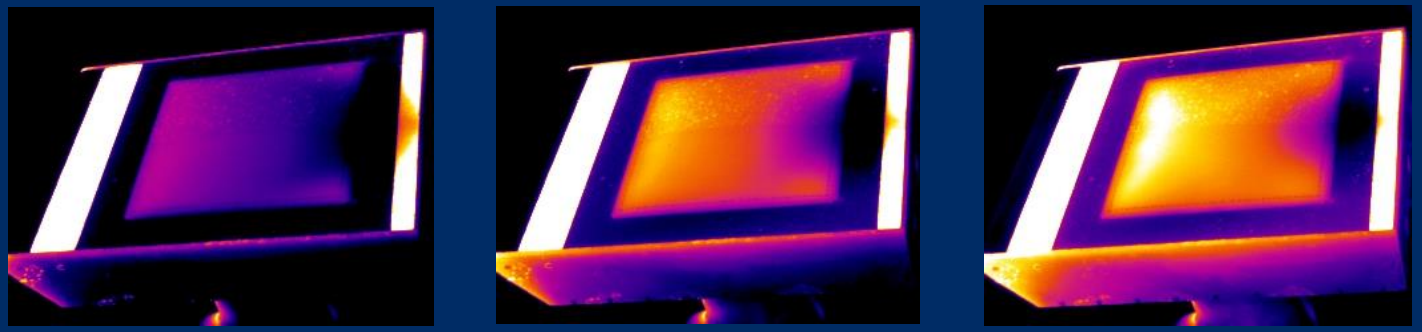
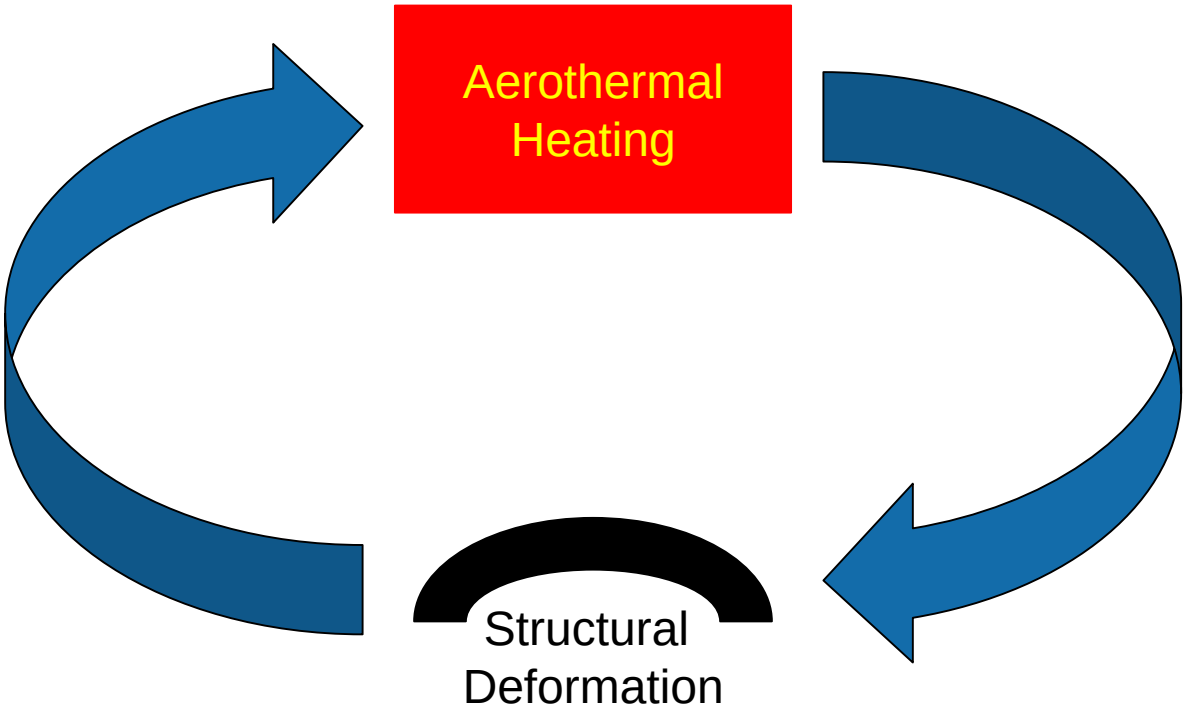


Thermomechanical Fluid-Structure Interaction in Supersonic Flows: Experiments and Simulation

Katharina Martin, Stefanie Reese, IFAM, RWTH Aachen University
Dennis Daub, Burkard Esser, Ali Gülhan, AS-HYP, DLR Köln

Motivation

Why study thermomechanical FSI?



Motivation

Ariane 5 flight 517

Buckling of nozzle cooling channels

Stahlkocher - **CC BY-SA 3.0**

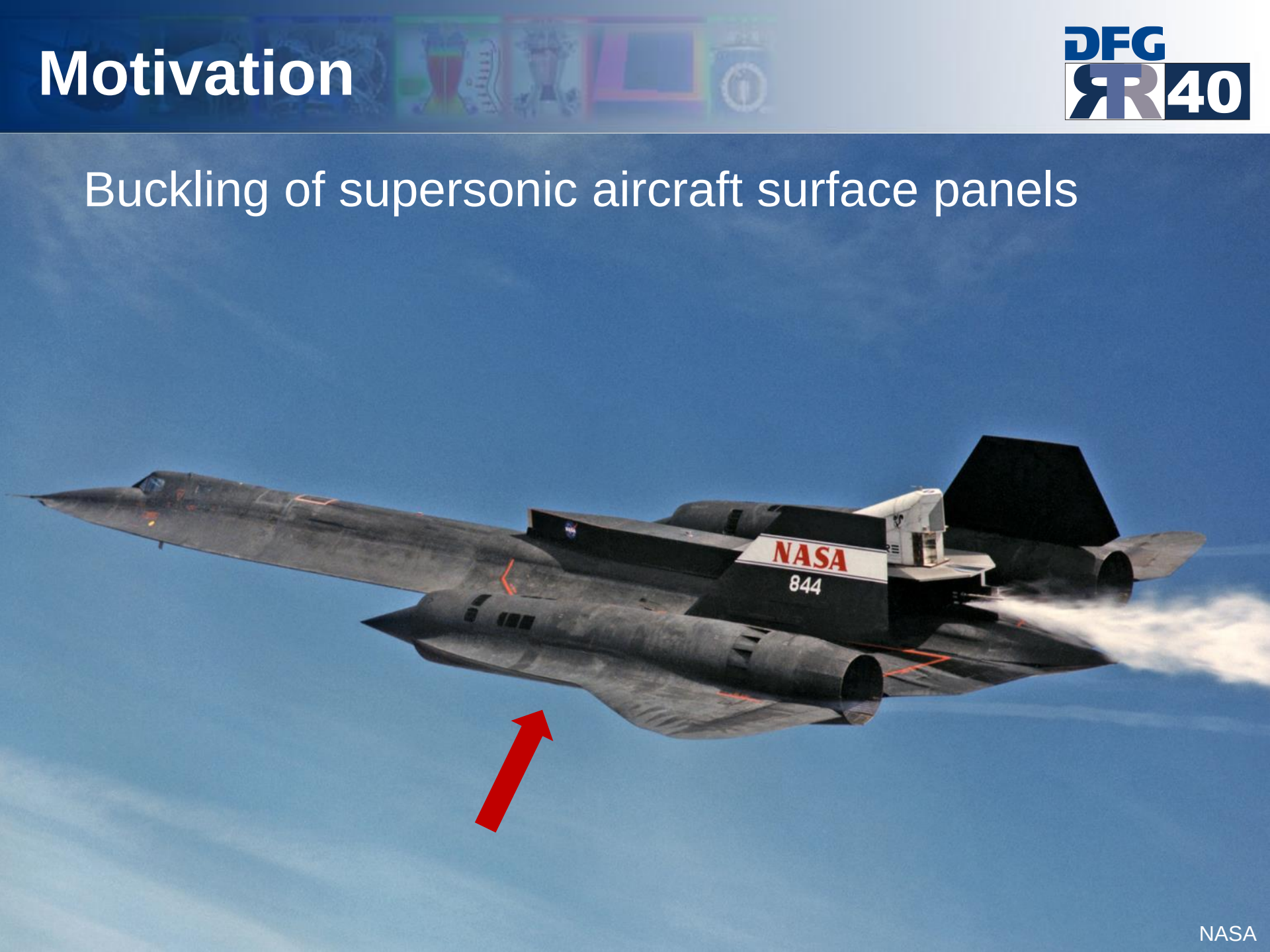
Motivation

Metallic thermal protection for reusable launchers

SpaceX - **CC BY-NC 2.0**

Motivation

Buckling of supersonic aircraft surface panels

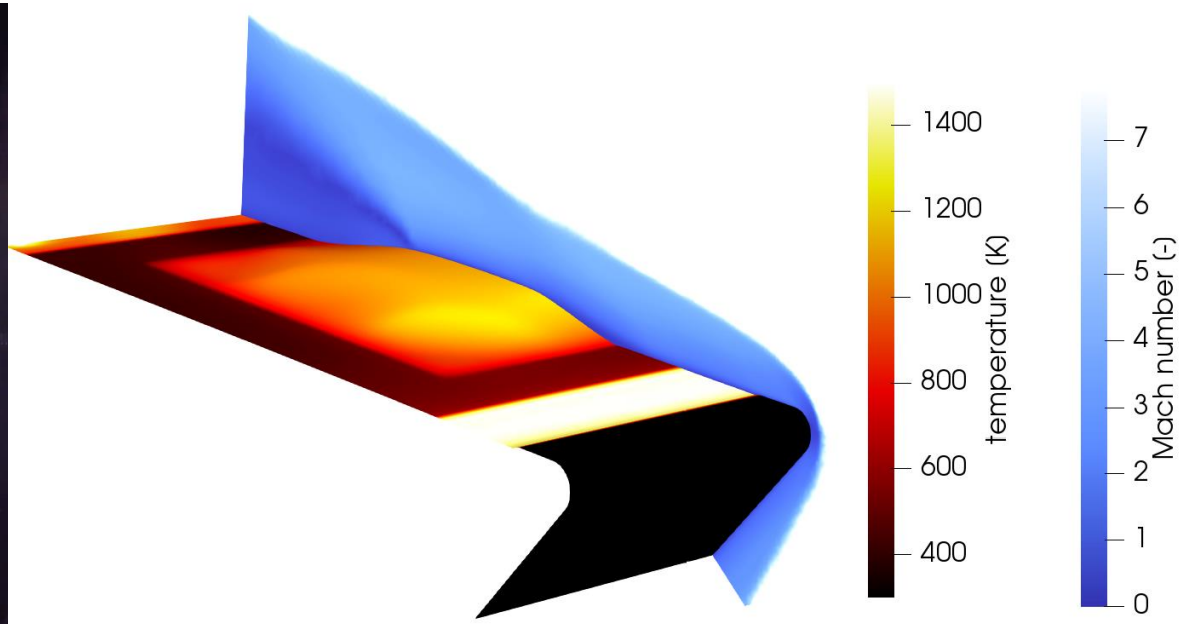


NASA

Motivation

Buckling of supersonic aircraft surface panels
Dennis Daub

Overview



Joint experimental and numerical study of fluid-structure coupled buckling problems using a generic configuration

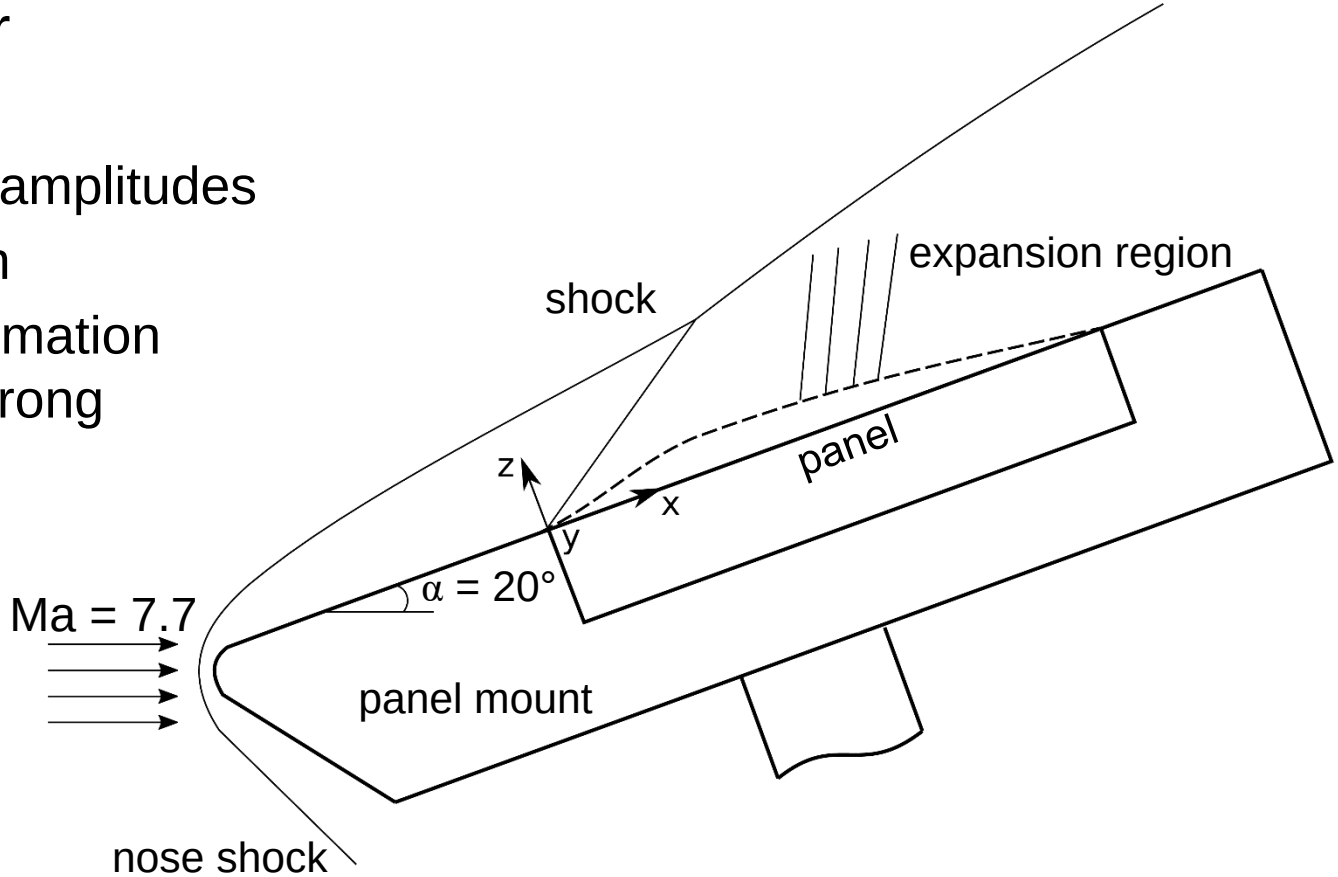
Supersonic Fluid-Structure Interaction in SFB TRR 40

- Turbulent SWBLI loads (D4 + D6 FP. 1/2)
- Flutter + Turbulent SWBLI (D6 FP. 3)
- Thermal buckling including plastic behavior (D10 + D6 FP. 3)

Modelling / Simulation

Main effects under investigation

- Buckling with high amplitudes
- Plastic deformation
- Interaction of deformation with flow field → strong localized heating



Effect of buckling on the flow

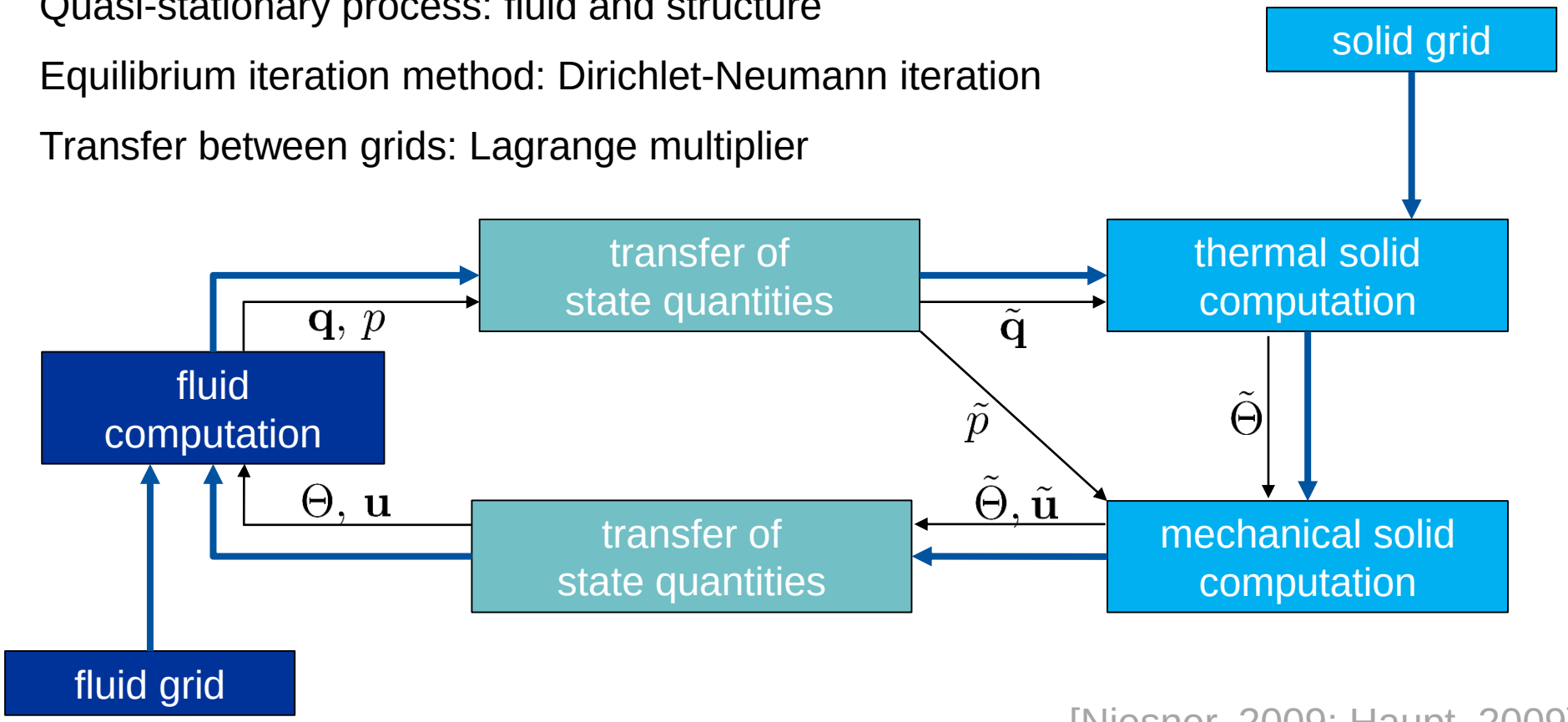
Fluid-structure interaction (FSI)

Coupling tool IFLS, TU Braunschweig

Quasi-stationary process: fluid and structure

Equilibrium iteration method: Dirichlet-Neumann iteration

Transfer between grids: Lagrange multiplier

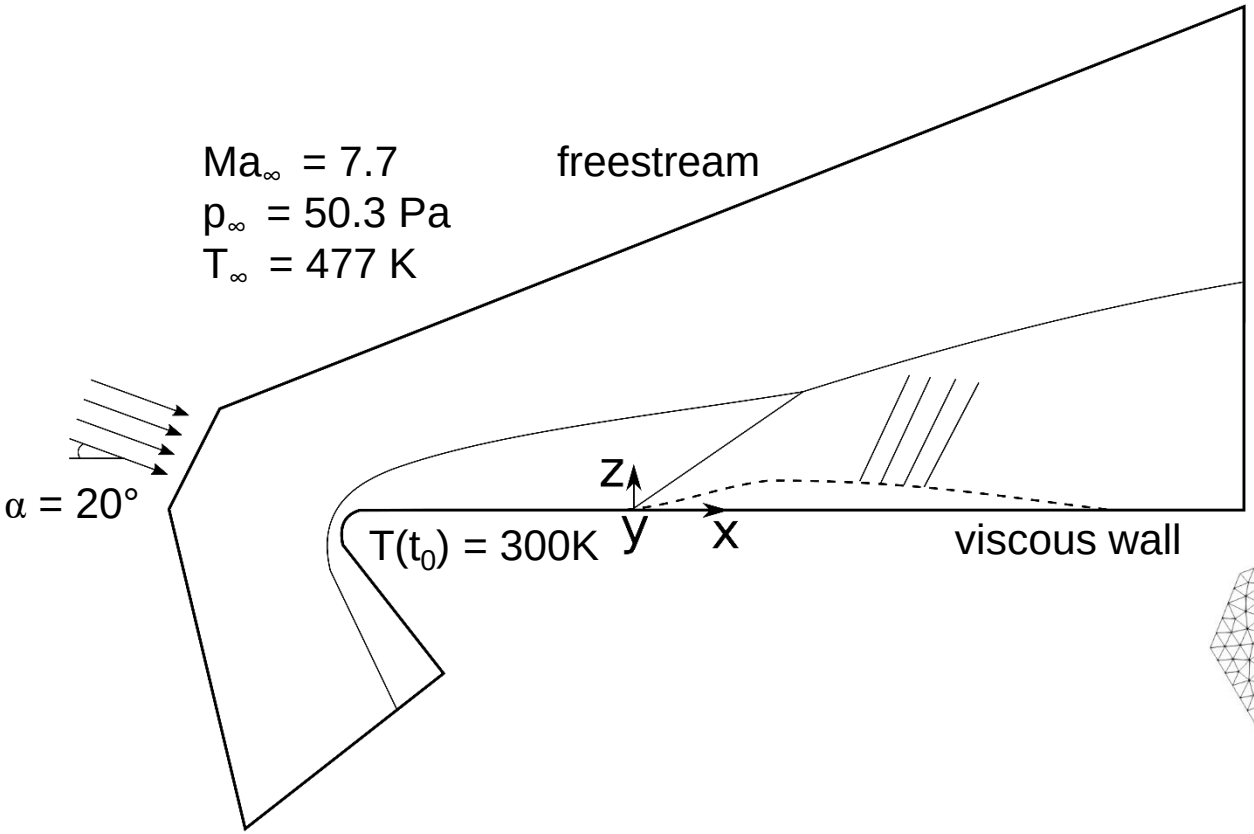


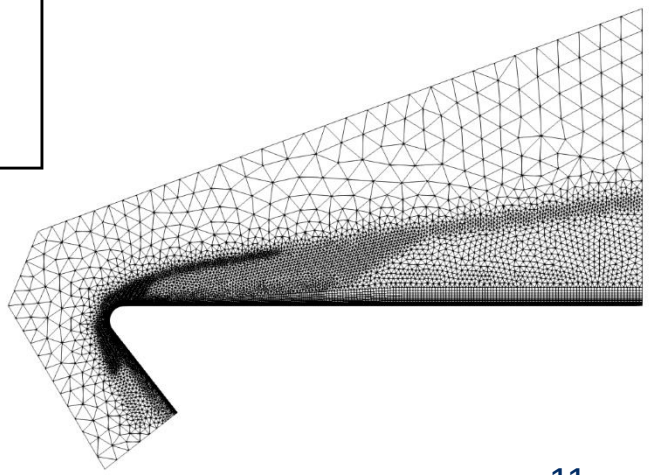
[Niesner, 2009; Haupt, 2009]

Technische Universität Braunschweig

Fluid computation

- DLR Tau solver; laminar flow; ideal gas $\gamma = 1.451$
- Hybrid mesh, structured layers on the wall
- Mesh deforms as panel surface deforms





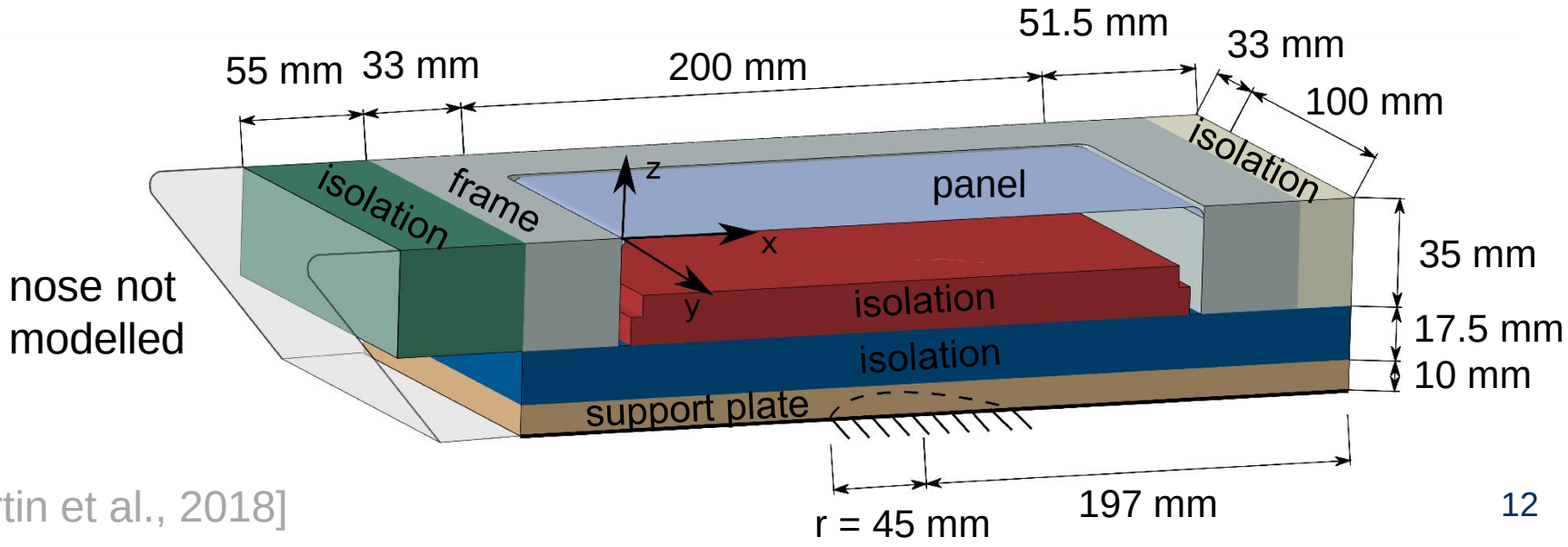
Structural Computation

Material:

- panel and frame: Incoloy 800 HT
- isolation: Schupp Ultra Board 1850/500
- support plate: copper

Material model:

- mechanical: viscoplastic with nonlinear isotropic hardening + thermal expansion
- thermal: heat flux (Fourier) and radiation



[Martin et al., 2018]

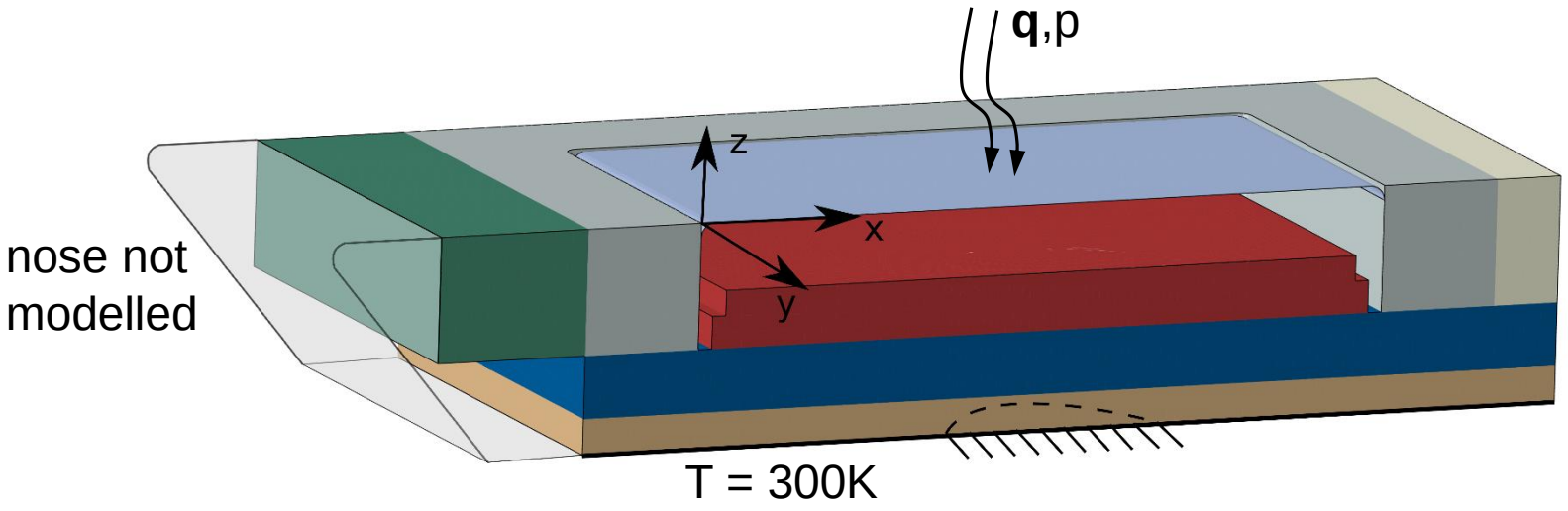
Boundary Conditions (BC)

Thermal boundary condition:

- bottom: temperature T = 300K
- top: heat flux **q** from fluid simulation
- cavity radiation between panel and isolation / radiation on top surface

Mechanical boundary condition:

- bottom: circular fixation
- top: pressure p from fluid simulation
- symmetrical BC at y = 0



[Martin et al., 2018]

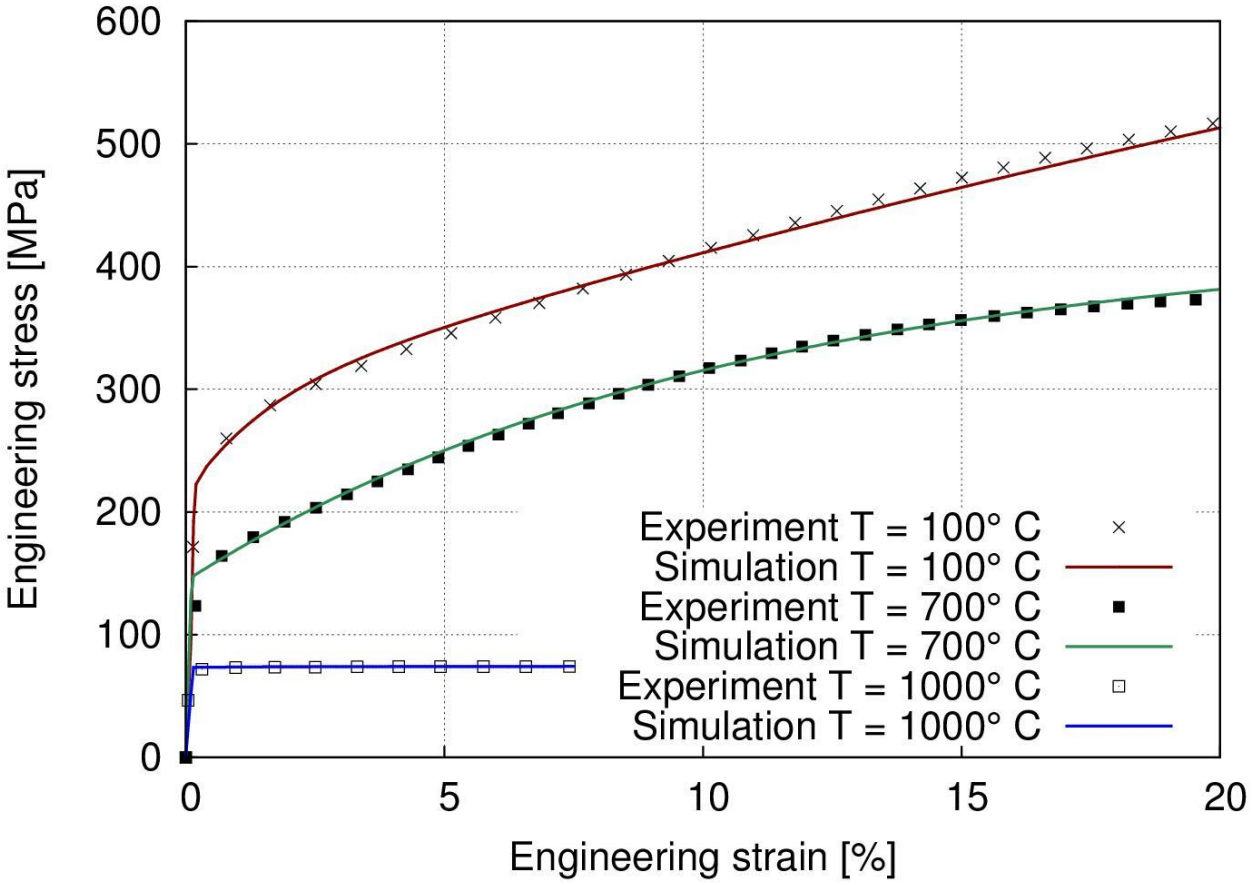
Material model for panel

- Viscoplastic material model with
  - nonlinear isotropic hardening
  - thermal expansion
  - temperature dependent material parameters
- implemented in an Abaqus UMAT
- modified for a plane stress state in order to also use it for shell elements
- thermo-dynamically consistent
- large deformations

[Martin et al., 2019]

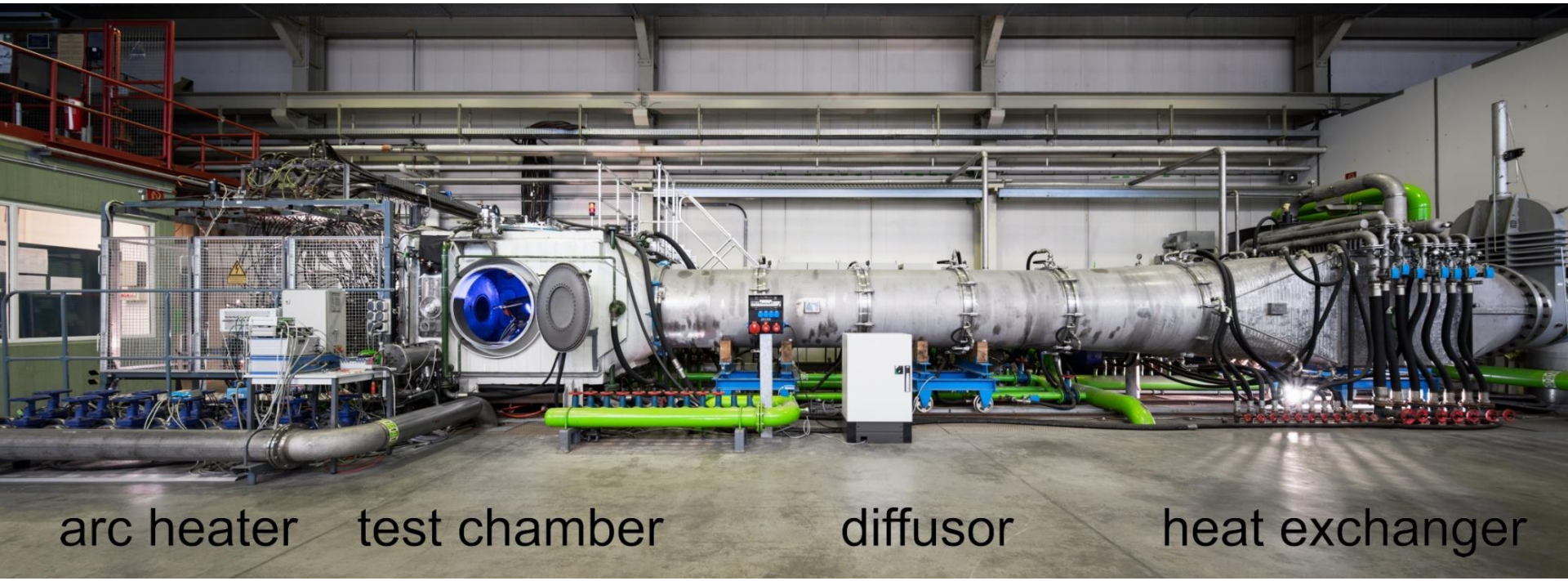
Material tests for Incoloy 800 HT

- Temperature range: 20°C – 1000°C
- loading rate: 0.5mm/min; 1mm/min



[Martin et al., 2018]

Arc-heated Wind Tunnel L3K



Ma_∞ = 7.7

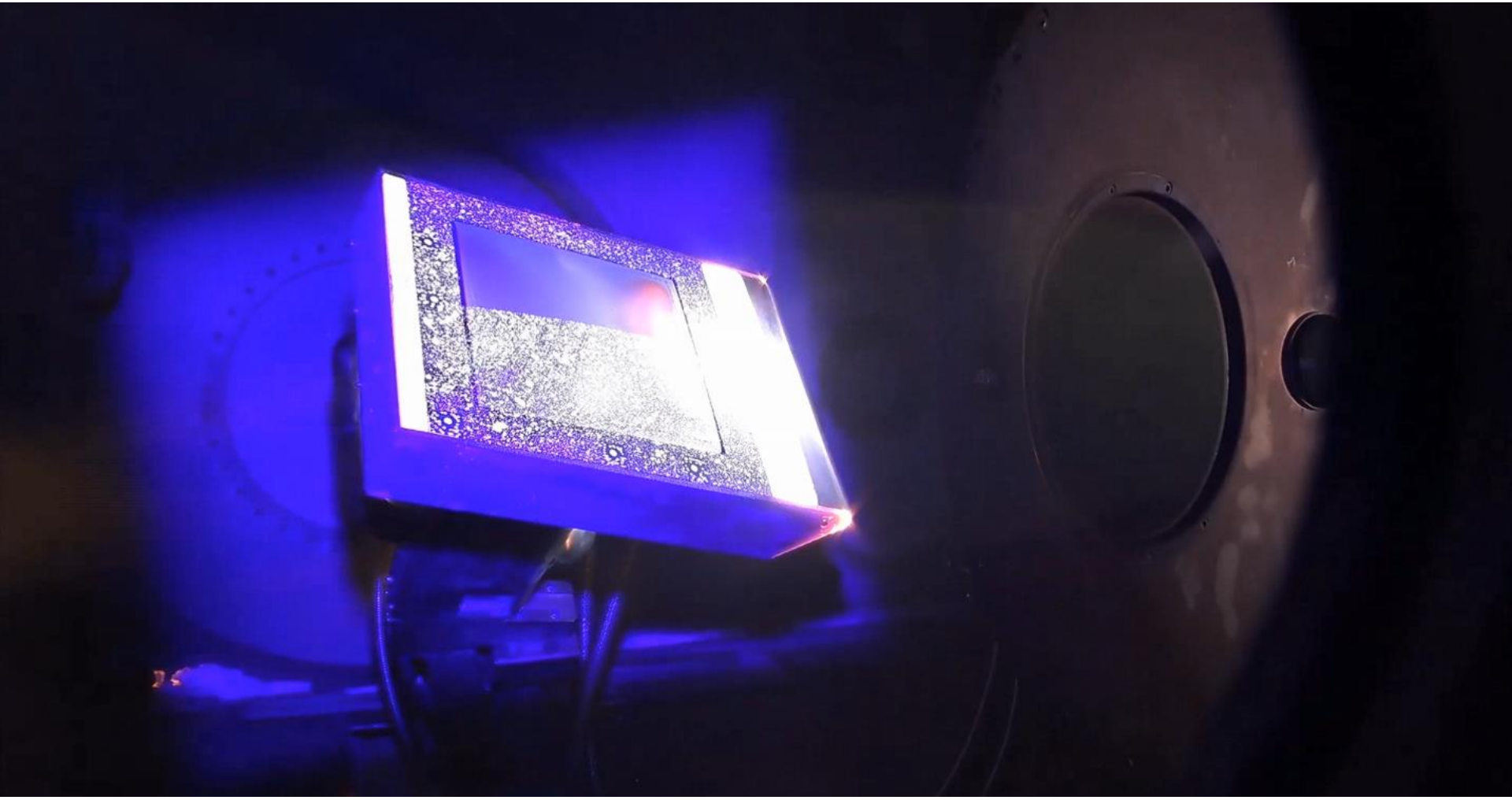
p_∞ = 50.3 Pa

T_∞ = 477 K

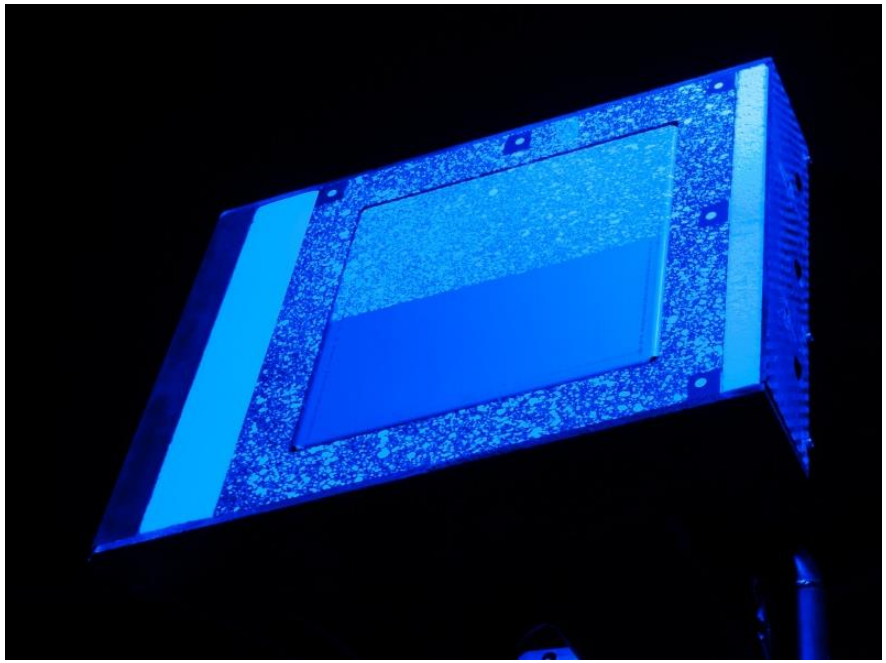
v_∞ = 3756 m/s

[Daub, 2020]

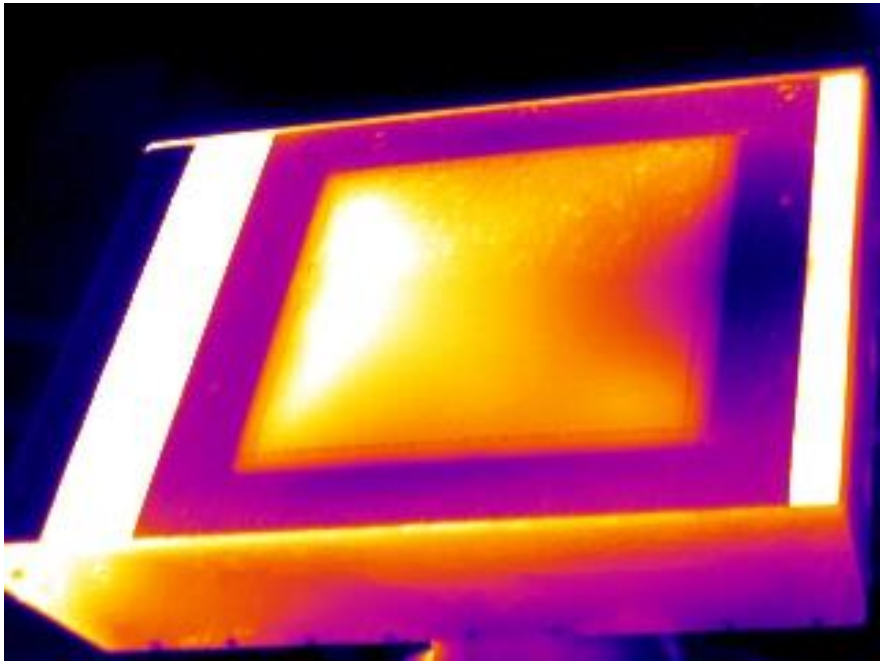
Wind Tunnel Run



Instrumentation

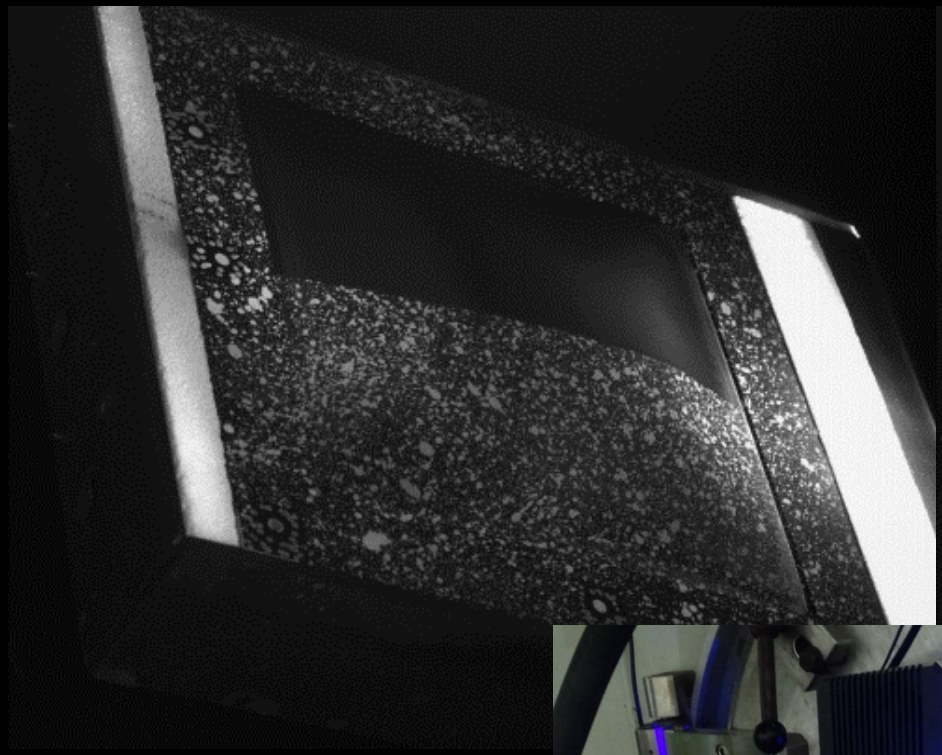


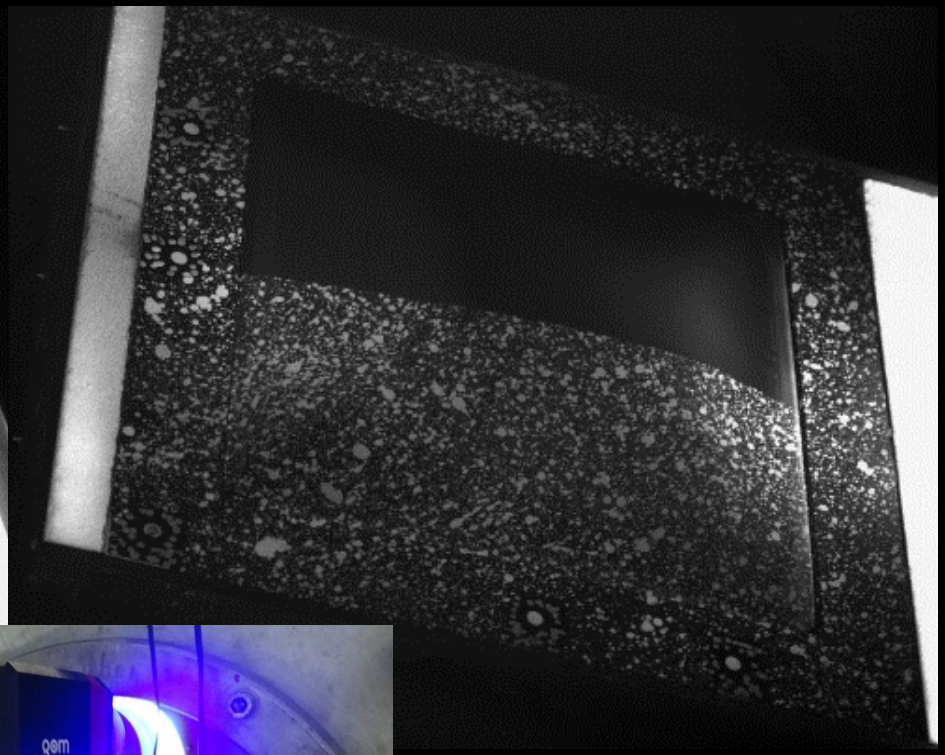
Digital Image Correlation (DIC)

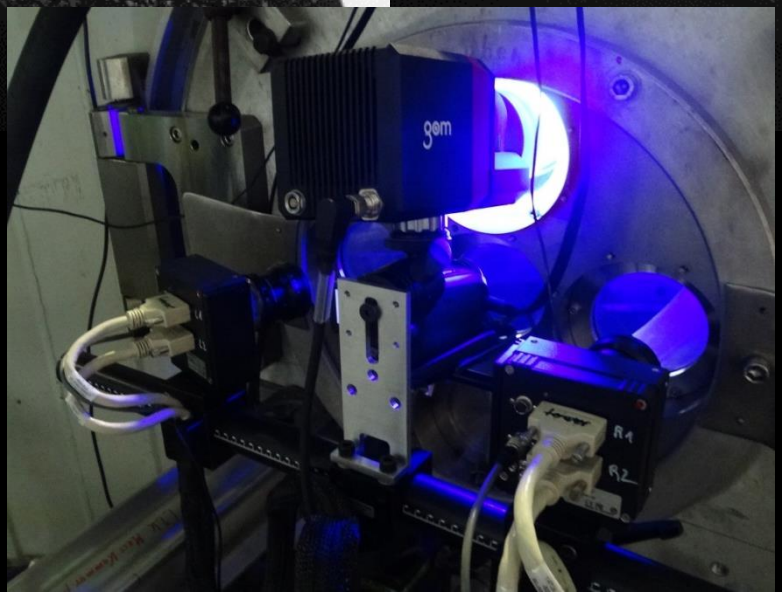


Infrared Thermography (IR)

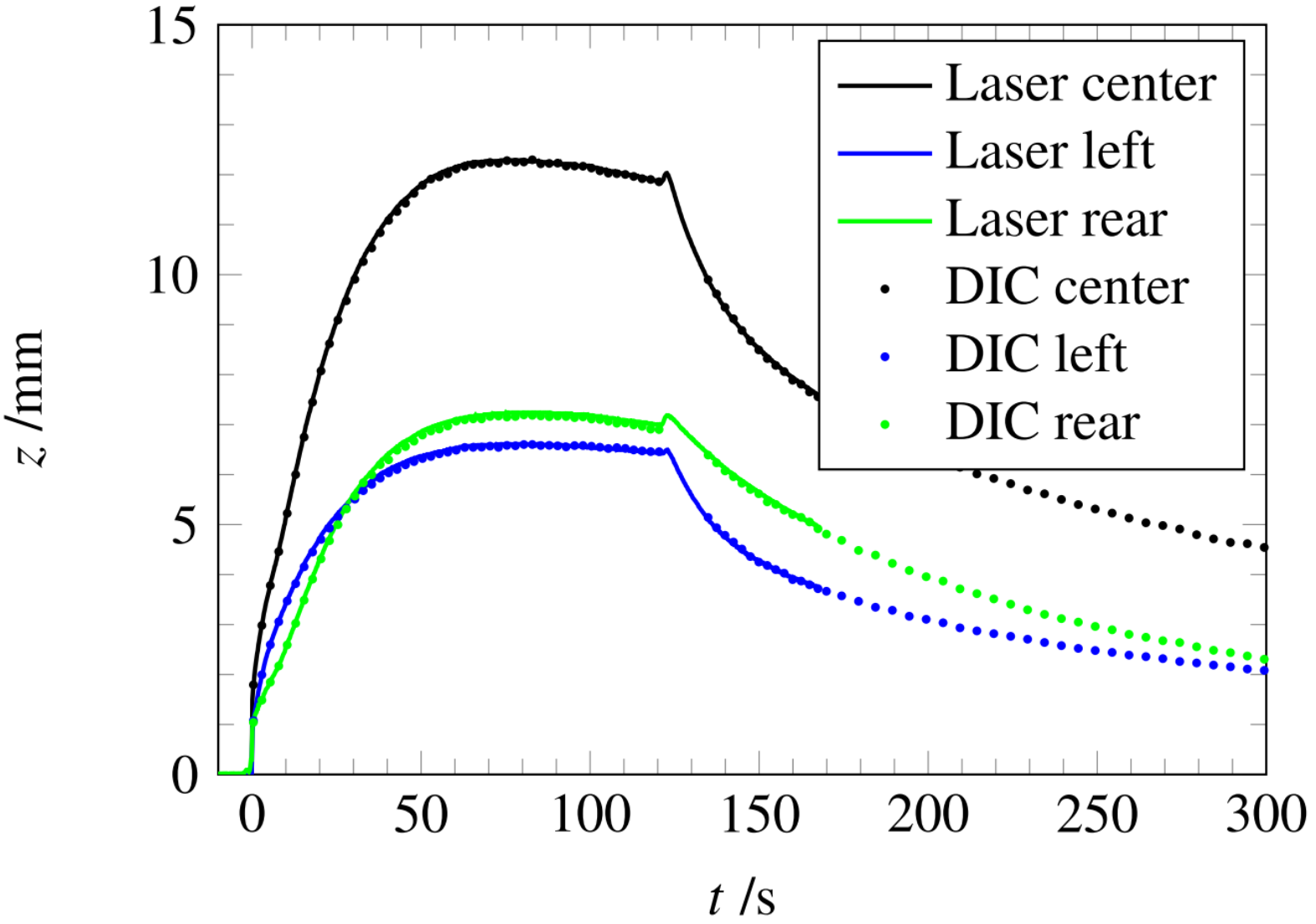
Digital Image Correlation (DIC)



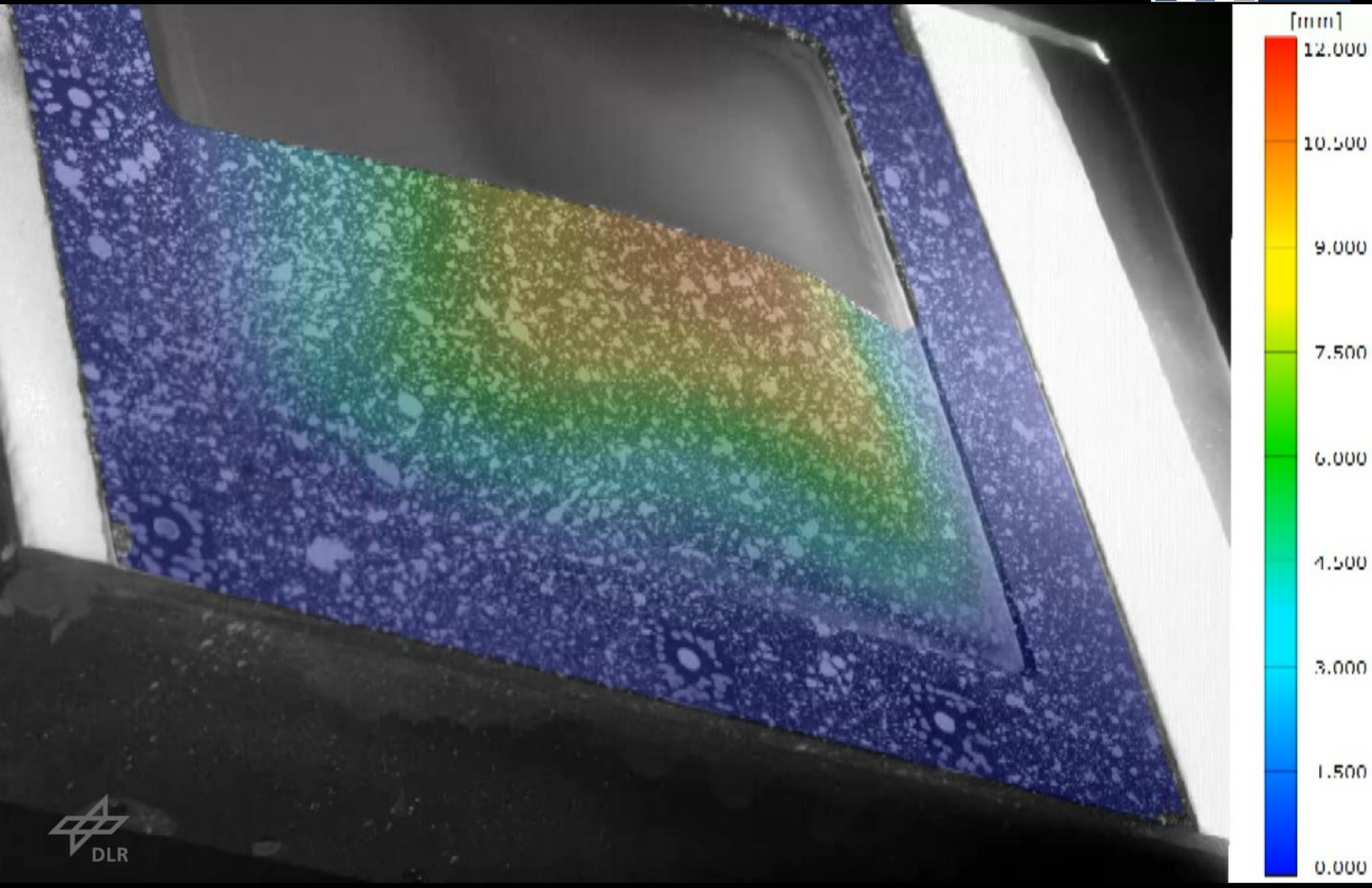




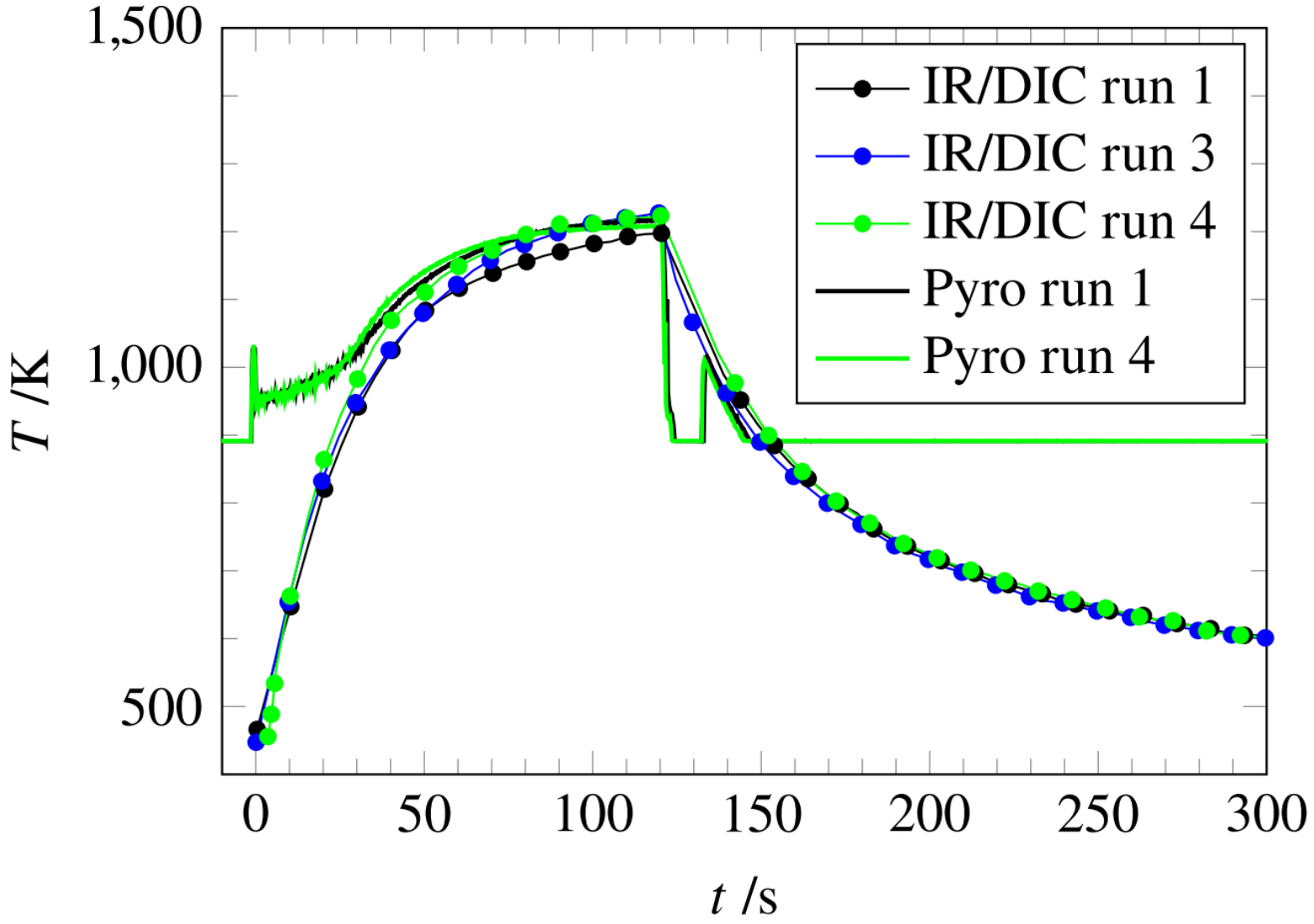
Validation (DIC)



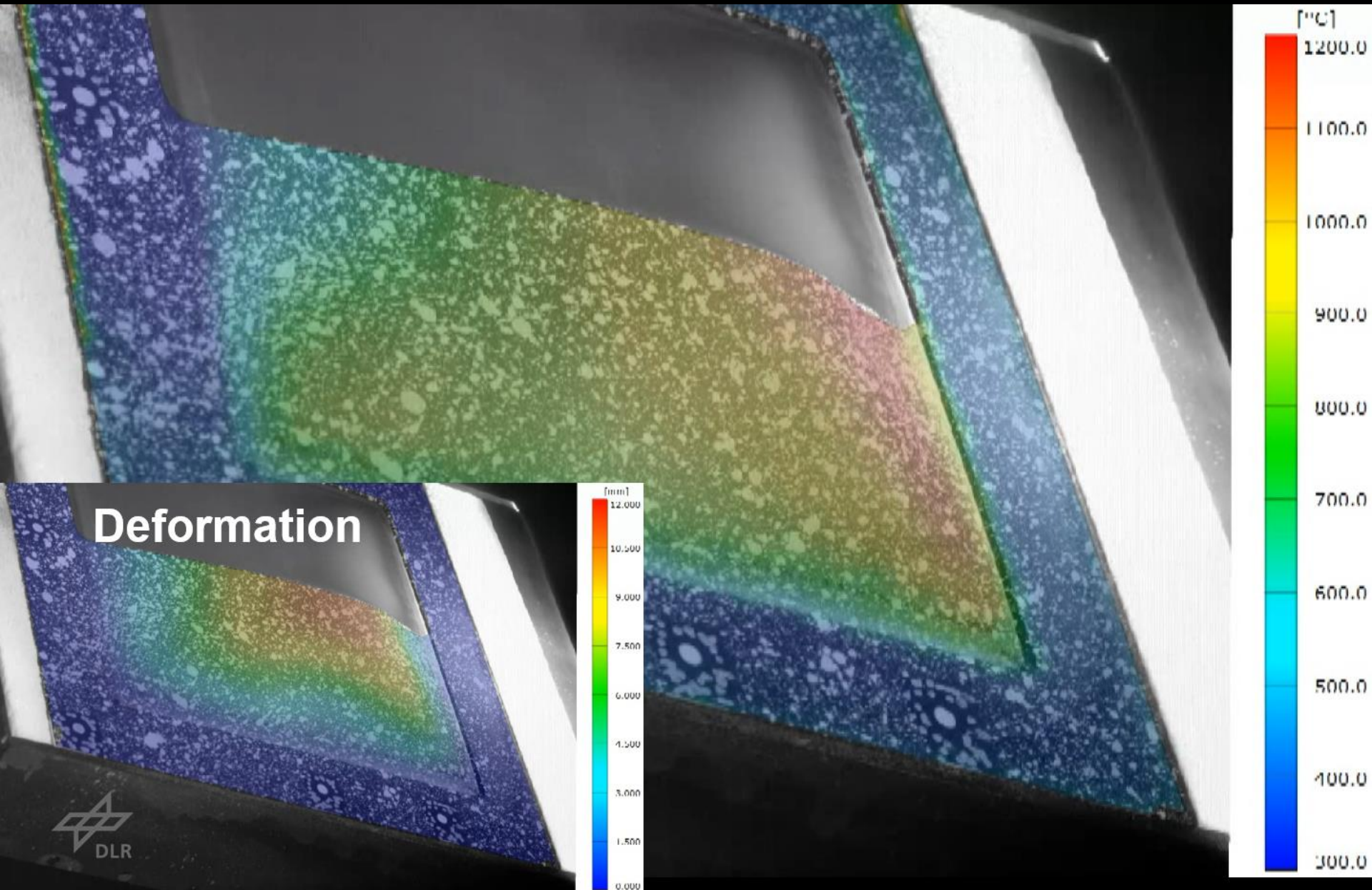
Deformation



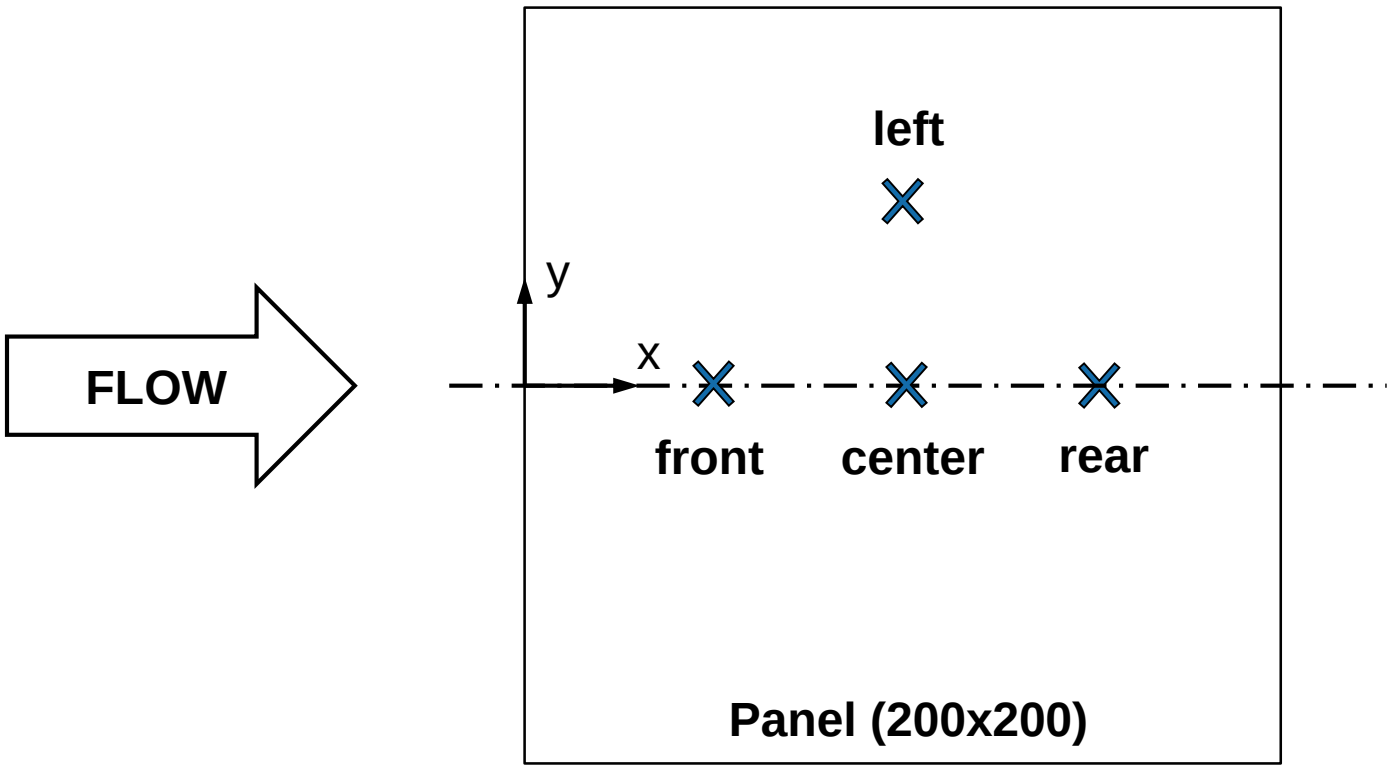
Validation (IR)



Surface Temperature

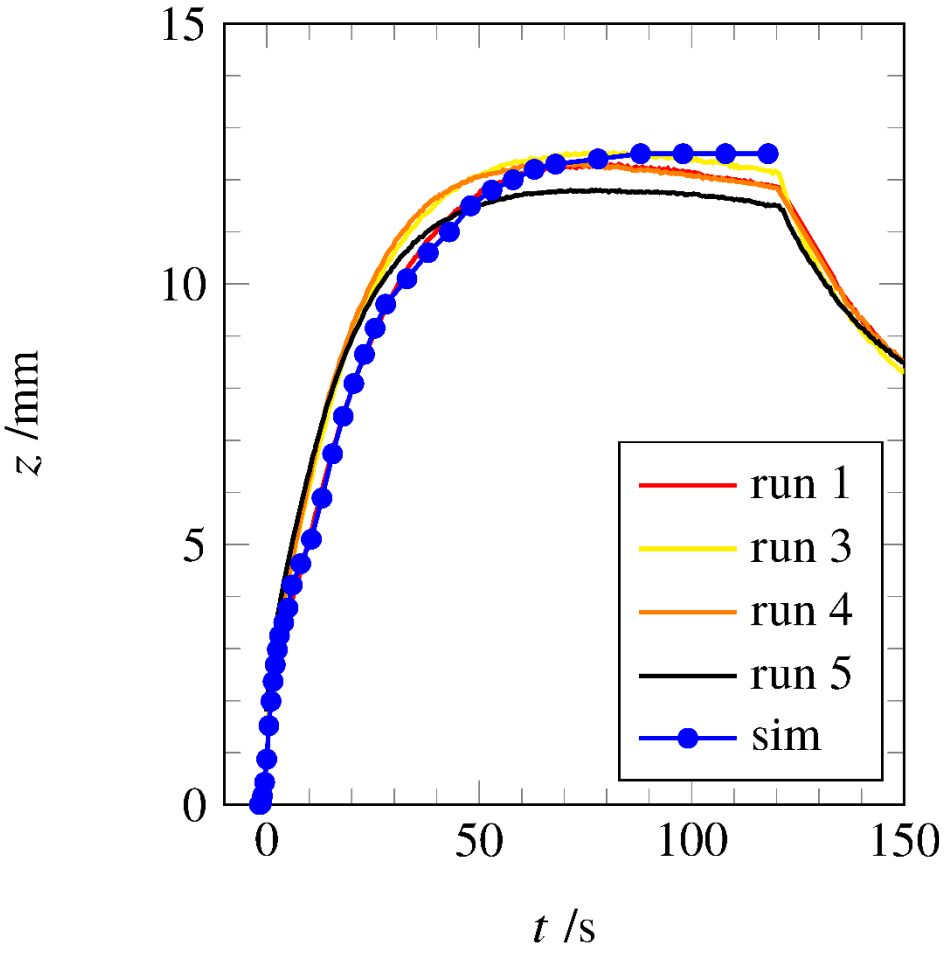


Reference Sensor Positions

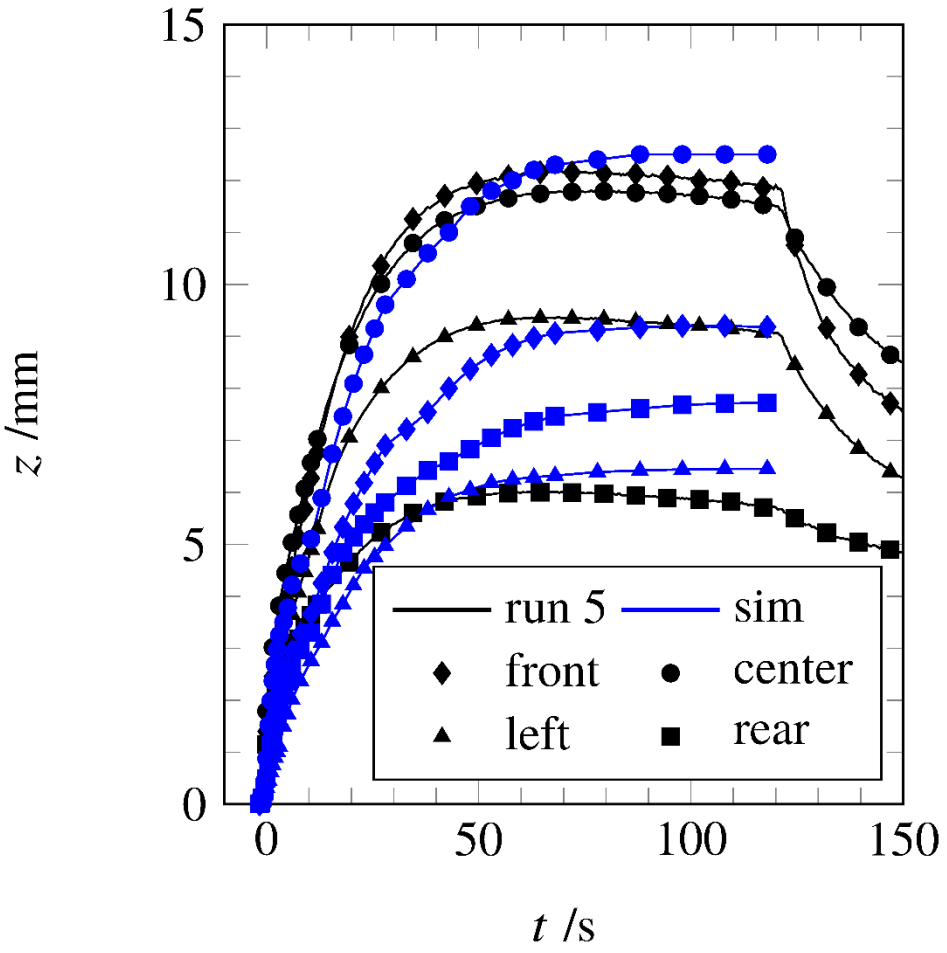


front	(50/0)
left	(100/50)
center	(100/0)
rear	(150/0)

Comparison of Displacement Exp/Sim

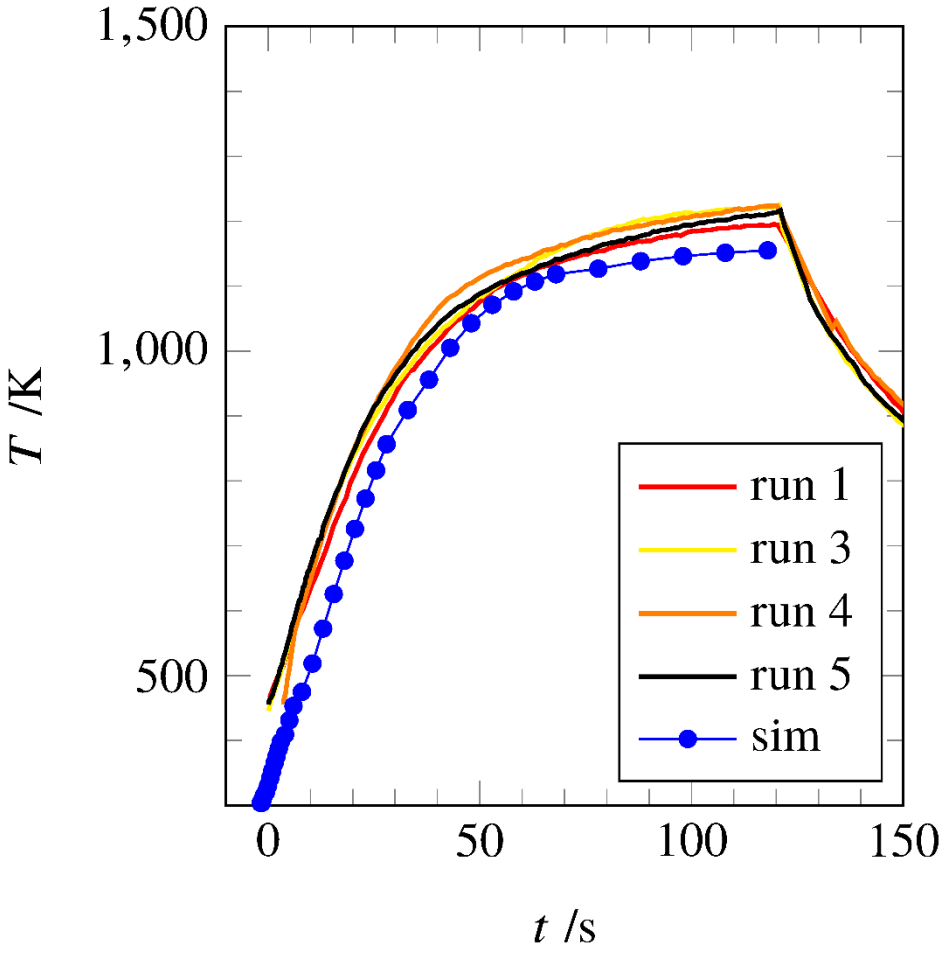


Comparison at the center of the panel

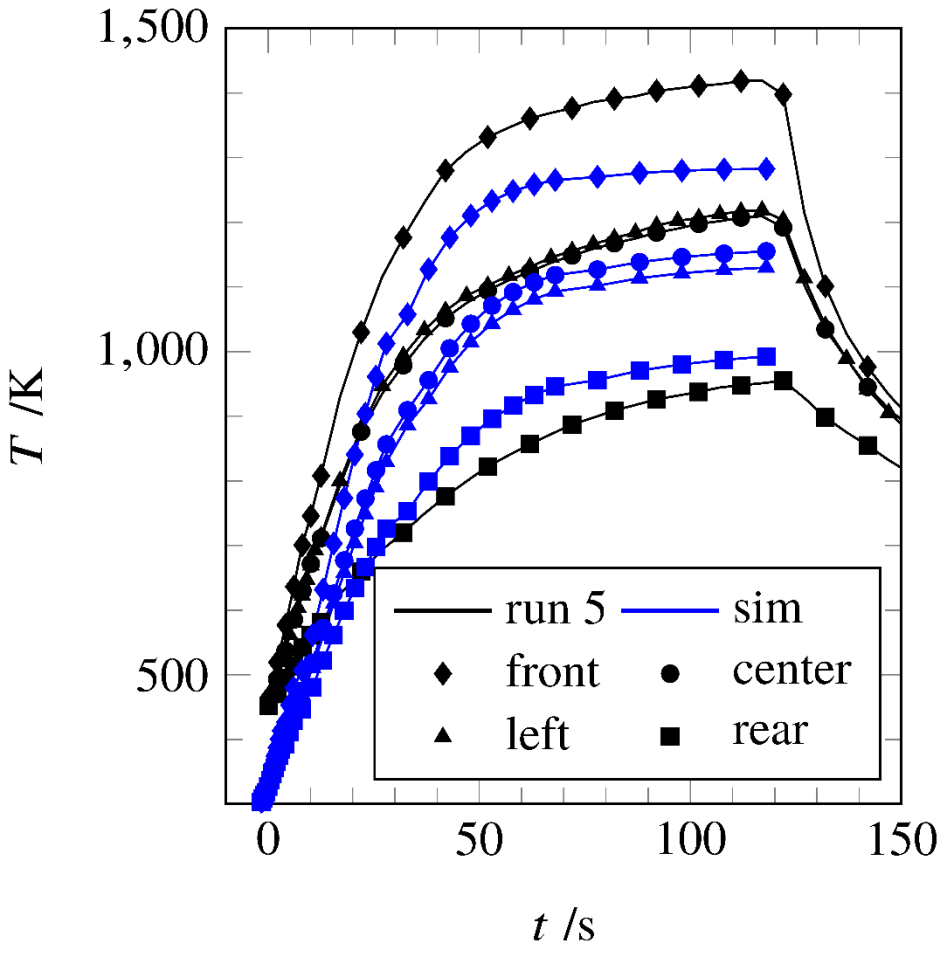


Comparison at four position of the panel

Comparison of Temperature Exp/Sim

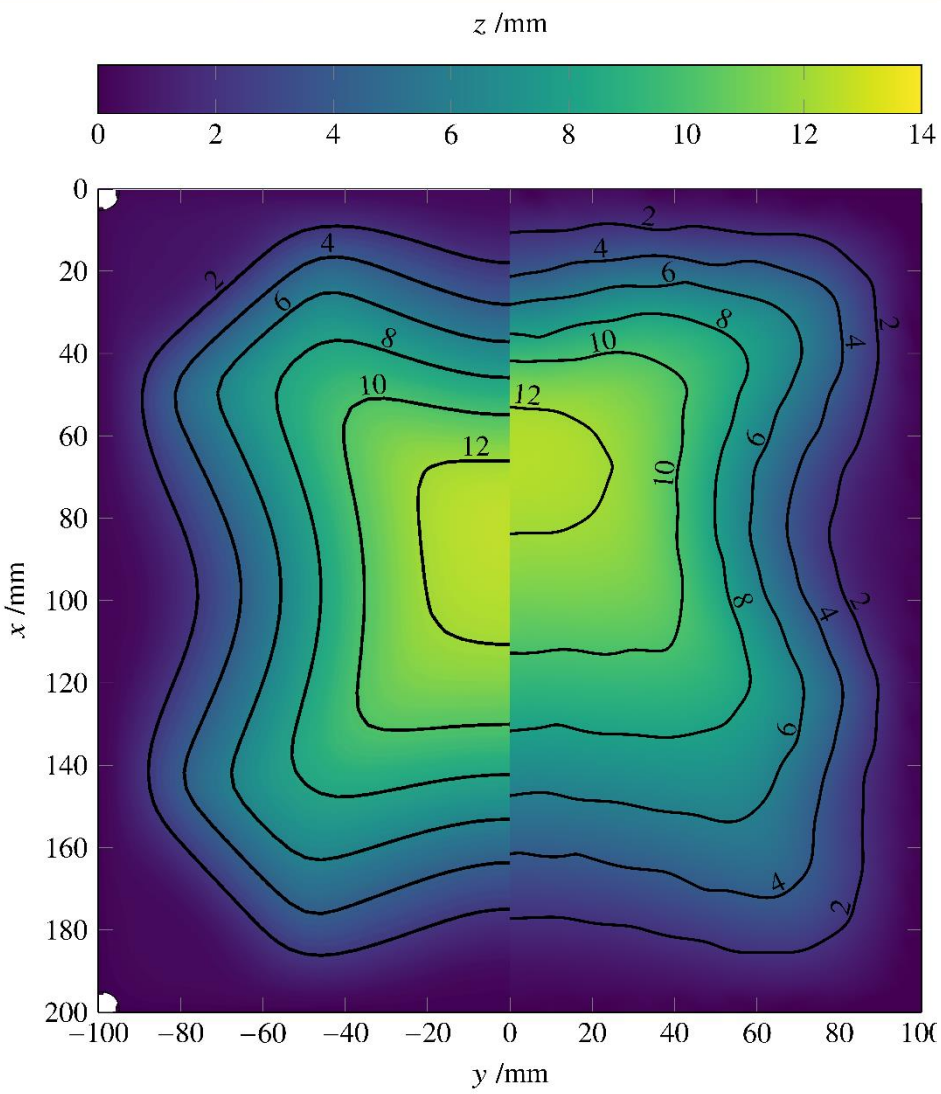


Comparison at the center of the panel

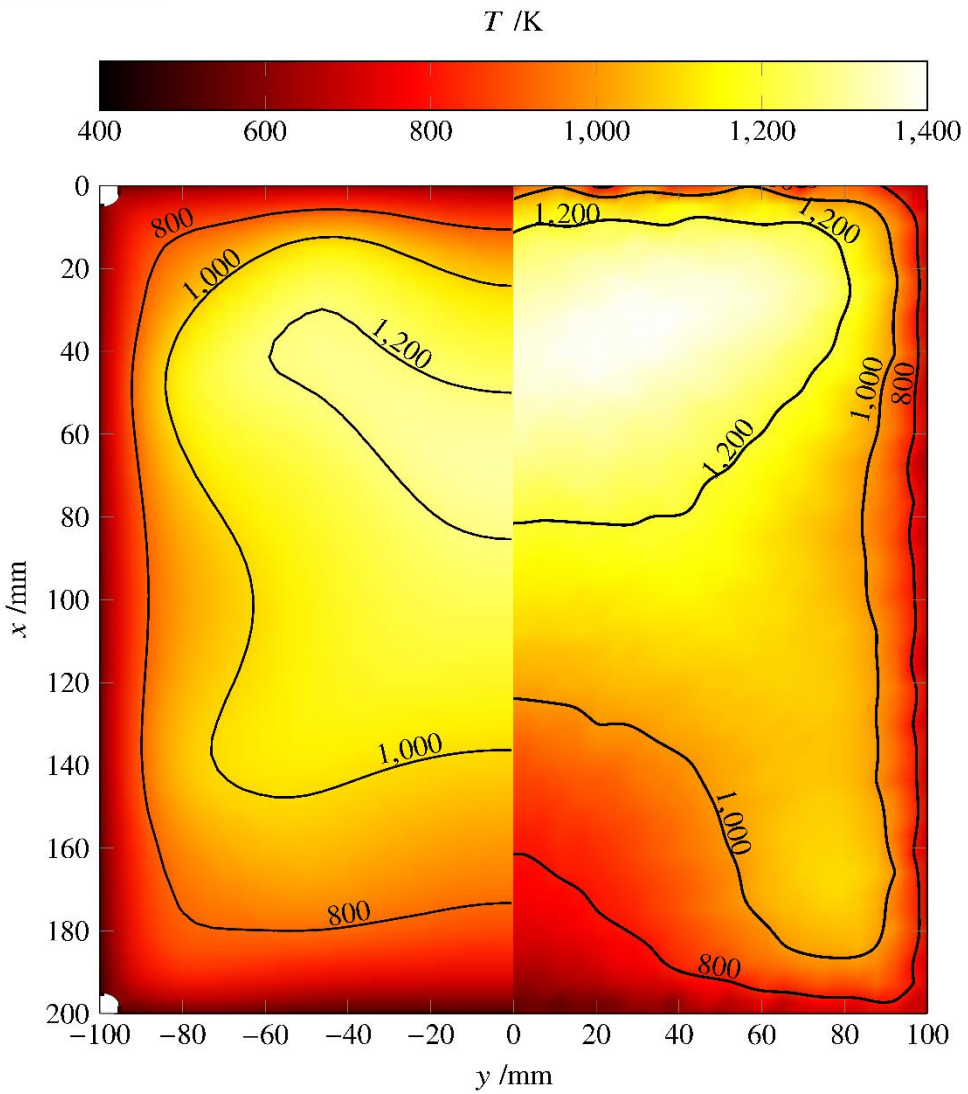


Comparison at four positions of the panel

Comparison Exp/Sim



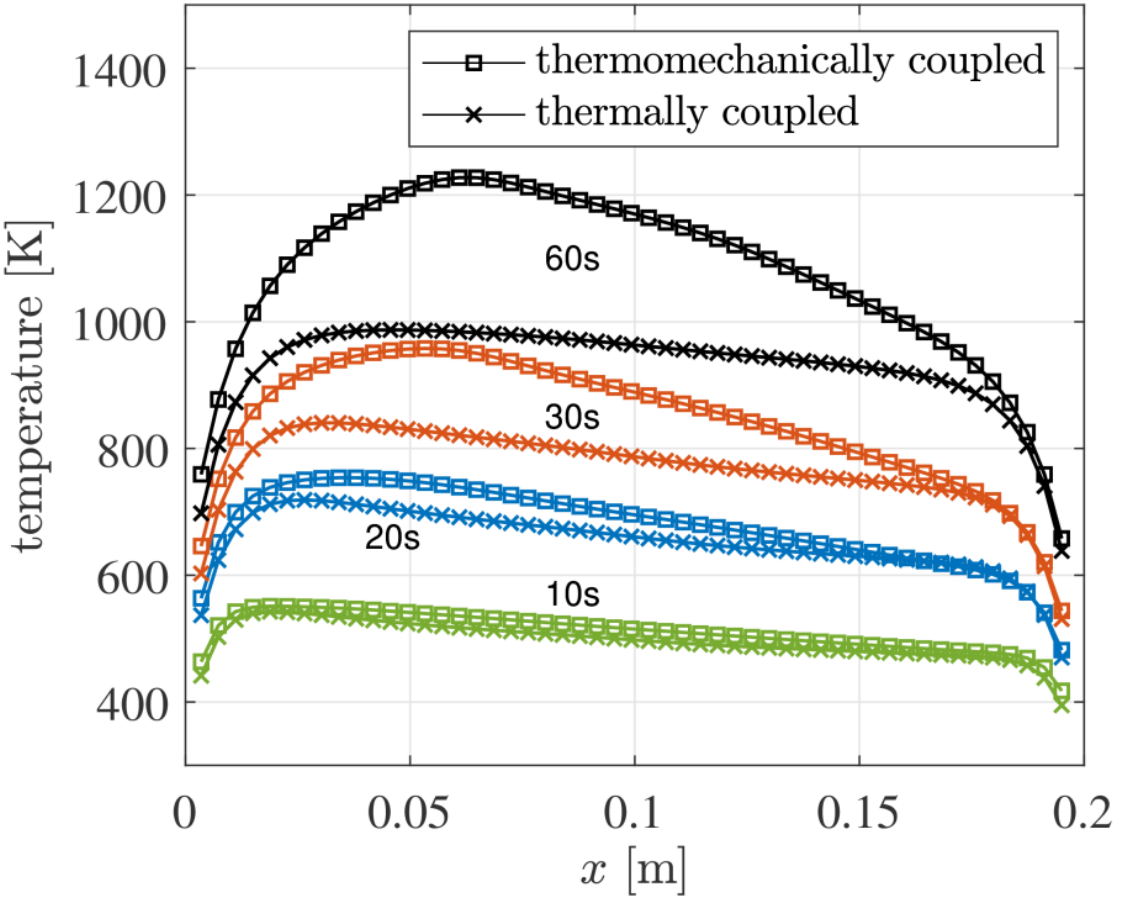
Comparison of displacement:
sim (left); exp (right)



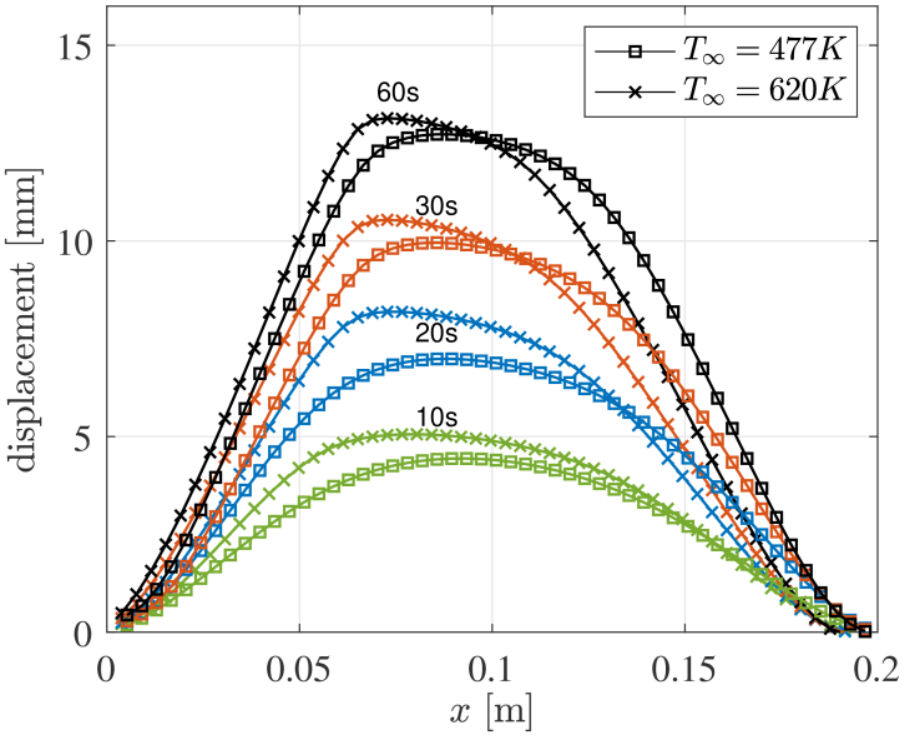
Comparison of temperature:
sim (left); exp (right)

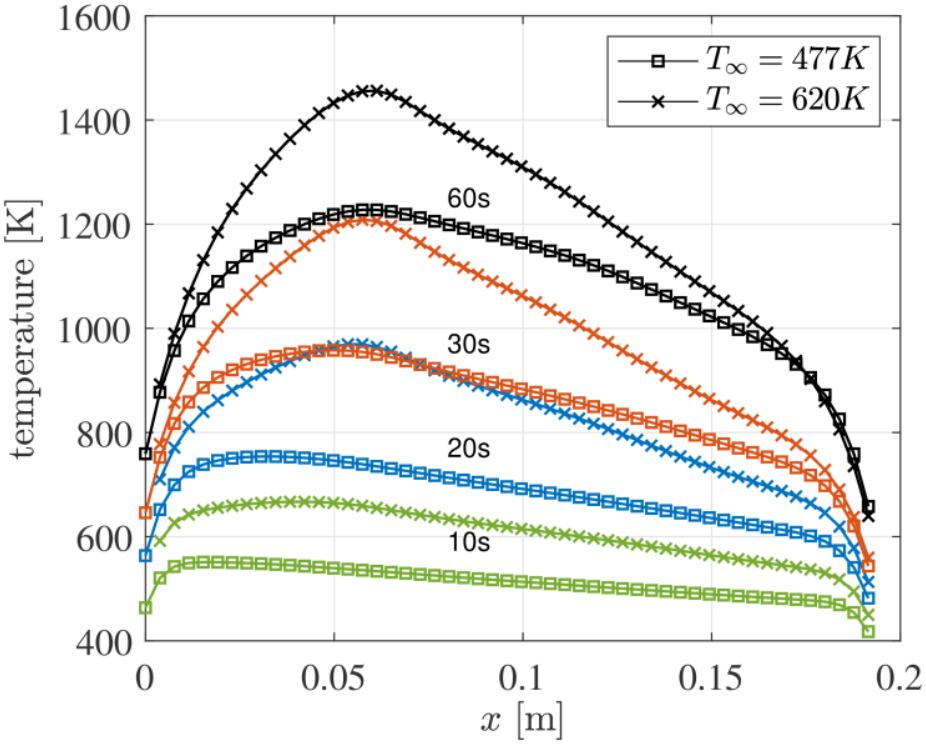
Discussion

More than 200 K difference between rigid and buckled case



Discussion





Influence of wall temperature on buckling shape

Conclusion

Interdisciplinary study of FSI in supersonic flow

- Fluid-Structure coupled simulations
- Modelling of plastic deformation
- Validation experiments with time-resolved full-field instrumentation

Obtained good agreement between simulation and experiments

- Strong localized (FSI driven) heating
- Significant plastic deformation

Thank you

Financial support by the Deutsche Forschungsgemeinschaft (DFG) for the SFB TRR 40 is gratefully acknowledged.