Review: The flow and heat transfer investigation inside tapered and straight two pass channels with rib turbulators

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Abstract. This paper is a review of the number of experimental and CFD experiments performed with rib turbulators about the heat transfer and the two pass channel. In respect to achieve higher thermal efficiency of gas turbines, efforts are made to raise the inlet temperature. The secondary fluxes resulting from the rib and U-shaped curvature play an important role enhancing heat transfer in the two pass ribbed channels. The ribs on the internal surface of the cooling passage will increase the strength of heat transfer. This paper deals with the effect of tapered and straight two-pass channels with the influence of the variable rib cross-section on flow and heat transfer enhancement.

1. Introduction
Modern gas turbines operate at a very high entry temperature that may reach 1370 degrees Celsius, which is crossing the highest permissible temperature, and the gas turbine blade may reach. In circulating the air at the inner passages, cooling is achieved. These internal passageways are detached by a 180° bend. The switch triggered secondary flow is an more important to inner turbine blade cooling. Various turn design have several the flow fields in turn zone of the multi pass duct. The Properties of the flow varies about the turn due to secondary flow, isolation flow, flow Collision flow and turn flow therefore play a significant role at the improvement of the pressure and the heat transfer for inner cooling of the turbine blade. The modern design of gas turbine requires lower pressure drops across its total duration and improved heat transfer improvements. Most of the experiments focused in the inland ducts of the gas turbine blade on fixed cross-sectional areas from entry to rotation. To reduce heat packing, gas turbine blades are usually tapered from hub to tip. These channels occur inside the blades of the high performance turbine to supply the outer surface of the rotor, which is subjected to a high temperature gas flow, with effective cooling.

Many variables affect the degree of heat distribution improvement in the ribbed channels:
- Orientation of rib
- Spacing of rib.
- Height of rib
- Cross-section of rib (square rib, sharp corners rib, rounded corners rib, etc.).
Together with a large range of channel sizes, these factors will contribute to very different degrees of enhanced heat transfer through the cooling Channels (aspect ratios).
2. Straight channel

2.1. Effects of rib orientation on heat transfer enhancement

The combined effects at the flow and heat transfer through two pass ducts with ribs for rib directions (N type, p type) and rib angles (30° -75°). The transfer of additional secondary flows through the downstream passage from the weakening of the energy loss and local flow secondary of the upstream flow secondary is primary factor for improving local heat transfer [1]. Gao et al. study the pairing of nine distinct rib orientations and the 180° bend in the U shaped passage of the ANSYS CFX industrial CFD at Re = 30000 on total friction loss and forced convection. Qualitative findings demonstrate that the Nusselt ratio and the average loss of pressure in the downstream passage are heavily influenced by the upstream geometry [2]. Mochizuki and Murata numerically investigated the influence of channel rotation and rib orientation on heat transfer in a square two pass channel at 180° sharp turn. The heat transfer in and after bend was improved in the stationary state, and the sharp-bend induced flow field dominated it. In both the arrangement of the rib and the rotation of the tube, the friction factor was more sensitive than heat transfer [3]. In the revolving two pass square channel, the influence of different 45° rib angle turbulator arrangement on the Nu number ratio was studied with rotated number up to 0.11, and with two channel orientations with respect to axis of rotated (β = 90, 135 deg). At an angle (+45° or -45°) to the main stream, five separate structures of rib turbulators are mounted on trailing and leading surfaces [4]. Tao and Zhao studied the influence of five angles of the rib (45°, 60°, 90°, 120° and 135°) of heat transfer properties in the U-shaped stationary ducts has been experimentally tested. The findings revealed that in a 60° ribbed channel, followed by 45°, 90° and 135°, the optimum Sherwood number ratio was identified; the rib angle and inclination of having major flow on local overall heat transfer [5].
Figure 2. (a) Geometric model; (b) Rib orientation definition; (c) Four rib channel with rib orientation [1].

Figure 3. arrangement of ribs [3].
2.2. Effect of the rib height and the rib Spacing on Heat Transfer Enhancement

Experimentally examines the effect of rib spacing in both non-rotating and rotating rectangular cooling ducts on pressure penalty, heat transfer improvement and the overall thermal efficiency. The leading and trailing surfaces, 45° angled ribs are mounted in the 1:2 rectangular channels [6]. The rib pitch varies, 10, 7.5, 5, and 3 rib pitch-to-height (P/e) ratios are considered. The influence of rib spacing in pressure penalty and heat transfer in stationary and the rotary U shaped channels has been experimentally studied. The findings showed the rib spacing of P/e = 3 achieved greatest heat transfer improvement, while P/e = 5 performed the maximum pressure loss [7]. The influence of the spacing of rib and height of rib on heat flow in the 1:4 tube is studied. The three variants in the rib spacing 1(P/e=2,5,5,10) with the ratio 0.078 e/D. Rib structure with e/D ratio=0.156 and a P/e ratio =10 was considered to investigate the effect of the rib height [8]. Experimental analysis was studied the influence rib spacing on heat transfer and friction in a revolving two-pass square tube. On the pressure side, the rib pitch-to-height (P/e) ratio ranges from 3.8 to 14.4 in the positive rotational direction, while the suction side holds a constant value of 10. The findings show that the rib spacing influence is more pronounced than the second passage in the first radially outward flow passage [9]. In a revolving two passage channel (aspect ratio 2:1), the spacing of rib influence on heat transfer was tested at an orientation angle of 135°. At a 45° flow angle, parallel ribs were added to the trailing and the leading of the revolving channel. Rib pitch to rib height ratios tested (5, 7, 5, and 10) [10].

![Figure 4](image1.jpg)  
**Figure 4.** Flow patterns around turn and ribs [10].

![Figure 5](image2.jpg)  
**Figure 5.** Rib -Spacing Considered in the Present Study [6].

2.3. Effect of the rib cross-section on Heat Transfer Enhancement

2.3.1 Solid rib. In rectangular channel with various forms of ribs, truncated prismatic on bottom surface, precise flow field and heat transfer properties were analyzed. The truncated prismatic ribs give a lower penalty for pressure (54.65 percent) than square ribs. The truncated prismatic ribs give improved thermohydraulic efficiency at lowest and 25-53 percent higher than the square ribs [11]. Fifi NM Elwekeel et al. study performed in horizontal air/mist and the air of rectangular duct, with the separate shaped ribs, to explore the flow friction, forced convection, and efficiency factor. Calculations are made for triangular, square ribs and cross sections of trapezoidal ribs. The average
mist cooling improvement is found to be around 1.8 times. In air/mist offers the greater enhancement of heat flow over the air with trapezoidal ribs [38] [12]. Ali et al. studied the effect of the change in the trapezoidal with the angle (5°, 10°, 15° and 20°) trapezoidal rib with decrease in the flow path height on the flow, and its consequent influence on the rise in heat transfer at the Re numbers (9400, 27,120, 44,600 and 61,480) used LCT and PIV techniques. The area of the secondary recirculation bubble has been found decrease at higher Re and higher trapezoidal angles, contributing the elimination of the hot spot directly downstream of the rib [13]. Numerical analysis records fluid flow and heat transfer properties in a cooling canal with separate crescent ribs mounted at one wall. In order to optimize thermal efficiency of cooling tube, three types of ribs are considered, i.e., a straight rib, a crescent rib concave to a stream-wise direction, a crescent rib convex to a stream-wise direction to a stream-wise direction [14]. The result shows that the best thermal efficiency is the case with crescent ribs concave pitch to height (6-12) ratio on the friction factor characteristics and local heat transfer were analyzed inside the rectangular channels roughened by the one main wall with pentagonal ribs. LCT was used to calculate the distribution of surface temperature and finally to show the local HTC at distinct Re (9400-58,850) over the ribbed surface. A major increase in the heat transfer augmentation directly behind the pentagonal ribs has been discovered at higher Reynolds number and pentagonal angle, contributing to prevention of the hot spots [15].

![Figure 6](image_url)

**Figure 6.** (a) overview of cooling-channel (b) straight-rib (c) crescent Rib concave to the stream-wise direction (d) crescent rib-convex to the stream-wise direction [14].

Sixteen rib structures with varying cross-sectional shape were numerically analyzed and the boot-shaped rib turbulators were found to have the best of the heat transfer output with the pressure drop equal to that square rib. The researchers have stated that the front surface slope of the rib is a crucial factor in deciding the achievement of the heat transfer because it influenced directly the size of the recirculate region [16]. Lei Wang and Bengt Sundén study the ribs of trapezoidal shape with reducing height there flow direction have been shown to provide the largest improvement in friction factor and heat transfer between the triangle, square and trapezoidal ribs with rising height in flow direction and decreasing height, and perhaps helpful in preventing creation of hot-spots [17].
2.3.2. Slit rib. Convective fluid flow and heat transfer in ribbed ducts using PIV and LCT techniques, respectively. The results indicate that the cribriform the rib of square shape Effective way obviate the forming hot spots and also decrease the reattachment length 45% [18]. In with detail turbulent kinetic energy (TKE) and turbulent statistics budget for same the permeable Shorter reattachment duration for the maximum stresses of Reynolds, TKE output and pressure transport was observed among all the tested configurations for incline split-slit rib [19]. The ability of PIV and LCT method was used to investigate influence of differ the trapezoidal angle of a continuous slit trapezoidal-rib (0°, 5°, 10°, 15°, and 20°) on the flow pattern and its corresponding effect on the heat transfer improvement at the set of Reynolds 61,480. The trapezoidal angle variance has been shown to efficiently regulate the small scale corner vortices behind the firm rib, thereby helping to prevent hot spots [20]. The thermal efficiency of the permeable shape of ribs placed on the bottom surface of the square two-pass duct was analyzed and show the split-slit design demonstrated the significant improvement in the heat transfer relative to solid and slit rib without any proportionate rise in the penalty pressure 2018 [21]. Five different geometric models, include rectangular slit ribs, (V-shaped) slits, (anti-shaped) slits, (broken V-shaped) slits, and (broken anti V shaped) slits ribs, have been examined. Results obtained show that due to the higher turbulence strength, the ducts with the broken-slits provide greater heat transfer efficiency [22]. In the rectangular channel with the solid, converging slit and alternating solid slit ribs placed transversely at a bottom wall, the heat transfer and frictional characteristics were analysed. As predicted, the converging slit rib greatly improved the rate of heat transfer in downstream locality and prevented creation of hot spot local [23]. Liu et al. study with the inclined angle of the holes varying from 0° to 45°, two pairs of perforated ribs are used and the cross-sections are, respectively. The total average number of Nusselt (Nu) for all inclined cases is significantly higher than for straight cases. The change ratio is around 1.85 percent - 4.94 percent. For the inclined hole situations, the average Nu in the half section toward the inclined path is expanded [24]. Experimental analysis the detailed of aerothermal properties in the duct with the set of the solid and the permeable pentagonal-ribs placed on bottom wall with the parallel and the inclined slit. Open area ratio set through studies is (0.125%, 12%, and 25%), respectively. The result shows that the flow from the inclined-slit pentagonal rib has a major effect on magnitude of the stream velocity, statistics of fluctuation and the vorticity [25].
2.4. Effect of channel aspect ratio on heat transfer enhancement

The heat transfer and flow in the rotational U-shaped smooth ducts with aspect ratios (AR=0.25, 0.5 and 1) were numerically analyzed. They findings revealed that the rotating influence on the heat transfer (AR) aspect-ratio duct in narrow was more important [26]. Wen-Lung Fu L et al. studied experimentally analyzes influence of buoyancy force and duct aspect-ratio W:H on the heat transfer with smooth walls and 45° ribbed walls in rectangular two-pass revolving channels. 4:1, 2:1, 1:1, 1:2, and 1:4 are the duct aspect ratios. The findings showed that, because it has the smallest pressure penalty, the 1:4 channel has stronger heat transfer [27]. The influences of ribs on heat transfer efficiency and cooling air flow properties are numerically tested under various working conditions in different aspect-ratios (AR) in U-shaped ducts. The wide of the duct (AR = 2:1) has a stronger increase factor than the narrow channel (AR = 1:2) and the heat transfer weight of ribs increases with an increase in the Reynolds number at inlet [28]. A experimental research based on the influence of the aspect-ratio =1:2, 1:1, and 1:6 on heat transfer of smooth and rib-turbulated rectangular ducts. They stated that of 1:2 aspect-ratio channels, there is a linear variance between the Re number and the normalized Nusselt number. Their analysis found that for the smooth and the ribbed channel with an aspect-ratio = 1:6, the maximum heat transfer was obtained [29]. Inside the smooth duct with different aspect-ratio at vary divider to tip wall lengths, flow and transition are numerically analyzed. The findings revealed that both pressure drop and heat transfer at the bend and outlet the passage were affected by divider-to-tip wall size [30].
2.5. Effect of turn geometry on (turbulent fluid flow and heat transfer)
In smooth U-shaped tube, the effect of bend geometry on the flow characteristics and heat transfer has been studied. This research found that when the external wall of the turn was closely linked without a rotund rim and the inner wall of the turn was semi-circular form, the best heat transfer efficiency was obtained [31]. The effect of turned vanes on pressure loss and heat transfer in two pass rectangle channel was numerically and experimentally studied. They found a decrease in pressure drop of 25 percent and could sustain the same degree of heat transfer with the use of inner-turning vanes in bend area [32]. The effect of the shape of the bend on overall heat transfer efficiency was investigated and proposed that symmetrical bulb structure increased a thermal effectiveness agent by 41% [33]. In the time-resolved particle picture velocimetry system is used in square cross-section U-shaped channels and different bend section configurations to study the properties of the internal flow area as shown in fig (12). A variety of essential conclusions are derived from the data. The structure of the section of the turn has an evident effect on the flow field properties for the main flow [34]. In two-pass, square duct with 180° sharp turn as shown in fig (13), empirical results for secondary flow patterns and heat transfer propagation are provided to explore the effects of the various turn design: straight, rounded, and circular-turn. The measured results show that the straight case has the strongest turn induced shift in heat transfer at the turn [35].
3. Tapered channels

The heat transfer influence of a tapered channel has been studied. The area of tapered ducts cross-section various frequently. The findings revealed that the tapered channel with ribs gave greater gains in heat transfer than straight ducts. However, no research on exit mass flow rate inside the variable cross-section channel with ribs has been published on the Nusselt number distributions [36]. Liu and Feng investigated the heat effect within inclined ducts or ducts with bleeding holes, researcher noted that the inclined channel or channel with bleeding holes would provide a greater effect of heat transfer in a way [37]. The pressure drop and heat transfer data were obtained by maintaining constant rib height, side height to the mean diameter ratio equal to (0.081), and the side slope height ratio equal to (6 17.8) for standard flow ribs. Heat transfer optimization was introduced on the basis of modified constant pumping capacity, constant pressure, and constant mass flow, drop, and performance of ribbed channels ranged from (0.8 to 0.6) times that of static air channel [38].
Figure 14. Graphic of the straight and tapered two-pass channels and the distribution of ribs direction [36].

4. Conclusion
It is possible to derive some concluding conclusions from these experimental and numerical studies:

- Rib mediated secondary flow has a significant effect on the transfer of heat to the channel. It is also important to refine the configuration of the rib to take advantage of the secondary flow caused by the rib. For eg, the rotation of the turbulator, such that it is not orthogonal to the mainstream flow. The heat transfer coefficients are greatly increased due to the angle of rib caused by secondary flow. The ideal space for ribs has been found to be about P/e =10.
- The slit ribs have the feature of preventing hot spot and the lower pressure than the solid rib. Reynolds number corresponding to onset of the flow permeability decreases with the increasing in open field ratio. The increasing in heat transfer with increasing the angle of perforation, the ratio of the open area, with the decrease in rib degree to the ratio of hydraulic diameter(Dh) and Re number
- Comparison of the average number of Nusselt and the friction factors of the different turn design shows that the computational simulations adopt the same behaviour as the experimentally revealed but the chosen turbulence model predicts an increase in heat transfer in the bend area. The overall thermal efficiency (sharp 180° bend with circular divider) is higher than in other situations.
- The average level of the heat transfer change for all ribbed channels is comparable. However, there are major variations in the pressure losses suffered in the duct. The 1:4 duct obtained the lowest pressure penalty thus, the thermal efficiency of the 1:4 duct is higher than the 1:2, 1:1 and 2:1 ducts respectively.
- The researchers revealed that tapered duct with the ribs has more heat transfer benefits than straight duct.

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