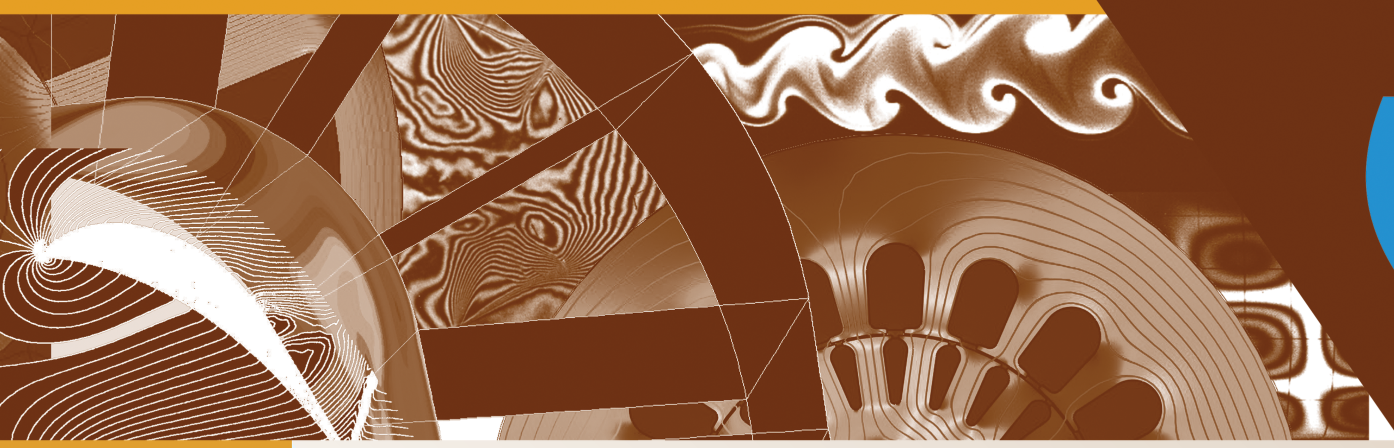

Institute of Thermomechanics
of the Czech Academy of Sciences

Department of Fluid Dynamics

SIMULATION OF SUPERSONIC FLOW THROUGH THE TIP-SECTION TURBINE BLADE CASCADE WITH A FLAT PROFILE

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Introduction

- Numerical simulation of 2D compressible flow through the tip-section turbine blade cascade
- OpenFOAM
- Favre-averaged Navier- Stokes equations completed by the two-equation SST turbulence model and the γ-Re$_\theta$ bypass transition model
- Study of relation between the inlet flow angle and the inlet Mach number
- Investigation of the effect of the shock-wave/boundary layer interaction on the skin friction coefficient
- Comparison with experimental data

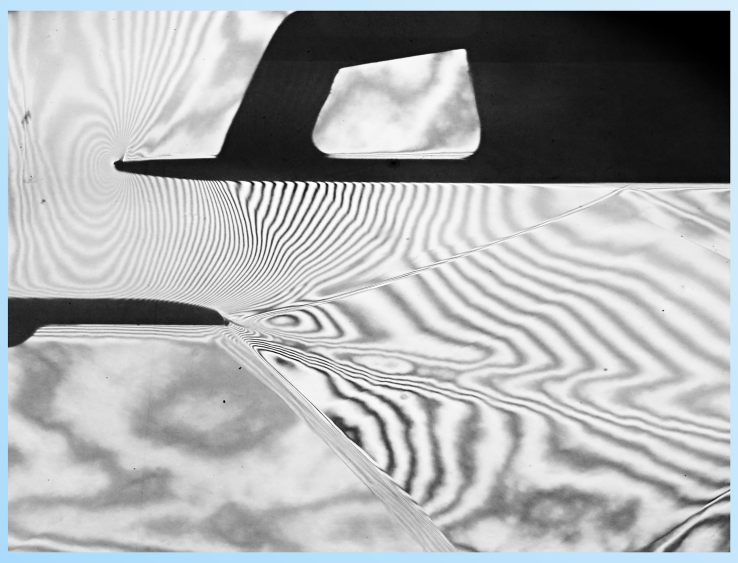
Mathematical model

- Finite volume method
- Favre-averaged Navier-Stokes equations with constitutive relations for ideal gas closed by heat-transfer model and γ-Re$_\theta$ bypass transition model (Langtry-Menter, 2009)
- LU-SGS numerical solver for turbulent compressible flows developed by Fürst, implemented in OpenFOAM package

Results

Measurements:

- Carried out in wind tunnel in Aerodynamic Laboratory in Nový Knín (Luxa and Šimurda, 2018)
- Optical and pressure measurements



Interferometric picture

Schlieren picture

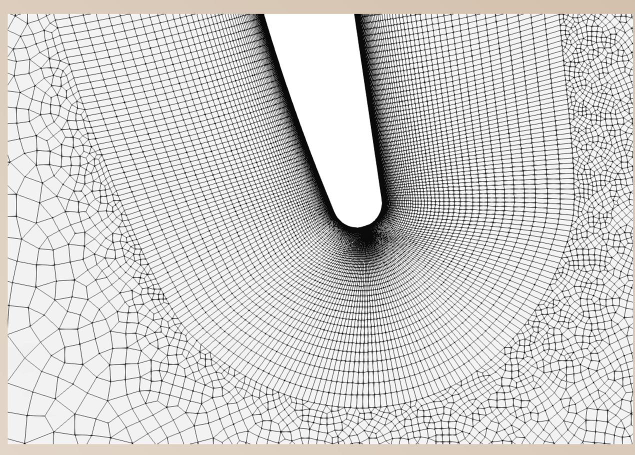
- Inlet Mach number: $M_1 = 1.2$
- Isentropic outlet Mach number: $M_{is} = 1.9$
- Reynolds number: $Re_{2is} = 1.96 \times 10^6$
- Free-stream turbulence intensity: $Tu \sim 1.5\%$

Numerical simulation:

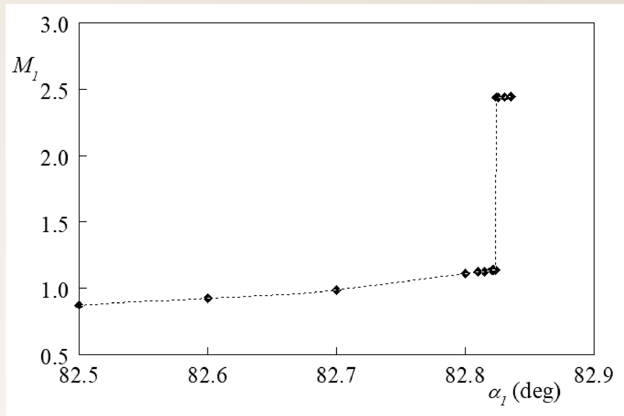
- "Standard" OpenFOAM solvers are unstable and inefficient for this flow regime.
- Problematic adjustment of flow conditions upstream the blade cascade because of definite link between the inlet Mach number and the inlet flow angle.
- The inlet Mach number is very sensitive to small changes of the inlet angle to the $\alpha_1 = 82.825°$ with a substantial change of the structure of shock waves upstream of the blade cascade.
- The study is carried for $\alpha_1 = 82.82°$, the corresponding inlet Mach number $M_1 = 1.135$ and the isentropic outlet Mach number $M_{2is} = 1.796$.

Computational mesh:

- Consists of $\sim$ 180 000 cells
- Nearest node from the wall: $y^+ \sim 0.8$
- One turbine blade, periodic boundaries
- Extended inlet part to reduce shock waves reflection

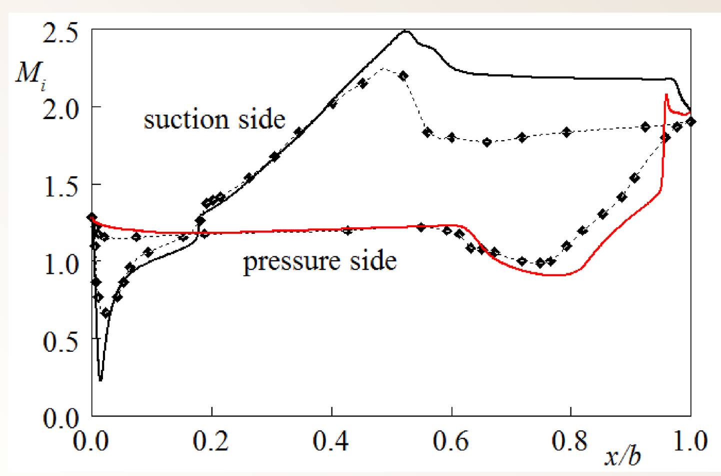


Detail of computational mesh

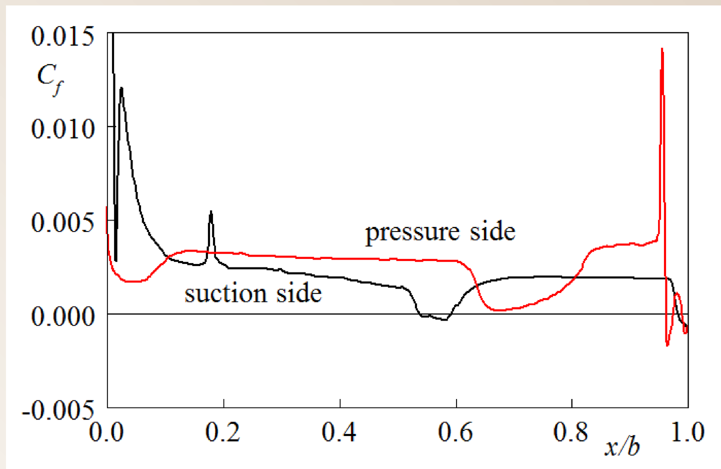


Dependence of the inlet Mach number on the inlet flow angle.

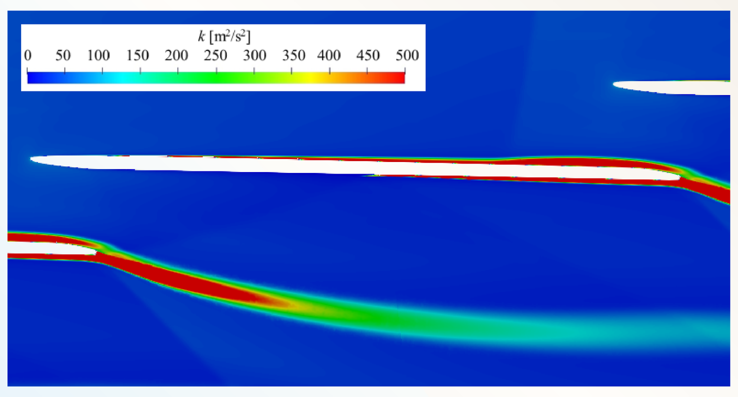
- Unstable flow regime in the vicinity of $\alpha_1 = 82.82°$
- Flow separation with transition to turbulence at $x/b \sim 0.5$
- Sudden change in surface curvature at $x/b \sim 0.19$ results in sharp increase of C_f



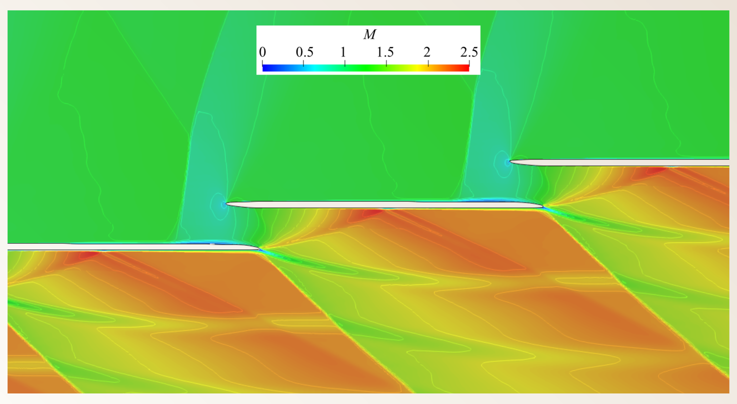
Distribution of the isentropic Mach number on the turbine blade



Distribution of the skin friction coefficient on the turbine blade



Field of the turbulent kinetic energy



Mach number isolines in the blade cascade

Conclusions

- The two-equation SST turbulence model with the $\gamma - Re_\theta$ bypass transition model was used for the simulation of supersonic flow through the turbine blade cascade TR-U-8 corresponding to the tip-section of the rotor blade cascade.
- Predictions carried out for the nominal conditions were concentrated on the adjustment of corresponding inlet conditions i.e. the inlet Mach number and the inlet flow angle upstream of the plane of leading edges due to supersonic inlet.
- Further the attention was given particularly to the numerical simulation of the shock-wave/boundary-layer interaction which in case of the laminar boundary layer usually leads to flow separation followed by the transition in separated flow. Therefore the effect of the shock-wave/boundary layer interaction on the skin friction coefficient was studied.
- Numerical results correspond to experimental data acceptably with the exception of the zone of the shock-wave/boundary-layer interaction on the blade suction side with the transition in separated flow because of the non-stationary character of the interaction.

Acknowledgement

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