The presence of the combined ribs and the WVGs shows the significant increase in heat transfer rate and friction loss over the smooth channel. In conjunction with the WVGs, the in-line wedge pointing downstream provides the highest increase in both the heat transfer rate and the friction factor. **Sukhmeet Singh *et al.***[**5**] in this investigation, thermo-hydraulic performance of rectangular ducts roughened with a new configuration of V-down rib having a small symmetrical gap equal to rib height created at the centre of both legs of V of continuous V-down rib. The symmetrical gap equal to rib height in both legs of V results in substantial improvement in the thermo-hydraulic performance parameter based on equal pumping power.. **S. C. Lau, *et al*.** [**6**] examined turbulent heat transfer and friction characteristics of fully developed flow of air in a square channel in which two opposite walls are roughened with aligned arrays of V-shaped ribs. The angles of-attack of the V-shaped rib arrays are 45°, 60°, 90°(same as 90° full ribs) 120°, and 135°. From this investigation, gives the 60° V shaped ribs with *p/e = 10* have the highest ribbed wall heat transfer and smooth wall heat transfer for a given air flow rate, and the highest channel heat transfer per unit pumping power. **Lanjewar *et al*** (**7**) experimentally investigated on heat transfer and friction factor characteristics of a rectangular duct roughened with W shaped ribs arranged at an inclination with respect to the flow direction and found that thermo hydraulic performance of W –down arrangement with angle of attack of flow as 60^0 gives the best thermo hydraulic performance.

3. EXPERIMENTAL SET-UP:

Experiments are performed in an experimental set-up as depicted in Fig. 3.1. The experimental system consists of a square channel of size 20mm x 20mm x 800mm and two pressure taps are provided for the measurement of the pressure across the test section, variable speed blower having the power of about 600watts no load speed of blower is 0-16000rpm air volume ratio is 3.5 m3/min weight of the blower is around 1.7 kg, An orifice meter, venture meter, U-tube manometer of is used for the measurement differential pressure head across the venture meter ,a differential manometer with a combination of water and benzyl alcohol (specific gravity = 1.046) as the monomeric fluids connected to the two pressure taps of the test section to measure the pressure drop across the test section, and gate valve used to regulate and control the compressed air flow rate, ribs are glued on the bottom surface of square duct by strong adhesives for roughening the duct.



1) Simple u-tube manometer 2) Venturimeter 3) Square Duct 4) Control valve 5) Air blower 6) Micro differential manometer 7) Pressure tap

Fig. 3.1: Experimental Set up

3.1 Methodology:

Blower sucks the air; air enters into the test section through the valve which controls the flow of air through the test section. Using venture meter and simple U-tube manometer the flow rate of air is maintained to required value, when air flow through the test section there is friction between air and surfaces of the square channel. Due to this pressure drop takes place. This pressure drop across the test section is measured by using Micro Differential manometer.

Same procedure is followed to obtained friction factor for different configurations of the ribs which are glued on the bottom surface of the square duct. But for rib roughened surface simple manometer can be used to measure the pressure drop across the test section.

3.2 Geometry and Computational Details:

Square- shaped ribs are mounted into the bottom surface of this channel to analyze the flow characteristics' in the square duct The sides of the channel are denoted as *L, H* and *W* and channel aspect ratio *(AR)* is *W/H* The geometrical parameters of ribs influencing the friction factor performance are shown in Fig.3.2. These parameters can be defined as Axial pitch *(p)*: the axial distance between the identical points of adjacent ribs is the pitch of the ribs configuration.

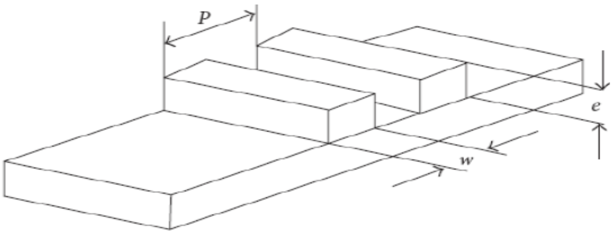


Fig. 3.2: Dimensions of ribs.

Ribs height *(e)*: the normal distance between the top of the rib surface and the surface of the wall upon which it is glued is the rib height.

Length of ribs (l): base length of ribs at which it glued upon surface of the wall.

The non-dimensional parameters are;

Rib height to channel hydraulic diameter ratio *(e/Dh):* this is the ratio of the height of the rib, measured above the surface upon which they are glued to the channel hydraulic diameter.

Pitch to height ratio *(p/e):* It is the ratio of the axial distance between two identical points of the adjacent Ribs to the Rib height.

3.3. Data reduction:

1) Flow rate through venture –meter:

$$Q_{th} = C_d \frac{A_0 A_1}{\sqrt{A_0^2 - A_1^2}} \sqrt{2g\left[\frac{\rho_w}{\rho_{air}} - 1\right] H} \text{ --------(1)}$$

A_1= Area of pipe; Ao=Area of venture.

Cd=co-efficient of discharge.

2) Mass flow rate: $m' = \rho Q$ ---------(2)

ρ= density of air

3) The Reynolds number based on the channel hydraulic diameter is given by:

$$Re = \frac{\rho V d_h}{\mu} \text{ ------ (3)}$$

μ=absolute viscosity of air Pa s

v=Average velocity of air through the duct.

4) A differential manometer connected to pressure taps measures the pressure drop across the test duct. In a fully developed duct flow using equation:

$$p_x - p_y = 2hg\rho_2\left[1 - \frac{\rho_1}{\rho_2}\left(1 - \frac{a}{A}\right) + \frac{\rho}{\rho_2}\frac{a}{A}\right] \text{ ------ (4)}$$

5) For rib roughened square channel the pressure drop across test section can be used by using the following equation.

$\Delta p = \rho w\ g\ h$ ------- (5)

ρw=density of water; g= gravitational constant

h= manometer head difference

6) The friction factor was determined in terms of pressure drop across the test duct and the mass velocity of air using equation.

$$ff = \frac{\Delta p}{\left[\left(\frac{4L}{h}\right) x \left(\frac{\rho v^2}{2}\right)\right]} \text{ -------- (6)}$$

7) The friction factor of the present study was normalized by the friction factor for flow in smooth duct is given by:

$Ff_t = 0.046Re^{-0.2}$ ------ (7)

4. RESULTS AND DISCUSSION

The results of present study are presented in terms of friction factor as a function of geometrical parameters of ribs. The friction factor (*ff*) based on Reynolds number.

Effect of Pitch to Height Ratio *(p/e)* on Friction Factor:

Fig. 4.2 and 4.4 effect of pitch to height ratio (p/e) on friction factor (*ff)* for different Reynolds number with attached ribs for *e/Dh*=0.2, 0.3 and 0.4 in a square duct. Friction factor have been plotted as function of pitch to rib height ratio (P/e) for different values of Reynolds number.

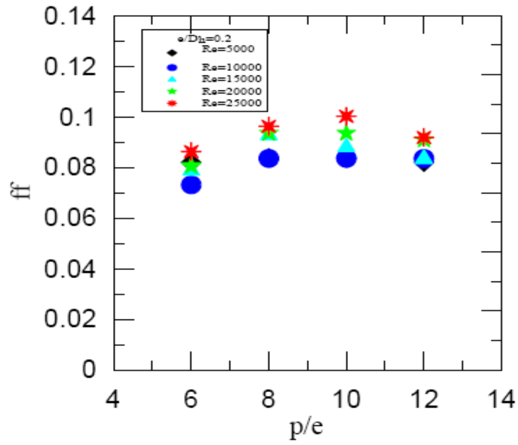


Fig.4.2 Friction factor v/s Pitch to rib height ratio (e/Dh=0.2)

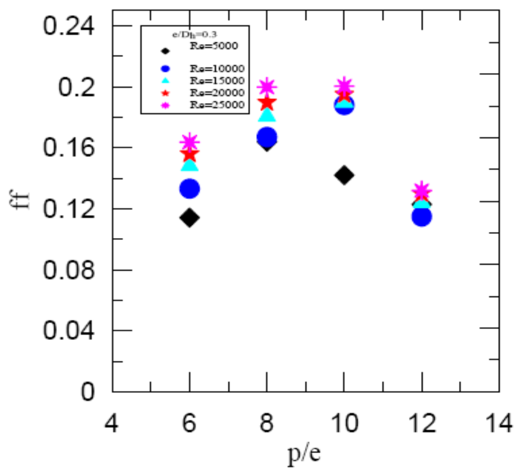


Fig.4.3: Friction factor v/s Pitch to rib height ratio (*e/Dh*=0.3)

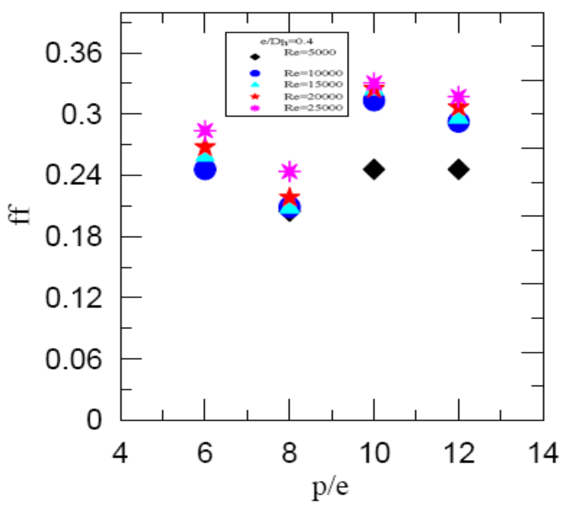


Fig.4.4: Friction factor v/s Pitch to rib height ratio (e/Dh=0.4)

From the above figures, for all values of e/Dh ,the friction factor attain maximum corresponding to pitch ratio (p/e) of 10 and on either side of this value, decrease in Friction factor has been observed. It is due to the fact that flow separation occurs downstream of a rib and re-attachment of free shear layer may not occur if relative roughness pitch (p/e) is less than about 8–10. In these figure results are compared and it was found that the value of friction factor for the value *of p/e (p/e*=8 and p/e=10) is 80% higher than the value of *p/e (p/e*=6).

4.3 Effect of Ribs Height to Channel Hydraulic Diameter Ratio *(e/Dh)* on Friction Factor (*ff*).

Effect of Ribs height to channel hydraulic diameter ratio (*e/Dh*) at different Pitch to height ratio (*p/e* = 8) for attached rib configuration on the friction factor (*ff*) is shown in Fig. 4.5 and 4.8 respectively. By observing these figures experimental result reveals that the friction factor is increasing with increasing *e/Dh*.

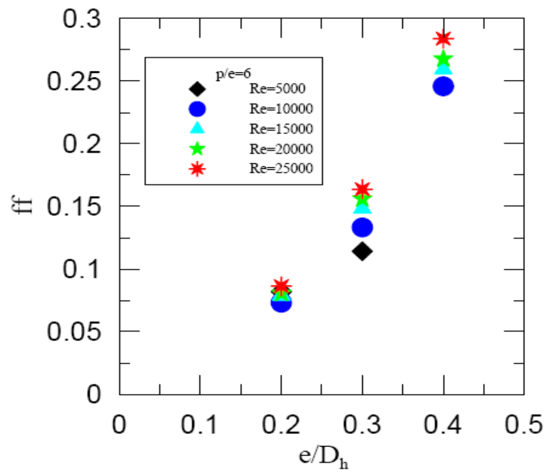


Fig.4.5: Friction factor v/s rib height to hydraulic diameter (*p/e*=6)

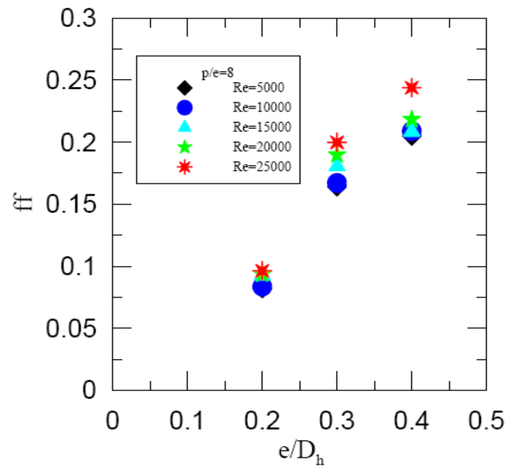


Fig.4.6: Friction factor v/s rib height to hydraulic diameter (*p/e*=8)

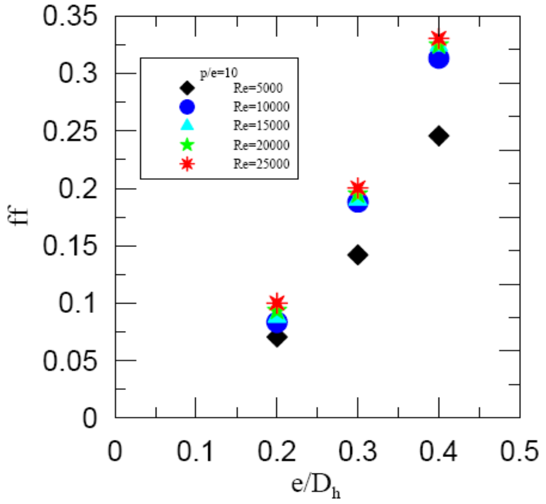


Fig.4.7: Friction factor v/s rib height to hydraulic diameter *(p/e*=10)

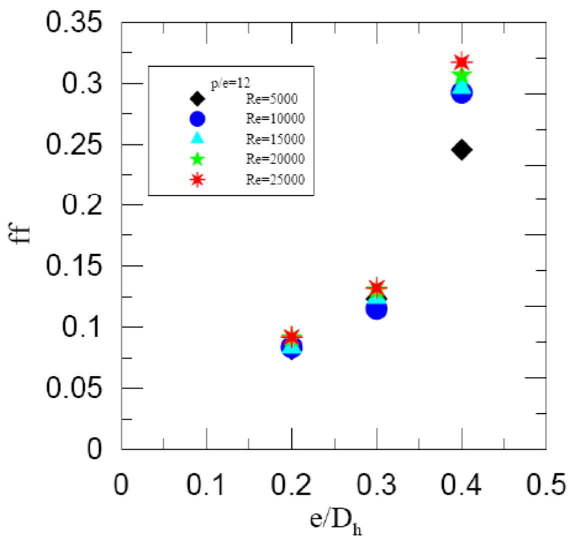


Fig.4.8: Friction factor v/s rib height to hydraulic diameter *(p/e*=12)

For all the Reynolds number, monotonically increase in friction factor has been observed as relative roughness height, (e/Dh) increases. It is due to the fact that as relative roughness height value increases; roughness geometry protrudes more turbulence, thereby, resulting in increase in friction factor.

4.4. Effect of Reynolds number (Re) on Friction Factor (*ff*):

The experimental results for friction factor in smooth square duct reasonably agree well within ±5% values estimated from correlation proposed by Blasius. Friction factor is decreasing with increasing Reynolds number in smooth channel, but in case of graphs obtained from square duct having ribs the friction factor is increasing with increasing Reynolds number because in these ducts better mixing of air takes place and also the ribs blocks more amount of air in ducts at higher Reynolds number.

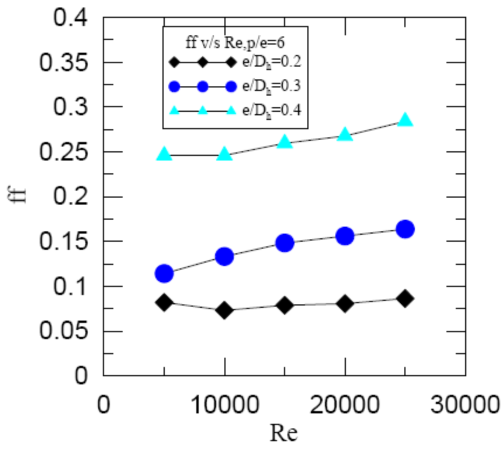


Fig.4.9: Friction factor v/s Reynolds number *(p/e*=6)

The friction factor is found to increase with Reynold number for different values of (e/Dh) for attached ribs and remains fairly constant at higher Reynold number as shown in figure 4.9 to 4.11

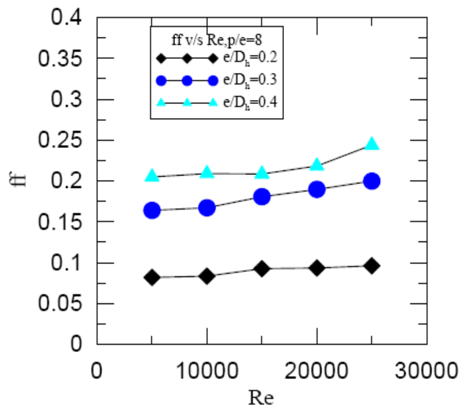


Fig.4.10: Friction factor v/s Reynolds number *(p/e* = 8)

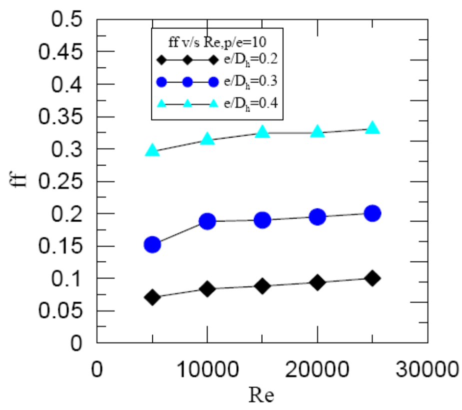


Fig.4.11: Friction factor v/s Reynolds number *(p/e*=10)

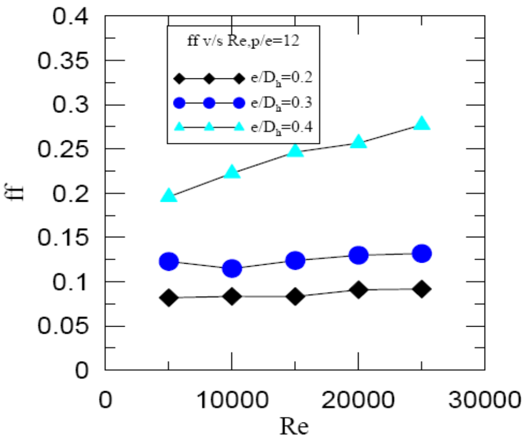


Fig.4.12: Friction factor v/s Reynolds number (*p/e*=12)

From the above figures it is observed that the friction factor ratio increased marginally for higher (e/Dh) ratios. The friction factor is found highest for an (e/Dh) ratio of 0.4. Therefore it can be said that though there was an increase in the heat transfer augmentation it was only at the cost of the pressure drop. Thus the present study on continuous attached ribs suggests that the friction factor of the continuous attached ribs with an (e/Dh) ratio of 0.4 is the high amongst the studied configurations.

From the figures it is observed that small increased in the friction factor as a Reynolds number increases.

CONCLUSION

In this study an experimental study has been performed for attached rib configuration to obtain pressure loss or friction factor for an air flow in square channel. By insertion of ribs it has been found that the ribs break the laminar sub-layer and create local wall turbulence due to flow separation and reattachment between consecutive ribs, which reduce the thermal resistance and greatly enhance the heat transfer. From the experimental results, it can be concluded as follows:

1. The air flow in the square channel, For attached ribs the friction factor attain maximum corresponding to pitch ratio (P/e) value of 10. On either side of these values, decrease in friction factor has been observed.

2. The friction factor is increased with increase in Rib height to channel hydraulic diameter ratio (*e/Dh*). Therefore in this study (*e/Dh*=0.4) presented the higher friction factors for attached rib configuration, that is 30% higher friction factor ratio compared to *e/Dh*=0.2 for attached. It is due to increase in *e/Dh* increases the blockage of the flow passage and therefore the friction factor is increased in the channel.

3. Reynolds number is not much affected on the friction factor .That is small increment in friction factor with increase in Reynolds number.

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