A Study of a Combined 2D Axisymmetric and 3D Cyclically Symmetric Finite Element Model of a Turbine Disk

by

Erika A. Davis

An Engineering Project Submitted to the Graduate Faculty of Rensselaer Polytechnic Institute in Partial Fulfillment of the Requirements for the degree of

MASTER OF MECHANICAL ENGINEERING

Approved:

Ernesto Gutierrez-Miravete, Project Adviser

Rensselaer Polytechnic Institute
Hartford, Connecticut
May, 2008
# CONTENTS

LIST OF TABLES ........................................................................................................... 4  
LIST OF FIGURES ....................................................................................................... 5  
LIST OF SYMBOLS ..................................................................................................... 7  
ACKNOWLEDGMENT .................................................................................................... 8  
ABSTRACT .................................................................................................................... 9  

1. Introduction ............................................................................................................. 10  
2. Methodology .......................................................................................................... 12  
3. Closed Form Solutions .......................................................................................... 15  
   3.1 Linear Elastic Solution ....................................................................................... 15  
   3.2 Thermoelastic Solution ....................................................................................... 18  
   3.3 Creep Discussion ............................................................................................... 21  
4. Closed Form Solution Verification ......................................................................... 21  
   4.1 Axisymmetric Finite Element Linear Elastic Solution .................................. 23  
   4.2 Axisymmetric Finite Element Thermoelastic Solution ............................... 24  
5. Combined 2D Axisymmetric and 3D Cyclically Symmetric Model ...................... 27  
   5.1 2D/3D Analysis - Case 1 .................................................................................. 33  
   5.2 2D/3D Analysis - Case 2 .................................................................................. 37  
   5.3 2D/3D Analysis - Case 3 .................................................................................. 41  
6. Discussion of Results ............................................................................................. 45  
7. Conclusions ............................................................................................................ 45  
8. References .............................................................................................................. 46
LIST OF TABLES

Table 1: Boundary conditions applied to 2D axisymmetric model..................23
Table 2: JT8D-219 performance at steady state takeoff..............................27
LIST OF FIGURES

Figure 1: A PW4000-94" cut away engine cross section ......................................... 10
Figure 2: Uncontained turbine disk failure (No. 1 engine) ........................................... 11
Figure 3: Uncontained turbine disk failure (No. 2 engine) ........................................... 11
Figure 4: Turbine disk terminology .............................................................................. 12
Figure 5: Blade attachment of turbine disk .................................................................. 13
Figure 6: Simple 2D and 2D/3D disk geometry .............................................................. 14
Figure 7: Plot of linear elastic radial stress versus radius .............................................. 17
Figure 8: Tangential stress versus radius ..................................................................... 17
Figure 9: Plot of thermoelastic radial stress versus radius .......................................... 20
Figure 10: Plot of thermoelastic tangential stress versus radius ................................... 21
Figure 11: Simple 2D axisymmetric model .................................................................. 22
Figure 12: Radial stress of 2D axisymmetric disk ......................................................... 23
Figure 13: Elastic strain of 2D axisymmetric disk .......................................................... 24
Figure 14: Body temperature of 2D axisymmetric disk ............................................... 25
Figure 15: Thermal strain contour plot of 2D axisymmetric disk .................................. 26
Figure 16: Total (elastic and thermal) strain of 2D axisymmetric disk ............................ 27
Figure 17: Three 2D/3D cases modeled in ANSYS ....................................................... 28
Figure 18: Case 1 dimensions for 2D/3D analysis ......................................................... 29
Figure 19: Sector angle held constant for all three cases .............................................. 30
Figure 20: Case 2 dimensions for 2D/3D analysis ......................................................... 31
Figure 21: Case 3 dimensions for 2D/3D analysis ......................................................... 32
Figure 22: Boundary Conditions for Case 1 .................................................................. 33
Figure 23: ANSYS mesh for Case 1 .............................................................................. 33
Figure 24: Radial distribution of applied temperature for Case 1 ................................. 34
Figure 25: Radial stress distribution for Case 1 .............................................................. 35
Figure 26: Elastic strain distribution for Case 1 .............................................................. 36
Figure 27: Thermal strain distribution for Case 1 ........................................................... 36
Figure 28: Boundary conditions for Case 2 ................................................................... 37
Figure 29: ANSYS mesh for Case 2 .............................................................................. 38
Figure 30: Radial distribution of applied temperature for Case 2 ..........................38
Figure 31: Radial distribution of stress for Case 2 ..............................................39
Figure 32: Radial distribution of elastic strain for Case 2 .................................39
Figure 33: Radial distribution of thermal strain for Case 2 ...............................40
Figure 34: Boundary conditions for Case 3 .....................................................41
Figure 35: ANSYS mesh for Case 3 ..............................................................42
Figure 36: Radial distribution of applied temperature for Case 3 .......................43
Figure 37: Radial distribution of stress for Case 3 ............................................43
Figure 38: Radial distribution of elastic strain for Case 3 .................................44
Figure 39: Radial distribution of thermal strain for Case 3 ...............................44
LIST OF SYMBOLS

α: coefficient of thermal expansion
ρ: density
k: thermal conductivity
ν: Poisson’s ratio
ε: strain
σ: stress
σ_r: radial stress
σ_θ: tangential stress
A: area
F: force
E: Young’s modulus
HTC: heat transfer coefficient
r: radius
ω: angular velocity
T: temperature
T_a: temperature at disk bore
T_b: temperature at disk rim
ℓ: length
ℓ₀: initial length
ACKNOWLEDGMENT

Many thanks to my father who stimulated my interest in aircraft as a child and for his encouragement of my choice to study engineering.
ABSTRACT

As more demands are made of aircraft engines (higher thrust, greater fuel efficiency, etc.), more complex modeling is often required to analyze the structural integrity of the engine components. The complexity of modeling has also increased with the technological capability of the software used. This project investigates two major contributors to the behavior of a turbine disk: linear elasticity and thermoelasticity. Closed form solutions of each of the two major contributors were analyzed and verified with a simple 2D axisymmetric finite element model. A more detailed 2D/3D combined axisymmetric and cyclically symmetric model was created in order to develop a better understanding of how to model turbine rotors.
1. Introduction

As the airline industry evolves, so too do the companies that support them. Greater demands are asked of gas turbine engines now than ever before. Engines must be designed to generate more thrust with higher fuel efficiency and reduced noise and emissions. The design limits are being pushed but at the same time must meet or exceed flight safety requirements.

![PW4000-94” Engine cut away cross section](image)

Rotating engine components have stringent requirements to maintain their structural integrity. The failure of a rotating part, such as a high pressure turbine disk, can be catastrophic in flight. A high pressure turbine disk has a large mass relative to all the other disks in the gas turbine, including the low pressure compressor, the high pressure compressor and the low pressure turbine (Figure 1: PW4000-94” Engine cut away cross section). This large mass, which rotates at several thousand rpm, has an extremely large inertia. If this particular part were to fail, it could easily penetrate through an engine case, nacelle, and fuselage, potentially killing passengers or bringing down the aircraft. In the case of the twin engine aircraft in Figure 2 and Figure 3, the event occurred on the tarmac and no one was injured.
There are many causes for disk failure, including, but not only, deficient material properties, defects in the part that caused crack propagation, and creep rupture from elevated temperatures. Stringent design and vendor requirements make these occurrences extremely rare. This project will explore how the disk, assuming that it behaves as a linear elastic material, is affected by centrifugal forces and by temperature.
2. Methodology

Heat transfer and structural analyses of turbine rotors are essential to the certification of engines as well as the lifing of hardware, redesigning parts, and addressing flight safety and field issues. Detailed finite element models are critical to ensure the fidelity of the analyses.

Turbine disks can typically be modeled axisymmetrically with the exception of the disk rim. The disk web and bore (Figure 4) can be modeled as 2D axisymmetric. Axisymmetric geometry is defined as a constant cross section when revolved around a center line.

The attachment area where the blade resides can contain very high stresses and must operate in an extremely high temperature environment. The attachment region
must be modeled as cyclically symmetric. A cyclically symmetric sector is defined as 360° divided by the number of blade attachments in the disk. Three-dimensional features such as the blade attachment, slots for cooling air and snap fits for air seals must be modeled to accurately capture what the disk experiences in operation (Figure 5).

![Figure 5: Blade attachment of turbine disk](image)

It is not desirable to model an entire disk but rather to model a sector of the disk. Large, detailed FE models require more time to solve for transient conditions. It is more feasible to take a representative slice of the disk, reducing both model size and time to a solution. A single sector is typically modeled but some special cases can require 2 or 3 sectors be modeled. Having a 2D/3D interface in the model also reduces the node count, since only a portion of the FE model is 3D and the rest is 2D.

A simplified turbine rotor disk (2D/3D with slot in the 3D volume to simulate attachment area) will be analyzed to develop a better understanding of how to model turbine rotors (Figure 6).
2D Axisymmetric Disk
Constant Cross Sectional Area

2D/3D Disk #1
Sector Angle = 5°
Number of Sectors = 72

Figure 6: Simple 2D and 2D/3D disk geometry
3. Closed Form Solution

3.1 Linear Elastic Solution

Linear elasticity is one of the easiest mechanical phenomena to comprehend. When a force is applied to a piece of material, either in tension or compression, the shape of the material changes. This applied force over some amount of area is called stress.

\[ \sigma = \frac{F}{A} \]

Strain is defined as the change in length over the initial length, or

\[ \epsilon = \frac{(\ell - \ell_0)}{\ell} . \]

Linear elasticity can be described using Hooke’s Law,

\[ \sigma = E \epsilon \]

where \( E \), Young’s modulus, is a property of the material. For isotropic solids, the relationship between stress and strain is as follows:

\[ \epsilon_x = \frac{1}{E} \left[ \sigma_x - \nu(\sigma_y + \sigma_z) \right] \]
\[ \epsilon_y = \frac{1}{E} \left[ \sigma_y - \nu(\sigma_z + \sigma_x) \right] \]
\[ \epsilon_z = \frac{1}{E} \left[ \sigma_z - \nu(\sigma_x + \sigma_y) \right] \]
\[ \epsilon_{xy} = \left[ \frac{1+\nu}{E} \right] \sigma_{xy} \]
\[ \epsilon_{yz} = \left[ \frac{1+\nu}{E} \right] \sigma_{yz} \]
\[ \epsilon_{zx} = \left[ \frac{1+\nu}{E} \right] \sigma_{zx} \]

The equilibrium equations are as follows:

\[
\frac{\partial \sigma_x}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} + X_x = 0
\]
\[
\frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} + X_y = 0
\]
\[ (\partial \sigma_{zx}/\partial x) + (\partial \sigma_{zy}/\partial y) + (\partial \sigma_z/\partial z) + X_z = 0 \]

For a disk with a hole in the center rotating at a constant angular velocity, \( \omega \), and with a density of \( \rho \), a simple linear elastic model can be created. Assuming that the inner radius is equal to \( a \), the outer radius is equal to \( b \), and that stress in the radial direction, \( \sigma_r = 0 \) at both the inner and outer radii, the stress field can be modeled as:

\[
\sigma_r := \frac{(3 + \nu)}{8} \cdot (\rho \cdot \omega^2) \cdot \left( b^2 + a^2 - \left( \frac{a \cdot b}{r} \right)^2 - r^2 \right);
\]

\[
\sigma_\theta := \frac{(3 + \nu)}{8} \cdot (\rho \cdot \omega^2) \cdot \left( b^2 + a^2 + \left( \frac{a \cdot b}{r} \right)^2 - \left( \frac{1 + 3 \cdot \nu}{3 + \nu} \right) \cdot r^2 \right);
\]

Other assumptions include uniform disk thickness (see Figure 11), a small thickness relative to the radius, constant stress through the thickness, and stress as a function of radius because of the symmetry.

For the case of a simple 2D axisymmetric finite element model, where \( a = 2" \), \( b = 14" \), \( \rho = 0.298 \) lbm/in\(^3\), \( \omega = 1275 \) rad/s, \( \nu = 0.3 \),

\[
\sigma_{r_f} := 2.458500000 \times 10^7 - \frac{9.637320000 \times 10^7}{r^2} - 1.229250000 \times 10^5 \cdot r^2
\]

and

\[
\sigma_{\theta_f} := 2.458500000 \times 10^7 + \frac{9.637320000 \times 10^7}{r^2} - 70775.00001 \cdot r^2
\]

Plots of radial and tangential stress for the given boundary condition can be seen in Figures 7 and 8.
Figure 7: Plot of linear elastic radial stress versus radius

Figure 8: Tangential stress versus radius
It can be seen that while both types of stress behave differently, neither is insignificant.

### 3.2 Thermoelastic Solution

Strain can also be a function of thermal expansion. When metal is exposed to a high temperature it expands, or grows.

\[
\varepsilon = (l - l_0)/l = \alpha (T - T_0)
\]

In reality, turbine disks are constrained to mating parts such as other disks in the turbine, air seals, and shafts. This constraint causes compressive stresses since the part is not free to move as it attempts to expand. The colder disk bore resists the pull of the hotter rim, creating large tensile stresses.

The equilibrium equation for an isotropic solid with an applied temperature is:

\[
(\partial \sigma_{ij}/\partial x_j) + X_i = \sigma_{ij,j} + X_i = 0
\]

The stress-strain relationship is:

\[
\varepsilon_{ij} = [(1+\nu)/E] \sigma_{ij} - (\nu/E) \sigma_{uu} \delta_{ij} + \alpha(T - T_0) \delta_{ij}
\]

The same disk as in the linear elastic problem, with a hole of radius \(a\) at the center and an outer radius of \(b\), is modeled as a thermoelastic problem below. The assumption that temperature is a function of radius only and that only plane stress is considered, the equilibrium equation becomes

\[
(\partial \sigma_r/\partial r) + (\sigma_r - \sigma_\theta)/r = 0
\]

The radial and tangential strain-displacement relationships are:
The relationships for radial stress and tangential stress with strain are:

$$\sigma_r = \frac{E}{(1-\nu^2)}[(\varepsilon_r + \nu \varepsilon_\theta) - (1 + \nu)\alpha(T - T_0)]$$

$$\sigma_\theta = \frac{E}{(1-\nu^2)}[(\varepsilon_\theta + \nu \varepsilon_r) - (1 + \nu)\alpha(T - T_0)]$$

By substituting the strain-displacement relationships, $\varepsilon_\theta$ and $\varepsilon_r$, into the relationships for $\sigma_r$ and $\sigma_\theta$, and then into the equilibrium equation and solving, a relationship for a thin disk with a radial temperature distribution at steady state conditions can be developed.

Plots of radial and tangential stresses can be seen in Figures 9 and 10 as a function of radius.
It can be seen in Figure 9 that the maximum stress occurs closer to the disk bore than the rim. This is due to the fact that the colder disk bore resists the expansion of the hotter rim, creating a maximum tensile stress at this location.
3.3 Creep Discussion

Creep is not an elastic phenomenon. It is a plastic deformation of a material at high temperature under an applied load. Although important in analyzing the capability of turbomachinery components using cyclic loading and transient finite element models, its time dependent nature was beyond the scope of this analysis.

4. Closed Form Solution Verification

A 2D axisymmetric finite element model of a simple disk was created in ANSYS (Figure 11). Due to symmetry, only the top half of the disk was modeled. The axisymmetric slice is offset in the y-direction to simulate a hole in the disk. Boundary conditions were applied at both the inner radius and outer radius of the disk (Table 1). The model was also constrained axially so that all stress, strain, and temperature were...
functions of radius only. Material properties such as $E$, $k$, and $\alpha$ from typical turbine disk material, Inconel 718, were used in the analysis.

Figure 11: Simple 2D axisymmetric model
### Table 1: Boundary conditions applied to 2D axisymmetric model

<table>
<thead>
<tr>
<th>Zone</th>
<th>HTC</th>
<th>Temperature (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
<td>1200</td>
</tr>
</tbody>
</table>

The disk geometry was modeled in ANSYS at a steady state condition for the linear elastic and thermoelastic solutions. A rotating speed, \( \omega \), of 12,170 rpm was used in the steady state analysis.

#### 4.1 Axisymmetric Finite Element Linear Elastic Solution

Although the contour plot of radial stress in Figure 12 is a combination of linear elastic and thermoelastic stress, it is interesting to note how the stress distribution is bounded. The maximum stress occurs at the expected location based on the plot of thermoelastic stress in Figure 9. This also indicates that given the high temperatures applied to the disk, the thermoelastic stress dominates.

![Figure 12: Radial stress of 2D axisymmetric disk](image)
The contour plot of elastic strain in Figure 13 also agrees with the mathematical solution in that the applied load, the spinning of the disk, \( X_r = \rho \omega^2 r \), is largest at the maximum radius. A maximum elastic strain is expected at the disk rim.

Figure 13: Elastic strain of 2D axisymmetric disk

### 4.2 Axisymmetric Finite Element Thermoelastic Solution

The applied body temperatures in Figure 14 illustrate the radial temperature distribution of the disk at steady state conditions. The applied disk rim temperature of 1200 °F was twice as large as the applied disk bore temperature of 600 °F. At steady state conditions, the bore temperature is over 150 °F hotter than the applied temperature. The rim temperature is highly dominant in this simple 2D axisymmetric model. However, there is a large enough gradient to view the thermoelastic effects of stress (Figure 12) and strain (Figure 15). The combined elastic and thermal strain can be seen in Figure 16.
Figure 14: Body temperature of 2D axisymmetric disk
Figure 15: Thermal strain contour plot of 2D axisymmetric disk

The thermal strain contour plot exhibits the same behavior as the elastic strain contour plot in Figure 13. Just as the load created by the spinning of the turbine disk was largest at the outer radius, so too is the load created by the disk rim exposed to gaspath temperatures. The rim sees the greatest radial strain since it is exposed to the highest temperature. Even the colder bore sees the effect of thermal strain.

The combined thermal and elastic strain is simply the sum of the two. This can be seen in Figure 16. The contour plot of the combined strains follows the same trend as the two contour plots of the individual strains, as expected.
5. Combined 2D Axisymmetric and 3D Cyclically Symmetric Model

Three combined 2D axisymmetric and 3D cyclically symmetric models were created in Unigraphics and analyzed with ANSYS. The JT8D-219 performance was used in the steady state analyses for each of the 3 cases (Figure 17).

<table>
<thead>
<tr>
<th>JT8D-219 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>XNH</td>
</tr>
<tr>
<td>T3</td>
</tr>
<tr>
<td>P3</td>
</tr>
<tr>
<td>T4</td>
</tr>
</tbody>
</table>

Table 2: JT8D-219 performance at steady state take off
In order to better understand the effects of temperature and stress on combined 2D/3D models, the interface between the 2D axisymmetric portion and the 3D cyclically symmetric portion of the disk was moved radially to investigate the effects.

The 2D/3D interface of Case 1 was moved below the bottom of the attachment area the same distance as the lug thickness (the lug is the portion of the disk rim that cradles the blade. The interface in Case 2 was moved below the attachment area by 3X the lug thickness and the interface in Case 3 was moved by 6X the lug thickness. The same sector angle of 5° was maintained for all three cases (Figures 18-21).
Figure 18: Case 1 dimensions for 2D/3D analysis
Figure 19: Sector angle held constant for all three cases

Sector Angle = 5°
Number of Sectors = 72
Figure 20: Case 2 dimensions for 2D/3D analysis
Figure 21: Case 3 dimensions for 2D/3D analysis
5.1 2D/3D Analysis – Case 1

**Figure 22**: Boundary Conditions for Case 1

<table>
<thead>
<tr>
<th>Z1</th>
<th>Coord1</th>
<th>Coord2</th>
<th>Z5</th>
<th>Coord1</th>
<th>Coord2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTC</td>
<td>200</td>
<td>500</td>
<td>HTC</td>
<td>200</td>
<td>500</td>
</tr>
<tr>
<td>T</td>
<td>T4</td>
<td>T4</td>
<td>T</td>
<td>T4</td>
<td>T4</td>
</tr>
<tr>
<td>Z2</td>
<td>Coord1</td>
<td>Coord2</td>
<td>Z6</td>
<td>Coord1</td>
<td>Coord2</td>
</tr>
<tr>
<td>HTC</td>
<td>100</td>
<td>200</td>
<td>HTC</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>T</td>
<td>T3</td>
<td>T3</td>
<td>T</td>
<td>T4</td>
<td>T4</td>
</tr>
<tr>
<td>Z3</td>
<td>Coord1</td>
<td>Coord2</td>
<td>Z7</td>
<td>Coord1</td>
<td>Coord2</td>
</tr>
<tr>
<td>HTC</td>
<td>100</td>
<td>100</td>
<td>HTC</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>T</td>
<td>T3</td>
<td>T3</td>
<td>T</td>
<td>T4</td>
<td>T4</td>
</tr>
<tr>
<td>Z4</td>
<td>Coord1</td>
<td>Coord2</td>
<td>Z8</td>
<td>Coord1</td>
<td>Coord2</td>
</tr>
<tr>
<td>HTC</td>
<td>100</td>
<td>200</td>
<td>HTC</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>T</td>
<td>T3</td>
<td>T3</td>
<td>T</td>
<td>T4</td>
<td>T4</td>
</tr>
</tbody>
</table>

**Figure 23**: ANSYS mesh for Case 1
The boundary conditions can be seen for Case 1 in Figure 22. A large heat transfer coefficient and high temperature were applied to the disk rim to simulate exposure to a gas path environment. Boundary conditions change throughout the web and bore to simulate exposure to regions with less cooling airflow as well as lower temperatures. The steady state analysis was run in ANSYS using the performance in Table 2.

Figure 24: Radial distribution of applied temperature for Case 1

The resulting radial stress, elastic strain and thermal strain can be seen in Figures 25-27.
Figure 25: Radial stress distribution for Case 1

Maximum stress occurs in the cyclically symmetric 3D portion of the model and where the disk is still considered full hoop. Compressive stresses occur in the blade slot. Since disks in the field generally crack under tensile loading in the attachment region, the emphasis is on the maximum tensile stress.
Figure 26: Elastic strain distribution for Case 1

Figure 27: Thermal strain distribution for Case 1
5.2 2D/3D Analysis – Case 2

Figure 28: Boundary conditions for Case 2

It was decided that for Case 2, an intermediate zone (Z101 and Z105) would be added to the 3D portion of the disk to model a gradual step down from higher temperatures and heat transfer coefficients. The zone area definition for the higher temperature (Z1 and Z5) remained the same as in Case 1. The same steady state analysis that was run for Case 1 was run for Case 2.
Figure 29: ANSYS mesh for Case 2

Figure 30 shows a contour plot of radial temperatures. Figures 31-33 show radial stress, elastic strain and thermal strain, respectively.

Figure 30: Radial distribution of applied temperature for Case 2
Figure 31: Radial distribution of stress for Case 2

Figure 32: Radial distribution of elastic strain for Case 2
Figure 33: Radial distribution of thermal strain for Case 2
5.3 2D/3D Analysis – Case 3

The same methodology was used for Case 3 as for Case 2 with the exception of larger intermediate “step” zones. The heat transfer coefficients and applied temperatures remained the same. The same performance was used in the ANSYS analysis.

Figure 34: Boundary conditions for Case 3
Figure 35: ANSYS mesh for Case 3

Figure 36 shows a contour plot of radial temperatures. Figures 37-39 show radial stress, elastic strain and thermal strain, respectively.
Figure 36: Radial distribution of applied temperature for Case 3

Figure 37: Radial distribution of stress for Case 3
Figure 38: Radial distribution of elastic strain for Case 3

Figure 39: Radial distribution of thermal strain for Case 3
6 Discussion of Results

The 2D axisymmetric model behaved as predicted by the mechanical equilibrium equation, the stress-strain relationships and the strain-displacement relationships. The 2D/3D analyses illustrated the fact that 2D turbine disk models are not adequate for detailed design. They are simply not accurate enough and do not account for any variation in symmetry. They are, however, adequate enough for a first pass analysis in conceptual and possibly preliminary design.

The 2D/3D models, while more time-intensive to set up, debug, run, and post-process, are more accurate. Stress concentrations in the attachment region can easily be seen by viewing a contour plot. Locations with large strains may be able to highlight regions in the disk to perform a creep analysis.

As can be seen in Figures 25, 31, and 37, the radial stress distributions of the three 2D/3D cases highlight the maximum stress locations. Given a nicely distributed radial temperature gradient, the stress concentration occurs in between the blade slots where the disk is still full hoop. For the same applied temperatures at the bore and rim (the zones on the side varied slightly between cases), the stress field at this location can clearly be seen.

Individual contributions of thermal and elastic strain can also be analyzed (Figures 26, 27, 32, 33, 38, 39) can also help an engineer determine which locations need to be modified by changing the design intent (geometry, cooling system, etc).

7 Conclusions

In order to accurately capture the effects the environment in an engine has on a turbine disk, a 2D/3D model is necessary. Since a truly 3D model of a disk is usually unrealistic – the set-up, run, and post-processing times outweigh the amount of information gleaned from the model, not to mention the cost and manpower required – a 2D/3D model is adequate. The 2D/3D interface must be located at least three times the 3D sector lug thickness in order capture the entire stress concentration field. Case 2 exemplifies this recommended methodology for future turbine disk analyses.
8 References


[8] http://www2.tech.purdue.edu/at/courses/aeml/powerplantimages/2blademounts.jpg
[9] http://www.flightglobal.com/articles/2006/06/06/207118/pictures-ge-investigates-
cause-of-american-airlines-boeing-767-200-uncontained-cf6-80a-engine.html