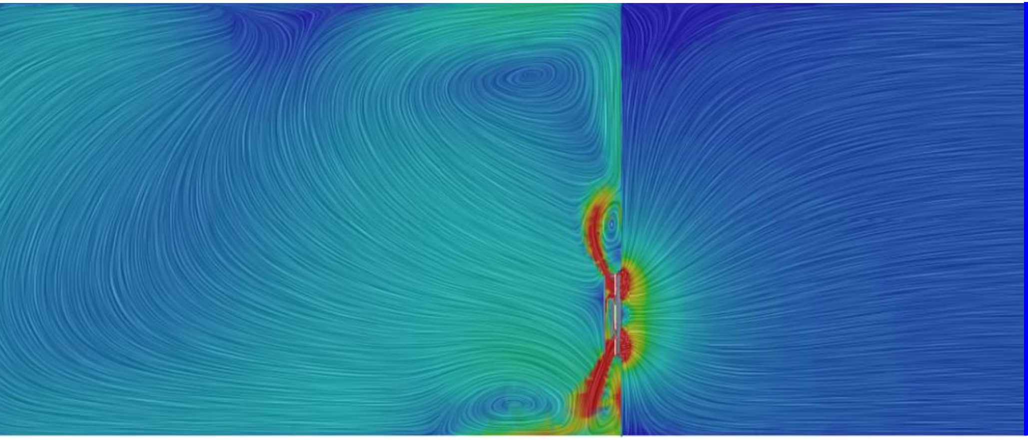

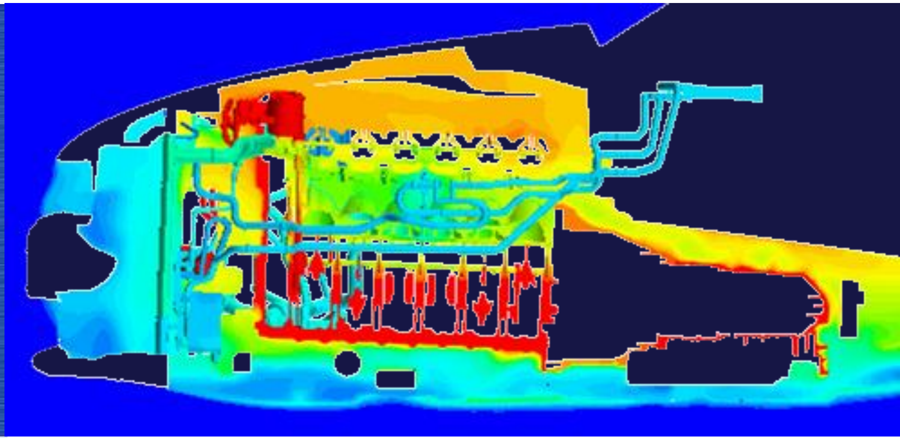

Virtual Flow and Thermal Performance Prediction for Automotive Accessory Units and their Integration into Underhood CFD Flow Analysis with Multi Thermal Systems

Dr. Gerald Seider
Dr. Fabiano Bet

Coventry, 16 May, 2013

Company Profile

INTEGRATED DESIGN ANALYSIS GmbH **InDesA**

Consulting, Engineering Services & Virtual Test Center

- Simulation and Analysis of complex fluid flow and heat transfer systems for engineering and industrial applications
- Virtual Performance Testing for automotive accessory units

STAR-CCM+

3D CFD/CHT Analysis

GT-SUITE

1D System Analysis

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Virtual Testing for Multi Thermal Systems

Overview

1. **Introduction to the concept of multi thermal systems simulation (MTSS)**
2. **Virtual bench testing at InDesA / Classification**
   - ❑ **Cooling Fans**
   - ❑ **Coolant Pumps**
   - ❑ **EGR Cooler**
3. **Conclusion with respect to the integration of test bench results into MTSS**

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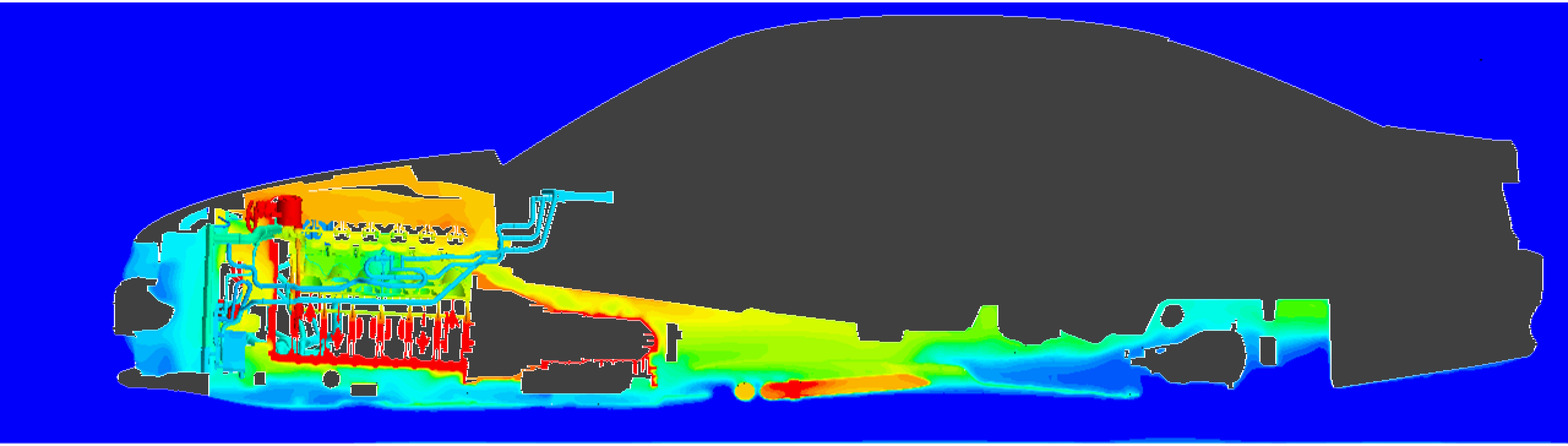
Virtual Testing for Multi Thermal Systems
CFD Flow Analysis with Multi Thermal Systems



thermal systems:

- underhood air flow
- coolant circuit
- engine oil circuit
- transmission oil circuit
- engine intake air /exhaust
- engine structure
- exhaust system structure

thermal transport:

convection
conduction
radiation

thermal inertia

transient analysis:

- thermal soak
- race track drive cycles
- engine warm-up

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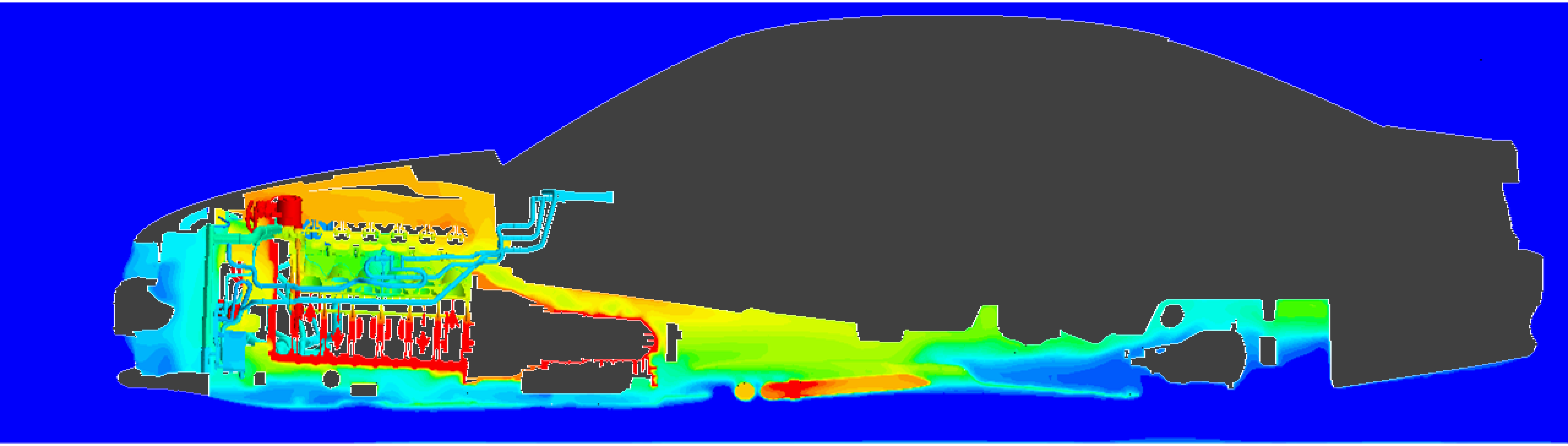
Virtual Testing for Multi Thermal Systems
CFD Flow Analysis with Multi Thermal Systems



heat sources:
- combustion
- friction
- electrical losses

heat transfer:
- radiators
- heat exchangers
- engine structure

powering convection:
- ram pressure
- coolant fans
- water pumps
- engine oil pump
- transmission oil pump
- engine pistons
- compressor

radiating heat:
- exhaust manifold
- exhaust pipes
- turbo charger

reflecting radiation:
- heat shields

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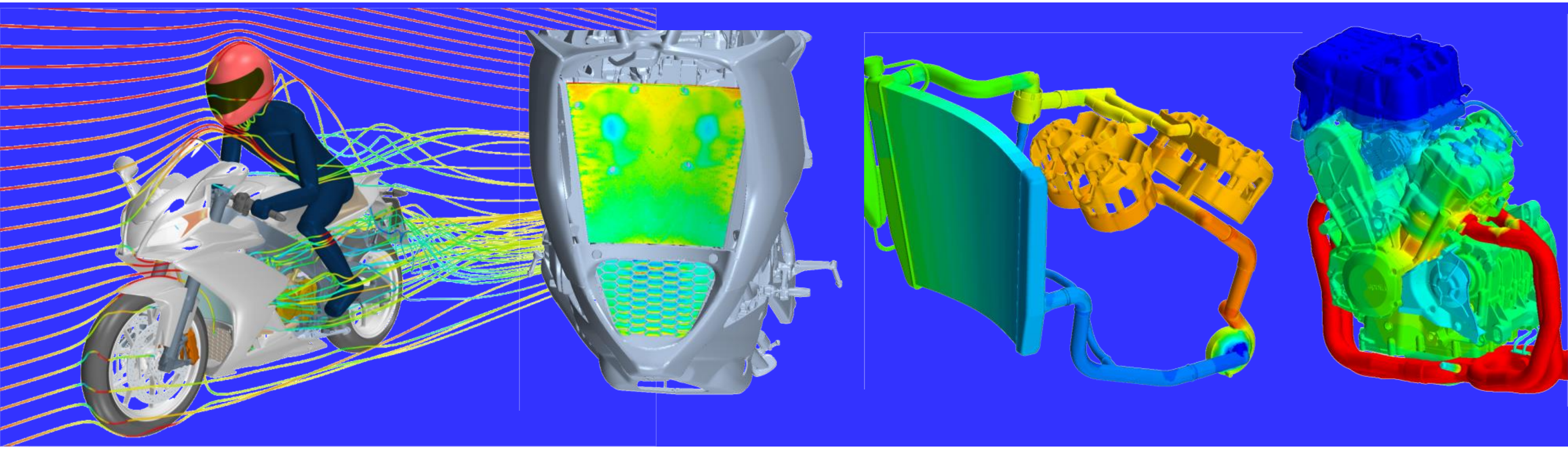
Virtual Testing for Multi Thermal Systems

CFD Flow Analysis with Multi Thermal Systems



Transient simulation with multi thermal systems is manageable in <u>one</u> simulation model *(Star-CCM+)* **but must be backed up by …**

1D system simulation to predict drive cycle behavior *(GT-SUITE)*
to manage transient boundary conditions.
(vehicle speed, engine load & speed, gear, frictional losses, combustion, water pump speed and control, etc.)

3D virtual bench testing of accessory units
to ensure simulation quality at a reasonable geometrical resolution.
(water pump, oil pump, cooling fans, heat exchangers, etc.)

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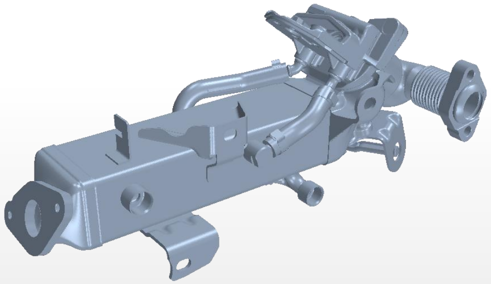
Virtual Testing for Multi Thermal Systems
InDesA's Virtual Test Bench Classification

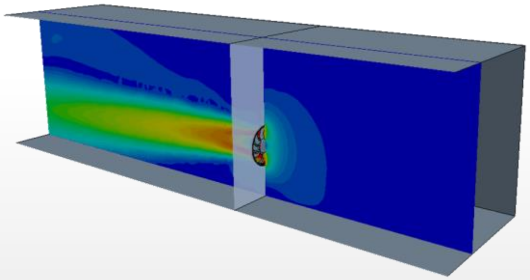
Type A



- isolated component in isolated test environment
- no interaction with other components

Example:
EGR cooler module

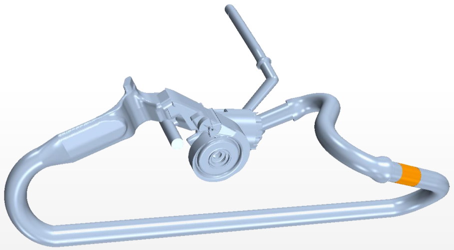
Type B



- standardized test environment
- interaction with other components

Example:
Two-chamber test cell for cooling fans

Type C



- unique test environment
- interaction with other components

Example:
Water pump assembly

STAR-CCM+ STAR-CCM+ STAR-CCM+

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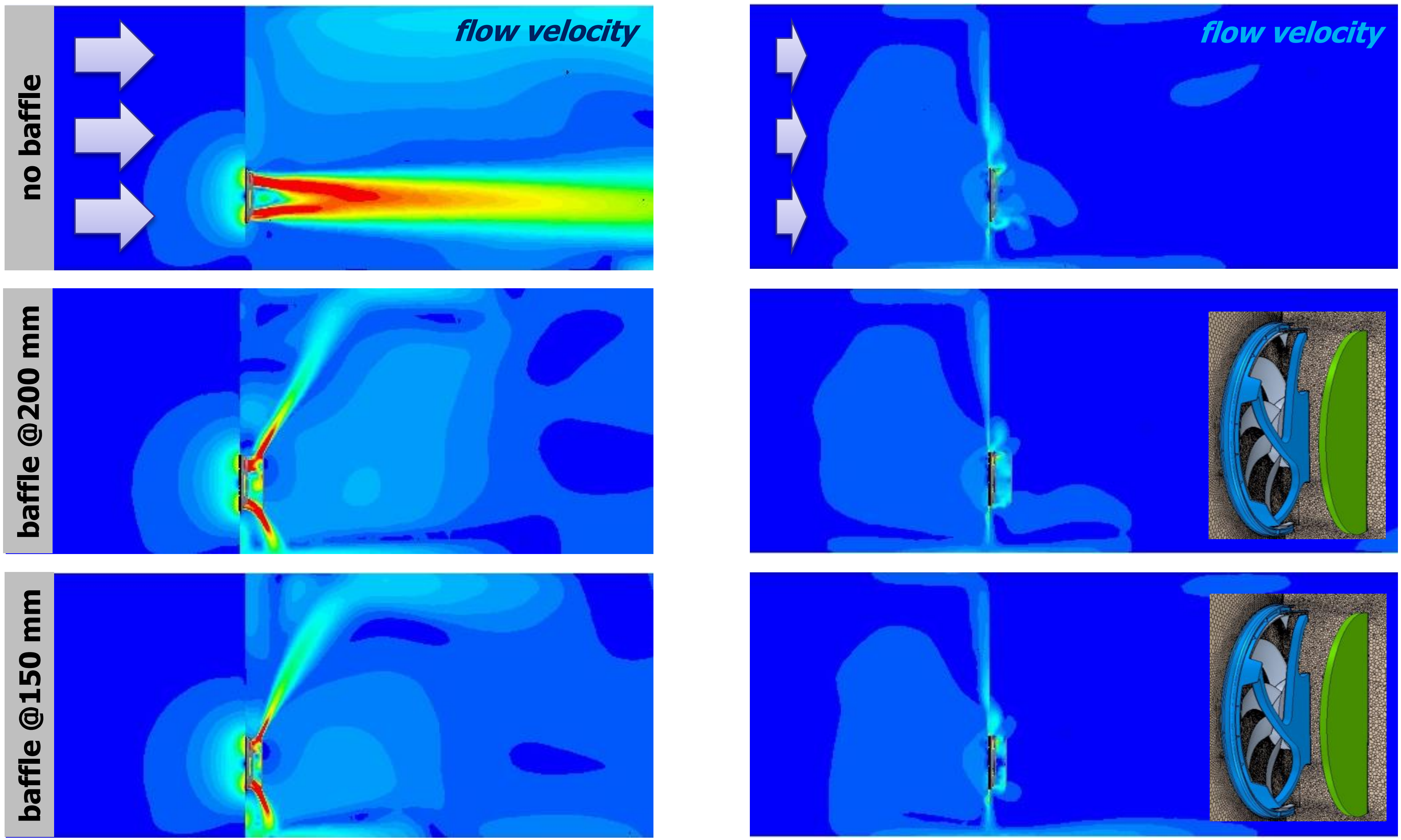
Virtual Testing for Multi Thermal Systems

2-Chamber Test Cell for Cooling Fans

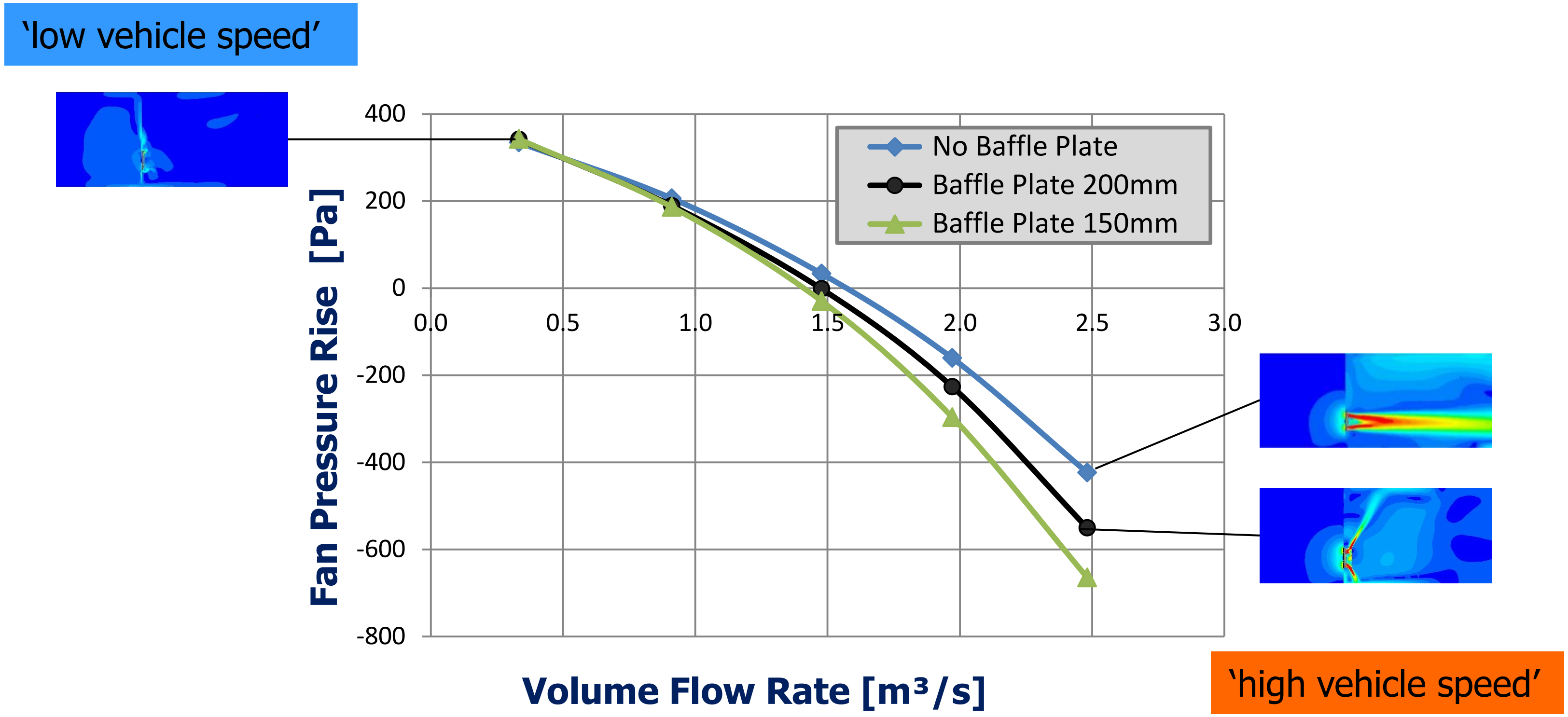
fan overblown – ‘high vehicle speed’

fan design operation – ‘low vehicle speed’



Virtual Testing for Multi Thermal Systems

2-Chamber Test Cell for Cooling Fans



In a two chamber test cell a baffle plate downstream of the fan has almost no impact on fan performance for low vehicle speeds.

Is that true for a realistic underhood environment?

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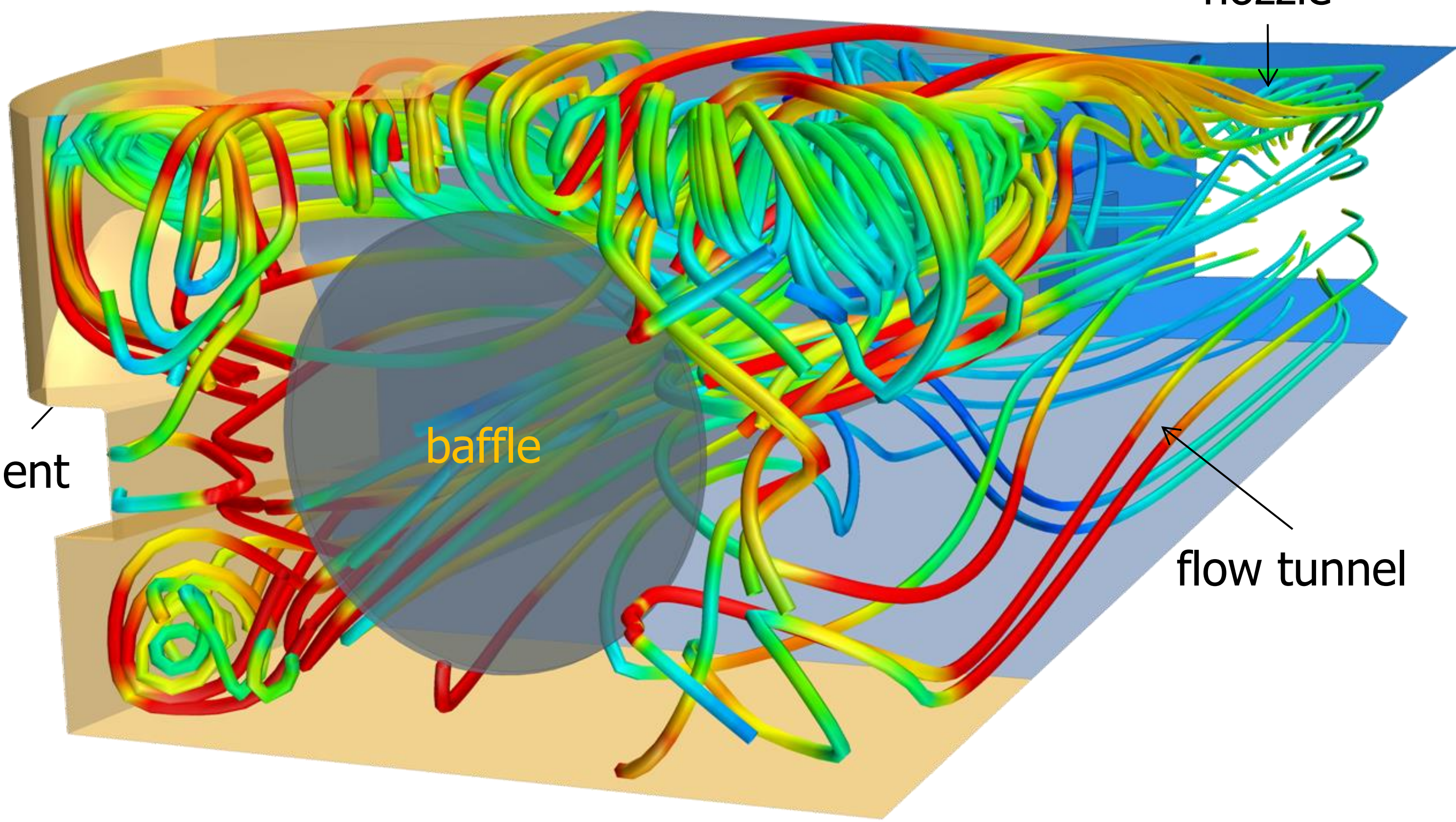
Virtual Testing for Multi Thermal Systems
Underhood Flow Tunnel for Cooling Fan Testing

InDesA has defined a standardized
underhood-flow tunnel
to account for flow deflection at walls of the engine compartment

scaled for various car sizes
- compact
- mid-size
- full-size



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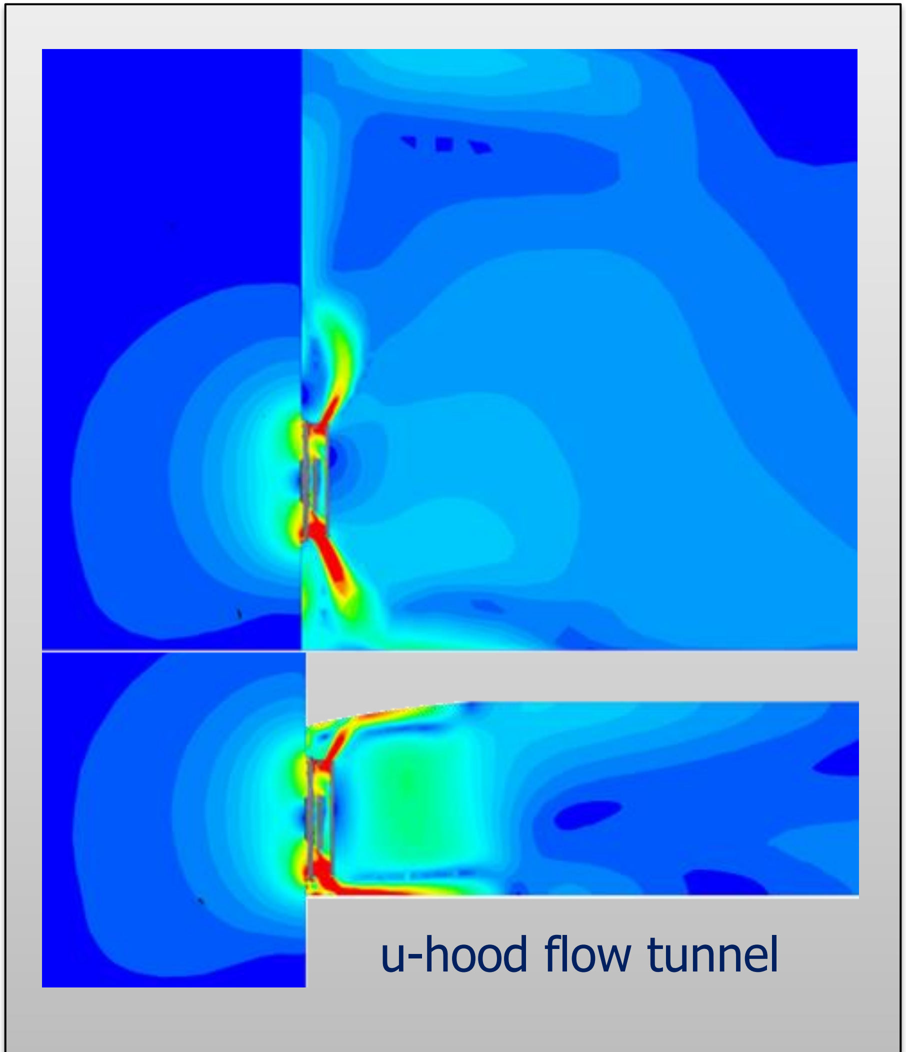
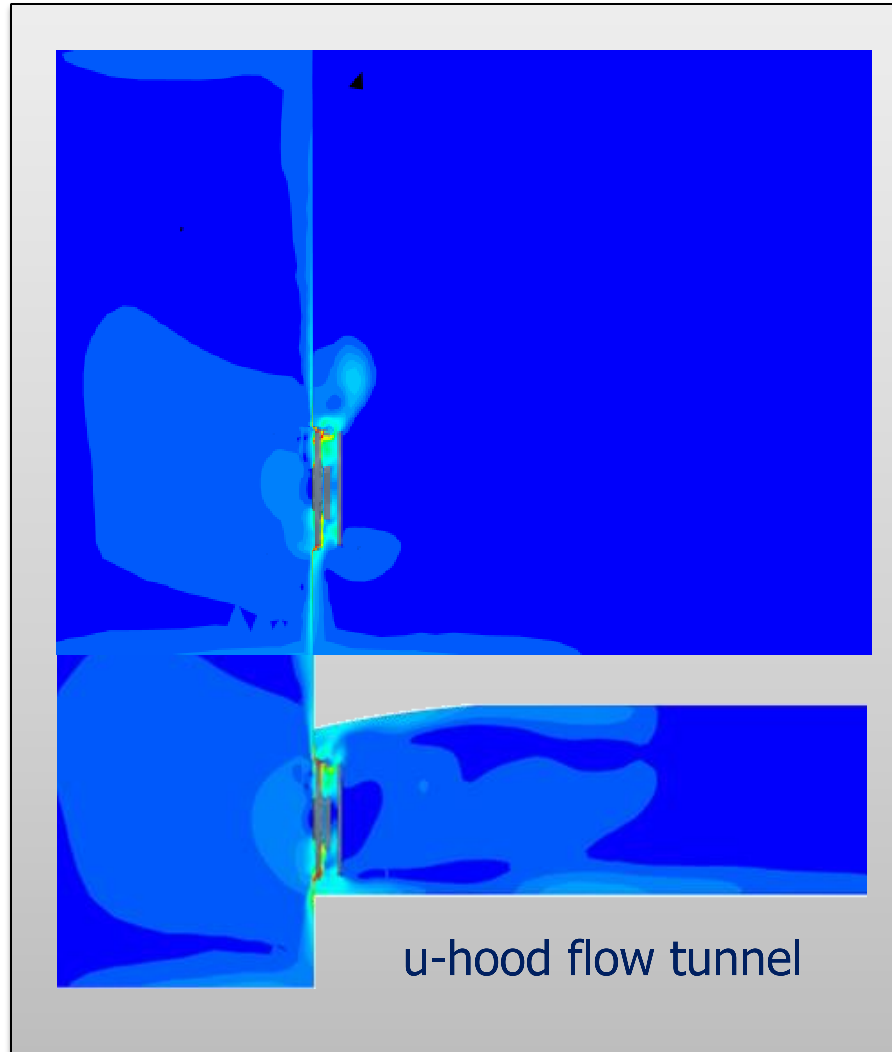
Virtual Testing for Multi Thermal Systems
2-Chamber Test Cell vs. Underhood-Flow Tunnel

fan overblown – ‘high vehicle speed’



fan design operation – ‘low vehicle speed’



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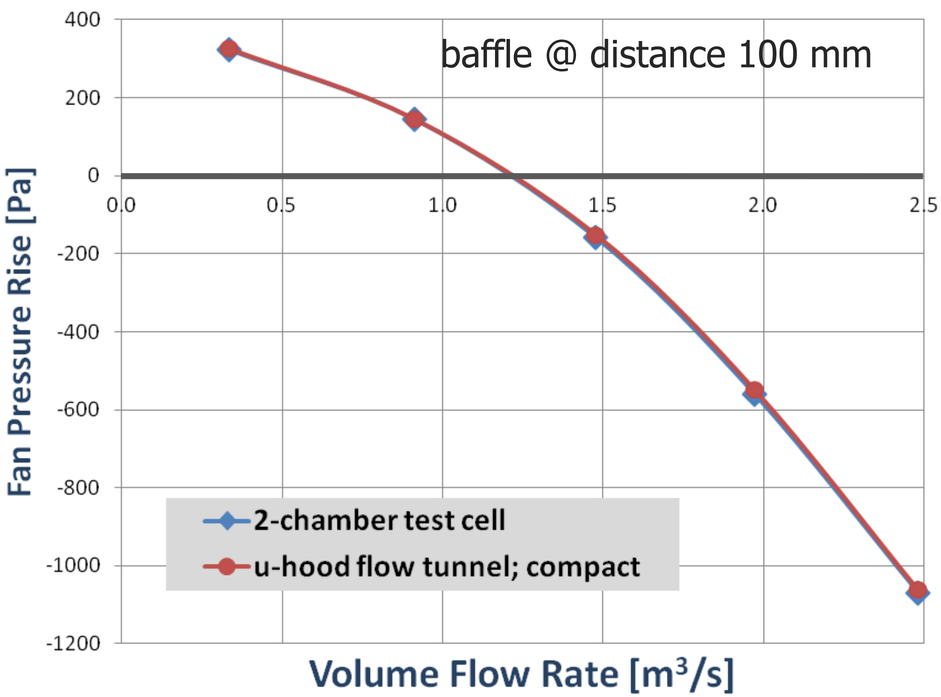
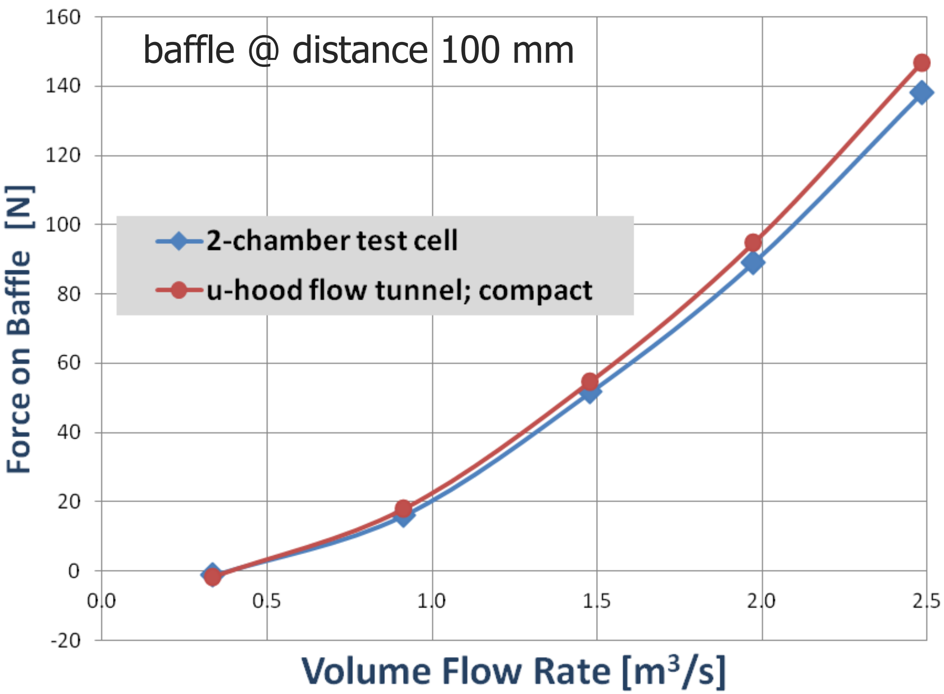
Virtual Testing for Multi Thermal Systems
2-Chamber Test Cell vs. Underhood-Flow Tunnel

Fan Performance



Force on Baffle Plate



2-chamber test cell and underhood flow tunnel predict same fan performance and small difference for the force on the baffle plate.

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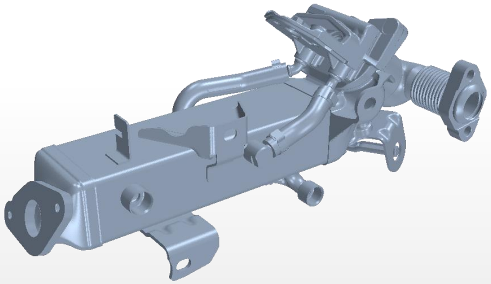
Virtual Testing for Multi Thermal Systems
InDesA's Virtual Test Bench Classification

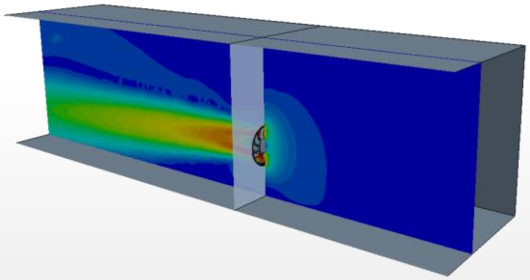
Type A



- isolated component in isolated test environment
- no interaction with other components

Example:
EGR cooler module

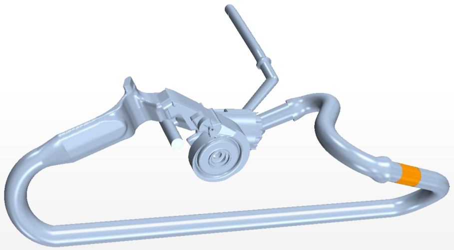
Type B



- standardized test environment
- interaction with other components

Example:
Two-chamber test cell for cooling fans

Type C



- unique test environment
- interaction with other components

Example:
Water pump assembly

STAR-CCM+ STAR-CCM+ STAR-CCM+

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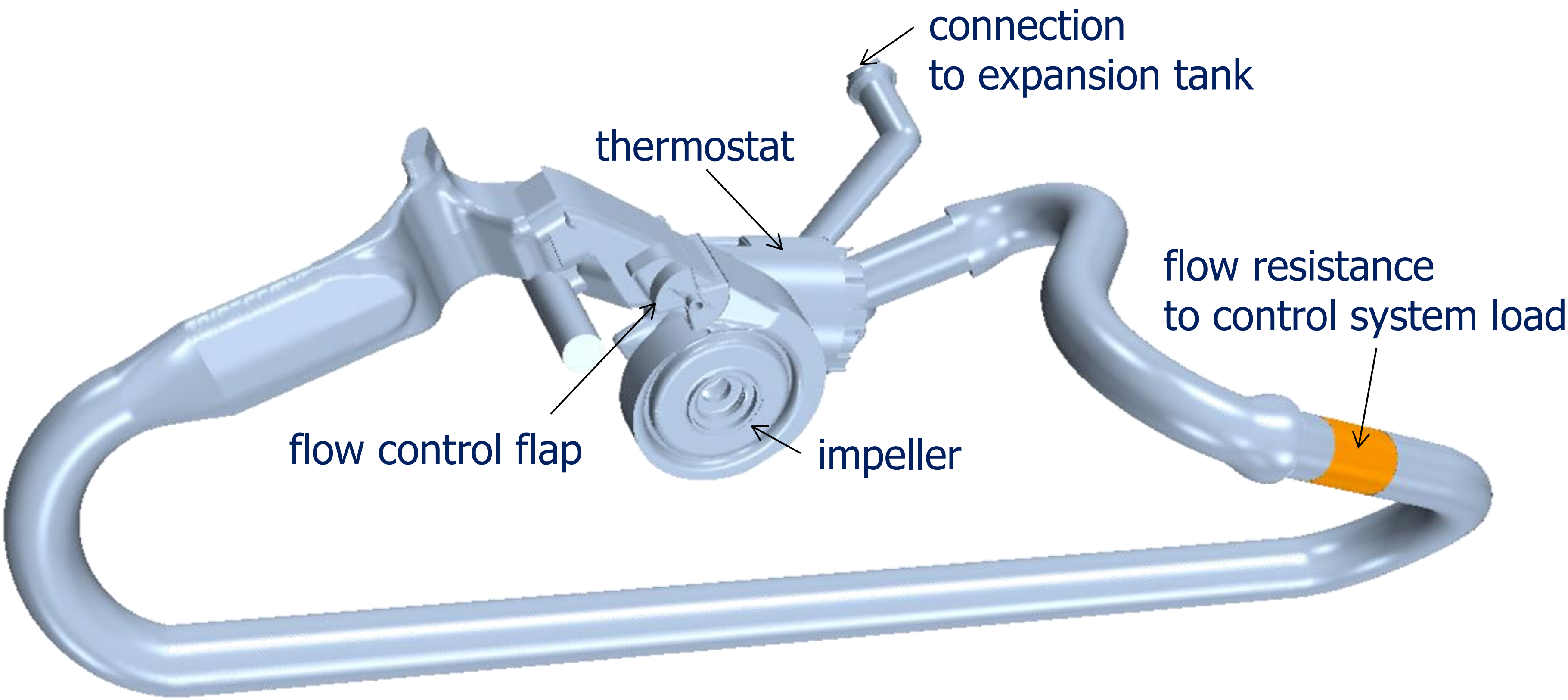
Virtual Testing for Multi Thermal Systems
Type C Test Bench for Water Pumps

Closed Loop Simulation
flow rate is controlled by impeller speed and loop resistance



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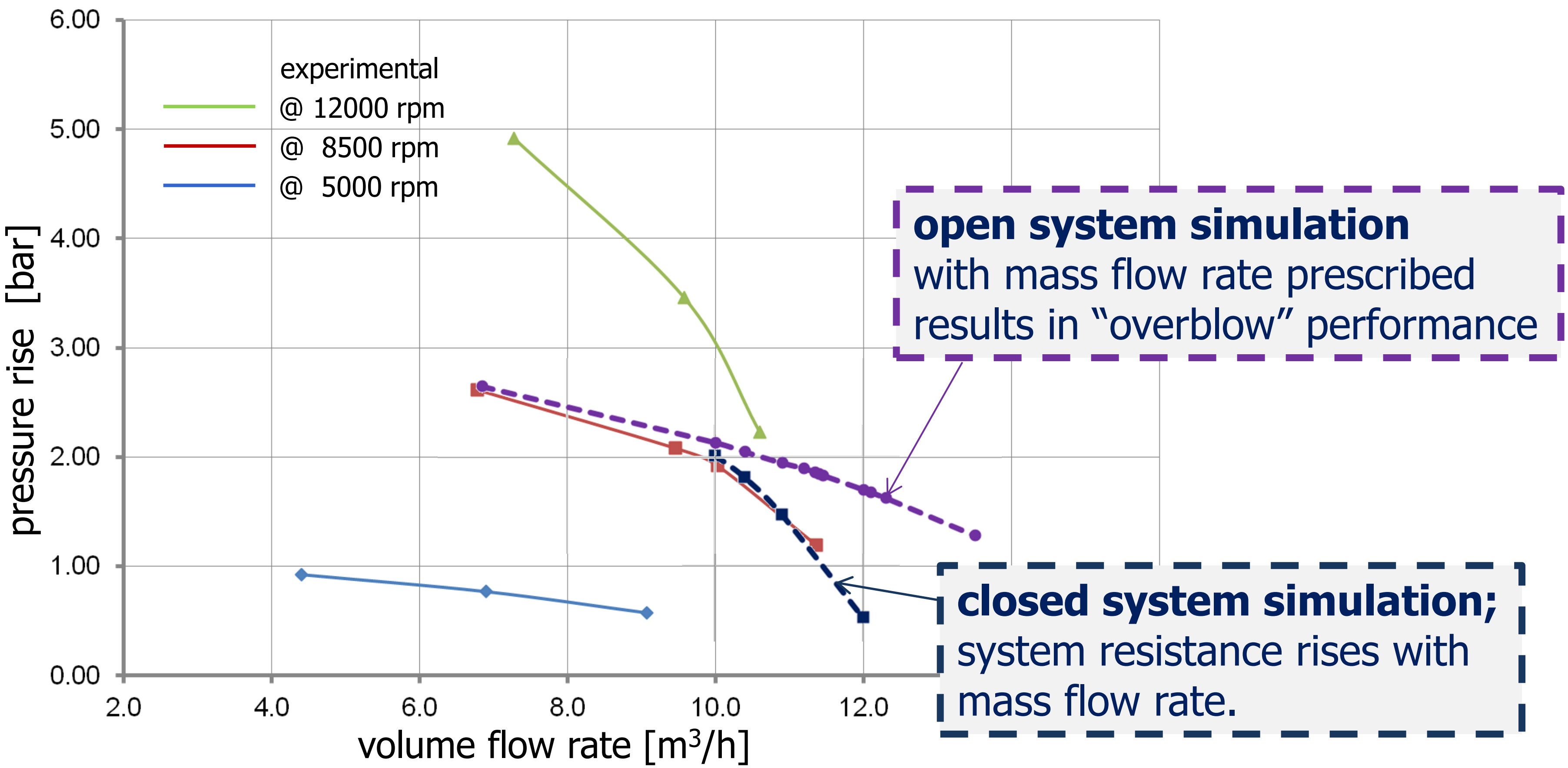
Virtual Testing for Multi Thermal Systems
Open vs. Closed System Simulation



Vapor pressure must be monitored at impeller!
At the onset of cavitation the simulation methodology must be changed for the impeller from MRF to true rotation and from one to two phase flow (VOF).

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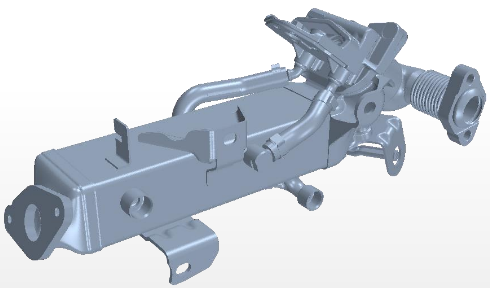
Virtual Testing for Multi Thermal Systems

InDesA's Virtual Test Bench Classification

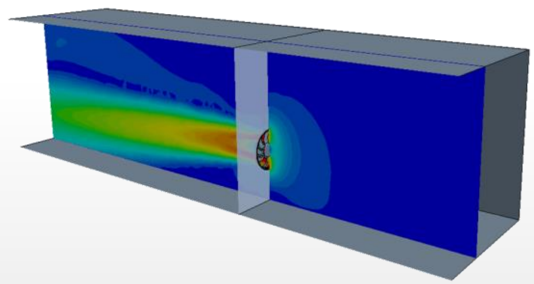
Type A



- isolated component in isolated test environment
- no interaction with other components

Example:
EGR cooler module

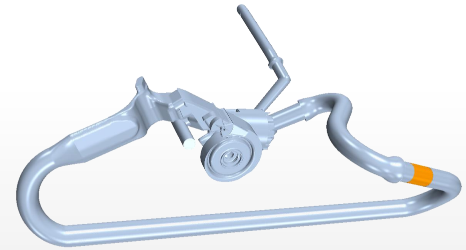
Type B



- standardized test environment
- interaction with other components

Example:
Two-chamber test cell for cooling fans

Type C



- unique test environment
- interaction with other components

Example:
Water pump assembly

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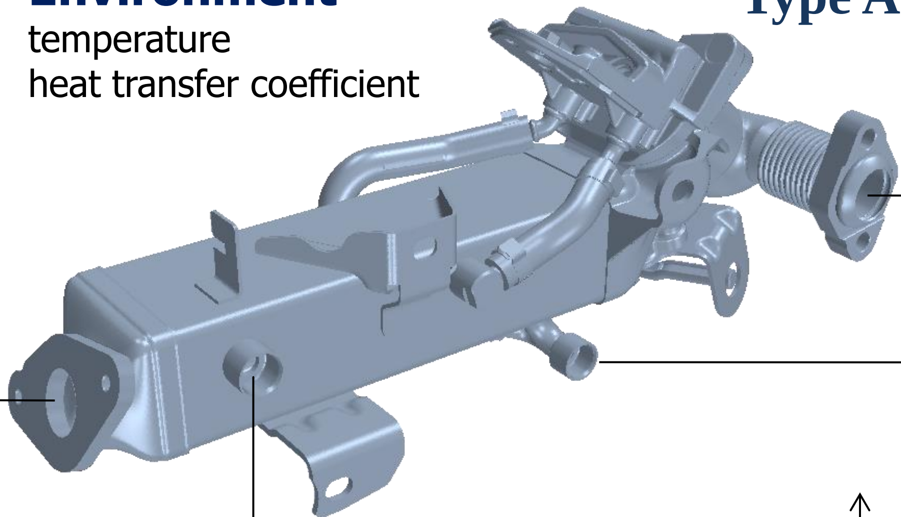
Virtual Testing for Multi Thermal Systems
Type A Test Bench for an EGR Cooling Module

Environment
temperature
heat transfer coefficient

Type A



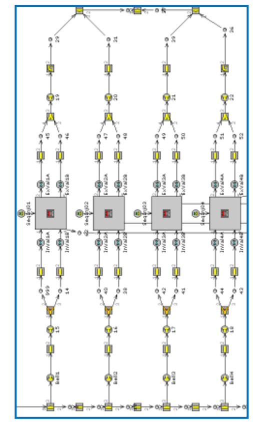
Exhaust

Coolant

Exhaust

Coolant

Flow Rates
optional from
GT-SUITE
engine model

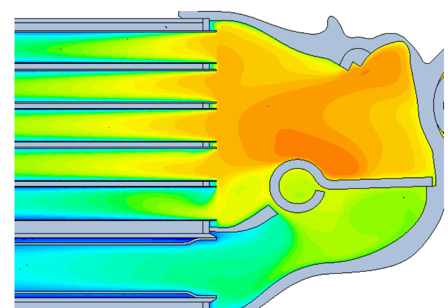


Model Set-Up with STAR-CCM+

- Thermal Fluid/Structure Coupling
- Full details of pipes or fin/plates
- EGR valve cooling and flow leakage at by-pass flap included

Additional Boundary Conditions

- Flap position for bypass-flow
- EGR valve position



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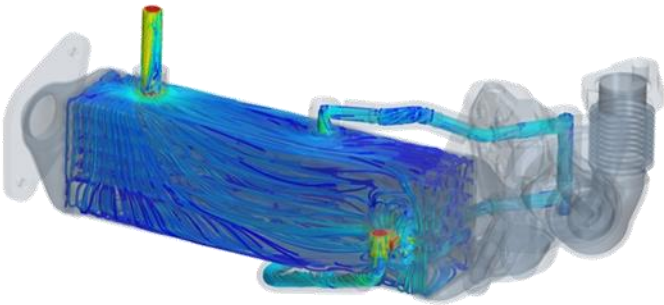
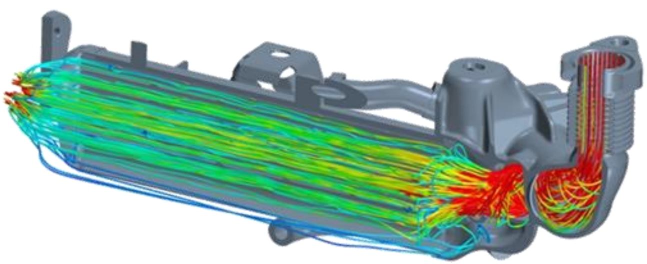
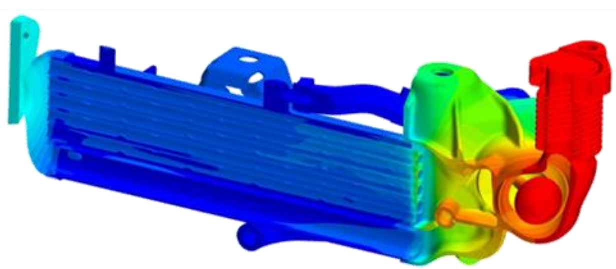
Virtual Testing for Multi Thermal Systems
Test Bench Results for an EGR Cooler





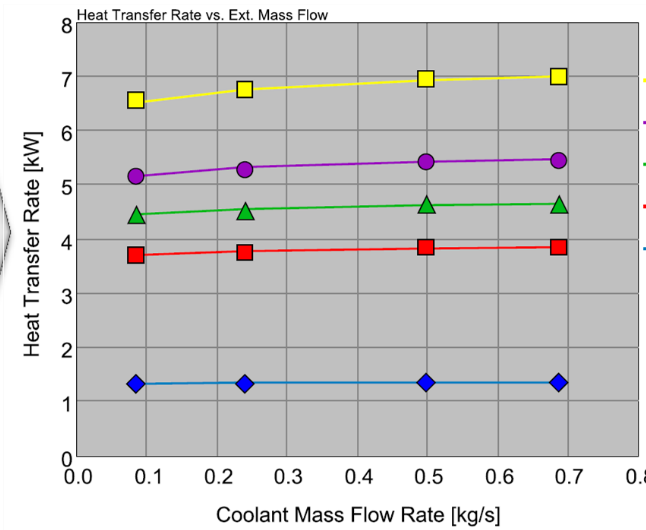


Coolant
- temperatures
- pressure loss
- onset of boiling
- volume flow rates
- flow uniformity

Exhaust
- outlet temperature
- pressure loss
- force on flap
- flow leakage

Structure
- temperatures
  esp. valve seat
- heat transfer

Nusselt Correlation
$Nu = f(Re, Pr)$



⇨ heat transfer for arbitrary operating conditions

For multi thermal systems simulation the methodology should be changed to dual-stream heat exchanger based on the Nusselt Correlation

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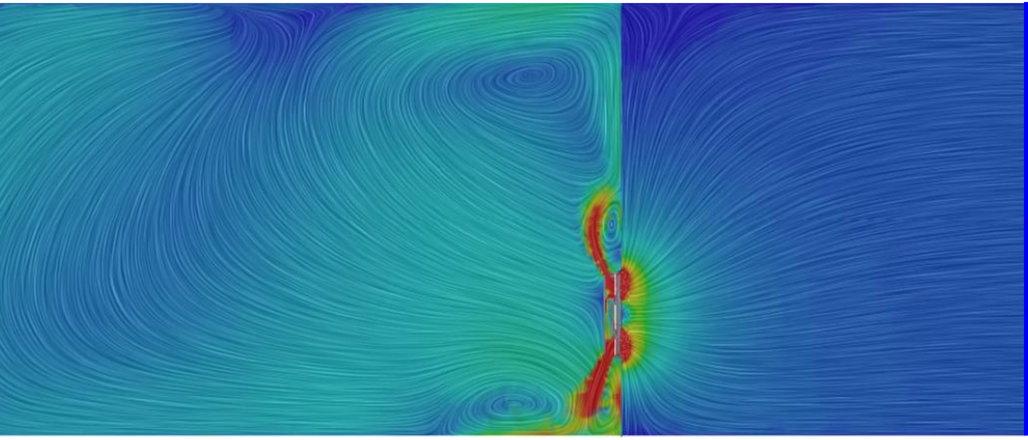
Virtual Testing for Multi Thermal Systems
Conclusion

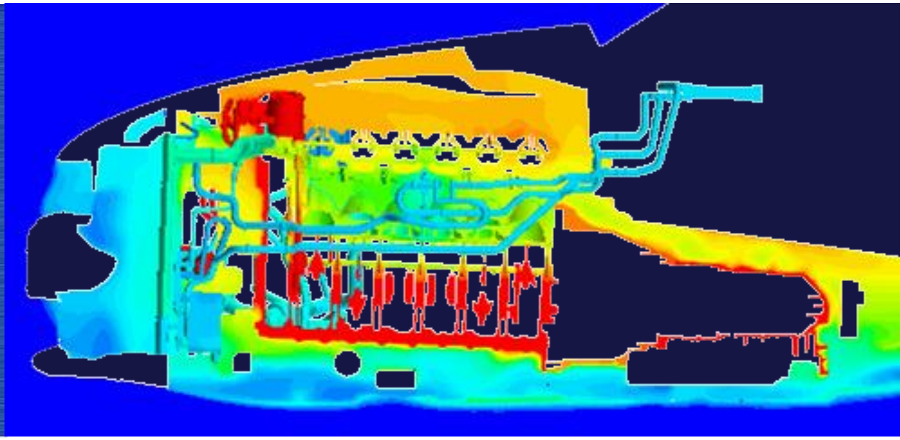
Virtual bench testing for accessory units is essential to manage multi thermal systems simulation (MTSS).

Sub-models for accessory units which power thermal convection and control thermal management can be tested and verified before being integrated into larger systems.

Virtual testing allows to find best practice methodology for the application in MTSS with respect to

- **accuracy**
- **mesh resolution and interfaces**
- **numerical solver**
- **convergence**
- **physical modeling**





Thank you for your attention.

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