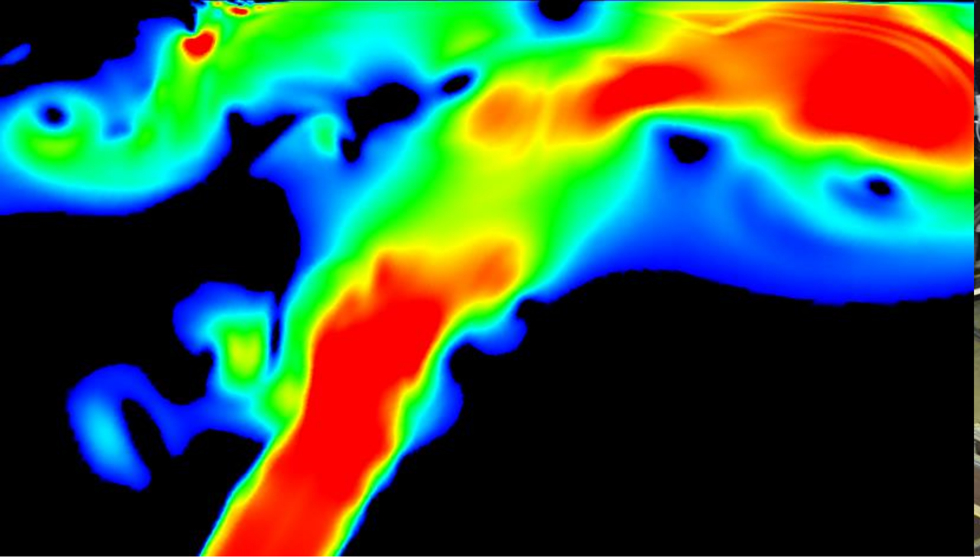
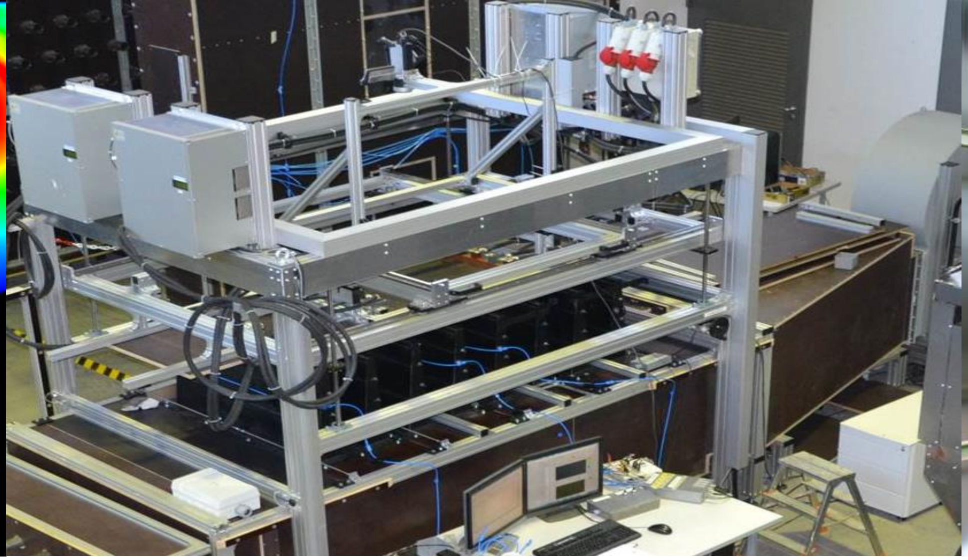




Development and experimental validation of numerical heat transfer models for impingement jets

IGF Project No. 22751 N

1st Project Advisory Committee Meeting

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

31st May, 2023

Institut für Industrieofenbau und Wärmetechnik
RWTH AACHEN UNIVERSITY

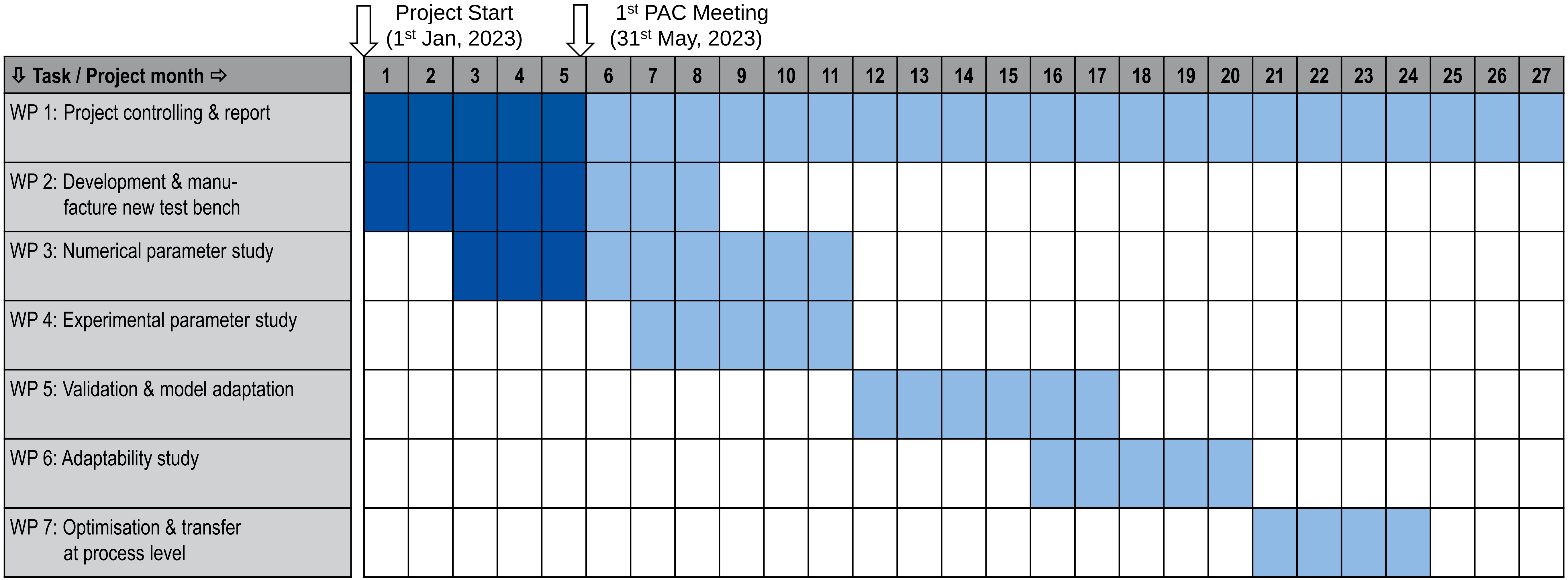
Project Framework

Project advisory committee (PAC)

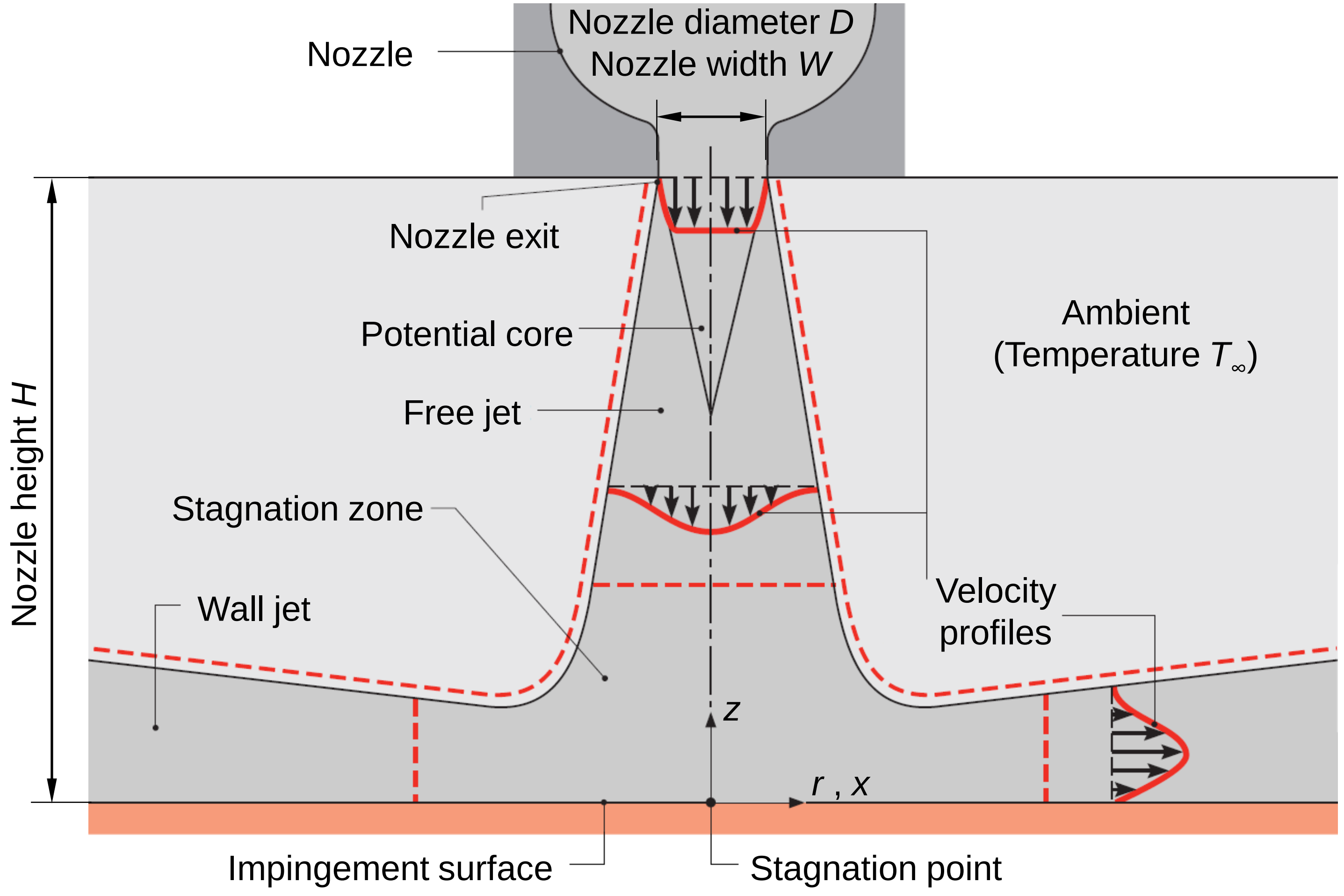
PAC chairperson: *tba*

Project Framework

Gantt chart



Impingement jet



Quelle: Bergman, T. L.; Lavine, A. S.: Fundamentals of Heat and Mass Transfer, 8th ed. Hoboken (NJ, USA): Wiley, 2017

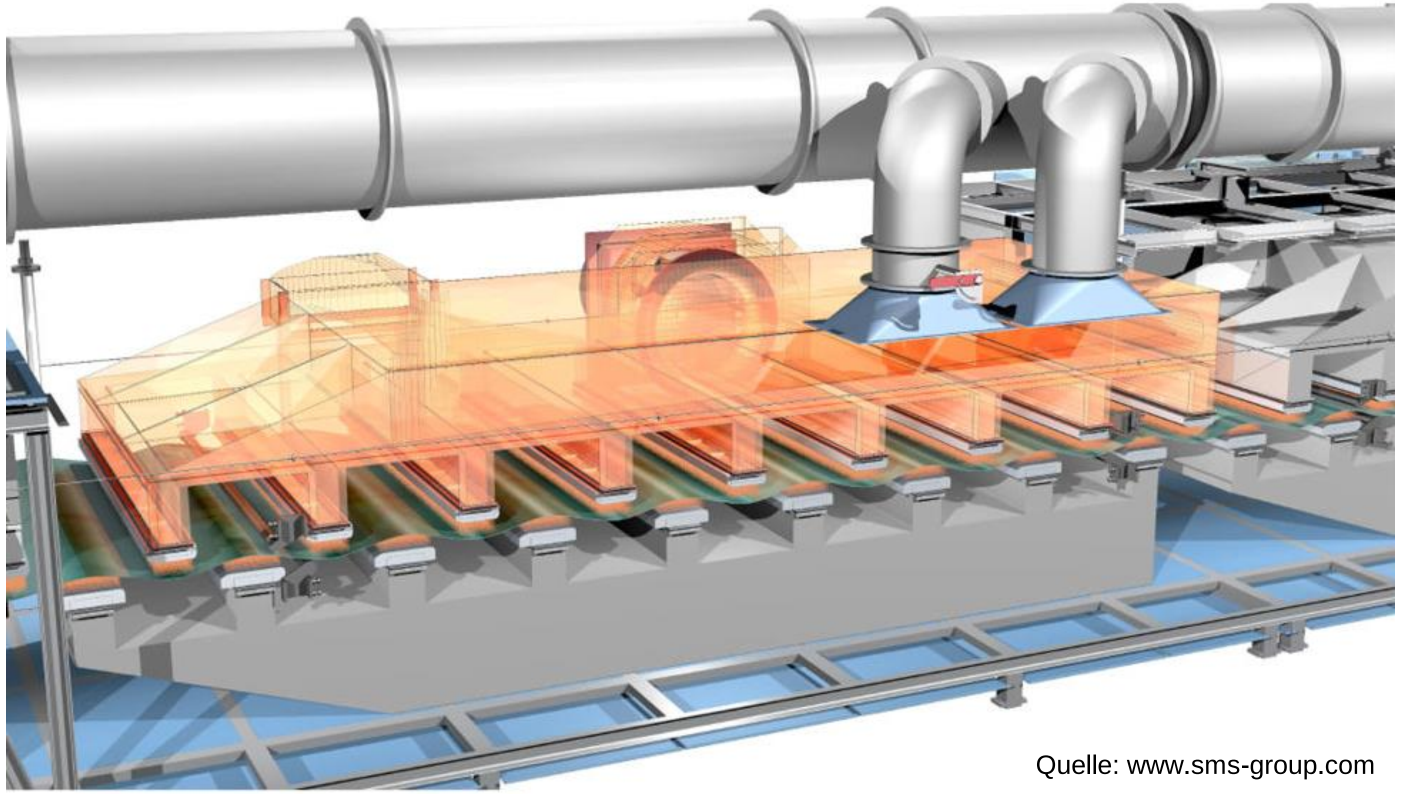
- Jet impacts vertically / possibly at an angle on impact surface
- Formation of a complex flow
- Convective heat transfer between impact jet and surface

Impingement jet application

- Cooling sections in continuous strip furnaces

- Advantages:
  - Fast, uniform cooling
  - Use of pressure pads in strip floatation furnaces

- Differentiation:
  - Slot nozzles
  - Round nozzles
  - Combined nozzle systems



Quelle: www.sms-group.com

Design of nozzle systems

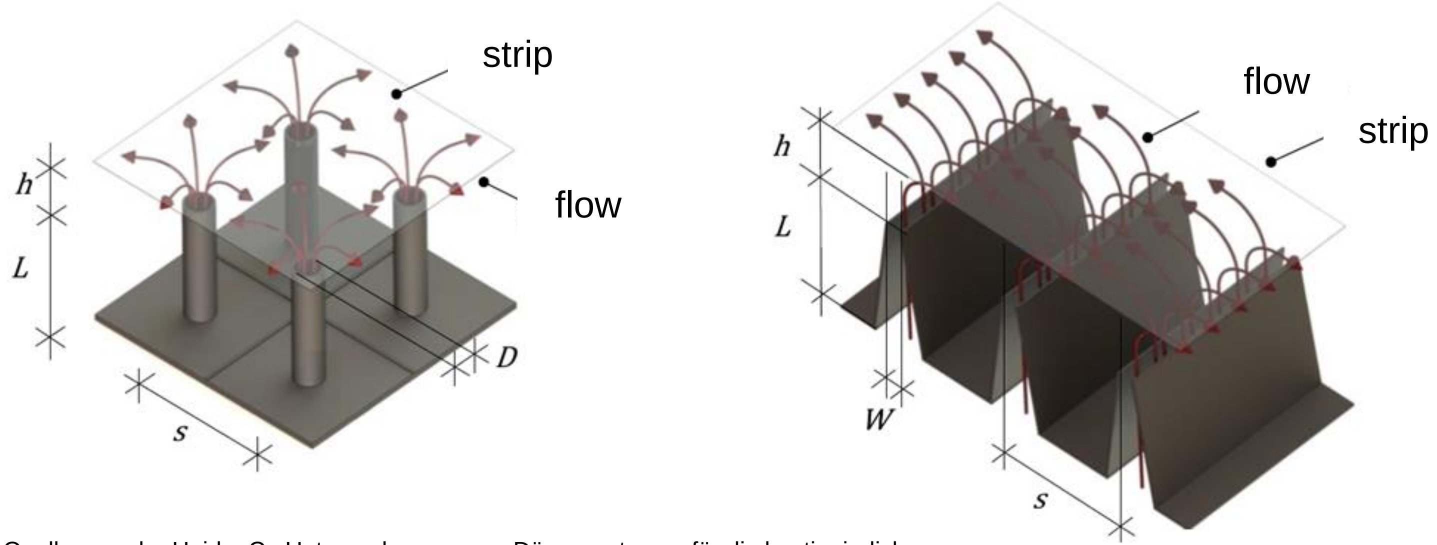
- Pre-design with Nußelt-relation

$$Nu = \frac{\alpha \cdot D_H}{\lambda} = f(Re, Pr, Geometry)$$

  - Limited availability in literature
  - Limited validity (geometry, Reynolds number)

- Detailed design
  - Measurements
  - Simulations

- Design targets
  - High heat transfer
  - Strip stability
  - Optimum fluid performance

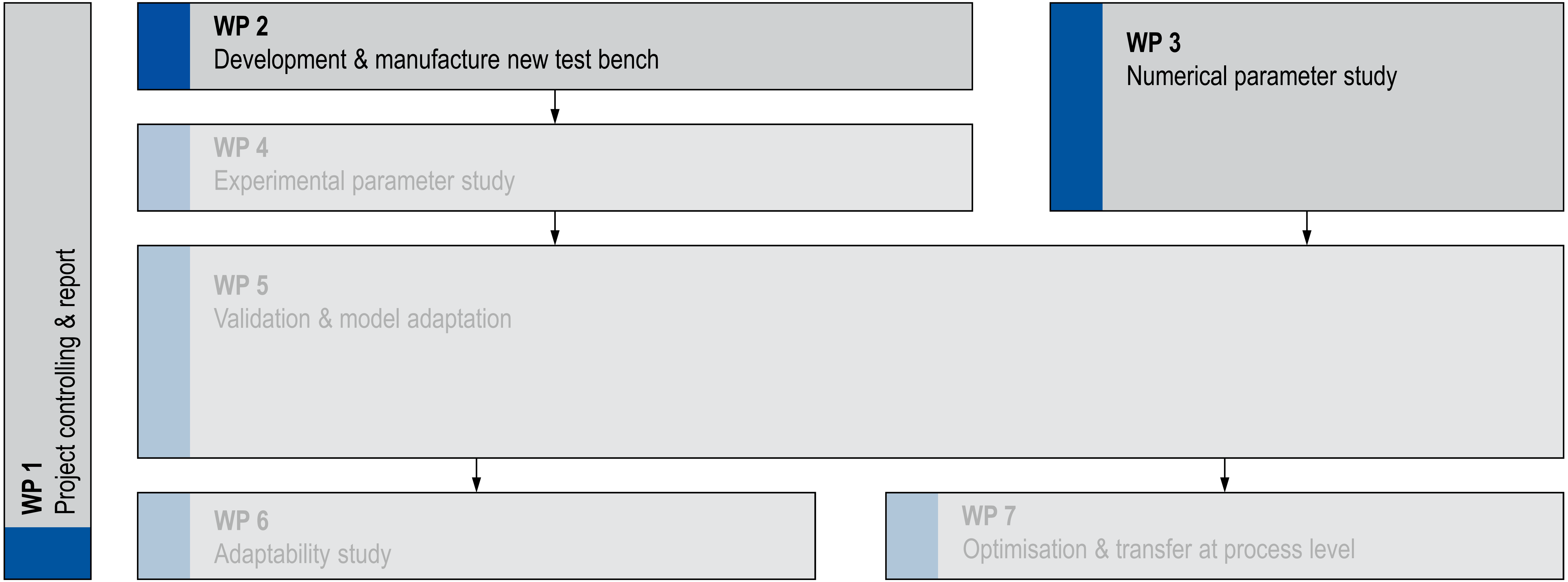


Quelle: von der Heide, C.: Untersuchungen von Düsensystemen für die kontinuierliche Wärmebehandlung von Metallbändern. Diss. RWTH Aachen University, 2018

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

Target-performance comparison

Work Package	Progress	Status
WP 1: Project controlling & report	Act: 20 % Tar: 20 %	☺
WP 2: Development & manufacture of the test bench	Act: 40 % Tar: 65 %	😐
WP 3: Numerical parameter study	Act: 5 % Tar: 30 %	☹
WP 4: Experimental parameter study	Act: 0 % Tar: 0 %	
WP 5: Validation & model adaptation	Act: 0 % Tar: 0 %	
WP 6: Adaptability study	Act: 0 % Tar: 0 %	
WP 7: Optimisation & transfer at process level	Act: 0 % Tar: 0 %	

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	▢

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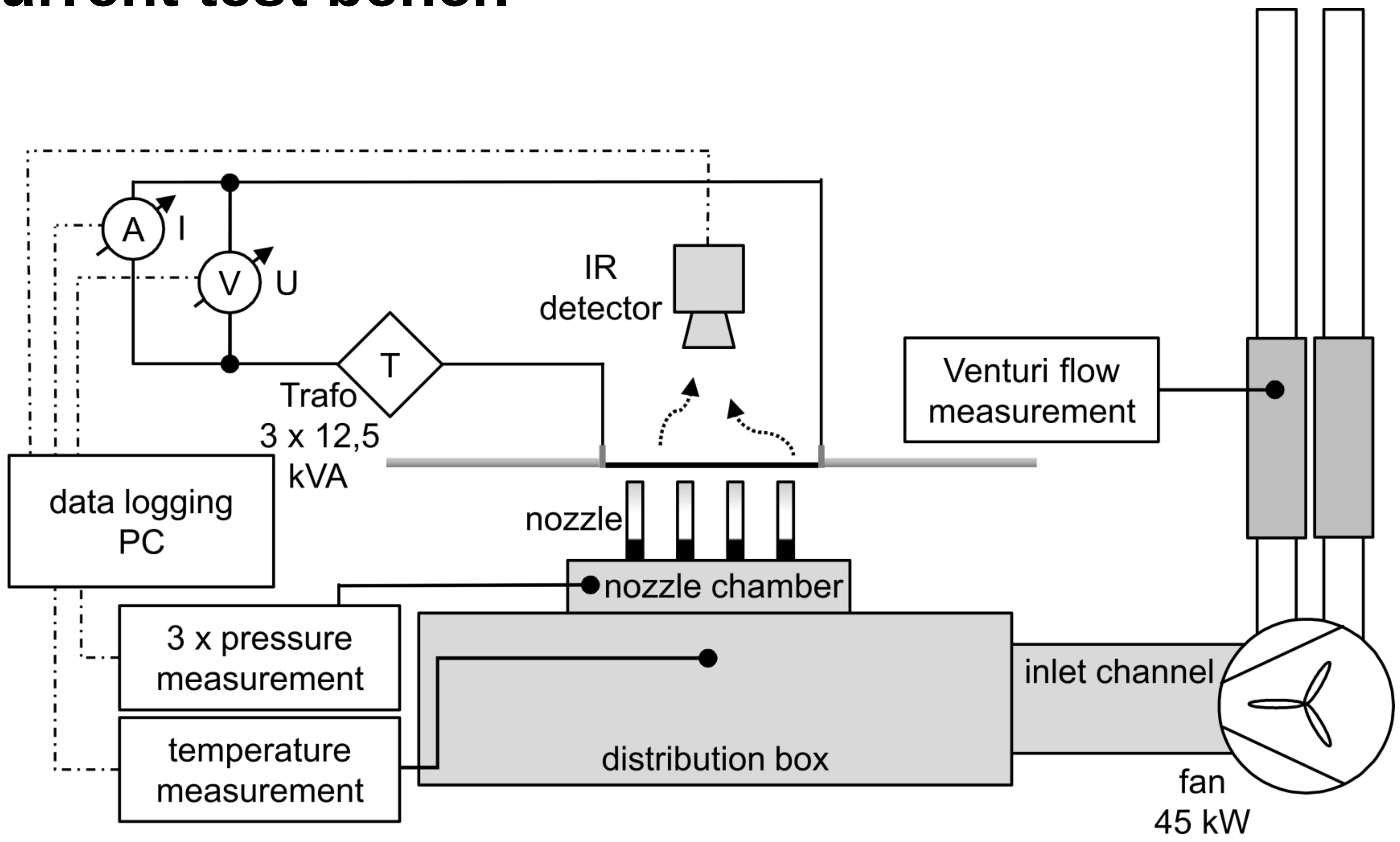
WP 2 - Development & manufacture new test bench

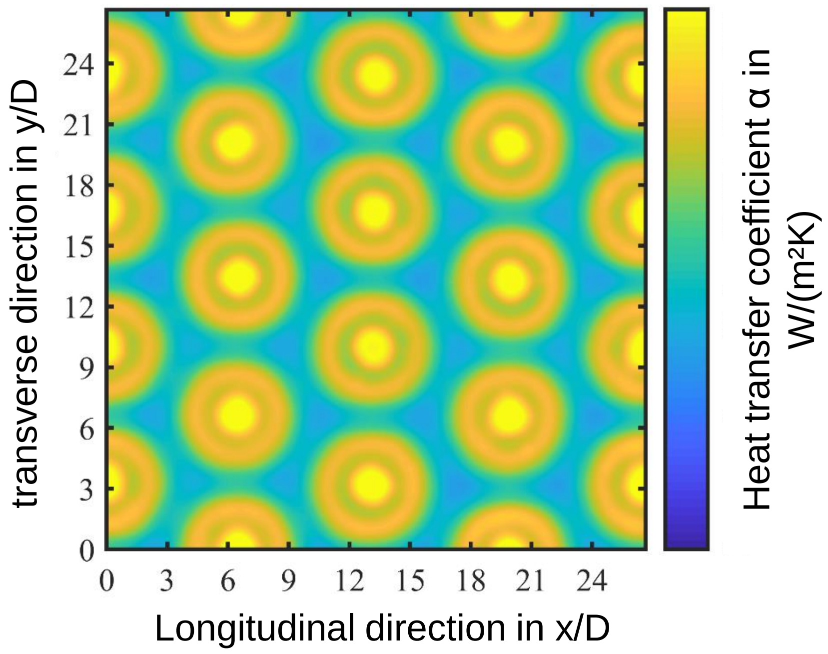
Current test bench

Dimensions
- Height: 5 m
- Width: 3.1 m
- Length: 6.6 m

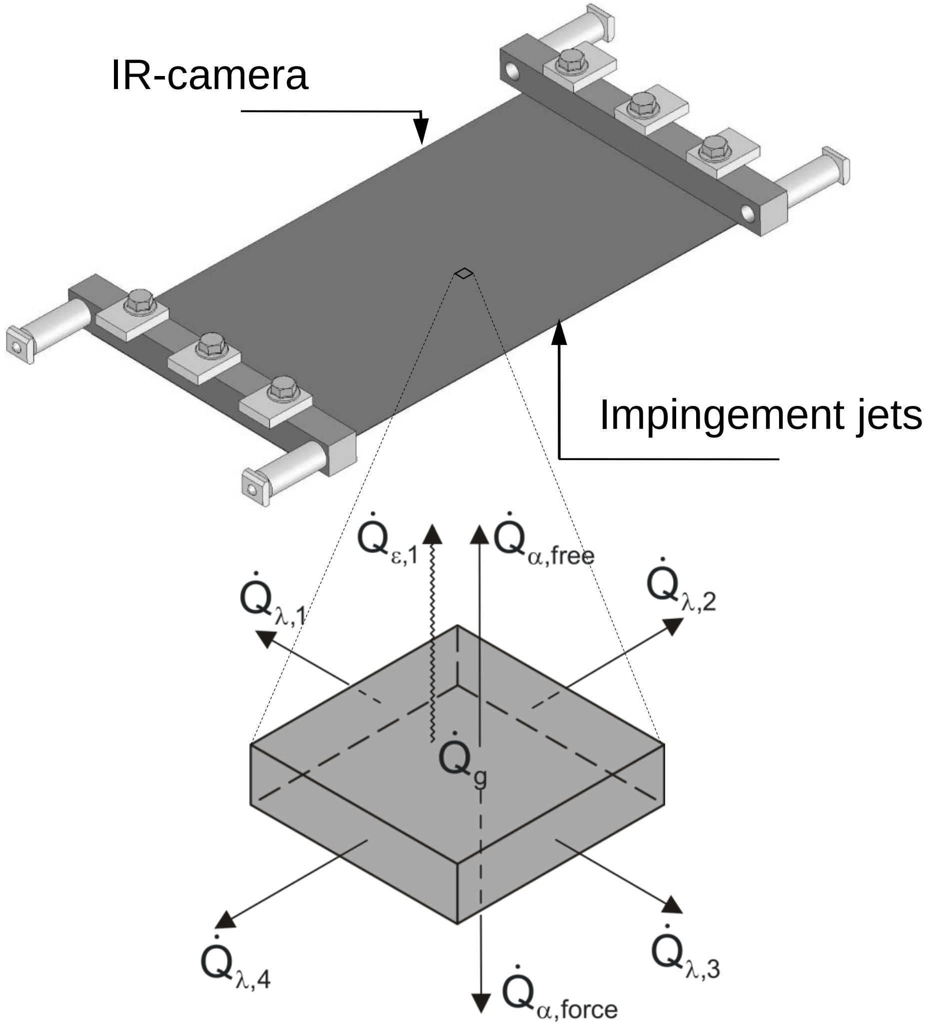
Measurement equipment:
> 100 000 €

Current test bench





Measurement principle heat transfer coefficient

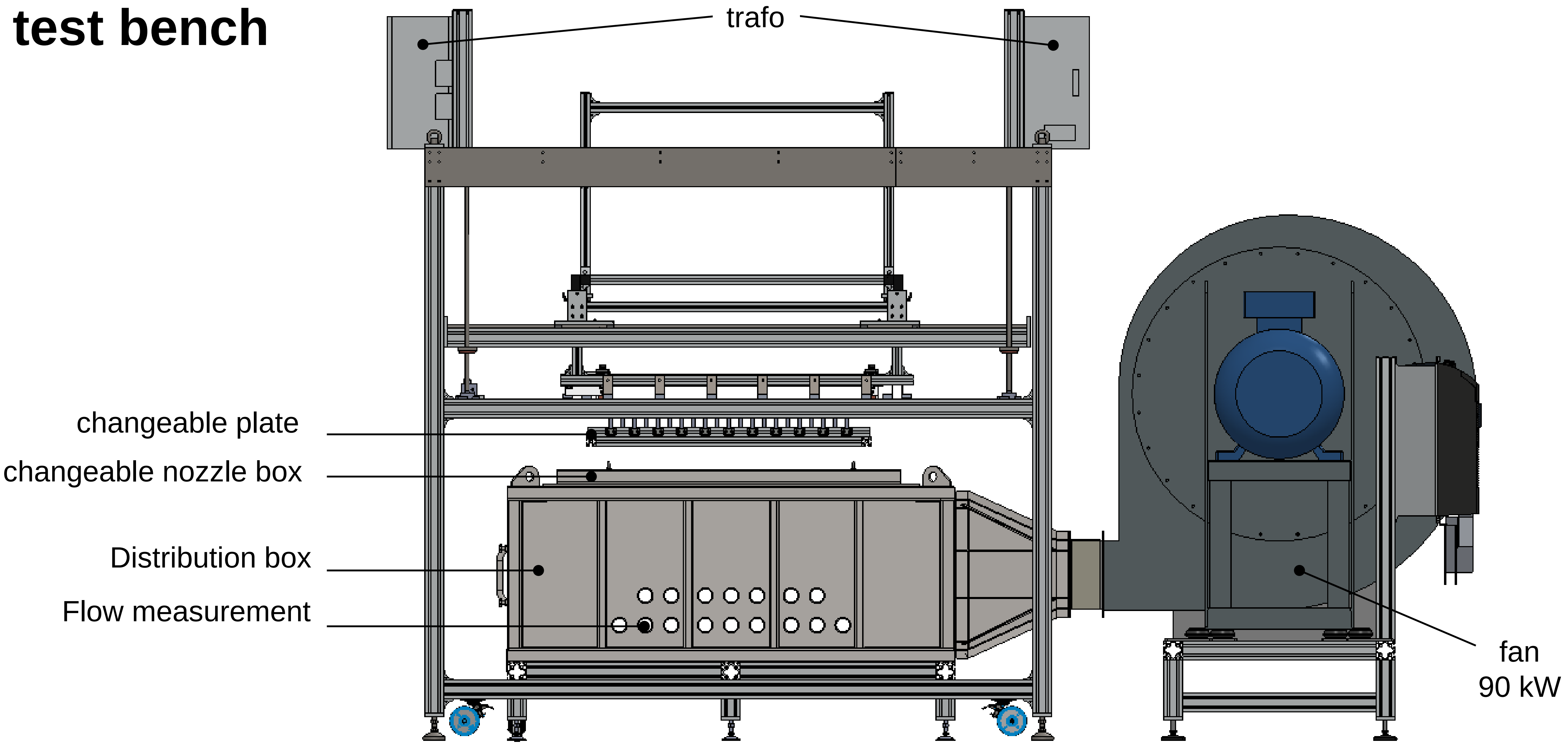


$\dot{Q}_g$	rate of energy generation:	$\dot{Q}_g = \frac{U \cdot I}{n_P}$
$\dot{Q}_{\alpha,free}$	heat transfer rate by free convetion	$\dot{Q}_{\alpha,free} = \alpha_{free}(T_i - T_\infty)A_P$
$\dot{Q}_{\varepsilon,n}$	heat transfer rate by radiation	$\dot{Q}_{\varepsilon,n} = \varepsilon_n \sigma (T_i^4 - T_\infty^4) A_P$
$\dot{Q}_{\lambda,k}$	heat transfer rate by conduction	$\dot{Q}_{\lambda,k} = \frac{\lambda}{s}(T_i - T_k)A_c$
$\dot{Q}_{\alpha,force}$	heat transfer rate by forced convection	$\dot{Q}_{\alpha,force} = \alpha_{force}(T_i - T_\infty)A_P$

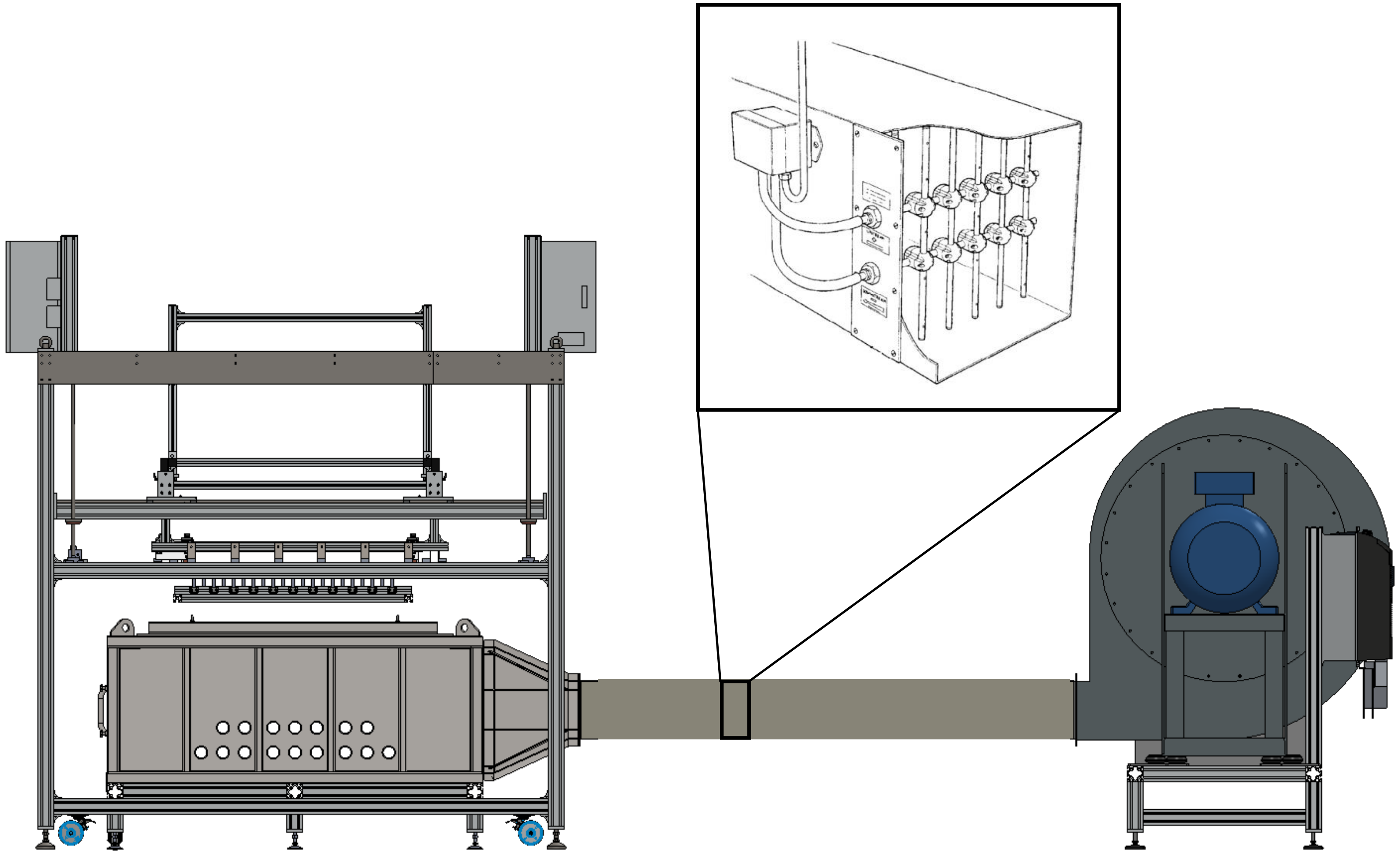
$$\dot{Q}_g = \dot{Q}_{\alpha,force} + \dot{Q}_{\alpha,free} + \sum_n \dot{Q}_{\varepsilon,n} + \sum_k \dot{Q}_{\lambda,k}$$

WP 2 - Development & manufacture new test bench

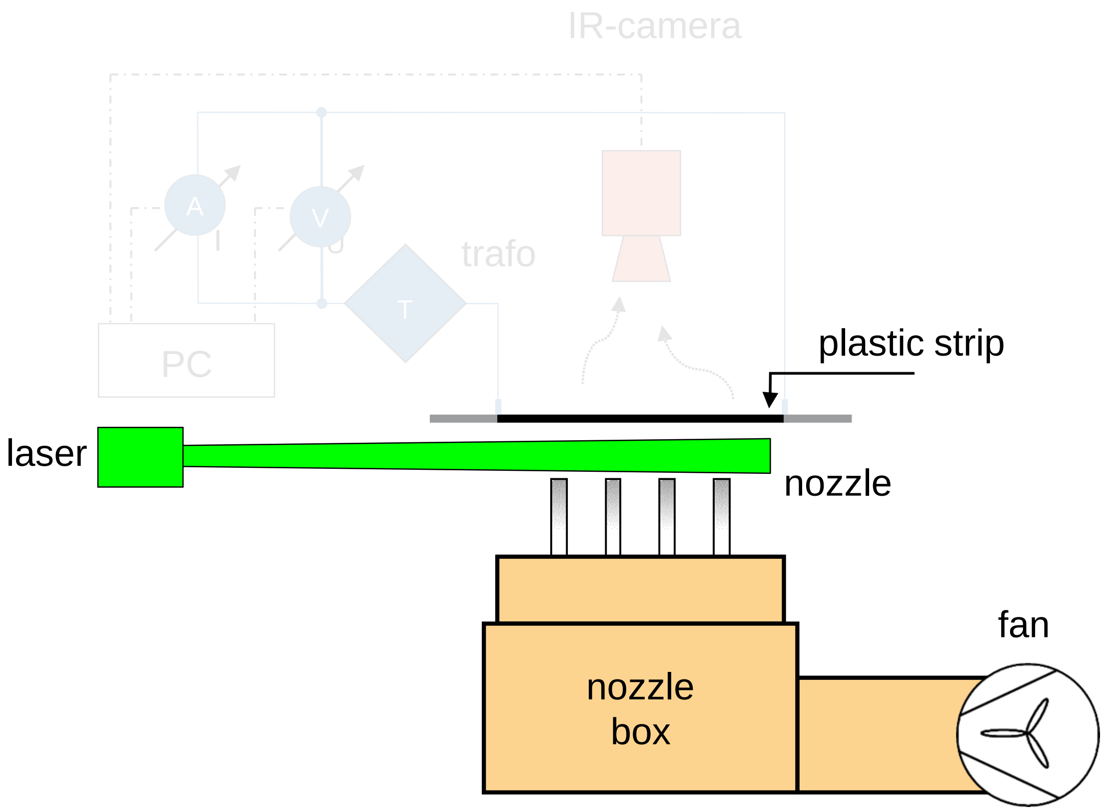
New test bench



New test bench – volume flow measurement



New test bench – Laser measurement



- Implementation of laser protection
  - organisational
  - technical
- Installation seeding device
  - Inlet/ Outlet section
  - Particle size
  - Particle quantity

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 ▢

WP 3 - Numerical parameter study

Aims of work package 3

Identification of influences of the numerical modelling,
selection of max. 3 suitable turbulence models

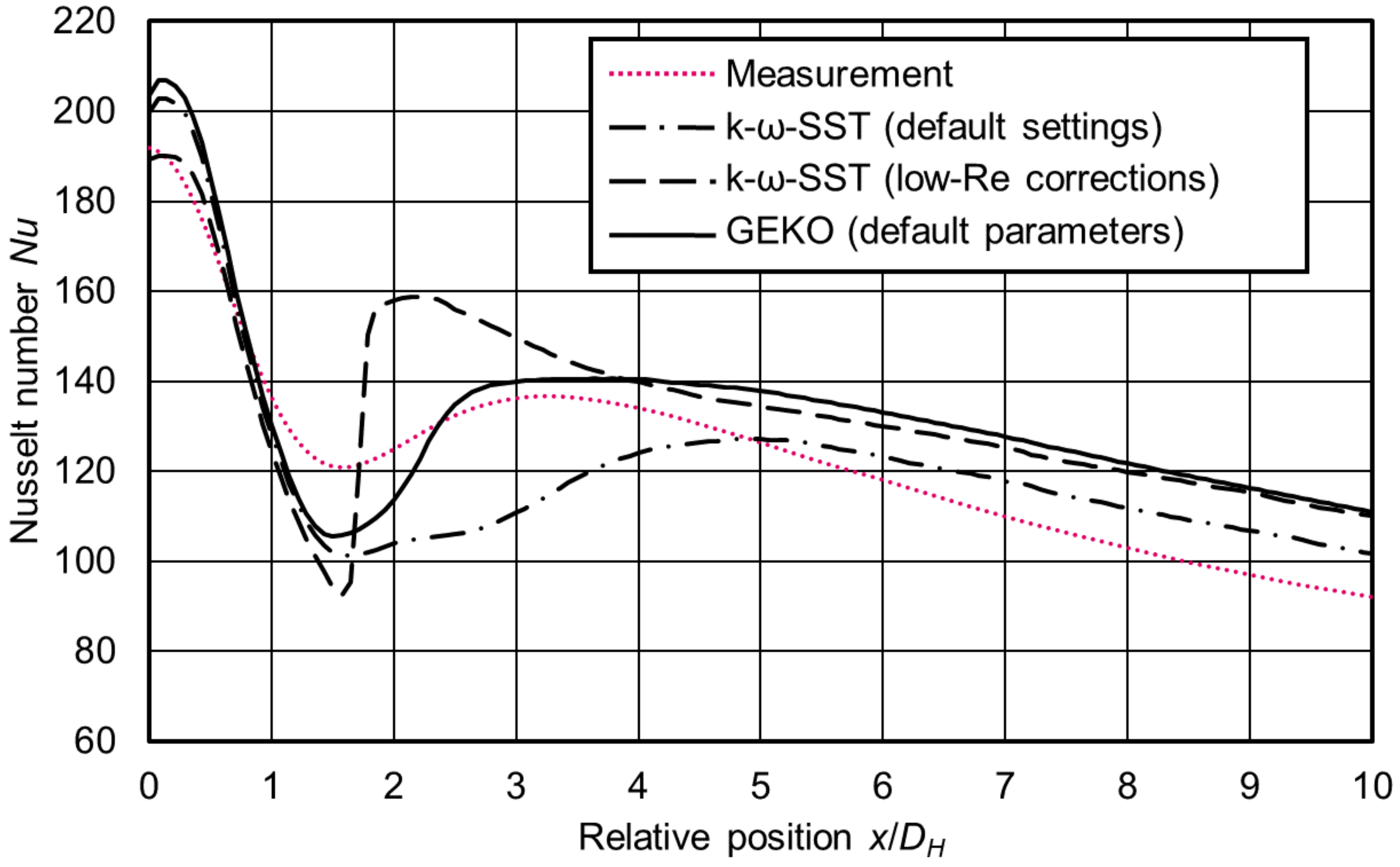
- Definition of 4 standard cases (1 RD, 1 SD, 1 RD field, 1 SD field)
- Pre-selection of potentially suitable turbulence models
- Mesh study, turbulence parameter study, variation of model options & boundary conditions
- Comparison LES ↔ RANS simulations

WP 3 - Numerical parameter study

Previous work Menzler

Applying the ANSYS GEKO Turbulence Model to Simulate Jet Impingement

- Based on k-ω model formulation
- Can be tuned without affecting model calibration, 6 free parameters
- Slot nozzle width 10 mm



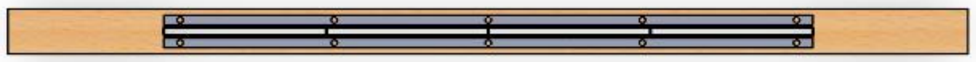
Definition standard cases

Slot nozzle

- Nozzle width: 10 mm
- Nozzle length: 1000 mm
- Nozzle exit area: 100 cm²

Slot nozzle field

- 5 times single slot nozzle
- Spacing changeable



Round nozzle

- No single round nozzle present
- Nozzle diameter: *25 mm*
- Nozzle exit area: *20 cm²*

Slot nozzle field

- must be manufactured
- Spacing fix

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 ▢

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Industrielle Gemeinschaftsforschung

Thinking the Future
Zukunft denken

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