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Heat Transfer Characteristics of a Different Shaped Dimpled/Protrusioned Pin Fin Wedge Duct for Turbine Blade using CFD

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ABSTRACT
The tip of the turbine blade is exposed to gas at high temperatures and speeds. Cooling in this region has a significant impact on the safety of the turbine blade. Generally, internal convective cooling and external film cooling are simultaneously used for cooling in the blade tip region. For some turbine blades, only an internal cooling channel is used so that the cooling of the blade tip is completely dependent on internal convective cooling. In recent years, in the tip region of the turbine blade, multiple augmentation devices such as fins, ribs, pins, and dimples / protrusions have gained a lot of attention to enhance heat transfer. Many computational simulations have been conducted in the meantime. The cooling performance of the blade inner tip area should be further investigated on the basis of analysis, especially when organised with a heat transfer enhancement structure. A very few studies have focused on the flow structure and heat transfer in a pin fin wedge duct with dimples/protrusions. A wedge duct is explored by a numerical process in this present work, with the result of various dimples or protrusion shapes placed on the heated end wall surface. The model of a wedge duct on Workbench of ANSYS 17.0 Program, with different shapes of dimples or protrusions for turbine blade. It is observed that the Pin fin-dimple wedge duct with trapezoidal dimples or protrusions form produces stronger heat transfer enhancement due to flow acceleration, increase in the region of impingement and shrinkage in the dimple of the flow recirculation field.

Keywords: *Computational fluid dynamics, gas turbine, turbine blade cooling, internal convective cooling, dimples/protrusions, Nusselt number*

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I. INTRODUCTION

1.1. Background

Gas turbines have developed over recent decades to raise the inlet temperature of turbines, which has risen gradually over the past sixty years between 1000 and 1100 K in the 1950s to the present state of the art between 1600 and 1800 K. Every 100 F (56 K) temperature rise of the flow leaving the combustion chamber has provided an average 8-13 percent increase in specific power output and a 2-4 percent improvement in the simple cycle performance, according to Boyce.

The common belief that a further increase in turbine inlet temperature could offer further performance advantages has been recently challenged by many researchers. Even though the turbine inlet temperature does not grow as quickly in the future as it did in the past, it is still far above the melting temperatures of the turbine blading alloys. Sophisticated cooling configurations have been developed for the first turbine phases to fill this void. In modern machines, high-pressure turbine blading's feature shower head film cooling at the leading edge, internal channels with devices designed to improve convective heat exchange, such as ribs or pin fins, impingement cooling on the inner surface of the vanes, trailing edge bleeding (TEB), and full coverage film cooling on pressure and suction side of the airfoil. The tip of the turbine blade is exposed to gas at high temperatures and speeds. The cooling in this area has a significant effect on the protection of turbine blades. Generally, for the cooling in the blade tip area, internal convective cooling and external film cooling are simultaneously followed. The performance of impingement cooling in the blade tip area should be given particular consideration. Smooth surfaces are used near the bending region in typical turbine blades, typically without any structures for enhancement.

In recent years, in the tip region of the turbine blade, multiple augmentation devices such as fins, ribs, pins, and dimples / protrusions have gained a lot of attention to enhance heat transfer. With increasing inlet temperature of the turbine, pin fin arrays cannot satisfy the need of the cooling alone. To be paired with the pin fin arrays, several more methods are also added. With slight loss of pressure, dimples and protrusions are fine options. In order to produce high turbulence kinetic power (TKE) flow and facilitate the heat transfer, dimples and protrusions are created to indent or protrude on a smooth surface. For this reason, the purpose of the study is to analyse the heat transfer characteristics of a different shaped dimpled/protusioned pin fin wedge duct for turbine blade using simulating software ANSYS 17.0.

1.2. Cooling strategies of the turbine

In serving a range of power needs, gas turbines play an incredibly important role and are primarily used for power generation and propulsion applications. Gas turbine engine output and efficiency depend to a large degree on the inlet temperatures of the turbine rotor: usually, the colder the better. In gas turbines, the heat transfer properties of the turbine blades are constrained by the combustion temperature and fuel efficiency. However, the use of efficient cooling technology is crucial in pushing the boundaries of hot gas temperatures while minimizing the melting of blade parts in high-pressure turbines. It also increases the heat transmitted to the turbine blade by increasing the turbine inlet temperature, and it is probable that the operating temperature will rise well above the allowable metal temperature. In such situations, poor turbine blade cooling results in undue thermal stress on the blades, allowing the blades to fail prematurely. This can add risks to the safe running of the engine.

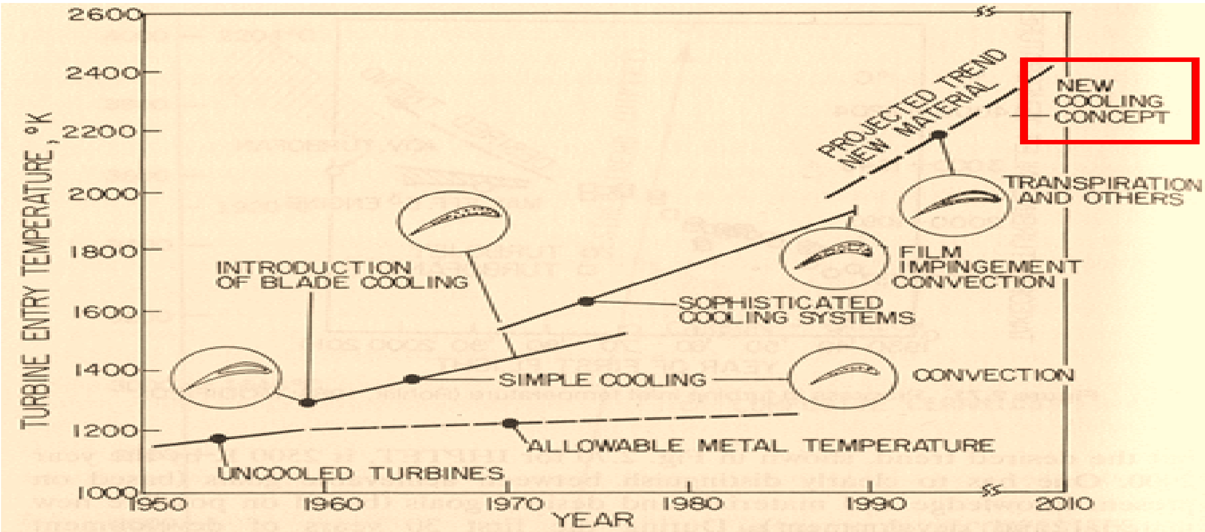

Figure 1 Development of turbine cooling systems over the last 60 years

Generally, in order to increase the thermal performance of the aero-engine, the blades and hubs of a gas turbine typically have to bear a rising temperature. Owing to the constraint of the sustainable temperature of the metal materials, the turbine's cooling strategies are becoming increasingly necessary and stressed. Low-temperature air is the cooling medium within the turbine blade. A typical turbine cooling structure is seen in the figure 1.2. The low-temperature cooling air enters the channel of the internal hub and flows through the blade's internal passages. Finally, it is expelled from the blade's trailing edge. Improving the turbulence intensity, breaking the boundary layers, and then removing the thermal load generated here is the fundamental theory of the increase in heat transfer.

1.3. Elements of turbine cooling

As applicable to gas turbine components such as high-pressure turbine vanes and blades, cooling technology consists of five main elements that must work in harmony, (1) internal convective cooling, (2) external surface film cooling, (3) choice of materials, (4) thermal-mechanical architecture, and (5) coolant fluid selection and/or pre-treatment.

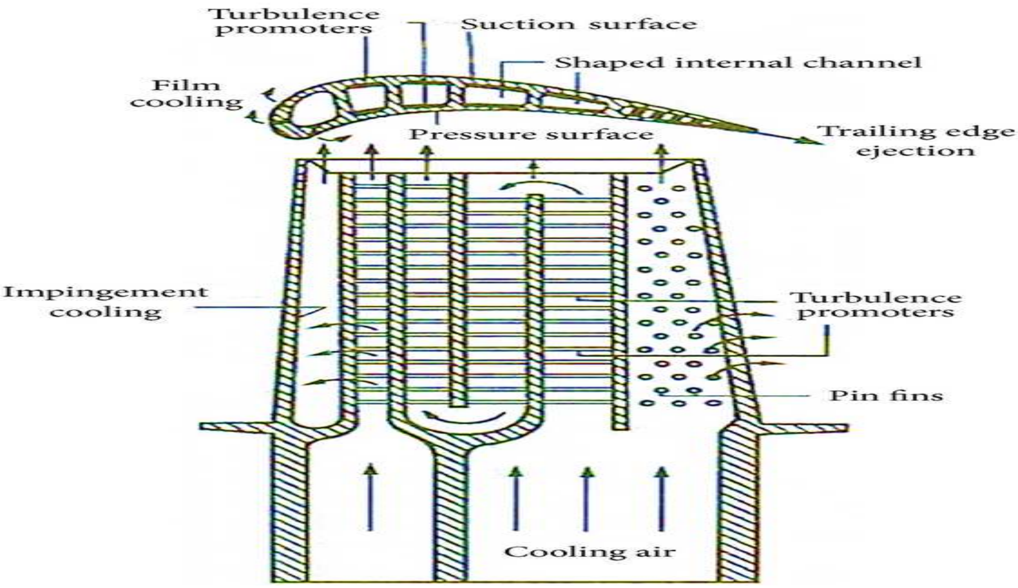

Figure 2 Typical cooling structure of gas turbine

Internal convective cooling is the art of directing coolant via the available pressure gradients into all regions of the component requiring cooling, while augmenting the heat transfer coefficients as necessary to obtain distributed and reasonably uniform thermal conditions.

Film cooling is the practice of bleeding internal cooling flows onto the exterior skin of the components to provide a heat flux reducing cooling layer.

High-temperature, high-strength nickel- or cobalt-based super alloys coated with yttria-stabilized zirconia oxide ceramics (thermal barrier coating, TBC) are the components most widely used in cooled sections. Today, protective ceramic coatings are actively used to increase the cooling power of the internal processes of convection (see Thermal Barrier Coatings).

These first three elements must be combined with the **thermal-mechanical design** of the components into a kit that has suitable thermal stresses, coating stresses, oxidation limits, creep-rupture properties, and aero-mechanical reaction.

The last aspect of the cooling design concerns the correct selection of the cooling fluid to execute the role needed with the least effect on the efficiency of the cycle. This is typically accomplished by using compressor air bleed from the compressor's most beneficial level, but it may also be accomplished using off-board cooling sources such as closed-circuit steam or air, as well as intra-cycle and inter-cycle heat exchangers.

1.4. Internal cooling

Internal cooling consists mainly in using convective heat transfer in internal channels to extract heat from the blade metallic wall to cool it down. To do so, more or less complex channels are hollowed out of the blade metal. Internal designs may therefore go from simple radial straight smooth channels extending from the hub to the tip, to long serpentine channels with turbulence promoters. A large panel of internal convective cooling systems has been developed since the first smooth channels in the 1960's to improve heat exchanges. A list of the available designs may be the following: surface roughness, rib arrays, jet impingement, dimples, pin fins and swirl chambers.

The main principles on which these systems are based are the augmentation of exchange surface through flow turbulence increase. Many different arrangements are possible and they may be classified following the heat transfer increase in comparison to a similar smooth channel without any cooling enhancement system. To be able to take into account any geometry, this parameter is commonly define as the ratio of the cooling systemNusselt number Nu to the smooth channel Nusselt number Nu_0. As the main objective of blade cooling, heat transfer maximization while minimizing the pressure drop penalties, the cooling systems may also be classified following ratio comparing modified channel friction factors f to smooth channel friction factors f_0.

1.5. Internal cooling heat transfer augmentation techniques

Rib turbulators, pin fins, dimpled surfaces, surfaces with rows of protrusions, swirl chambers, and surface roughness [1] are the methods used to increase convective heat transfer rates for internal cooling of turbine airfoils of gas turbine engines. In order to enhance mixing, both of these systems work to enhance secondary flows and turbulence levels, in some cases to form coherent fluid movements in the form of stream wise-oriented vortices. Such vortices and secondary flows work not only to increase secondary heat advection away from surfaces, but also to increase the output of three-dimensional turbulence by increasing shear and generating velocity gradients over large volumes of flow. These then provide higher turbulence transport magnitudes over greater portions of the flow fields. By increasing surface areas for convective heat transfer, all of the devices listed also have some heat transfer augmentation. Optimum thermal safety with limited use of coolant air and coolant mass flow rates as minimum as possible, and limited pressure drop penalties inside coolant passages is the ultimate goal for such internal cooling technologies.

1.5.1. Pin fin arrays

Pin fins or pedestals are typically organized into arrays as used for internal cooling and extend between two opposite walls of an internal cooling passage. Pin fins are typically used in sections of turbine airfoils where higher levels of increase in heat transfer are needed and where high pressure drops are tolerated and even desired in many situations.

High Reynolds coolant numbers, combined with high coolant pressure ratios, are ideal for heat transfer. The trailing edges of airfoils fall into this group. However, it has always acquired a large amount of heat by the time the coolant reaches the trailing edge, and the task of removing heat from trailing edge components is more complex relative to other sections of the airfoil.

Around the same time, output constraints on the width of the trailing edge slots preclude the coolant from being sufficiently limited, thereby forcing the flow to be determined upstream. Pin fins or pedestals provide sufficient structural protection near the trailing edge and are successful in allowing the pressure to stay high over much of the cooling circuit, while providing the required constraint near the trailing edge to reduce the consumption of coolant to the desired degree.

1.5.2. Dimple Surfaces

Dimples are indentation arrays around the surfaces. These are most commonly circular in form, but a number of other shapes, including triangular and tear-drop, have also been used. Arrays of dimples are a useful internal cooling strategy because they create several vortex pairs that enhance local distributions of Nusselt numbers as they advect downstream. They are remarkable for the penalties they create for low pressure drop, which is because they do not protrude into the flow and produce large levels of shape drag. With this advantage, dimples give advantages for cooling later turbine stages where cooling air is used for lower pressure. They are also advantages because the pressure drop they create through an airfoil passage is comparatively minimal, allowing desirable pressure margins to be retained in more downstream areas of the airfoil interior.

In comparison to rib turbulators and pin fins, which require additional material and weight, another advantage is that dimple processing eliminates material from internal cooling passage components.

1.5.3. Rib Turbulators

Rib turbulators are frequently positioned around the surface in the shape of rectangular cross-sectional bars that are often bent with respect to the direction of bulk flow. They work to start the flow, combine the flow, and even create vortices and three-dimensional gradients of velocity when they protrude into the flow. In cooled airfoils, rib turbulators or trip strips are general purpose heat transfer augmentations.

The cooling scheme may be optimised in such a way that the airfoil mid-body is not overcooled by modifying the key geometric parameters, trip strip height, channel blockage, direction, and spacing, while providing the requisite escape temperatures at the leading edge and trailing edge where film cooling may be needed. Ribs are rarely rectangular in cross-section as used inside turbine components due to casting limitations. Instead, owing to manufacturability constraints, they also keep more rounded profiles.

1.5.4. Swirl Chambers

Swirl chambers are internal flow passages arranged with either spinning vanes, internal inserts, or inlets and outlets designed to induce large-scale flow swirling (relative to the dimensions of the chamber) usually around the main chamber axis. This large-scale swirling and the pairs of Görtler vortex that are generated increase the transport rates of surface heat.

II. LITERATURE REVIEW

In recent years, in the tip region of the turbine blade, multiple augmentation devices such as fins, ribs, pins, and dimples / protrusions have gained a lot of attention to enhance heat transfer. Many computational simulations have been conducted in the meantime. Recently, a variety of experiments have been presented on inner cooling heat transfer augmentation techniques. A brief overview of the relevant literature is listed in this chapter to highlight the amount of work already published in the open literature on the development of augmentation techniques for internal cooling heat transfer.

2.1. Previous work

Ligrani et al. (2003) By comparing the flow structure, heat transfer, and friction factor of all these systems, some standard cooling strategies, including pin fin arrays, dimple, and rib turbulator, were summarised. The convective heat transfer can be distinctively enhanced by the pin fin arrays. In addition, pin fin arrays will increase the reliability of the structure of the hollow trailing edge area of the blade [3].

Several experiments have been carried out on the heat transfer effects of the pin fin arrays. The heat transfer efficiency and friction factor of pin fin arrays with distinct height-to-diameter ratio and array orientations were analysed by **Metzger et al. (1982).** The findings showed that both of the above factors were significant in influencing the convective heat transfer of the channel with pin fins[4, 5].

In order to calculate the heat transfer coefficient and resistance, **Chen et al. (1997)** used the naphthalene sublimation technique. The study showed that for channels with drop-shaped pin fins, the heat transfer improvement was higher than for channels with circular pin fins [6].

Choi et al. (2007) a series of studies were performed to research the results of pin fin arrays with various angles of inclination and concluded that the inclination of the pin fin arrays caused the rise in heat transfer to deteriorate [7].

Chyu et al. (2007) a liquid crystal imaging technique was used to test the output of pin fins with circular, cubic, and diamond shape heat transfer. The findings revealed that the transfer of heat from the arrays of cubic pin fin and diamond pin fin arrays is greater than that of the arrays of circular shaped pin fin arrays [8].

Furthermore, **Zhou and Catton (2011)** In a plate-pin fin heat sink with different pin cross section (square, circular, elliptical, NACA profile, and drop-from) the flow and heat transfer was measured by a numerical approach and concluded that the square cross section pin-fin had the best heat transfer increase of all the pin fins investigated[9].

Later, **Siw et al. (2012)** via a comprehensive experiment, the heat transfer efficiency of triangular, semicircular, and circular shaped pin fins was investigated. The findings calculated by hybrid liquid crystal imaging showed that the largest heat transfer increase was provided by the triangular shaped pin fin array but also followed by the highest friction factor [10].

With the elevated turbine inlet temperature, the need for cooling alone can not be fulfilled by pin fin arrays. Thus, to be blended with the pin fin arrays, several other methods are added. With minor lack of pressure, dimples and protrusions are fine options. Dimples and protrusions are produced on a smooth surface to indent or protrude in order to produce high kinetic energy turbulence (TKE) flow and facilitate heat transfer. Many research, including dimple forms, dimple depth, and so on, have been carried out to figure out the impact of the dimple geometrical factor on the heat transfer and flow structure.

Ligrani et al. (2001) Experiments to visualise the flow pattern of the airflow in the vicinity of the dimple were performed and the heat transfer enhancement process was clarified. Periodic appearance and shedding of the vortex pair will, according to his theory, boost the speed of the turbulence and thus greatly increase the heat transfer [11].

Burgess and Ligrani (2005) lot of experimental studies have been carried out to examine how the width of the dimple impacts the amount and friction factor of the Nusselt tube. Experimental findings found that vortices and related secondary flow with higher turbulence strength were caused by a deeper dimple. For a stronger heat transfer boost, higher turbulence mixing is responsible. The channel pressure penalty [12] could also be raised by deeper dimples, though.

Park and Ligrani (2005) heat transfer and friction factor of surfaces assigned to dimples in various cross sections have been investigated. Cylindrical types were regarded as circular, triangular, and titled. The local distribution of heat transfer revealed that the spherical shaped dimple had the highest value for heat transfer [13].

Rao et al. (2015) to explore dimples of various forms, that is, circular, teardrop-shaped, elliptical, and inclined elliptical, experimental and computational tests were conducted. The teardrop-shaped dimple has the highest value for heat transfer augmentation based on its findings [14].

Other scholars have also published experimental and computer experiments on the shape of dimples, the depth of dimples, and the configuration of dimples [15-19].

Luo et al. (2016, and 2018) to research the effects of dimple configurations, dimple depth, and converging angle in a pin fin channel / duct on the heat transfer and flow structure, computational methods were used. The dimple-pin fin channel results showed a tremendous output of heat transfer increase [20-23].

Many experiments have been carried out progressively, based on the effects of protrusion on the flow system and heat transfer.

Kithcart and Klett (1996) On flat plates with hemispherical dimples, hemispherical protrusions, and rectangular protrusions, skin friction and heat transfer were measured. The results showed that the heat transfer with lower pressure drop penalty was greatly improved by hemispherical dimples [24].

Hwang et al. (2008) the coefficients of heat transfer on dimple or protrusion walls were tested. The findings obtained by the transient liquid crystal thermochromics showed that the double protrusion-wall provided the best value for heat transfer but was also correlated with the largest decrease in pressure [25].

Kim et al. (2012) in a cooling passage with a protrusion-in-dimple wall, a numerical analysis was carried out and the heights of the protrusions were the geometry parameters for their study. They indicated that when the dimensionless height of the protrusion was 0.05, the pressure drop and heat transfer were increased [26].

Xie et al. (2013) conducted more studies on the role of the internal protrusion in a dimple. The key design parameters were the positions of the protrusion installed in the dimple cavity along the stream-wise direction. This research culminated in a significant improvement in the fluid flow area in the region of the inner-protruded dimples. Cases with internal protrusion installed in the dimple's rightmost central location yielded the highest improvement in heat transfer [27].

Besides, **Xie et al. (2015)** Using a numerical approach, they explored a rectangular channel with teardrop dimples or protrusions. The study claimed that the teardrop dimple / protrusion displayed improved heat transfer efficiency at a lower Reynolds number relative to a hemispherical dimple / protrusion [28].

Hwang et al. (2010) Local heat transfer and thermal output were investigated with transient TLC (thermochromics liquid crystal) technique on periodically dimple-protrusion plates. The findings showed that the thermal efficiency at a given Reynolds number for all the plates tested was similar [29].

Lan et al. (2011) In the Reynolds number range of 10,000 to 60,000, mixed ribs, dimples, and protrusions and five cases of separate combinations were studied. The findings showed that in a rectangular tube, the combination of rib and protrusion techniques had the ability to provide low-pressure drop penalty heat transfer enhancement [30].

Luo et al. (2017, 2018) Toanalyse the flow structure and heat transfer properties of a channel / duct with dimples / protrusions, a numerical approach was used. According to their results, converging angle channels demonstrated a stronger improvement in heat transfer but was also followed by a greater loss of pressure. In comparison, the protrusion cases provided improved heat transfer and greater loss of friction compared to the dimple cases [31, 32].

Wang et al. (2019) The heat transfer properties of a dimpled / protusioned pin fin wedge duct with multiple converging angles for turbine blades have been investigated. According to their data, the larger converging angle pin fin-dimple wedge duct achieves higher heat transfer enhancement due to flow acceleration, impingement area rise, and flow recirculation region shrinkage, but it is also followed by a much larger friction factor. A wider converging angle pin fin-protrusion wedge duct induces greater heat transfer increase due to flow acceleration and more extreme impingement on the protrusion, but it is often associated with a greater pressure penalty [33].

III. PROBLEM FORMULATION AND RESEARCH OBJECTIVES

3.1. Problem Formulation

The development of internal cooling configurations for gas turbine engines is subject to several major restrictions. In addition to heat transfer and thermal concerns, meeting these restrictions includes simultaneous consideration of multidisciplinary problems, such as output, airfoil surface cooling requirements, aerodynamic losses, supply of coolant, second law losses, required volume capacity, airfoil shape, and pressure drop penalties. As a result, current and future trends for advanced turbine part cooling architecture include parallel production of internal cooling technology of external thermal safety systems, such as film cooling, including consideration of adjacent conjugate conduction differences in adjacent solid components, as well as related penalty problems with aerodynamic pressure loss.

Designers, designers and researchers must build internal cooling systems with combinations of various devices together within one coolant passage to satisfy these specifications. Optimal thermal safety and minimum pressure loss penalties are the resulting targets. The cooling efficiency of the blade inner tip area should be further investigated on the basis of analysis, especially when organised with a heat transfer enhancement structure. The flow configuration and heat transfer in a pin fin wedge duct with dimples / protrusions have been the subject of very little research. The integrated configuration of pin-fin and multiple shapes of dimple / protrusion is used in the cooling channel in this current work. The heat transfer efficiency of the internal tip area of the blade is analysed and the optimum configuration is obtained by discussing parameters of dimple / protrusion.

3.2. Research Objectives

In this study, a wedge duct, with the effect of different dimples or protrusions shapes mounted on the heated end wall surface is investigated by a numerical method. The simulation programme ANSYS 17.0 were used for study of the heat transfer physiognomies of a wedge duct, with the effect of different dimples or protrusions shapes for turbine blades.

The main objectives of the present work are as follows:

- To analyze the heat transfer physiognomies of a wedge duct, with the effect of different dimples or protrusions shapes for turbine blades
- To develop dimpled/ protusioned pin fin wedge duct model and validation on CFD model will be carried out with comparison of previous work carried out by **Wang et al. (2019) [33]**
- Effect of different dimples or protrusions shapes in the cooling performance of the blade internal tip region
- To simulate the flow and temperature fields in turbine blade passages.
- To observe which configurations and parameters that gives the best results.

IV. METHODOLOGY

This section mentions the steps that have been taken place to achieve the objectives of the work.

1. Firstly we design the model of a wedge duct, with different shape of dimples or protrusions for turbine blade on Workbench of ANSYS 17.0 Software.
2. After designing the model it is transferred to ANSYS for CFD analysis.
3. Meshing of model and Name selection is done on CFD pre-processor.
4. The boundary conditions are applied on the model and numerical solutions are calculated by using solver.
5. The finite volume method is used in solving the problem.
6. The solution is calculated by giving iterations to the mathematical and energy equations applied on model.
7. The results can be visualized in the form contours and graphs by CFD post processor.
8. Applying formulas for calculating convective heat transfer and heat transfer coefficient.
9. Result analysis.

4.1. Definition of parameters

For the airflow in the studied dimple-pin fin channels, Reynolds number is defined as: $\boldsymbol{Re} = \frac{\rho u D_h}{\mu}$

where $\boldsymbol{\rho}$ is the density of the air inlet, $\boldsymbol{u}$ is the average velocity of the air inlet, $\boldsymbol{D_h}$ is the hydraulic diameter of the wedge duct inlet, and $\boldsymbol{\mu}$ is the dynamic viscosity of air at the inlet.

The heat transfer coefficient is defined as: $\boldsymbol{h} = \frac{q}{T_w - T_{in}}$

Where q is the wall heat flux, T_w is the temperature of the endwall surface, and T_{in} is the temperature of air at the inlet.
The Nusselt number is defined as: $Nu = \frac{h\, D_h}{K_a}$

Where K_a is the thermal conductivity of air.

The friction factor is defined as: $f = \frac{2\Delta P}{\rho u^2} \cdot \frac{D_h}{L}$

Where ΔP is the total pressure drop of the wedge duct. $\Delta P = P_{in} - P_{out}$,$L = L_c + L_i + L_o = 200\ mm$.

V. GEOMETRY SETUP AND MODELLING

The study uses the CFD model in this section to investigate the heat transfer physiognomies of a wedge duct, with effect of different dimples or protrusions shapes mounted on the heated end wall surface of a turbine blade.

5.1. Geometrical details of computational model

The geometry for conducting simulation study is drawn from **Wang et al. (2019) [33],** a research scholar with exact sizes. The details of the computational model of conventional designare shown in Figure 3. As shown in the figure, the extended length of the inlet segment and outlet segment are L_i = 20mm and L_o = 20mm; respectively. The converging segment of the channel is L_c = 160mm in length. The width of the channel is W = 30mm: The stream wise distance between the two pin fins is S_y = 30mm.

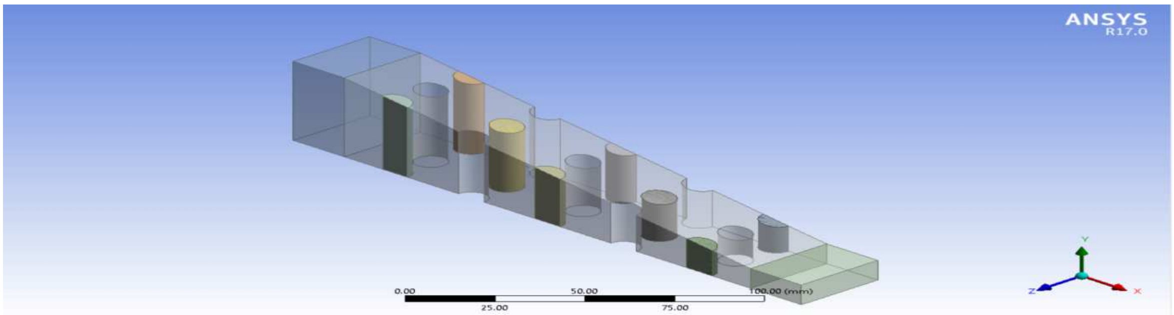

Figure 3 Geometrical model of Conventional design

The dimples or protrusions are situated centrally between the pin fins with a span wise distance S_x = 15mm away from the pin fins. The diameter of the circular shaped pin fins is d = 10mm: The diameters of the hemispherical dimple and protrusion are d_m = 10mm and d_p = 10mm; respectively.

After than in the proposed designs, different shape dimple/protrusion (i.e. triangular and trapezoidal) is employed in the cooling channel. The part of the model designed in ANSYS (fluent) workbench 17.0 software.

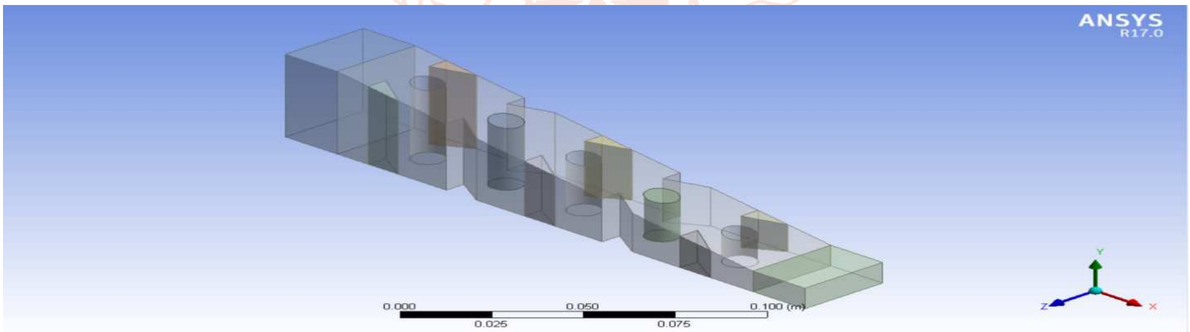

Figure 4 Geometrical model of proposed design having triangular shaped dimple/protrusion.

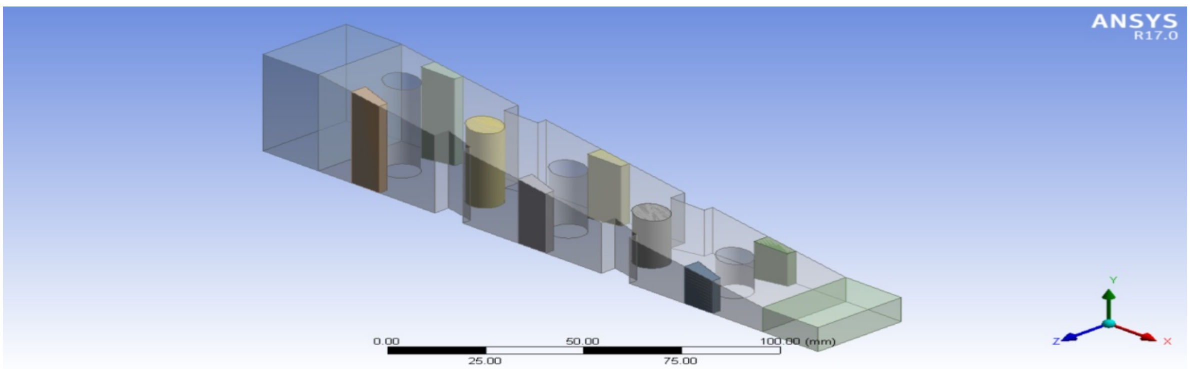

Figure 5 Geometrical model of proposed design having trapezoidal shaped dimple/protrusion.

5.2. Meshing
In the pre-processor step of ANSYS FLUENT R 17.0, a three-dimensional discretized model was developed.

Table 1 Meshing detail of various models

S. No.	Parameters	Hemispherical dimple and protrusion (Conventional design)	Triangular dimple and protrusion (Proposed design)	Trapezoidal dimple and protrusion (Proposed design)
1	Curvature	On	On	On
2	Smooth	Medium	Medium	Medium
3	Number of nodes	22509	152918	160670
4	Number of elements	18254	561249	544604
5	Mesh metric	None	None	None
6	Meshing type	Tetrahedral	Tetrahedral	Tetrahedral

5.3. Model Selection and Solution Methods
Fluent 17.0 has been used to calculate computationally. In science, the method used to separate the governing equations was a finite element. For this convective word, the scientists have used a simpler algorithm, for the coupling with the pressure velocity, the SIMPLE algorithm.$\boldsymbol{k}-\boldsymbol{\varepsilon}$turbulence model used to calculate the steady state, three-dimensional turbulent flow, and heat transfer.The heat transfer equations and fluid flow structure contains the mass, momentum and energy conservation equation. The equations are as follows:

The mass conservation:

$$\frac{\partial(\rho u_i)}{\partial x_i}=0$$

The momentum conservation:

$$\frac{\partial(\rho \overline{u_i}\overline{u_j})}{\partial x_j}=-\frac{\partial \bar{P}}{\partial x_i}+\frac{\partial\left(\mu+\mu_t\left(\frac{\partial \overline{u_i}}{\partial x_j}+\frac{\partial \overline{u_j}}{\partial x_i}\right)\right)}{\partial x_j}$$

The energy conservation:

$$C_p\overline{u_i}\frac{\partial(\rho\bar{T})}{\partial x_i}=\frac{\partial\left(\lambda\frac{\partial\bar{T}}{\partial x_i}\right)}{\partial x_i}-C_p\frac{\partial\left(\frac{\mu_t}{Pr_t}\frac{\partial\bar{T}}{\partial x_i}\right)}{\partial x_i}$$

5.4. Boundary Conditions
The inlet and outlet segments are adiabatic in this analysis. On the end wall and the pin fin surfaces a continuous heat flux of 3280 W/m² is applied. The surface of the end wall and the surfaces are known as slip-free boundaries. The ideal gas air is used as a fluid with a thermal conductivity and viscosity depending on the linear temperature. The air flow temperature at the inlet is 297.55 K and turbulence rate is 5%.

VI. RESULTS AND DISCUSSIONS
The section investigates the heat transfer physiognomies of a wedge duct, with effect of different shapes of dimples or protrusions mounted on the heated end wall surface of a turbine blade at different Reynold's number.

6.1. CFD validation
The work carried out by **Wang et al. (2019) [33]** are referenced and the results are introduced into this study. To verify the accuracy of the CFD results, computations corresponding to the work by **Wang et al. (2019) [33]** were carried out. The geometry that used for validation of numerical computations was considered as same as the geometry shown in Fig. 3. By way of CFD analysis, the value of the Nusselt has been measured at a different Reynold's number. In contrast with values derived from analyses by **Wang et al. (2019) [33]** the values in the Nusselt numbers estimates of the CFD modelling were compared.

Table 2 Comparison of the CFD results and the Wang et al. (2019) [33] results

S. No.	Reynold's number	Nusselt number	
		Wang et al. (2019) [33]	Present CFD computation
1.	10,000	102	105.987
2.	30,000	238	242.4339
3.	50,000	333	337.9307

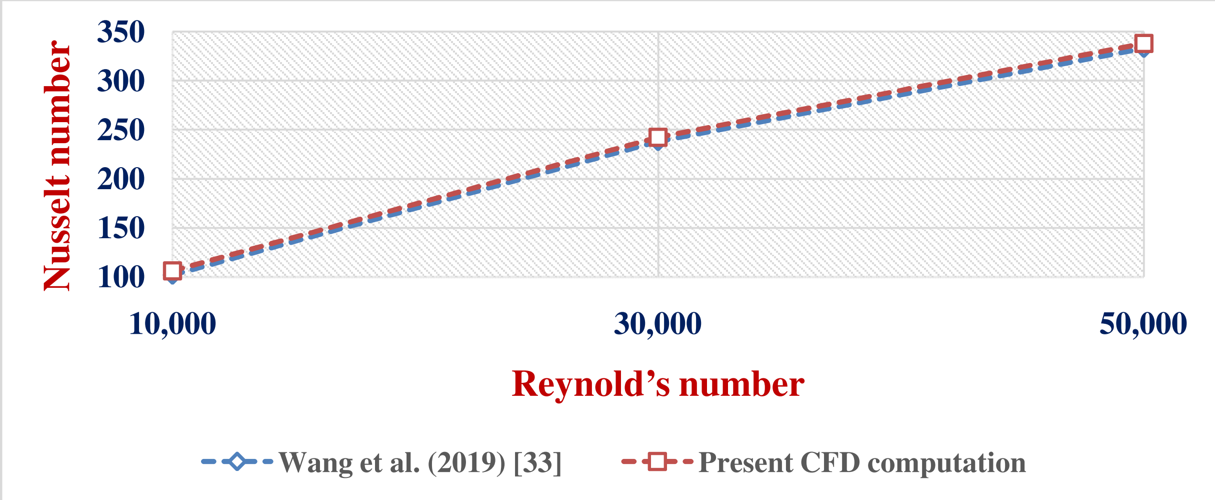

Figure 6 Comparison of the Nusselt number values of CFD results and the Wang et al. (2019) [33] results

From the above graph it is found that the CFD results show a favorable and decent match with the **Wang et al. (2019) [33]** results.

6.2. Effect of different dimples or protrusions shapes for turbine blades

In this section, different shape dimple/protrusion is employed in the cooling channel. The heat transfer performance of the blade internal tip region are investigated and the optimal structure is obtained by discussing dimple/protrusion parameters.

6.2.1. Design having triangular dimple and protrusion

- **For Re = 10000**

For this case fluid is flowing at Re =10000. The temperature, velocity, pressure contours and value of Nusselt number is shown below:

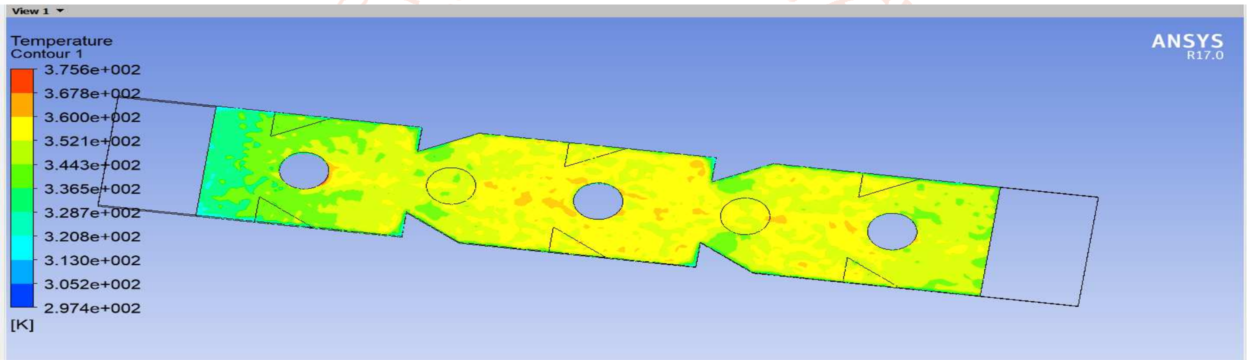

Figure 7 Temperature contour at Re=10,000 having triangular dimple and protrusion

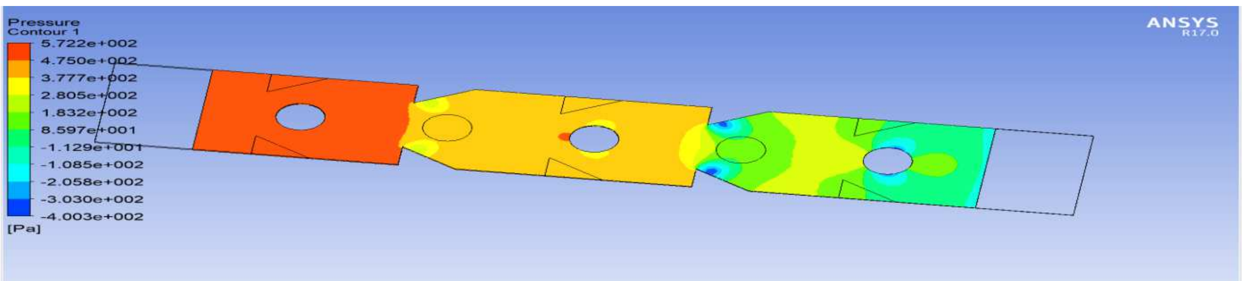

Figure 8 Pressure contour at Re=10,000 having triangular dimple and protrusion

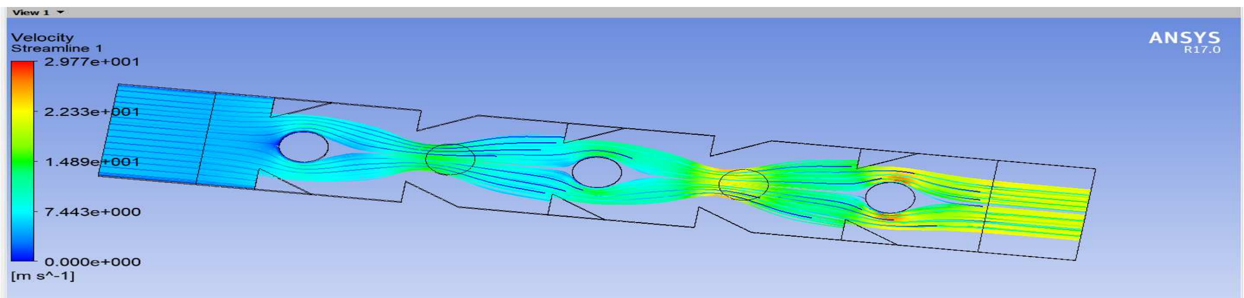

Figure 9 Velocity contour at Re=10,000 having triangular dimple and protrusion

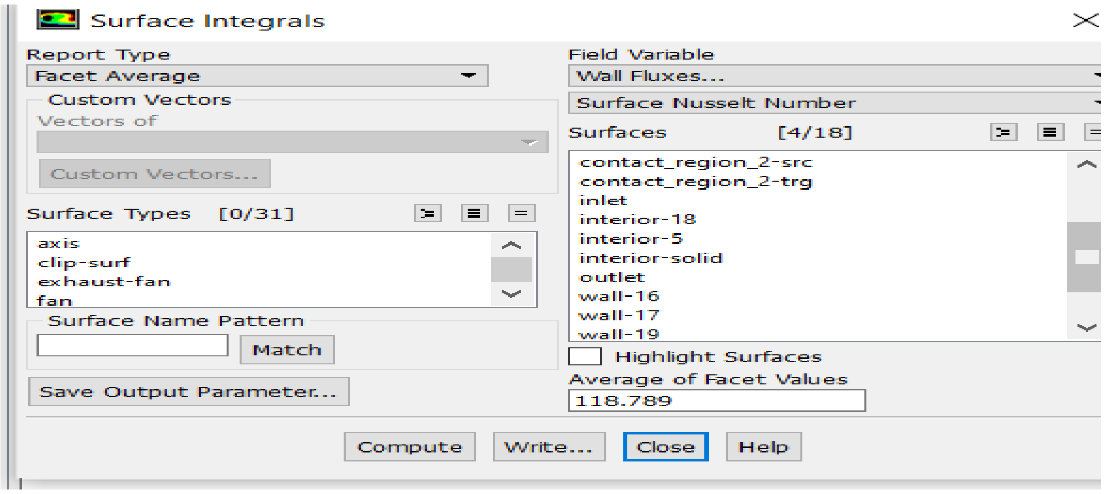

Figure 10 Value of Nusselt number at Re=10,000 having triangular dimple and protrusion

Table 3 Nusselt number value at different Reynold's number for triangular dimples or protrusions shapes for turbine blades

S. No.	Reynold's number	Nusselt number
		Triangular dimple and protrusion (Proposed design)
1.	10,000	118.789
2.	30,000	298.408
3.	50,000	355.841

6.2.2. Design having trapezoidal dimple and protrusion

➢ **For Re = 10000**

For this case fluid is flowing at Re =10000. The temperature, velocity, pressure contours and value of Nusselt number is shown below:

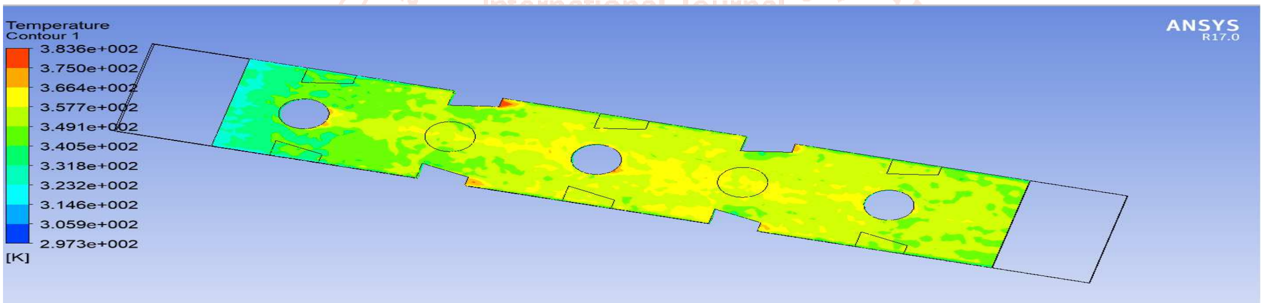

Figure 11 Temperature contour at Re=10,000 having trapezoidal dimple and protrusion

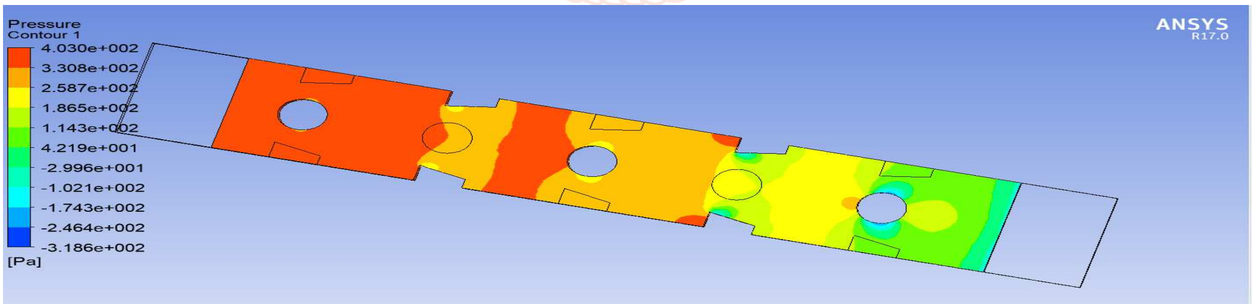

Figure 12 Pressure contour at Re=10,000 having trapezoidal dimple and protrusion

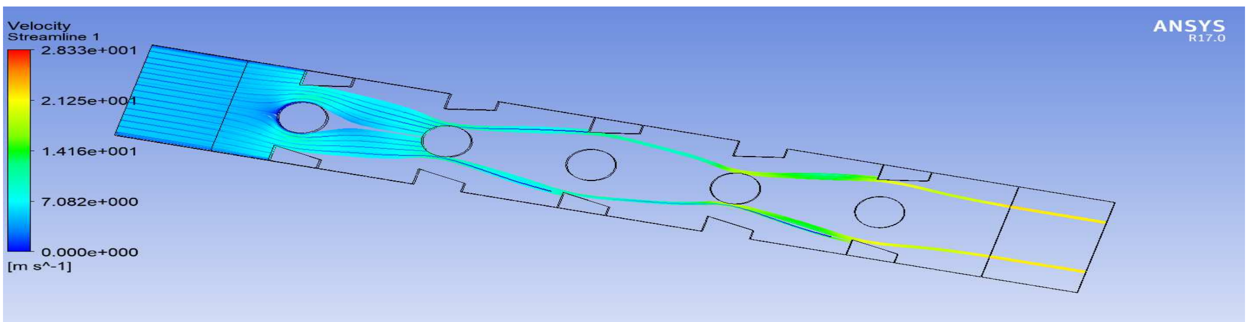

Figure 13 Velocity contour at Re=10,000 having trapezoidal dimple and protrusion

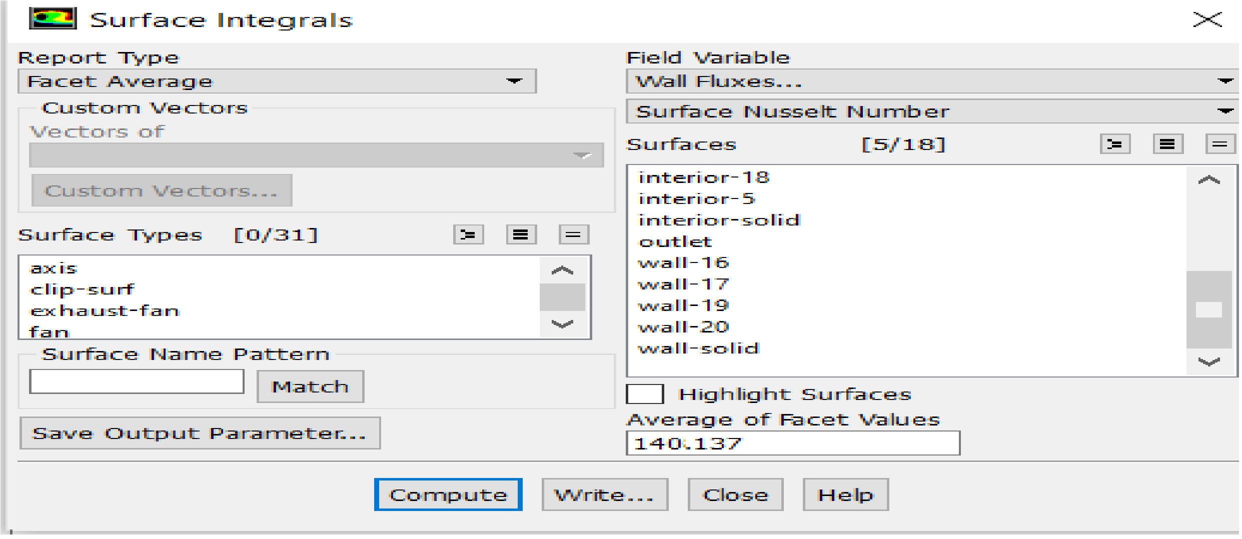

Figure 14 Value of Nusselt number at Re=10,000 having trapezoidal dimple and protrusion

Table 4 Nusselt number value at different Reynold's number for trapezoidal dimples or protrusions shapes for turbine blades

S. No.	Reynold's number	Nusselt number
		Trapezoidal dimple and protrusion (Proposed design)
1.	10,000	140.137
2.	30,000	331.114
3.	50,000	382.257

6.3. Comparison between different dimples or protrusions shapes for turbine blades

To improve previous understandings and to distinct the contribution of dimples or protrusions shapes to the overall thermal performance of proposed design, different dimples or protrusions shapes for turbine blades are compared in this section.

Table 5 Comparison of Nusselt number value for different dimples or protrusions shapes for turbine blades

S. No.	Reynold's number	Nusselt number		
		Hemispherical dimple and protrusion (Conventional design)	Triangular dimple and protrusion (Proposed design)	Trapezoidal dimple and protrusion (Proposed design)
1.	10,000	102	118.789	140.137
2.	30,000	238	298.408	331.114
3.	50,000	333	355.841	382.257

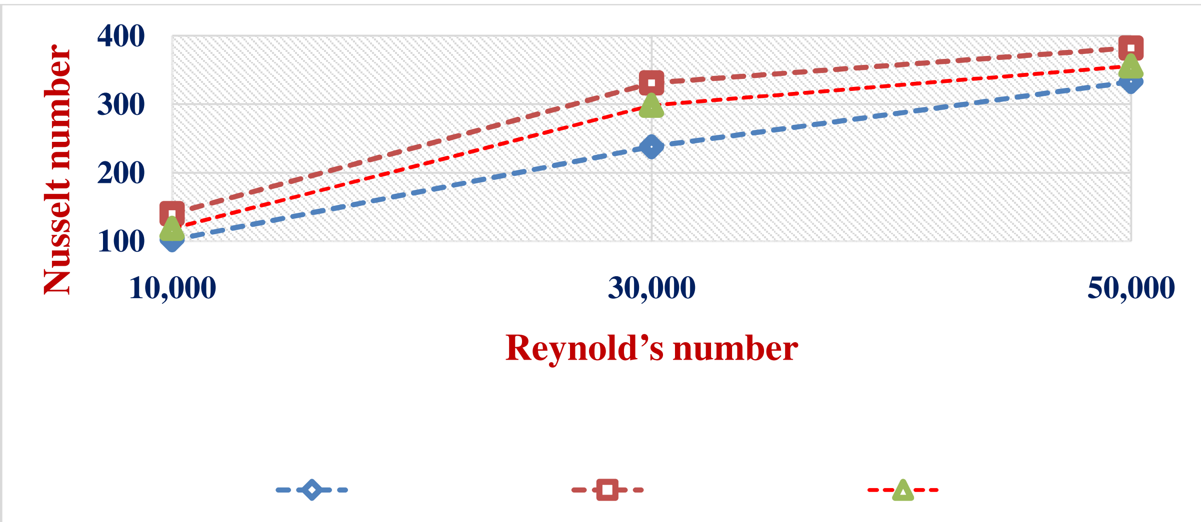

Figure 15 Nusselt number value for different dimples or protrusions shapes for turbine blades

VII. CONCLUSIONS

In this study, a numerical method is utilized to investigate the flow structure and heat transfer characteristics of a pin fin-dimple/protrusion channel with the effect of different dimples or protrusions shapes mounted on the heated end wall. The conclusions are as follows:

- Pin fin-dimple wedge duct with trapezoidal dimples or protrusions shape produces better heat transfer enhancement due to flow acceleration, increase of impingement region and shrinkage of the flow recirculation region inside the dimple.
- Cooling performance of the channel improved after optimizing the dimple/protrusion structures.
- At different values of Reynold's number, as the average Nusselt number improved, the Nusselt number for the proposed solution was 14.71% higher than the traditional design.
- The normalized area-averaged Nusselt number for Reynold's number = 50,000 shows the best heat transfer augmentation.
- From the temperature distributions on the solid surfaces in the turning bend, the solid surface temperature significantly decreases with the arrangement of trapezoidal dimples or protrusions shape as compared to triangular and hemispherical dimples or protrusions shape.

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