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EFFECTS OF CONTINUOUS AND FRACTURED RIBS PLACED AT THE ENDWALL SURFACE UPSTREAM OF THE TURBINE-VANE LEADING-EDGE

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ABSTRAK

Kehilangan tekanan total, aliran yang acak dan deras di hilir area keluar saluran turbin adalah beberapa efek dari peningkatan input temperatur masuk yang diinginkan di bagian hulu saluran baling-baling turbin. Energi yang jumlahnya besar dari aliran silang di dekat bagian tengah baling-baling aktual diangkut ke hilir oleh aliran yang acak ini yang sering mengakibatkan kerugian aerodinamis dan penurunan panas. Untuk membandingkan pengaturan yang berbeda, perbandingan dua geometri, dampak penambahan berbagai konfigurasi rusuk di bagian hulu dipelajari untuk mengetahui efektivitas penambahan panas. Efek rusuk terdepan di bagian tengah aliran dari lorong baling-baling diperiksa secara kuantitatif dalam penelitian ini dengan menggunakan teknik komputasi dinamika fluida (CFD). Dengan menggunakan persamaan energi Reynolds Averaged Navier-Stoke, geometri dimodelkan dengan memilih kondisi batas yang sesuai. *Mesh polihedral* digunakan dengan lima belas lapisan prisma pada permukaan *endwall* dan *vane* untuk menangkap fisika aliran yang dekat dengan area endwall. Meskipun dua konfigurasi yang digunakan menunjukkan pengurangan relatif pada koefisien kehilangan tekanan total, namun, rusuk yang retak mengurangi bilangan Nusselt lebih dari 10% di sepanjang daerah keluar saluran. Data mendemonstrasikan perbedaan yang dapat dipertimbangkan pada kehilangan tekanan secara keseluruhan antara kedua konfigurasi tersebut.

Kata kunci: baling-baling, aliran tengah, kehilangan tekanan total, perpindahan panas

ABSTRACT

Total pressure loss, chaotic and heavy flow downstream of the turbine passage exit area are a few effects of the desired increase in inlet temperature input at the upstream part of the turbine vane passage. Huge amount of energy from the cross-flows near the middle of the vane actual chord are transported downstream by this chaotic flow which often results in aerodynamic loss and differential heat penalties. To compare the different arrangement, comparisons of the two geometries, the impact of adding various rib configurations upstream are studied for heat augmentation efficacies. The leading-edge rib(s) effects at the mid-stream of the vane passage are quantitatively examined in this work using computational fluid dynamics (CFD) technique. With the employment of Reynolds Averaged Navier-Stoke energy equations, the geometries are modelled choosing the appropriate boundary conditions. Polyhedral mesh is used with fifteen prism layer mesh at the endwall and vane surfaces to capture the flow physics close to the endwall area. Although the two configurations employed showed relative reduction in the total pressure loss coefficient, however, the fractured ribs produced superior outcomes of Nusselt number reduction of over 10% along the passage exit region. The data demonstrate a considerable difference in the overall pressure loss between the two configurations.

Keywords: *vane-blade, mid-stream, total pressure loss, heat transfer*

1. INTRODUCTION

Both designers and academics are interested in curtailing secondary flow in turbine cascades. The majority of current turbine blade passage design methods are based on two-dimensional flow analysis. Some of the problems associated with turbine end walls are flow separation, a passage vortex, a horseshoe vortex, and certain minor but highly intense corner vortices at the end wall-blade junction which often alters the aerodynamic flow trajectories. Close to the endwall, flow separation, a horseshoe vortex, a passage vortex, and a few small but highly intense corner vortices at the endwall-blade junction may impact the turbine's aerodynamic performance and increase heat transfer from the hot fluid to the blade and endwall surfaces. Despite other reduction methods, using parabolic fillets and leading-edge bulbs, [1, 2] compare the overall pressure losses owing to secondary flows. The usage of fillets reduces losses, according to the findings of [1, 2]. However, when using a bulb, there is an increase in losses. According to [3], [4, 5, 6, 7], the consequences of employing linear-endwall fillets on secondary flows in a cascade are investigated. The cascade investigations use the vane profile of a gas turbine engine. The findings of [4, 1, 2, 3] reveal that the leading-edge fillet affects the patterns of secondary flows, which are largely responsible for the decreases in turbine passage aerodynamic losses. The fillet geometry determines the extent of the reductions in aerodynamic losses, including overall pressure losses and heat transfer. In this work, the focus of the research is the investigation of the performance of continuous and broken ribs at the mid-stream of the turbine vane passage. The purpose of the studies is to investigate the inclusion or non-inclusion of the rib(s) in the gap between the combustor and the turbine.

2. METHOD

In this computational research, three cases are tested for the purpose of efficacy comparisons. The geometries are modeled according to [8, 9]. The geometries tested include the baseline without any modification, the continuous rib case, and the broken rib case. Computational fluid dynamics (CFD) software, Star-CCM+ is employed to solve the grid generated for the fluid domain. The grid generated from the fluid domain is 1.6E6 for the baseline case and modified endwall respectively. No-slip boundary condition and at the intake and outflow section, there is a velocity inlet and a pressure outlet, respectively. At the leading and trailing edges, periodic boundaries are provided. To maintain symmetry, all other borders are made into walls. To save computational resources and time, the domain is modeled halfway. Thermal specification ($50 W/m^2$) is invoked at all the end walls for modified and baseline cases.

3. RESULT AND DISCUSSION

The velocity boundary layer profile in Figure 1 is specifically used to bench-mark the experimental investigation of [9]. The boundary layer is about 10% of the span of the free stream velocity. The magnitude of the free stream flow is 11m/s.

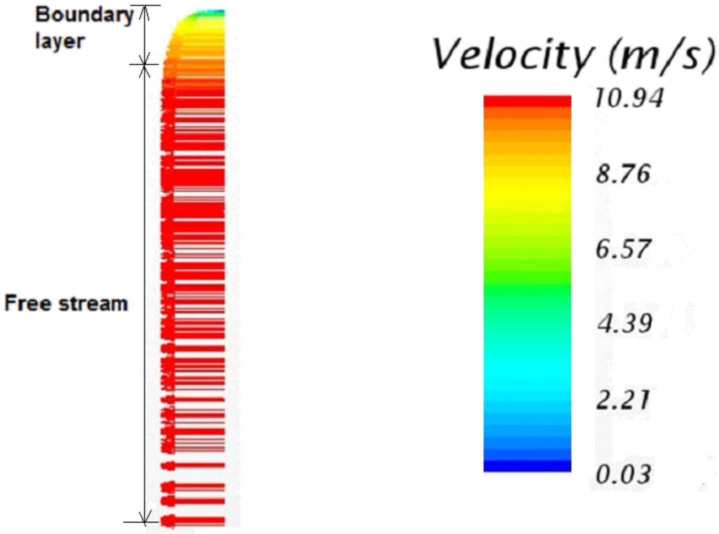
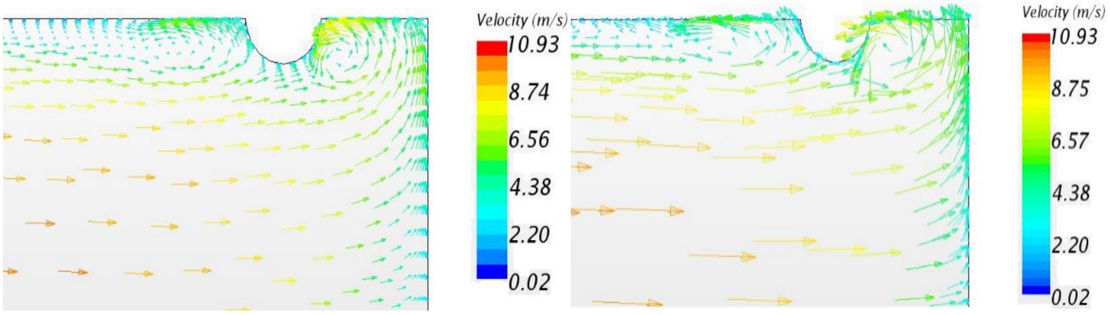


Figure 1: ***Inlet velocity profile***

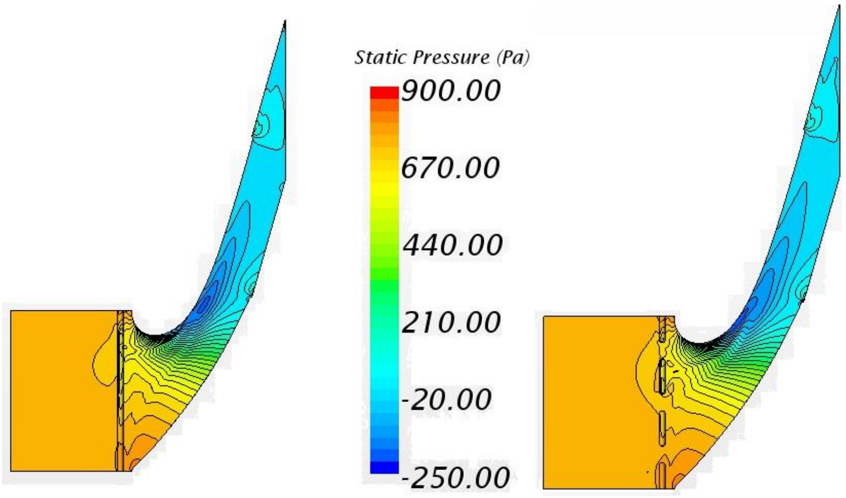
The velocity vector is presented at the symmetry plane in Figure 2. In Figure 2, both the broken rib and the continuous rib show the roll up at the stagnation edge of the turbine surface. High magnitude (+8m/s) is recorded around the corner close to the endwall. However, the discontinuous rib shows bigger size of the roll up.



(a) **(b)**

Figure 2: ***Velocity vector at the axisymmetry plane (a) Continuous Rid (b) Broken-Rib***

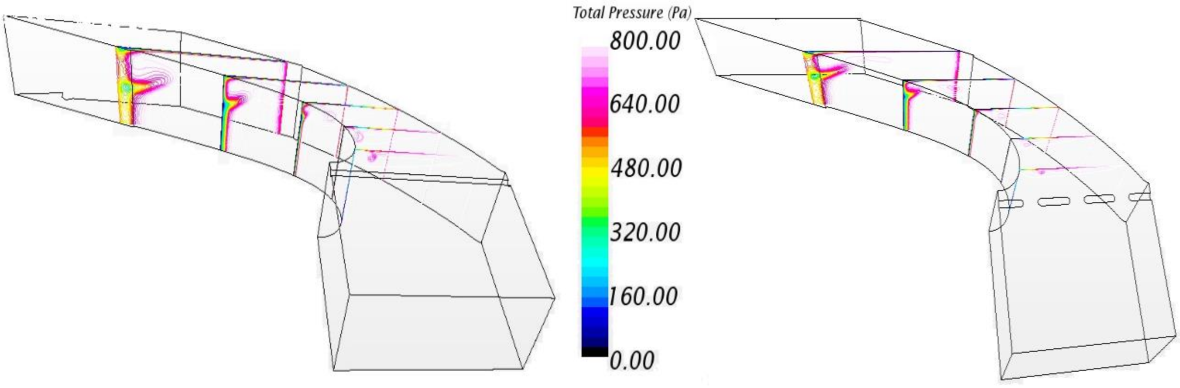
The static pressure on the endwall is presented in Figure 3. From the figures, there is no significant difference particularly at the downstream of the turbine passage. Generally, high values of static pressure are recorded at the upstream of the passage. The low values at the downstream implies flow acceleration close to the endwall.



(a) **(b)**

Figure 3: ***Static Pressure Distribution at the endwall (a) Continuous Rid (b) Broken-Rib***

The development and the effects of the rib along the passage is represented by five pitchwise planes of the total pressurecontours Figure 4 for both modified endwalls. The passage vortex is about the same in terms of the size and magnitude.



(a) **(b)**

Figure 4: ***Total pressure planes (a) Continuous rid (b) Broken-rib***

However, in Figure 5, the line plot shows the baseline, continuous and the discontinuous rib. At the pressure side, the two endwall modifications outperform the baseline case in most parts of the figure. The exceptions occurs at the Y/P = -0.23 and -0.26 where there is high entropies generated due to the cross flows towads the SS and the interaction of the flow with the bump walls.

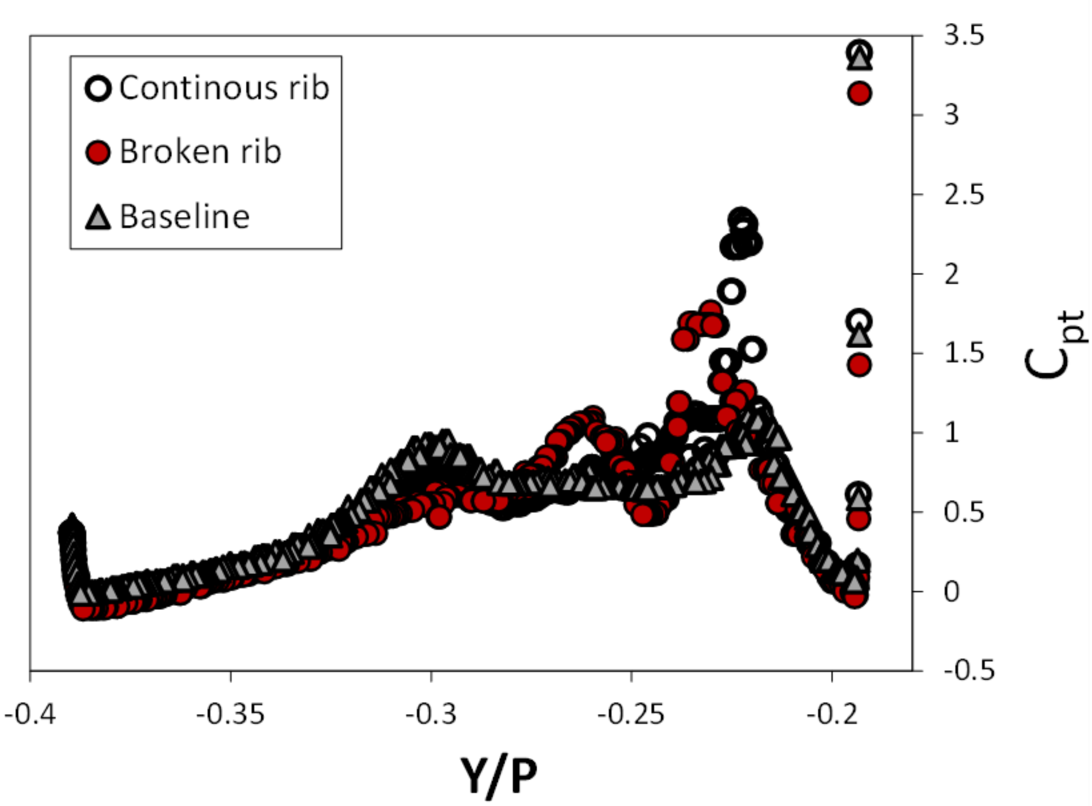


Figure 5: ***Total pressure at the 0.04m from LE, 2.5%S on the EW***

The computations of the static and total pressure coefficients are carried out by employing Equations 1 & 2 where P_b, P_s, P_{in}, and P_t are local static pressure, reference static pressure, reference total pressure, and the total pressure.

$$C_p = \frac{(P_b - P_s)}{0.5\rho U^2} \tag{1}$$

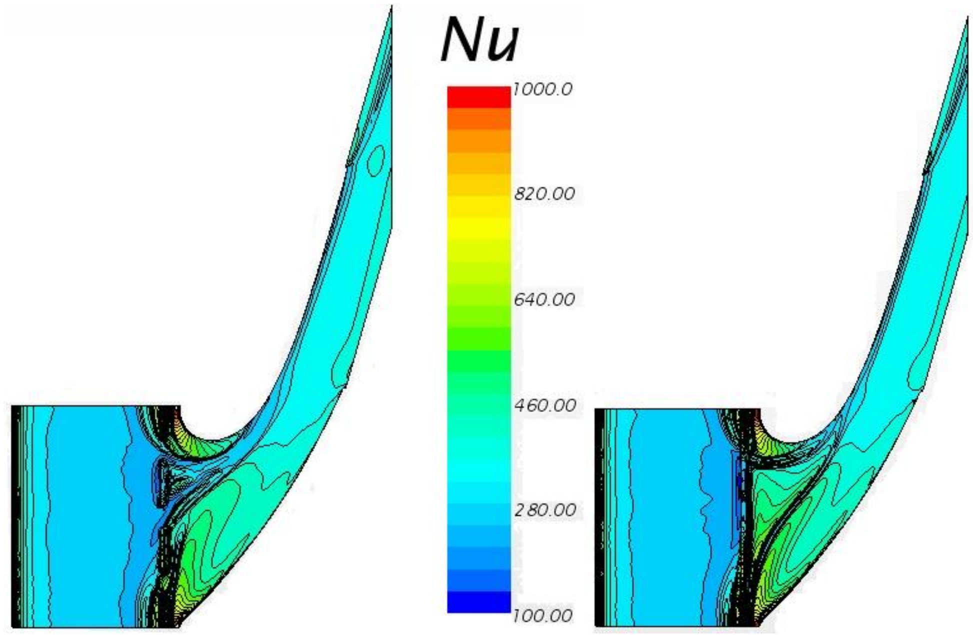
$$C_{pt} = \frac{(P_{in} - P_t)}{0.5\rho U^2} \tag{2}$$

The heat transfer comparisons are presented in Figures 6, 7 and 8. The computation of the heat transfer with respect to the axial chord (C_{ax}) is done by employing Equation 3, where q_f is the heat flux, T_l , T_{in} are the local and reference temparatures while k is the thermal conductivity

$$Nu = \frac{(q_f C_{ax})}{(T_l - T_{in})k_a} \tag{3}$$

From Figure 6, the continuous rib seems to augment more heat transfer at the leading edge region. However, the downstream region is not affected much as the two figures are similar at that region. The advection of the heat across the region from the pressure side to the suction side can be observed around the mid passage of the blade. This mid-passage corresponds to the throat region. Although the comparisons in Figure 7 for all the three cases tested revealed that there is higher heat transfer at the leading edge regions of the two modified endwalls compared to the baseline; the lower heat transfer is favored by two modified endwalls at the downstream regions of the passage as shown in Figure 8. From Figure

8, high heat transfer can be seen at the suction and pressure sides for app the three cases due to the flow boundary layers at the walls. The trailing wakes for all the three cases augment the heat transfer at the trailing-edge regions.



(a) **(b)**

Figure 6: Nusselt Number distribution at the endwall (a) Broken-Rib (b) Continuous Rid

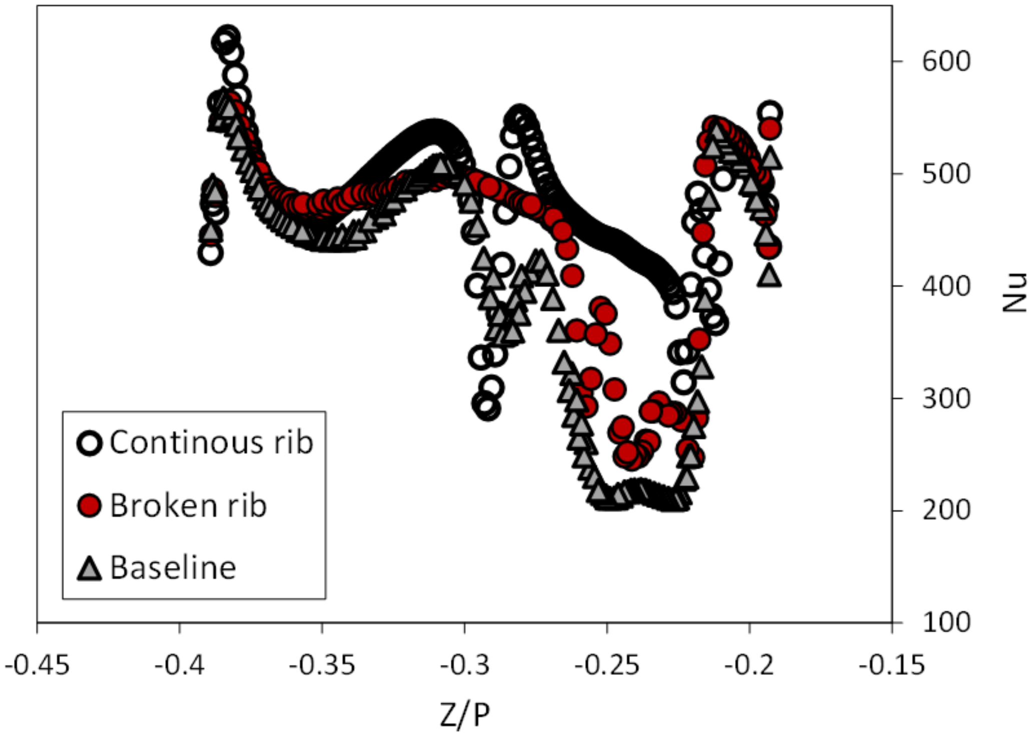


Figure 7: Nusselt Number distribution at 0.04m downstream of the leading edge

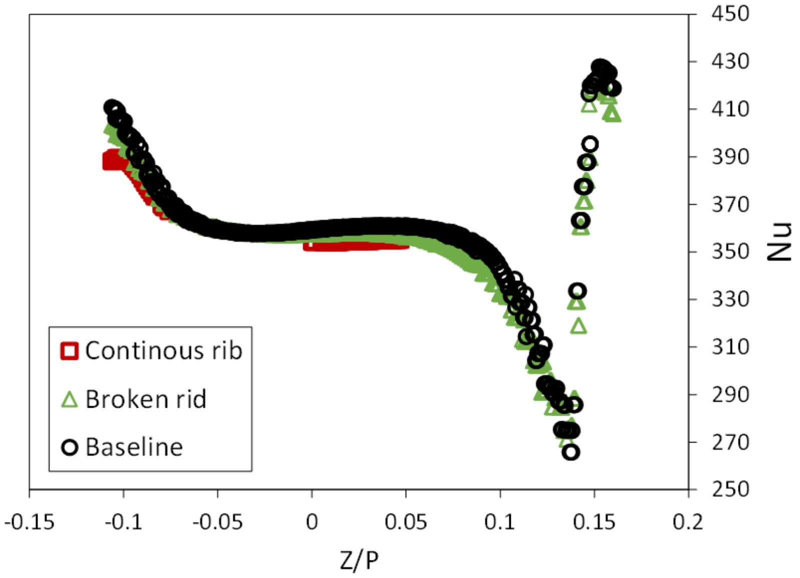


Figure 8: Nusselt Number distribution at 0.04 m downstream of the trailing edge

4. CONCLUSION

The Investigation of two different leading edge ribs are carried out using computational fluid mechanics. The discretization was done using polyhedral unstructured mesh of about 1.6E6 for all the three case respectively.

The results show that the broken-rib produced better result of about 10% *Nu* reduction when compared with that of the continuous rib. But in general, the inclusion or the use of rib produces reduction in the total pressure loss coefficient downstream of the passage. There is also reduction in the magnitude of the non-dimensional Nusselt number distribution particularly at the downstream part of the modified endwall (broken-rib) when compared with the baseline case. This shows that inclusion of the rib(s) in the design of turbine endwall has promising pros for turbine utilization.

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