Aerodynamics and Heat Transfer Studies of Parameters Specific to the IGCC-Requirements: Endwall Contouring, Leading Edge Filleting and Blade Tip Ejection under Rotating Turbine Conditions

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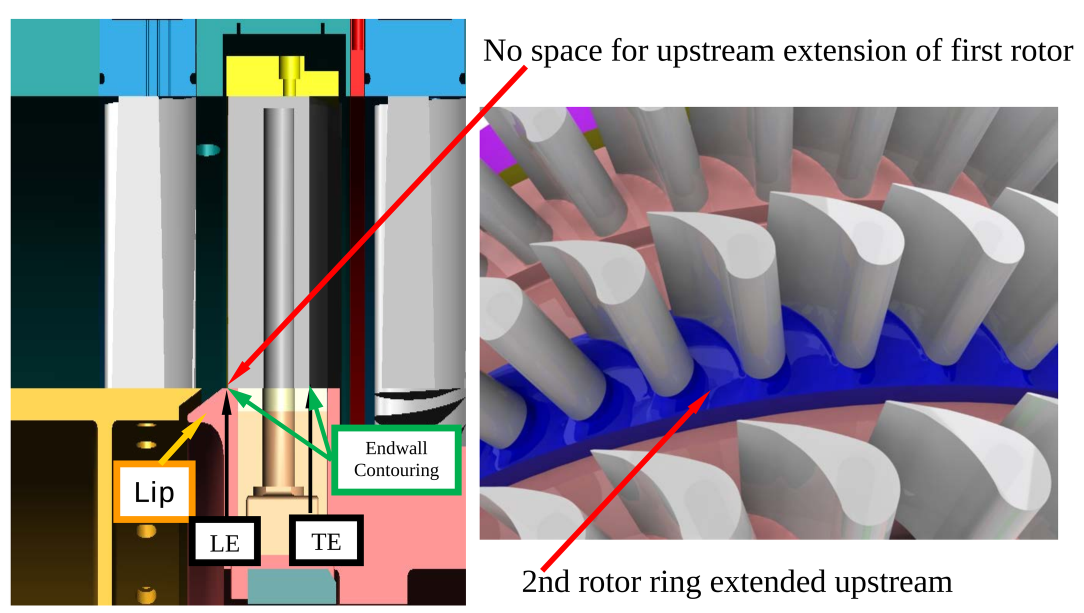
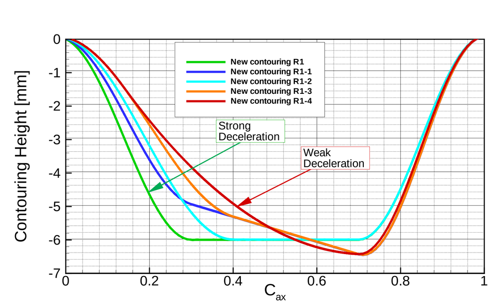
Effect of Purge Flow on Aerodynamics Performance and Film Cooling Effectiveness on a Rotating Turbine with Non-Axisymmetric Endwall Contouring

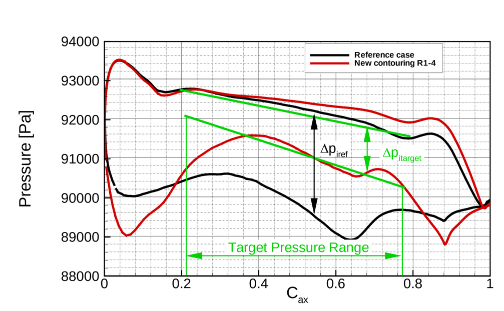
The impact of the purge mass flow injection on aerodynamics and film cooling effectiveness of a high pressure turbine with non-axisymmetric endwall contouring is investigated. The three-stage multi-purpose turbine research facility at the Turbomachinery Performance and Flow Research Laboratory (TPFL), Texas A&M University is utilized. The rotor includes non-axisymmetric endwall contouring on the first and second rotor row. While in the case of the second rotor, the endwall contouring has brought substantial reduction in secondary flow losses and thus an efficiency increase, the first rotor shows different behavior due to its immediate exposure to the purge flow injection. The purge flow investigation involves the reference case without endwall contouring. Efficiency, pressure, temperature and film cooling effectiveness distributions are determined for purge mass flow ratios of MFR= 0.5%, 1.0% and 1.5%. The small amount of the injected mass flow drastically changes the development of the secondary flow structure of the contoured first turbine row.



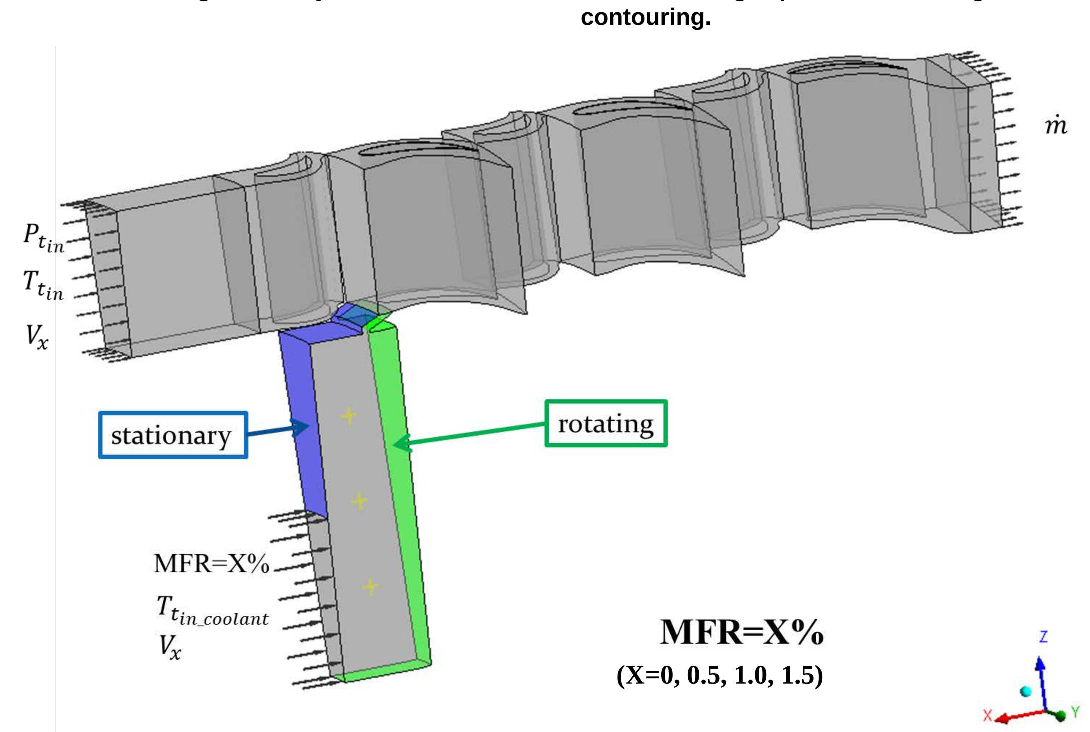
Position of the circumferential gap for ejection of purge flow (left), extension of the contouring upstream of second rotor endwall contouring.

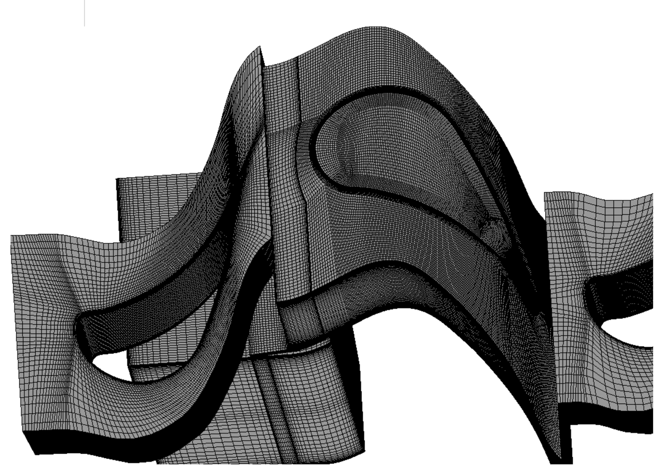


Variation of deceleration rate defined by the diffusion length to obtain the best endwall contouring efficiency.

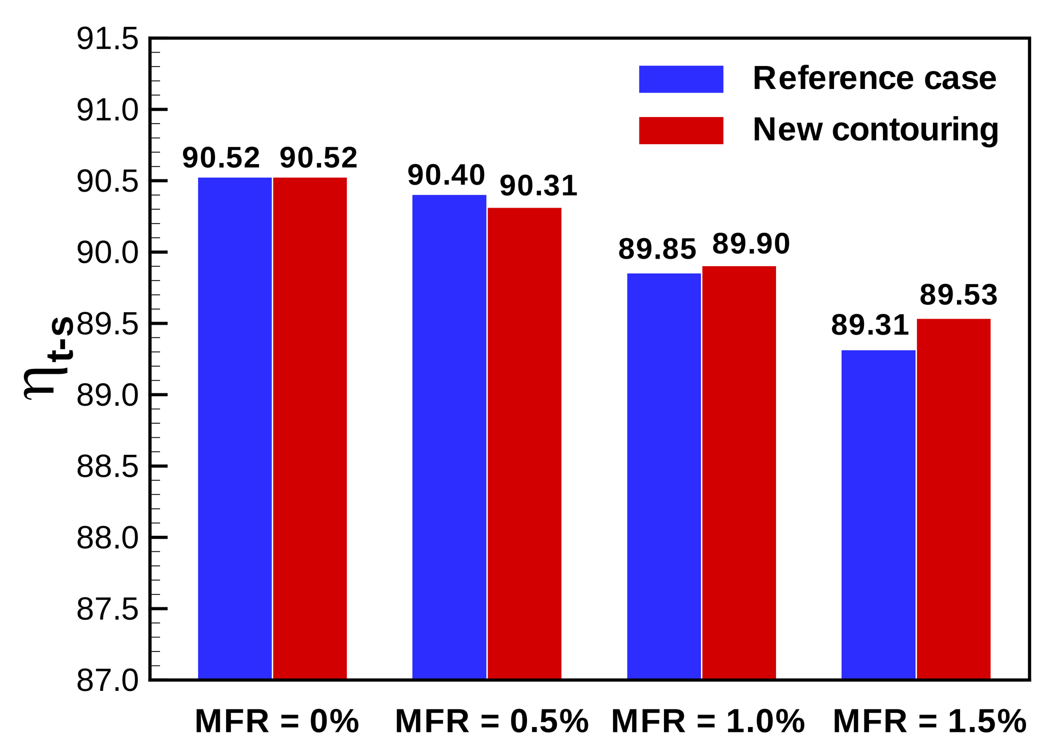


Pressure distributions directly at the hub for reference case and contoured case with target pressure to design the contouring.

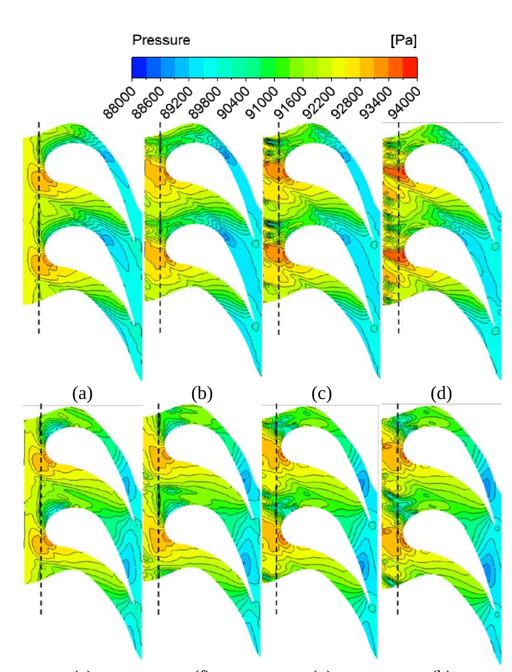




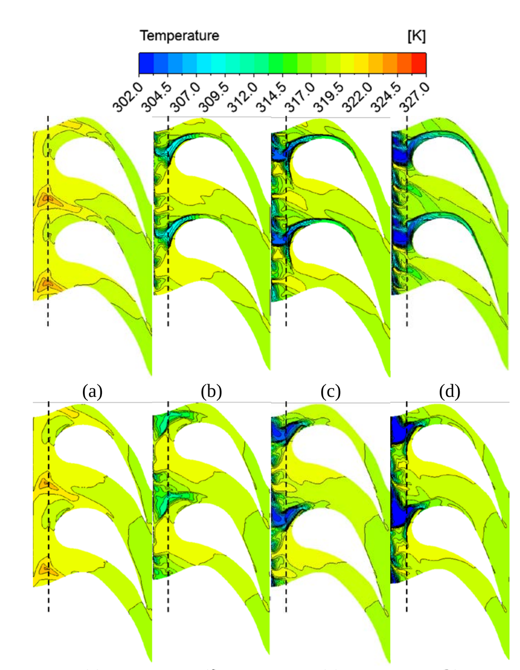
Computational domain and boundary condition settings for the TPFL three-stage HP turbine with the purge flow cavity (top); Top view of the mesh for the first stage (left).



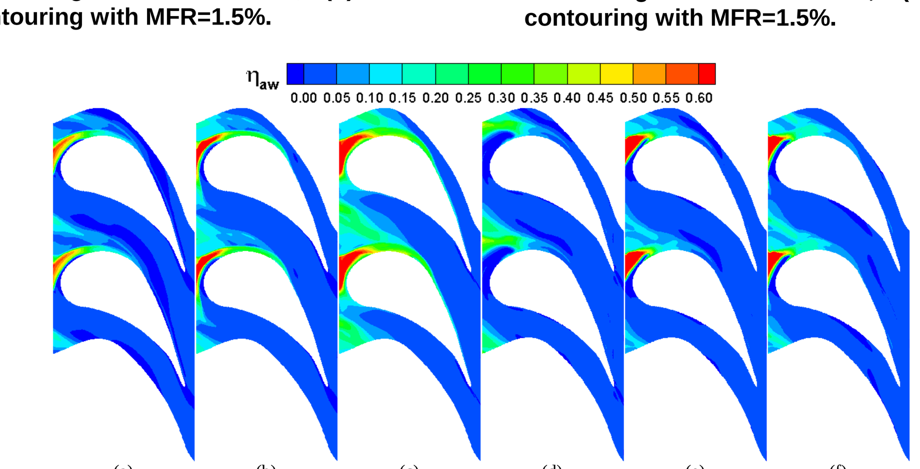
Total-to-static efficiency for reference cases and contoured cases at different MFRs.



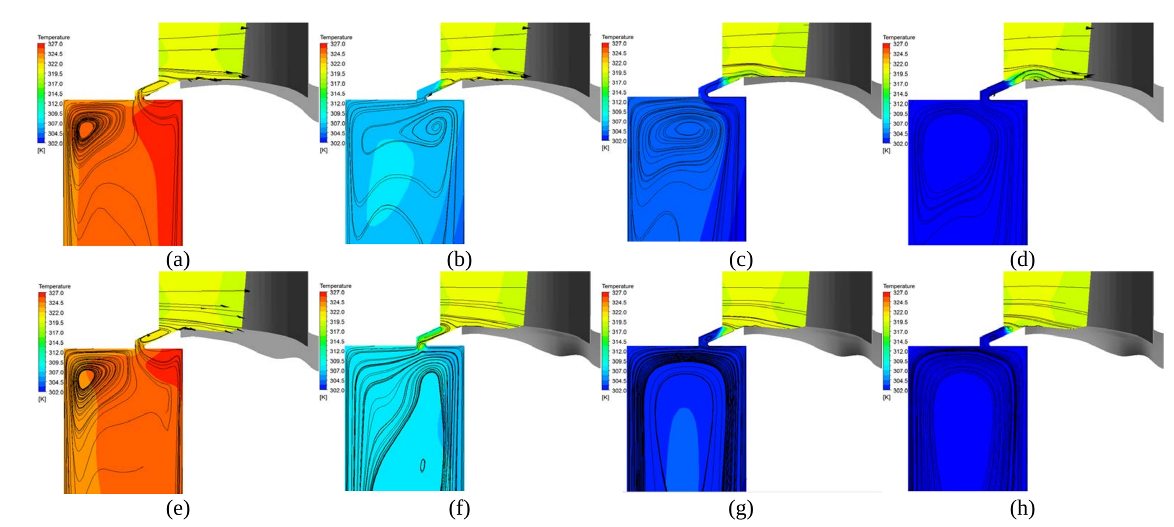
Pressure distribution at 0% span: (a) Reference case with MFR=0%; (b) Reference case with MFR=0.5%; (c) Reference case with MFR=1.0%; (d) Reference case with MFR=1.5%; (e) New contouring with MFR=0%; (f) New contouring with MFR=0.5%; (g) New contouring with MFR=1.0%; (h) New contouring with MFR=1.5%.



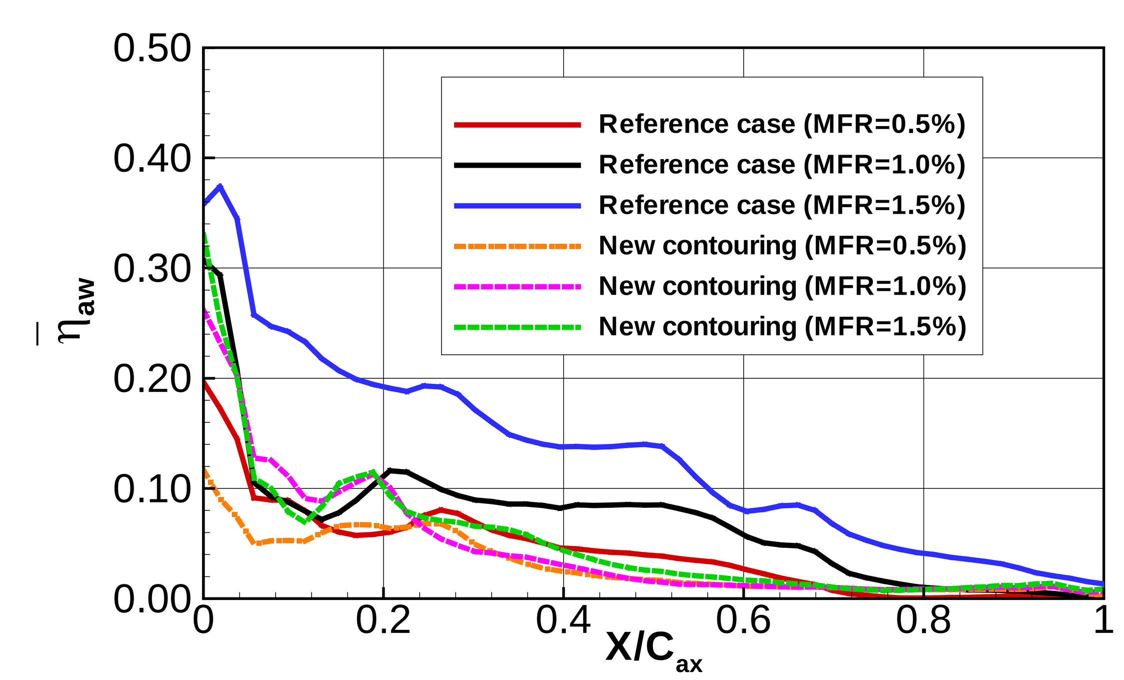
Temperature distribution at 0% span: (a) Reference case with MFR=0%; (b) Reference case with MFR=0.5%; (c) Reference case with MFR=1.0%; (d) Reference case with MFR=1.5%; (e) New contouring with MFR=0%; (f) New contouring with MFR=0.5%; (g) New contouring with MFR=1.0%; (h) New contouring with MFR=1.5%.



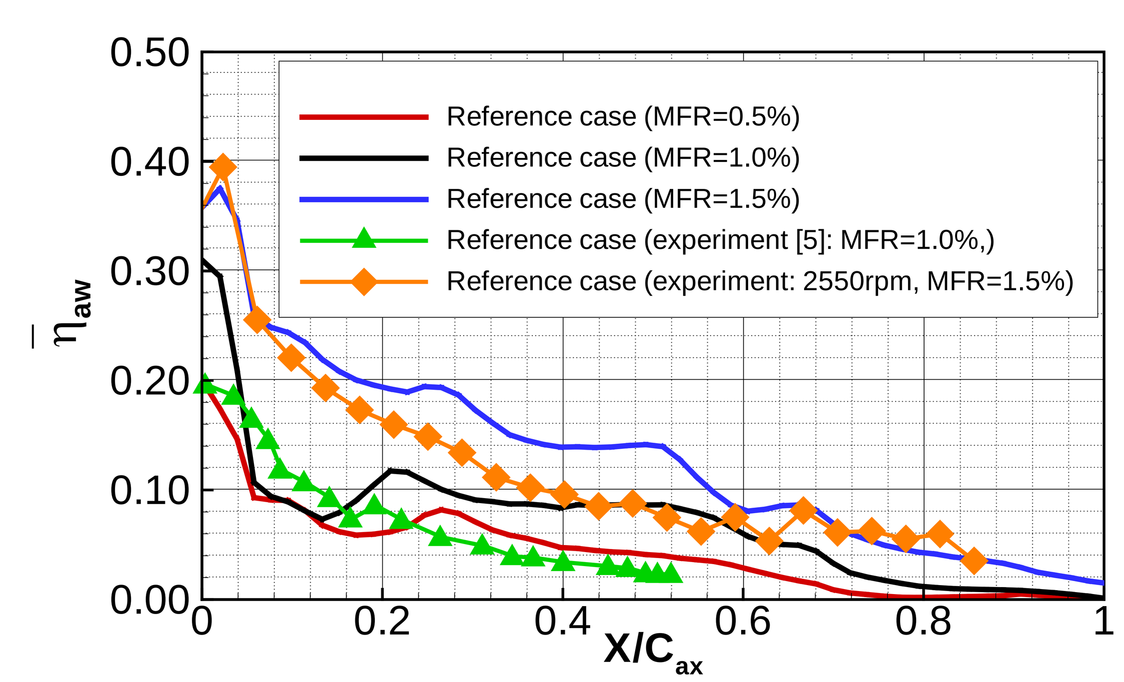
Adiabatic film cooling effectiveness: (a) Reference case with MFR=0.5%; (b) Reference case with MFR=1.0%; (c) Reference case with MFR=1.5%; (d) New contouring with MFR=0.5%; (e) New contouring with MFR=1.0%; (f) New contouring with MFR=1.5%.



Temperature distribution (contours) and surface streamlines (black solid lines) at pressure side: (a) Reference case with MFR=0%; (b) Reference case with MFR=0.5%; (c) Reference case with MFR=1.0%; (d) Reference case with MFR=1.5%; (e) New contouring with MFR=0%; (f) New contouring with MFR=0.5%; (g) New contouring with MFR=1.0%; (h) New contouring with MFR=1.5%.



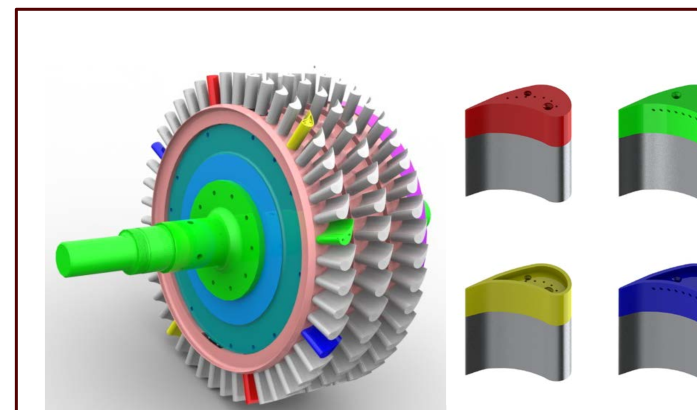
Pitchwise averaged adiabatic film-coolilng effectiveness along the rotating platform passage (CFD).



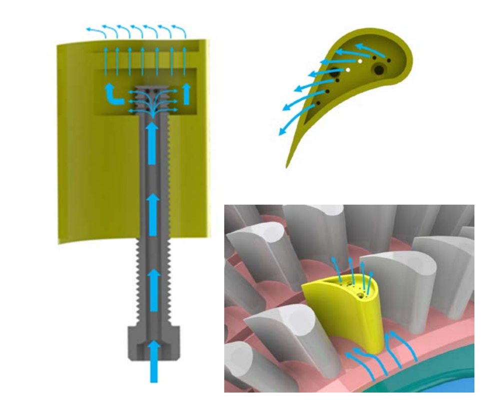
Comparison of the pitch-wise averaged film effectiveness between reference case and previous experimental data under similar conditions

Prediction of Plane tip with tip hole cooling

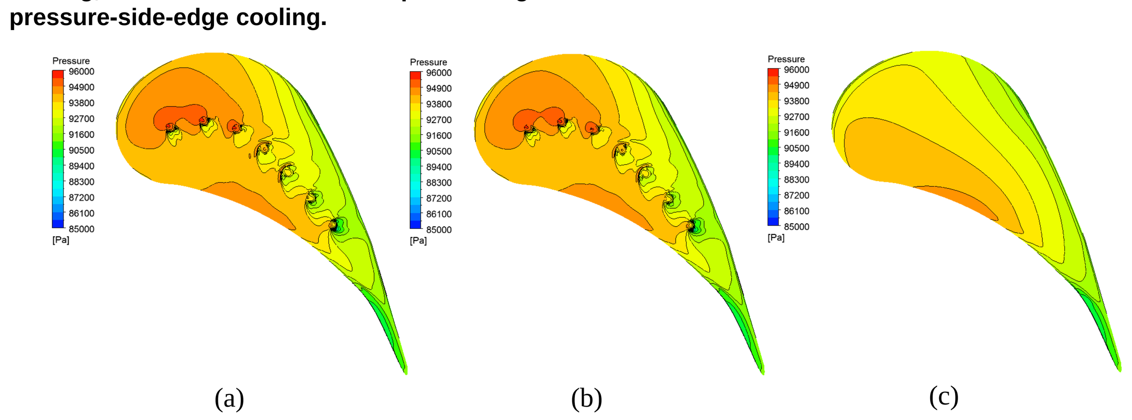
Four pairs of rotor blades with different cooling configurations have been manufactured and axis-symmetrically installed at the first rotor row. Currently preliminary numerical simulations have been performed for plane tip with tip hole cooling. The results show that around 50% area of the blade tip is covered by the film cooling, while other 50% is exposed to the mainstream.



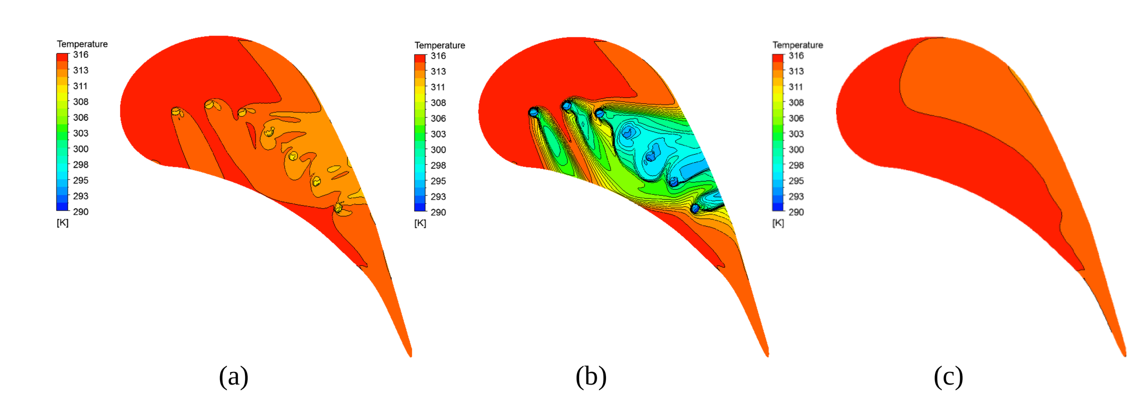
Four different rotor blade tip configurations have been designed and studied: plane tip with tip hole cooling (red), plane tip with pressure-side-edge compound angle hole cooling (green), squealer tip with tip hole cooling (yellow) and squealer tip with pressure-side-edge compound angle hole cooling (blue). Seven perpendicular holes along the camber line are used for the tip hole cooling, whereas seven 45˚ compound angle holes for pressure-side-edge cooling.



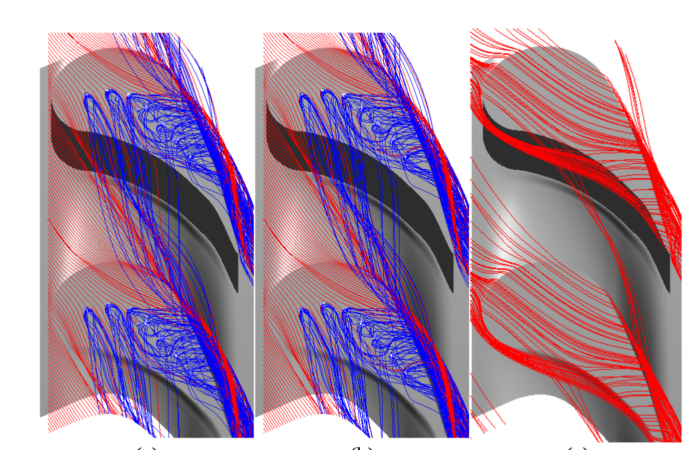
The coolant flow is injected from the bottom of the bolt and then diffuses into the plenum through radially distributed holes near bolt tip. Finally the coolant flow is ejected through the cooling holes.



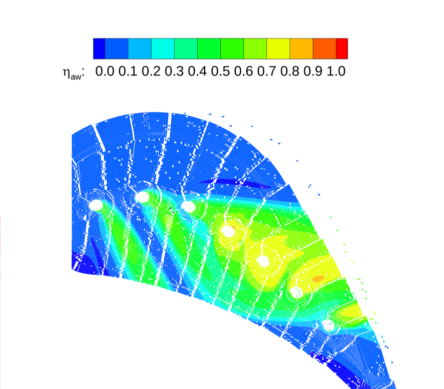
Pressure distribution at blade tip: (a) $T_{t,\ coolant}$=318K, (b) $T_{t,\ coolant}$=300K, (c) without film cooling.



Distribution of the adiabatic wall temperature at blade tip: (a) $T_{t,\ coolant}$=318K, (b) $T_{t,\ coolant}$=300K, (c) without film cooling.



Flow structures observed in rotating frame at the blade tip region: (a) $T_{t,\ coolant}$=318K, (b) $T_{t,\ coolant}$=300K, (c) without film cooling (red streamlines mark the mainstream and blue ones mark the cooling jets).



$$\eta_{aw} = \frac{T_{aw,f_0} - T_{aw,f}}{T_{aw,f_0} - T_c}$$

Distribution of adiabatic film cooling effectiveness at blade tip under global blowing ratio of one.