Turbine Endwall Contouring Using a Hybrid Experimental and Numerical Optimization Approach

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Contents

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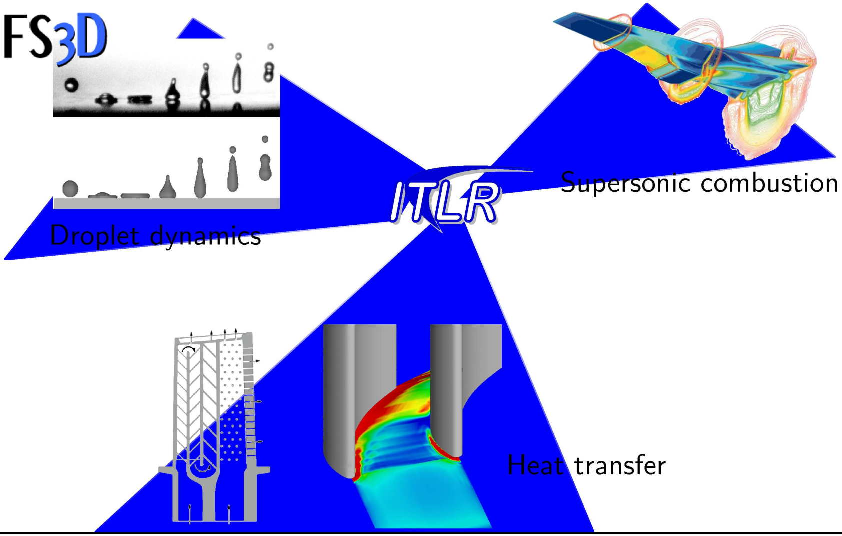


Project description

Heat Transfer in 3D Vane Passages

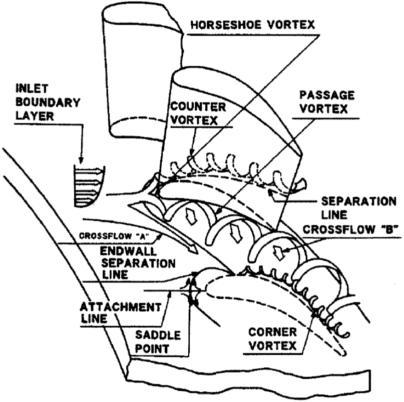
Systematic Generation and Investigation of Contoured Vane-Endwall Geometries for Turbomachines Using the Ice Formation Method

Duration: July 2010 - December 2014

Joint Venture between German Research Foundation (DFG) and Research Association for Combustion Engines (FVV) in collaboration with ITLR

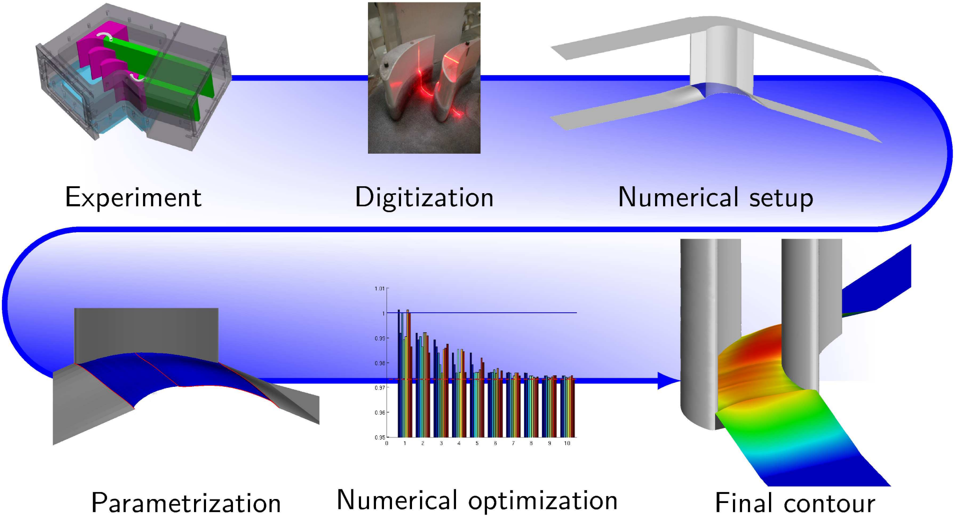
Project goal and background

Project goal: Generation of vane endwall contour which alters flow field in such way that endwall heat transfer is reduced



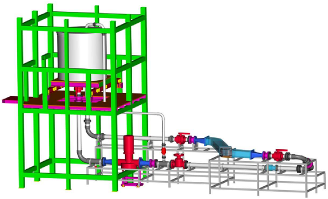
Flow features in vane row flow field after Takeishi et al. [2]

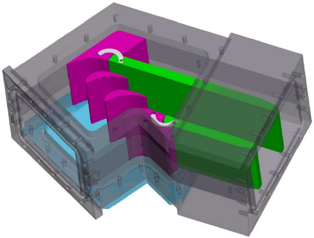
Hybrid experimental and numerical approach



Ice Formation Method

- Natural optimization method
- Baseline geometry cooled below freezing temperature of water and exposed to convective water flow
- Resulting ice layer optimized with respect to minimum energy dissipation
- Method implies only minimum restrictions to optimization space

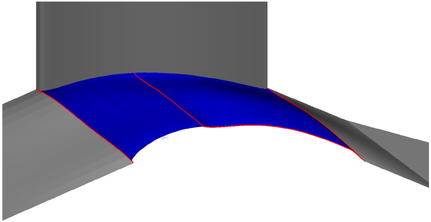




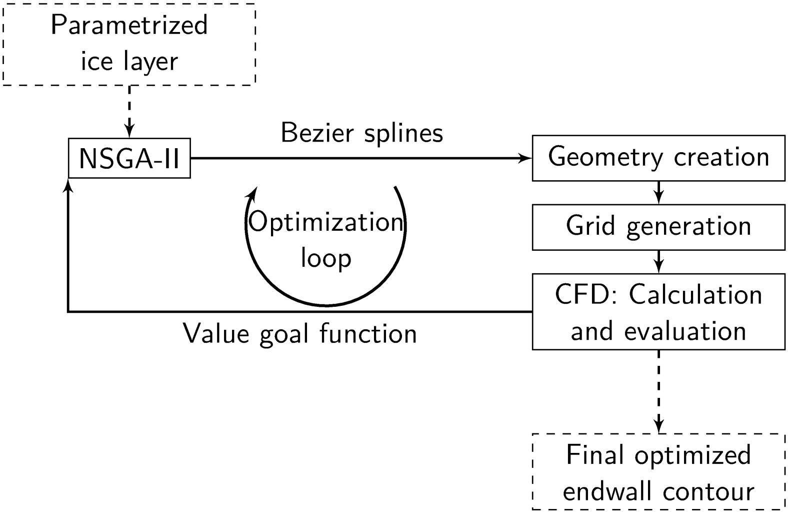
Pictures taken from [1]

Numerical optimization approach

- Goal function of IFM is minimum energy dissipation → Trade-off between min. pressure loss and min. heat transfer
- Further numerical optimization with only minimum endwall heat transfer as goal function
- Genetic algorithm NSGA-II from Deb et al. [3] coupled with three-dimensional fluid dynamics
- Parametrization of digitized ice layer with Bezier splines → Systematic variation of endwall contour geometry

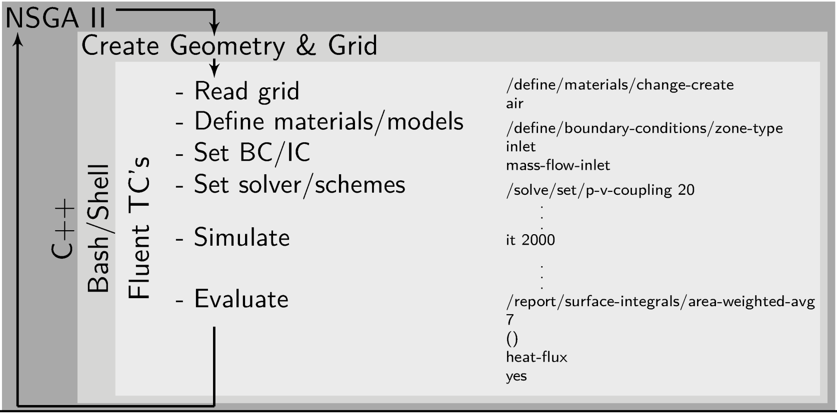


Numerical optimization approach

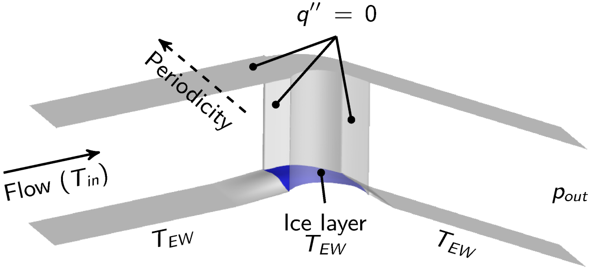


Fluid dynamics in optimization

- Fluid dynamics simulations with ANSYS Fluent 12.1
- BC/IC set-up, simulation and evaluation scripted to run automatically in optimization → Bash/Fluent command language



Solution domain and boundary conditions



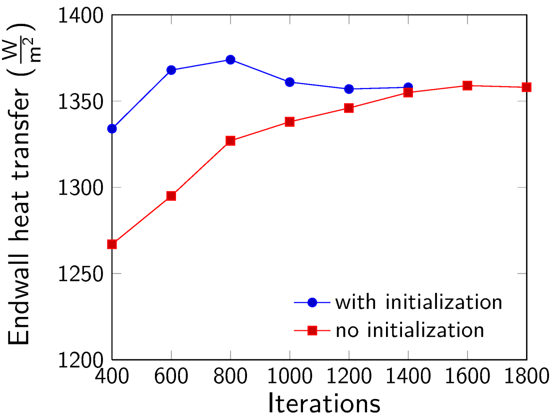
Picture taken from [1]

- Steady state
- SIMPLE algorithm
- Fluid: air
- Compressible
- Sutherland's law

- Spatial discretization: 2nd order
- Turbulence: SST low-Reynolds-number-formulation
- Grid: $\approx$ 4 M Cells; $y_1^+ \approx 1$
- $Re = 49{,}900$
- $\Delta T = T_{in} - T_{EW} = 50K$

Domain initialization

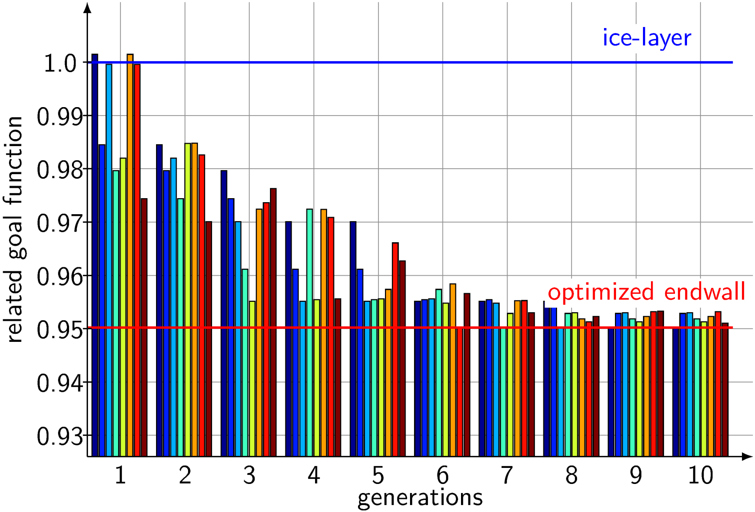
- Initialization of domain with solution from flat endwall to save computation time → Approx. 1000 iterations for convergence



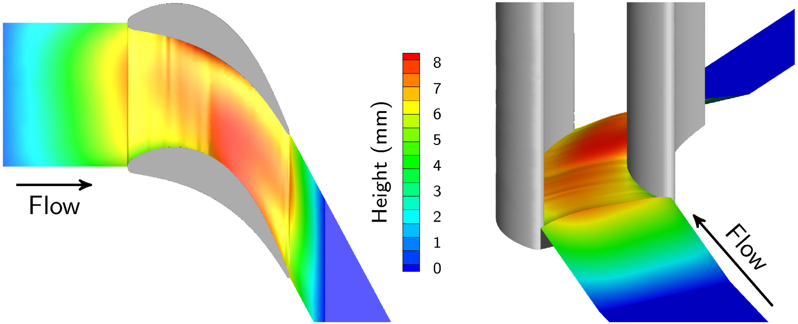
Parameters numerical optimization

- Ice layer as initial endwall contour
- Goal function: Minimum endwall heat transfer
- 16 decision variables (control points of Bezier splines)
- Genetic Algorithm: Mutation probability $P_{\text{mut}} = 0.2$; Crossover probability $P_{\text{cross}} = 0.8$
- Simulation of 10 generations with 8 individuals per generation $\rightarrow$ total of 80 CFD simulations
- Simulation time: $\approx$ 160h on 8 core i7 machine

Progress of goal function

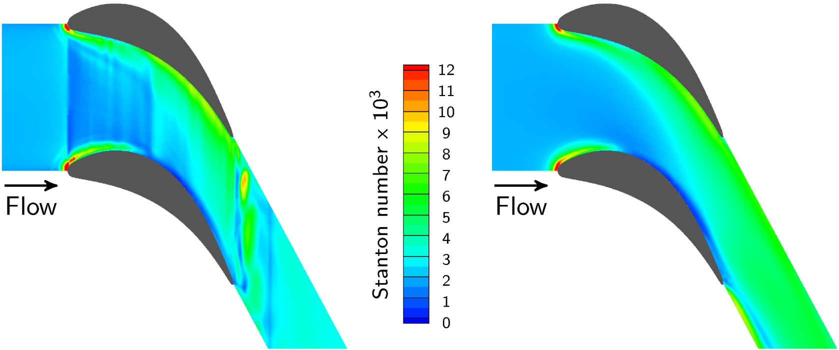


Final endwall contour



- Main feature: Elevation in middle of vane passage with height maximum at rear suction side
- Stanton number reduction of 12.3% compared to baseline case (flat endwall); total pressure loss increased by 0.8%

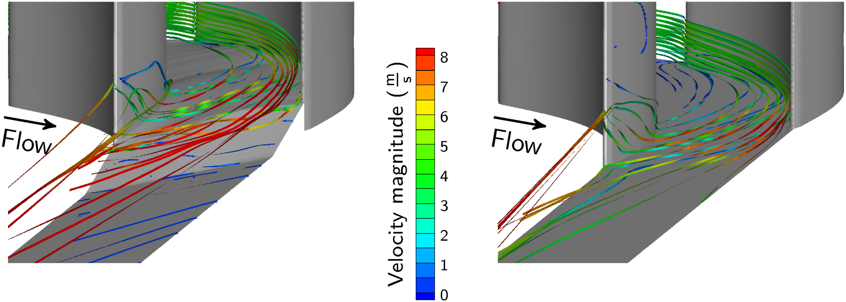
Endwall heat transfer



Contoured endwall   Flat endwall

- Heat transfer reduction in vane passage
- Heat transfer reduced downstream of trailing edges

Streamlines in vane passage

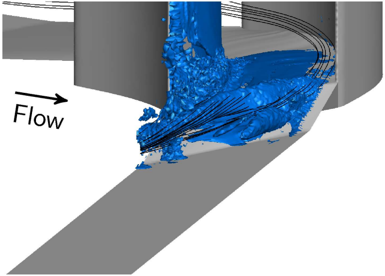


Contoured endwall

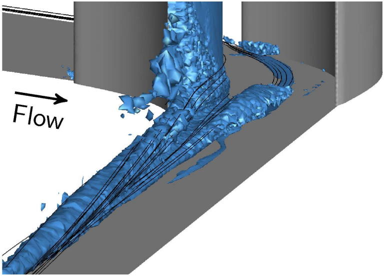
Flat endwall

- Flow guided closer to vane pressure side
- Turning of flow from pressure to suction side shifted towards exit of vane passage

Visualization of vortex cores



Contoured endwall



Flat endwall

- Turning of passage vortex delayed
- Passage vortex deflected towards next vane row

Conclusions

- Hybrid experimental and numerical optimization approach
- Numerical optimization combines three-dimensional CFD with genetic algorithm
- Novel endwall contour found which reduced Stanton number by 12.3%
- Turning of flow from pressure to suction side further downstream for contoured endwall than for flat endwall
- Passage vortex deflected towards next vane row for contoured endwall

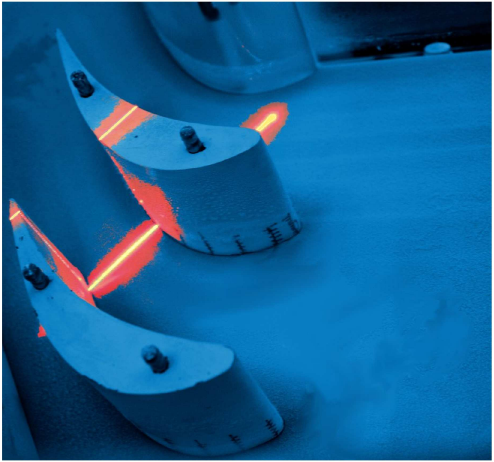
References

[1] Haase K., Winkler S., Weigand B., Neumann S.O. **Turbine Endwall Contouring Using a Hybrid Experimental and Numerical Optimization Approach**, Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition, IMECE2012-87430

[2] Takeishi K., Matsuura M., Aoki S. and Sato T., **An experimental study of heat transfer and film cooling on low aspect ratio turbine nozzles**, Journal of Turbomachinery, **112**(1), pp. 488-496, 1990

[3] Deb K., Pratap A., Agarwal S., Meyarivan T., **A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II**, Vol. 6 of IEEE Transactions on Evolutionary Computation, 2002

Thanks for your attention! Questions welcome.



Definitions

- Reynolds Number

$$Re_C = \frac{C u_{\text{ex}}}{\nu_\infty}$$

C	-	Vane chord length	ν_∞	-	Kinmatic viscosity of incident flow
u_{ex}	-	velocity at cascade exit			

- Area-averaged Stanton Number

$$\overline{St} = \frac{\overline{q''}}{\Delta T\, c_p\, \rho\, u_{PE}} \quad \text{with} \quad \overline{q''} = \frac{\int_{A_{EW}} q''\, dA_{EW}}{\int_{A_{EW}} dA_{EW}}$$

$\overline{q''}$	-	Specific heat flux	ρ	-	Density
ΔT	-	Temperature difference	A_{EW}	-	Area of endwall
c_p	-	Specific heat capacity			

Pictures Test Section