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Conjugate Heat Transfer Analysis Using Steady State Approach on Stator-Rotor Configuration

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Abstract: In order to improve gas turbine performance, modern gas turbine engines operate at higher turbine inlet temperatures, along with material modifications and cooling technologies. But increasing turbine inlet temperature above certain value may also result in lowering the overall cycle efficiency. So, the prediction of turbine inlet temperature is predominant. The temperature from the combustion chamber may not be always uniform. Moreover the thermal stresses on blades also be limited to achieve for reasonable durability goals. The migration of the hot streaks in gas turbine might induce the high temperature corrosion and thermal fatigue. Thus the hot streak regions in the turbine blades are predicted. The present study is focused on conjugate heat transfer analysis on stator-rotor configuration. The blades are designed using design software and the computational work was done using FLUENT. The results shows that the major hot streaks are found in the leading edge of stator blade and some parts of both the leading and trailing edge of rotor blade.

Keywords: Turbine inlet temperature, Turbine blades, Hot streak regions.

I. INTRODUCTION

The gas turbine engine is the heart of the aircraft. The engine's most important part is turbine. The useful work is extracted from heat energy is converted using the turbine. Recent trend for turbo machinery is to keep the operating temperature of the turbine to be operated at elevated levels along with material considerations and cooling techniques. The fuel economy has been increased since its operating metal temperate are higher.

Thus the turbine Inlet temperate has a significant impact over decades and considerably increasing its temperature for its efficiency. As the Turbine inlet temperature increases, the heat transferred to the blades in the turbine also increases. But still increasing turbine inlet temperature above certain value may also result in lowering the overall cycle efficiency. Moreover, the combustor outlet temperature may not be uniform always.

Hence prediction of turbine metal temperate or hot streak is important. The hot streak may also migrate to induce the thermal fatigue and the thermal corrosion on the blades.

The present computational study deals with conjugate heat transfer analysis over the axial turbine stator rotor configuration in a steady state approach and predicting the regions of hot streaks over the blades.

The thermal gradients of the blade may be over or under predicted if poor assumptions are made on calculating the metal temperatures of the surfaces exposed to the fluid.

The adiabatic flow assumption can cause errors in the prediction of turbine temperature on blades. The time-dependent variations from combustor have both Positive and negative temperature streaks. Thus, the Prediction of major hot streak region on the stator – rotor blade configuration is needed.

II. DESIGN OF STATOR-ROTOR BLADE

The turbine design process will be determined by its gas angles at each stage at the mean radius, blade loading coefficient, determination of number of stages, degree of reaction, rotational blade speed, determination of number of blades and degree of reaction. Stator is the stationary part in the gas turbine.

The flow is axially entering from the combustion chamber to the stator. Usually prime numbers are preferred for rotor configuration. The numbers will change for multiple stages.

The stator blades are lesser in blade height. Rotor is the rotary part in the gas turbine. The flow from the stator enters to the rotor. Usually odd numbers are preferred for rotor configuration. The numbers will change for multiple stages. The rotor blades are higher than the stator.

TABLE I. DESIGN OF BLADES

PARAMETERS	Stator	Rotor
Mean radius(cm)	21.6	20.6
Annulus Area(m2)	0.0626	0.0833
Blade Height (cm)	5.36	6.12
Number of Blades	90	71
Chord(cm)	4.77(Root), 4.26(Tip)	3.657(Root), 3.24(Tip)
Pitch(cm)	3.76	2.16
Max Thickness of the blade (cm)	0.85(Root), 0.83(Tip)	0.575(root),0.254(tip)

PARAMETERS	Stator	Rotor
Gas Inlet Angle(deg)	0 (Root), 0(tip)	47.30(root), 18(tip)
Gas Outlet Angle(deg)	62.15(Root), 56.85(tip)	50.51(root), 54.51(tip)

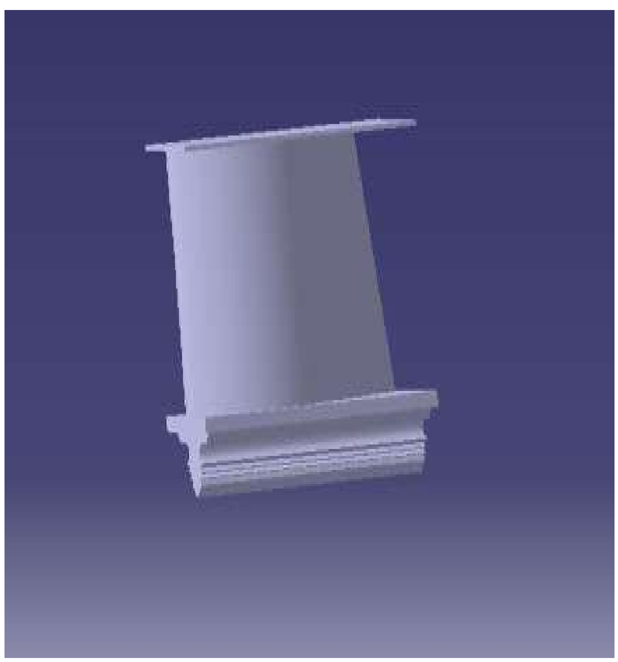

Figure 1. CAD model of Stator blade

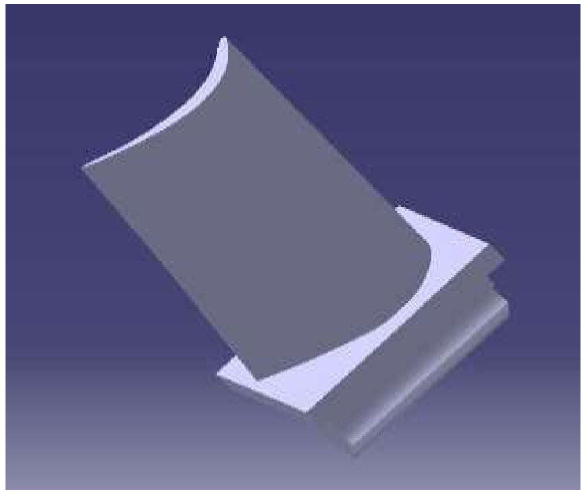

Figure 2. CAD model of Rotor blade

III. COMPUTATIONAL FLUID DYNAMICS

Computer based simulations for the analysis of systems involving the fluid flow, heat transfer and associated phenomena It enables for the creation of 'virtual prototype' of the system or the device by the computationally – based iterations for the model which are to be analysed , the predictions of the model how it will perform can also be determined.

The usual domain shape of the Turbine computational domain is like curvy domain not like rectangular domain as in the case of the wing analysis.

The curvy domain is important here because of the periodic nature can be utilized that is the analysis of the single blade can be superimposed to the other blades too. Another assumption made here is assuming the Rotor blade to be fixed at an instance namely the blade is at rest for the analysis of the conjugate heat transfer between the stator – rotor configurations. The computational domain is made in Fluent software. The blade data and other dimensions of the stator-rotor blades are imported to the workbench using iges format. In the computational domain, the fir tree arrangement has been removed and the stator tip part is removed and the Blades of the stator – rotor turbine is only considered.

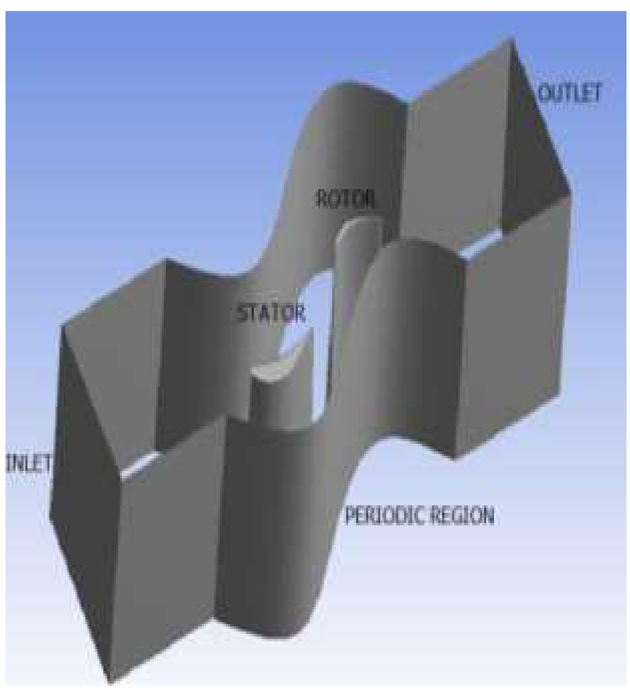

Figure 3. Nomenclature of the domain

A. Boundary Conditions

The boundary condition uses fluid flow medium is Heated Air which is taken as ideal gas and flow is assumed to be highly incompressible region i.e. near to the compressibility factor hence here the density of the heated air will be varying. The blade material is Nickel Alloy. The datum of this same from literature. The wall is set to be as no-slip free condition. Inlet Condition is velocity of the heated air is 100 m/s, 160 m/s and 270m/s. The temperature of 650K, 900K, 1200K with the pressure of 3.45 bar respectively. The Stator- Rotor both considered single as the Wall1 region. The total to static pressure ratio is 1.45. The courant number should be less than 0.5. The wall boundary condition is attained for Y+ <=1. The nickel- Alloy, the density of the material is 8900 kg/m^3.The specific heat Cp=460.6J/kg-k with the thermal conductivity is 91.74 w/ m-K. The heat transfer coefficient is 62w/m^2-K. The line by line solver of the algebraic equations are the most popular solution procedure and to ensure the correct linkage between pressure and the velocity SIMPLE Algorithm is used.

The solver model used is K-ε. This turbulence model is commonly used in CFD application to stimulate the flow characteristics. This model has two equations describes about the turbulence by means of two transport partial differential equations called turbulent kinetic energy and the rate of dissipations of the kinetic energy. This model is first used by Launder and Spalding, 1974. The principle behind this model is rate of change of K-ε + Convectional transport of K-ε= Transport of K-ε by diffusion + Production rate of K-ε-Destruction rate of K-ε.The energy equation is ON. The formulation is implicit and the time is steady state. The type of the solver is density based.

B. Meshing

Meshing is discretizing the domain into number of elements. If the number of the cells are larger in numbers, the accuracy towards the solution will be more.. In general, the unstructured non-uniform meshes are preferred for the analysis.

The fine meshes are adapted in the regions of the point of concentration and the coarser meshes at the relatively lesser change values. The skew factor used is 0.7 to 0.8.The meshing method is Automatic Control method by the Ansys and the fine mesh is employed. The grid independent evaluation is made for the meshing. The coarse and the medium mesh elements are 09125672, 10121234 and corresponding nodes are 15606571 and 18750678 respectively. The number of elements are 12858066 and the number of nodes are 19287099.

IV. RESULTS & DISCUSSIONS

1)For the velocity of 270 m/s and the initial temperature of 1100 K,

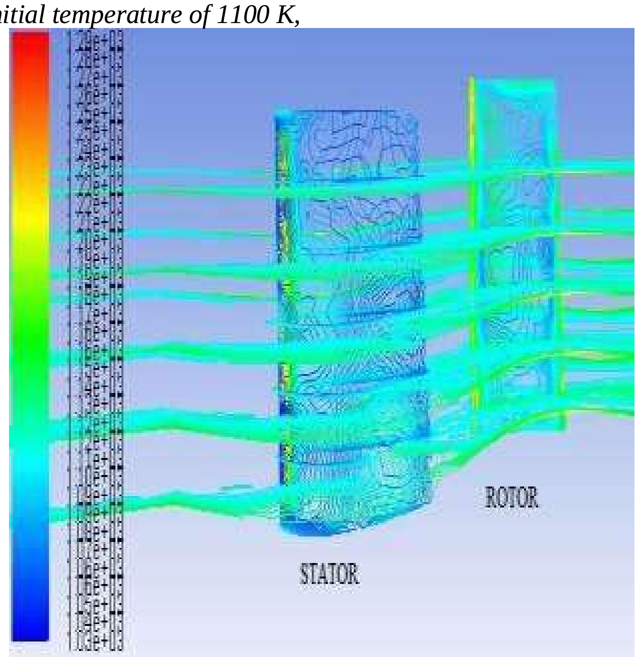

Figure 4. Hot streak region migration observed at Stator- Rotor Configuration at 1100 K

The temperature increases in the leading edges of the Stator turbine vane is due hot streak migration through it. It is clearly shows that the migration of the hot streak are seen in the rotor too on both leading edge and trailing edge of the blades.

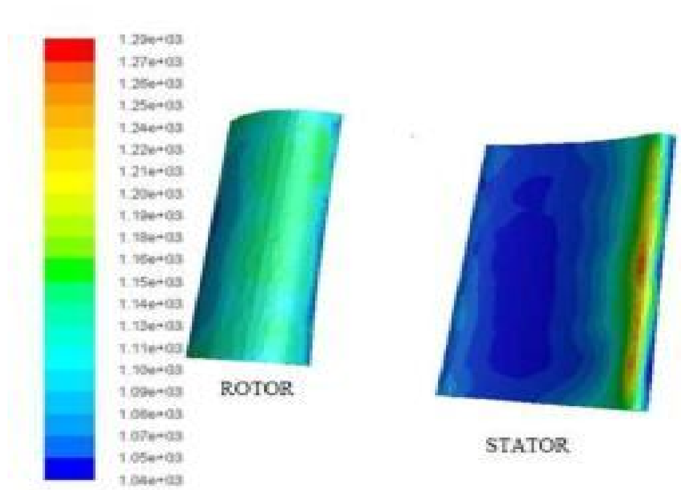

Figure 5. Static Temperature profile of the Stator-Rotor configuration at 1100 K.

The stator temperatures are higher in certain part of the leading edge due to the migration of the heat streaks.

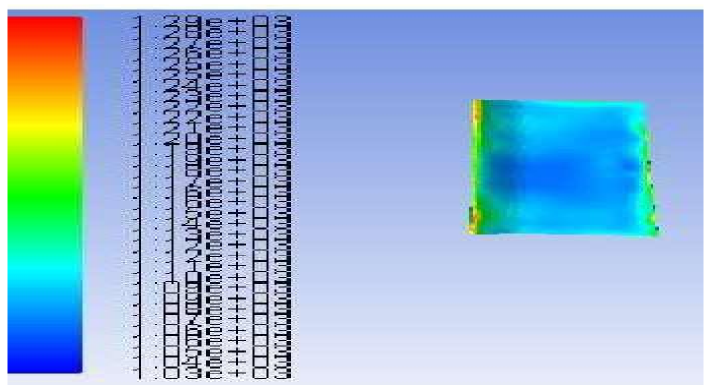

Figure 6. Static Temperature profile of the Rotor Blade at 1100 K.

The variation of the static temperatures over the rotor blade are higher in both leading and trailing edge of the blade due to the hot streaks at 1100 K. The temperature increases in the leading edges of the Stator turbine vane as like previous case. It is clearly shows that the migration of the hot streak are seen in the rotor too on both leading edge and trailing edge of the blades also.

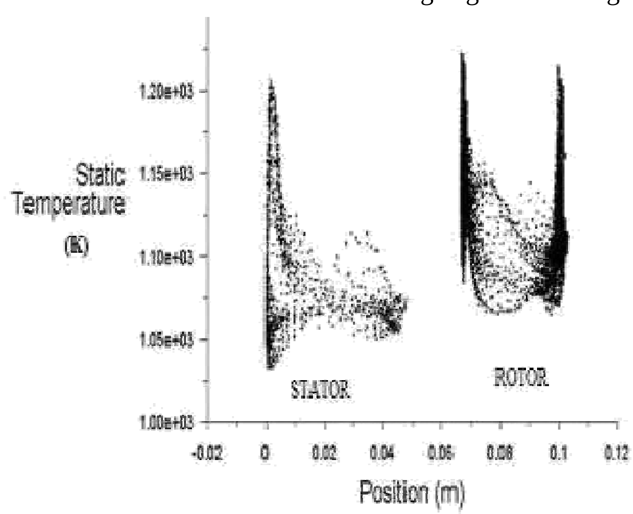

Figure 7. Static Temperature plot of the Stator-Rotor configuration at 1100 K.

The first profile indicates the Stator and the second profile indicates the rotor blade. The leading edge of the Stator has the higher temperature so the peak is present and the both leading & trailing edge of the Rotor blade has the higher temperature, so the two peaks are present on it.

2) For the velocity of 160m/s and the initial temperature of 900 K,

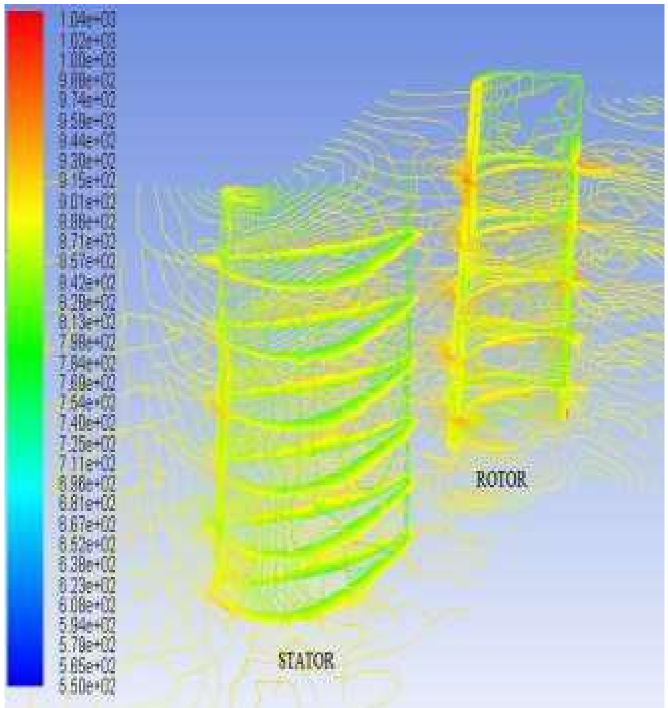

Figure 8. Hot streak region migration observed at Stator- Rotor Configuration at 900 K

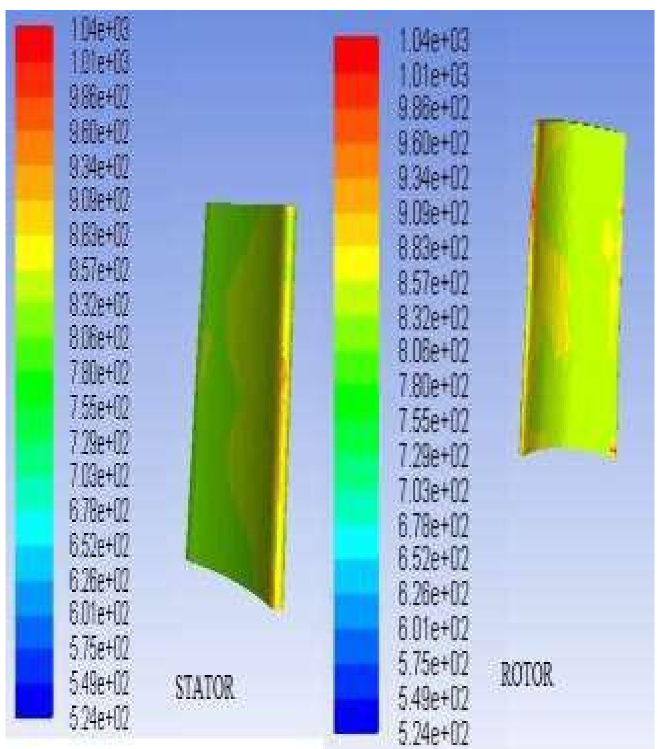

Figure 9. Static Temperature profile of the Stator-Rotor configuration at 900 K.

The higher temperature are observed at the leading edge of the Stator vane, there is a slight increase of temperature at the remaining regions. When compared to the rotor, the variation of the temperature is higher at the leading edge of the blade as well as trailing edge too.

The leading edge of the Stator has the higher temperature so the peak is present and the both leading & trailing edge of the Rotor blade has the higher temperature, so the two peaks are present on it.

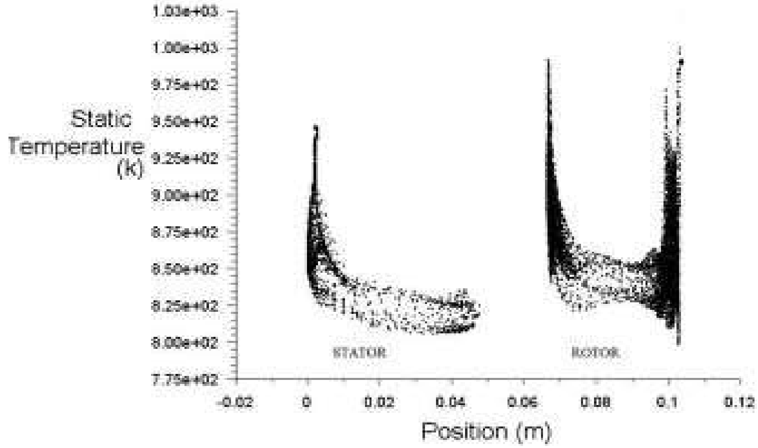

Figure 10. Static Temperature plot of the Stator-Rotor configuration at 900 K.

The rotor has two peaks in the rise of temperature due to the migration of hot streaks from the stator and we also observed that there is the negative streaks are observed too at the remaining part of the stator and the rotor blades.

3) *For the velocity of 100 m/s and the initial temperature of 650 K,*

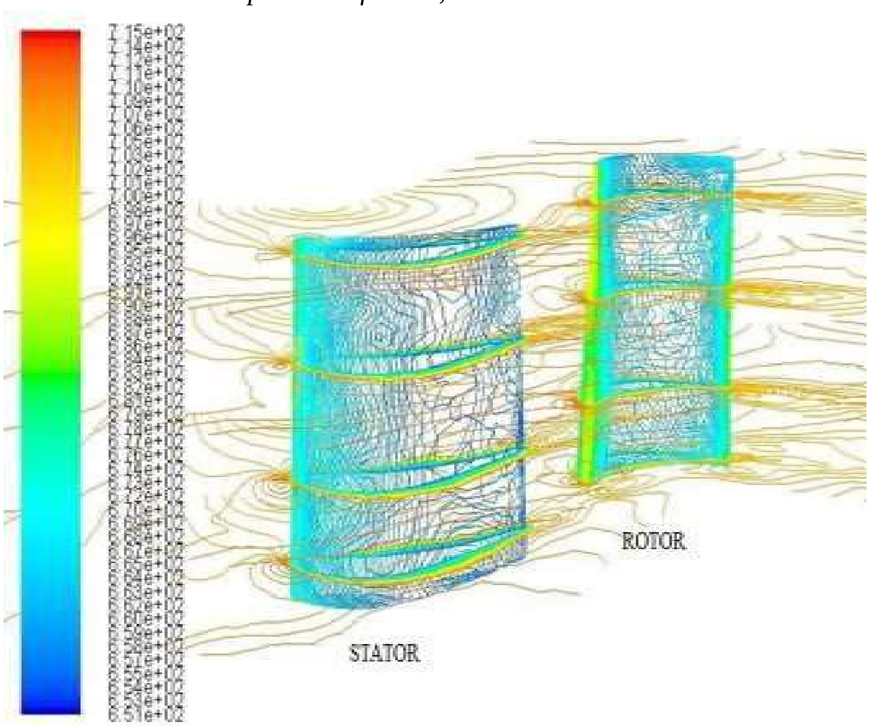

Figure 11. Hot streak region migration observed at Stator- Rotor Configuration at 650 K

The hot streak migration causes the leading edge of the stator to experience the temperature at its highest level. The migration of the hot streaks from the stator leads to the rotor causes the temperature to be higher at both its edges of the blade. This leads to sudden increase of temperature experienced at blades.

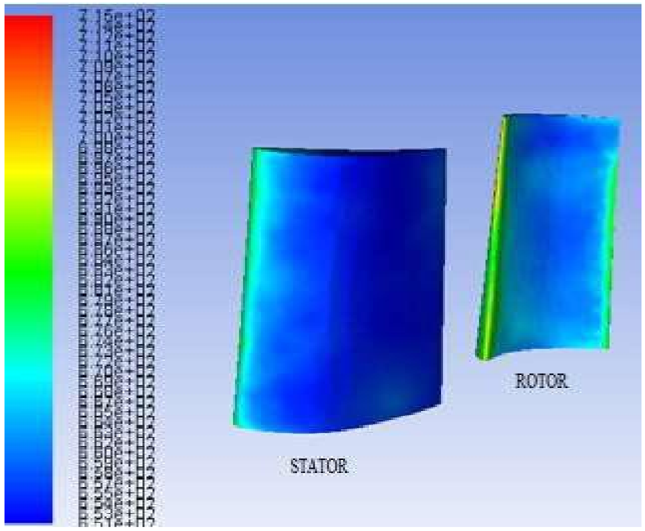

Figure 12. Static Temperature profile of the Stator-Rotor configuration at 650 K.

When compared to the Stator blade, the Rotor blade experiences the higher temperature because of the temperature effects due to hot streak migration. Thus the temperature effects trend remain the same for this case too.

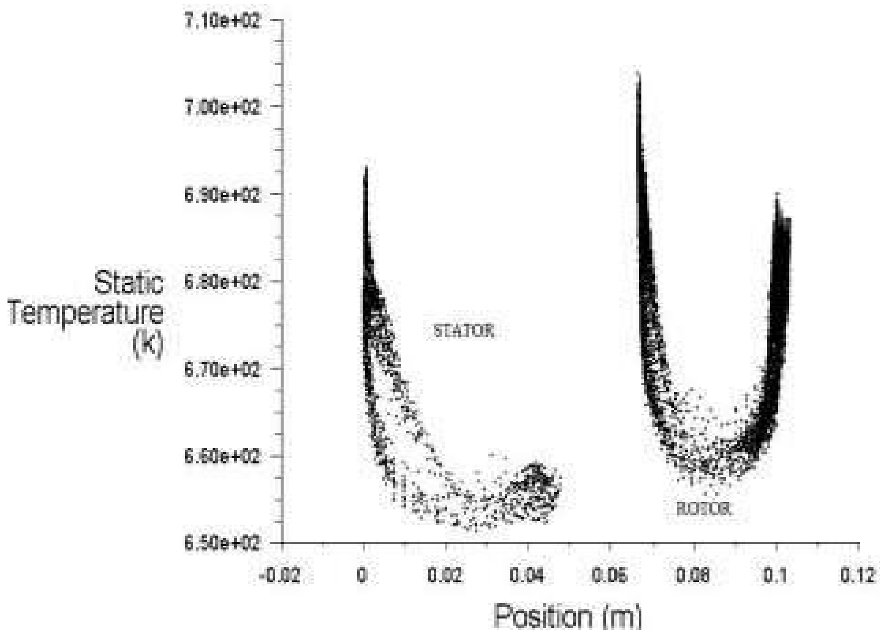

Figure 13. Static Temperature Plot of the Stator-Rotor configuration at 650K.

The temperature increases in the leading edges of the Stator turbine vane is due hot streak migration through it. It is clearly shows that the migration of the hot streak are seen in the rotor too on both leading edge and trailing edge of the blades.

V. CONCLUSION

The flow characteristics over the stator and rotor is determined. And the major hot streak regions are present over the leading edge of the Stator and for the case of rotor both leading edge and trailing edge, the hot streak region is present for all the cases of temperature of 650 k, 900k and 1100k with the same pressure ratio of 3.45 bar and with different velocities of 100 m/s, 161 m/s, 270 m/s. In future work the graphical representation of the hot streak migration can be determined with unsteady heat transfer approach with non-linear approach using harmonic methods. The future work is conjugate heat transfer analysis of the blade configuration using experimental setup.

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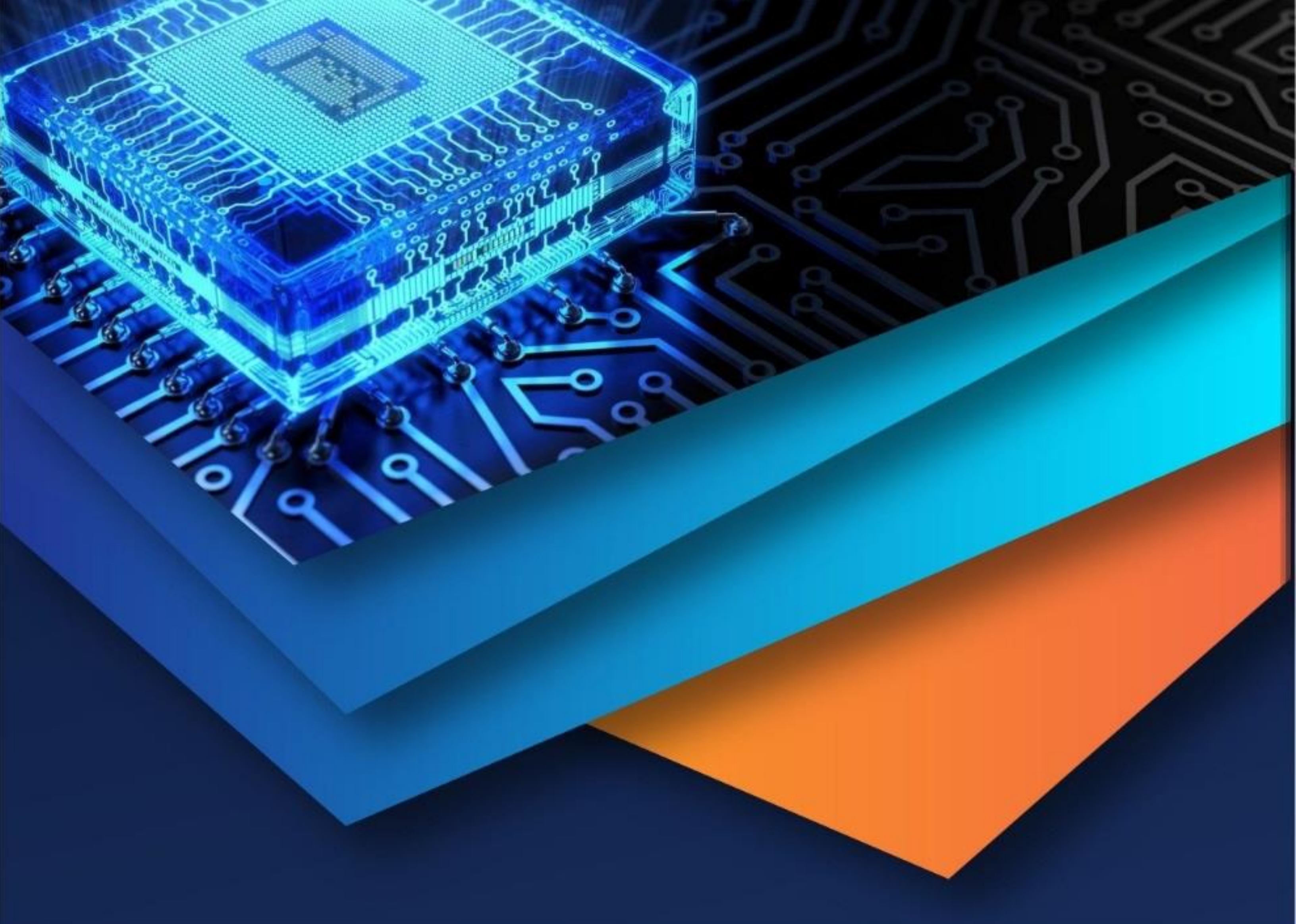

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