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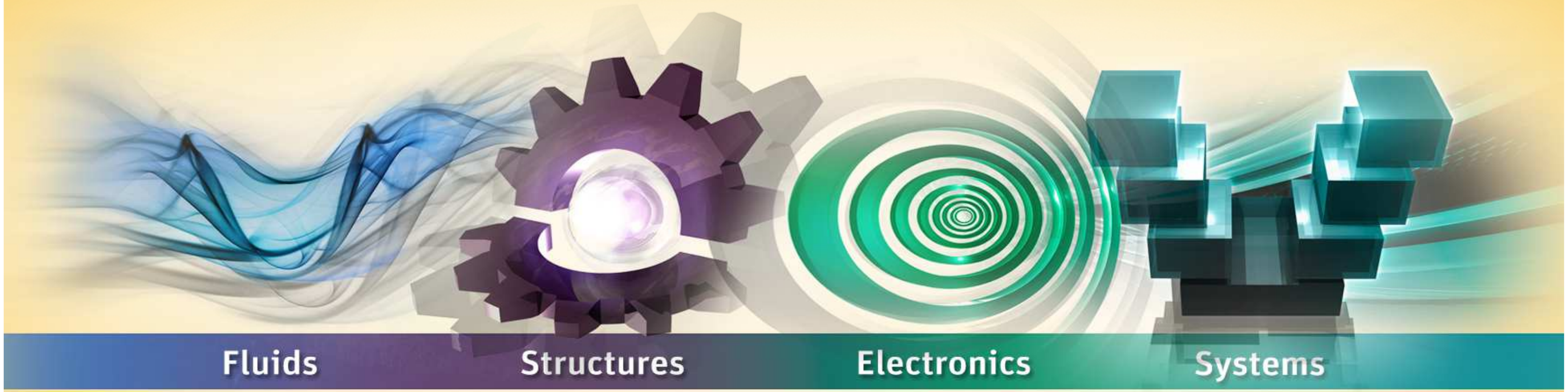
LES Simulation of Turbulent Flow and Heat Transfer in Cavities of a Heat Sink



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Presentation ACUM 2014, Nürnberg, 03.06.2014

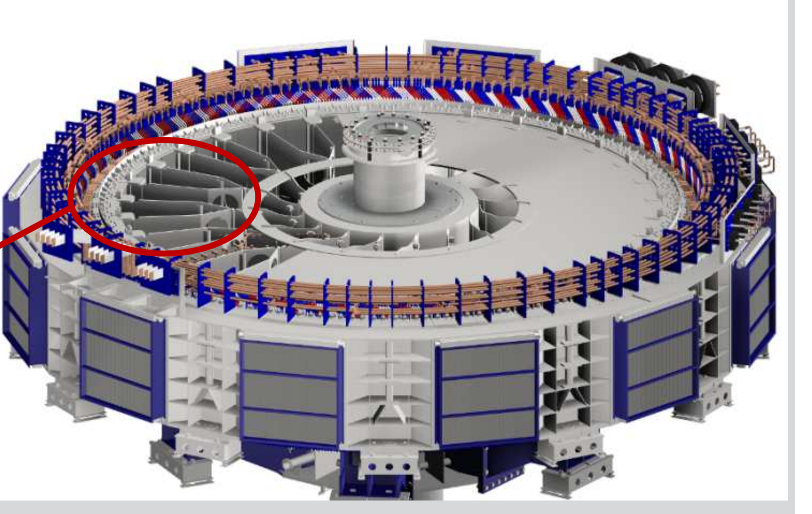
Generator in Hydro Power Plant

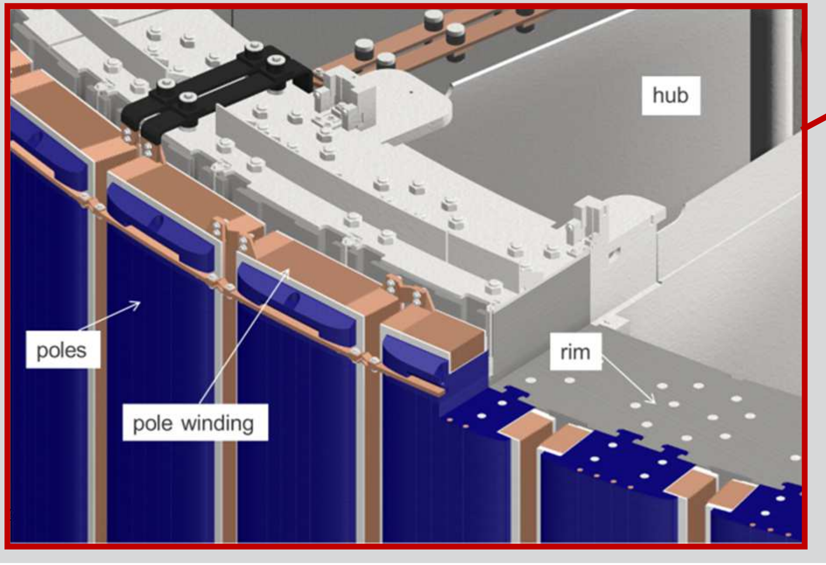
- **High electric current**
- **Ohmic resistance**

→ Heat generation in pole windings

→ Pole windings on rotor are cooled with air to guarantee thermal stability of the material

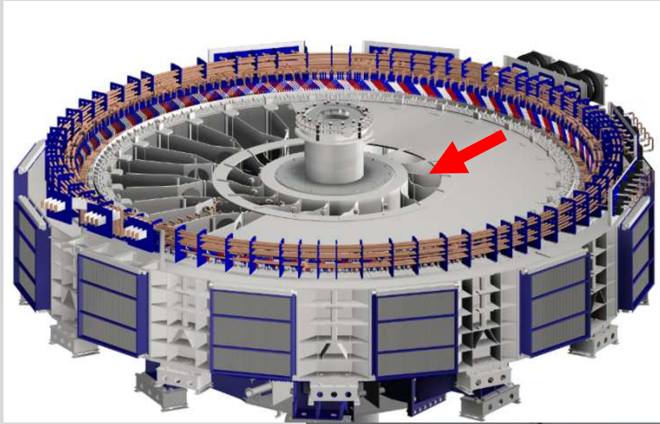
http://www.voith.com/de/s2_vh_peixe_large_hydro.png

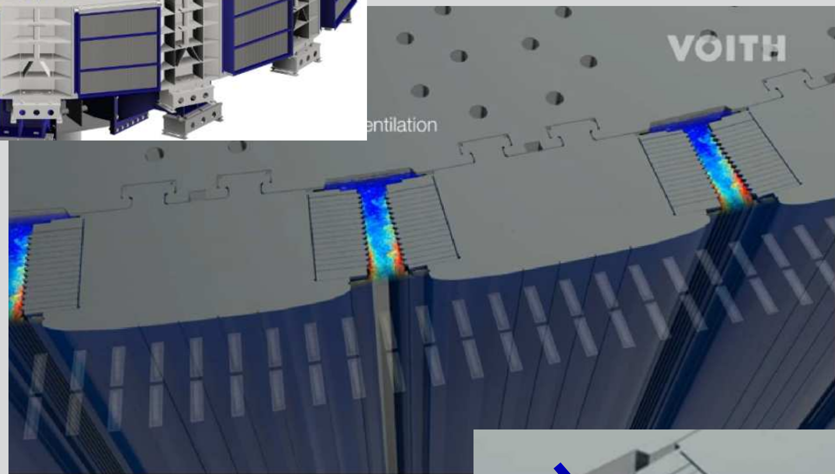




Cooling via Convection

- „RIM-ventilation“ is the preferred ventilation method for large salient poles hydro generators

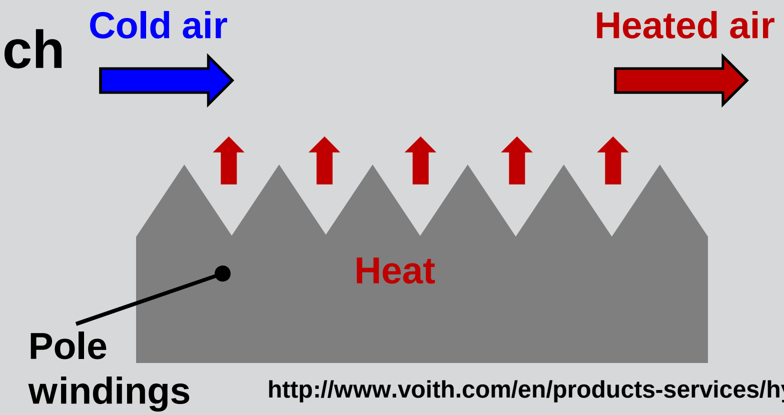


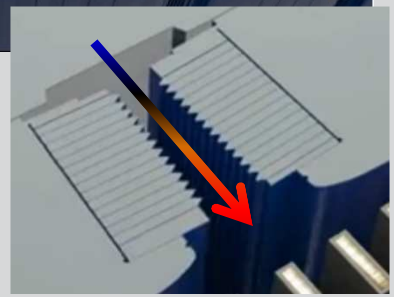


- Rotor hub acts like a centrifugal pump transporting air radially outwards

→ Air is channeled along the pole windings, which are thereby cooled via convection

→ Compliance of the temperature limit (insulation material)





http://www.voith.com/en/products-services/hydro-power/generators-557.html

I	Test case description
II	Objectives
III	Precursor investigations
IV	Modeling
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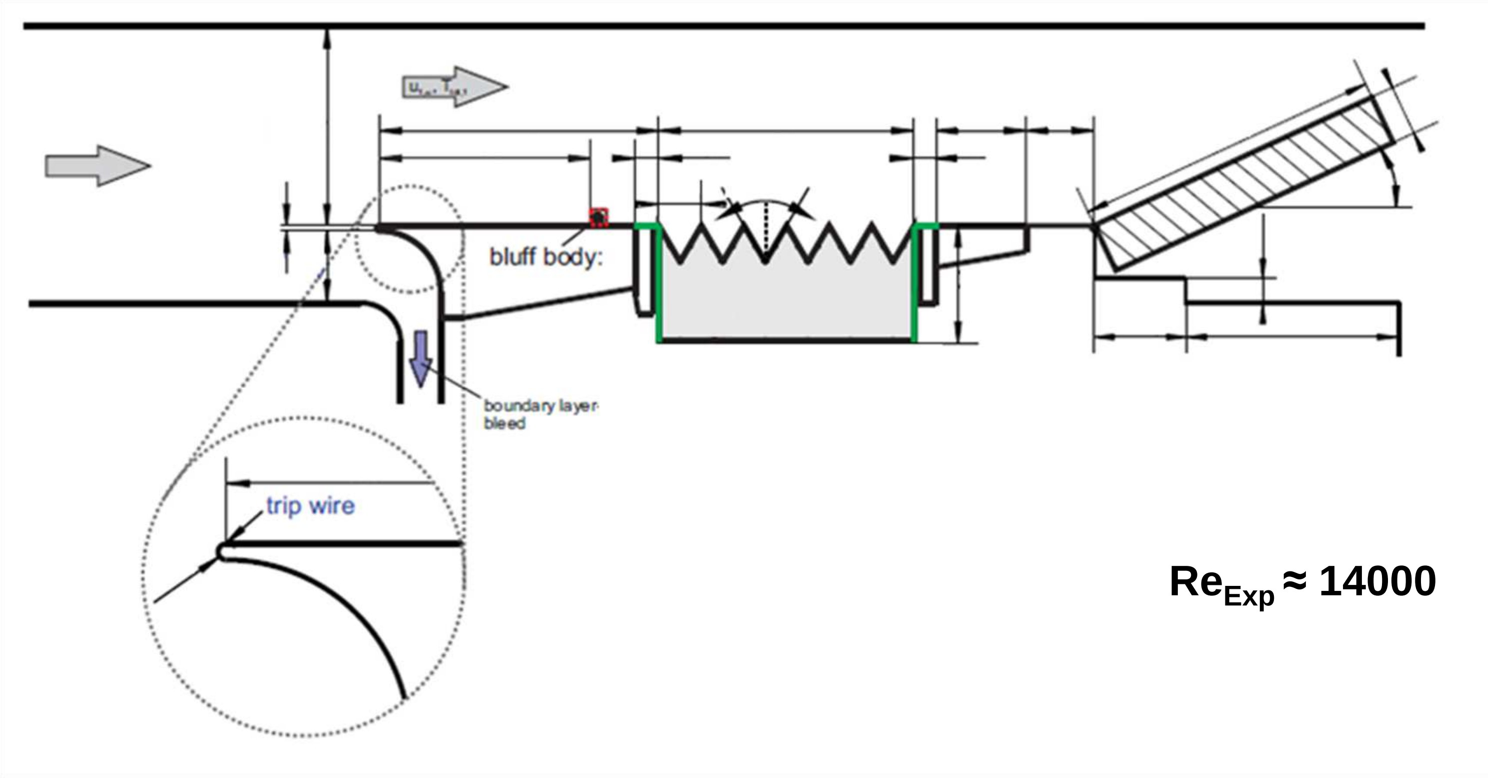
Test Case Description

- **Numerical investigation of the air flow around pole windings**
  → Use of simplified, scaled and generic geometry
- **Hot air flows around a cuboid and is then cooled via convection in six cavities**
- **Experimental data from wind tunnel measurements are basis for investigation and comparison with CFD simulation results**



$Re_{Exp} \approx 14000$

Objectives

- **Numerical prediction of the cooling process: aerodynamic + thermodynamic / heat transfer in cavities**

  →Gain deeper understanding of pole winding cooling process (e.g. influence of turbulence and its modeling)

  →Optimisation of convective cooling process

  →Reduce risk of cooling issues

  →Higher utilization factor in the generator with positive impact on overall plant construction costs

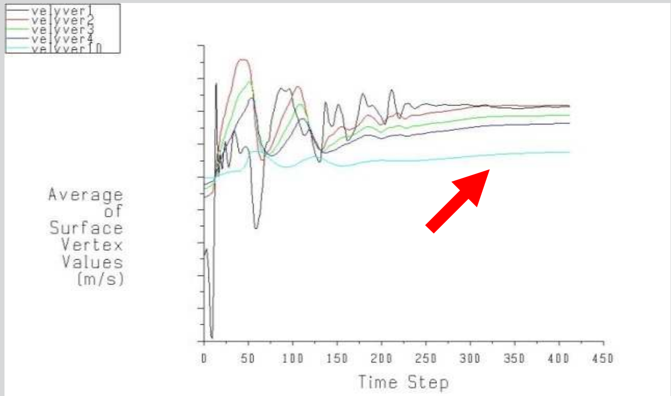
- **Validation / applicability study of scale-resolving turbulence models**

http://www.voith.com/de/s1_vh_motor_generator.png

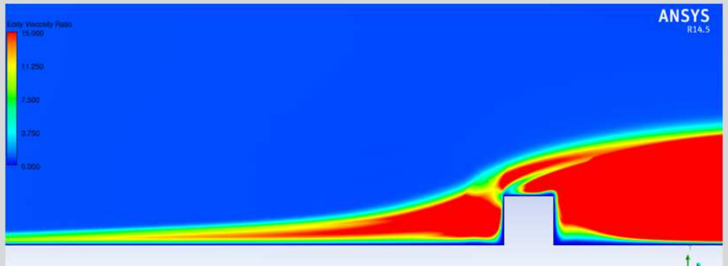
Precursor Investigations

- Suitable turbulence model?
- RANS → Differences in velocity magnitude and turb. kinetic energy in comparison to the experimental data
- SAS → Fallback in stationary solution
- Hybrid formulation - DES/DDES
  → Missing clear spatial seperation of RANS/LES zone causes unphysical flow around cuboid

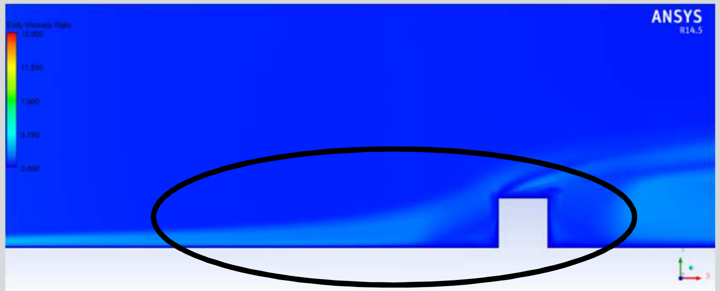
→ Turbulence modeling with LES



Monitors of instantaneous SAS velocity values



URANS : Eddy viscosity ratio



DES/DDES: Eddy viscosity ratio
→ no RANS boundary layer shielding visible

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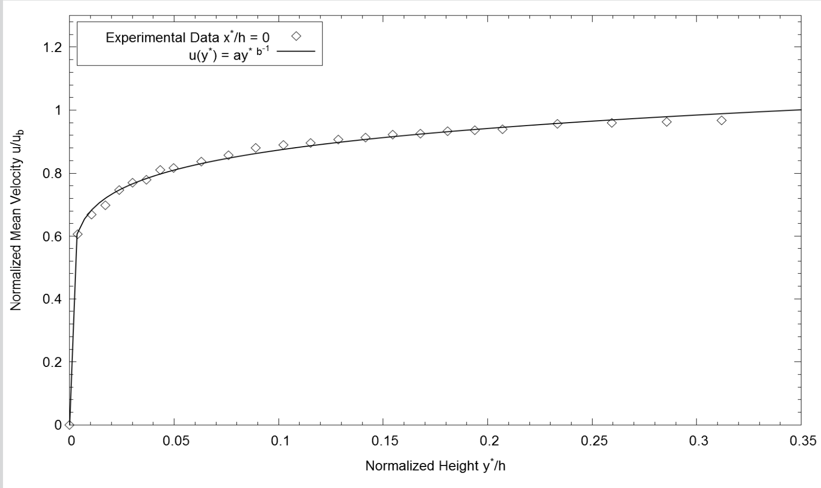
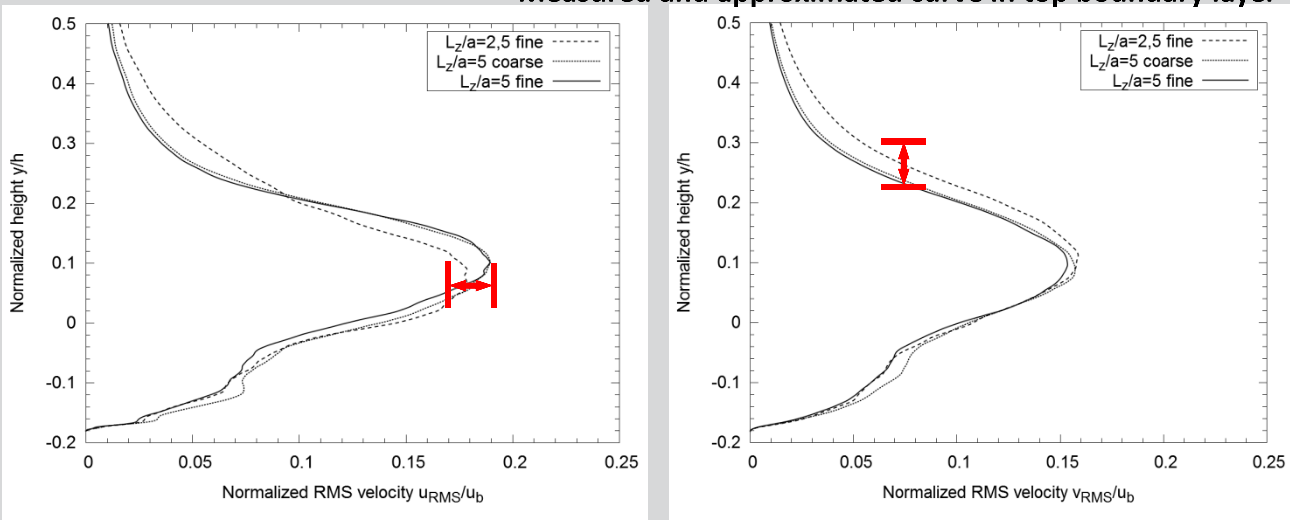
Precursor Investigations

- **Influence of upper boundary layer?**
  → displacement thickness δ^*_{top}:
  $\delta^*_{top}/h = 0{,}02$
  → Neglection



Measured and approximated curve in top boundary layer

- **Necessary lateral extension L_z (periodicity) of the solution domain and suitable lateral grid resolution Δz compared to cuboid edge length a?**
  → $L_z/a = 5$,
  fine : $\Delta z/a = 1/24$

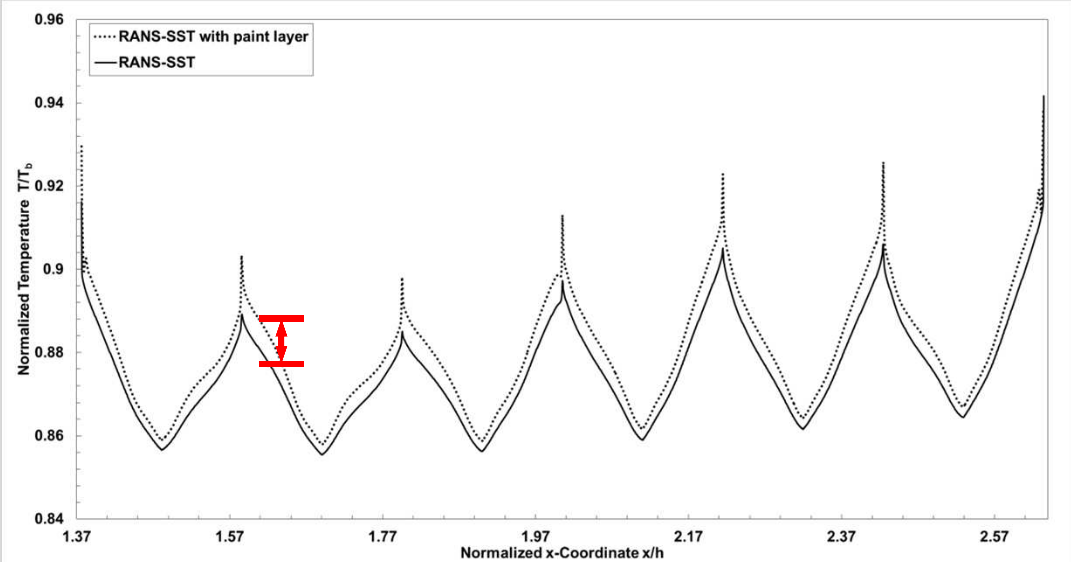


Comparison of velocity fluctuations in 6th cavity generated by different combinations of lateral domain size and lateral grid resolution

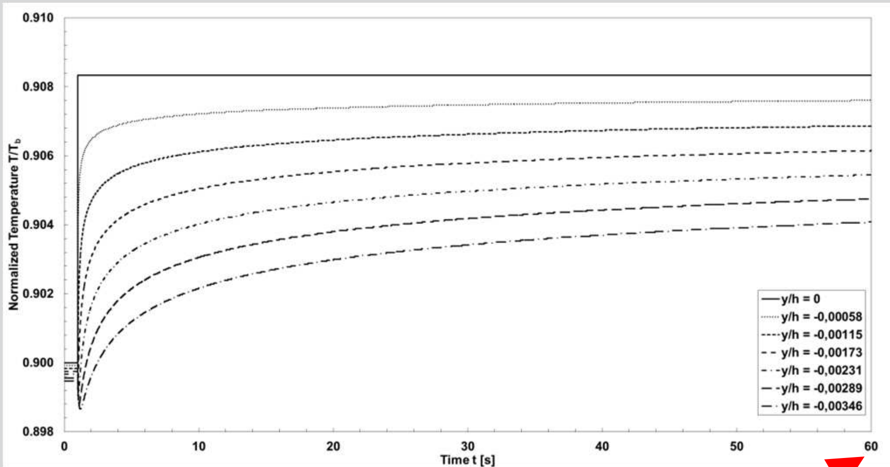
Precursor Investigations

- **Influence of the paint layer on the heat sink surface? (infrared measurements)**

  → Consideration



- **Initial temperature in the heat sink?**
  →I . Splited LES (only aerodynamic) and RANS (aero- and thermo-dynamics) to generate initial conditions
  →II. Final LES (aero- und thermodynamics)



Simplified 1D approach gives an idea of heat transfer time scale in cooling body

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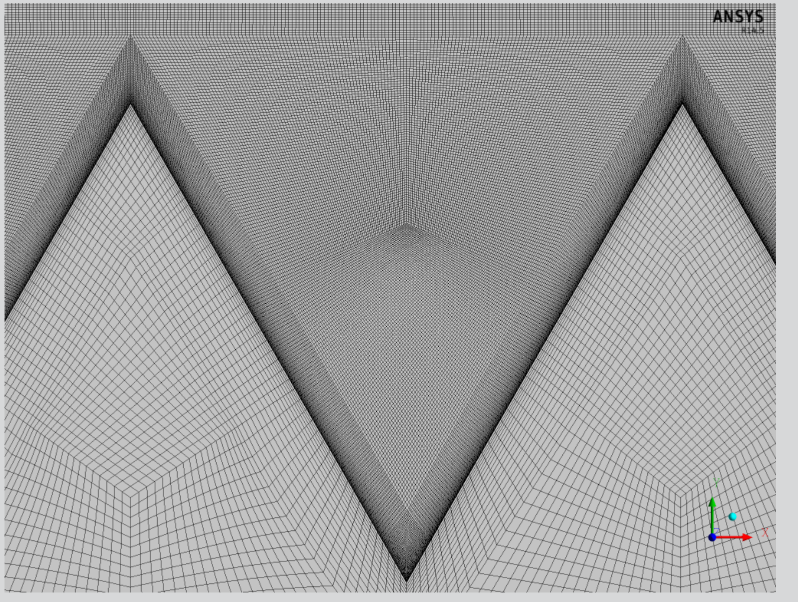
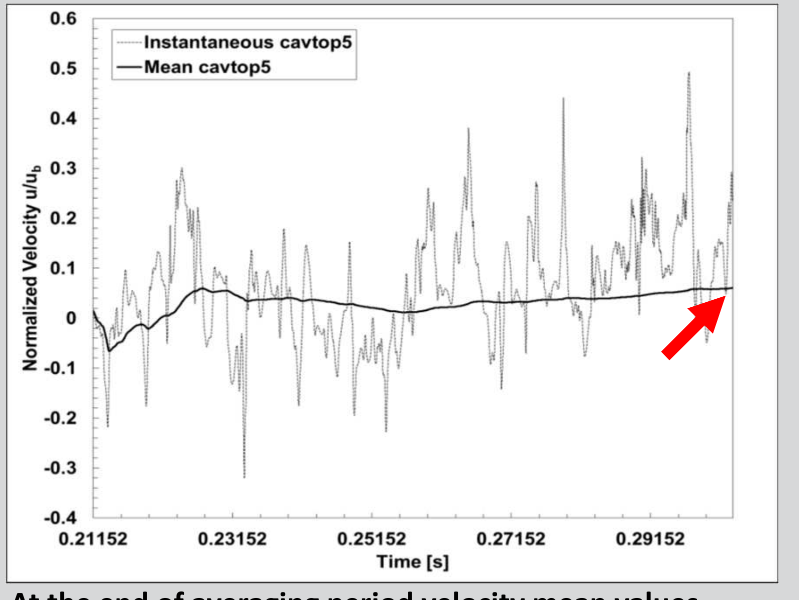
Modeling

- **Subgrid model:** **WALE**
- **Number of cells:** **85 Mill.**
- **Time step:** **$\Delta t = 2 \cdot 10^{-5}$ s**
  → CFL ≈ 2
- **Convergence criteria (RMS residuals):** **$< 6 \cdot 10^{-5}$**
- **Calculation time:** **0,54 s**
- **Averaging time:** **0,16 s**





At the end of averaging period velocity mean values still have small gradients in time

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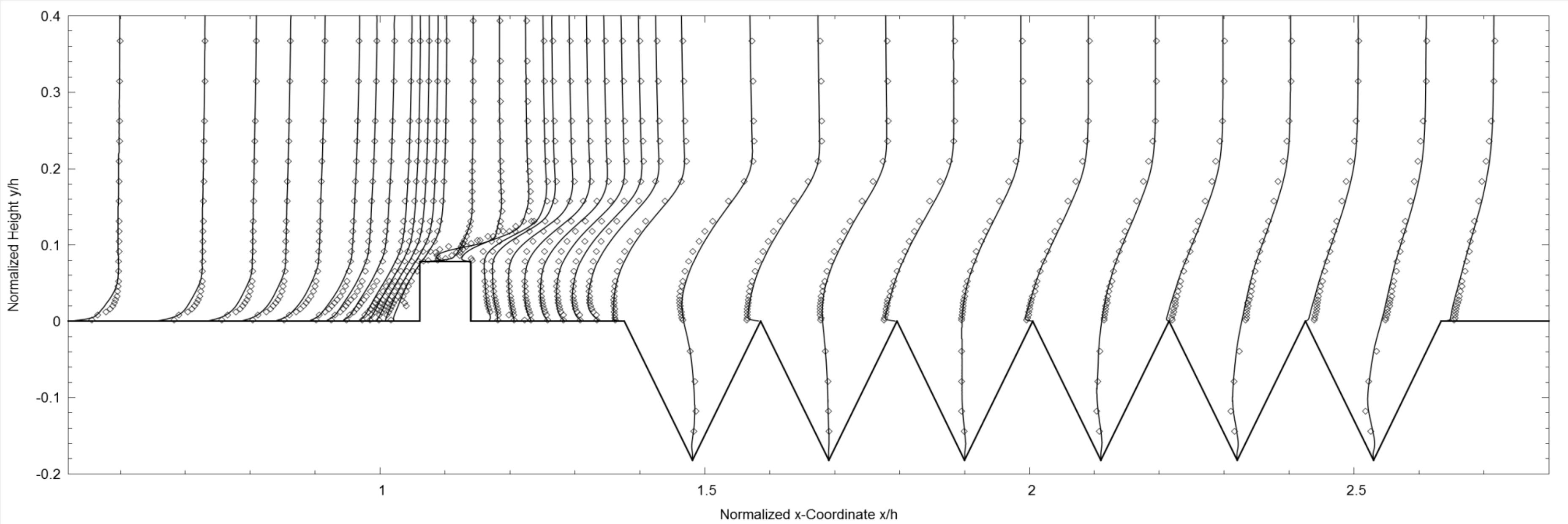
Results

- **The global flow pattern**
  Comparison of the mean velocity profiles $u(y)/u_b$ of :
  ◇ - the experiment
  — - the LES result



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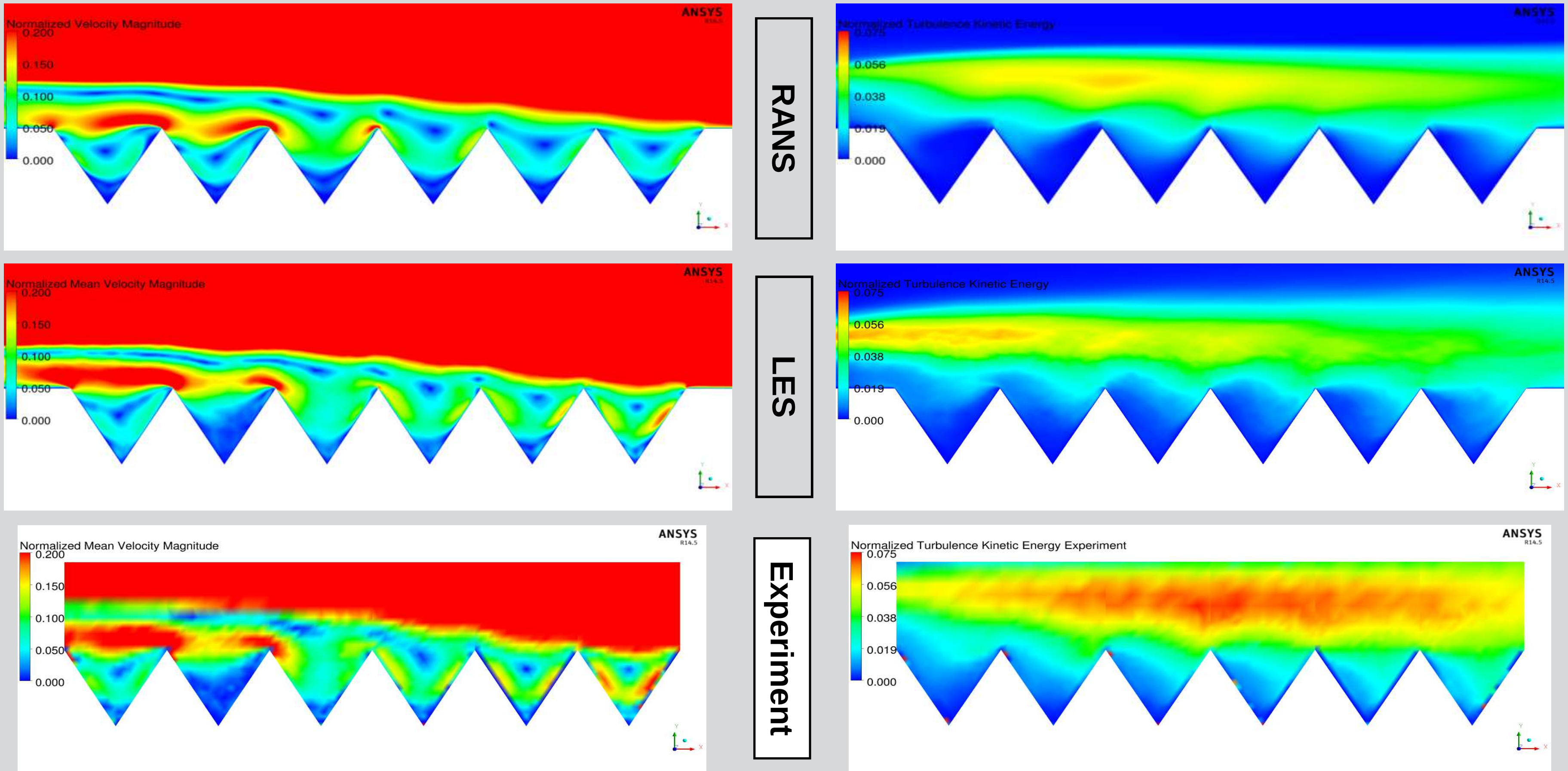
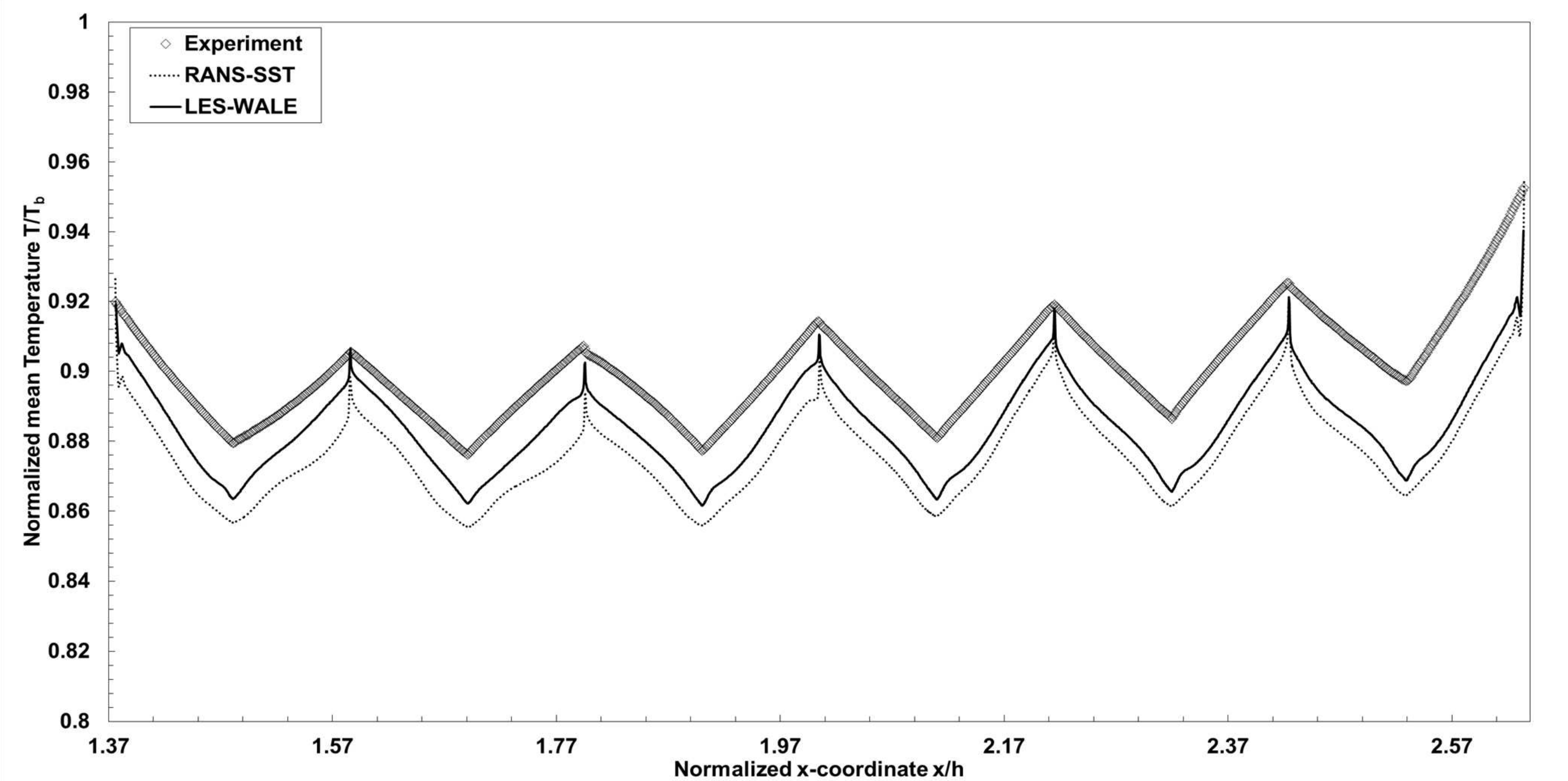
Results

- **Mid plane**
  Comparison of the normalized mean velocity magnitude $|\vec{u}|/u_b$ (left) and the normalized turbulence kinetic energy $k/{u_b}^2$ (right)



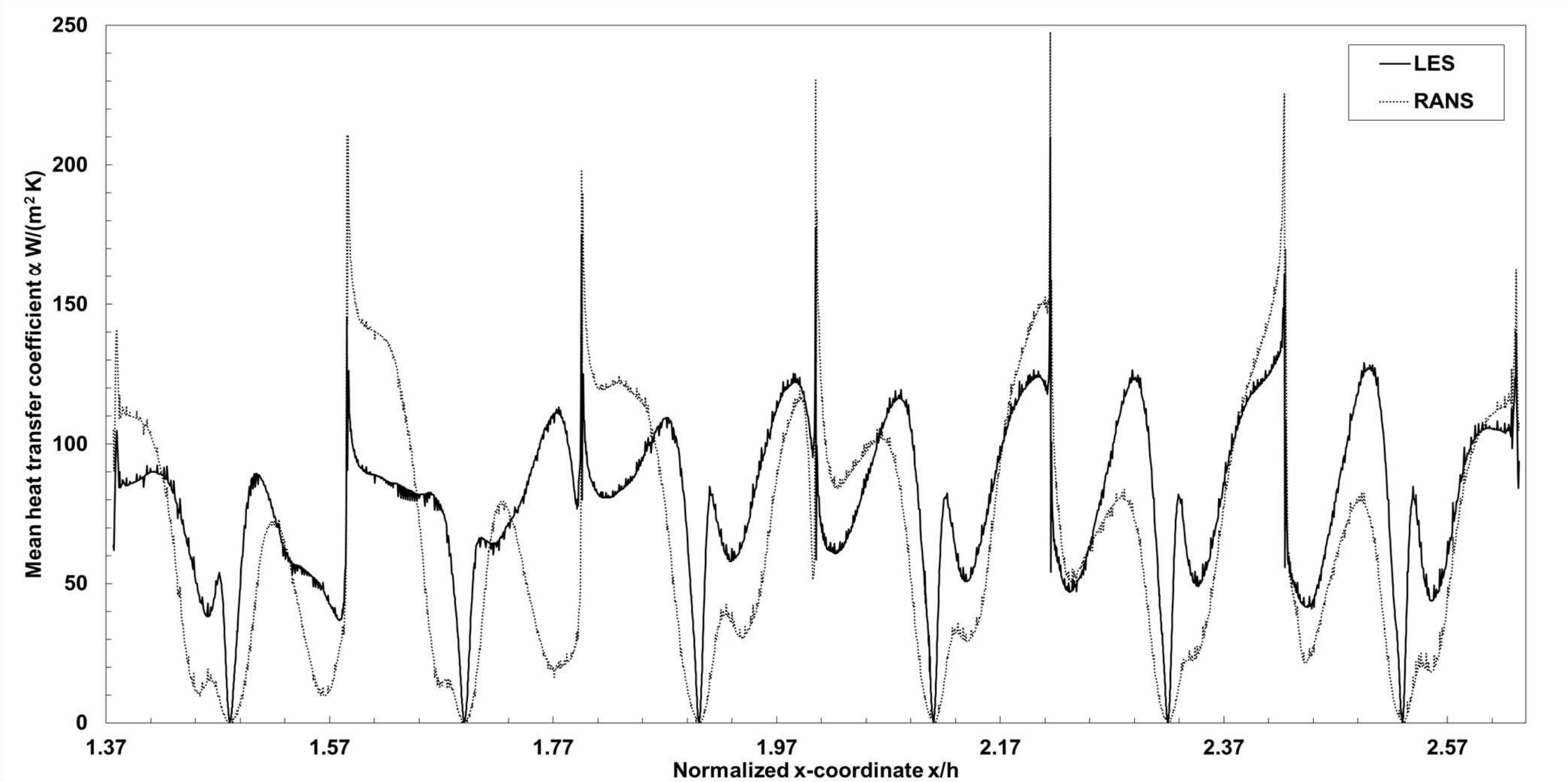
Results

- **Surface of the heat sink cavities**
  Comparison of the normalized mean temperature T/T_b
  (LES temperatures not yet in 100% thermal equilibrium due to very different LES & CHT time scales)



Results

- **Surface of the heat sink cavities**
  Comparison of the mean heat transfer coefficient α



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Conclusion

- Qualitatively good agreement of the velocity profiles, quantitatively especially in the surrounding of the cuboid
- Agreement of stationary surface temperature

- Differences in boundary layer curve in front of the cuboid
- Systematic deviation of the velocity and turbulent kinetic energy in the free shear layer / mixing layer
- Not yet stationary heat flux in LES computation
- No fully statistically reliable mean values and fluctuations due to very different time scales of LES and CHT

- Evaluation is difficult due to the underlying experimental uncertainties

→ LES modeling extremely expensive and has led so far to only moderate improvement in results accuracy in comparison to RANS modeling

Outlook

- **Extensive monitoring of LES/CHT required**
- **Two-point correlations → Lateral domain extension sufficiently large ?**
- **Time step reduction**
  → CFL ≤ 1
- **Larger averaging period and total CFD simulation time**
  → More reliable statistical flow averaging
  → Consideration of low frequency turbulence events
  → Stationary mean heat flux possible?
  → Influence of 3d secondary flows in wind tunnel?
  → Influence of neglected free-stream turbulence at inlet boundary condition of ELES domain (free-stream turb. kin. energy $k/u_b^2<0.001$)?
- **Decoupling of flow and heat transfer calculation by an external manual iteration loop between LES and CHT**
  → Acceleration in reaching a thermal steady state?
- **Reliable experimental data are essential**

The investigation was supervised and supported by:

Thomas Frank	(ANSYS Germany GmbH, Otterfing)
Florian Menter	(ANSYS Germany GmbH, Otterfing)
Bastian Vogt	(Voith Hydro Holding GmbH & Co. KG, Heidenheim)
Thomas Scherer	(Voith Hydro Holding GmbH & Co. KG, Heidenheim)