Analysis of the Hot Gas Ingress into the Wheel Space of an Axial Turbine Stage

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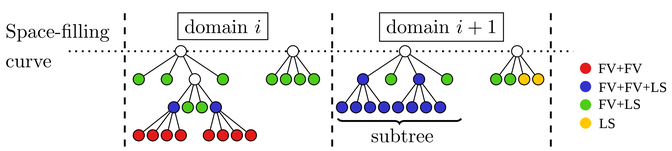
Motivation

- Investigation of hot gas ingress in a one-stage axial turbine with 30 stator and 62 rotor blades including the wheel space by large-eddy simulation (LES) and Reynolds-averaged Navier-Stokes equations (RANS).
- Analysis is focused on flow field around the rim seal and in the cavity between the stator and rotor disks for two cooling gas mass flow rates.
- Validate numerical results with experimental data by Bohn et al. [1]
- Develop an efficient zonal RANS/LES method to reduce the domain size of the computationally more expensive LES approach to the flow field around the rim seal and in the cavity between the stator and rotor disks to reduce overall computational costs.

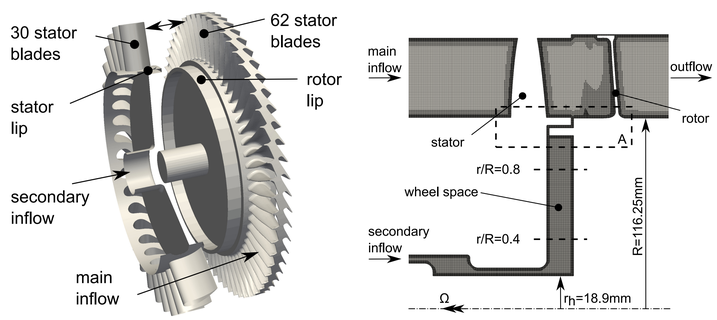
Computational Setup

Multi-physics simulation on subset of a shared hierarchical Cartesian base grid with:

- A semi-Lagrange level-set (LS) solver for rotating embedded moving boundaries.
- Multiple finite volume (FV) solvers to solve the compressible Navier-Stokes equations and Reynolds-averaged Navier-Stokes equations.
- Partition based on hierarchical Cartesian base grid ensures no MPI communication in cell value exchange in FV-FV and FV-LS coupling.



Domain decomposition of a quadtree multi-physics grid with cells used for discretization and coupling of multiple finite volume (FV) solvers and level-set (LS) solver.

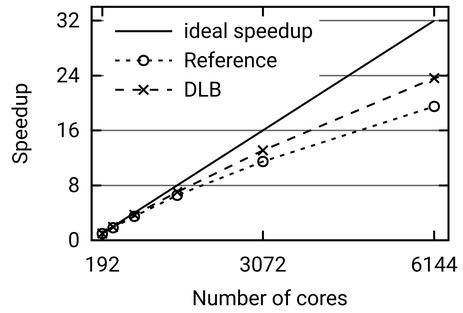


Dimensions and computational mesh in an axial plane of the full 360° axial turbine stage.

- Reduced computational setup based on a sector of the full 360° axial turbine geometry without considering the curvature of the turbine used to develop the FV-FV coupling necessary for zonal RANS/LES method.

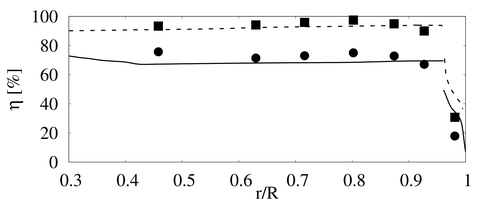
Computing Resources

- Average of 450 million FV-cells for full 360° simulation.
- Distributed over 64 nodes of the Hawk system, with 4096 cores used.
- 70 to 150 CPU hours of computing time per single rotation depending on the operating condition.
- Large load variations due to adaptive mesh refinement require dynamic load balancing [2].

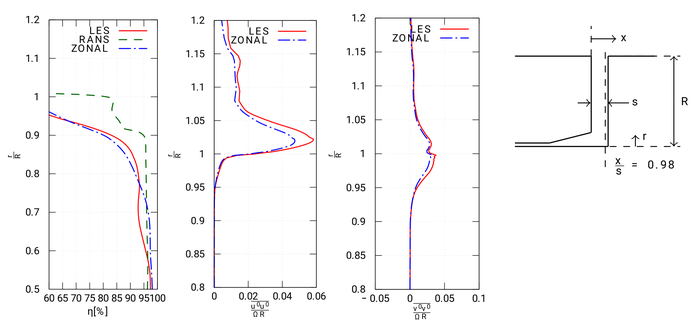


Scalability for a turbulent jet simulation using the DLB measurement with 192 cores as reference [2].

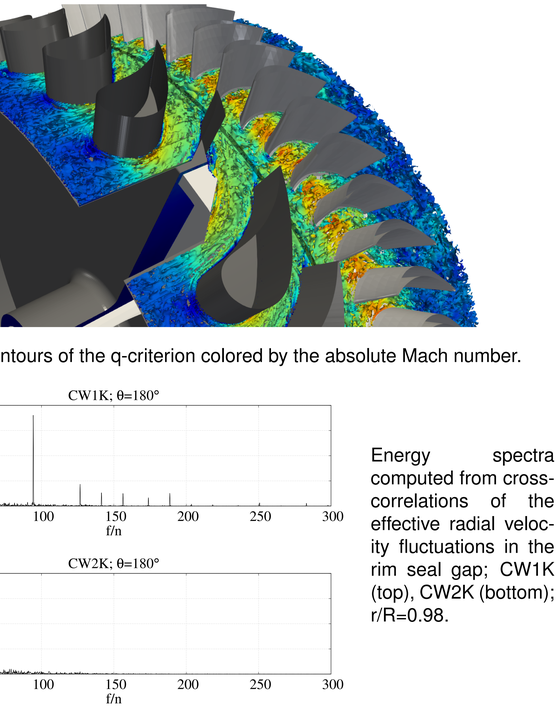
Results



Radial distribution of the time and azimuthally averaged cooling effectiveness; LES: CW1K $(-)$, CW2K $(- - -)$, exp. data [1]: CW1K (•), CW2K (▪).



Radial distributions of the cooling effectiveness η and the components of the Reynolds-Stress tensor $\overline{u'u'}$ and $\overline{v'v'}$ at the axial position $x/s = 0.98$.



Energy spectra computed from cross-correlations of the effective radial velocity fluctuations in the rim seal gap; CW1K (top), CW2K (bottom); r/R=0.98.

Conclusion

- The flow field in an axial turbine stage was predicted by LES for two cooling gas mass flow rates.
- Instantaneous results strongly depend on the cooling gas mass flow rate.
- For the lower cooling gas mass flux several of the wheel space harmonics are excited resulting in a reduced cooling effectiveness.
- Comparison of zonal approach with pure LES shows good agreement in instantaneous and time-averaged flow field.
- Zonal RANS/LES method will be used in future work to predict the hot gas ingress in axial turbines more efficiently.

References

1. Bohn, D. and Wolff, M. Entwicklung von Berechnungsansätzen zur Optimierung von Sperrgassystemen für Rotor/Stator-Kavitäten in Gasturbinen. (2001)
2. A. Niemöller, M. Schlottke-Lakemper, M. Meinke, W. Schröder. Dynamic load balancing for direct-coupled multiphysics simulations. *Computers a. Fluids 199(104437) (2020)*
3. T. Hösgen, M. Meinke, W. Schröder. Large-eddy simulations of rim seal flow in a one-stage axial turbine. *Journal of the Global Power and Propulsion Society 4, 309321 (2020)*