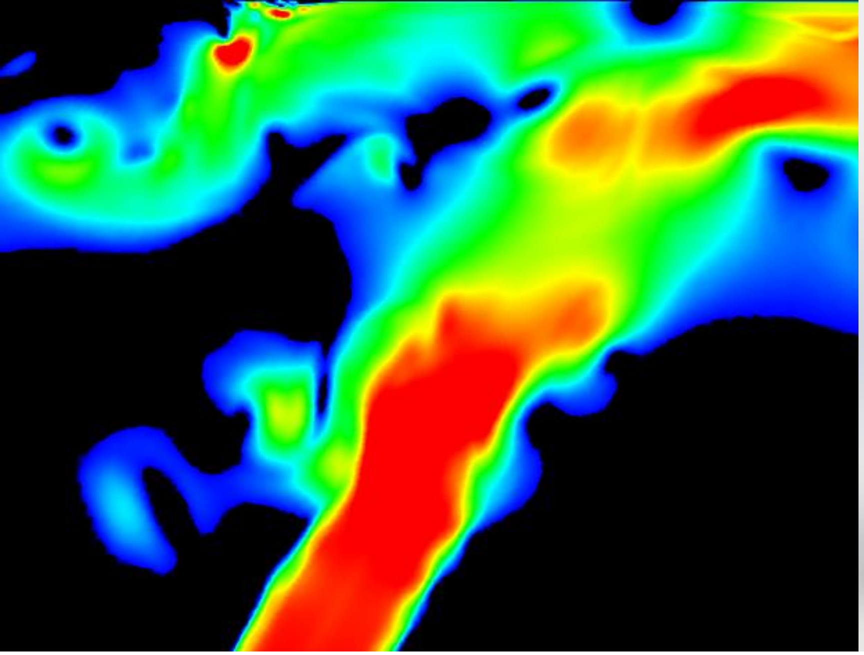
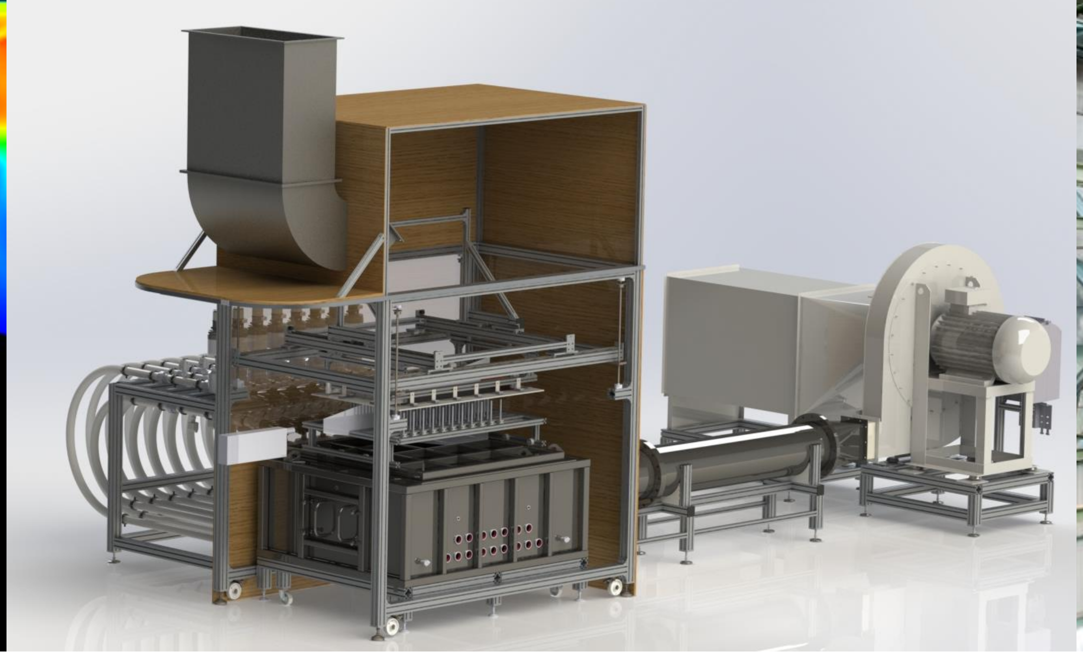




Development and experimental validation of numerical heat transfer models for impingement jets

IGF Project No. 22751 N

2nd Project Advisory Committee Meeting

Eileen Trampe, M.Sc. Univ.-Prof. Dr.-Ing. Herbert Pfeifer

29th Nov, 2023

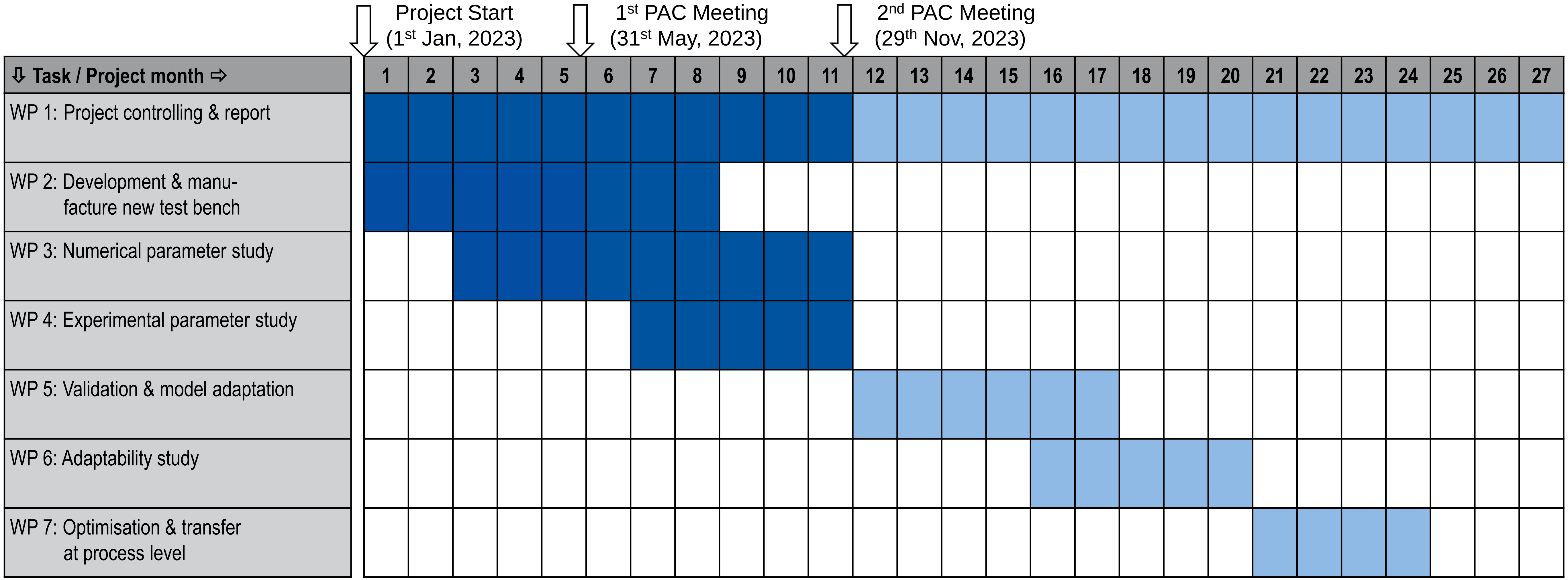
AiF iGF
IOB Institut für Industrieofenbau und Wärmetechnik
RWTH AACHEN UNIVERSITY

Project Framework

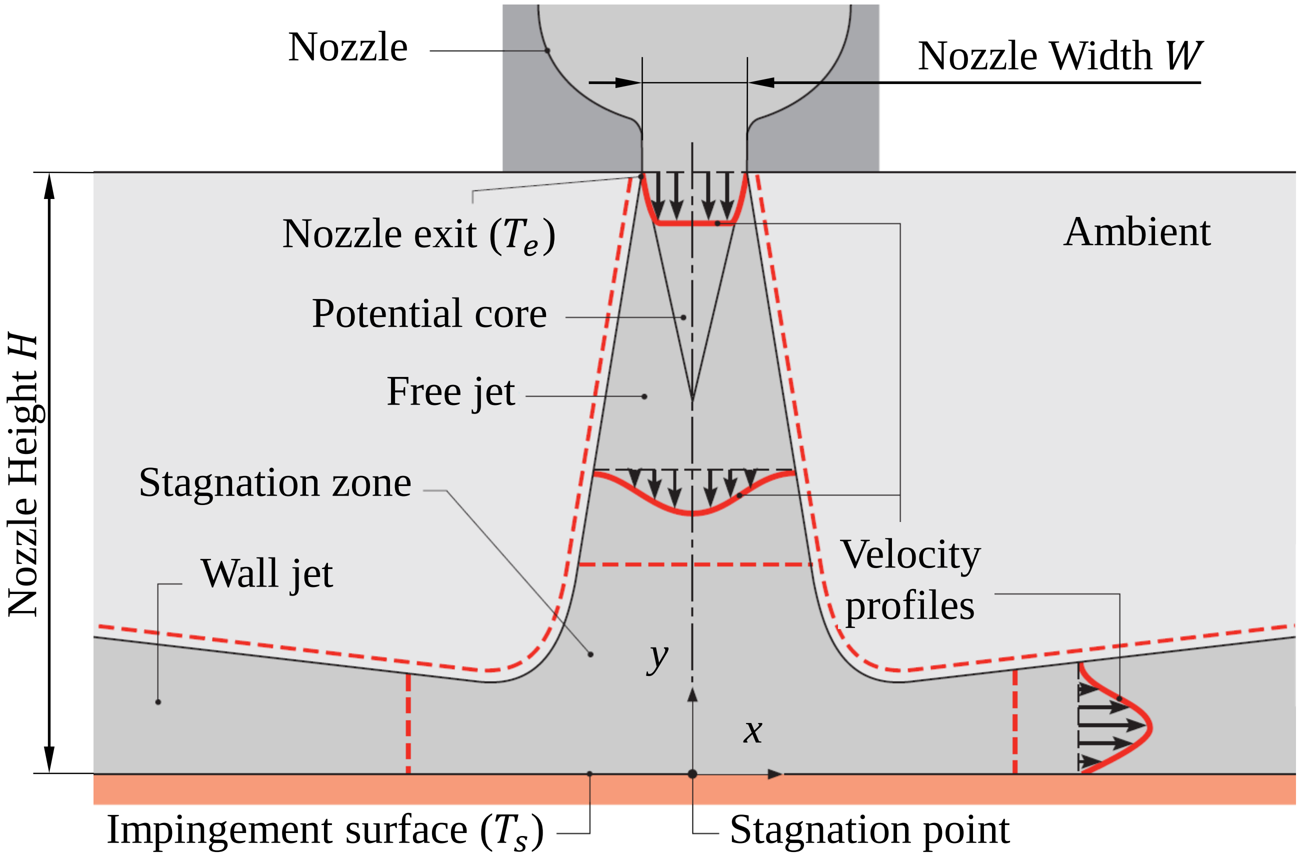
- Funding: Research Association of Industrial Furnace Manufactures
- Project duration: 01.02.2021 - 30.09.2023
- PAC chairperson: Dr. Tobias Mertens, Otto Junker GmbH

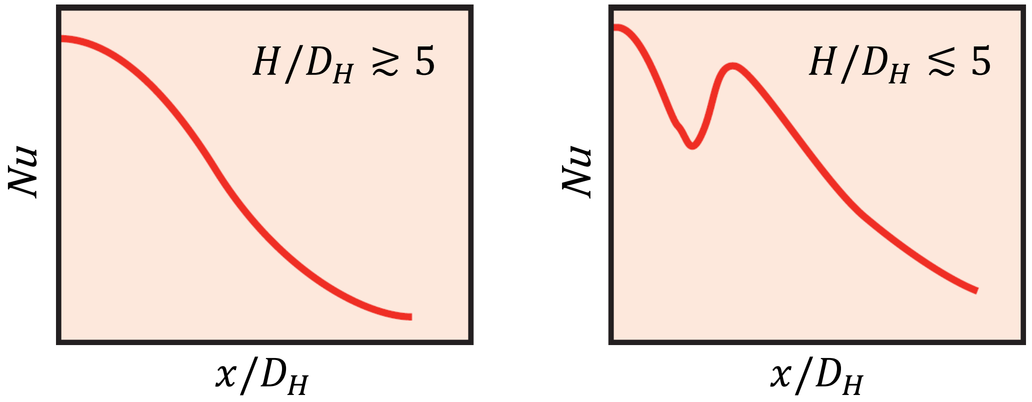
Project Framework

Gantt chart



Impingement Jets





$$Nu = \frac{hD_H}{k_F} = f(Re, Pr, Geometry)$$

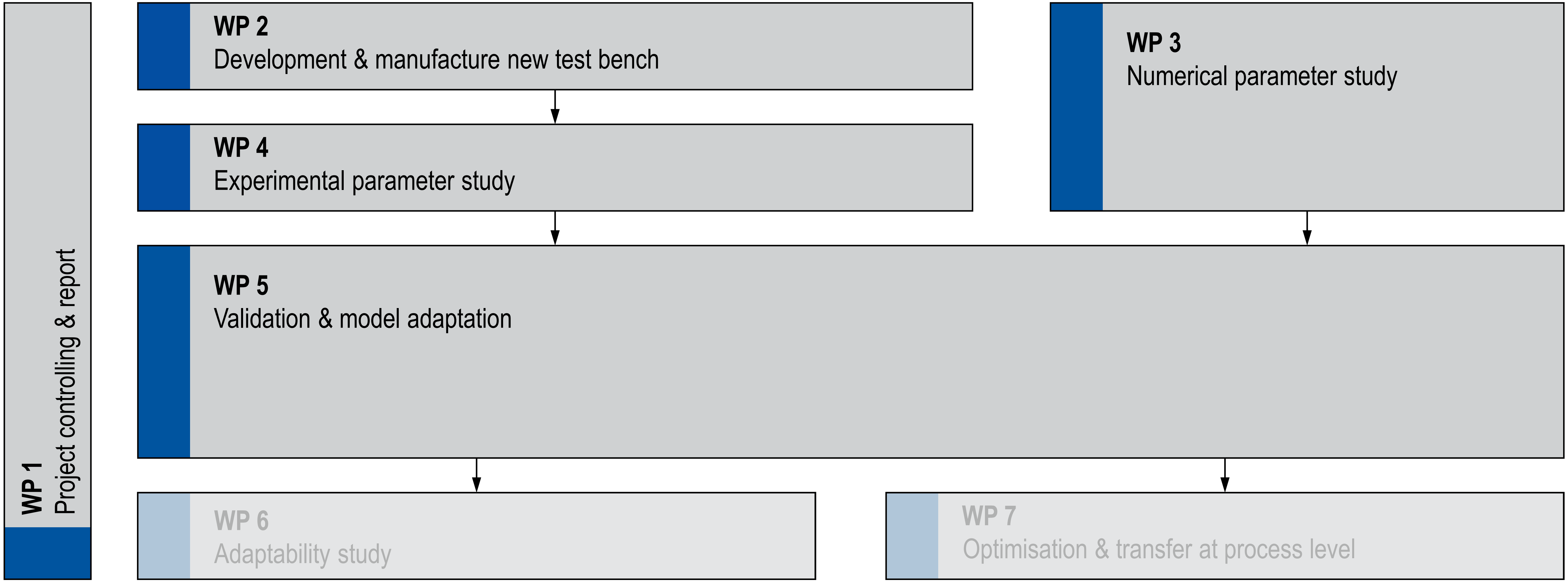
$$h = \frac{q}{T_s - T_e} \quad , \quad D_H = D = 2W$$

[1] T. L. Bergman, A. S. Lavine, *Fundamentals of Heat and Mass Transfer*, 8th ed., Wiley, Hoboken (NJ, USA) **2017**.

Project objectives

1. Construction of a test bench for the optical flow measurement of impact jets
2. Development of a numerical model for the simulation of local Nußelt numbers of nozzle fields on impact surfaces
3. Development of a simplified numerical model for the simulation of mean Nußelt numbers of nozzle fields on impact surfaces
4. Validation and evaluation of the models

Project structure



Project Status

Milestone schedule

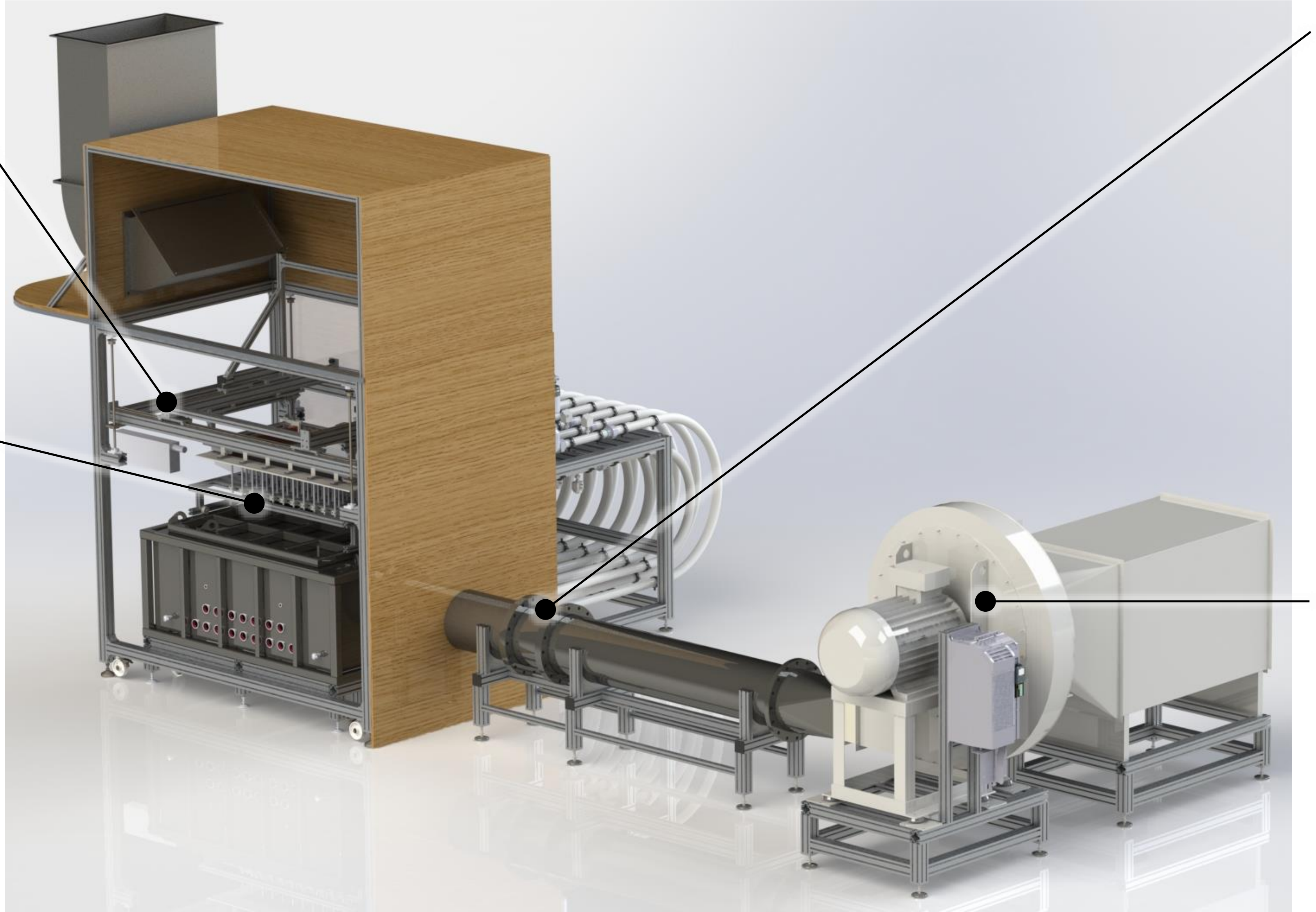
Milestone	Target	Actual
M1: Project started	01st Jan, 2023	01st Jan, 2023 ✓
M2: New test bench functional	31st Aug, 2023	*exp. Q I / 2024*
M3: Experimental parameter study completed	30th Nov, 2023	
M4: Numerical model created	31st May, 2024	
M5: Investigations completed	31st Dec, 2024	
M6: Project completed	31st Mar, 2025	

WP 1 - Project controlling & report

Work stages

• Project started	✓
• Documents university available	✓
• Interim report	⋮
• Final report	▢

WP 2 - Development & manufacture new test bench



Strip take-up

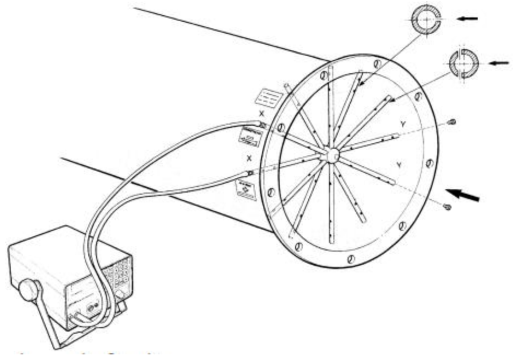
- Strip distance adjustable by electric motor
- Strip area
  630 x 1160 mm
- Side plates can be removed to examine the strip edges

Nozzle field

- Exchangeable
- Investigations of:
  - Nozzle geometry
  - Nozzle spacing

Volume flow measurment

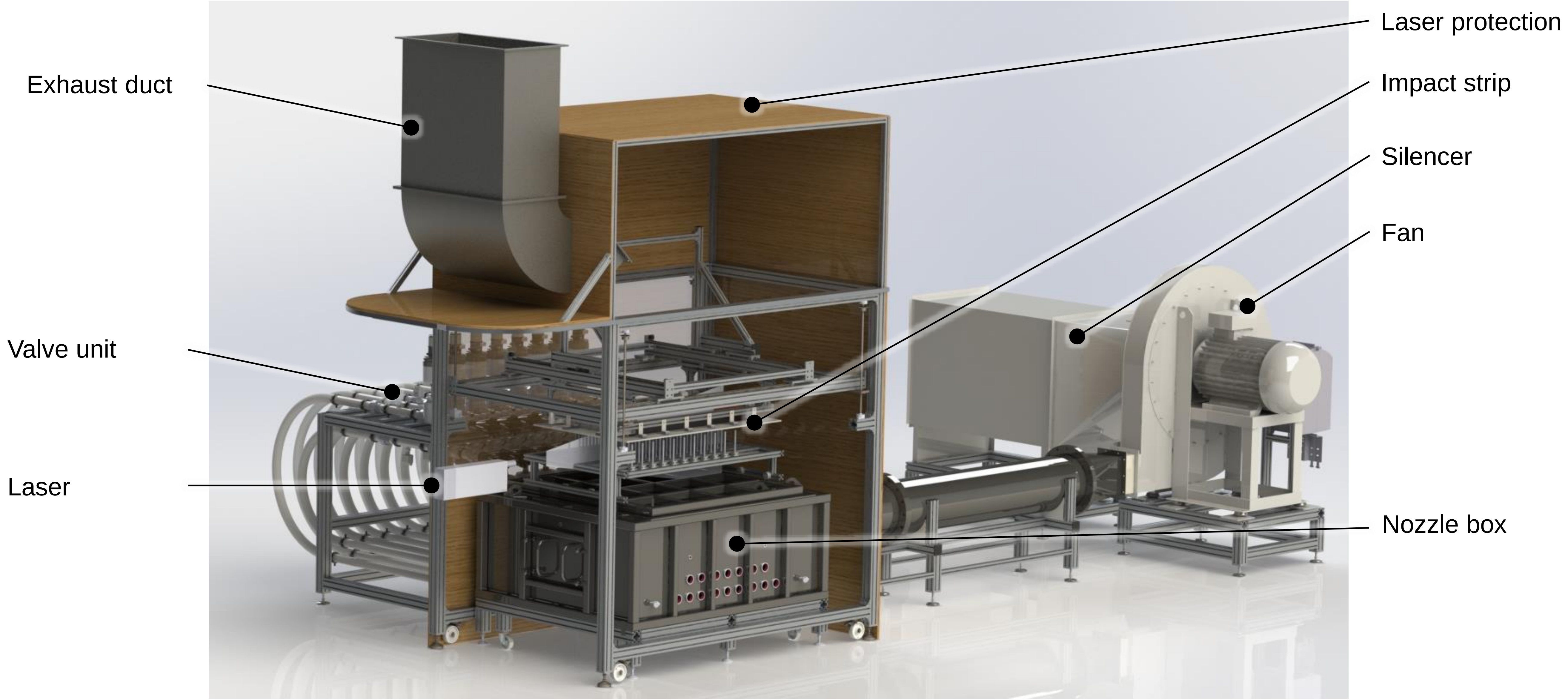
- Wilson-Staugitter
- ø 388,8 mm cross sectional area
- Inlet: 5 · D
  Outlet: 2,5 · D
- u_{min} = 1,5 m/s
- Precision: ± 5 %



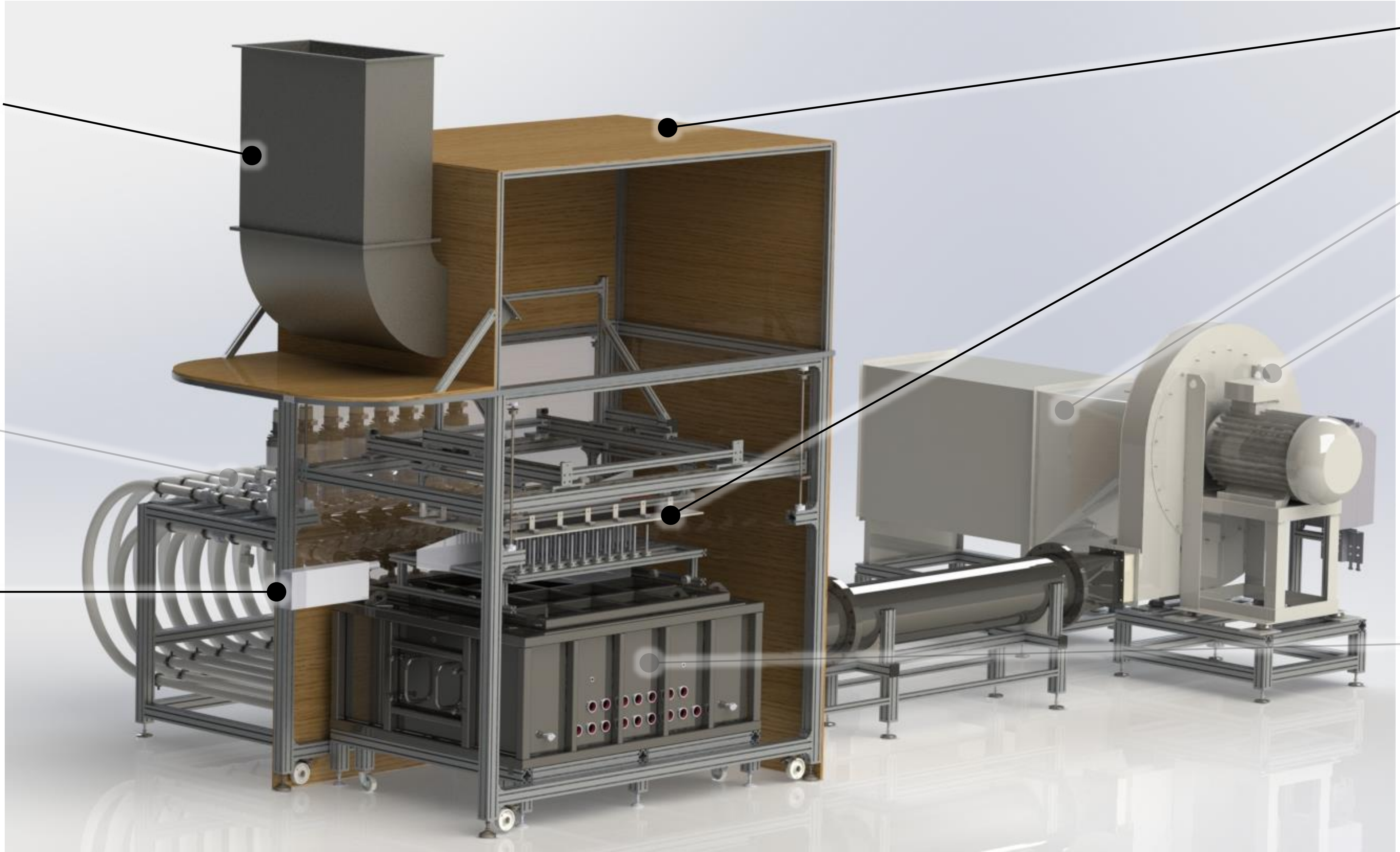
Fan

- Pressure increase:
  20.000 Pa (22.800 Pa max.)
- Volume flow:
  10.880 m³/h (15.000 m³/h max.)
- max. speed: 3000 min^{-1}
- Power: 84 kW (90 kW – Motor)

WP 2 - Development & manufacture new test bench



WP 2 - Development & manufacture new test bench



WP 2 - Development & manufacture new test bench

Work stages

- Design of the new test bench ✓
- Procurement and preparation of individual parts ✓
- Complete assembly of the test bench ⋮
- Commissioning of the test bench ▢

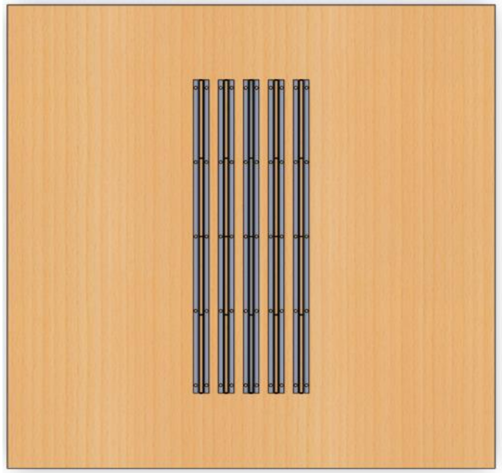
Definition standard cases

Slot nozzle

- Nozzle width: 5 mm
- Nozzle high: 100 mm
- Nozzle length: 1000 mm
- Nozzle exit area: 100 cm²

Slot nozzle field

- 5 times single slot nozzle
- Spacing: 70 mm

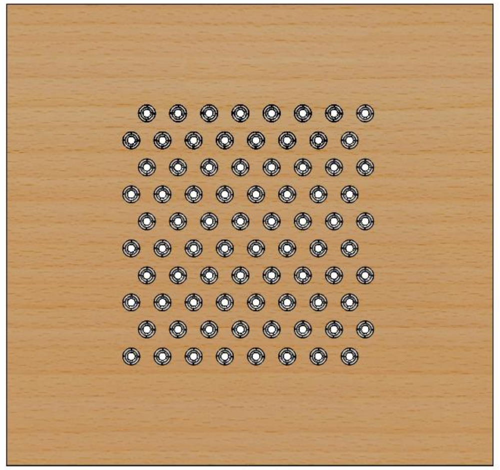


Round nozzle

- Nozzle diameter: 25 mm
- Nozzle high: 80 mm
- Nozzle exit area: 20 cm²

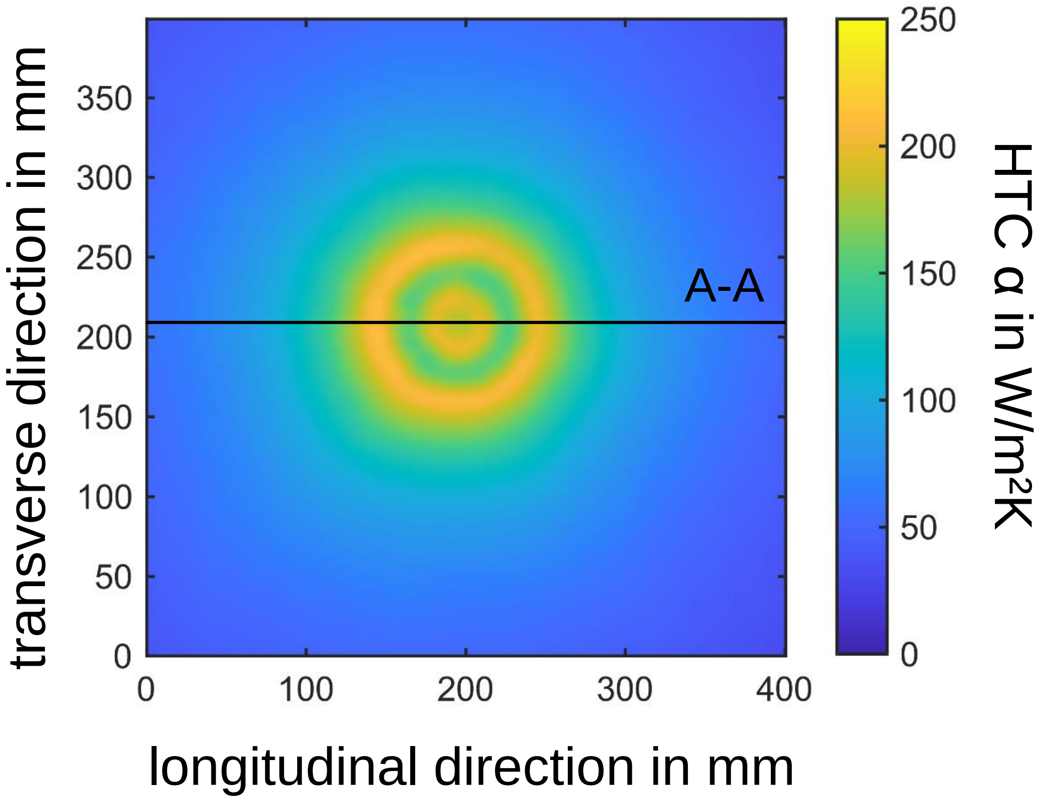
Round nozzle field

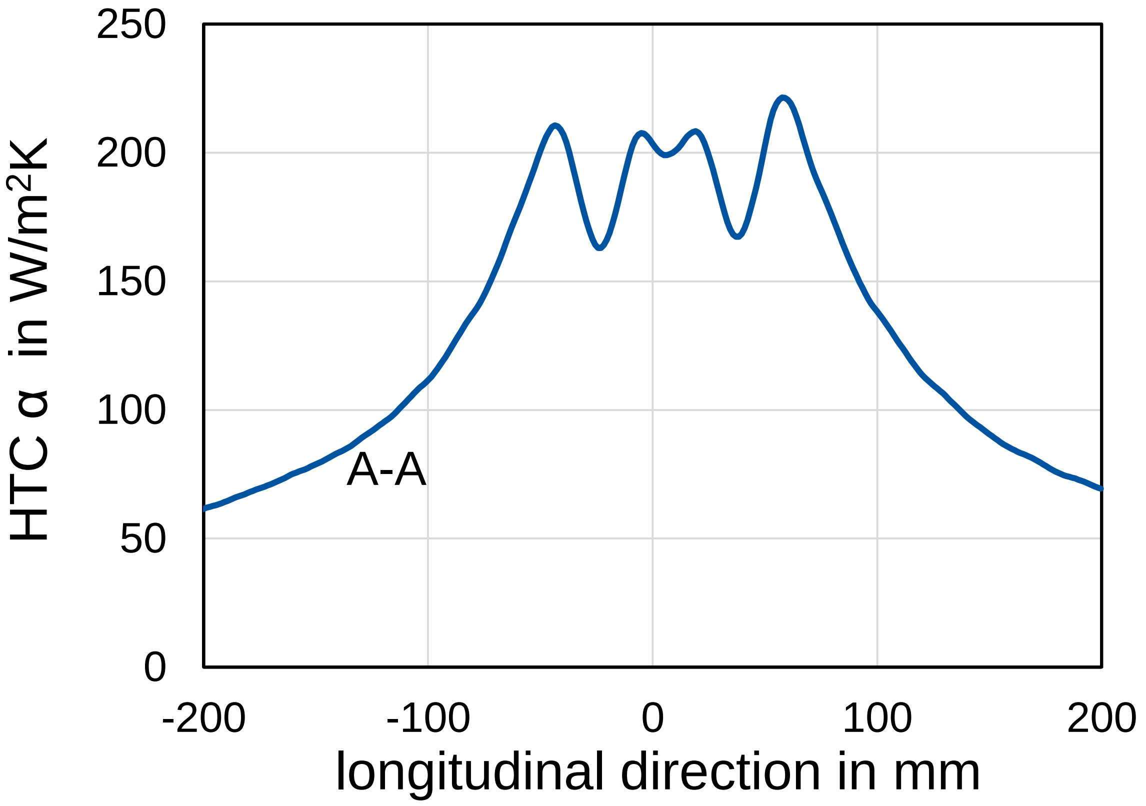
- Nozzle diameter: 25 mm
- Nozzle high: 30 mm
- Spacing: 100 mm



Measurement of the heat transfer coefficient (htc)

Round nozzle, d = 25 mm, H = 50 mm, p = 1550 Pa



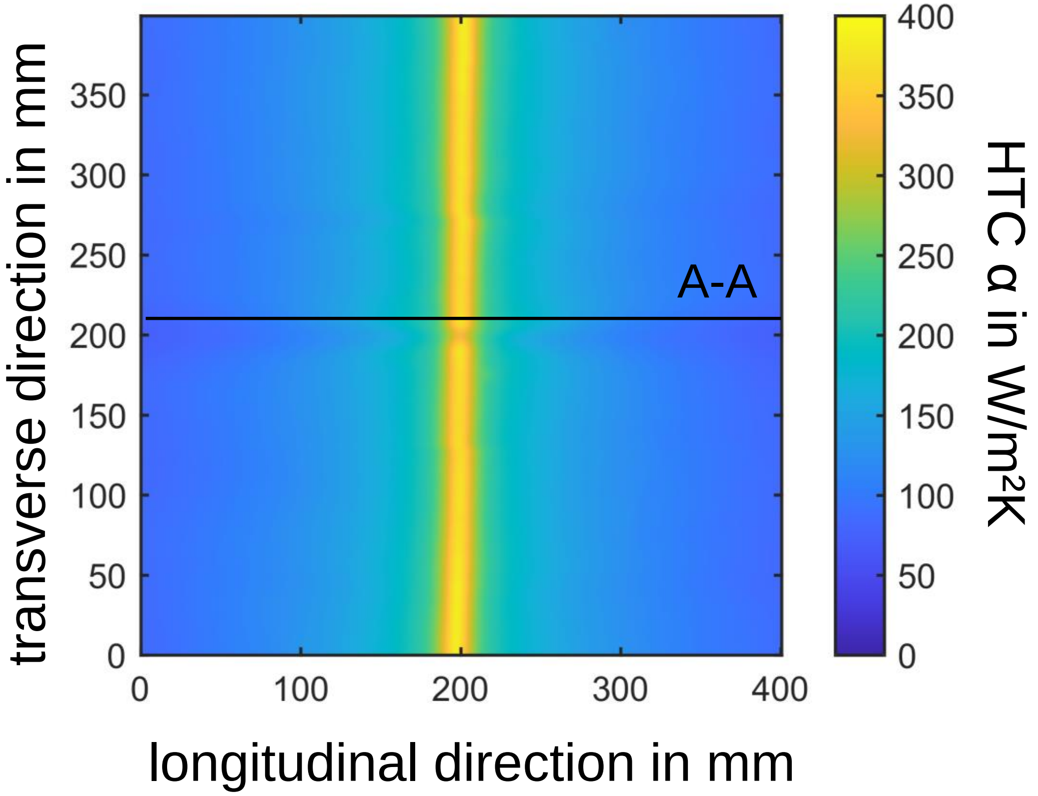


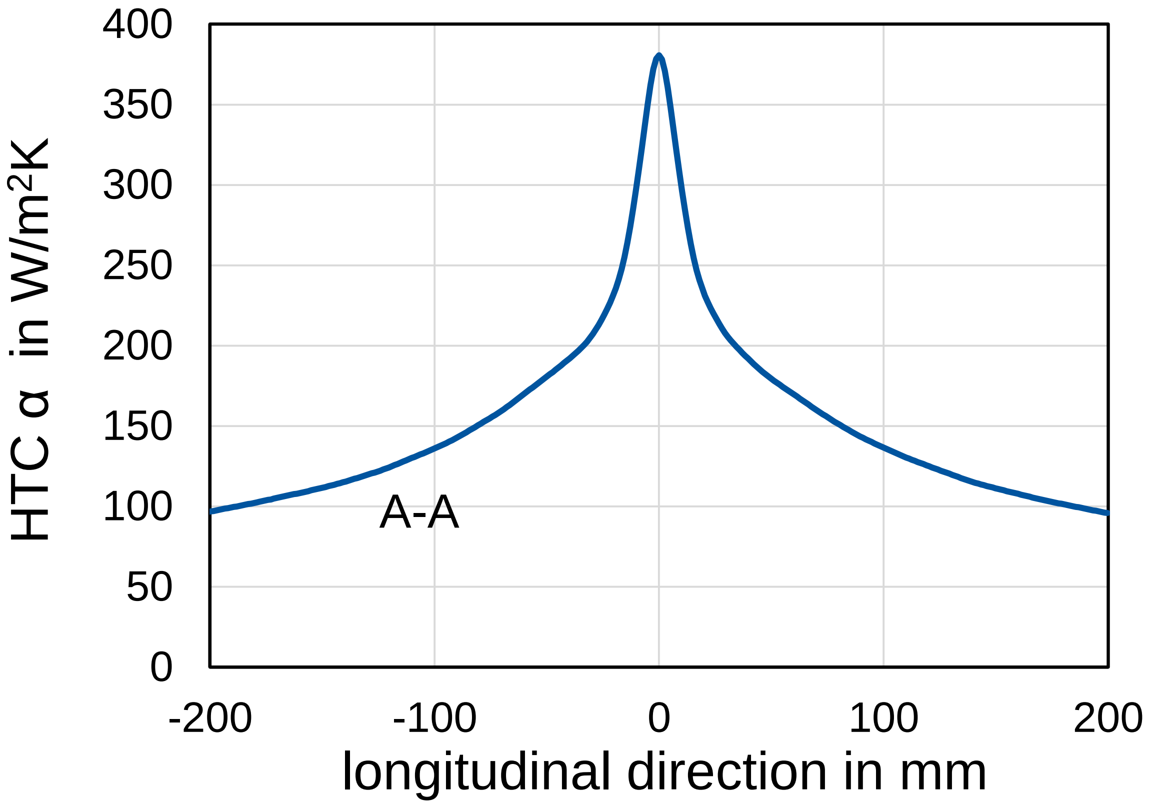
IOB Institut für Industrieofenbau und Wärmetechnik

RWTH AACHEN UNIVERSITY

Measurement of the heat transfer coefficient (htc)

Slot nozzle, w = 5 mm, H = 50 mm, p = 1520 Pa





WP 4 - Experimental parameter study

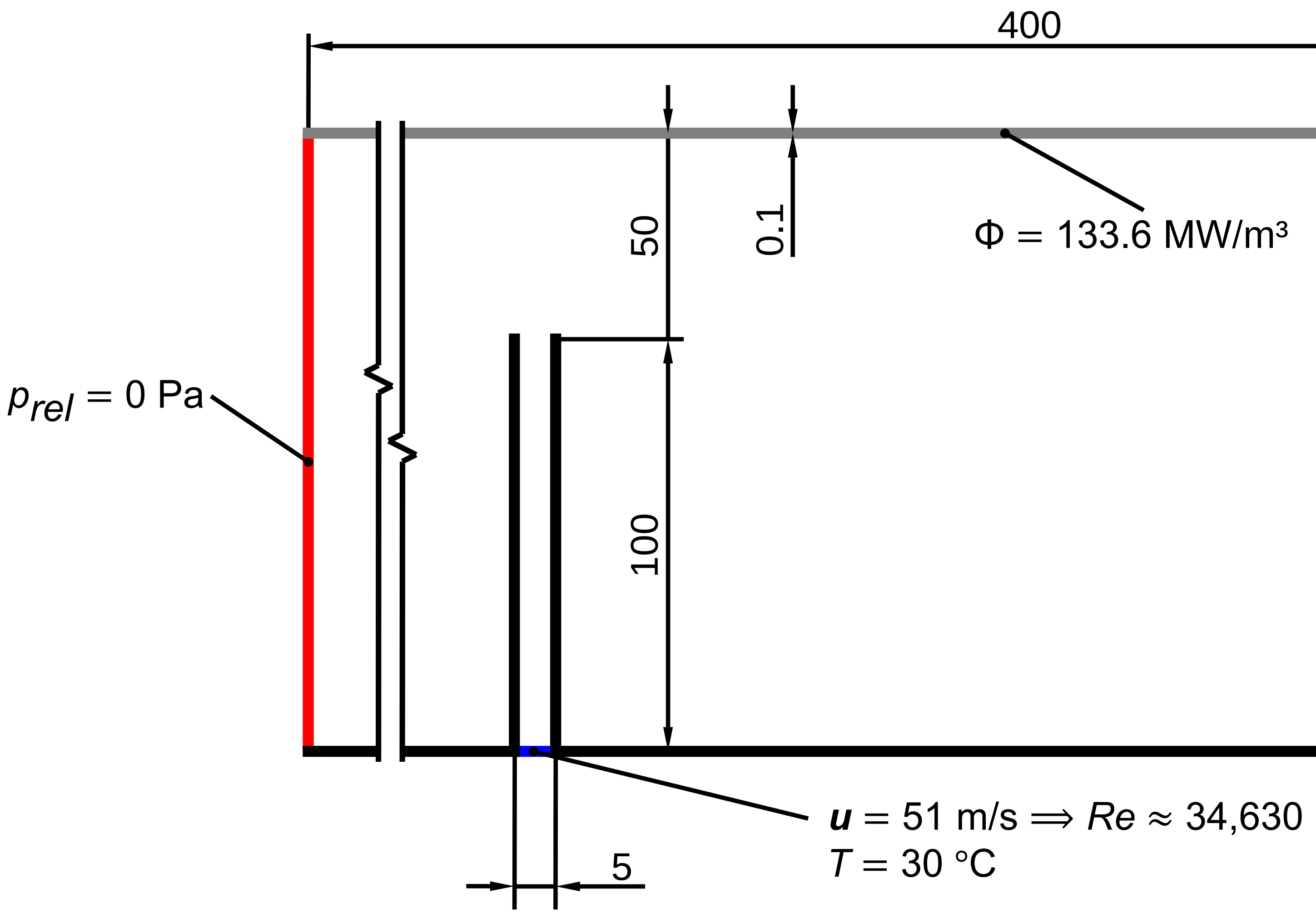
Work stages

- Manufacturing nozzles and nozzle fields ✓
- Heat transfer measurements ✓
- Flow measurements ▢
- Analysing the measurements ⋮

WP 3 - Numerical parameter study

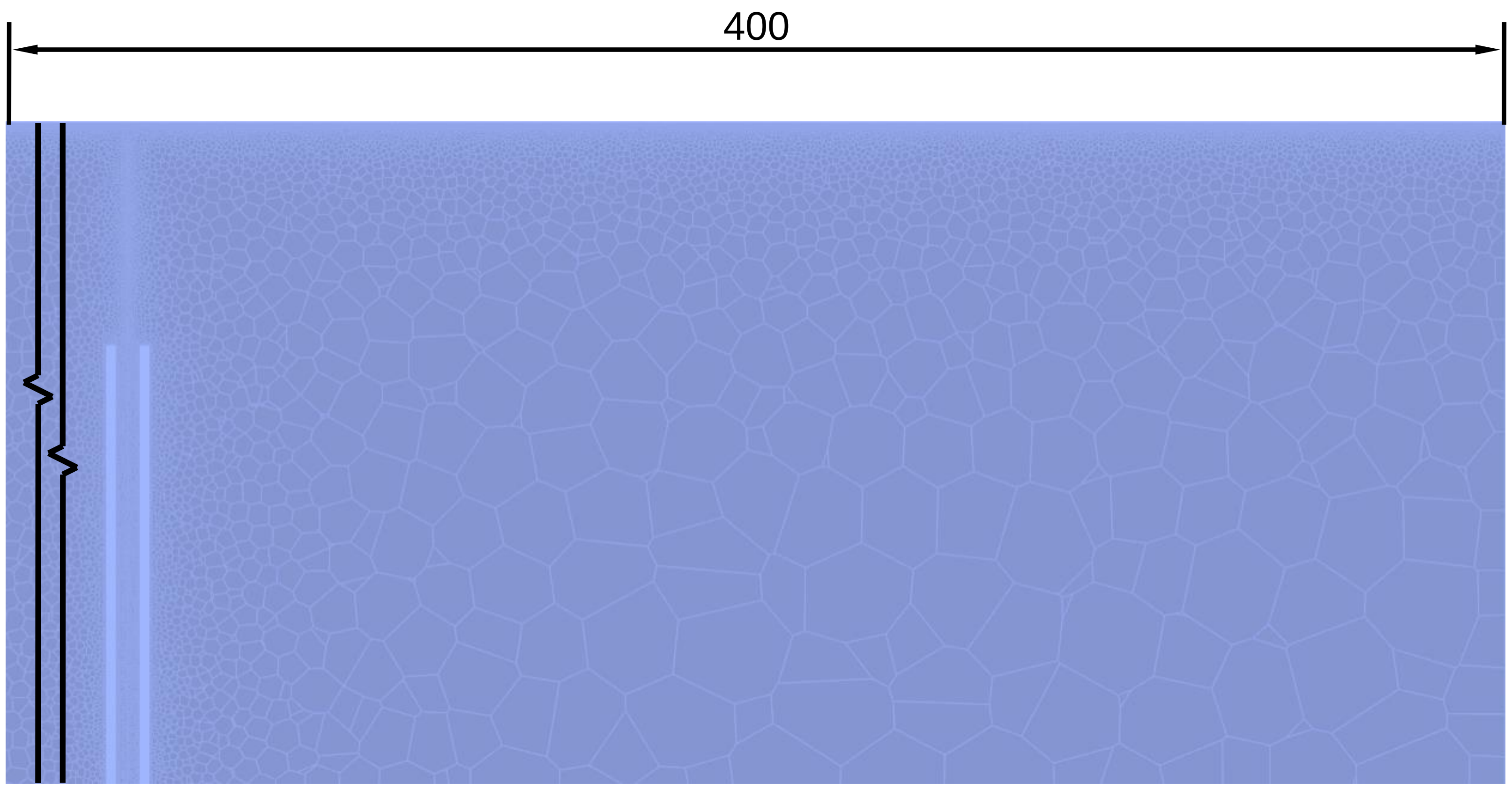
Flow Domain

$H / D_H = 5$



WP 3 - Numerical parameter study

Computational Grid



Grid study

I. 4.3 Mio cells, $y^+ \approx 1.19$

II. 7.6 Mio cells, $y^+ \approx 0.89$

III. 15.3 Mio cells, $y^+ \approx 0.59$

Comparision of CFD Turbulence Models used Impinging Jet Problems

Turbulenz model	Computational cost	Impinging jet transfer coefficient prediction	Nu error	Ability to predict secondary peak
k-ε Model	●○○○	●○○○	15 - 60 %	●○○○
k-ω Model	●○○○	●●○○	10 - 30 %	●●○○
Realizable *k-ε*	●○○○	●●○○	15 - 30 %	●●○○
Algebraic Stress Model	●○○○	●●○○	-	●○○○
Reynolds Stress Model	●●●○	●●○○	25 - 100 %	●●○○
Shear Stress Transport (SST)	●●○○	●●●○	20 - 40 %	●●○○
V^2f Model	●●○○	●●●●	2 - 30 %	●●●●
Large Eddy Simulation	●●●●	●●●●	-	●●●●

[1] N. Zuckerman, N. Lior, *Jet Impingement Heat Transfer: Physics, Correlations, and Numerical Modeling*, Advances in Heat Transfer, Elsevier, Vol. 39, **2006**.

Comparision of CFD Turbulence Models used Impinging Jet Problems

Turbulenz model	Computational cost	Impinging jet transfer coefficient prediction	Nu error	Ability to predict secondary peak
k-ε Model	●○○○	●○○○	15 - 60 %	●○○○
k-ω Model	●○○○	●●○○	10 - 30 %	●●○○
Realizable *k-ε*	●○○○	●●○○	15 - 30 %	●●○○
Algebraic Stress Model	●○○○	●●○○	-	●○○○
Reynolds Stress Model	●●●○	●●○○	25 - 100 %	●●○○
Shear Stress Transport (SST)	●●○○	●●●○	20 - 40 %	●●○○
~~V^2f Model~~	~~●●○○~~	~~●●●●~~	~~2 - 30 %~~	~~●●●●~~
Large Eddy Simulation	●●●●	●●●●	-	●●●●

[1] N. Zuckerman, N. Lior, *Jet Impingement Heat Transfer: Physics, Correlations, and Numerical Modeling*, Advances in Heat Transfer, Elsevier, Vol. 39, **2006**.

Modelling

Shear stress transport k-ω turbulence model

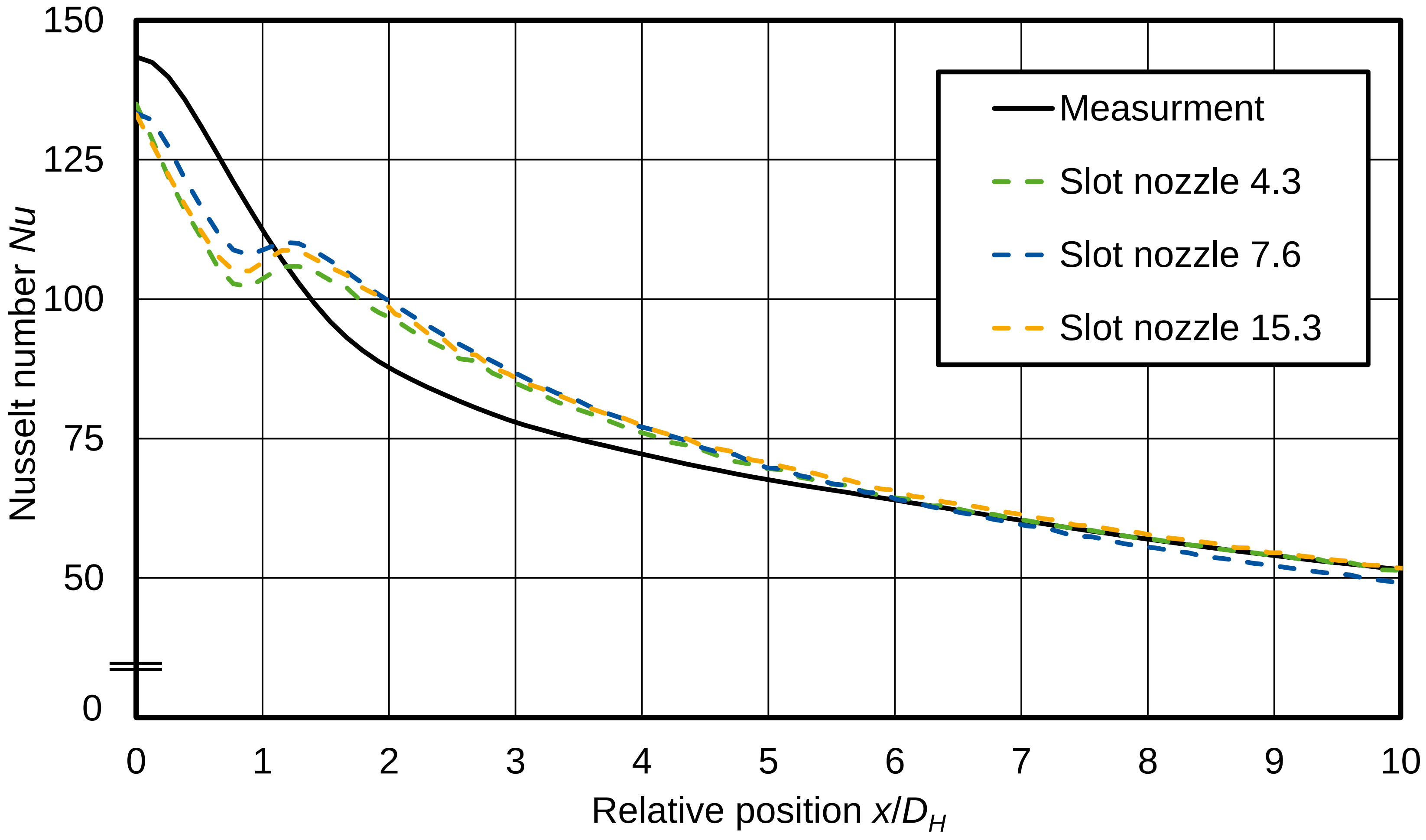
- Introduced in 1993 by *ANSYS Inc.*
- Blend the robust formulation of the k-ω model in the near-wall region with the free-stream independence of the k-ε model
- 5 Additional options for state solutions which are set by default

Generalized k-ω (GEKO) turbulence model

- Introduced in 2019 by *ANSYS Inc.*
- Based on k-ω model formulation
- Can be tuned without affecting model calibration by adjusting 6 free parameters
- Investigation of the optimum parameters for impact jets by Menzler in 2022

WP 3 - Numerical parameter study

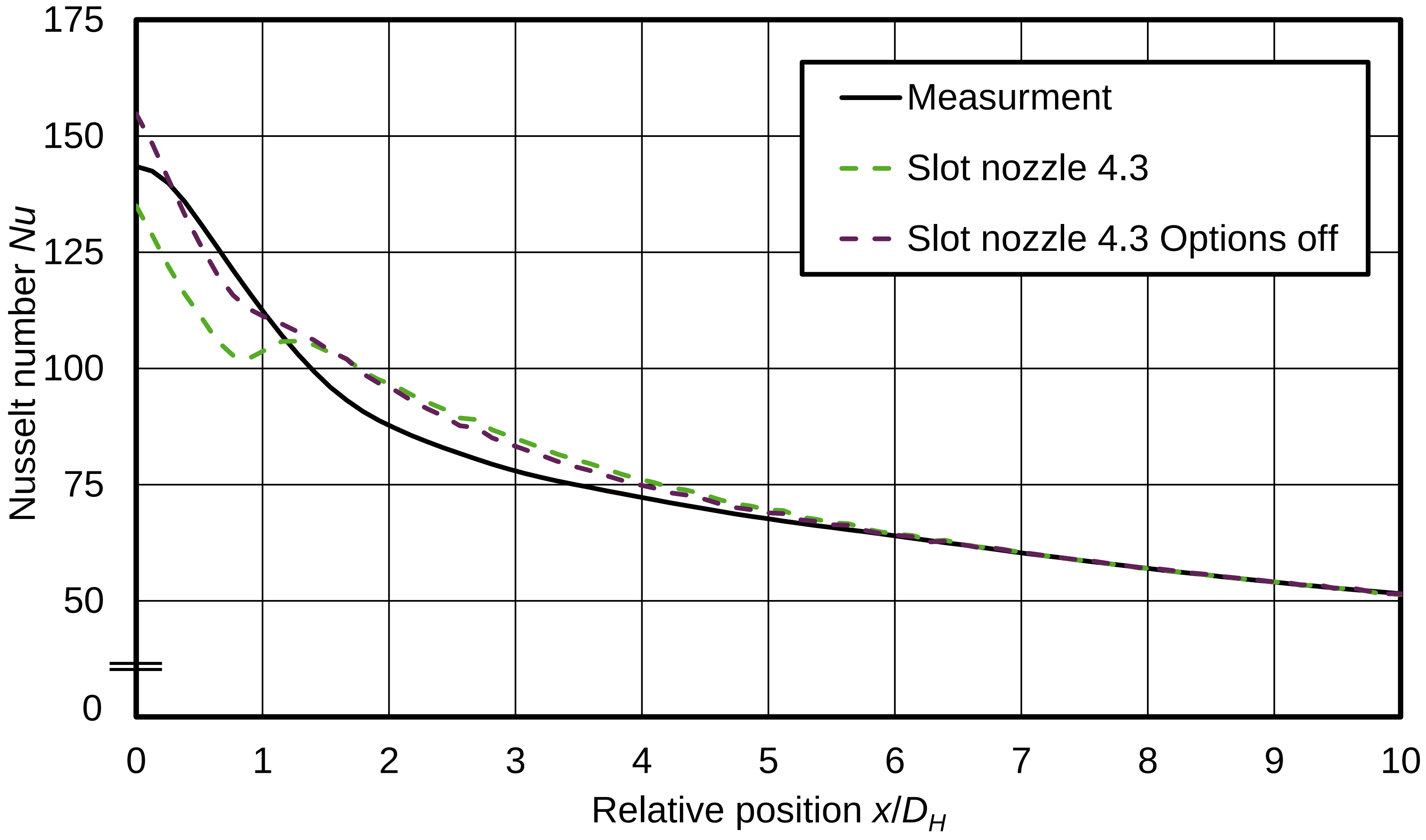
Results: The shear stress transport (SST) k-ω turbulence model



	Meas.	Model 4.3	Model 7.6	Model 15.3
Nu_{SP}	143.5	135.0 *- 6.3 %*	133.4 *-7.6 %*	133.1 *-7.8 %*
$\overline{Nu}$	75.3	75.9 *+ 0.7 %*	76.6 *+ 1.7 %*	77.0 *+ 2.1 %*

WP 3 - Numerical parameter study

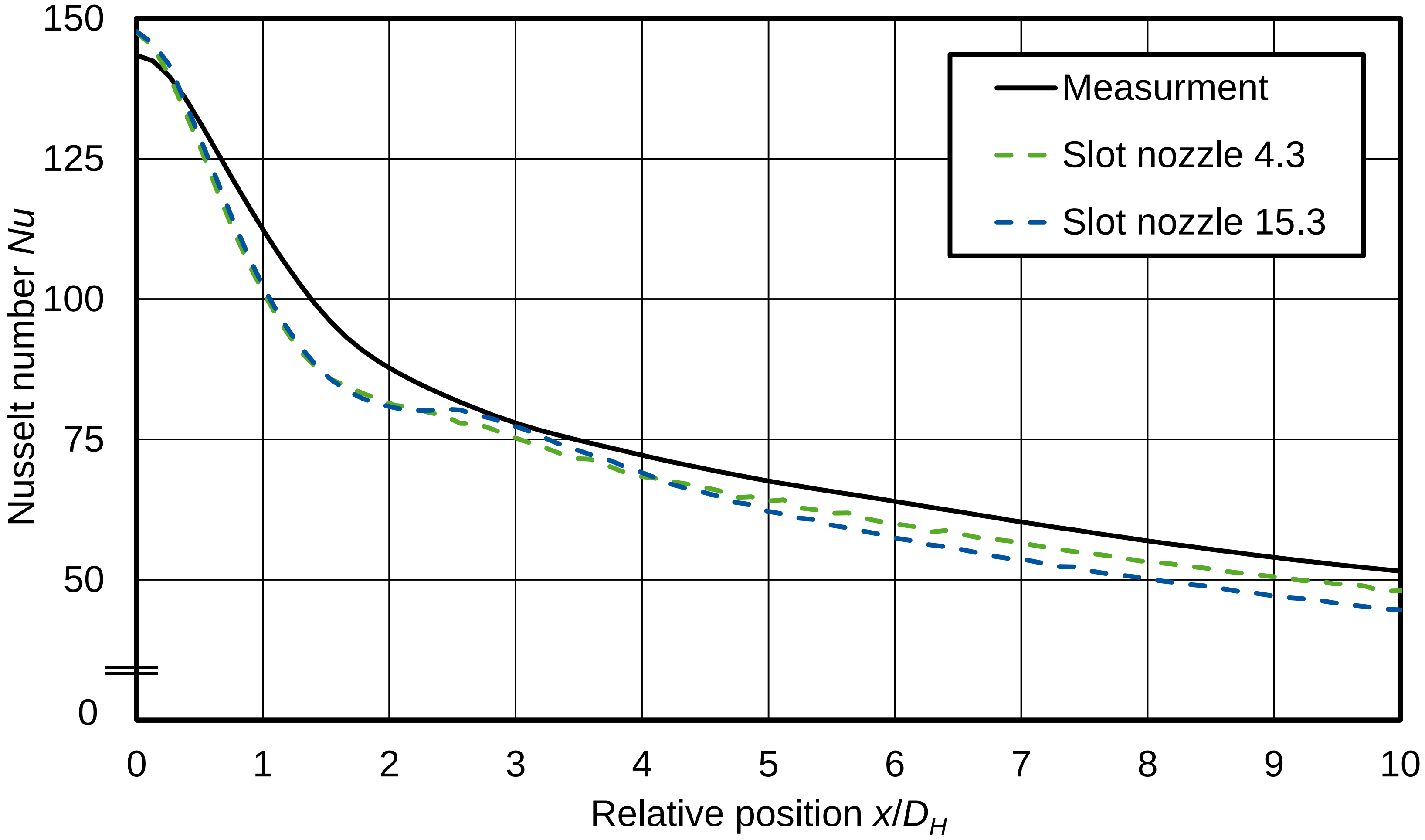
Results: The shear stress transport (SST) k-ω turbulence model



	Meas.	Model 4.3	Model 4.3 Options off
Nu_{SP}	143.5	135.0 *- 6.3 %*	154.8 *+ 7.3 %*
$\overline{Nu}$	75.3	75.9 *+ 0.7 %*	77.2 *+ 2.4 %*

WP 3 - Numerical parameter study

Results: The generalized k-ω (GEKO) turbulence model

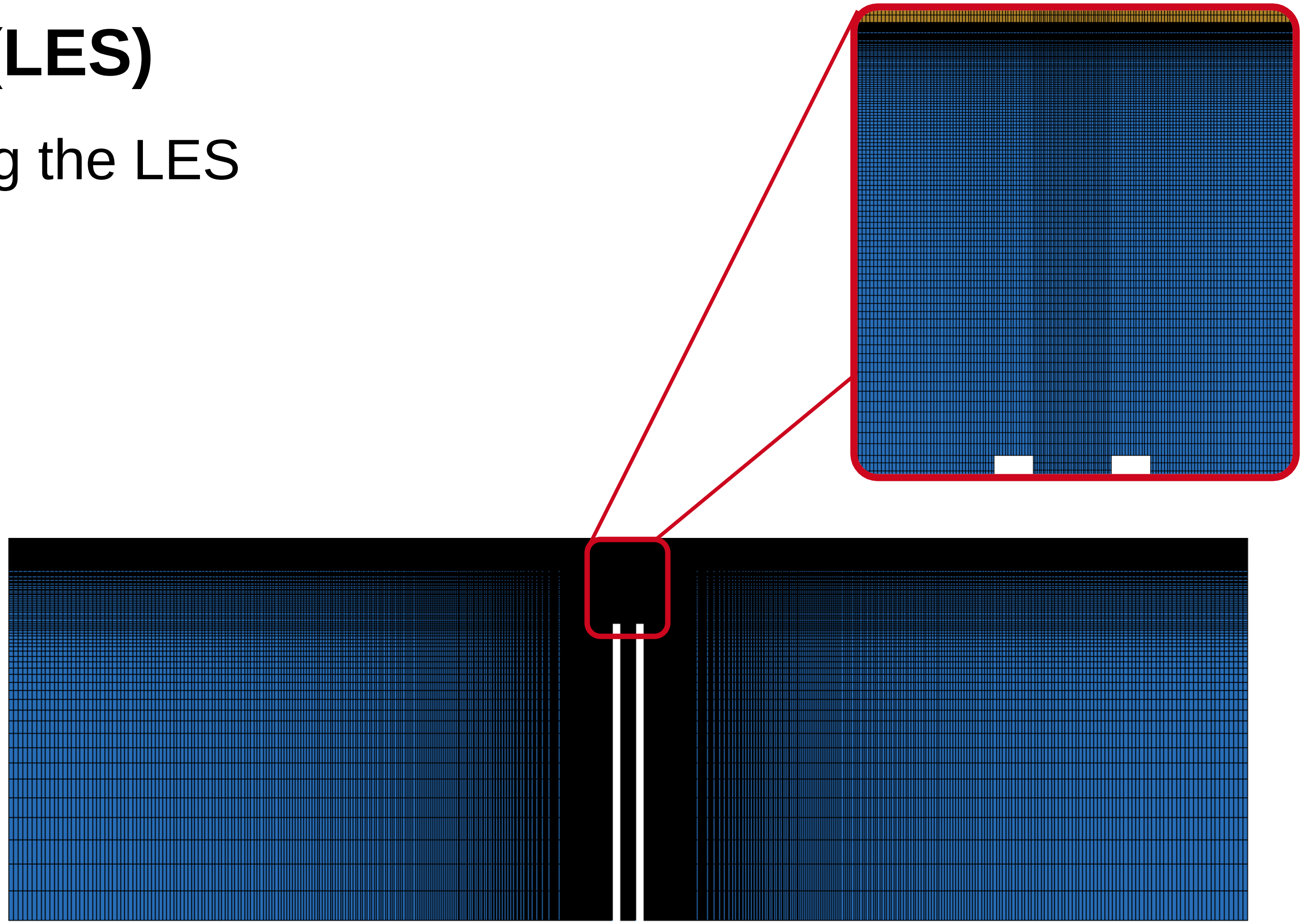


	Meas.	Model 4.3	Model 15.3
Nu_{SP}	143.5	147.6 + *2.8 %*	147.7 + *2.9 %*
$\overline{Nu}$	75.3	71.1 - *5.9 %*	70.0 - *7.7 %*

Preparing Large Eddy Simulation (LES)

High demands on the grid quality for solving the LES

- Integral length scale l_o / cell volume > 4.8
- Dimensionless wall distance $y^+ < 1$
- Aspect ratio between 0.5 and 2.0



Structured hexahedral 28 Mio cells grid

WP 3 - Numerical parameter study

Work stages

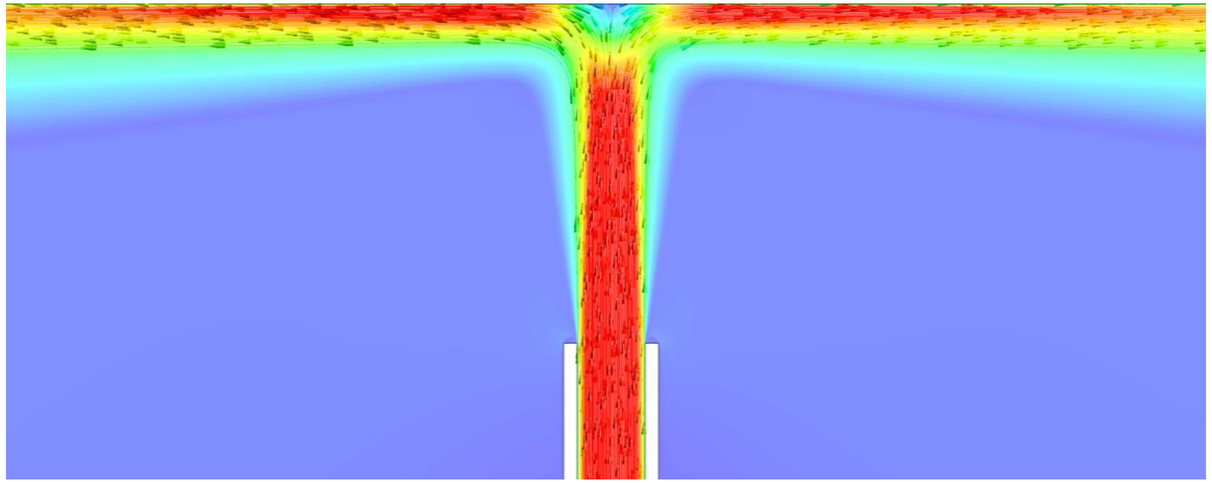
• Geometry design for the numerical parameter study	✓
• Meshing for LES	✓
• LES & evaluation	⋮
• Meshing for RANS Simulation	✓
• RANS Simulation & evaluation	✓
• Validation on the turbulence models with LES	▢

Current status

- Construction of a test bench for the optical flow measurement of impact jets
- Realization of RANS simulations with the SST k-ω and GEKO turbulence model
- Construction of a grid for the LES

Outlook

- Carrying out the PIV measurements
- Investigation of the options of the k-w models
- Performing the LES
- Comparison of the LES and RANS simulations



Thinking the Future
Zukunft denken

Eileen Trampe, M.Sc.

Department for Industrial Furnaces and Heat Engineering
RWTH Aachen University
Kopernikusstr. 10
52074 Aachen
GERMANY

Tel.: +49 (0) 241 80-26051
E mail: trampe@iob.rwth-aachen.de

Industrielle Gemeinschaftsforschung

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages