Effect of Branched Film Cooling Holes on Creep Life of Gas Turbine Blade using Larson Miller Parameter

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ABSTRACT

Abstract:The gas turbine has become an important, widespread, and reliable device in the field of power generation, transportation and other applications. As the demand for power increase, the power output and thermal efficiency of gas turbine must also increase. Increasing temperature leads to increase in both power output and efficiency. Hence, a refined cooling system must be developed for continuous safe operation of gas turbines with high performance. Various cooling techniques areused for cooling, out of which the cooling with the branched holes is amongst theeffective ping technique reported. Due to high temperature,progressive and localised structural damage occurs which leads to creep failure. Significant deformation and fracture of gasturbineparts like turbine blades are the results of their long-term exposure to high temperature and mechanical loads and hence the creep. Creep caused failure is an important failure mode for the turbine blade. Thus estimation of the creep life becomes necessary concern. Over the years, various models have been developed and studied for the creep life assessment. This study provides an insight into use of anti-vortex cooling hole technique to increase the creep life of turbine blade. Larson-Miller Parameter has been used to calculate the creep life of the gas turbine blade and comparison has been made between the blade with cooling holes and blade without holes. The study shows significant increase in creep life of gas turbine blade with branched film cooling holes as compared to blade without holes.

Keywords: ***Gas Turbine, Creep life, Larson-Miller parameter, Film Cooling etc.***

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1. INTRODUCTION

Gas Turbines have been playing vital role in various fields like aerospace industries and power generation plants. With the rise in demand for power, increasing the gas turbine efficiency is of great importance. This led to the increase in Turbine Entry Temperatures (TET) [1,2]. Nowadays, Gas Turbines operate in the elevated temperature range of 500^{0}C and 1200^{0}C**.** However, this rise in the turbine entry temperature imposes a huge challenge on the working of turbine blades and degradation of other components. The rise in temperature by 16 ^{0}C above the critical temperature of turbine blade material may bring down the life to half of its original value.

In addition to higher Turbine Inlet Temperature Gas Turbines are also subjected to heavy mechanical loadings in the form of centrifugal and gas pressure forces. This further leads to failure of gas turbine blades in fatigue, oxidation, corrosion and creep [3]. Design and development of gas turbine blade is done from special materials like super alloys to withstand hazardous conditions inside the GT [4].To tackle the failure and improve creep life, counter measures currently applied to the hot gas components include film cooling, internal cooling, impingement flow thermal barrier coating or a combination of all. Film cooling holes help significantly to keep the surface temperature of blade well below melting point of blade material[5]. With the use of these technologies it is possible to operate Gas Turbines at a very high temperature and sometimes even above the melting point of GT blade material [6].

Although, gas turbine blade is manufactured from super alloys to withstand hazardous conditions inside the GT they undergo failure by various mechanisms [7]. As a consequence of operating the gas turbine at higher temperature and stresses, the turbine blades are subjected to deformation in the form of creep. Creep is phenomenon where a constant load and temperature both act simultaneously for a very long period of time [8].Creep damage of the gas turbine blade is the major cause of blade life reduction especially, near the cooling hole regions used in film cooling technique [9]. Hence to estimate the life of GT blades, evaluation of time required for the initiation of creep needs to be investigated.

Determination of creep life includes various mathematical calculations and models, based on different materials and conditions [10]. A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high pressure gas produced by the combustor. The turbine blades are often the limiting components of gas turbines. The material strength of the blades often imposes limits on the thermal load these components can bear. Due to this reason the cooling of gas turbine blades becomes more significant. Better cooling designs have the potential to extend the blade life span, enhance higher inlet temperature, and use of optimum compressor bleed air. Film cooling [11] is extensively used to protect hot gas path components in the gas turbine. Innovative film cooling hole design have the ability to further enhance the durability and strength of these components.

In 2008 a novel concept was introduced by Heidmann and Ekkad which was conceived and designed at NASA Glenn Research Center. The Branched film cooling hole design concept was introduced to mitigate the effects of counter rotating vortex pair which reduces the effectiveness of circular cross section film cooling holes at high blowing ratios[12]. In this study the main focus is on preparation of creep life assessment model based on Larson-Miller parameter method for industrial gas turbine in which branched film cooling holes cooling technique is used for better cooling effectiveness.

2. COOLING OF GAS TURBINE BLADE

Cooling technologies and processes used in blade cooling also have significant effect on the blade life since the creep is a function of temperature and stresses acting on the blade from the root to the tip. Cooling of blades plays a vital role in increasing the service life of turbine blades. Film Cooling, Steam cooling, convection cooling are various methods of cooling of turbine blade. Among which film cooling is most effective method of turbine blade cooling. Film cooling is the technique where the cold air taken through compressor is fed in turbine blade through hub and cooling passages which are made in turbine blades. Through the research since many years' various types of cooling holes were invented and effectiveness were checked. In 2008 NASA developed a new type cooling method [12] i.e. Anti-Vortex cooling hole technique. This hole consisted of a main hole and side branched holes at each side. The main advantage of this type of hole was the vortices formed by normal cylindrical hole were cancelled by these branched film cooling holes. Due to this the cool film remains attached to the blade surface and we get more cooling effectiveness than the other cooling methods.

As this advanced cooling method has proved effective it becomes necessary to test its effect and how it has affected the life of blade. The paper will focus on estimation of creep life of turbine blade as creep is a major failure found in turbine blade which is composition of both temperature and stress.

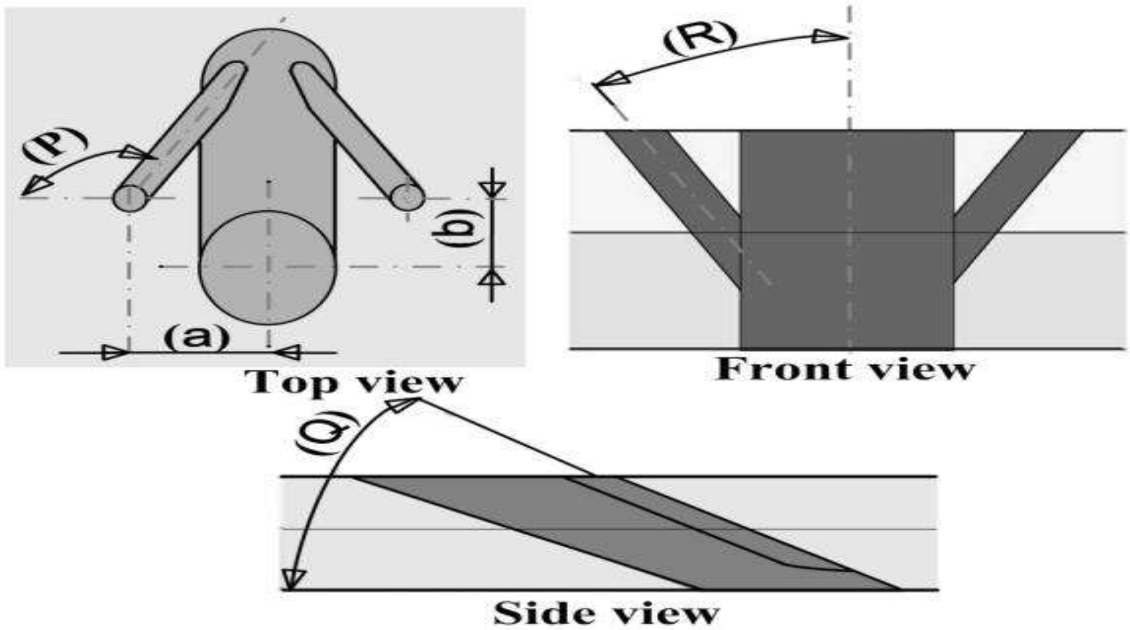

Fig- 1: Design of anti-vortex holes and different configurations by Dhungel (2009)[13]

2.1 Parameters Affecting Cooling Effectiveness

(i) Effect of Hole geometry:Branched film cooling holes hole had higher effectiveness than cylindrical holes.

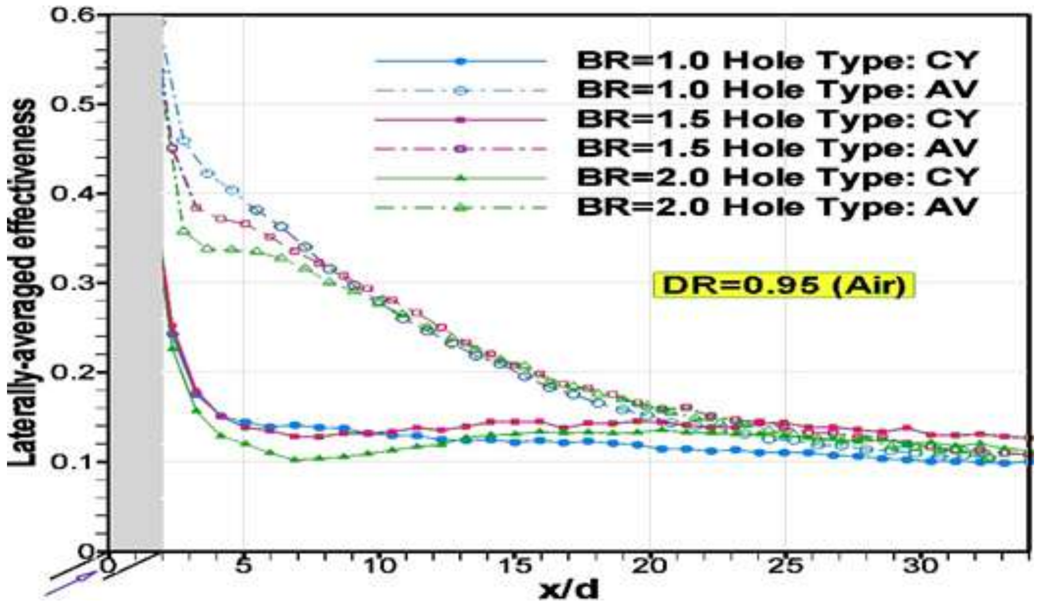

Fig-2: Comparison of laterally-averaged film cooling effectiveness for the two geometries [14]

(ii) Effect of Blowing Ratio: It was seen that even at far downstream region effectiveness was higher for branched film cooling holes.

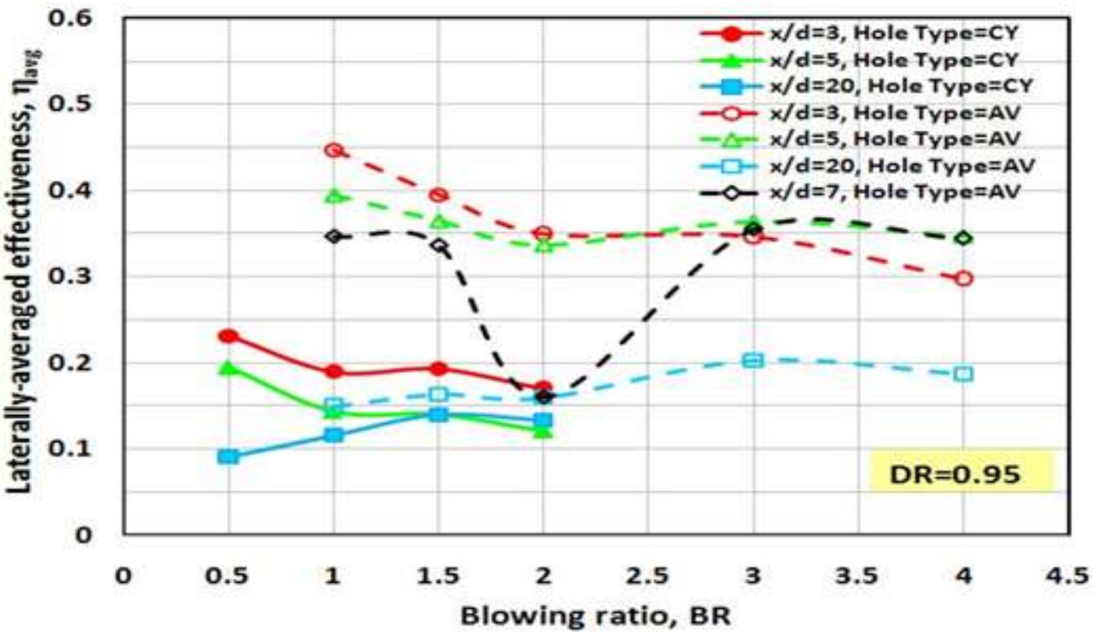

Fig- 3: Laterally-averaged effectiveness as a function of blowing ratio [14]

3. LARSON MILLER METHOD

Advancement in Gas turbines began in 1940s and with the advent of Larson Miller Parameter in 1952 much work was done in creep life assessment of Gas Turbine blade. The well-known and quite successful Larson-Miller method of extrapolating stress rupture and creep results is based on the contention that the absolute temperature compensated time function and is dependent on the applied stress levels and is characteristic of a particular material [15, 16]. This Larson-Miller equation is given by

$$log\sigma = function[T(C + logt)] \quad (1)$$

The time t is stress rupture life at a stress σ or time to accumulate a certain amount of creep strain (say, 0.1% or 0.2%) at that stress level [17]. Larson-Miller further proposed that the constant C may have a universal value of 20.

For above function to work, a new parameter is introduced as Larson-Miller parameter (P). At operating temperature, we can calculate stress by appropriate method. Since Larson-Miller parameter is logarithmic function of σ, we can find Larson-Miller parameter by logarithmic curve of stress Vs Larson-Miller parameter.

Thus, by knowing operating temperature T, Larson-Miller Parameter P and constant C (approximately as 20), we can find creep life t_r by equation [18]

$$P = T[logt_r + C]$$

Where T is in ^{0}R and t_r is in hours.

For Inconel 718, modified [19] form of Larson-Miller Parameter equation is

$$P = (460 + T)(25 + logt_r) * 10^{-3}$$

The Larson-Miller method has proven satisfactory for many steels and super alloys and is often used not only for extrapolative purpose but also for comparative evaluation of different alloys. Larson-Miller parameter is used to calculate the creep life of the various components like blades, discs etc. This method also plays a vital role in life assessment of critically affected areas with high temperature and stresses.

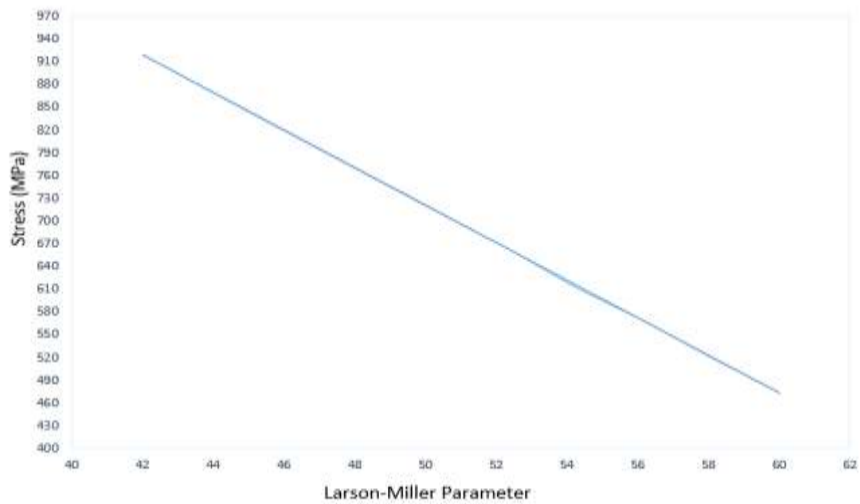

Fig- 4: Larson Miller parameter curve (19)

4. METHODOLOGY

(i) Generate CAD model of Blade Profile using NX UG software from available research data and modify if required.

(ii) To develop 3D finite element model to identify stress concentration on the gas turbine blade with branched holes using ANSYS.

(iii) To calculate strain values to corresponding stress.

(iv) Calculation of critical stress to corresponding temperature.

(v) To perform a feasibility study and facilitate the creep life estimation model.

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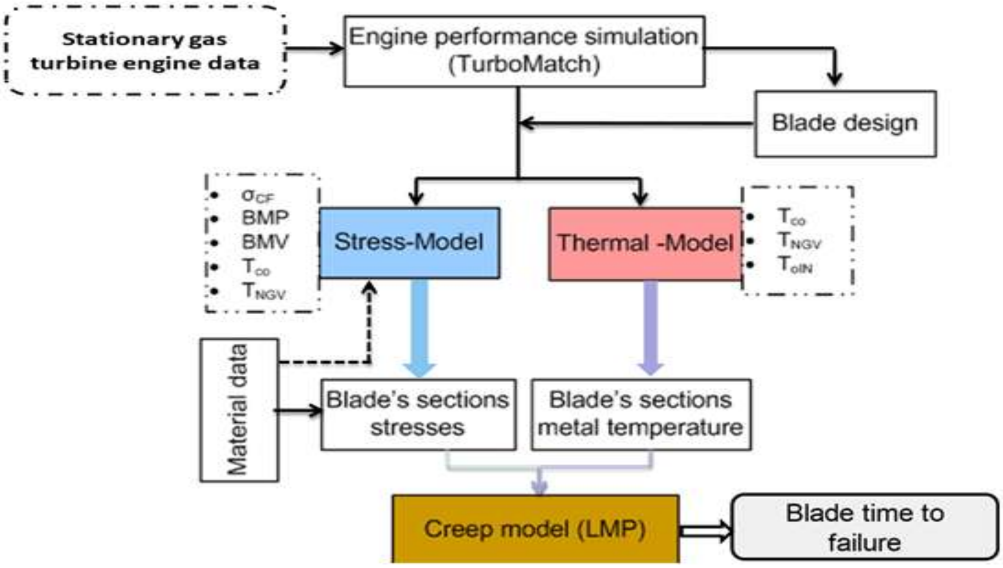

Fig- 5: Methodology [1]

5. COUPLED FIELD ANALYSIS

5.1 Operating Parameters:

The blades wereanalysed for the model [20] with the coupled field analysis with thermal and mechanical loads acting both simultaneously. The operating parameters for the analysis were as follows:

1	Turbine Inlet Temperature	850 °C
2	Velocity of Hot Gas	462 m/s
3	Cold Air Temperature	200 °C
4	Cold Air Velocity	53 m/s
5	Axial Force	3.82N
6	Tangential Force	248.2N
7	Centrifugal Force	38039 N
8	Speed	10800 rpm
9	Power	7 MW

Table- 1. Boundary conditions for coupled field analysis. [20,21]

5.2 Analysis of Gas Turbine Blade:

Couple field analysiswas performed for blade without holes as well as for the blade with branched film cooling holes. The temperature profile, stress distribution and deformation results for both the blades are as follows:

A] Blade without holes B] Blade with branched holes

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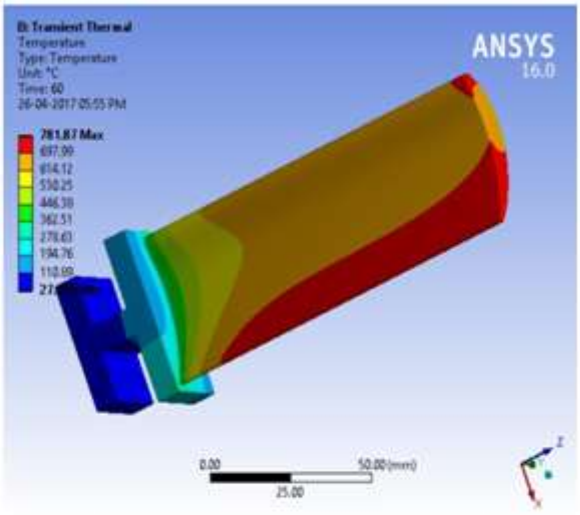

Fig- 6: Temperature Profile

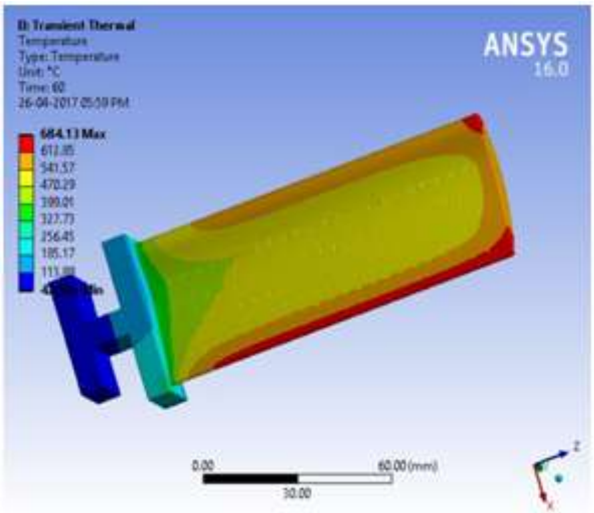

Fig- 7: Temperature Profile

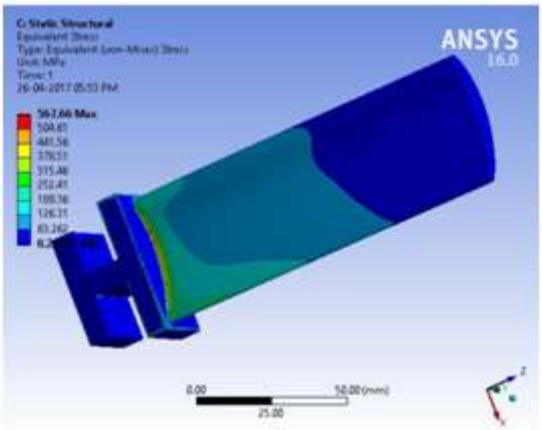

Fig- 8:Von Mises Stress

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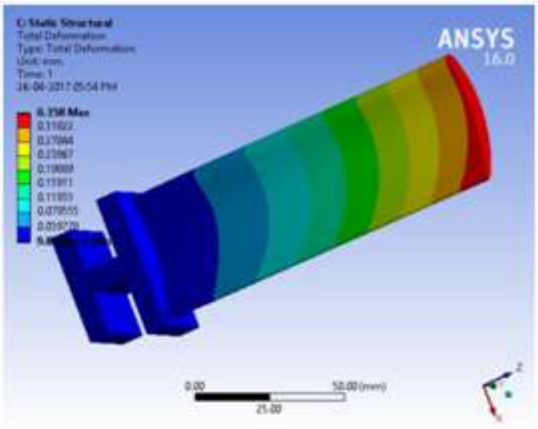

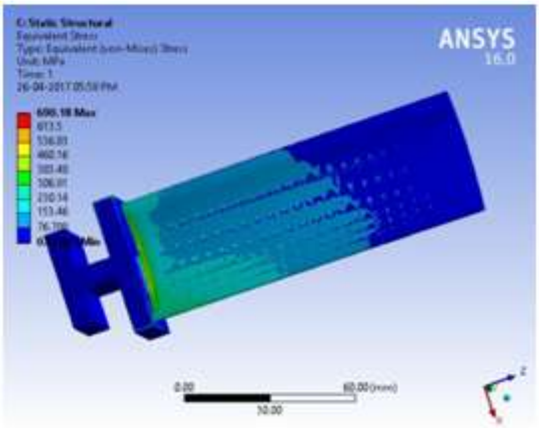

Fig- 9:Von Mises Stress

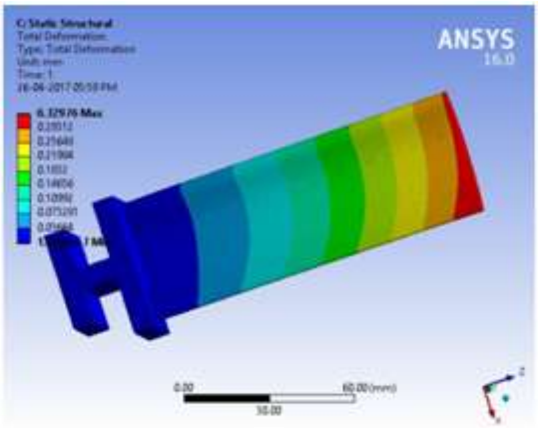

Fig- 10: Deformation of Blade

5.3 Results of Couple Field Analysis:

Sr. No.	Parameter	Blade without holes	Blade with holes
1.	Temperature Distribution	27.019 – 781.87 °C	42.606-684.13°C
2.	Total Heat Flux	$1.4422*10^{-5}$ -1.6535W/mm^2	$2.9547*10^{-5}$-1.4825 W/mm^2
3.	Eq. (von-Mises) Stress	567.66 MPa	690.18 MPa
4.	Eq. Elastic Strain	0.0044966	0.004216
5.	Total Deformation	0.358mm	0.32976mm
6.	Creep Life	40,391.6 Hrs	53,855.4 Hrs

Table-2: Results of couple field analysis.

6.CONCLUSION AND FUTURE WORK:

The study provides insight into the concept of anti-vortex cooling used to improve the cooling effectiveness and use of Larson-Miller parameter for creep life assessment of blade. Coupled field analysis was performed for both the blades with cooling holes and without cooling holes.From the results obtained, it can be concluded that the blade designed with the cooling holes has decrease in total heat flux, reduction in equivalent elastic strain and drastic decrement in temperature. Even though the stresses are found to be more in the blade that with the cooling holes but due to decrease in the temperature above the blade surface, creep life has found to be increased by about 25-30%.

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