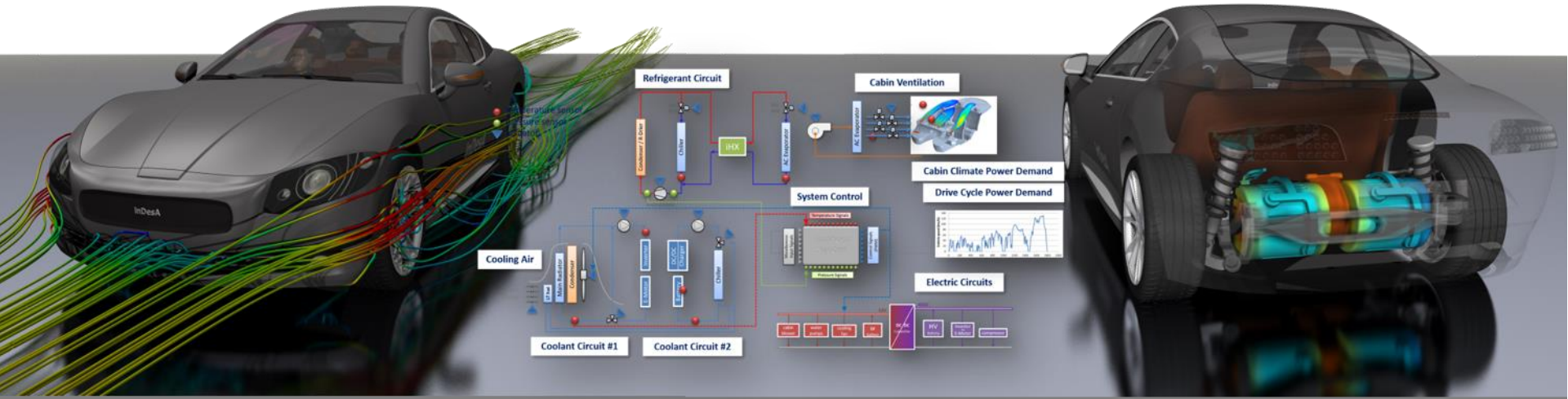
INTEGRATED DESIGN ANALYSIS GmbH InDesA

An Integrated Simulation Strategy for the Thermal Design and Analysis of Electric Vehicles

Gerald Seider, Fabiano Bet

London, UK

06/06/2019



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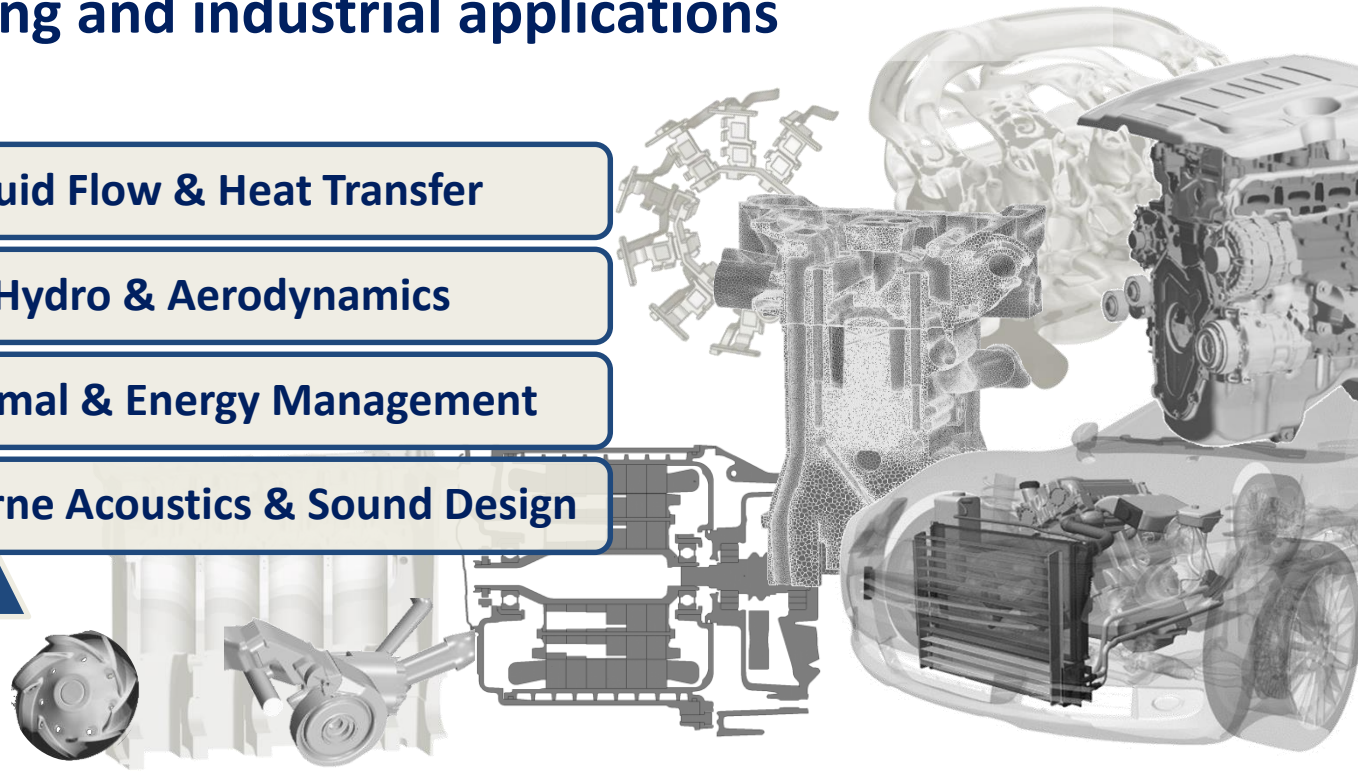
Thermal Design and Analysis of Electric Vehicles
InDesA Competence

Simulation and Design Analysis of complex systems for engineering and industrial applications

- Fluid Flow & Heat Transfer
- Hydro & Aerodynamics
- Thermal & Energy Management
- Air-borne Acoustics & Sound Design



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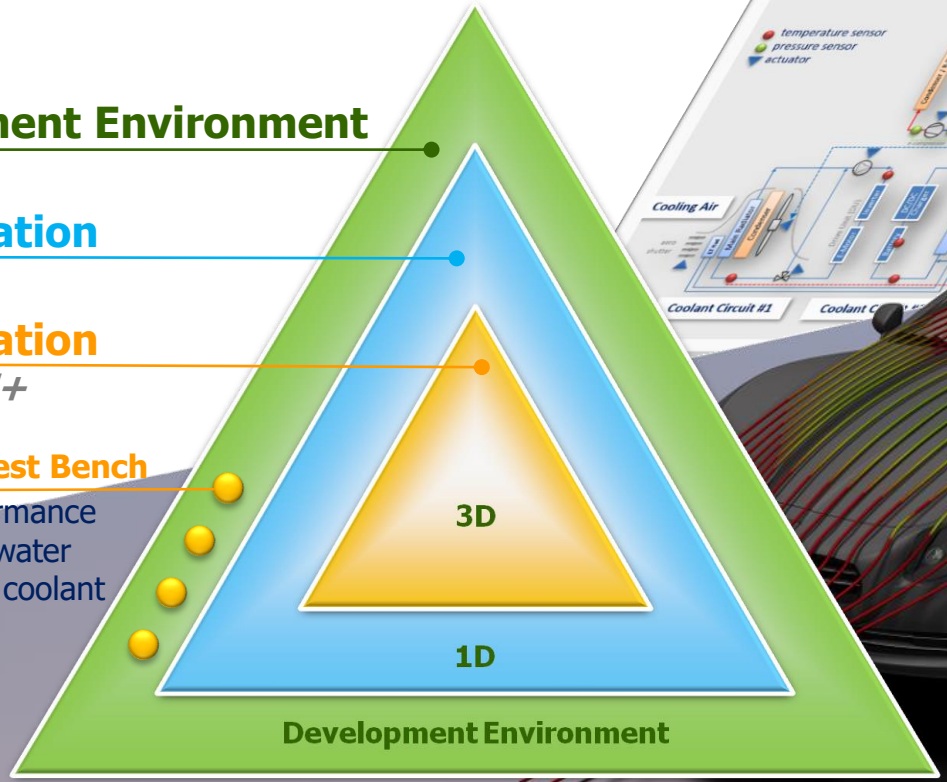
Thermal Design and Analysis of Electric Vehicles
Integrated Design Analysis

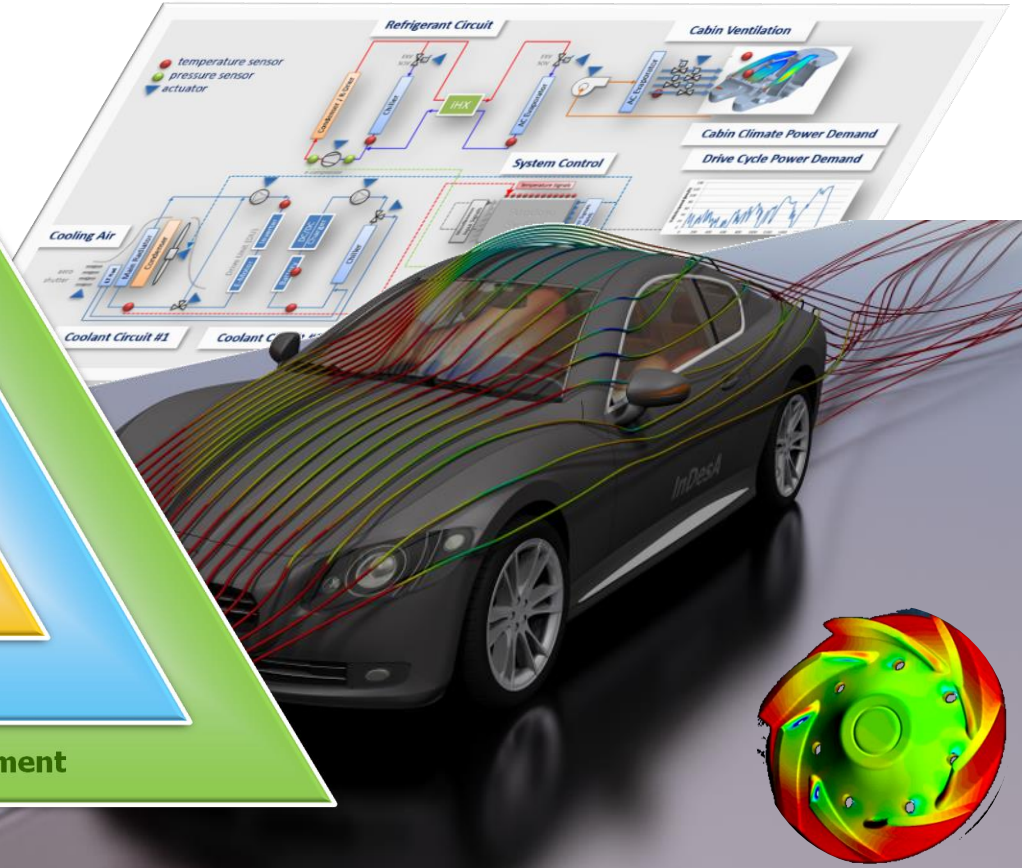
Development Environment
of customer

1D Simulation
GT-SUITE

3D Simulation
STAR-CCM+

3D Virtual Test Bench
e.g. for performance prediction of water pump for low coolant temperatures





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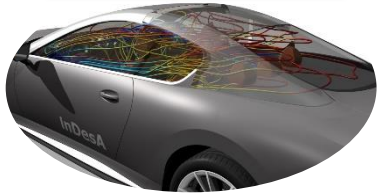
Thermal Design and Analysis of Electric Vehicles
1D and 3D Thermal & Energy System Simulation

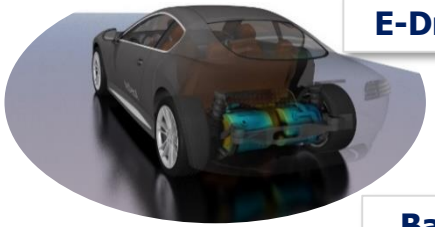
Solar Radiation

3D

Cabin Comfort

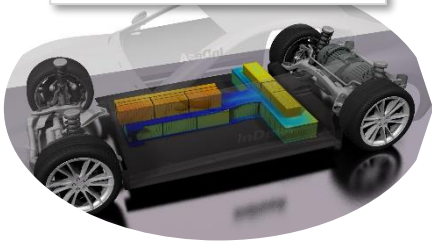


E-Drive Thermal

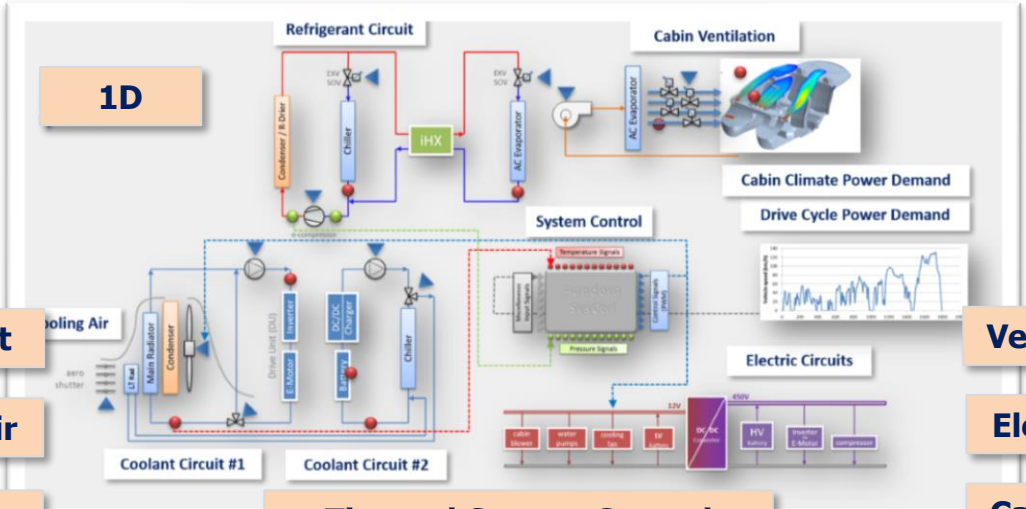


Aerodynamics

Battery Thermal



1D



Refrigerant Circuit

FE Cooling Air

Coolant Circuit

Thermal System Control

Vehicle & Drivetrain Control

Electric Circuitry

Cabin Ventilation

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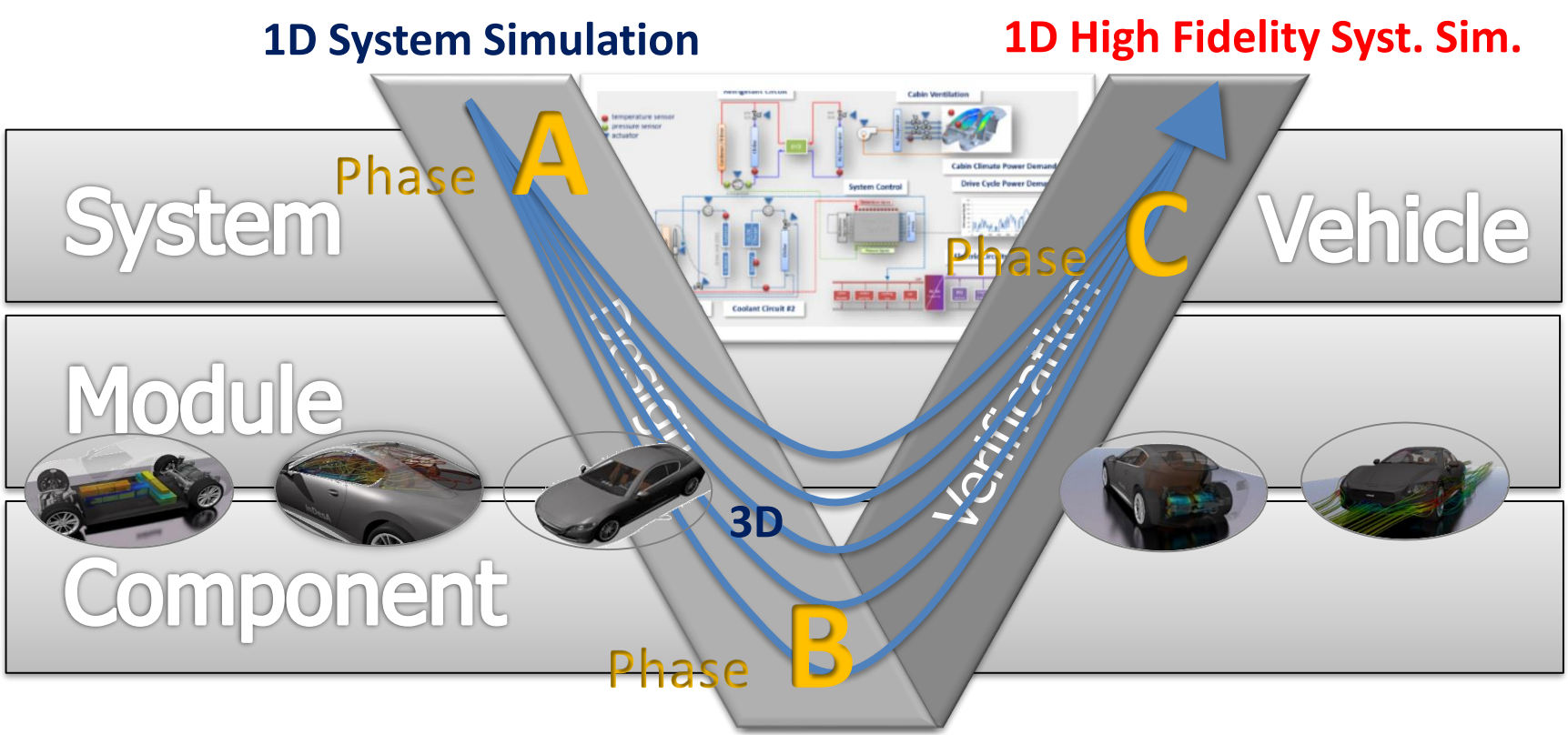
Thermal Design and Analysis of Electric Vehicles
Towards 1D High Fidelity System Simulation



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Thermal Design and Analysis of Electric Vehicles
Towards High Fidelity System Simulation

Phase

A Early design	Quick evaluation of coolant and refrigerant circuit configurations with regard to cooling/warm-up requirements and range; **1D** System simulation: Use of simple component objects and control strategies.
B CAD design	Evaluation of module behaviour and performance to calibrate 1D component objects and derive new 1D high fidelity compounds. Module/component simulation: Use of **3D** CFD/CHT simulation
C Verification	Verification of coolant and refrigerant circuit configurations with regard to cooling/warm-up requirements and range with full control functionalities; **1D** System simulation: Use of high fidelity component objects and controls.

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Thermal Design and Analysis of Electric Vehicles
Baseline Schematic of Thermal and Electric System

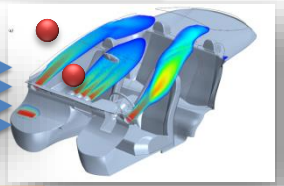
temperature sensor
pressure sensor
actuator

Refrigerant Circuit

EXV
SOV
Condenser / R-Drier
Chiller
iHX
EXV
SOV
AC Evaporator
e-compressor

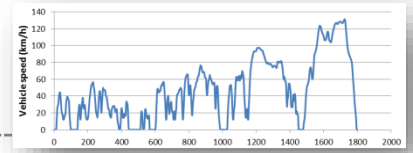
Cabin Ventilation

AC Evaporator



Cabin Climate Power Demand

Drive Cycle Power Demand



System Control

Temperature Signals
Miscellaneous Input Signals
Pandora SysCtrl
Control Signals (PWM)
Pressure Signals

Cooling Air

aero shutter
LT Rad
Main Radiator
Condenser
Drive Unit (DU)
Inverter
E-Motor
DC/DC Charger
Battery
Chiller

Electric Circuits

12V
450V
cabin blower
water pumps
cooling fan
LV Battery
DC/DC Converter
HV Battery
Inverter E-Motor
compressor

Coolant Circuit #1

Coolant Circuit #2

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Thermal Design and Analysis of Electric Vehicles
Derivation of 1D Component Library

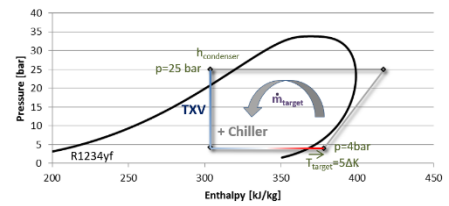
Derivation of Refrigerant Circuit Components for GT-SUITE Library

Component test bench measurements for existing components used to build and calibrate GT-model with all available input with regard to geometry.

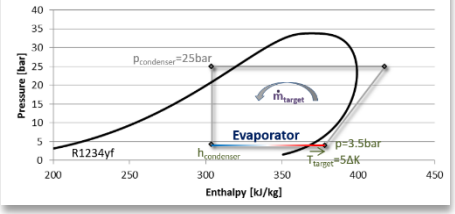
Find correlations with regard to heat transfer, pressure loss/rise, flow rate, etc. to scale components in size and performance.

Based on existing components the entire refrigerant circuit can be rescaled and adapted to new vehicles, test conditions, strategies, etc.

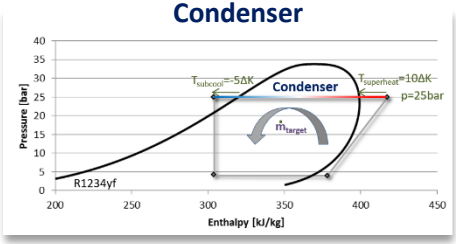
TXV + Chiller



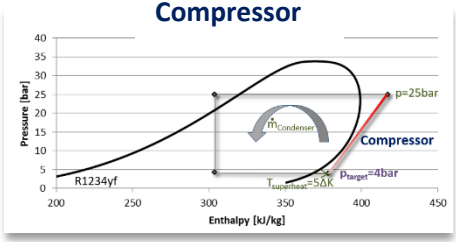
Evaporator



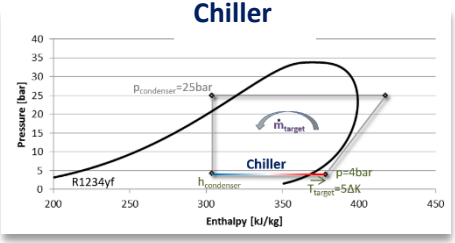
Condenser



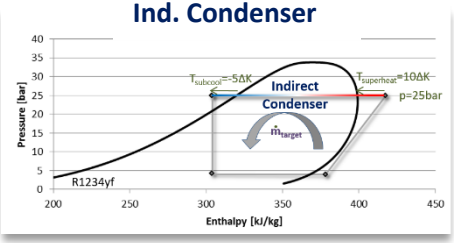
Compressor



Chiller



Ind. Condenser



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Thermal Design and Analysis of Electric Vehicles
Circuit Ceck with Standard Sensitivity Study

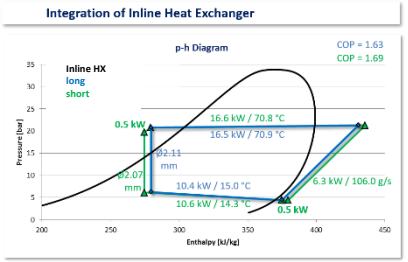
Model Check with Standard Sensitivity Study

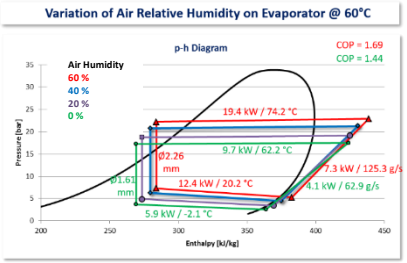
… change only a single parameter and investigate how the system behaves

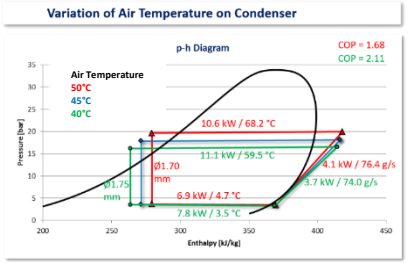
Standard Sensitivity Study to ensure

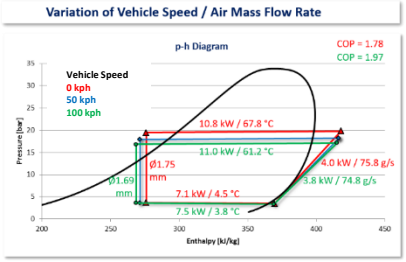
… simulation runs stable, fast and converges for various operating conditions
➔ requirement to simulate dynamic drive cycles in larger systems

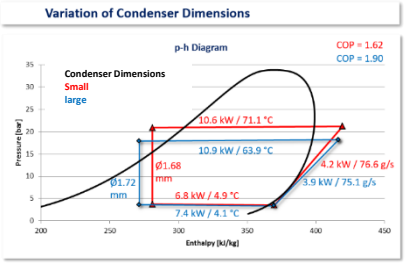
… solutions and results are reasonable!

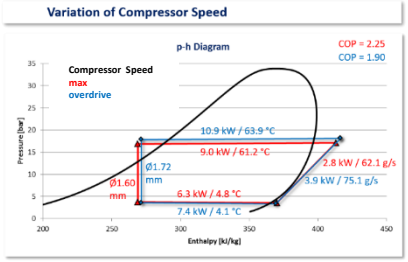












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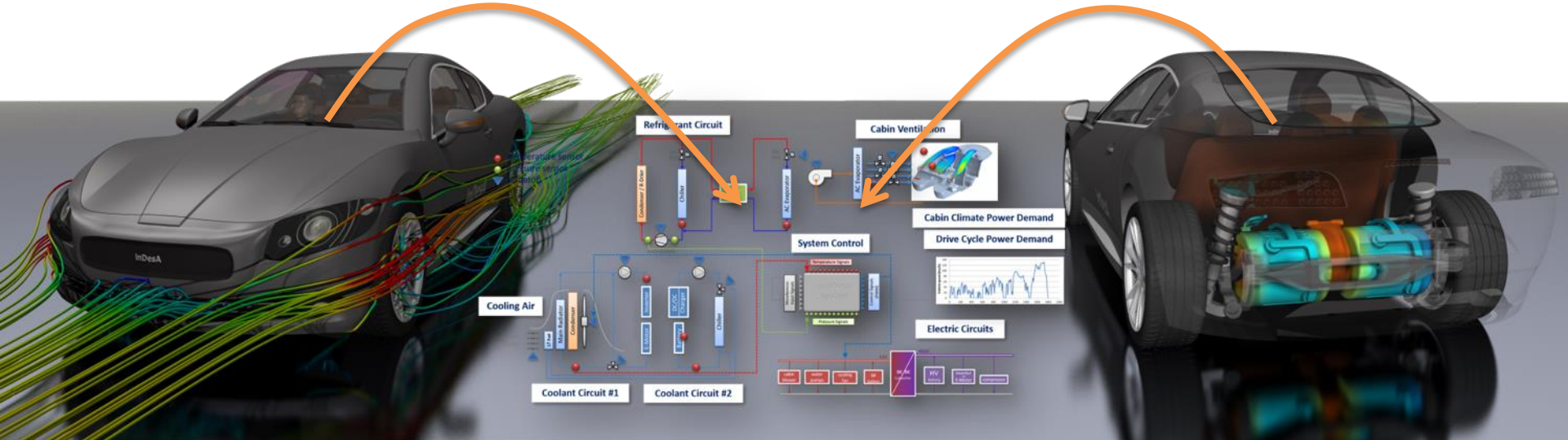
Thermal Design and Analysis of Electric Vehicles
3D Thermal System Simulation

3D CFD/CHT simulation relevant for HVAC System Design

- Vehicle aerodynamics and underhood flow
- Cabin heating with solar radiation
- Cabin cooling and ventilation
- E-Drive Thermal System
- Battery Thermal System



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B

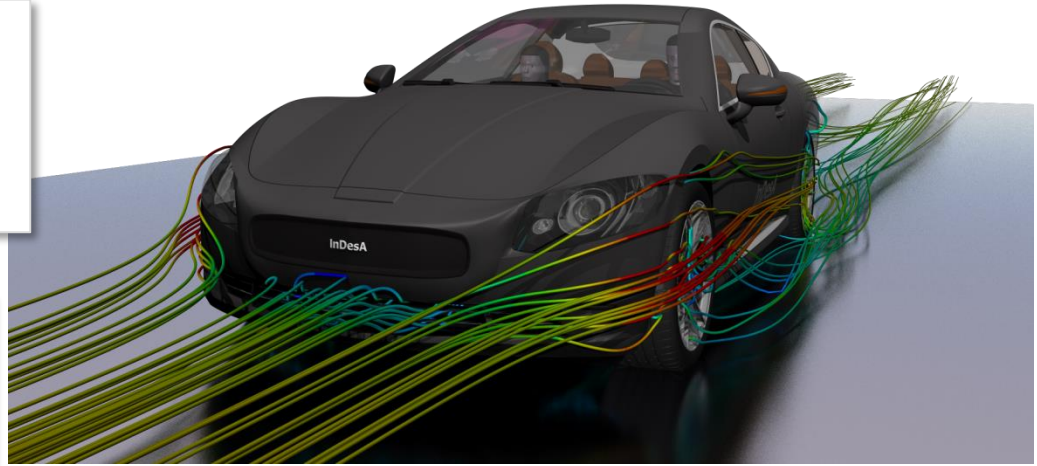
Thermal Design and Analysis of Electric Vehicles
Aerodynamic and Underhood Flow

Exterior and Underhood Flow Simulation

- Vehicle Aerodynamics
- Flow through Condenser/Radiator and Fan Module (CRFM)
- Vehicle underfloor Flow

Prediction of

- Aerodynamic drag
- Mass flow rates and losses through CRFM
- Heat Release from Radiator/Condenser
- Heat Transfer Coefficients (Cabin, Transmission)



Relevance for 1D System Simulation

- Aerodynamic drag
- Calibration of cooling air flow model (CRFM)
- HTC's for cabin exterior

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B

Thermal Design and Analysis of Electric Vehicles
Cabin Flow and Heat Transfer with Solar Radiation

Cabin Thermal Comfort Simulation

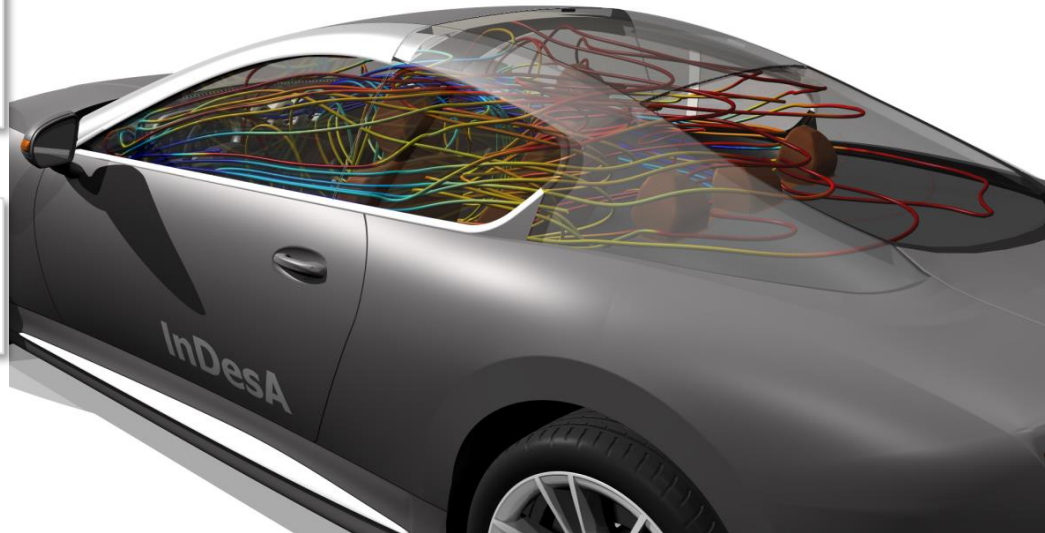
- CFD Cabin flow
- CHT Cabin Structure (body frame, windows, seats, etc.)
- Solar Radiation

Prediction of

- Cabin warm-up / cool-down
- Thermal comfort
- Thermal Balance Analysis

Relevance for 1D System Simulation

- Calibration of multi-zone cabin model
- HTC's at windows, walls and other boundaries



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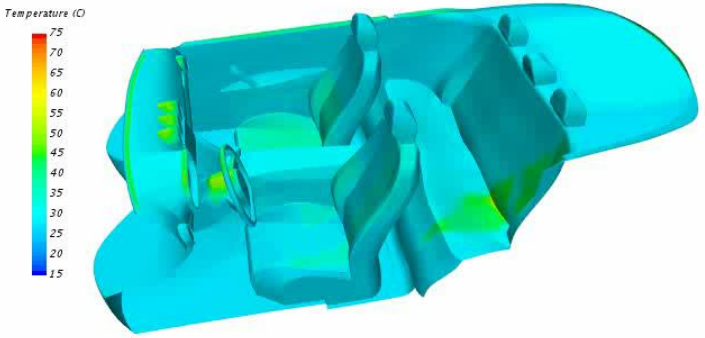
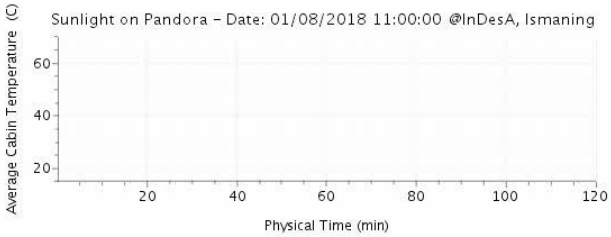
B Thermal Design and Analysis of Electric Vehicles
I. Cabin Warm-up through Solar Radiation

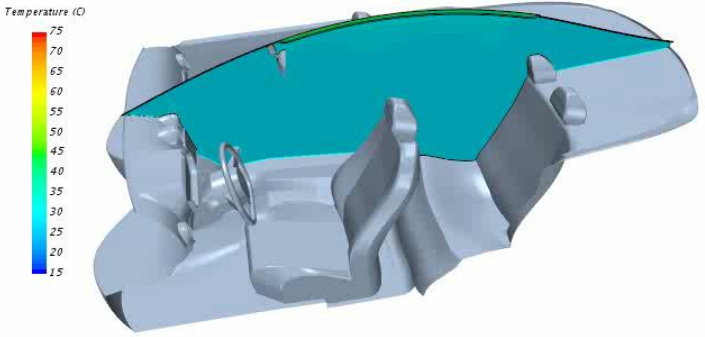
Warm-up Scenario:

01/08/2018 11:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 011° 40’
sun shine; no clouds

Simulation time 2 hours
Cabin start temp. 28°C







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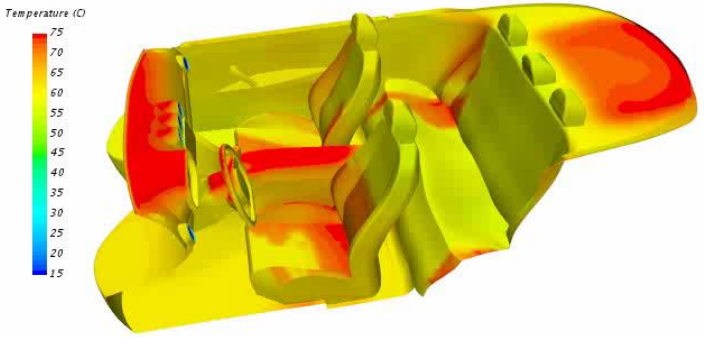
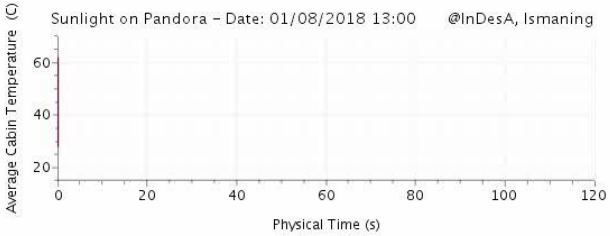
B Thermal Design and Analysis of Electric Vehicles
II. Cabin Cool Down through Air Conditioning

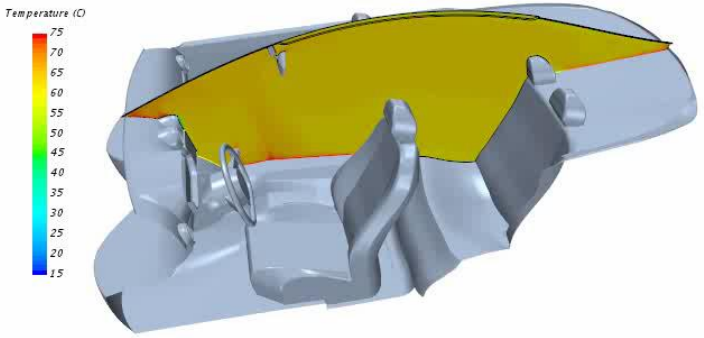
Cool-Down Scenario:

01/08/2018 13:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 11° 40’
sun shine; no clouds

Simulation time 2 minutes
Avg. cabin start temp. 62°C
Vent temp. 10°C
Vehicle speed: 0 kph







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Thermal Design and Analysis of Electric Vehicles
E-Drive Thermal Analysis

E-Drive Thermal Analysis

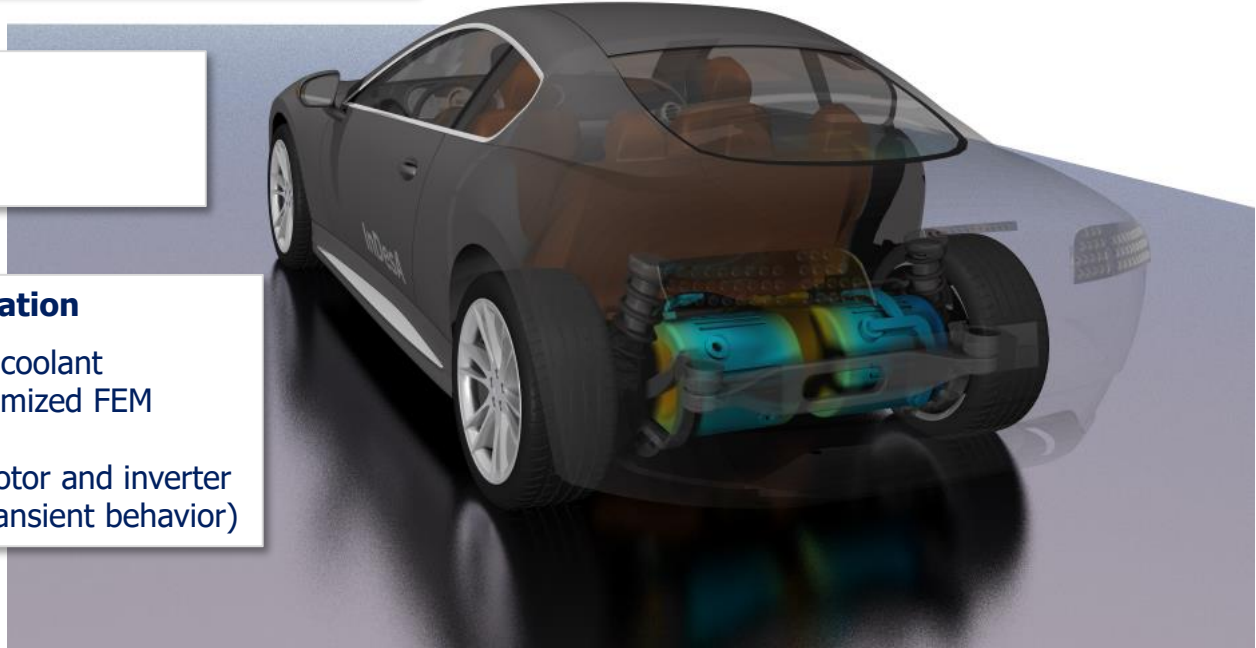
- E-Motor (water cooled)
- Inverter (water cooled)
- Transmission (air cooled)

Prediction of

- Local component temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from component to coolant
- Calibration of 3D GT-SUITE customized FEM model for e-motor
- Calibration of 1D models for e-motor and inverter with regard to thermal inertia (transient behavior)



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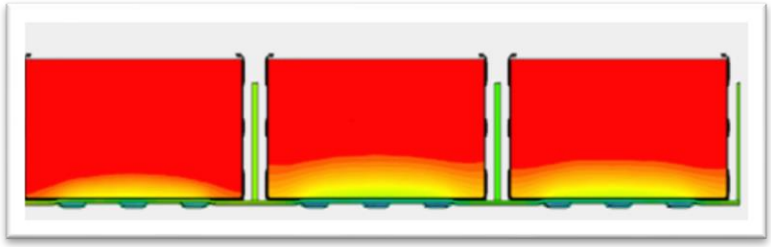
B Thermal Design and Analysis of Electric Vehicles
Battery Thermal Analysis



Battery Thermal Analysis

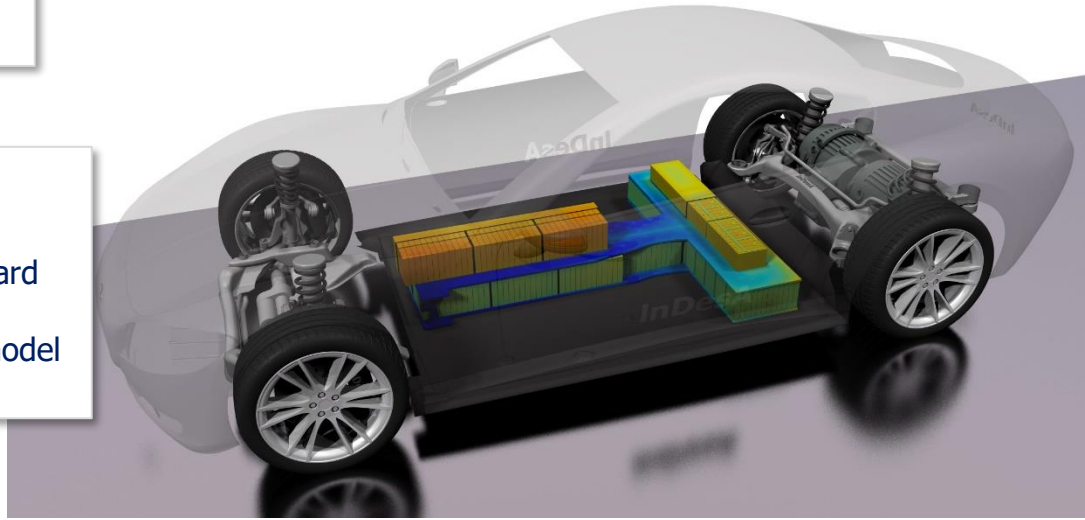
- Battery packs
- Cold Plate (water cooled)

Prediction of

- Local component/cell temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from battery to coolant
- Calibration of 1D models for battery with regard to thermal inertia (transient behavior)
- Calibration of 3D GT-Suite customized FEM model for battery



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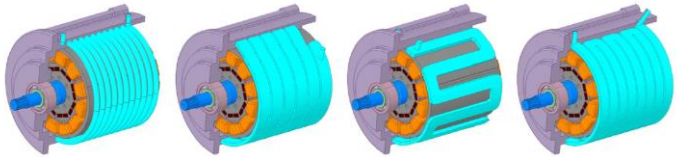
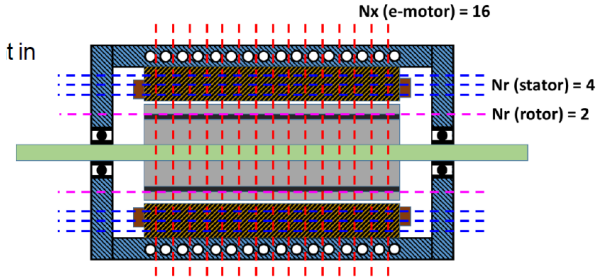
Thermal Design and Analysis of Electric Vehicles
E-Drive Unit – Towards a High Fidelity 1D Model

A

1D Simple or Parametric Model

- Fast to implement
- Fast to scale





GT

B

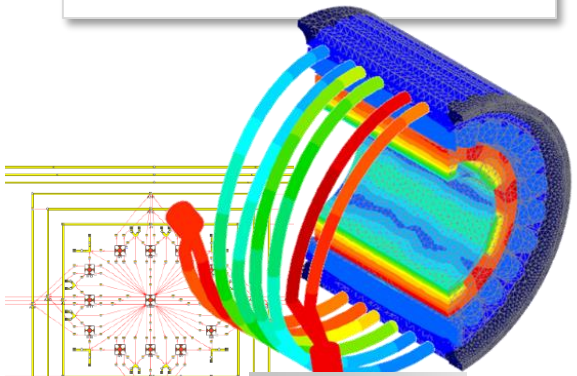
3D CFD/CHT Model with vehicle environment

- Fully coupled flow and thermal solution
- high accuracy
- heat transfer to transmission and ambient included.

C

1D High Fidelity Model with integrated FEM Model

- Calibrated with regard to 3D CFD/CHT model.
- high accuracy
- Fully integrated into 1D system simulation
- Multi thermal mass model can be derived to reduce simulation times.



GT

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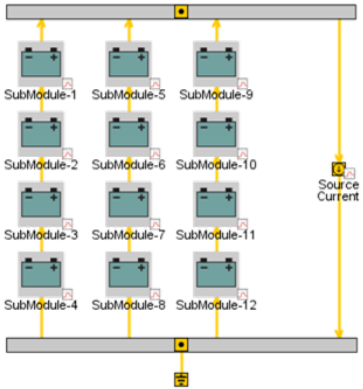
Thermal Design and Analysis of Electric Vehicles
Battery Model – Towards a High Fidelity 1D Model

A

1D Simple or Parametric Model

- Fast to implement
- Fast to scale
- Quick to connect to electrical system

cell

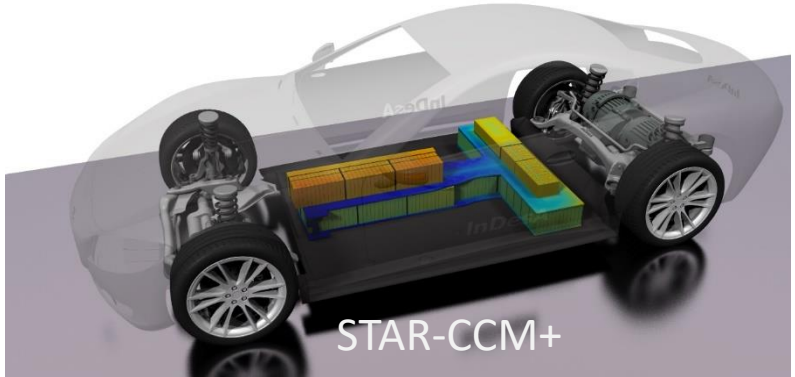


GT

B

3D CFD/CHT Model with vehicle environment

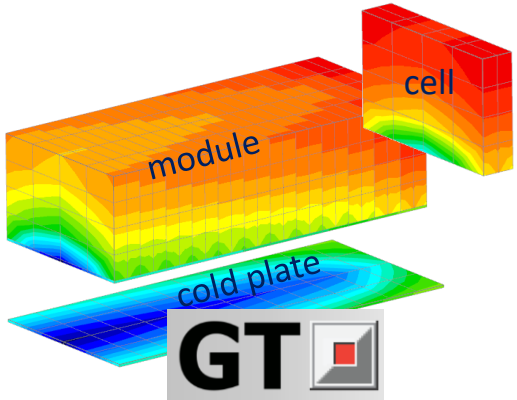
- Fully coupled flow and thermal solution
- high accuracy
- heat transfer to water cooled cold plate and housing



C

1D High Fidelity Model with integrated FEM Model

- Calibrated with regard to 3D CFD/CHT model.
- high accuracy
- Fully integrated into 1D system simulation
- Multi thermal mass model can be derived to reduce simulation times.



GT

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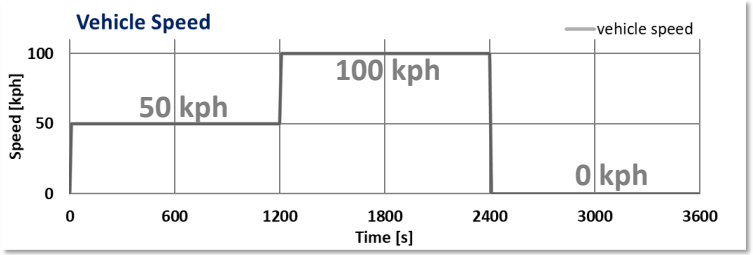
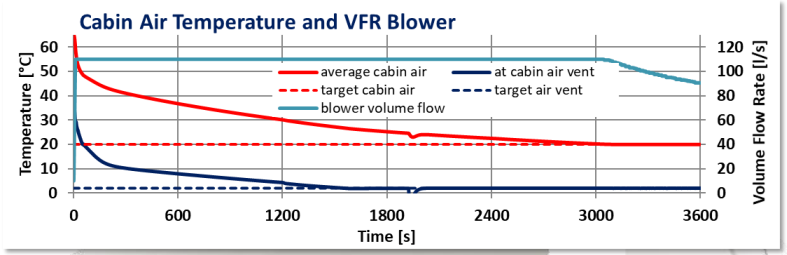
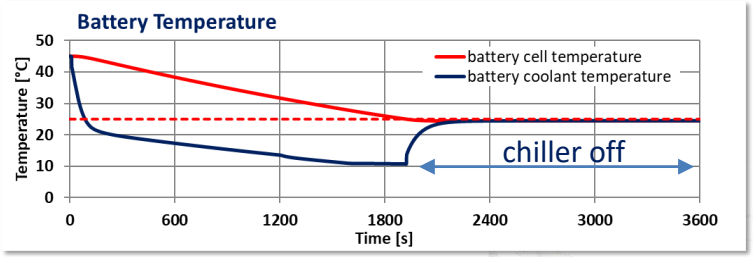
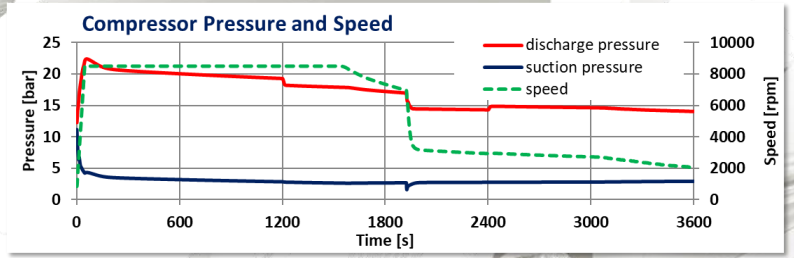
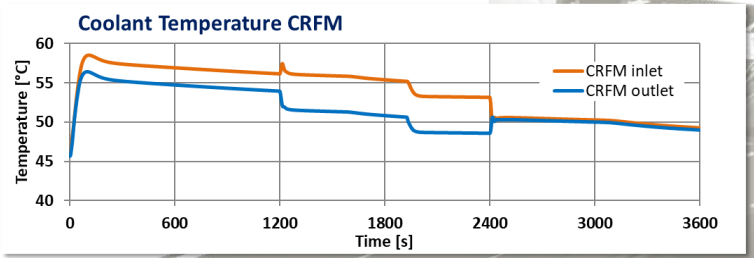
Thermal Design and Analysis of Electric Vehicles
Results for a Standard Pull-Down Procedure

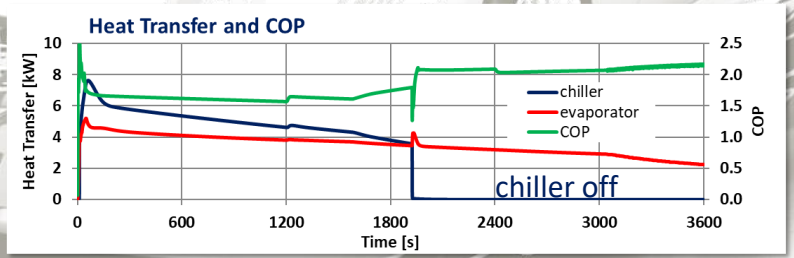












InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Summary

- InDesA maintains a complete suite of 1D/3D simulation methods to cover and manage complex thermal and energy systems of electrified vehicles; adapted to different stages of the virtual development process (V-cycle) i.e. from the early design stage towards the final digital twin.
- InDesA uses a simulation strategy of consecutive steps **A B C** to generate 1D high fidelity system simulation models in GT-SUITE, where …

  A is based on a library of components to find the best concept to fulfil the system targets

  B is based on 3D CFD/CHT models as 3D CAD become available to improve and calibrate 1D sub-models for modules.

  C integrated 3D FEM models are used for 1D systems simulation to achieve high fidelity results.
- System model includes the complete coolant and refrigerant circuit, vehicle and drivetrain, cabin, HV components and electric circuit and control functions.
- Results can be obtained for any drive cycle and ambient conditions and be used to develop and test control functions to optimize system efficiency and hence vehicle range.

Thank you for your Attention!

Gerald Seider, Fabiano Bet
London, UK
06/06/2019