Universität Rostock

Traditio et Innovatio

Hybrid RANS-LES method for investigation of local flow structures and heat transfer on structured surface

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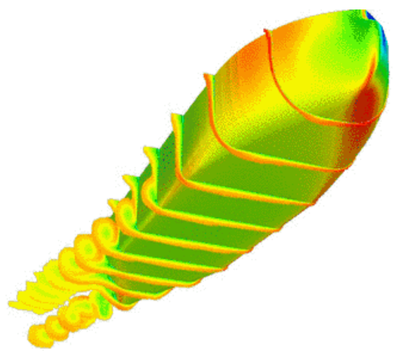
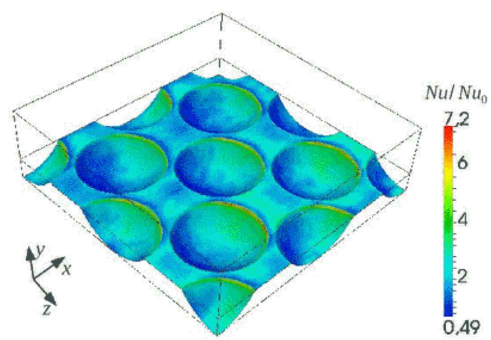
Chair of Modeling and Simulation

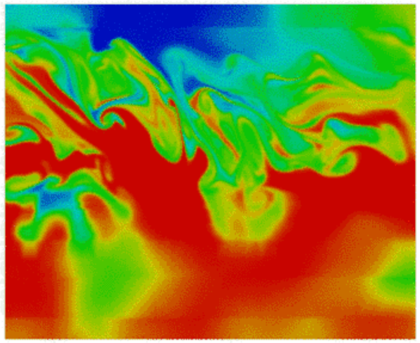
Institute of Modeling and Simulation (LEMOS)

- founded in October 2010
- started with 3 scientists, today: 10 PhD students and 2 PostDocs
- main fields of research:

Shiphydrodynamics	Thermo-Fluid-Dynamics	Mixing with chem. Reactions



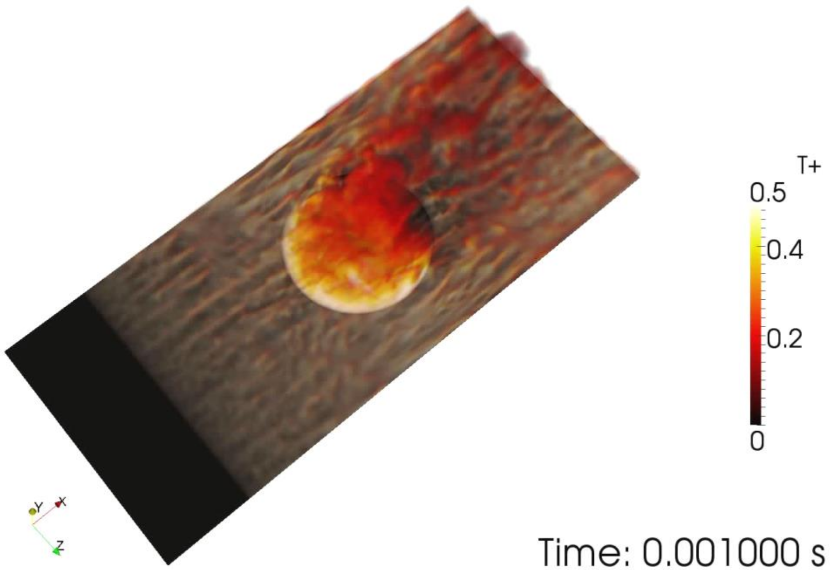


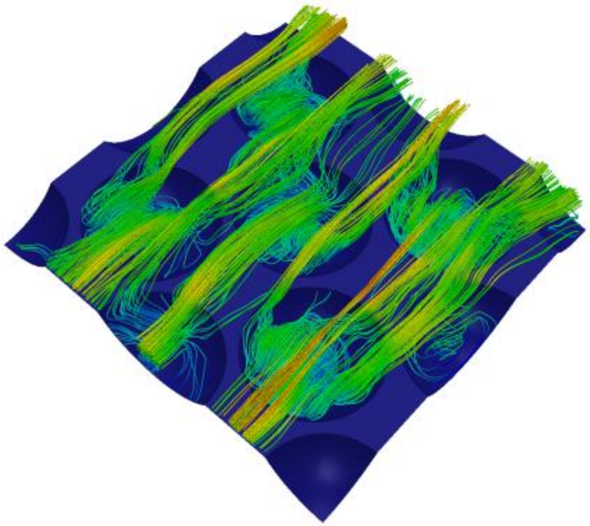


- Hardware:
  - HPC „Neptun“ 2700 cores
  - HPC „Titan“ 3800 cores (2016)

Heat exchanger – using dimples

- using dimples to reduce resistance and enhance heat transfer in heat exchangers, turbine blades, …
- numerical and experimental investigations including surface optimization on flow structures and heat transfer





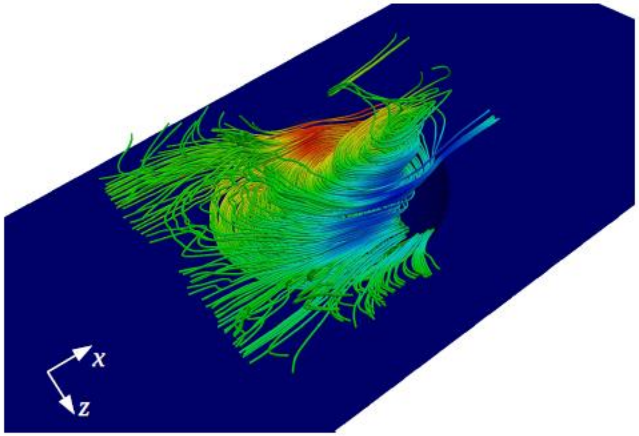
$(t/D = 0.26)$

Dimples

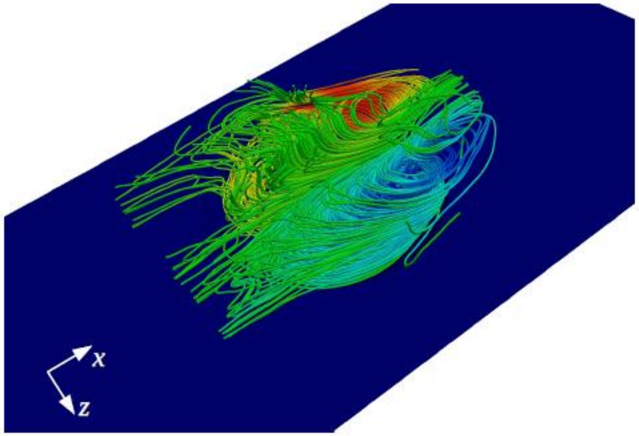
- Proper Orthogonal Decomposition (POD)

$$u_i(\mathbf{x}, t) = \sum_{n=1}^{N} a^{(n)}(t)\Phi_i^{(n)}(\mathbf{x})$$

- Analysis shows energetic relevant structures
- Transport of fluid out of the dimple characterized by tornado-like structures



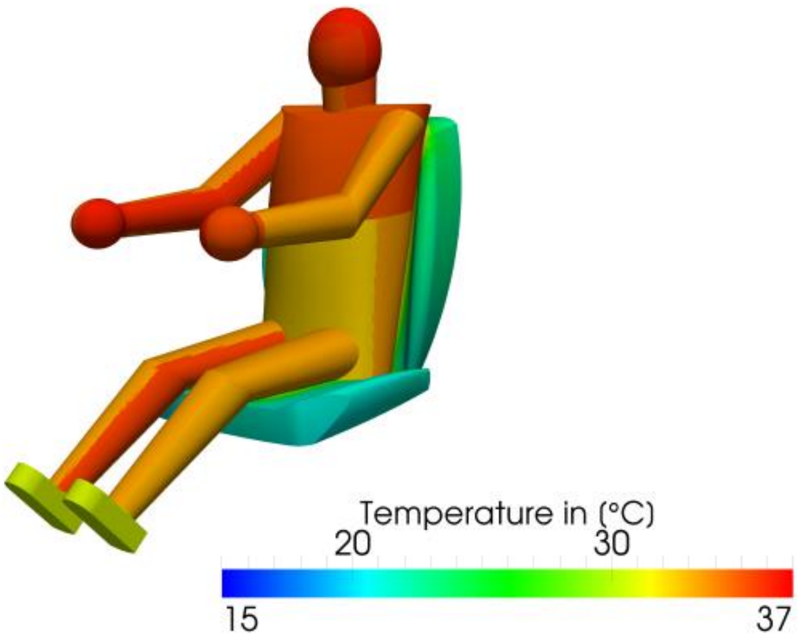
(a) $\Phi_u^{(1)}$

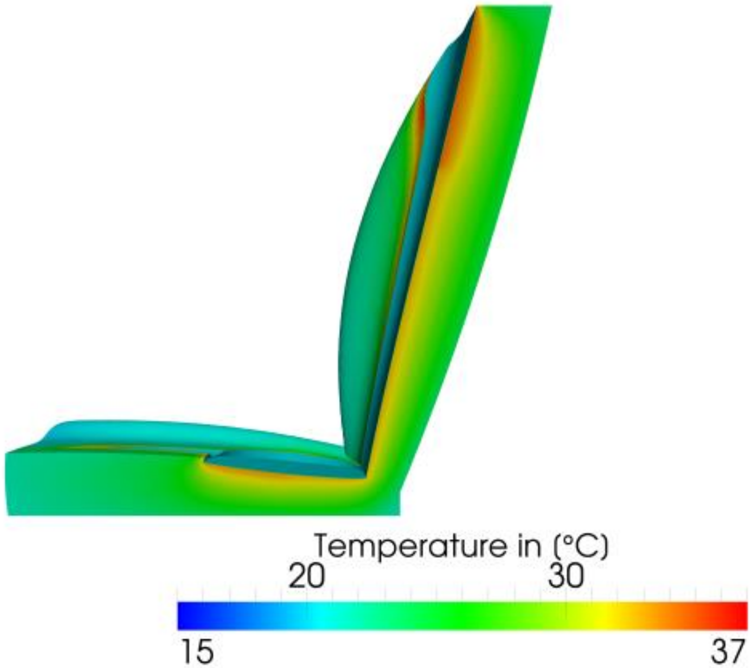


(b) $\Phi_u^{(2)}$

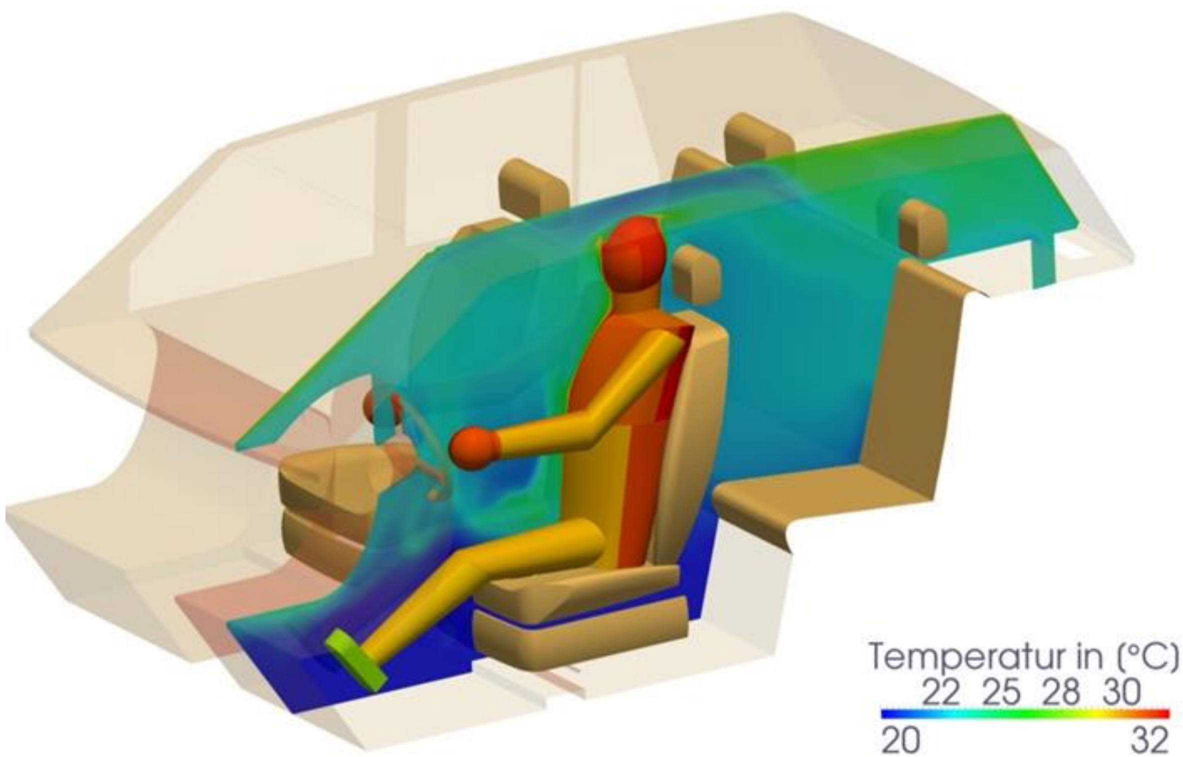
Thermal comfort in a car cabin

- temperature at the human body and temperature profiles within the seat (heat conduction)
- assuming ideal contact
- calculation of heat flux through CHT method





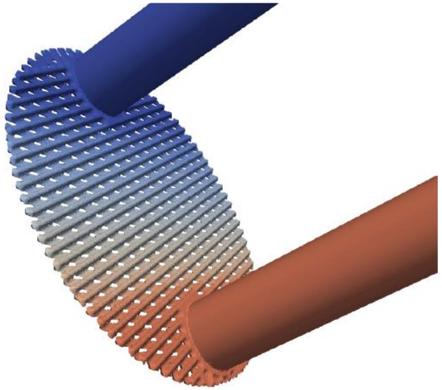
Thermal comfort in a car cabin



- in summary using shear stresses, sector integrated heat fluxes and humidity → local comfort index (Fanger, Zhang)

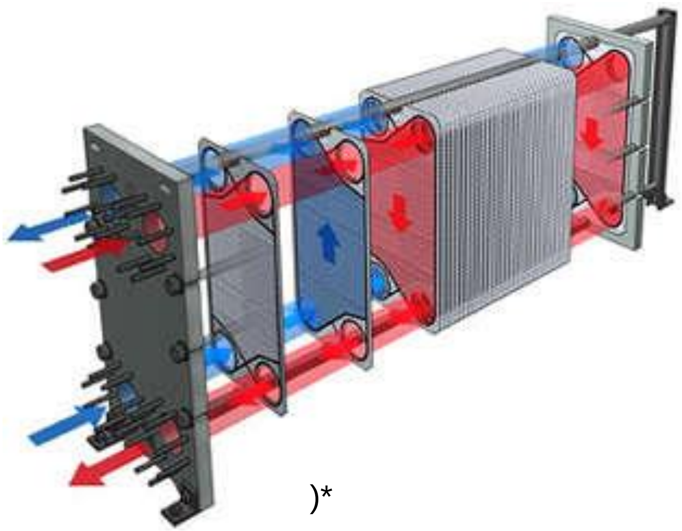
Hybrid RANS-LES method for investigation of local flow structures and heat transfer on structured surface

Outline



1. **Motivation / Introduction**
2. **Numerical methods**
3. **Heat transfer / pressure loss / Vortex structures**
4. **Summary / Outlook**

Plate-and-Shell heat exchanger (PHE)



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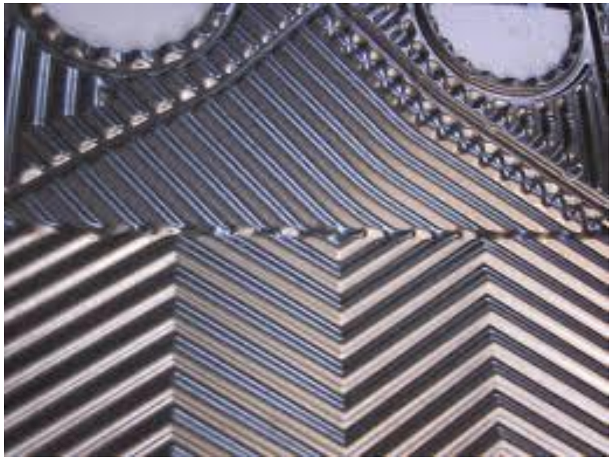
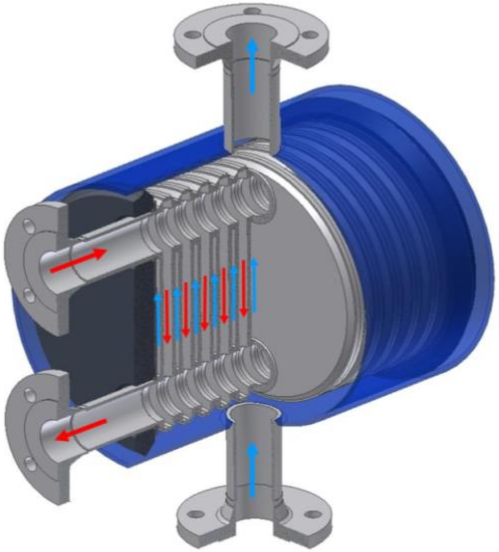


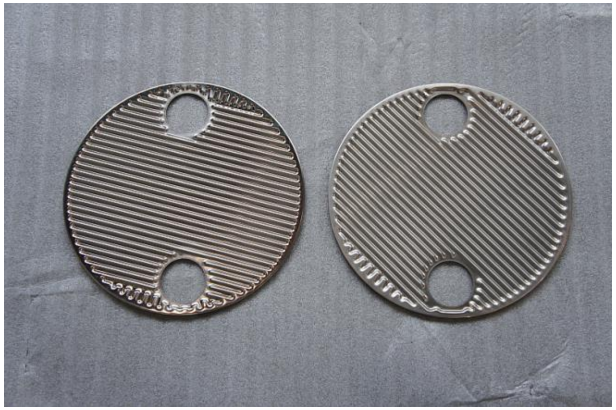
- Standard: rectangular shape
  - simple, robust
  - homogeneity of flow
- Defined surface patterns enhance mixing processes to increase heat transfer rates

) http://www.amos.de*

Plate-and-Shell heat exchanger (PHE)

- object of interest:
  - **circular PHE**





- properties:
  - robust, simple
  - no sealing needed due laser welding
  - ensures an uniform pressure distribution at the outer walls
  - flow homogeneity can *not* be ensured

LEMOS Hybrid LES/RANS

- influence of unsteady loads
- Using RANS in the boundary layer → heat fluxes for higher Prandtl numbers are captured
- basis of calculation: hybrid LES-RANS Model

$$\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial(\overline{u}_i \overline{u}_j)}{\partial x_j} = -\frac{\partial \overline{p}^*}{\partial x_i} + \frac{\partial(\tau^l_{ij} + \tau^t_{ij})}{\partial x_j}$$

$$L = C \cdot k^{3/2}/\varepsilon$$

$$\Delta = \sqrt{0.5(d^2_{\max} + \delta^2)},\ \ d_{\max} = \max(d_x, d_y, d_z),\ \ \delta = (\text{the cell volume})^{\frac{1}{3}}$$

$$\Downarrow$$

- $L > \Delta \rightarrow$ the cell is in LES area.
- $L < \Delta \rightarrow$ the cell is in URANS area.

LEMOS Hybrid LES/RANS

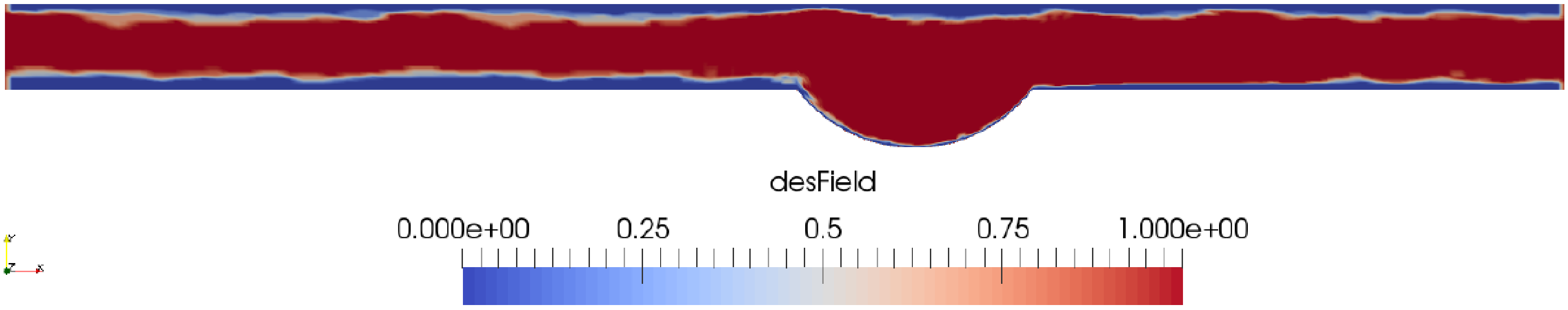
- Calculation of turbulent stresses according to selected region
- LES: $\Longrightarrow \nu = \nu_{SGS} = C_D \delta^2 |S_{ij}|, \quad S_{ij} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)$
- RANS: $\Longrightarrow \nu = \nu_{t,\ \kappa-\omega-SST}$
- Smoothing function between LES and RANS region

$$\nu(x) = \frac{\nu_t - \nu_{SGS}}{\pi} \arctan\left(\frac{-40x}{x_2 - x_1} + 10\frac{x_2 - x_1}{x_2 - x_1}\right) + \frac{1}{2}(\nu_t + \nu_{SGS})$$

$$x = \frac{\left(\frac{L}{\Delta} - x_1\right)}{x_2 - x_1}, x_2 = 1.05, x_1 = 0.95$$

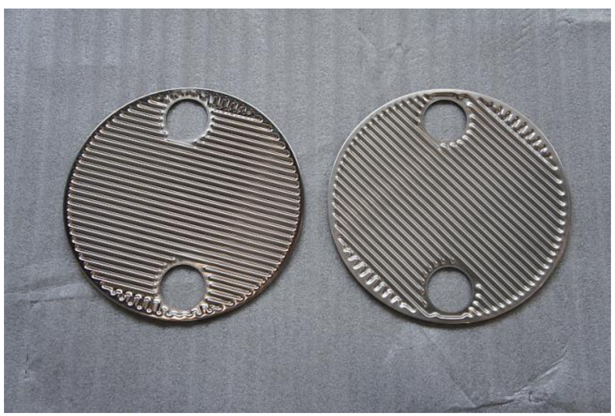
LEMOS Hybrid LES/RANS

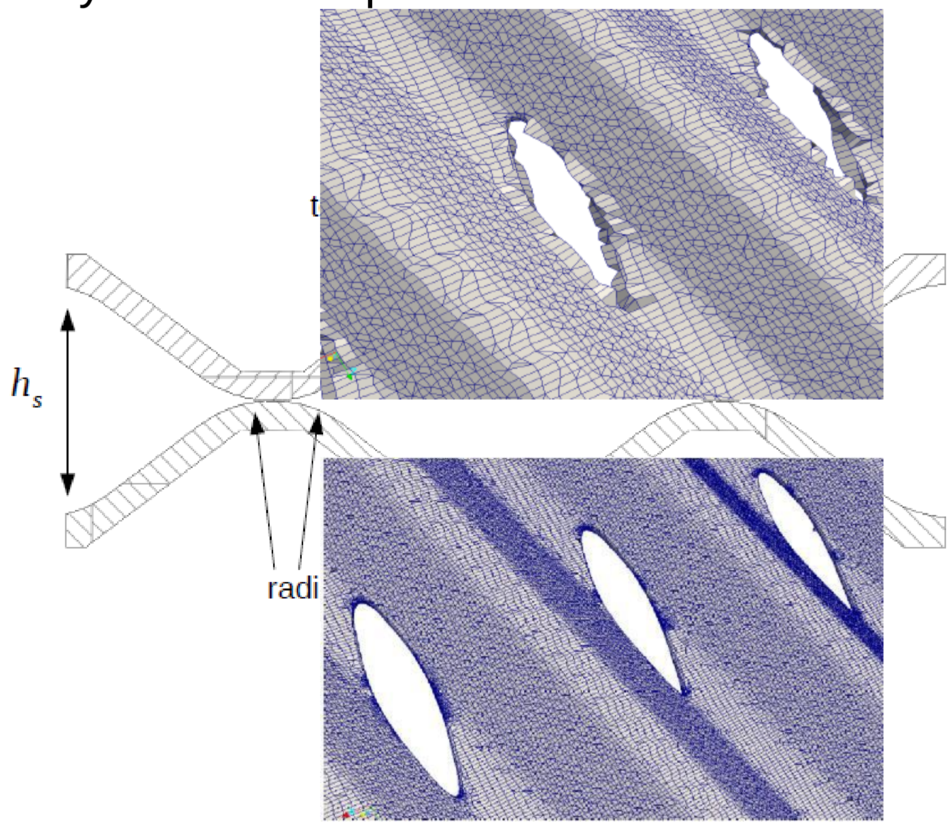
- RANS / LES Regions for turbulent flow over dimpled surfaces



Mesh generation

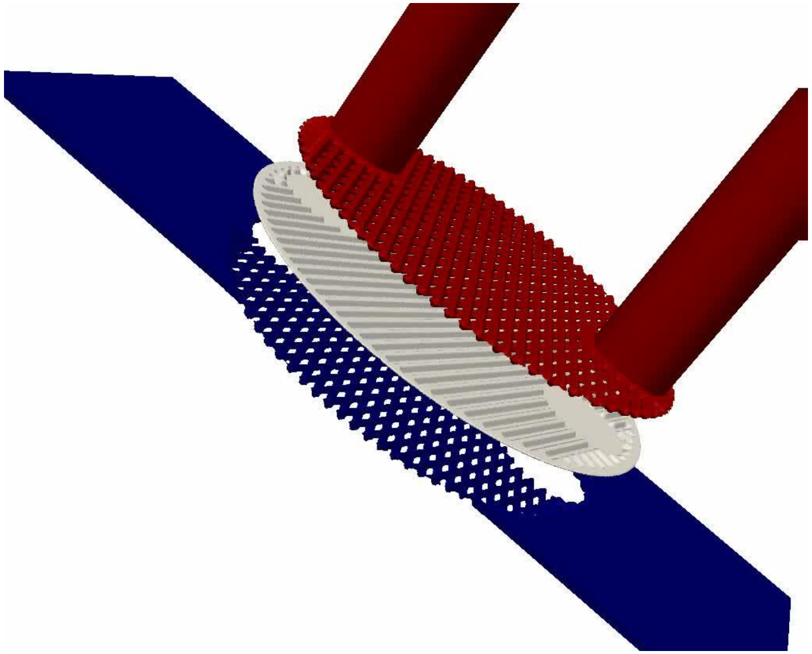
- Detailed grid convergence studies
- careful mesh generation especially the contact points

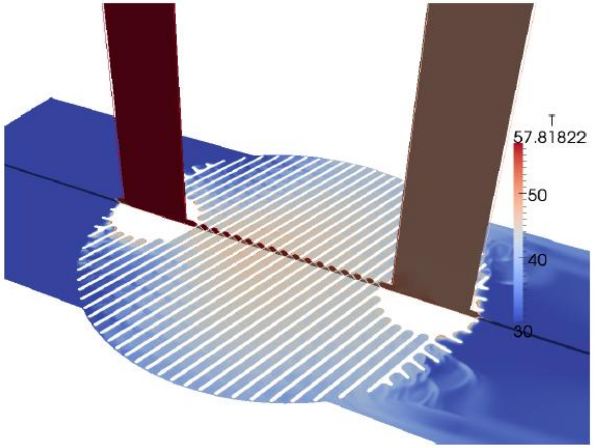


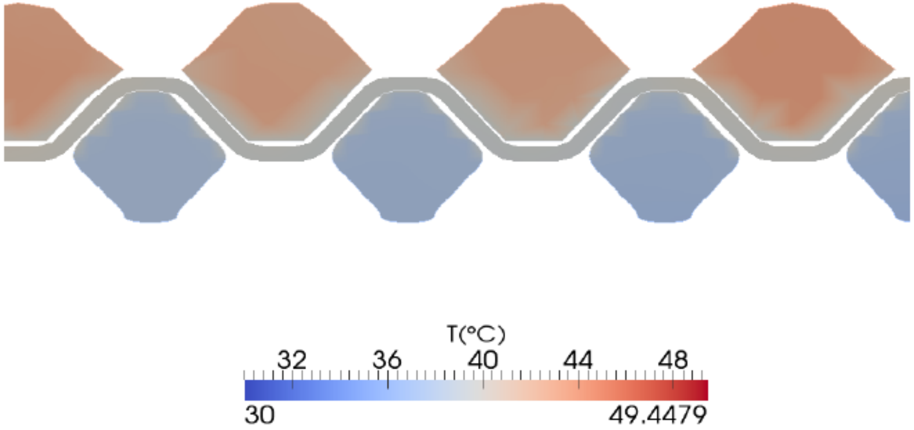


Conjugate heat transfer (CHT)

- Conjugate Heat Transfer (CHT)
- Direct Coupling of hot and cold fluid side





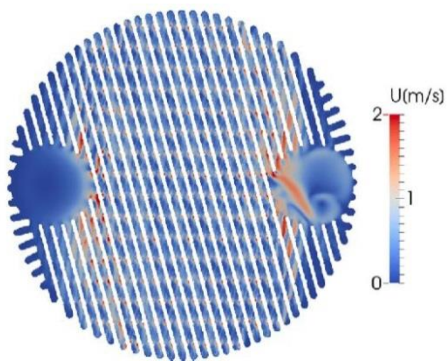


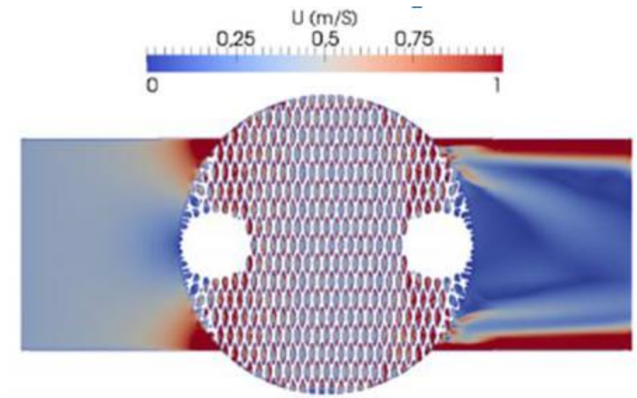
Conjugate heat transfer (CHT)

- Velocity and temperature distribution

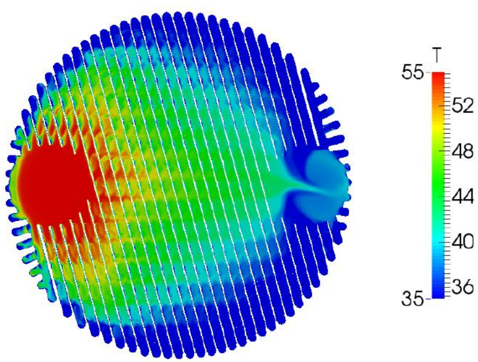
Hot **Cold**

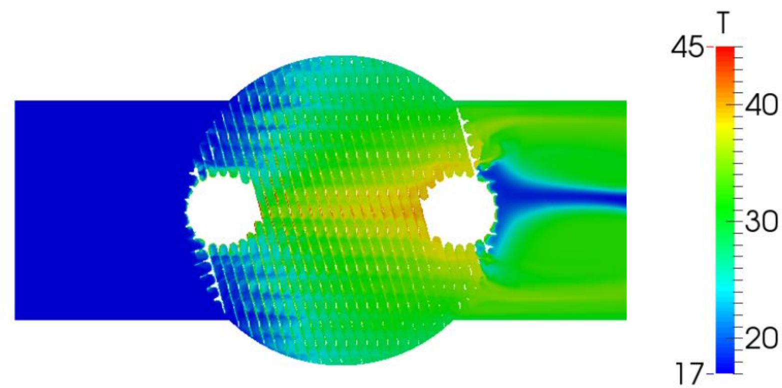
Velocity





Temperature

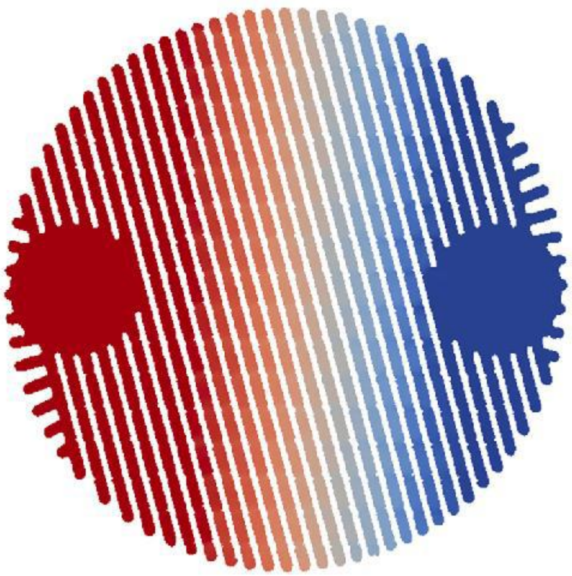


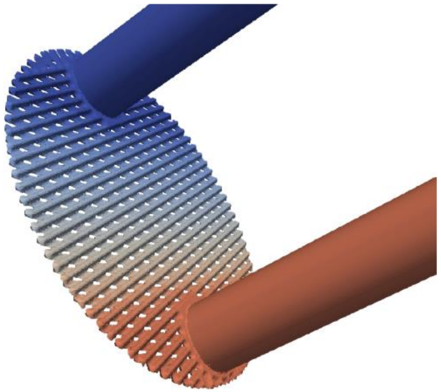


- Detailed temperature distribution for both channels

Circular PHE

- pressure distribution:





- good comparison to experiments
- nearly constant pressure gradient in streamwise direction
- Symmetric pressure distribution in lateral direction

Conjugate heat transfer (CHT)

- Integral results of experiment / simulation

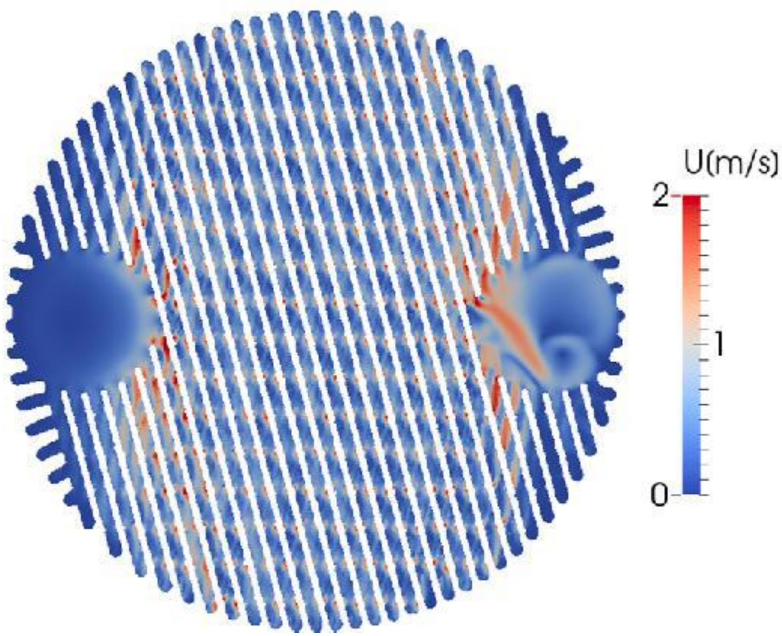
$\dot{R}e$	400		800		1200	
	f	Nu	f	Nu	f	Nu
Experiment	3.35	29.5	3.23	33.2	3.16	35.89
Simulation	3.67	34.8	3.42	37.4	3.4	41.9

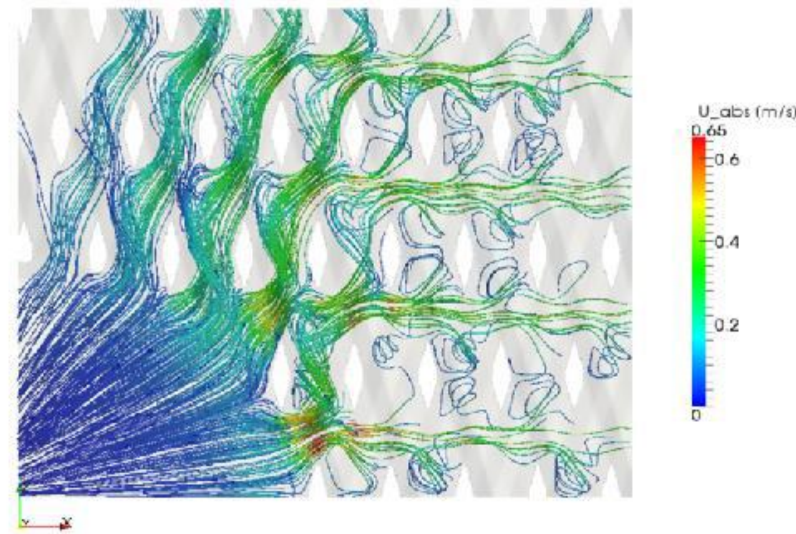
- Nearly constant friction factor
- Slightly increasing Nusselt number for higher Reynolds numbers

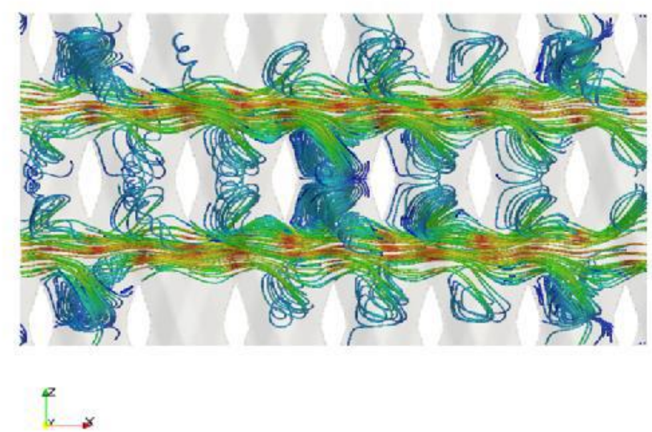
→ **Good agreement of experimental and numerical results**

Results PHE

- Flow structures



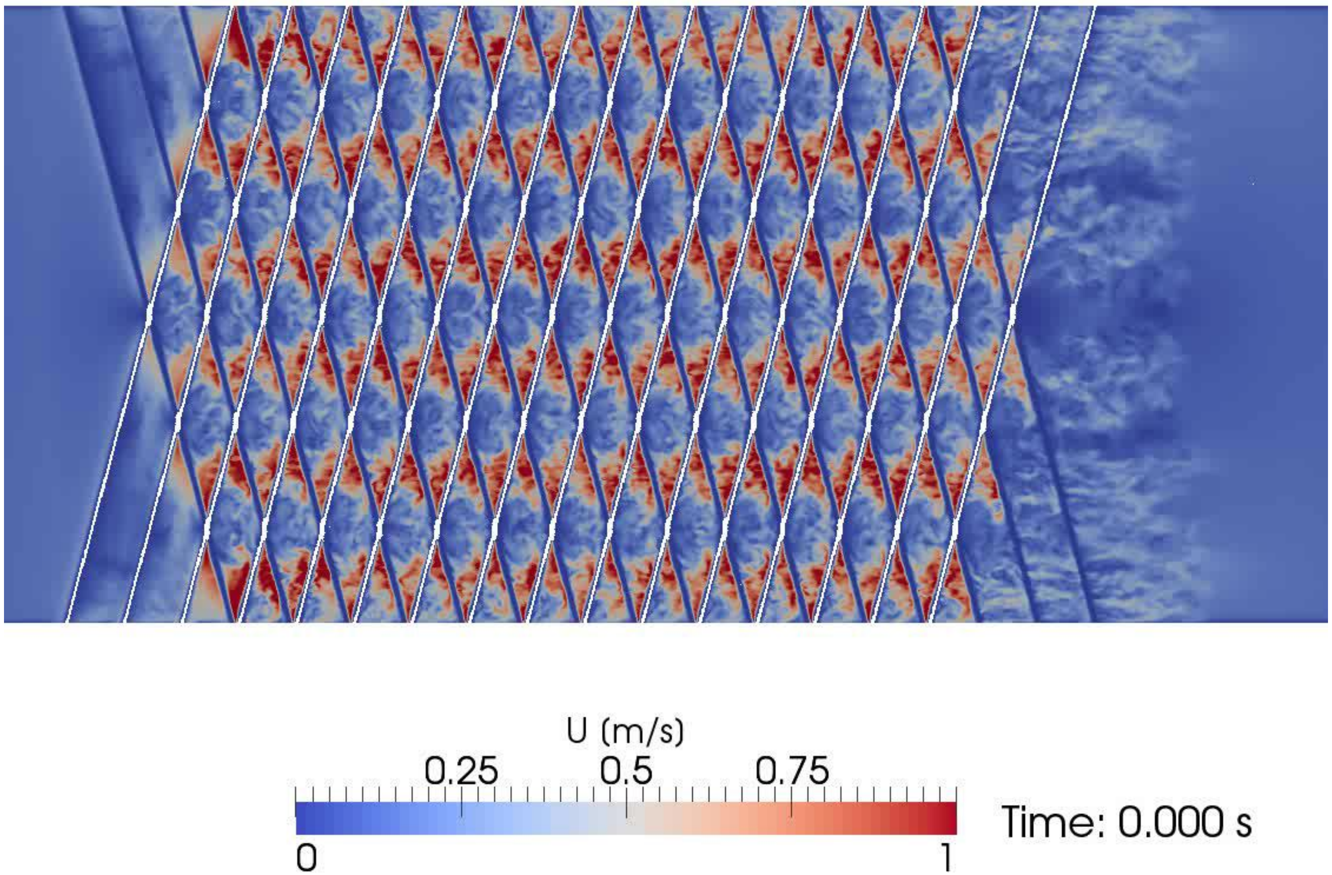




- Flow distribution homogeneous
- Flow channels evolving through contact points
- Recirculation zone behind contact points

Vortex structures

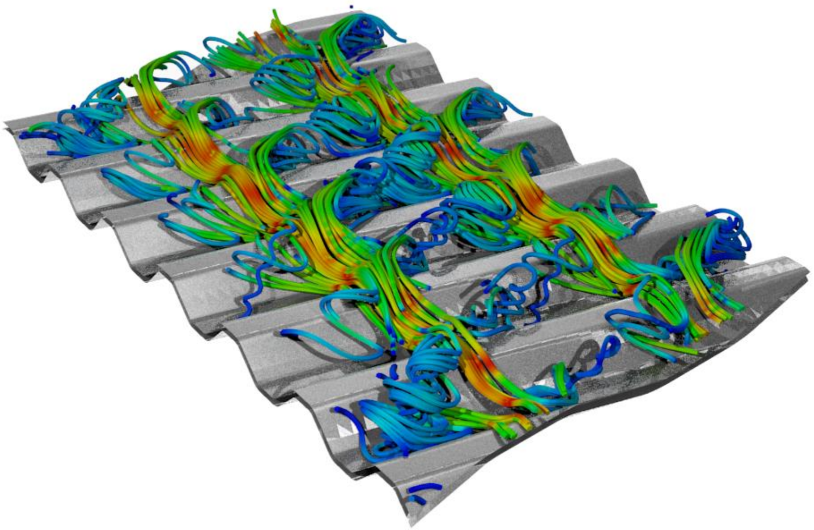
- Time resolved simulations using hybrid methods:



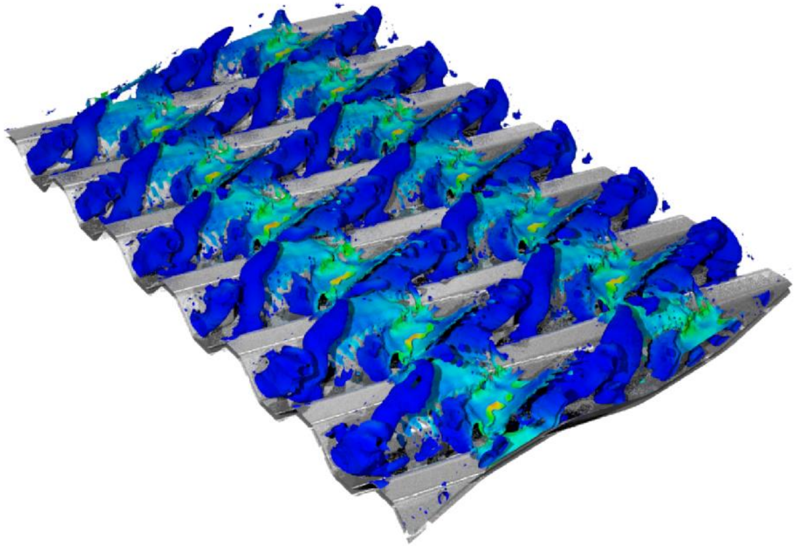
Modification of corrugation profiles

- Flow structures characterized by
  - Stable recirculation zones
  - Evolving shear layer structures

Streamlines



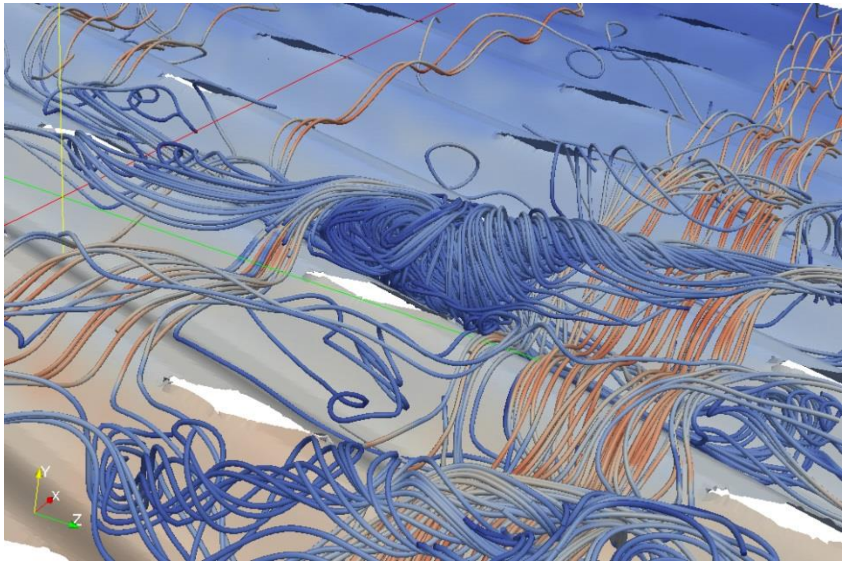
λ_2 ***- surfaces***



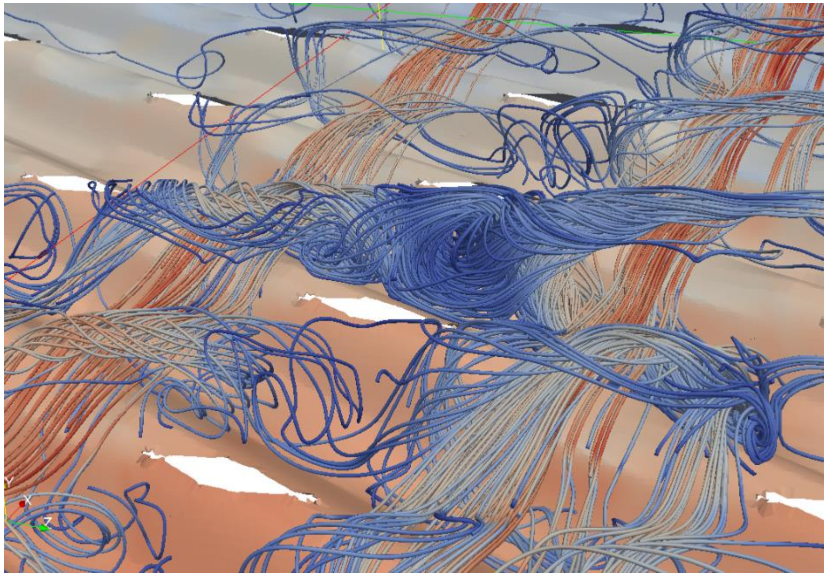
Modifaction of corrugation profile

- Increase of thermo-hydraulic performance up to 10%
- Comparison of vortex structures

original



dimples



Summary / Outlook

- Application of hybrid methods for heat transfer analysis
- Homogeneous flow field within the circular PHE from experiment and simulation
- Numerics show complex vortex structures including shear layer structures
- Variation of corrugation profile to reduce recirculation zones and heat transfer enhancement
- Application of hybrid methods for general heat transfer problems

Thank you!

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