Multi-Physics Design of High Temperature Gas Turbine Blades in Jet Engines

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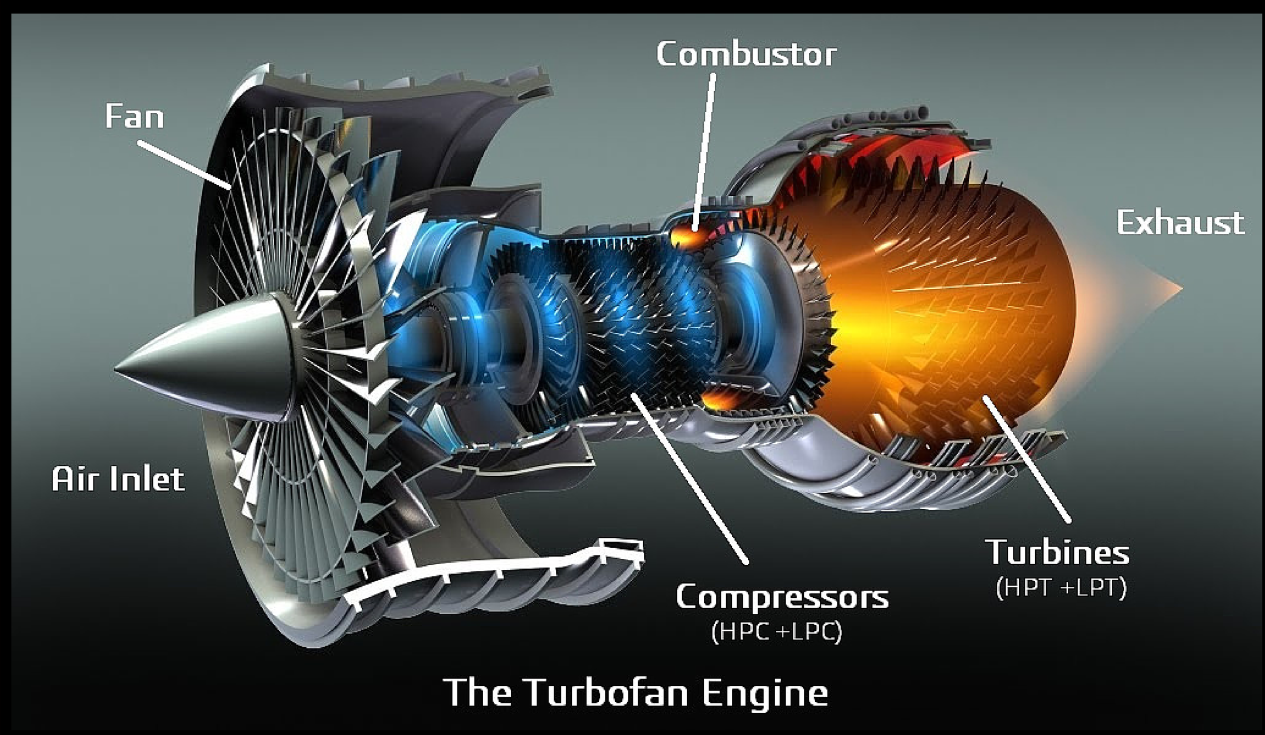
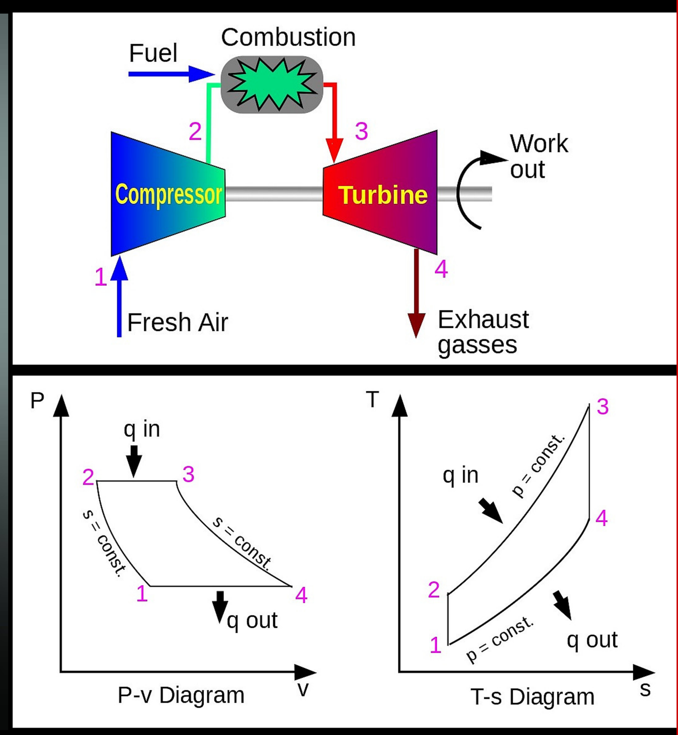


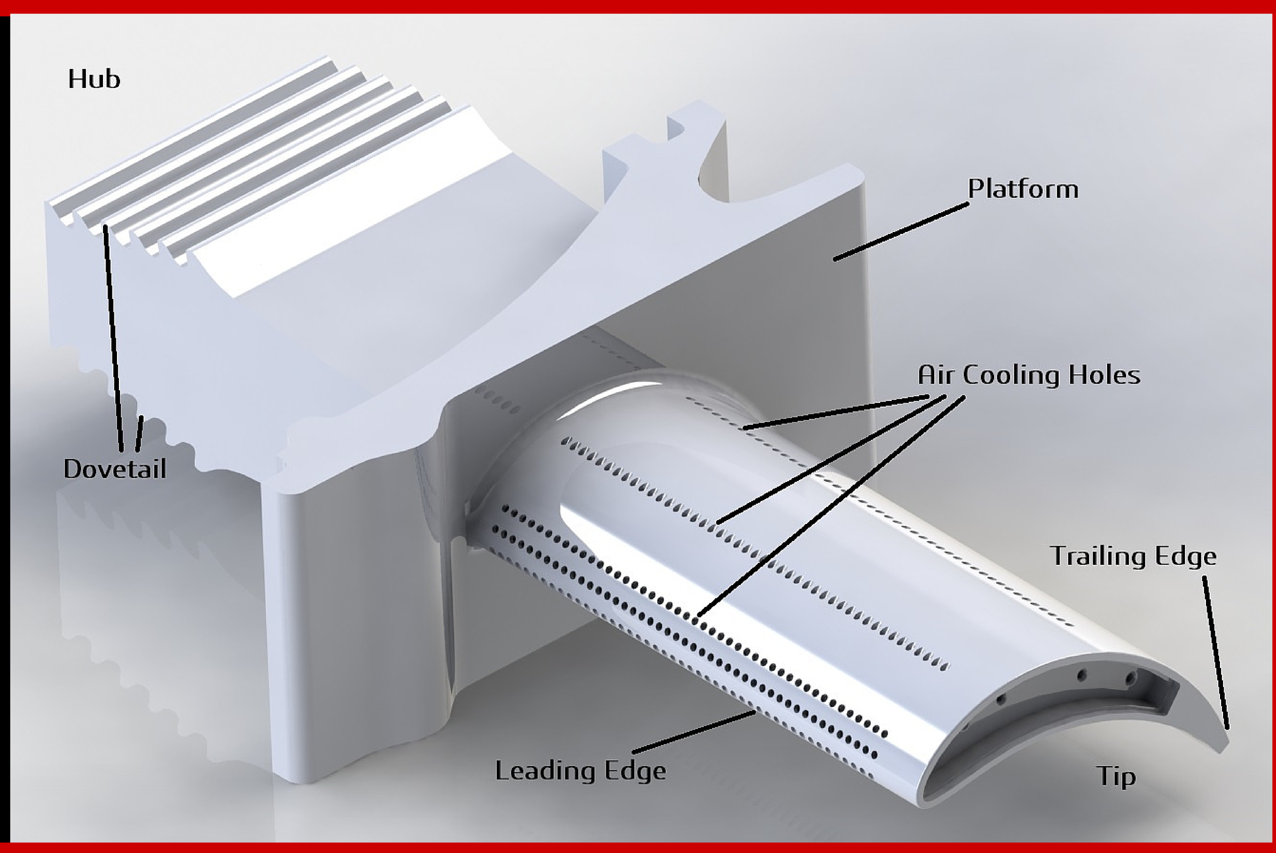


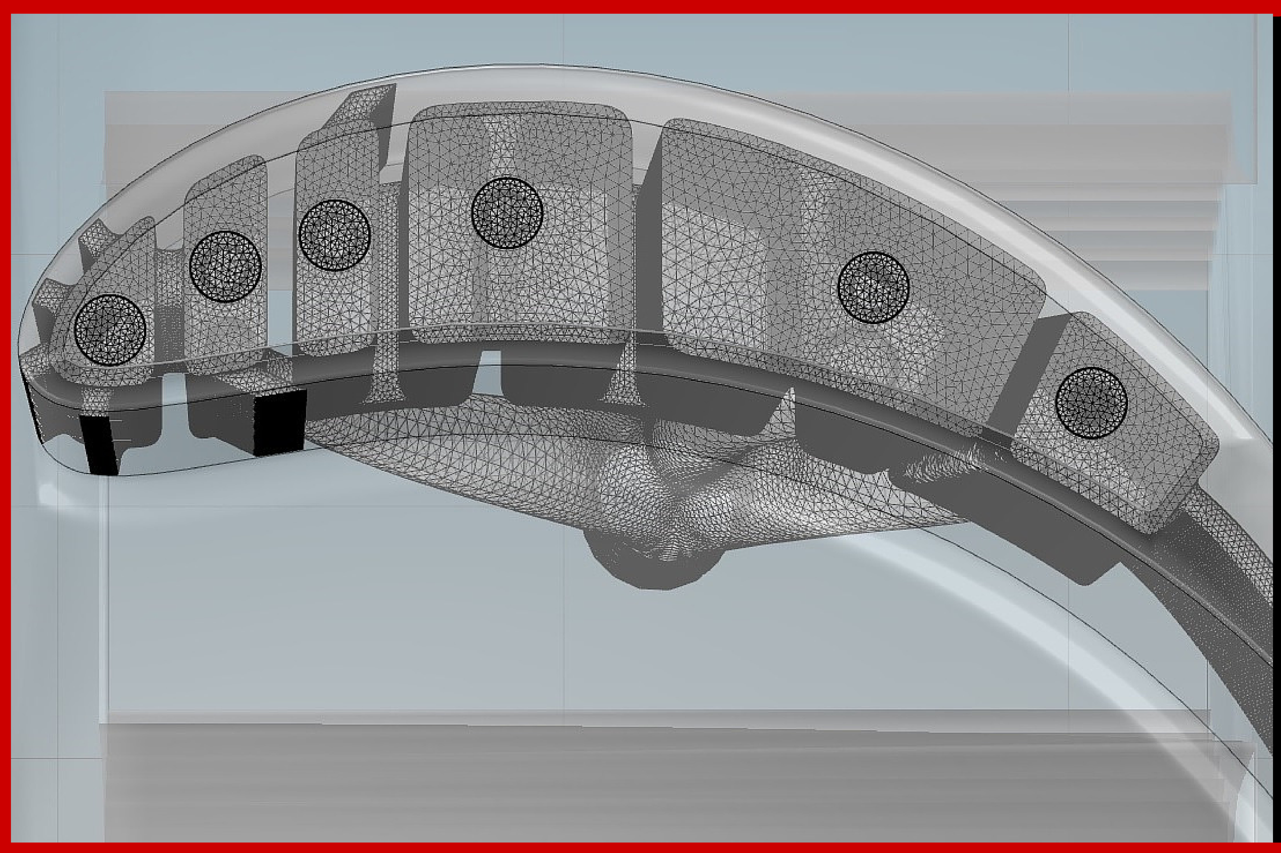
Introduction - How does the Jet Engine Work?

Jet Engines are External Combustion Gas Turbine Engines that work on the principle of the Brayton Cycle. The Brayton Cycle involves three thermodynamic processes - isentropic compression, isobaric (constant pressure) combustion and isentropic expansion.

The Process involves:

- Intake of atmospheric air at flying altitude through the Fan
- Isentropic Compression of air through a series of Low Pressure (LPC) and High Pressure Compressors (HPC) - Ranges from 1-8 stages of LPC and 6-16 stages of HPC.
- Isobaric Combustion of the Air Fuel Mixture releasing gases at high temperature and pressure.
- Isentropic Expansion of the hot gases through High Pressure (HPT) and Low Pressure Turbines (LPT) - Ranges from 1-2 stages of HPT and 4-7 stages of LPT.
- Exhaust gases pushed out through a small diameter nozzle producing a high velocity jet.

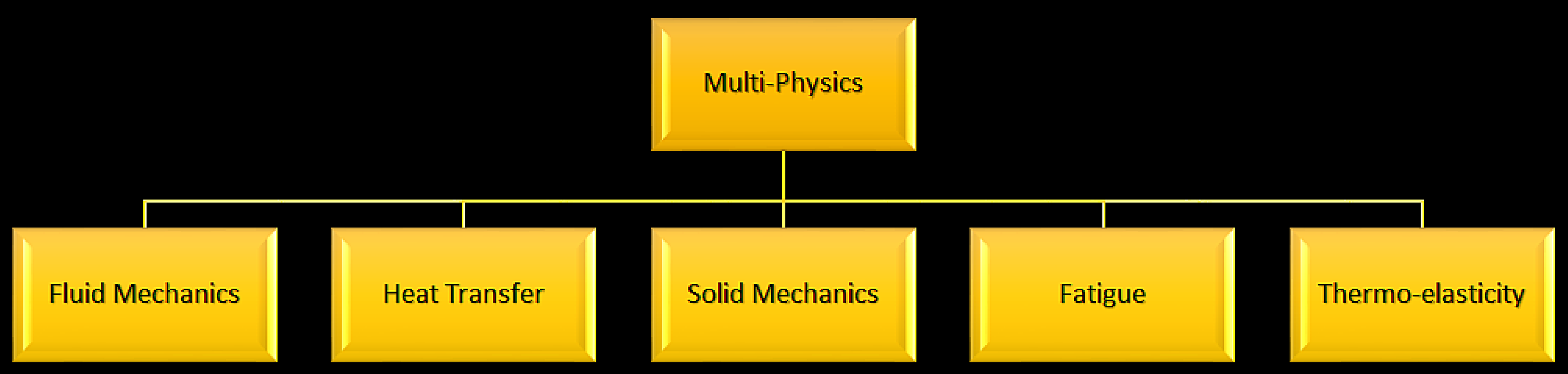




Research Motivation/Goals/Impact

- The Turbine Blades are responsible for extracting energy from the gases exiting the combustor and are thus subject to high pressures and temperatures over 1300 C.
- The exposure to such extreme environments and temperatures makes the material selection and design of a turbine blade one of the most challenging and expansive industrial enterprise today.
- Optimization of geometric design of the airfoil, external blade profile, shapes and number of internal cooling channels in order to increase the range of working temperatures. This would ultimately lead to better fuel efficiencies and more powerful and environmentally safe jet engines.
- Specifically, the work combines the effect of multiple physics phenomena on the turbine blade that highlights the importance of the effect of each physics on the other.

Multiphysics

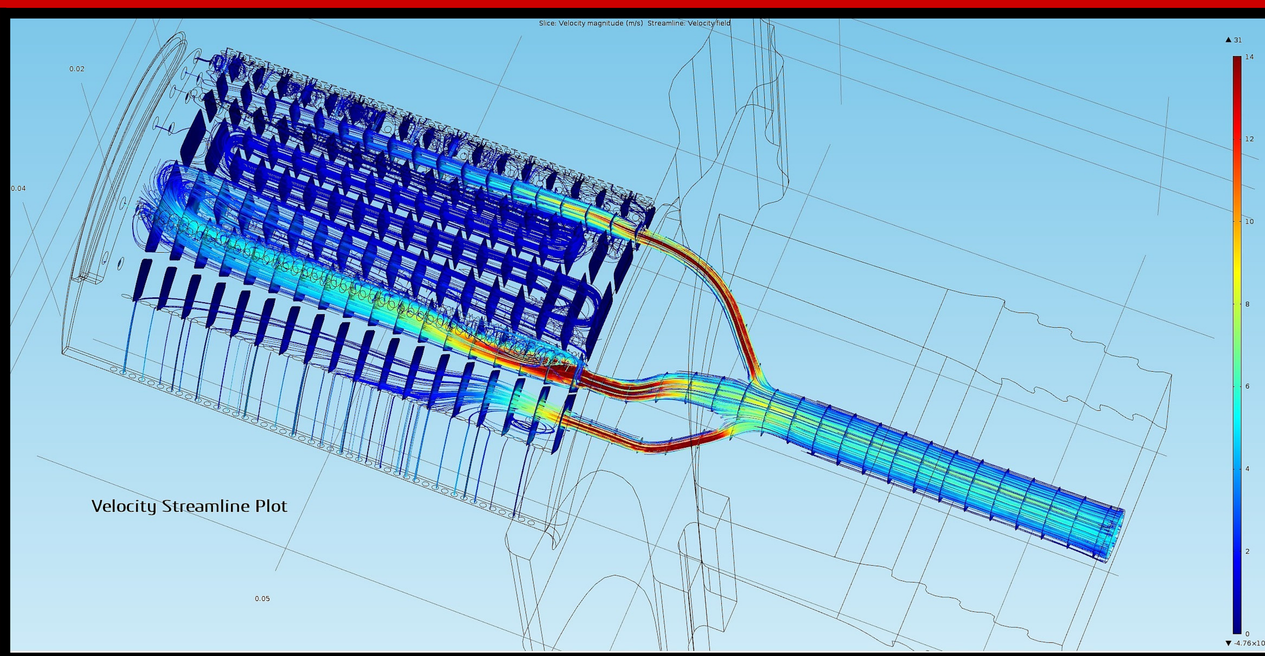


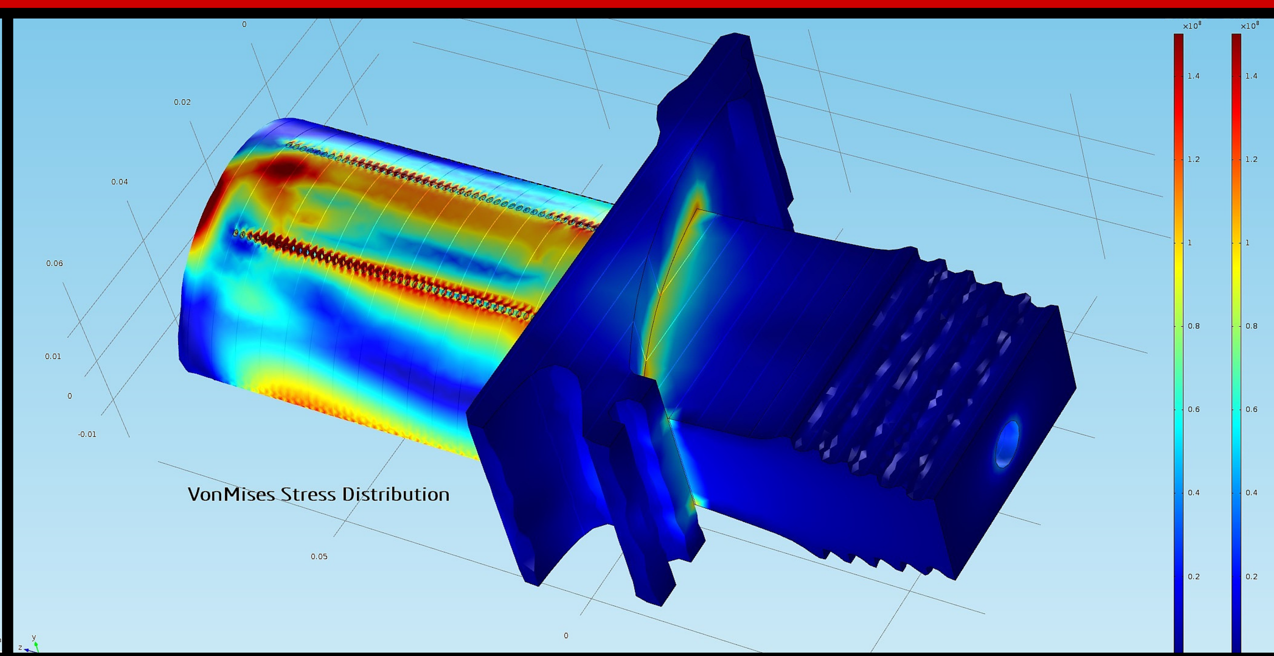
Multiphysics

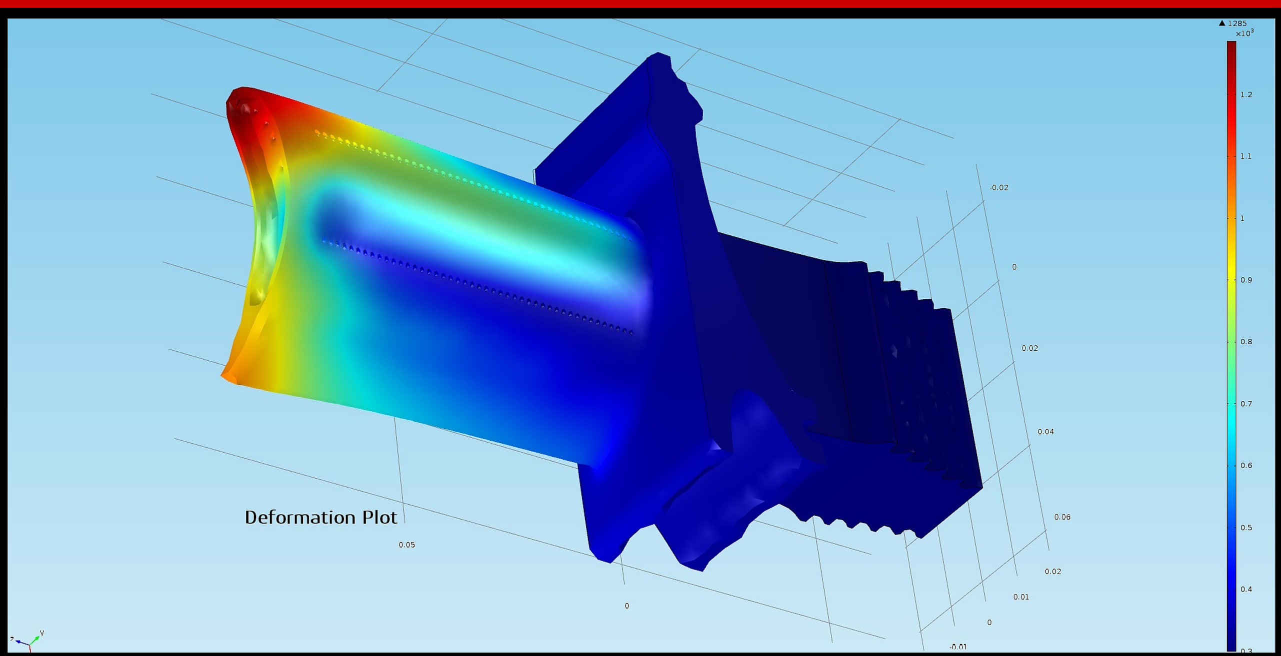
The complete design of a turbine blade involves the coupling of various physics modules in order to achieve a comprehensive computational simulation of the events occurring during real operation of a jet engine.

The various essential physics modules coupled in the analysis in COMSOL include:

- Fluid Mechanics (Flow Simulation through the cooling channels)
- Heat Transfer (Between Cooling Air and the Turbine Blade with the Thermal Barrier Coating)
- Solid Mechanics (To account for Thermal Expansion and Creep)
- Plasticity and Fatigue (Thermal Fatigue)
- Thermoelasticity







Results, Achievements and Future Work

- Simulation Results above show the streamline **VELOCITY PROFILE** of the flow of bleed air from the compressor through the internal cooling channels, depicting different critical regions.
- Flow simulation also gave results for **PRESSURE DISTRIBUTIONS** throughout the cooling channels.
- **TRANSVERSE TEMPERATURE PROFILE** sections are also plotted as a result of the coupling between the heat transfer and fluid mechanics physics modules, depicting the regions of maximum temperature which have been found to be at the upper tip of the leading edge.
- **VON MISES STRESS DISTRIBUTIONS** are obtained for the stresses arising from mechanical loads as a result of the hot gases and thermal stresses due to temperaure variations across the blade body.
- Exaggerated **DEFORMATION PLOTS** show the regions subject to maximum distortion from the original dimensions of the part.
- **CREEP** and **FATIGUE** interactions are studied, thus calculating the estimated lifetime of the part before plastic deformation and fracture.
- Further developments in advanced techniques like Transpiration Cooling can be used to achieve higher heat transfer coefficients for High Temperature applications.
- The turbine blades are subjected to extreme working conditions of fluctuating high gas pressure and temperatures reaching 1400 C in addition to the inertial centrifugal forces arising from the rotation of the blades at high rpms. This lays the basis for the need to develop new materials and alloys which possess unprecedented mechanical properties including but not limited to high strength, resistance to fatigue, creep, oxidation and hot corrosion.

References

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