TRANSIENT THERMAL ANALYSIS OF A TURBINE ROTOR

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ABSTRACT

The turbine rotor of a gas turbine engine is subjected to temperature variations in short periods of time due to the start and stop cycles of the engine. This causes sudden changes in the temperature with transient thermal stresses being induced into the turbine rotor. The transient effects are due to the changes in the material properties like-Density, Specific heat and Youngs Modulus. The estimate of the thermal stresses induced in the turbine rotor due to change in temperature is important in determining the type of an aeroengine..

In this study an effort has been made to estimate the effects of the transient thermal in the turbine rotor using Finite Element Analysis. A typical turbine rotor in the form of a Bladed Disk called blisk is considered for transient thermal analysis using the Numerically Integrated Structural Analysis (NISA) package.

The blisk material is considered as MAR M 247 and the properties of the material are updated to the model. The appropriate boundary conditions depicting the actual environment in which the turbine rotor works in an aeroengine are also updated. The results show that the maximum temperature occurs at the tip of the blade and decreases as we go into the disk.

The Transient Thermal Analysis was successfully completed and the results obtained. The thermal stresses due to large temperature gradients are higher than the steady state stresses. The large thermal stresses occur before reaching the steady state value.

1.0 Introduction

Transient thermal analysis is the thermal analysis wherein boundary conditions and properties change with time. This is to say that the constraints such as ambient temperature, thermal coefficient and material properties etc. are time dependent. Transient thermal analysis is important in analyzing models that are subjected to boundary conditions and material properties that vary with time and temperature.

Turbine rotors used in aeroengines are subjected to high temperature rise as they are subjected to many start and stop cycles. Since the turbine rotor is subjected to large temperature variation, the material properties such as Specific heat, Enthalpy and Youngs modulus undergo variation with time. In such conditions there is the probability of failure of the turbine rotor if the turbine rotor is not designed taking into consideration the transient effects.

There are many finite element analysis packages available for conducting the transient thermal analysis. Some of the packages are NISA, NASTRAN, PRO-MECHANICA, ALGOR, COSMOS, etc. Most of these packages use standard pre and post processors like Display III, Pattran, Fem gem, Fem new, etc. From an analysis using these packages, temperature distribution and instantaneous thermal stresses induced under transient conditions can be estimated. These packages allow the designer to vary the ambient temperature with time, vary the convective thermal coefficients and heat flux with time and/or temperature and also allow for heat generation to be applied.

A typical turbine rotor in the form of a bladed disk has been analyzed for transient thermal using NISA. One Radial Sector of a Blisk, which includes one blade of the turbine rotor, is considered for the analysis. From the analysis the temperature distribution is obtained.

Although the analysis is straight forward using these packages, the boundary conditions need to be applied judiciously in order to realistically model the actual situation. Moreover the choice of number of elements for modeling, time interval for calculation, type of elements and the locations at which boundary conditions are updated are essential for the accurate estimation of transient temperature and stress distribution.

2.0 Modeling the BLISK

The Blisk is modeled using a CAD package AutoDesk Mechanical Desktop 3.0 (AMD 3.0). Since the disk is an axissymmetric body only a sector model of the turbine rotor with one blade in the form of a Blisk (Bladed Disk) is modeled.

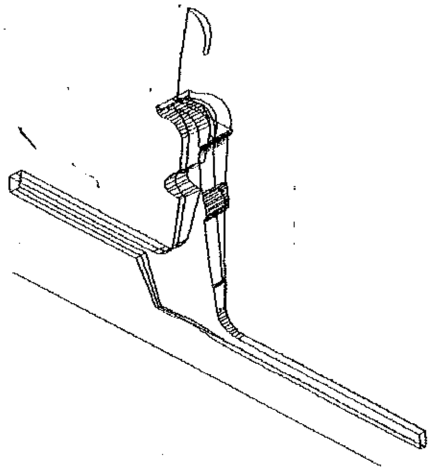

Figure 1 Modeled Blisk

The turbine disk is cut along a curved path. The camber line of the hub profile is offset on either side of the perpendicular blade by half the pitch distance. Then the turbine disk was cut by a wired plane consisting of camber line and arm of the disk as two edges of the plane.

The figure 1 shows the sector model of the blisk. The model from AMD 3.0 is translated to IGES format using the Initial Graphics Exchange Specification (IGES) translator. This IGES formatted model was transferred to Display III preprocessor for discritization.

3.0 Discritization of the Model

The IGES format of the model is read in NISA Display III. In NISA the IGES format is converted into a database file. The model is then discritized using hexahedron 3D solid elements. The figure 2 shows the meshed blisk.

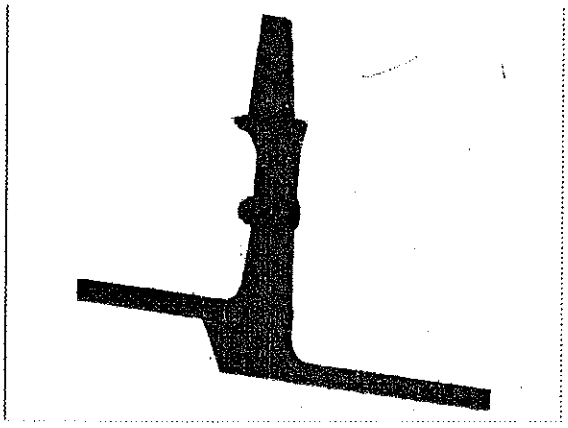

Figure 2 Meshed Model for FEA

The type of elements selected supports steady state and transient thermal analysis, Orthotropic material properties, Temperature dependent material properties, Nonlinear radiation and convection boundary conditions with temperature dependent emissivity and film coefficients, Time dependent film coefficient and emissivity, Time dependent ambient temperature and Phase change

There are 1137 elements in the model and the aspect ratio of these elements is around 2.3 – 3.0 which is well within the desired limit (Ref 9, 15). The elements are also checked for distortion.

4.0 Material Properties.

Material properties used on the model serve as a basic link between the finite element entities and the actual property values. For thermal analysis the material properties that are required are Density, Thermal Conductivity, Specific Heat (Ref 10, 15). The material of the Blisk is considered as a nickel-based alloy designated by the trade name MAR M 247 (Ref 1), which has the following material properties at room temperature.

Young's Modulus	$1.44x10^9$ N/m^2.
Density	8530 Kg/m^3.
Poisson's Ratio	0.3
Thermal conductivity	12.30 W/m K.
Specific Heat	461.0 KJ/Kg K.

These material properties were used on the sector model of the blisk.

5.0 Boundary Conditions.

Boundary conditions are the conditions updated on the model to simulate the actual environment in which the turbine rotor operates.

The following are the different Boundary conditions to be applied for the transient thermal analysis.

5.1 Convective Boundary conditions.

Thermal co-efficient values are updated on the blisk. On the blade the thermal co-efficient value varies on both the pressure and suction surface (Ref 2, 12).

The convective thermal coefficient distribution around the blade surface was obtained based on the available experimental results on a turbine blade cascade (Ref 4). The results are available for a range of Reynolds number $1.14 \times 10^6 - 2.24 \times 10^6$, exit Mach numbers 0.773 – 1.321 at a constant turbulence intensity 1.8% at the cascade inlet.

The estimated thermal coefficient distribution for the blade surfaces from (Ref 4) are

	Pressure	Suction
Blade Hub	720	240
	690	275
	660	295
	630	320
	600	345
	570	365
	540	390
	510	415
	480	435
Blade tip	450	460

For the disk surface the thermal coefficient is taken as the mean value of the thermal coefficient values on the pressure and suction surfaces at the hub of the blade.

All the thermal coefficient values are in W/m^{2}K.

5.2 Ambient Temperature.

The Blade of the turbine rotor is considered to be subjected to a steadily increasing ambient temperature from 400° C to a high temperature of 1280° C in a period of 10.0 seconds and this temperature was maintained for another 10.0 seconds. The total time period for the analysis is taken as 20 seconds. The ambient temperature is associated with a time-amplitude curve to simulate a condition wherein the ambient temperature varies with time. The ambient temperature for the disk portion is assumed to be at a constant temperature of 400° C.

The time-amplitude curve defines the variation of temperature with respect to time (Ref 13, 14). The transient analysis depends mainly on this variation. The time amplitude curve can be obtained by specifying the time and the amplitude where the amplitude is the ratio of the temperature at that particular point of time to the maximum temperature specified. If the time amplitude curve is a simple, linear curve as it is considered in this case we can specify only the first and the last point.

	Time (sec's)	Amplitude
1.0	0.0	0.0
2.0	5.0	0.65625
3.0	10.0	1.0
4.0	15.0	1.0
5.0	20.0	1.0

5.3 Initial Temperature

An initial temperature of 400° C is applied to the Blisk. This initial temperature is applied to simulate the initial temperature at which the Blisk is maintained in an aeroengine before combustion starts.

5.4 Phase Change

During the blisk operation temperatures of upto 1300 degrees are reached and this may cause a phase change (Ref 1,2,7). But in this analysis Phase change is not considered.

6.0 Analysis Data

These data are required for the purpose of specifying the parameters like flux tolerance, time step size, total time of the analysis etc (Ref 5, 6). for analyzing the model. The following are the data.

6.1 Heat Control Data.

This data is important for steady and transient thermal analysis as it defines the control parameters for iterations, tolerances, convergence etc. of the solution (Ref 8, 11).

For the Blisk the following iteration and tolerance values have been assumed.

Maximum No of iterations	- 10
Flux (convergence) tolerance	- 0.001

6.2 Time Integration Data.

This data defines the time integration control parameters needed for the analysis. It defines the type of integration scheme, the initial time step, maximum time for the analysis, time step size.

For the Blisk Crank-Nicholson integration scheme has been assumed (Ref 15). The initial time step is taken as zero seconds. The maximum time of analysis is 20 seconds and the time step size is 0.1 seconds

6.3 Temperature History Data.

This data is used to specify the nodes for which temperature history plots are desired. By specifying the nodes we can get an output that will be a graph of temperature Vs time.

In the example the nodes along the tip of the blade, the midsection and the hub were considered. For the disk the nodes at the hub and rim of the disk were considered.

6.4 Temperature output Data.

This data is used to specify the time steps at which temperature printout is desired. In this the starting and ending time at which the temperature of each node can be obtained is to be specified.

10 time steps have been specified for the blisk. At these 10 steps the temperature of the nodes can be obtained. The 10 steps are

	Start time	end time	increment
1.	0.0	2.0	2.0
2.	2.0	4.0	2.0
3.	4.0	6.0	2.0
4.	6.0	8.0	2.0
5.	8.0	10.0	2.0
6.	10.0	12.0	2.0
7.	12.0	14.0	2.0
8.	14.0	16.0	2.0
9.	16.0	18.0	2.0
10.	18.0	20.0	2.0

7.0 Results

Transient thermal analysis is carried out for the blisk under the following conditions

The initial temperature is at 400° C. The anbient temperature around the blade alone rises from 400° C to 1280° C in 10.0 seconds and then remains at 1280° C for another 10.0 seconds.

The temperature distribution across the Blisk at first time step (at 1.0 seconds), fifth time step (at 10.0 seconds) and final time step (at 20.0 seconds) were estimated and are shown in figures 4, 5 and 6.

The Figure- 3 shows the temperature distribution at a time step of 1.0 seconds on the Blisk. The ambient temperature around the blade at this time is 488° C The maximum temperature on the blsik occurs in the tip of the blade and has a value of 425.7° C. the minimum value is 424.2° C and occurs at the hub of the disk.

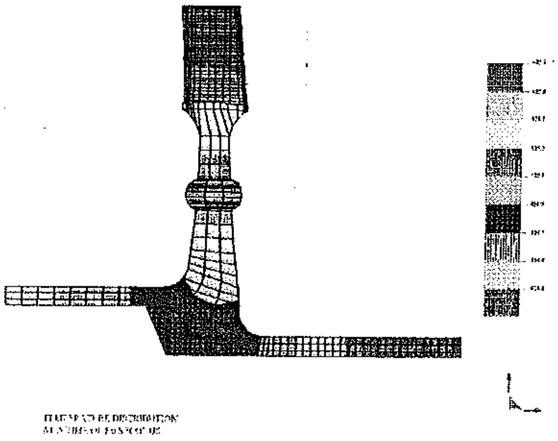

Figure- 3
Temperature distribution at time 1.0 seconds

The Figure- 4. Shows the temperature distribution on the Blisk at a time step of 10.0 seconds. At this time step the ambient temperature around the blade is 1280. In this the maximum temperature is 657.3 ° C and occurs at the tip of the blade while the minimum temperature is 642.2 ° C and occurs at the hub of the disk.

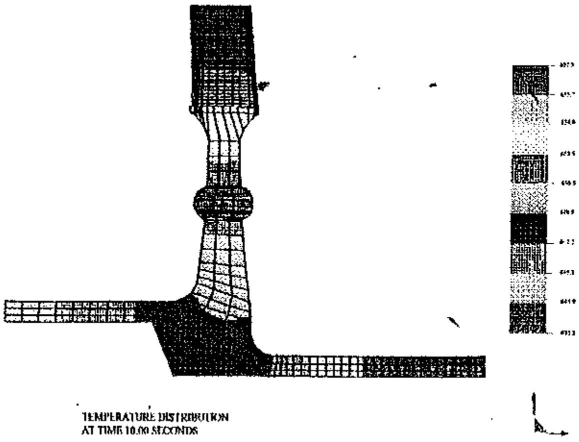

Figure- 4
Temperature distribution at time 10.0 seconds

The Figure- 5 shows the temperature distribution on the Blisk at the time step of 20.00 seconds. At this time step the ambient temperature is 1280. In this the maximum temperature is 658.7° C and occurs at the tip of the blade while the minimum temperature is 642.2° C and occurs at the hub of the disk.

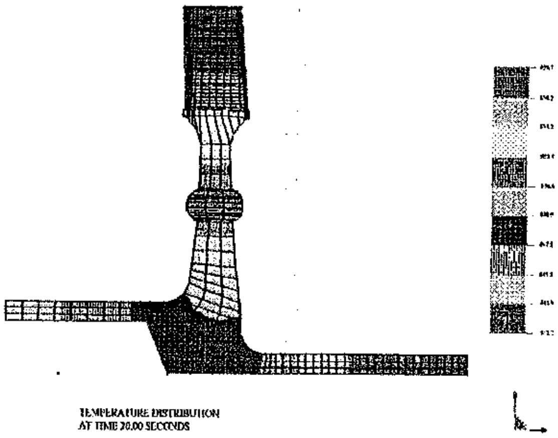

Figure- 5
Temperature distribution at time 20.0 seconds

The temperature history plots of the nodes selected in the blade show a higher temperature than the elements in the disk. The nodes selected in the tip of the blade have a higher temperature than the nodes in the rest of the blade.

The figure-6 shows the variation of temperature with time of nodes at the tip, midsection, hub of the blade. It also shows the variation of the temperature of the nodes at the midsection and hub of the disk with time.

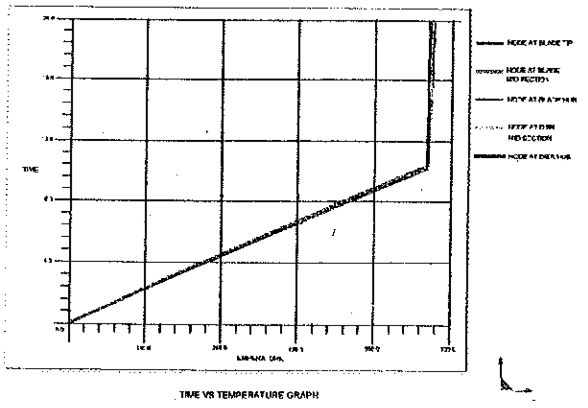

Figure- 6
Time Vs Temperature graph

From the history graphs figure- 6 it can be seen that the temperature of the nodes at the tip of the blade reaches a higher value than that of the nodes in the rest of the Blisk. It can also be seen that for the time period wherein the ambient temperature rises from 400 ° C to 1280 ° C the nodal temperature too rise consequentially but for the remainder of the time period the temperature becomes steady.

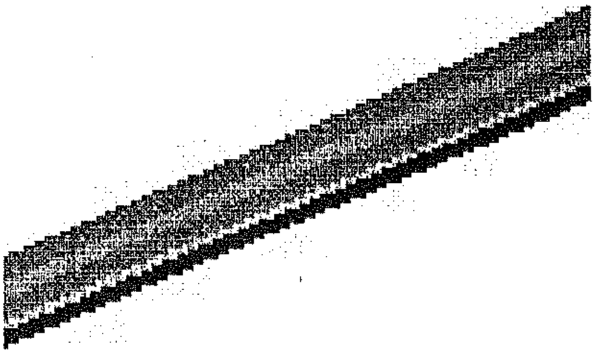

Figure- 7

Figure- 7 shows a zoomed image of part of the history graph shown in figure- 6

8.0 Conclusion

The transient thermal analysis is carried out. The initial temperature of the blisk is at 400 ° C. The ambient temperature for the blade rises from 400 ° C to 1280 ° C in 10.0 seconds and then remains at 1280 ° C for another 10.0 seconds.

The temperature of the blisk reaches steady state condition at 10.4 seconds. The transient thermal analysis depends on the ambient temperature variation specified.

Eventhough the ambient temperature reaches a high of 1280 ° C the maximum temperature in the blisk is 658.7 ° C as there is a large heat dissipation from the disk region which has a larger area exposed to a temperature of 400 ° C.

Due to this large heat dissipation temperature gradients are nominal. The overall temperature variation is of only 3.5^0 after 1.0 second and 15^0 after 10 seconds. This temperature gradients gets built up gradually with the rise in ambient temperature around the blade, as this rise is linear.

9.0 Acknowledgements

For interactive discussions and suggestions to Dr. V.Krishnamurthy and Mr. Jayaraman.

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