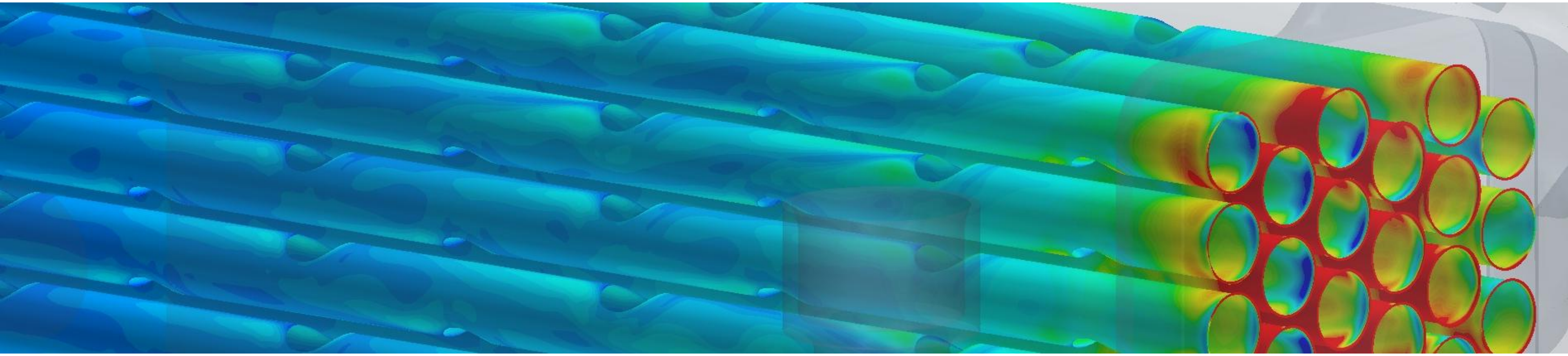
GT 2012 CONFERENCE
Steigenberger Hotel, Frankfurt/Main Airport

INTEGRATED DESIGN ANALYSIS GmbH InDesA



Virtual Bench Testing of Ancillary Components to Populate GT-ISE Objects for OEM Library

Dr. Gerald Seider
Dr. Fabiano Bet

Frankfurt, 22 October, 2012

Company Profile

INTEGRATED DESIGN ANALYSIS GmbH **InDesA**

Consulting- &
Engineering Services

Simulation and Analysis
of complex fluid flow and heat transfer systems
for engineering and industrial applications

- **Engine & VehicleThermal Management**
- **Heat Exchanger Thermal Analysis**
- **Pumps / Fans / Turbomachinery Flow and Thermal Analysis**
- **Aerodynamics and AeroAcoustics**

  and more …

3D CFD/CHT Analysis

STAR-CCM+

1D System Analysis

GT-SUITE

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Virtual Bench Testing to Populate GT Objects
What to expect?

We want to give answers to:

Why is virtual testing beneficial to the virtual creation process?

How can Supplier and OEM better interact building up a simulation environment in GT-SUITE?

We want to demonstrate:

How to speed up the simulation process with virtual bench testing.

How to improve the quality of input data for multi-physics system simulation in *GT-SUITE*!

… for a pipe bundle EGR Cooler

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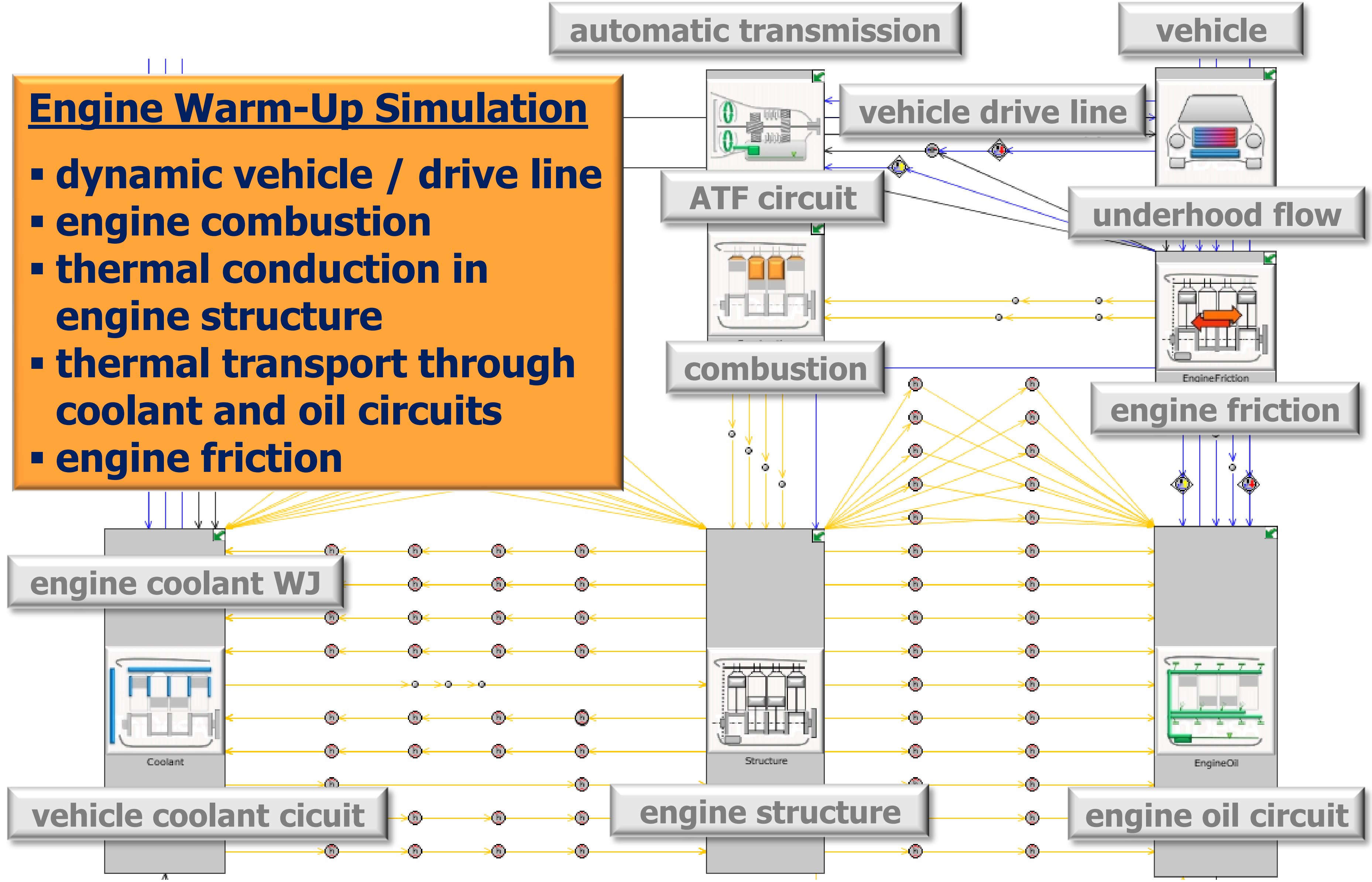
Virtual Bench Testing to Populate GT Objects
Example for Multi-Physics System Application

Engine Warm-Up Simulation

- dynamic vehicle / drive line
- engine combustion
- thermal conduction in engine structure
- thermal transport through coolant and oil circuits
- engine friction



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Virtual Bench Testing to Populate GT Objects
Engine Warm-Up Simulation

Engine warm-up simulation is a typical OEM application

- ❑ **for the prediction of fuel consumption for warm-up drive cycles.**
- ❑ **for the assessment of thermal management and friction reduction techniques.**

About 2500 parts need to be specified!

- ❑ **Geometry from CAD data**
- ❑ **Physical properties**
  - ➢ **from physical bench testing**
  - ➢ **from virtual bench testing**

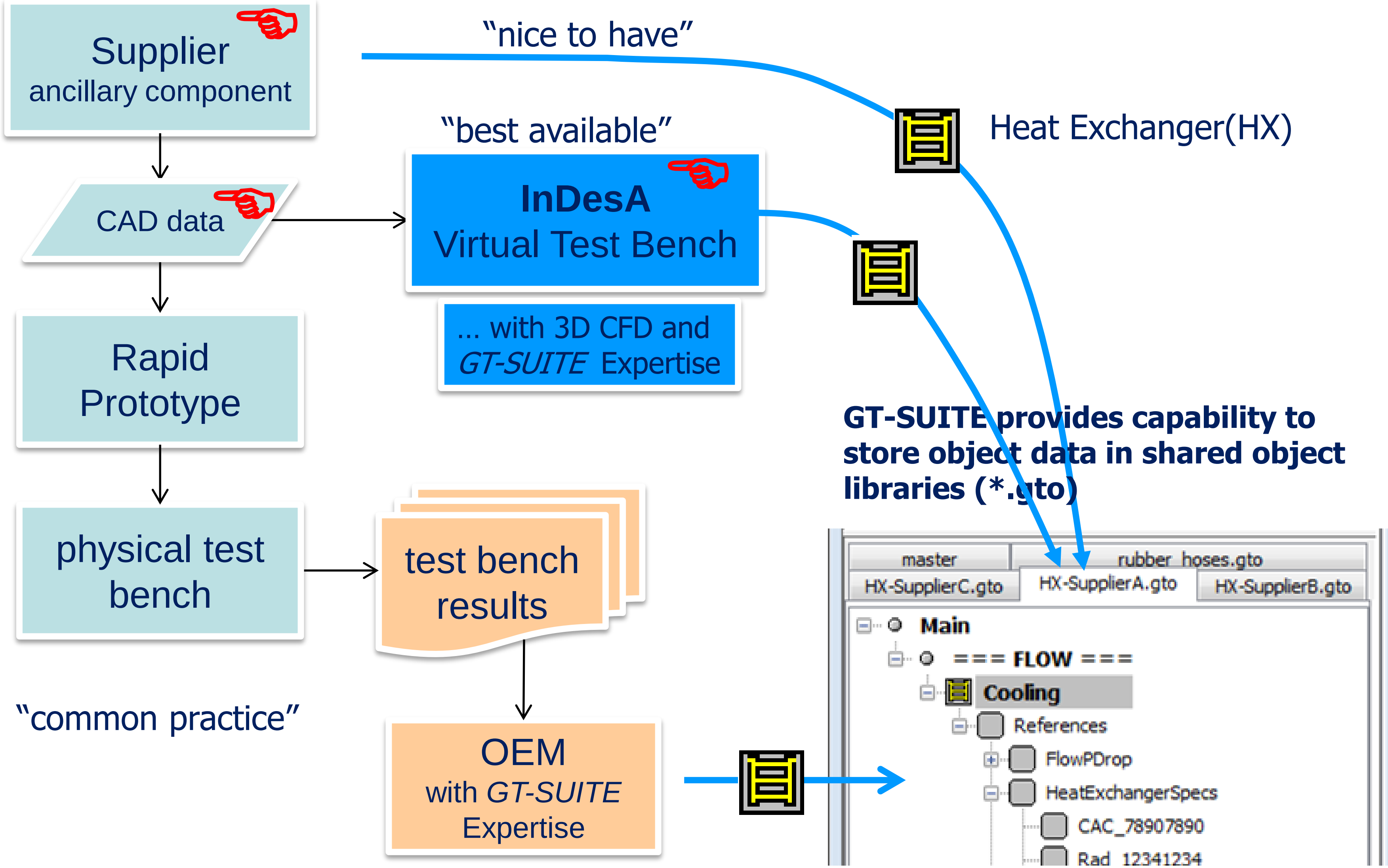
- ❖ **Internal data (OEM)**
- ❖ **Supplier data**

⇨ **data hunting takes considerable amount of time**

Total Number of Parts	2457
Components	989
Connections	1468
Parts on Map	2140
Internal Parts	317
Flow	925
Mechanical	124
Thermal	592
Control	816

Virtual Bench Testing to Populate GT Objects

How to speed up the virtual creation process ?

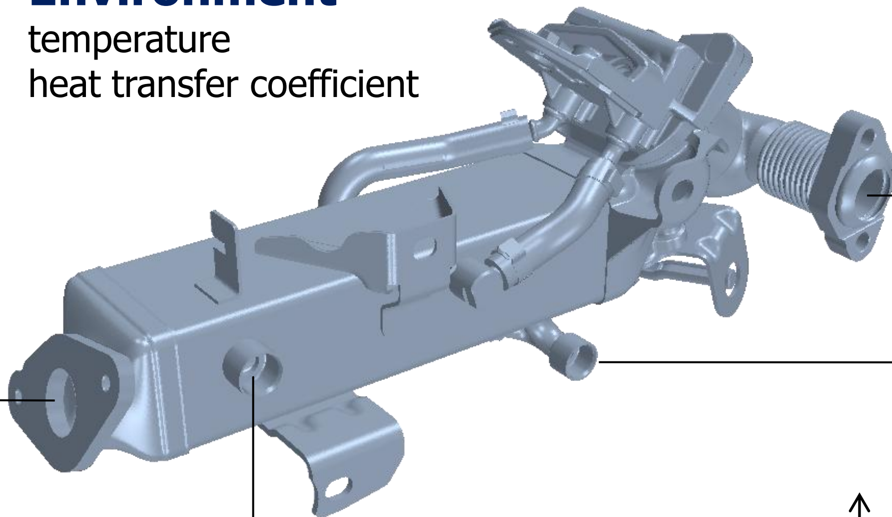


Virtual Bench Testing to Populate GT Objects

Test Rig Set-Up for an EGR Cooler Module

Environment

temperature
heat transfer coefficient



Exhaust

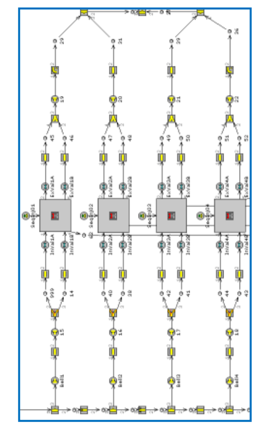
Coolant

Exhaust

Coolant

Flow Rates

optional from
GT-SUITE
engine model

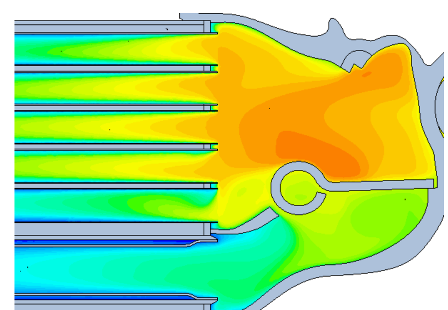


Model Set-Up with STAR-CCM+

- 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 Bench Testing to Populate GT Objects

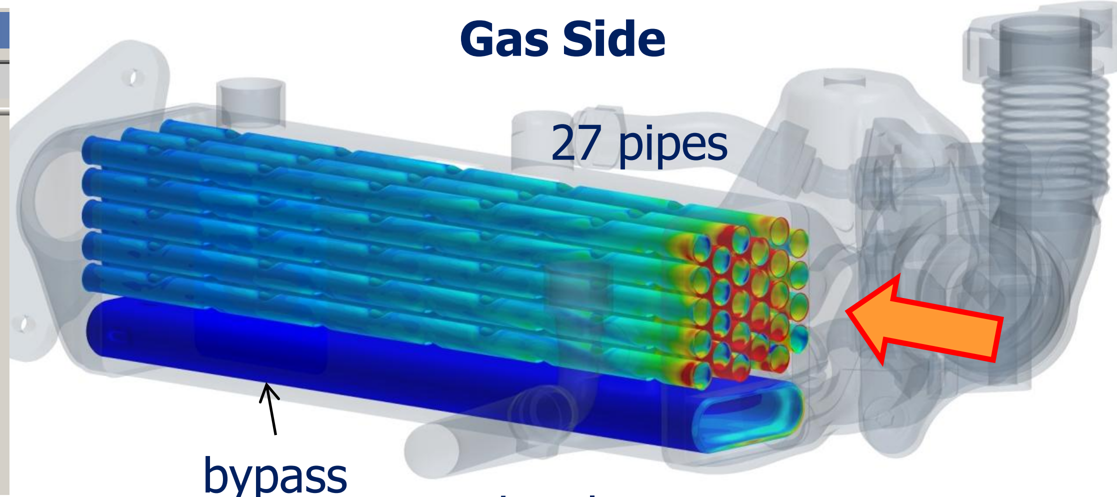
Pipe Bundle EGR Cooler Module

Edit Object: EGR_Geom

Template: HxGeneral

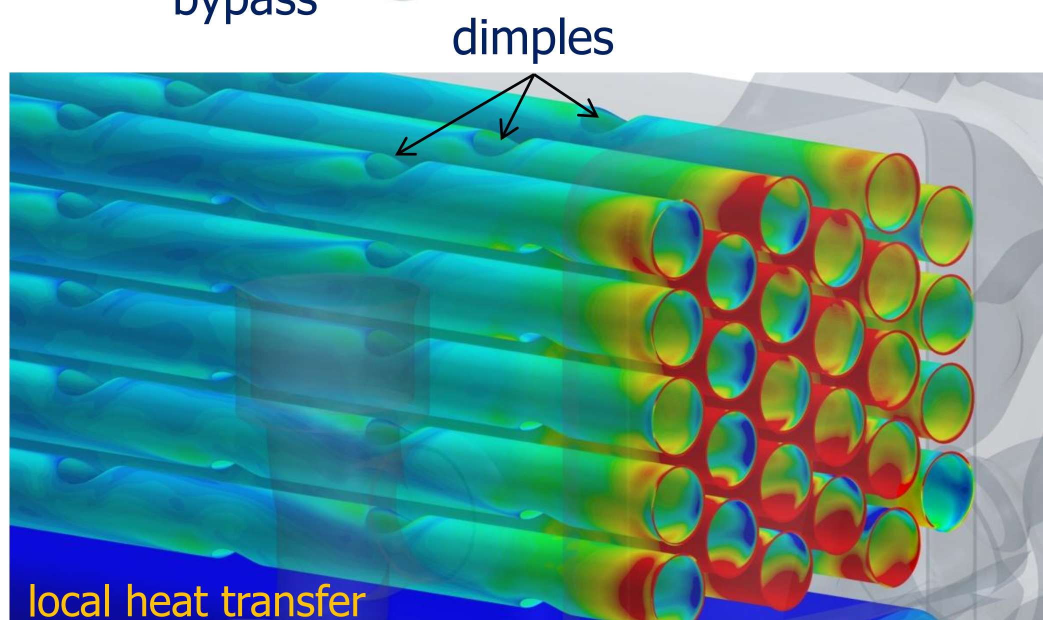
Attribute	Unit	Object V...
Reference Length	mm	7.5
Heat Transfer Area (One Tube)	mm^2	5066
Flow Area (One Tube)	mm^2	44.18
Volume of Fluid	liter	0.2565
Fraction of Volume in Heat Exchanger Core		0.8
Number of Identical Tubes in Heat Exchanger Core		27
Inlet Pipe Reference Diameter	mm	25
Outlet Pipe Reference Diameter	mm	25

HxType | Internal (Master) | External (Slave) | Structural Material



for discretized HX use only 1 pipe:

Fraction of Volume in Heat Exchanger Core		1
Number of Identical Tubes in Heat Exchanger Core		1



- dimple design by InDesA to enhance heat transfer through turbulence

⇨ only turbulent flow

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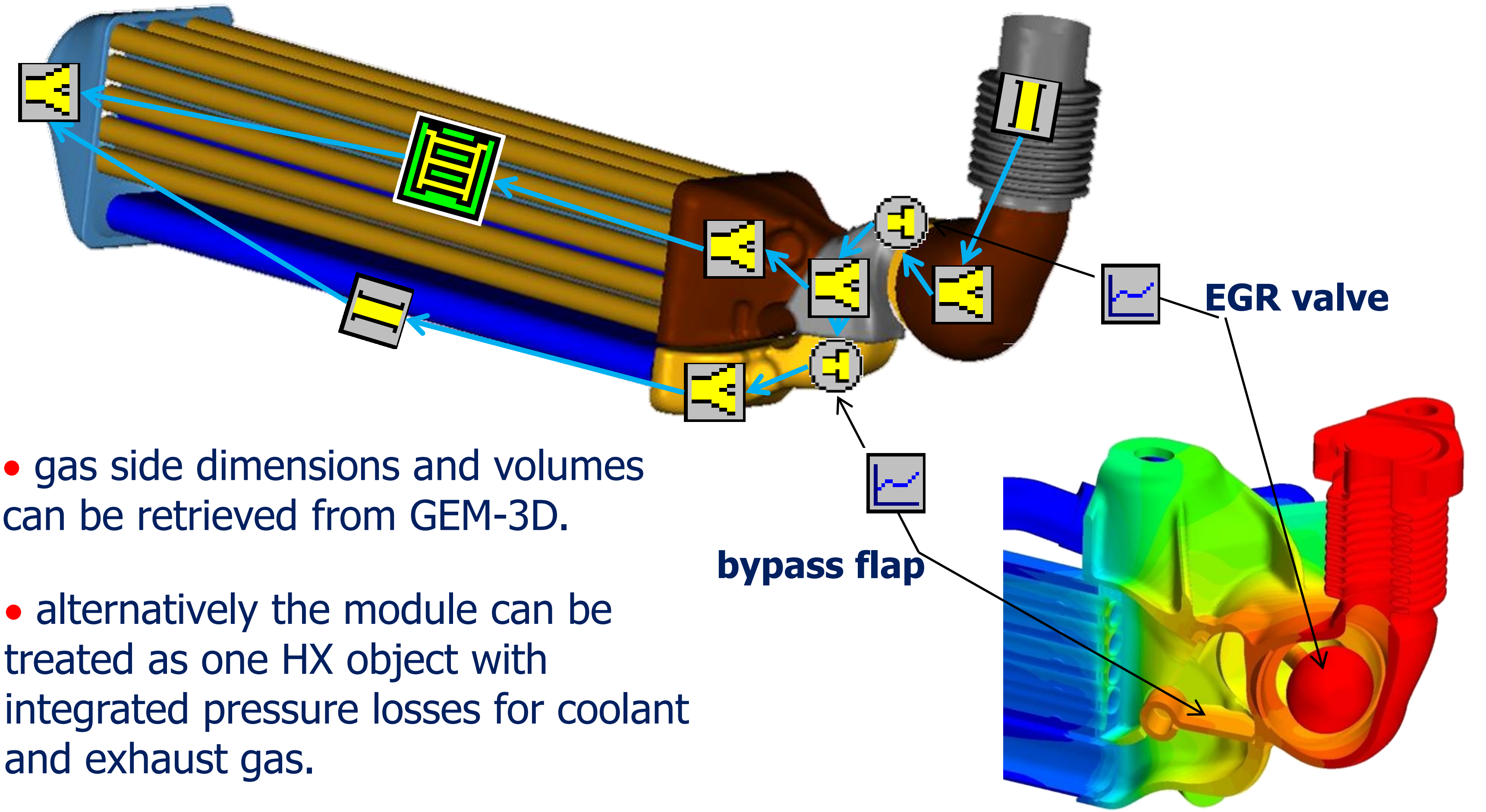
Virtual Bench Testing to Populate GT Objects
Decomposition of EGR Cooler with GEM3D

Gas Side Decomposition of Cooler Module with GEM 3D



- gas side dimensions and volumes can be retrieved from GEM-3D.

- alternatively the module can be treated as one HX object with integrated pressure losses for coolant and exhaust gas.

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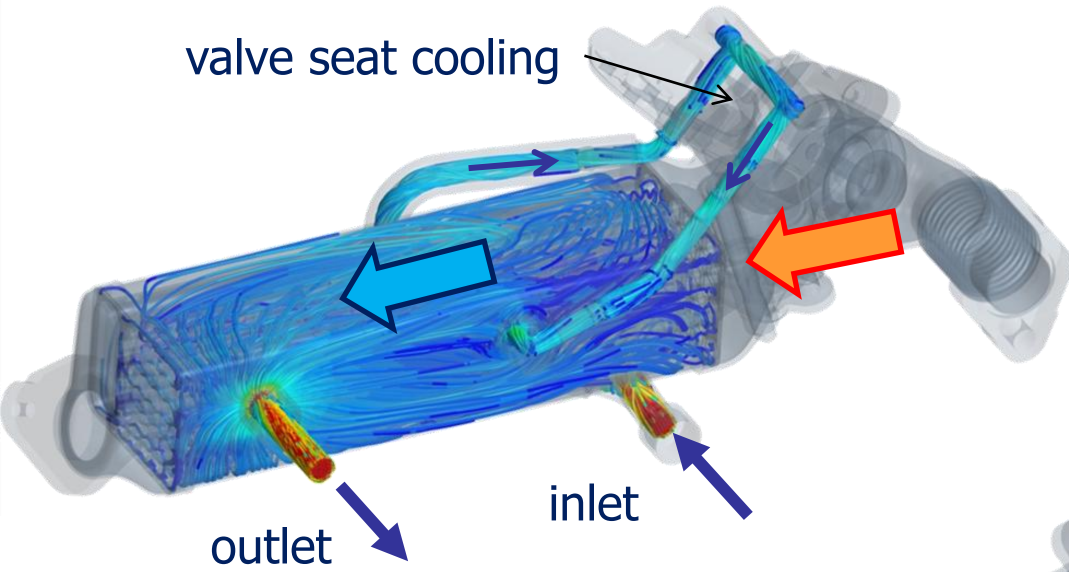
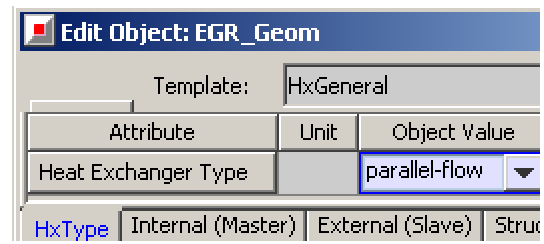
Virtual Bench Testing to Populate GT Objects
Coolant Flow through EGR Cooler Module



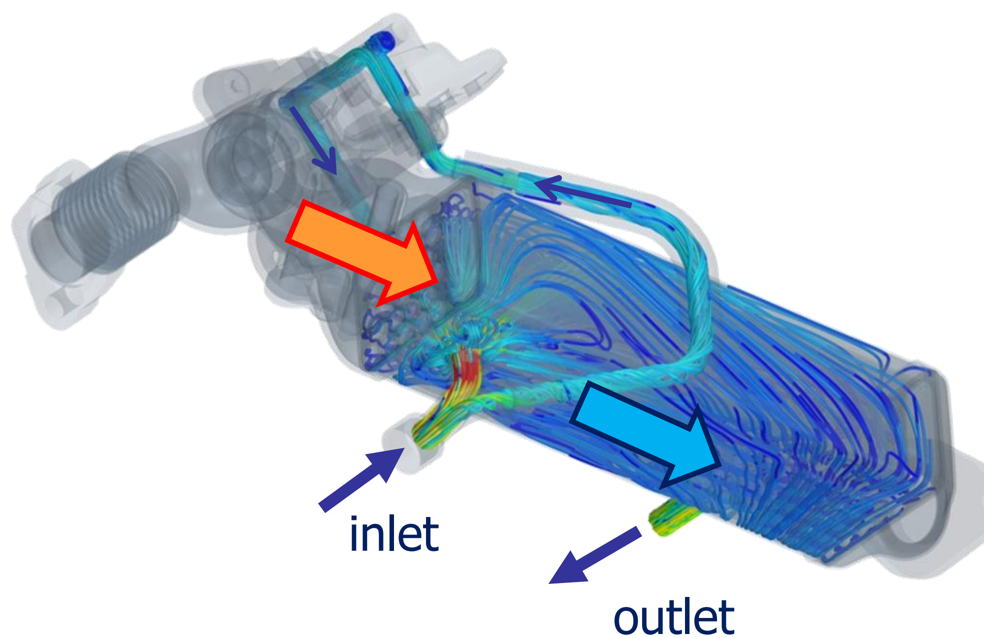
Coolant Side

Heat Exchanger Type:
parallel flow with some cross flow



- most EGR coolers are designed as parallel flow heat exchanger due to cooling requirements at the hot end (→ e.g. valve seat cooling).

- some cross flow is involved at the coolant inlet and outlet or due to baffles placed in the water jacket.



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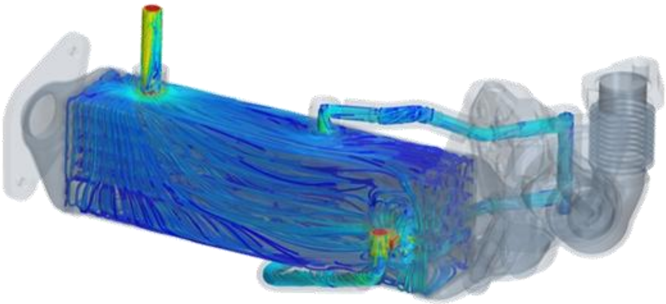
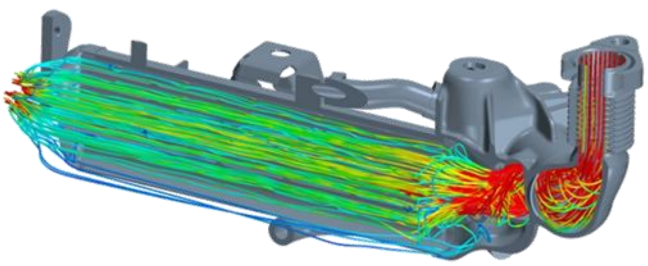
Virtual Bench Testing to Populate GT Objects

Test Rig Results for an EGR Cooler



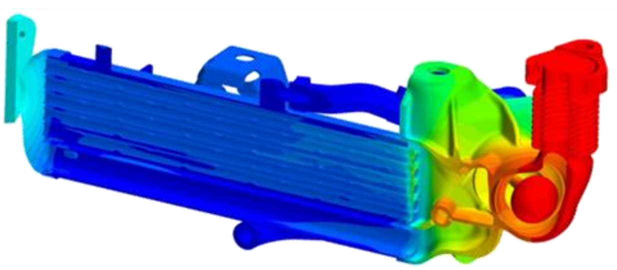
Coolant
- temperatures
- pressure loss
- onset of boiling
- volume flow rates
- flow uniformity

Pressure Loss
Δp ; α

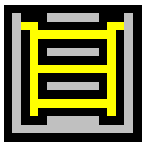


Exhaust
- outlet temperature
- pressure loss
- force on flap
- flow leakage

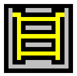
Pressure Loss
Δp ; α



Structure
- temperatures
  esp. valve seat
- heat transfer



Nusselt Correlation
Nu = f (Re,Pr)

GT heat exchanger object: 

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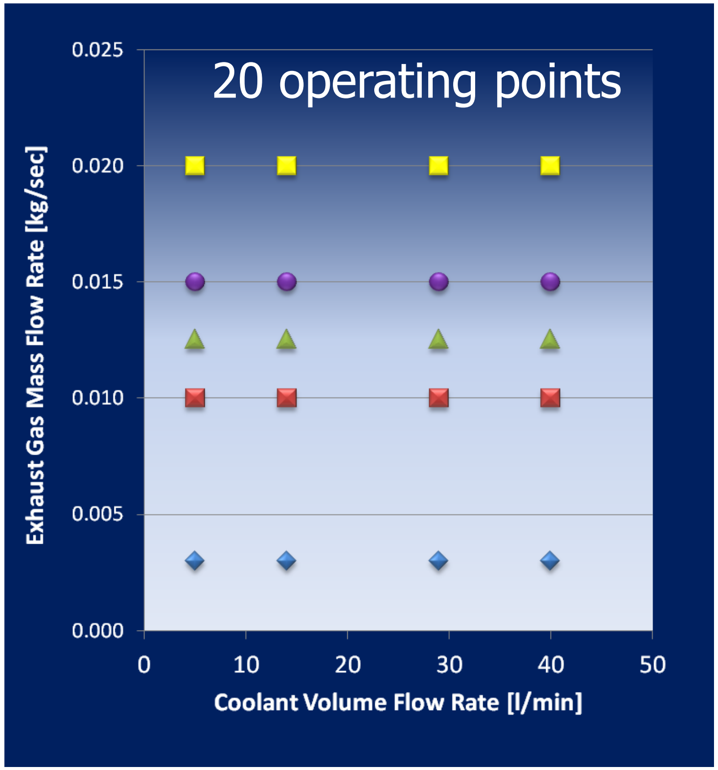
Virtual Bench Testing to Populate GT Objects

The InDesA Virtual Test Rig

Parallel Cluster with 112 Nodes

(14 Blades, each with 2 Intel Xeon/Nehalem Quad-Core Prozessors and InfiniBand Switch, Integrated Storage Area Network)

- compute time: 1 day for 14 steady flow operating points *)



*) for STAR-CCM+ model with 14 million cells

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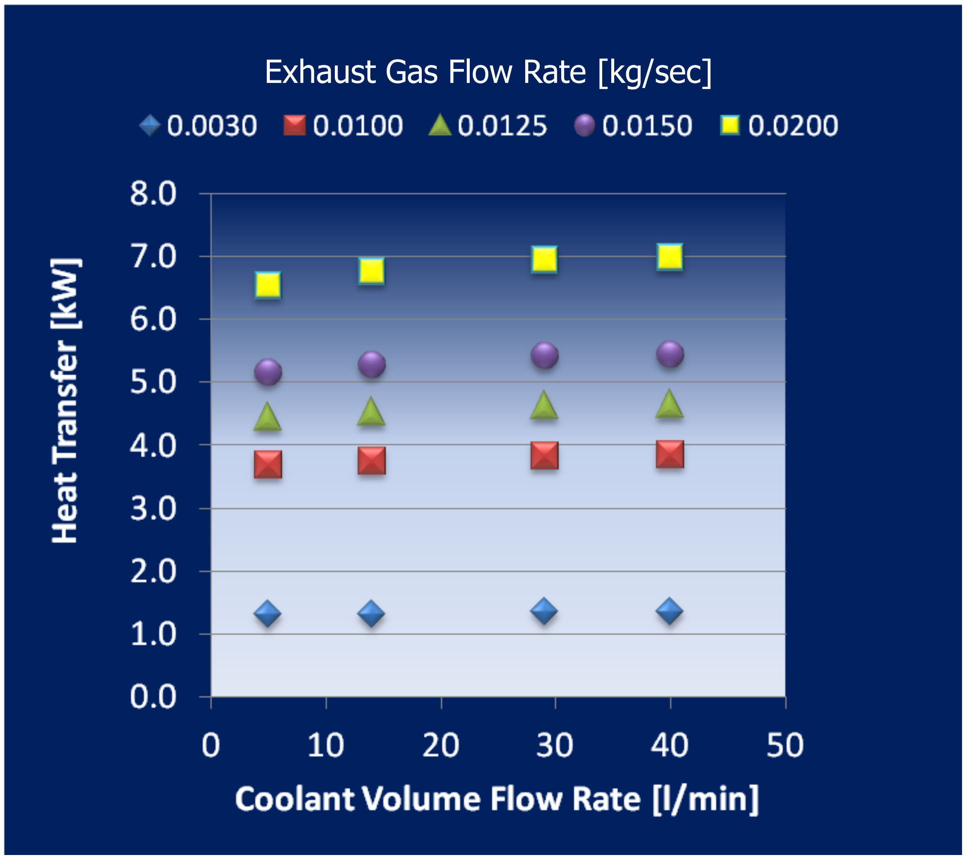
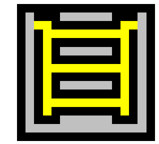
Virtual Bench Testing to Populate GT Objects

Virtual Test Rig Results & Transfer to GT-SUITE





Edit Object: EGR_HT_Data

Template: HxNuMap

Attri...	Internal Inlet Temperature	Internal Inlet Pressure	Internal Flow Quantity	External Inlet Temperature	External Inlet Pressure	External Flow Quantity	Performance Quantity
Unit	degC	bar		degC	bar		
1	550	def	0.003	90	def	5	1315.9
2	550		0.01	90		5	3698
3	550		0.0125	90		5	4442.8
4	550		0.015	90		5	5159.3
5	550		0.02	90		5	6547.9
6	550		0.003	90		14	1315.3
7	550		0.01	90		14	3755.3
8	550		0.0125	90		14	4531.2
9	550		0.015	90		14	5281.8
10	550		0.02	90		14	6756.7
11	550		0.003	90		29	1346.5
12	550		0.01	90		29	3834
13	550		0.0125	90		29	4635.5
14	550		0.015	90		29	5416
15	550		0.02	90		29	6953
16	550		0.003	90		40	1346.8
17	550		0.01	90		40	3844.4
18	550		0.0125	90		40	4651.5
19	550		0.015	90		40	5437.6
20	550		0.02	90		40	6992.3

gas inlet temperature: 550°C
coolant inlet temperature: 90°C

Prediction Fidelity:
InDesA has computed over 30 different EGR coolers of various designs.
Prediction accuracy has been checked and approved by supplier,
e.g. at the Automotive Research Experiment Station / Michigan State University.
Accuracy of simulation lies within test bench accuracy of 2-3 % for the heat transfer rate.

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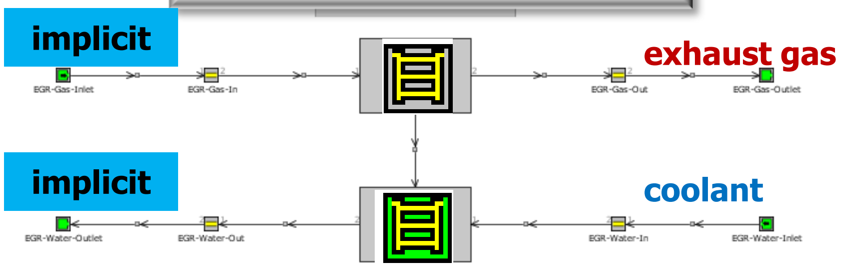
Virtual Bench Testing to Populate GT Objects

Virtual Test Rig Results & Transfer to GT-SUITE

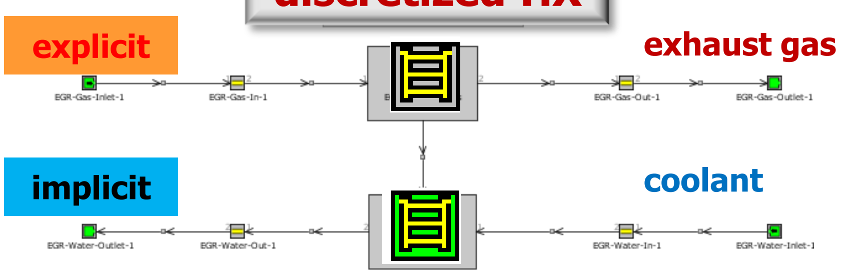
non-discretized HX



REGRESSION ACCURACY OF OVERALL HEAT TRANSFER
Mean Relative Error (%) = 0.323259

****

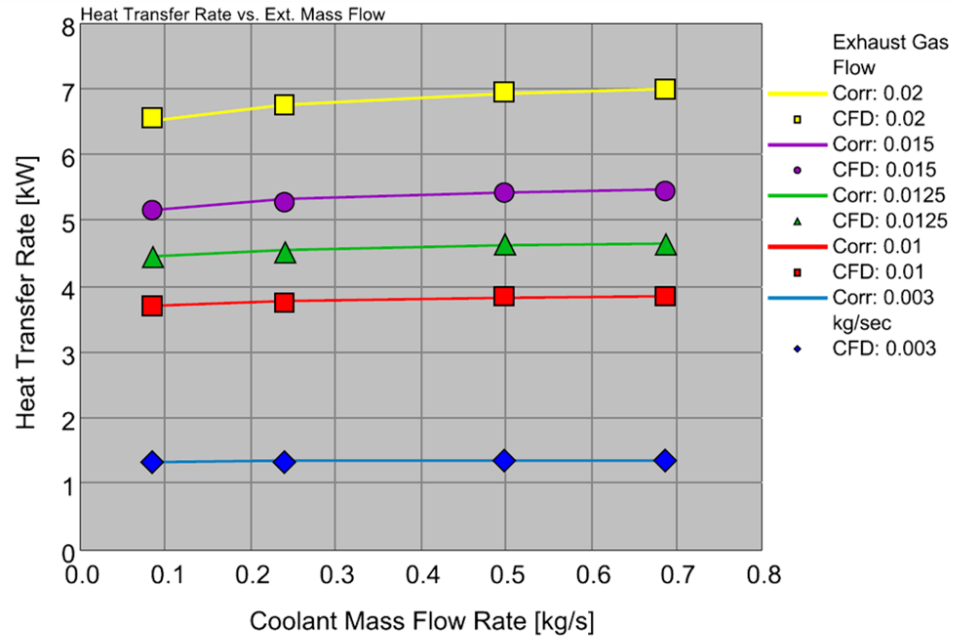
discretized HX



REGRESSION ACCURACY OF OVERALL HEAT TRANSFER
Mean Relative Error (%) = 0.415198

****

Nu Correlation



- excellent agreement of CFD data points with GT regression for Nu-correlation from low to high mass flow rates.

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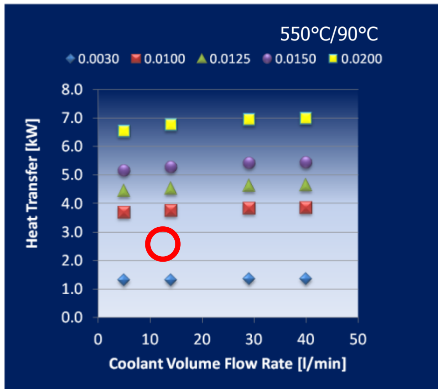
Virtual Bench Testing to Populate GT Objects

Transient Simulation with Pulsating Flow

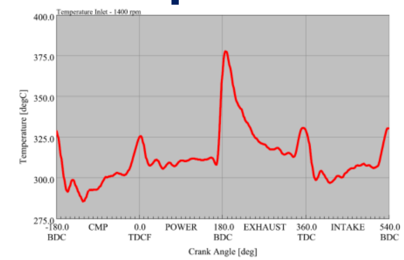


Mean flow conditions:

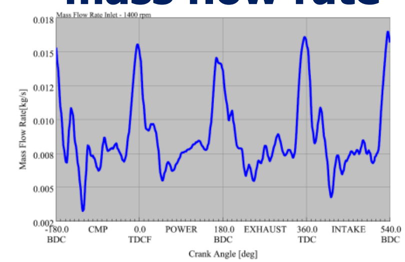
○	Exhaust	Coolant
inlet temperature	450 °C	90°C
flow rate	5.86 g/sec	12.5 l/min
inlet pressure	1.8 bar	2 bar

transient b.c. from GT-POWER analysis:

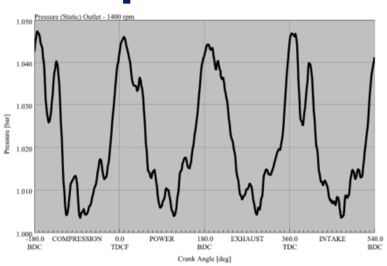
temperature

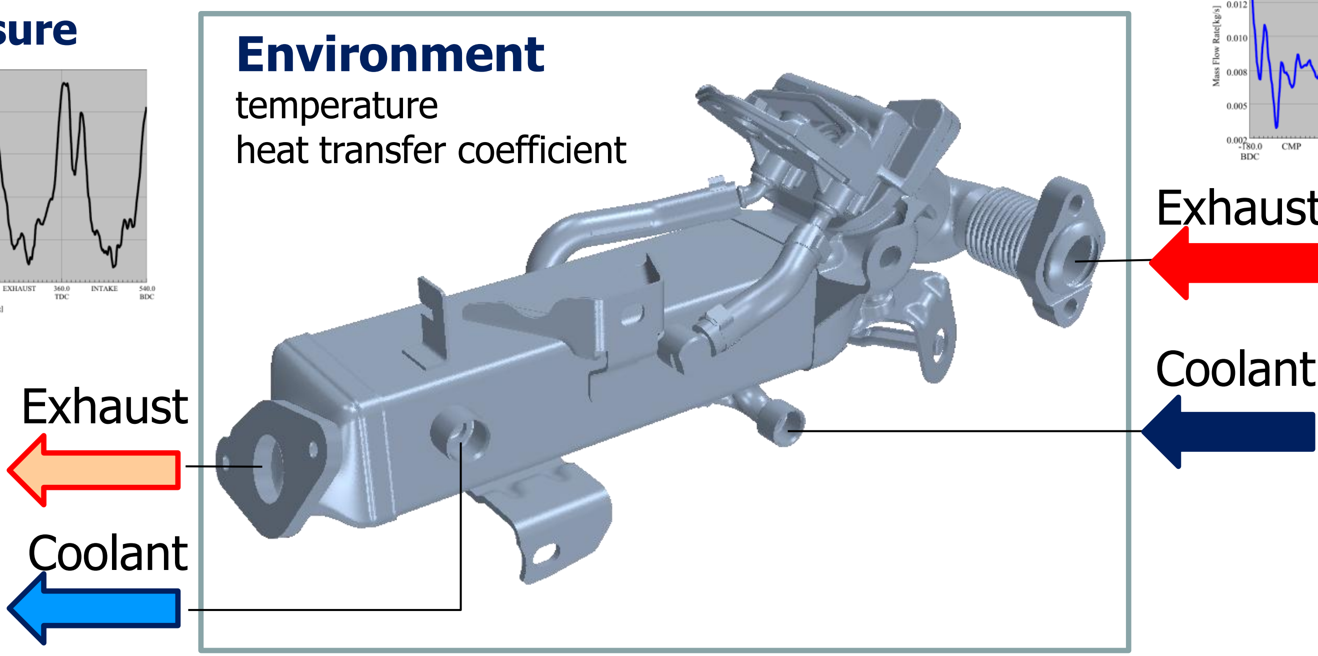


mass flow rate



pressure





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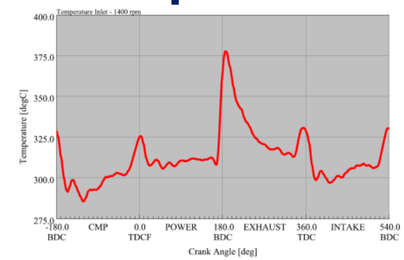
Virtual Bench Testing to Populate GT Objects

Transient Simulation with Pulsating Flow

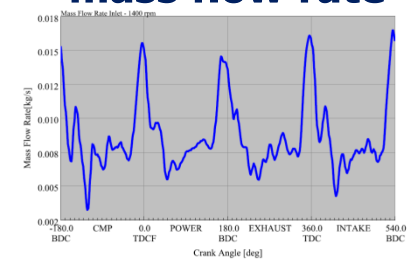
CFD Results after 10 cycles	stationary simulation	transient simulation	enhancement factor
heat transfer rate	1.82 kW	1.96 kW	1.08
pressure loss	534 Pa	841 Pa	1.57

transient b.c. from GT-POWER analysis:

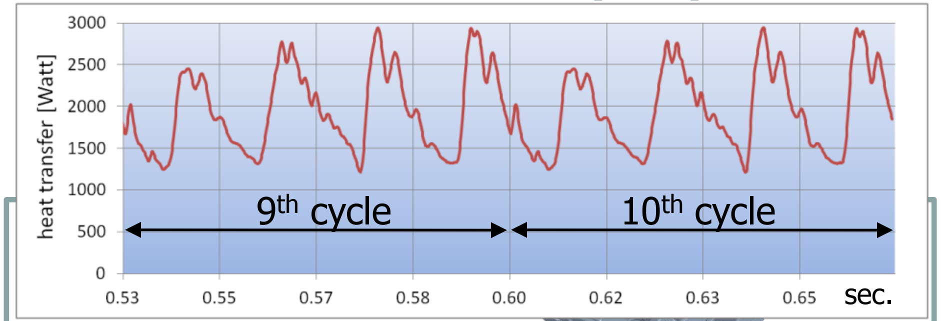
temperature



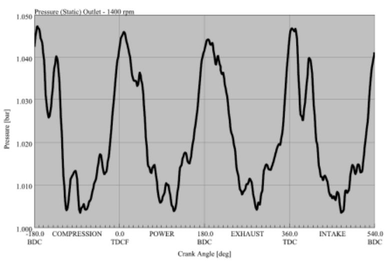
mass flow rate

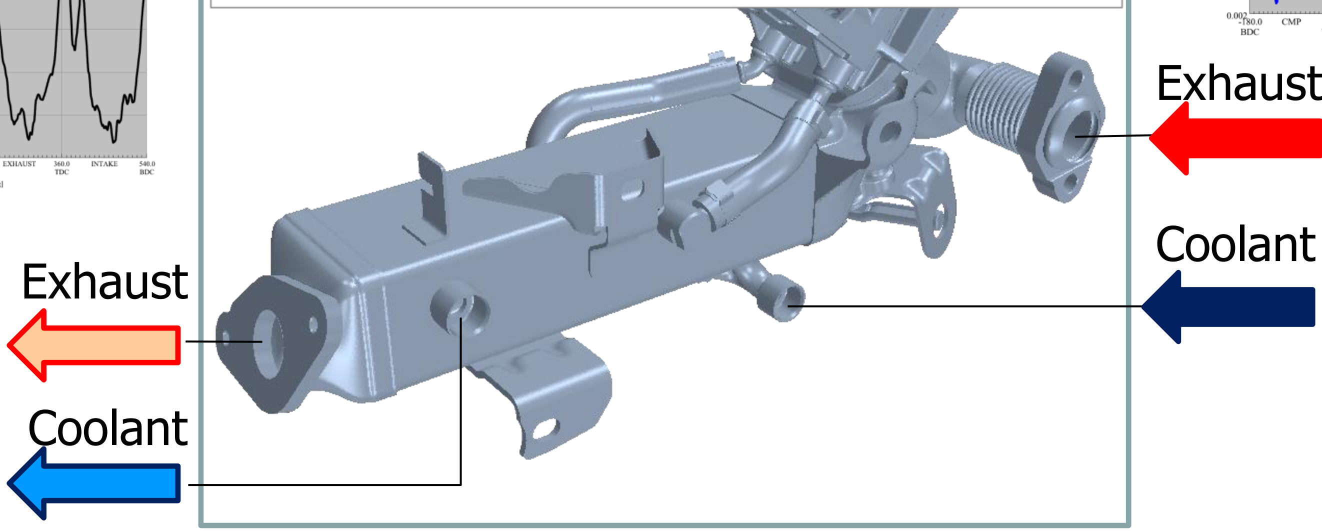


heat transfer (CFD)



pressure





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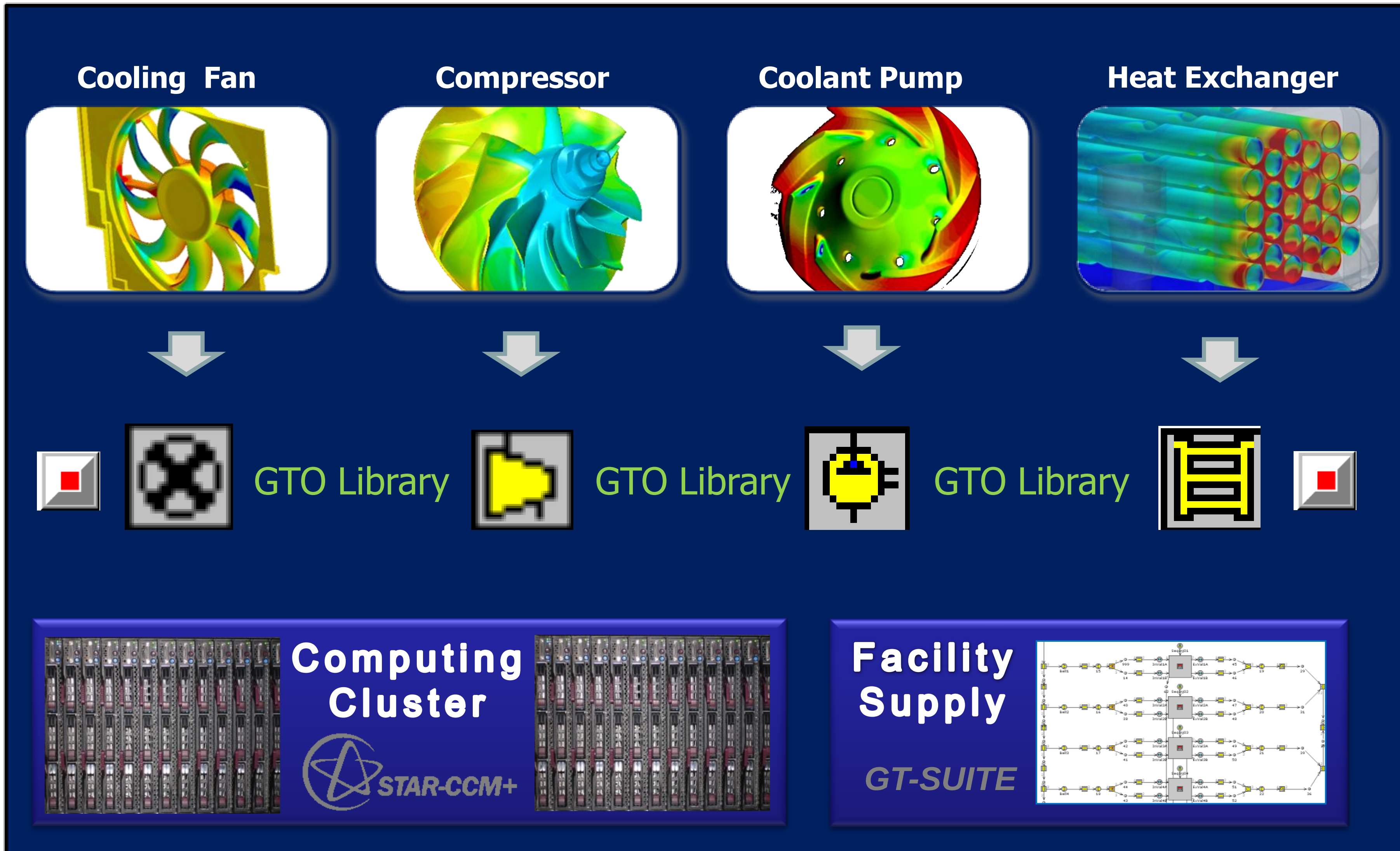
Virtual Bench Testing to Populate GT Objects

Capability of the InDesA Test Facility Center



Virtual Bench Testing to Populate GT Objects

Conclusion

Standardized Virtual Bench Testing

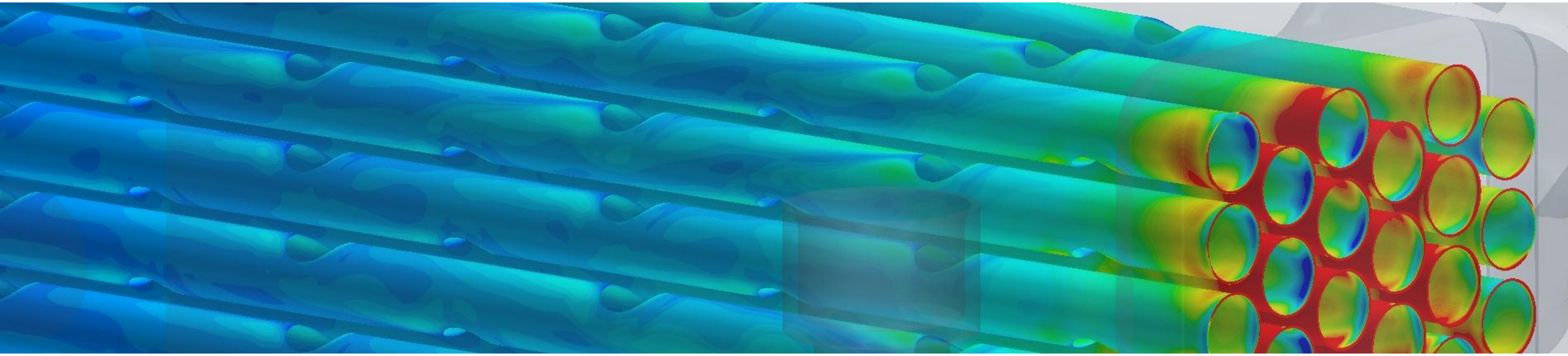
… significantly speeds up the virtual creation process between supplier and OEM at lower costs.
👍 no need for prototypes and physical bench testing

… feeds OEM directly with populated and tested objects for GTO-Library
👍 complementary use of 3D CFD and GT-SUITE and Post-Processing

… enhances input data for GT-SUITE Pre-Processing
👍 virtual test data fit very well with Nu-Correlation

… is capable to predict heat transfer for pulsating flow.
👍 complementary use of 3D CFD and GT-POWER

besides …
the virtual test bench can be packed, stored and reproduced anytime.



Thank you for your attention.