November 9, 2017

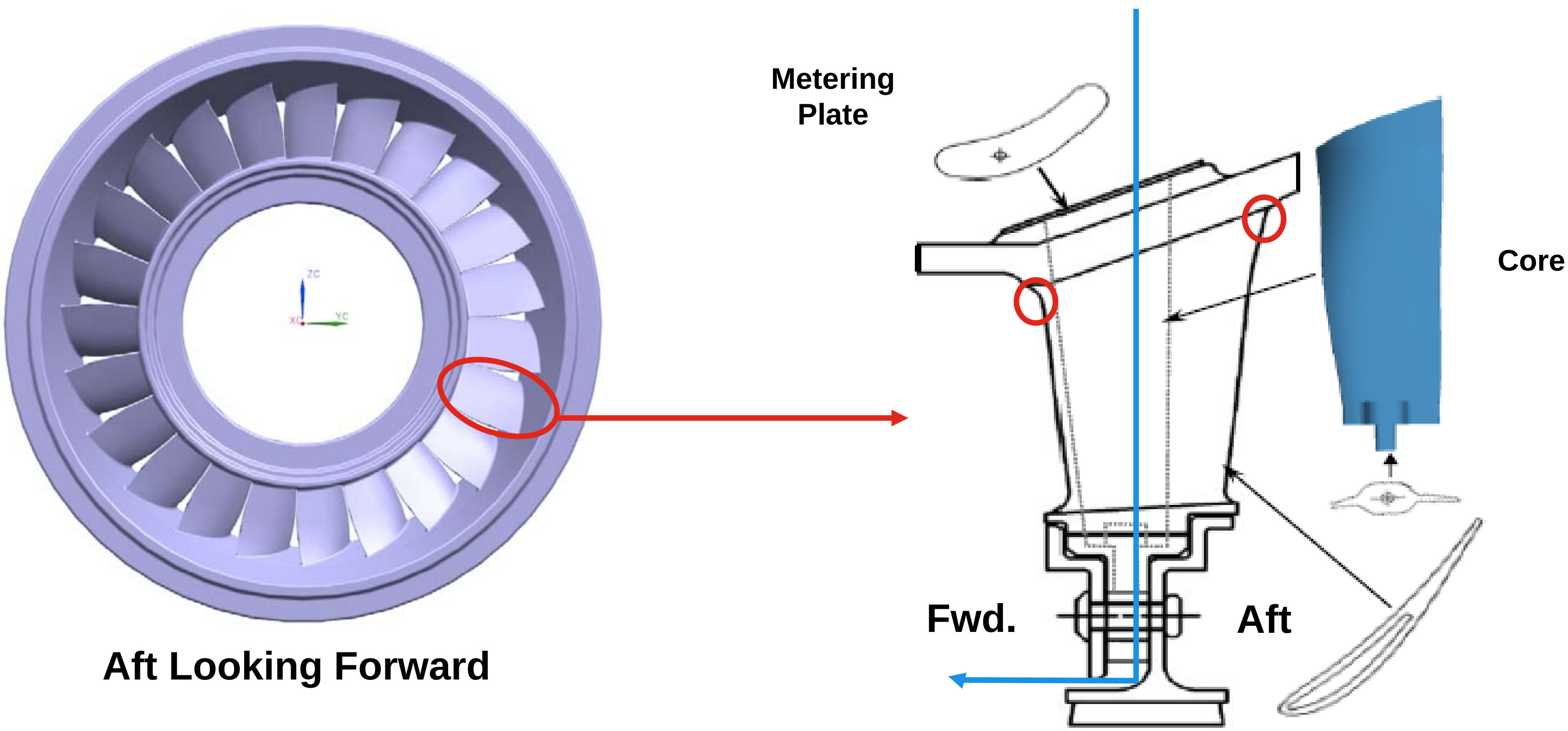
Thermal Mechanical Analysis of an Internally Cooled Stator

Honeywell
THE POWER OF CONNECTED

Agenda

- Background
- Analytical Root Cause Study
  - Transient Thermal Model Analysis
  - Transient Stress Model Analysis
- Recommended Corrective Actions
- Conclusions

Background



Aft Looking Forward

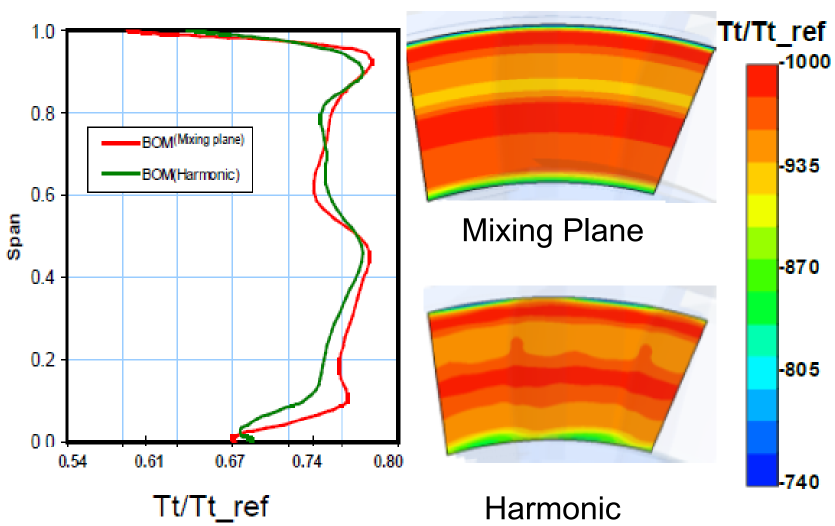
- ○ Represents areas where cracking occurs in the field

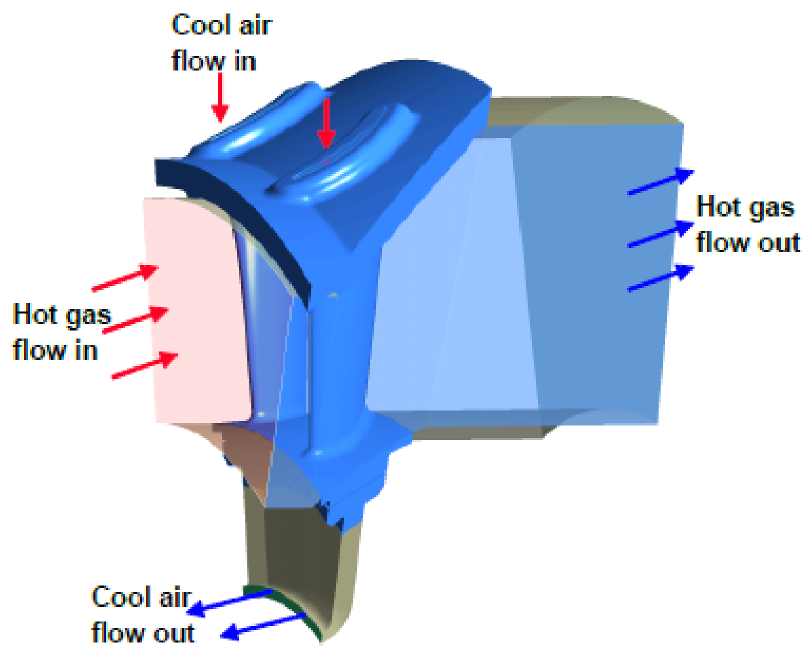
Analytical Root Cause – CHT Thermal Model

- A Steady State Conjugate Heat Transfer (CHT) Thermal Model was built. CHT was used to obtain boundary conditions for 3D Transient Conduction Model.

- Boundary Conditions

	Hot Gas (from Fine_Turbo)		Cooling Air (from engine cycle definition)	
	inlet	exit	inlet	exit
Mixing Plane	Tt(r); Pt(r); Flow angles(r)	Ps(r)	Tt; Pt; Flow angle	Ps
Harmonic Approach	Tt(r,θ); Pt(r,θ); Flow angles(r,θ)	Ps(r,θ)	Tt; Pt; Flow angle	Ps



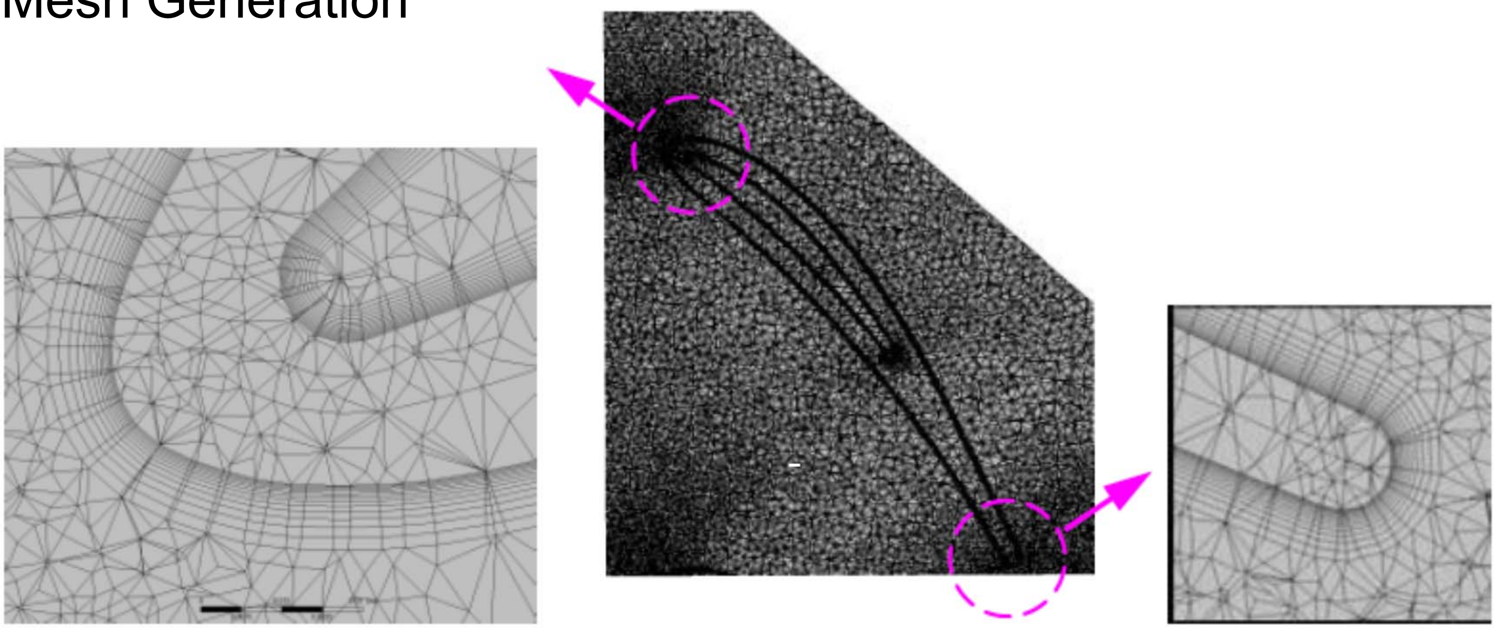


CHT Model Domain ANSYS CFX

Honeywell
THE POWER OF CONNECTED

Analytical Root Cause – CHT Thermal Model

- Mesh Generation



  - 17 million cells – 2.8 million in the solid and 14.2 million in the fluid.
  - Prism cells used for interface between solid and fluid region to resolve the boundary layer (higher accuracy).
  - Tetrahedral (Unstructured) cells used everywhere else.

Honeywell
THE POWER OF CONNECTED

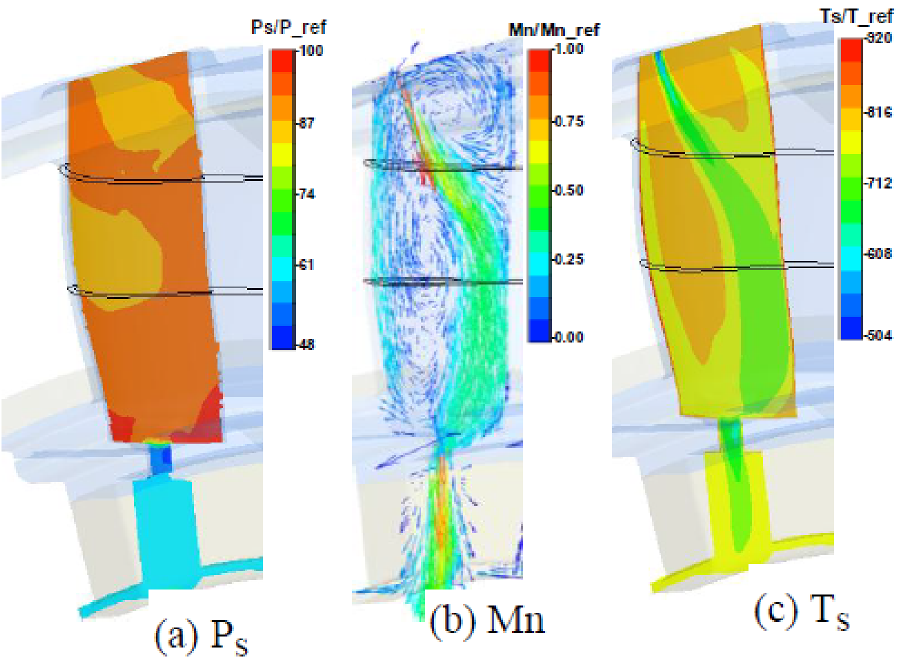
Analytical Root Cause – CHT Thermal Model

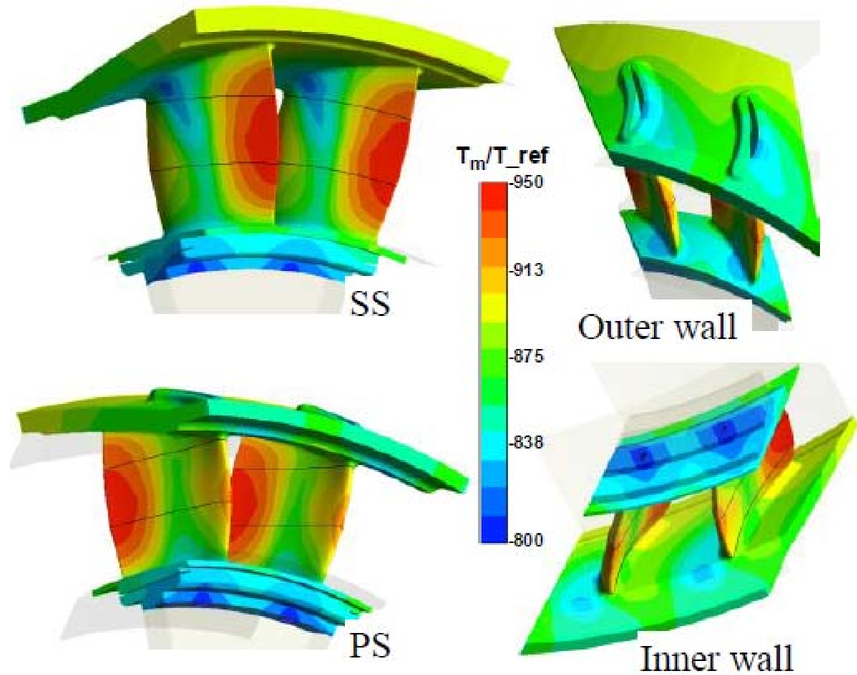
- Turbulence Model
  - Multiple turbulence models were study – Std k-ε, Shear-Stress Transport (SST) k-ε, BSL Reynolds Stress model and SSG Reynolds stress model.
  - Renormalization Group (RNG) k-ε model.
    - Practical and most commonly utilized for engineering flows and heat transfer simulations because of the robustness, reasonable accuracy and computation time.

- Near-Wall Treatment (Boundary Layer Calculation)
  - Two approaches available:
    1. Wall Function
       - Economical, robust, and reasonably accurate in most high Reynolds number flow problems. Coarse mesh near the wall.
    2. Enhanced Wall Treatment – selected for this study.
       - Two layer approach
       - viscosity-affected region

Honeywell
THE POWER OF CONNECTED

Analytical Root Cause – CHT Results





- Low Pressure regions can affect backflow margin.
- Inlet flow biased towards suction side trailing edge before exiting.
- Large recirculation zones on leading edge and trailing edge tip.
- Recirculation zones detrimentally affect internal heat transfer.

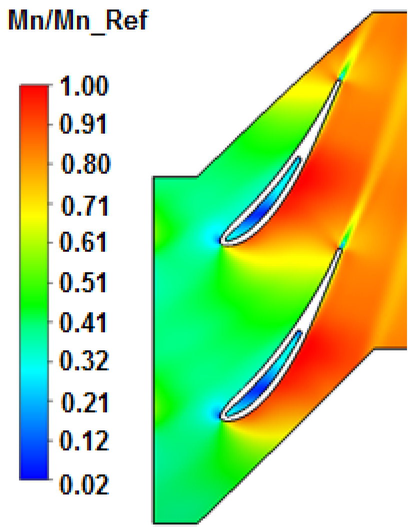
- Cooler vertical region in the spanwise direction in the middle of the airfoil between LE and TE. Cold stop on leading edge suction side.
- Largest temperature gradient on the leading edge region.
- shrouds considerable cooler than airfoil

Better Internal Cooling Flow Distribution is Needed

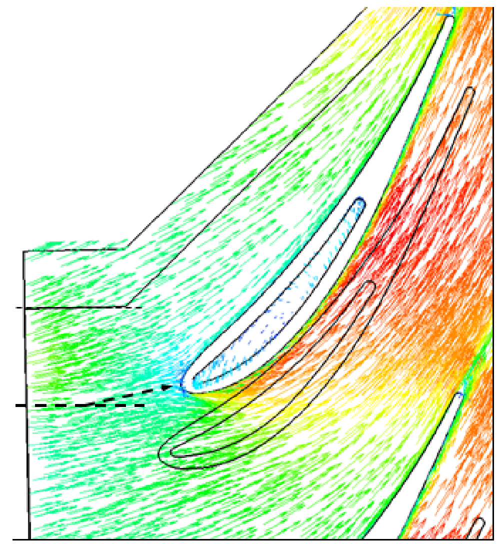
Honeywell
THE POWER OF CONNECTED

Analytical Root Cause – CHT Results

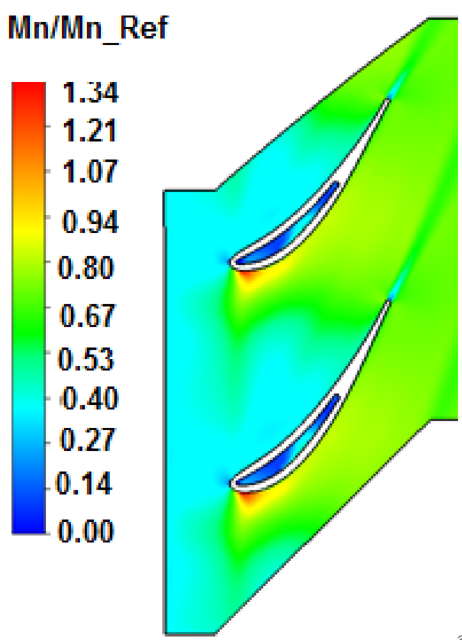
50% Radial Span



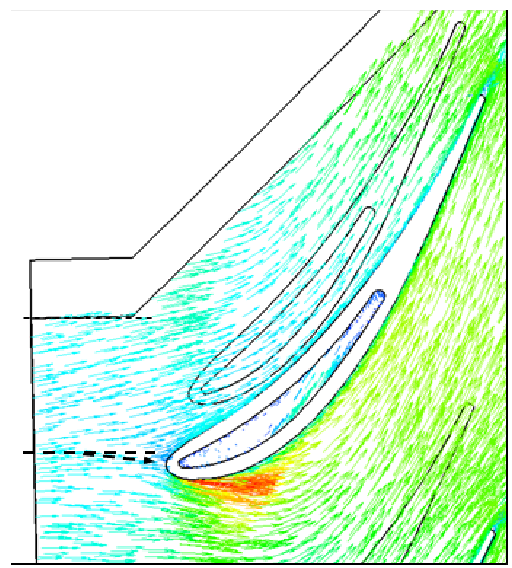
Aligned Incidence Angle



100% Radial Span

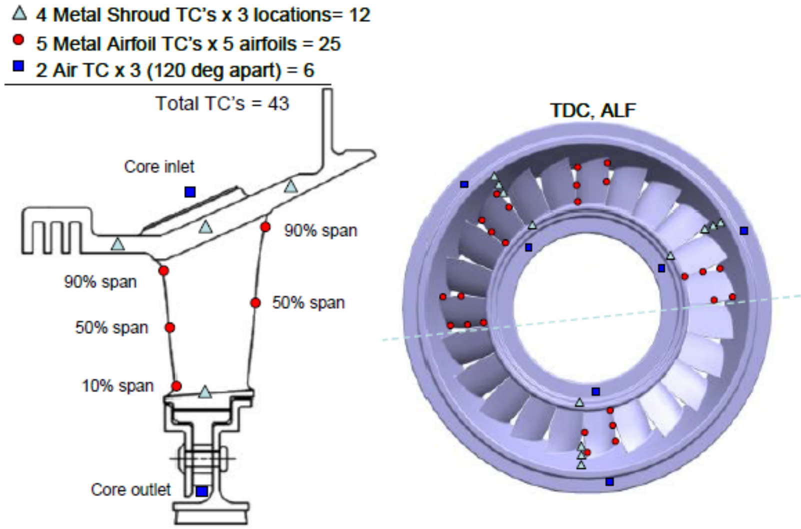


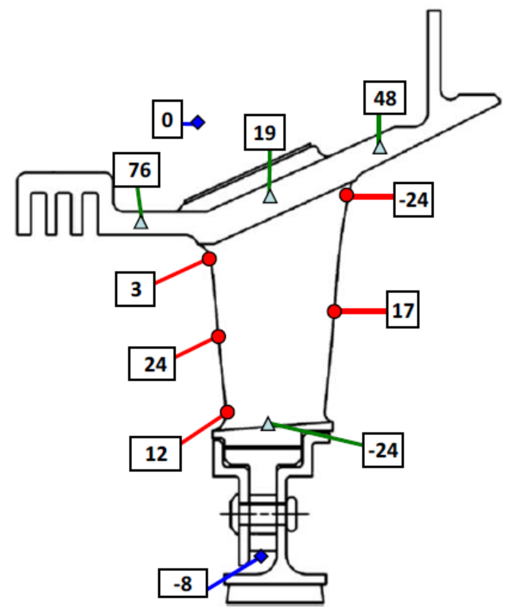
High speed flow at LE suction side is due to Positive incidence



Honeywell
THE POWER OF CONNECTED

Analytical Root Cause – CHT Validation





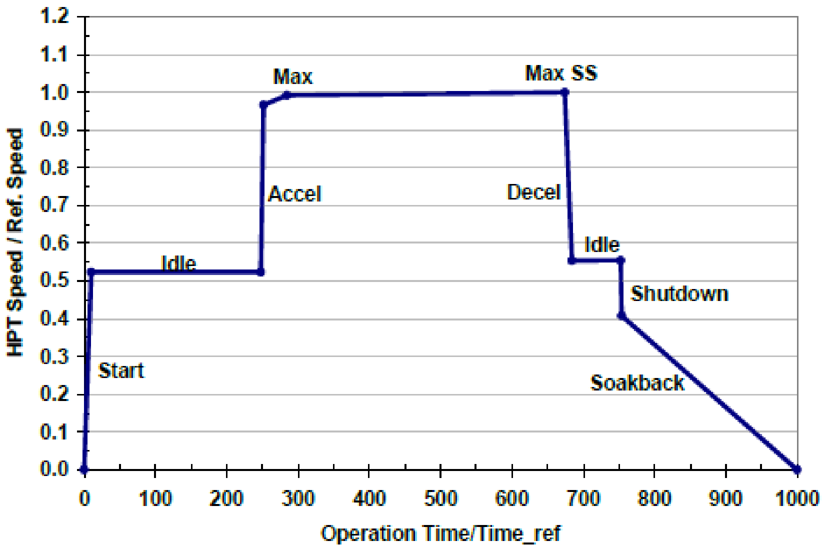
- Thermal Survey – 43 T/C's distributed in 11 locations over the stator.
- Minimum of 3 redundancies included per location to capture circumferential variation.

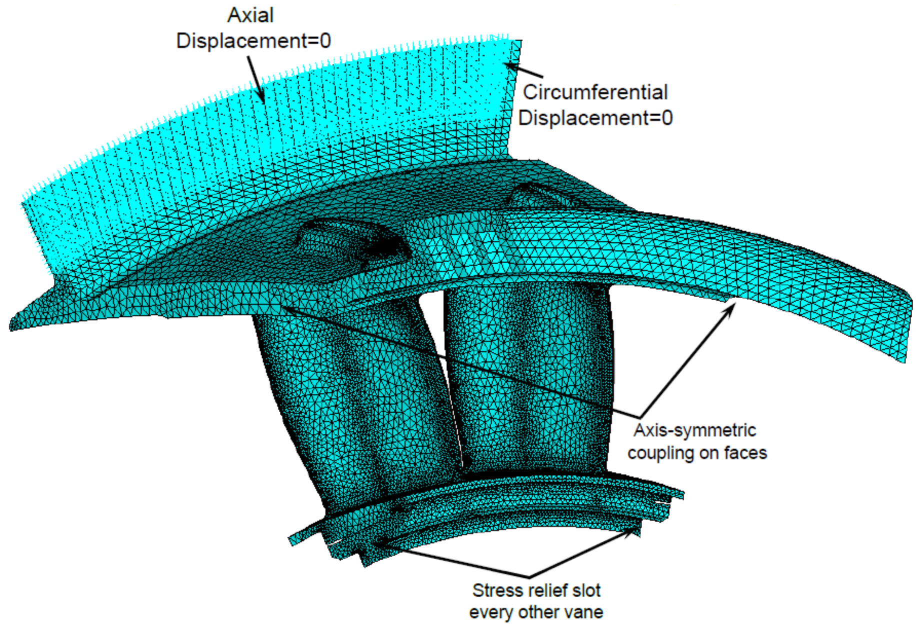
- Stator temperature difference (CHT - Measurement).
- Airfoil was in good agreement within 24 K.
- The internal cooling flow exit temperature prediction was within 8 K.
- Outer shroud metal temperature is over predicted by 76 K mainly to the imposed adiabatic boundary condition.

CHT Model Adequately Matches TC Data

Honeywell
THE POWER OF CONNECTED

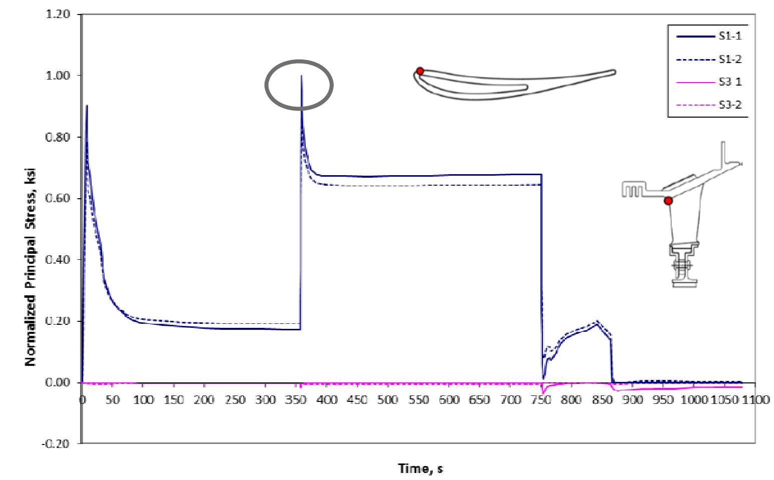
Analytical Root Cause – Stress Model

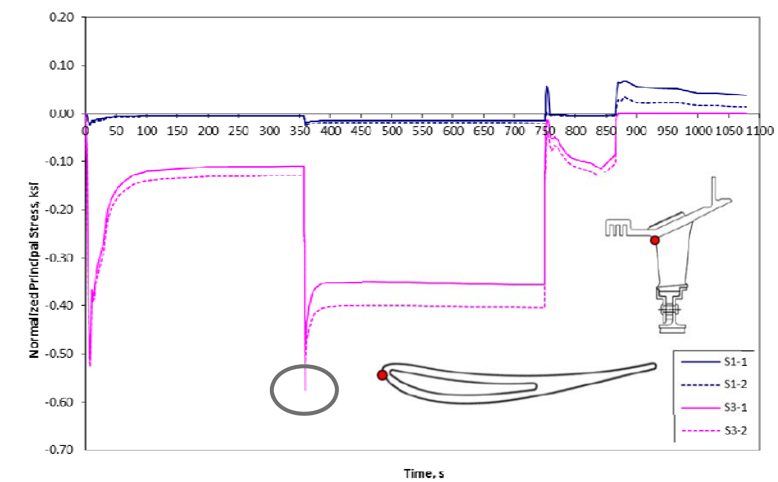


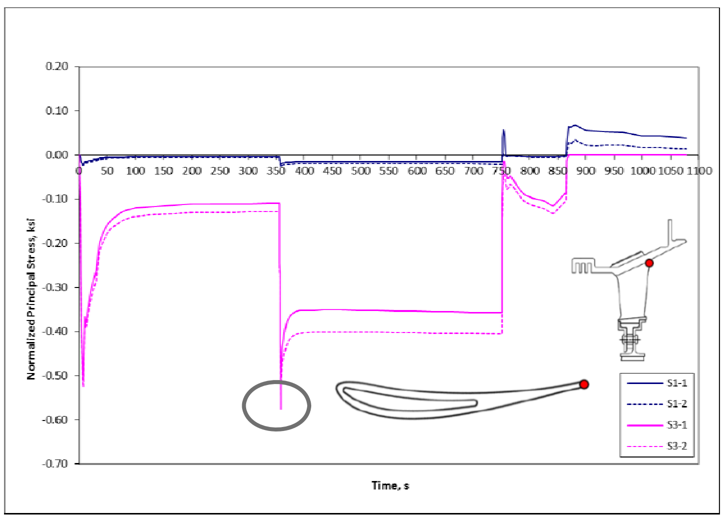


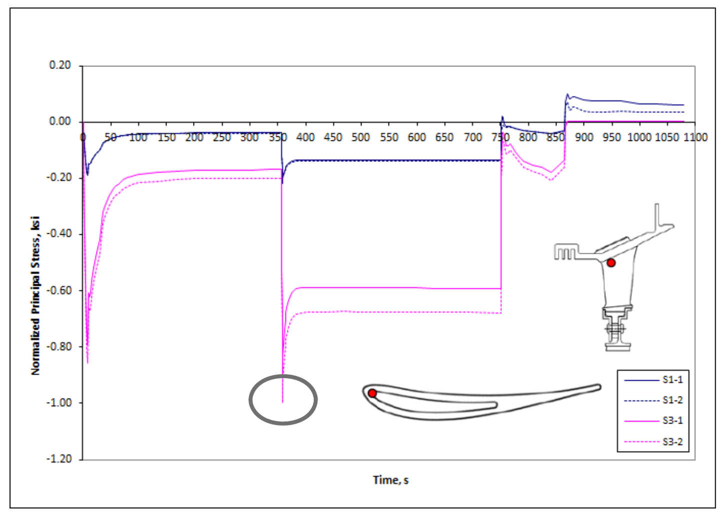
- Fully featured two vane ANSYS stress model includes cooling core definition, airfoil fillets, and stress relief ID slot
- Thermal analysis performed using NX Thermal using boundary conditions from CHT model; finite difference & finite volume
- High density tetrahedral mesh; ~500K elements & ~750K nodes
- Assumed pressure loads are insignificant as compared to thermal loads
- Coupled OD shroud to model 360 axis-symmetric ring

Analytical Root Cause – Stress Results





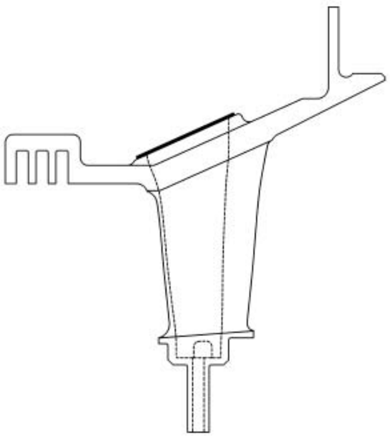




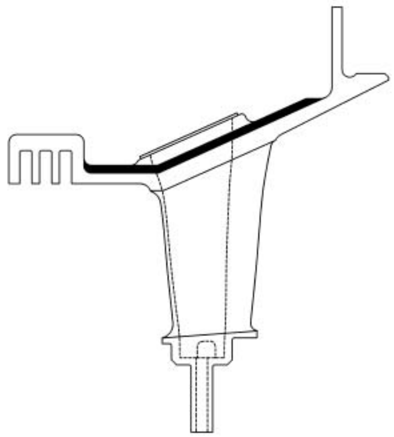
Out of Phase TMF Occurs at Critical Locations

Potential Corrective Actions - Configurations

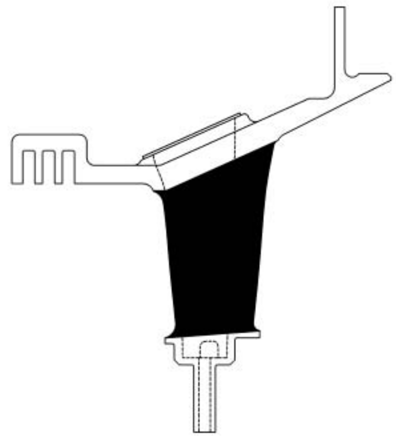
Metering Plate Removed



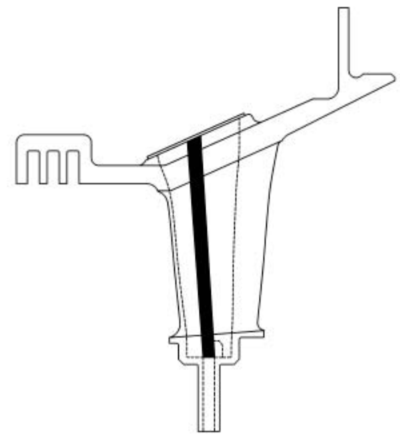
Thinner OD Shroud

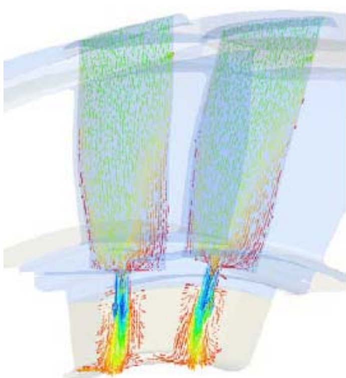


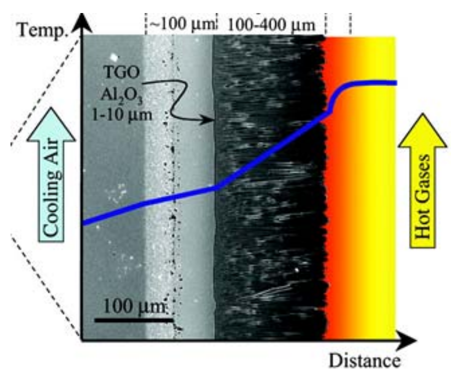
TBC Coating



Isolation Tube

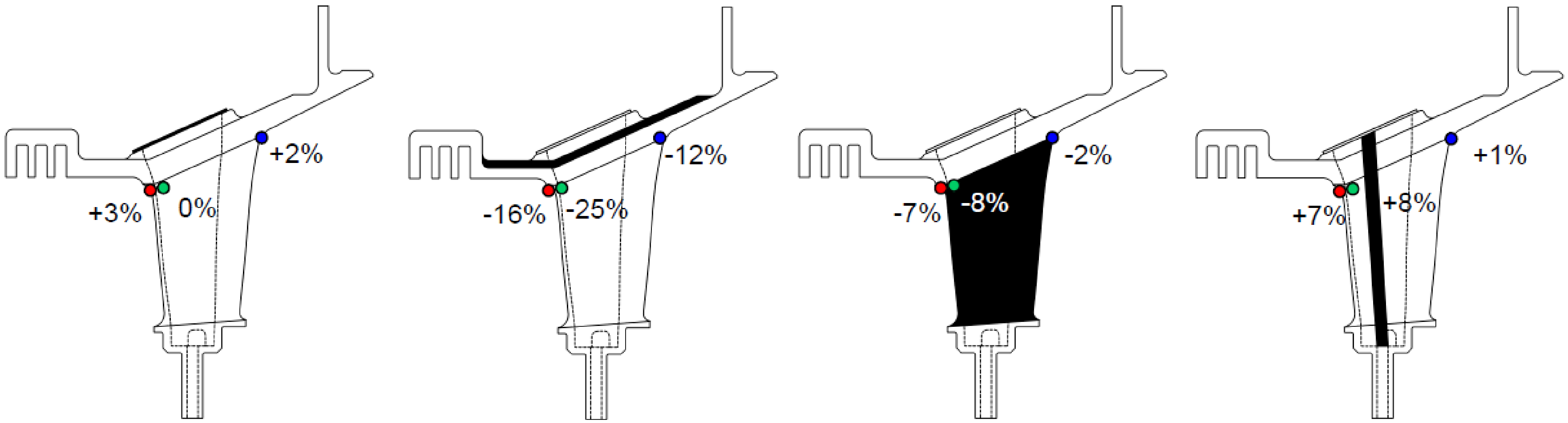






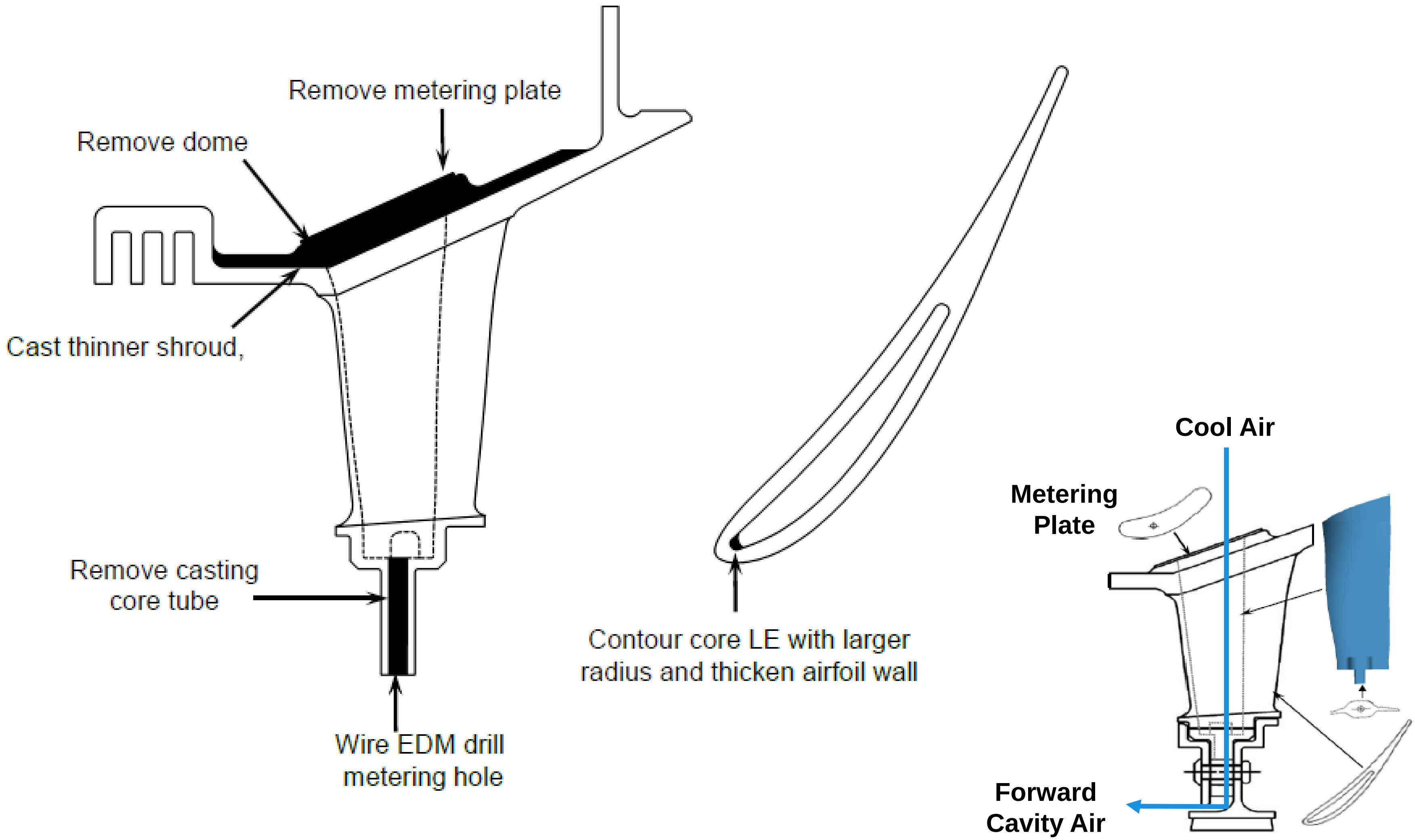
Improve Cooling and Reduce Thermal Flight

Potential Corrective Actions – Stress Results



- Removing metering plate improves overall metal temperatures but slightly increases stresses at critical locations.
- Thinning the OD shroud decreases shroud thermal time constant reducing thermal fight (airfoil-shroud) and reducing stress.
- TBC coating increases airfoil thermal time constant reducing thermal fight (airfoil-shroud) and reducing stress.
- Isolation tube reduces airfoil time constant increasing thermal fight (airfoil-shroud) and increasing stress.

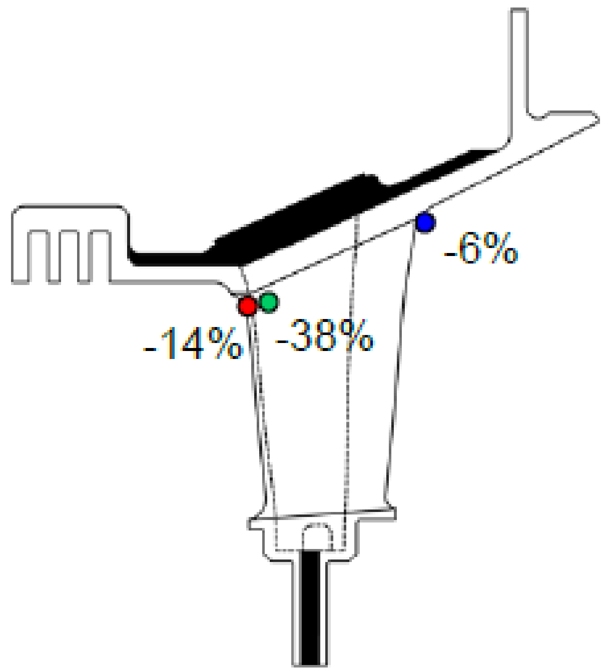
Corrective Actions – Optimum Configuration



Durability and Cooler Forward Cavity Air Achieved

Conclusions

- Recommended configuration is a compromise between cost, durability and cooler exit cool air used to cool turbine disk.
- Reducing airfoil overall temperature reduces oxidation and corrosion attack.
- Thinner OD shroud decreases thermal flight between airfoil and shroud.
- Thicker leading edge reduces stress at critical location.
- Part durability expected to increase by 5x at critical locations.



- Manufacturing Changes:
  - External airfoil casting tooling stays the same. Additional machining to thin OD shroud.
  - Internal core requires new tooling.
  - Metering plate removed.
  - ID metering hole wide EDM.

Easy Practical Solution, High Impact to Durability