A Modular Approach to Physical Modeling Using MATLAB, Simulink, and Simscape for Automobile System Modeling At Volvo Cars

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Integration and Prototype at Volvo Cars

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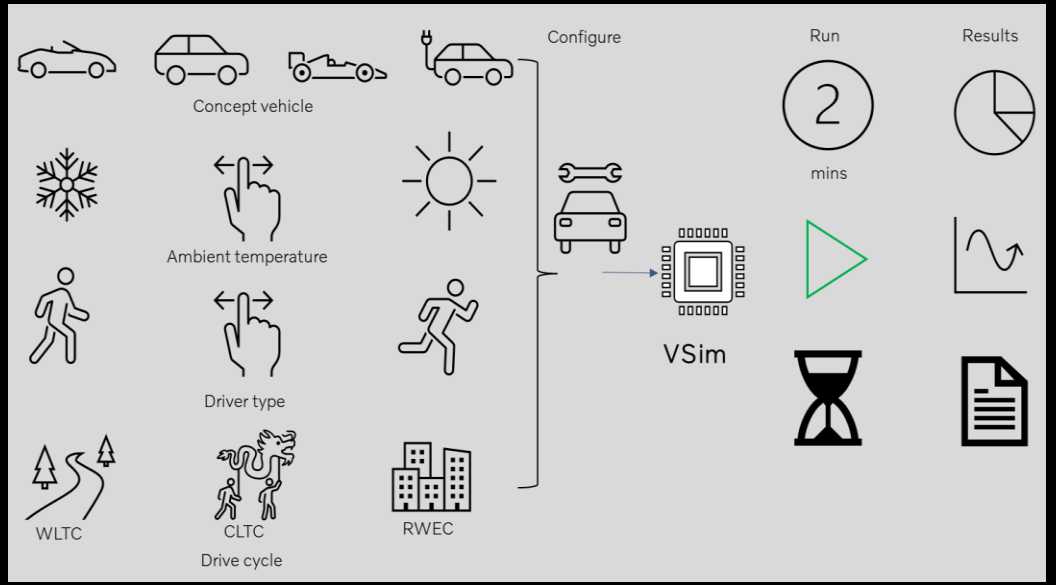
VSim is a physical simulation platform at Volvo Cars

VOLVO

What is the purpose of VSim?

Engineers use VSim to:

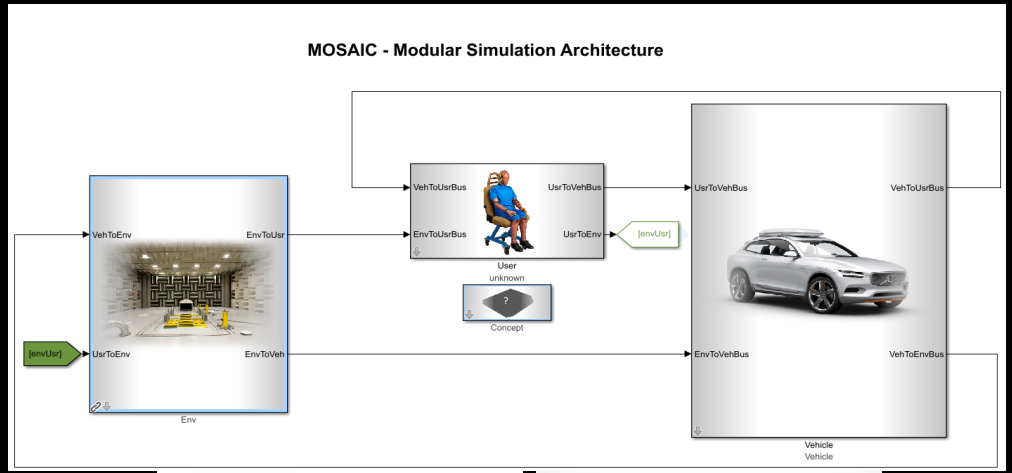
- Reduce energy consumed by the vehicle
- Balance target performance with efficiency requirements
- Build “just accurate enough” physical models
- Increase sharing of expertise between departments
- Shorten development time



WLTC : Worldwide harmonized light vehicles test cycles.
CLTC : China light-duty vehicle test cycle.
RWEC : Real world energy consumption cycles.

VSim in detail

VSim is a Modular simulation architecture (MOSAIC)



MATLAB SIMULINK

fmi FUNCTIONAL MOCK-UP INTERFACE

Process & Tools:

- GUI
- Post processing
- DoE
- CI & Test automation
- CM & Version control

VSim - Modeling guidelines

VVA2000 - MAAB Guidelines

VVA2001 - Prohibited standard blocks inside plant models

VVA2002 - Strong typing of signals

VVA2003 - Zero-crossing options

VVA2004 - Model Advisor

VVA2005 - StateFlow in physical systems

VVA2006 - Model Referencing

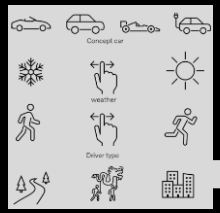
VSim enables

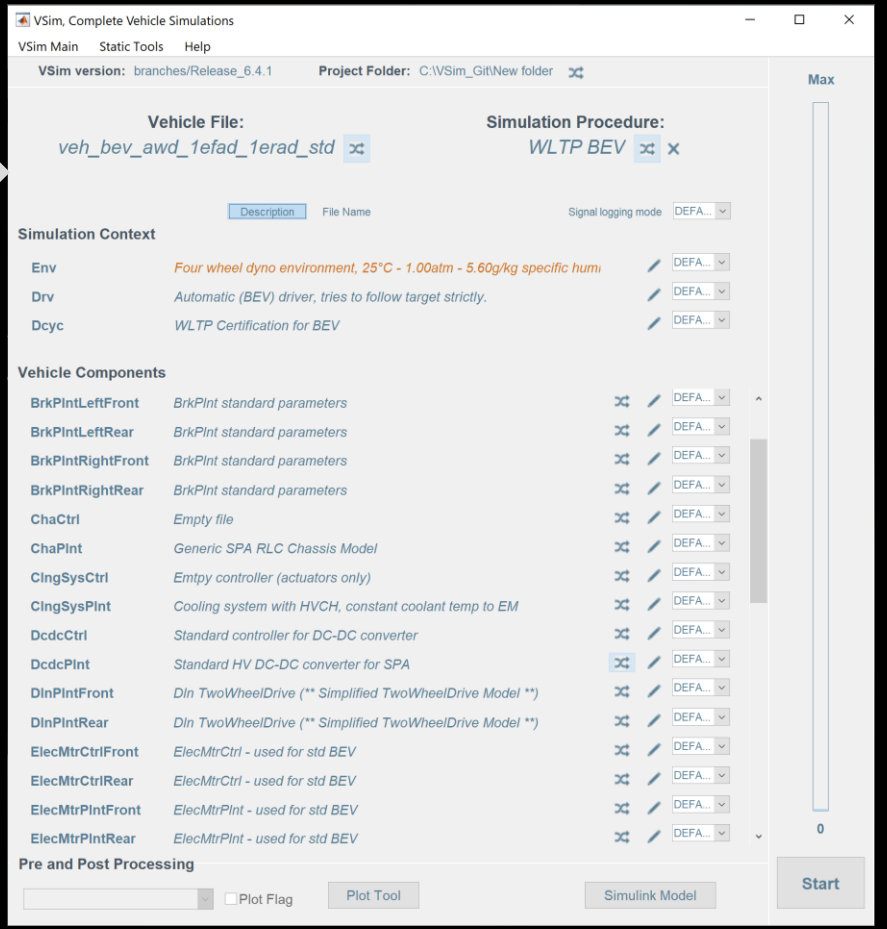
Vehicle system configuration

Automatic results and report generation stored in common database.

Parallel solver capabilities to design new functions for every concept car.

Large data generation for ML and AI tools.





VSim community

Advanced engineering projects, concept development, function developers and certification responsibilities

VSim Users

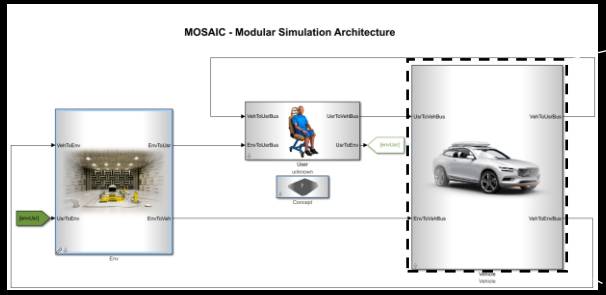
Top-model integration, development
Platform Maintenance and Gateway keeping
Enabling Automated Testing and CI

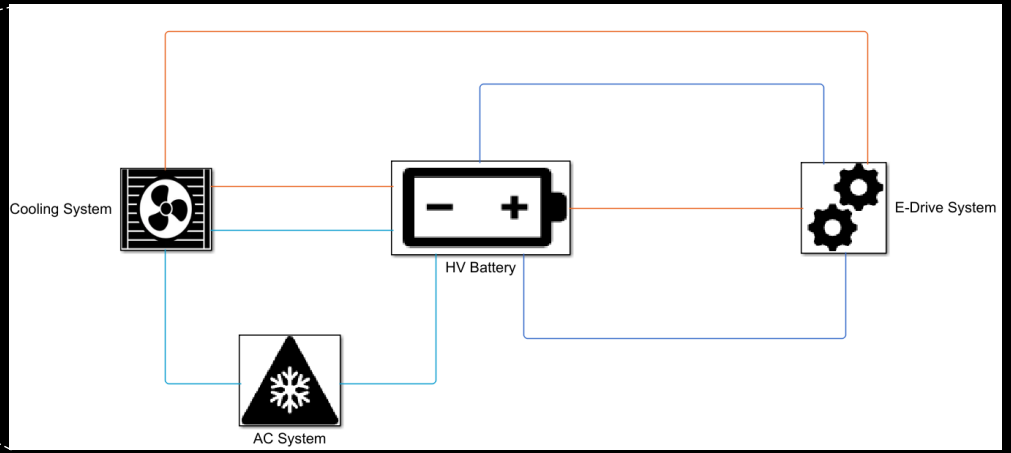
VSim Integrators

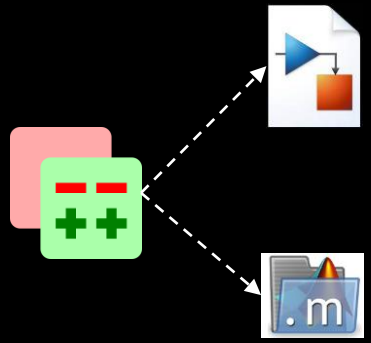
Physical & control model developers within the respective departments

VSim Model Developers

VSim simulation layout & features







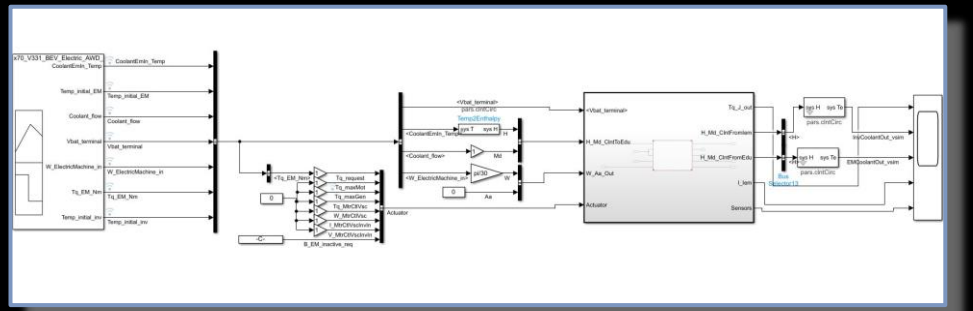
- Vehicle configuration model
- Component plant model
- Protected component plant model
- Component control model

- Component plant datafile
- Component control calibration datafile
- Initialization file
- VSim global parameter files
- GUI scripts
- Post-processing scripts

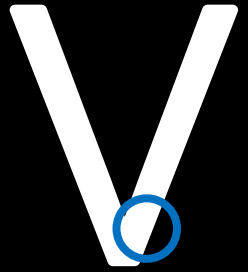
VSim development process and ensuring quality

Testing @unit or component

Electric Machine Plant



Testing life cycle



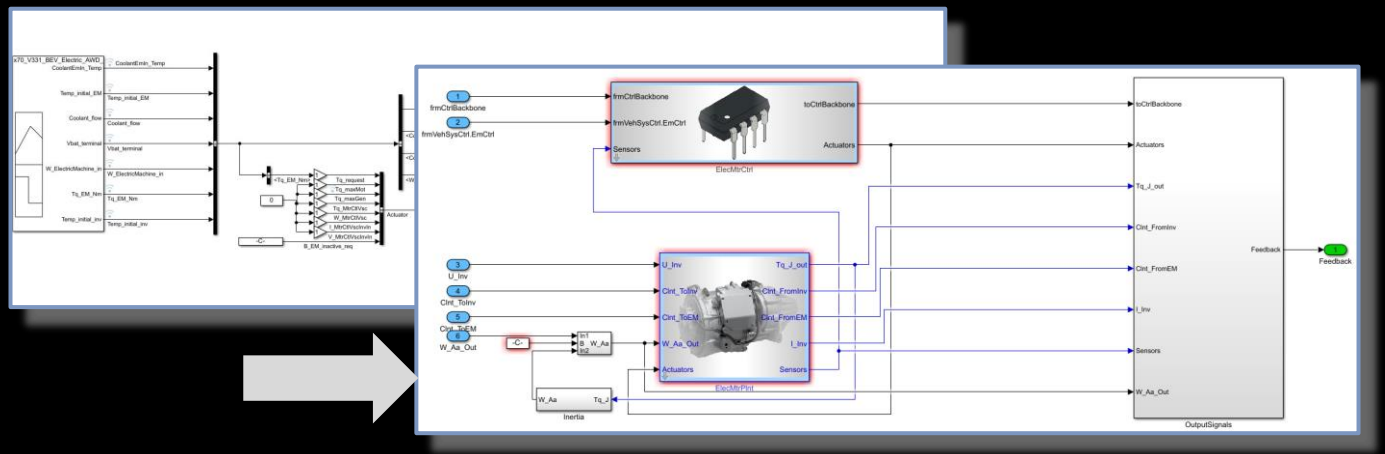
Verification and validation model

Gateway tests for component

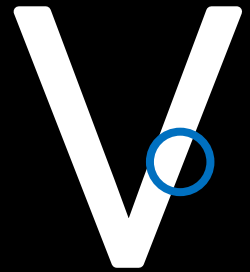
- Open-loop testing
- Modeling guidelines check
- Component validation

Component

Testing @Subsystem



Testing life cycle



V-Model

Subsystem tests

- Control + plant in a loop with simulated bus
- Subsystem validation

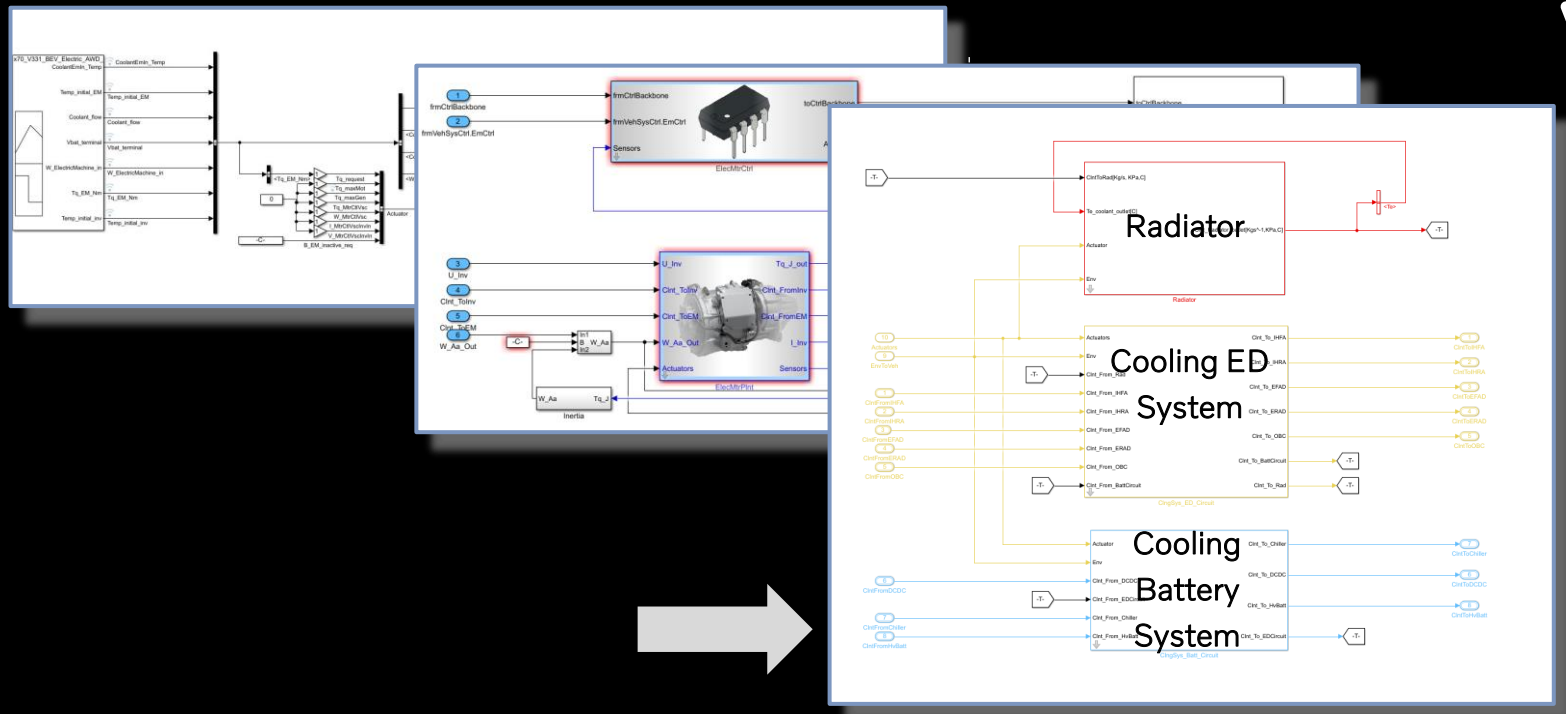
Component

Subsystem

Testing @system integration

Testing life cycle

Electric Machine Plant



V-Model

System integration tests

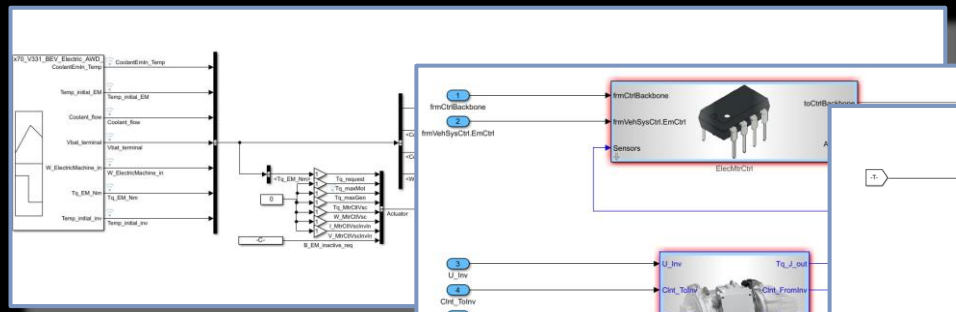
Component

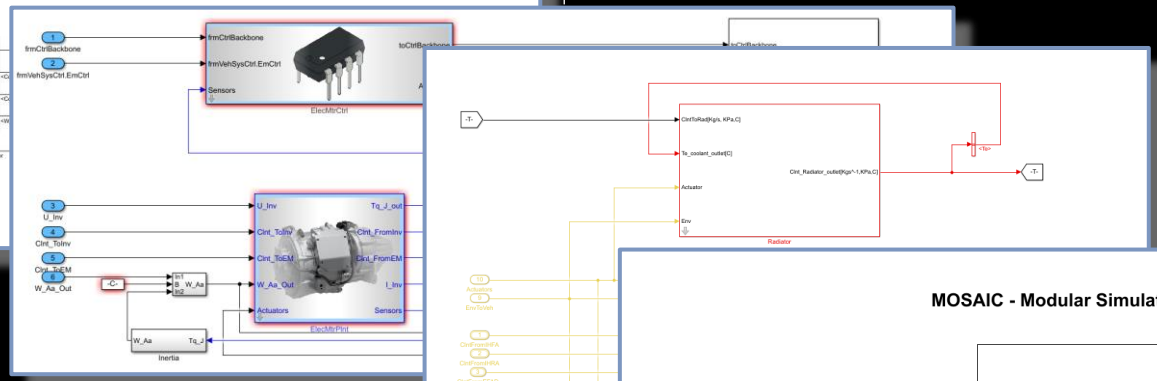
Subsystem

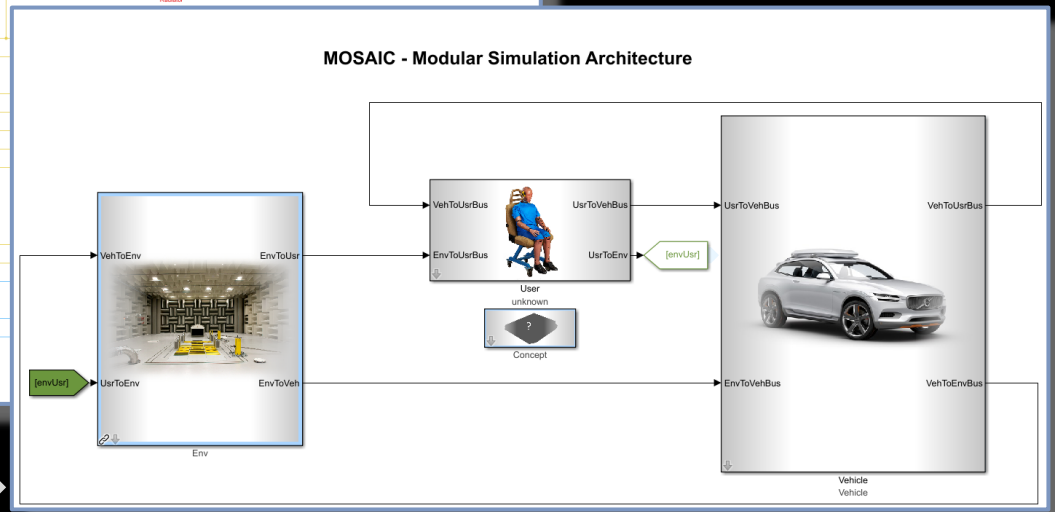
System integration

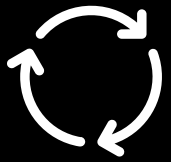
Testing @virtual vehicle

Electric Machine Plant









Complete integration & release

- Verification against RW data
- Running certification cycles (such as WLTC, CLTC, RWEC)

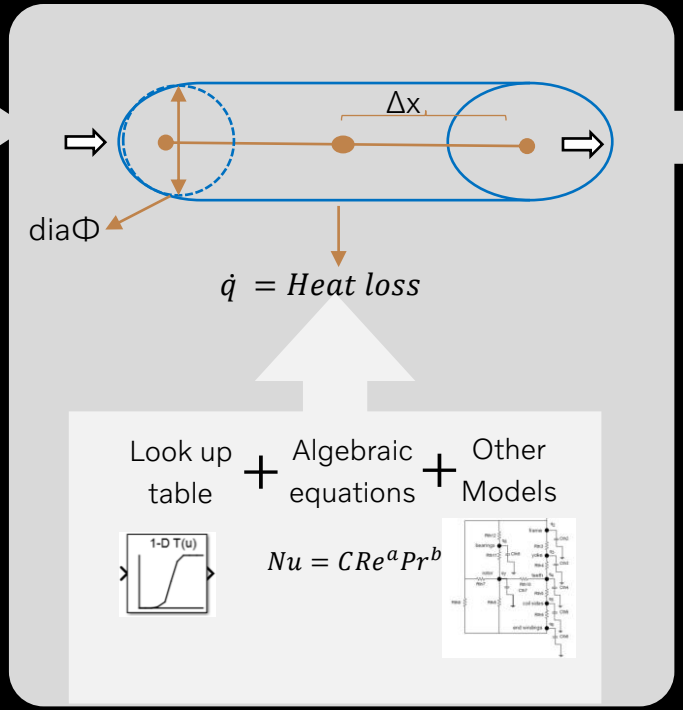
V-Model

How to build modular physical components?

An example of 1D thermal system – standard HEX overview

Source

$\dot{m}, P_{Total\_in}, T_{in}$



Sink

$\dot{m}, P_{Total\_out}, T_{out}$

Conservation of
- Mass
- Momentum
- Energy

1) $\frac{d\rho}{dt} + \nabla . (\rho v) = 0$

i) Incompressible $\dot{m}_{out} = \dot{m}_{in}$, $u = \frac{\dot{m}_{in}}{\rho(T) * area}$

2) $\frac{du}{dt} = -\frac{1}{\rho(T)} \nabla P + \frac{\mu(T)}{\rho(T)} \nabla^2(u)$

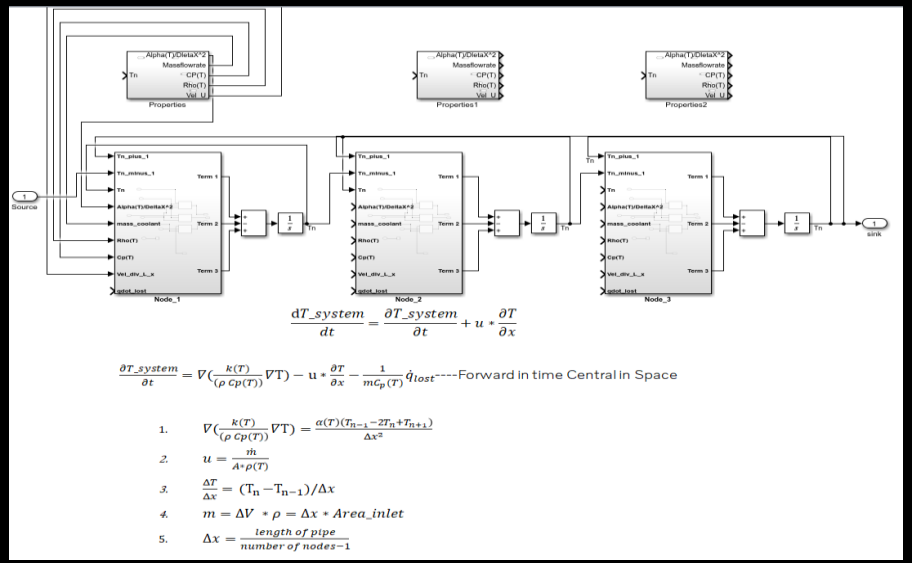
ii) $p\_total\_out = p\_total\_in - Ploss(T, \dot{m})$ ..CFD table

3) $\frac{d\,e}{dt} = \frac{1}{\rho(T) Cp} (-\nabla\, \dot{q} dv$ –work rate done)

iii) T= $\int (\nabla (\frac{k(T)}{(\rho\, Cp(T))} \nabla T) - u * \frac{\partial T}{\partial x} - \frac{1}{mC_p(T)} \dot{q}_{lost}$)dt

Overview of models in VSim using MATLAB, Simulink and Simscape

A 1D MATLAB and Simulink model using Forward in time central in space (FTCS) method

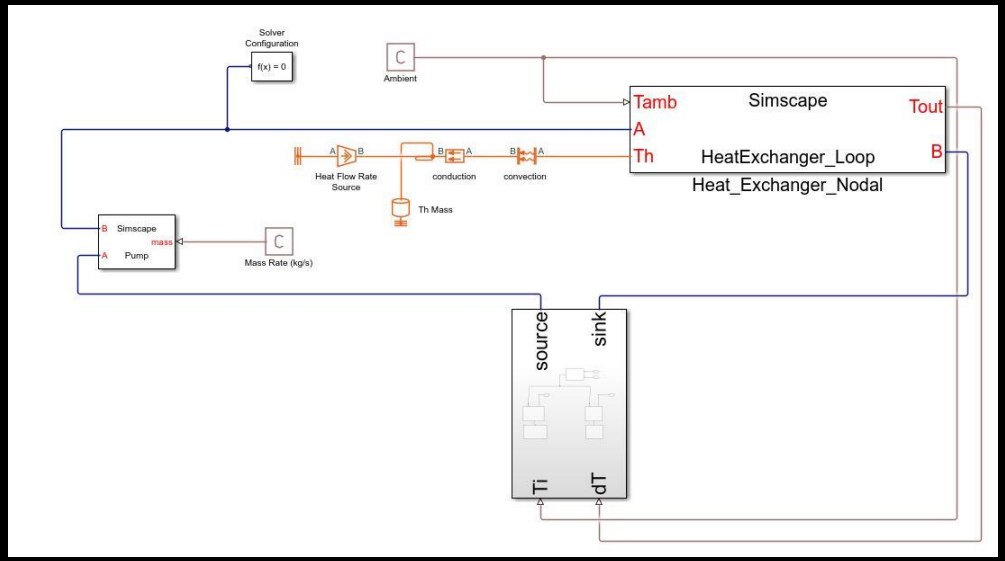


$$\frac{dT\_system}{dt} = \frac{\partial T\_system}{\partial t} + u * \frac{\partial T}{\partial x}$$

$$\frac{\partial T\_system}{\partial t} = V\left(\frac{k(T)}{(\rho\, Cp(T))}\nabla T\right) - u * \frac{\partial T}{\partial x} - \frac{1}{mC_p(T)}\dot{q}_{lost}$$ ----Forward in time Central in Space

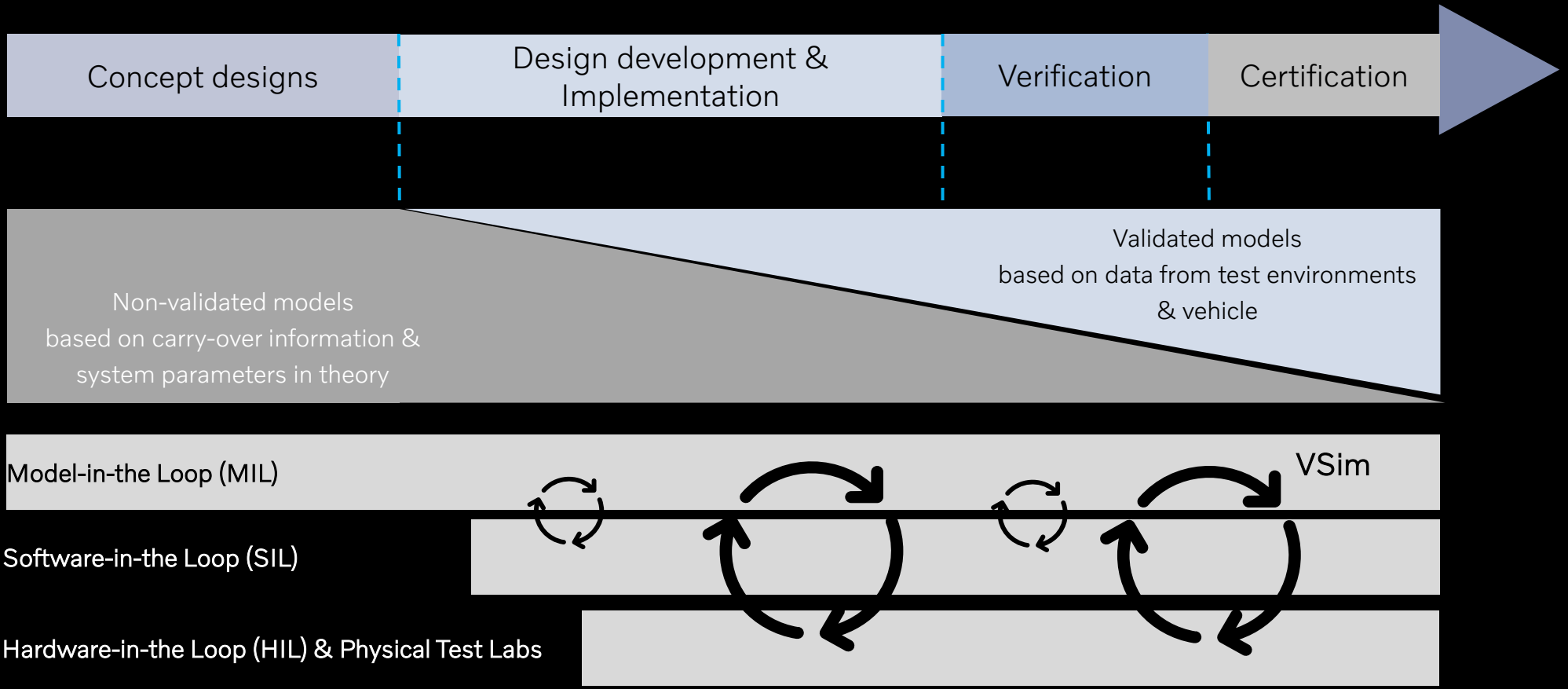
1. $V\left(\frac{k(T)}{(\rho\, Cp(T))}\nabla T\right) = \frac{\alpha(T)(T_{n-1} - 2T_n + T_{n+1})}{\Delta x^2}$
2. $u = \frac{\dot{m}}{A * \rho(T)}$
3. $\frac{\Delta T}{\Delta x} = (T_n - T_{n-1})/\Delta x$
4. $\dot{m} = \Delta V * \rho = \Delta x * Area\_inlet$
5. $\Delta x = \frac{length\ of\ pipe}{number\ of\ nodes - 1}$

A 1D Simscape model



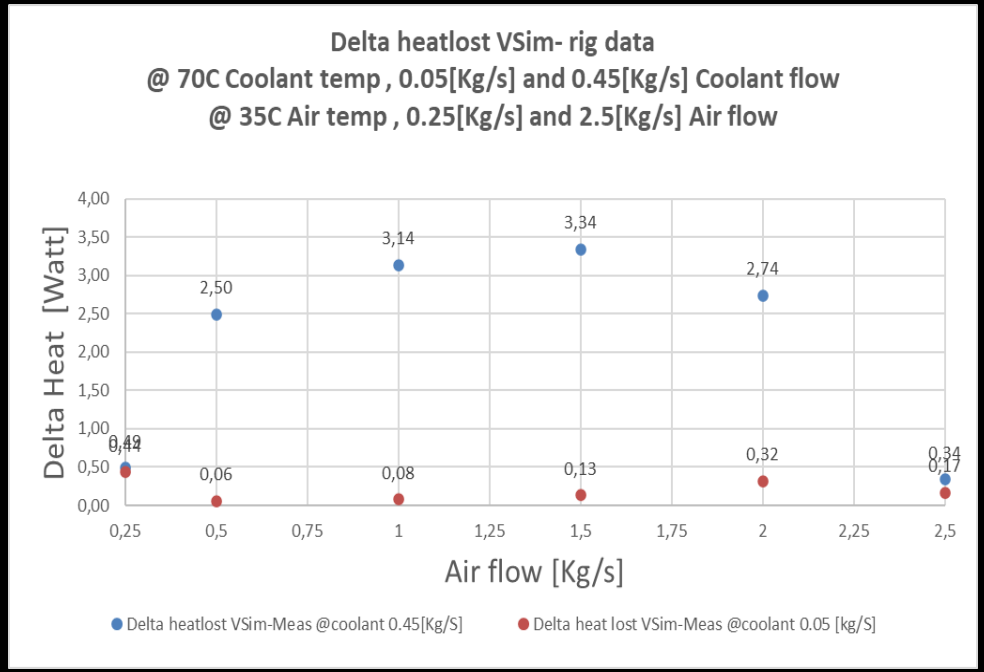

```
opts = odeset('RelTol',1e-4,'AbsTol',1e-3); % Set Tolerances in MATLAB
[time,T] = ode45(@(t,T) HexTherm(t,T,T_Source,T_Sink,M_dot,Q_lost,Tcycle),tspan,IC0,opts); % Solve ODE  in MATLAB
function dTdt = HexTherm(t,T,T_in,T_out,M_dot,Q_lost,Tcycle) ); % function to call the FTCS  in  MATLAB
```

How to utilize and validate models?

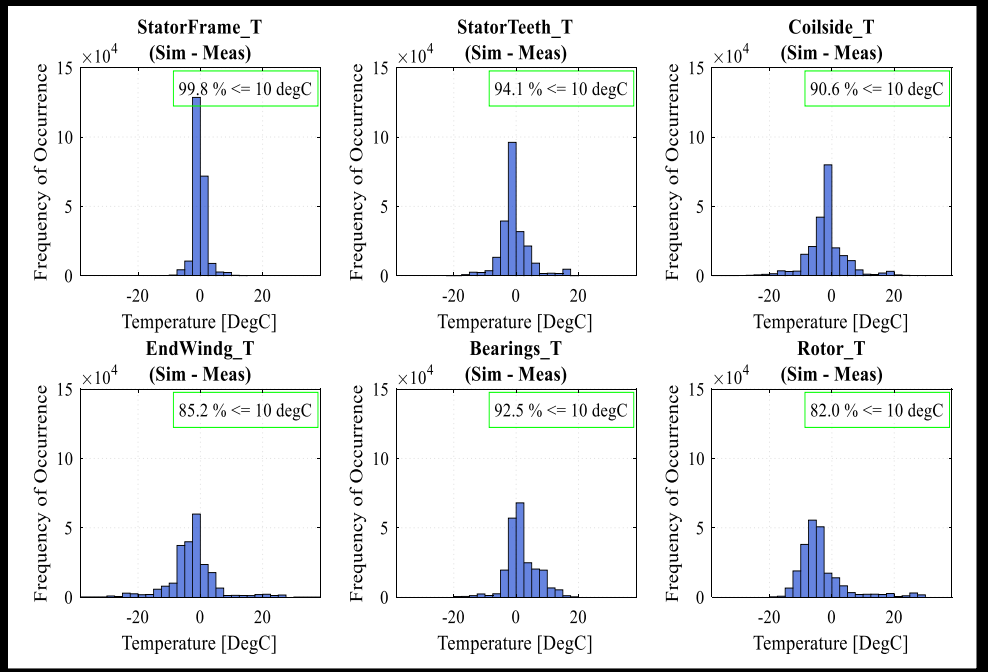

Concept designs
Design development & Implementation
Verification
Certification
Non-validated models based on carry-over information & system parameters in theory
Validated models based on data from test environments & vehicle
Model-in-the Loop (MIL)
Software-in-the Loop (SIL)
Hardware-in-the Loop (HIL) & Physical Test Labs
VSim

Component testing and validation with rig data

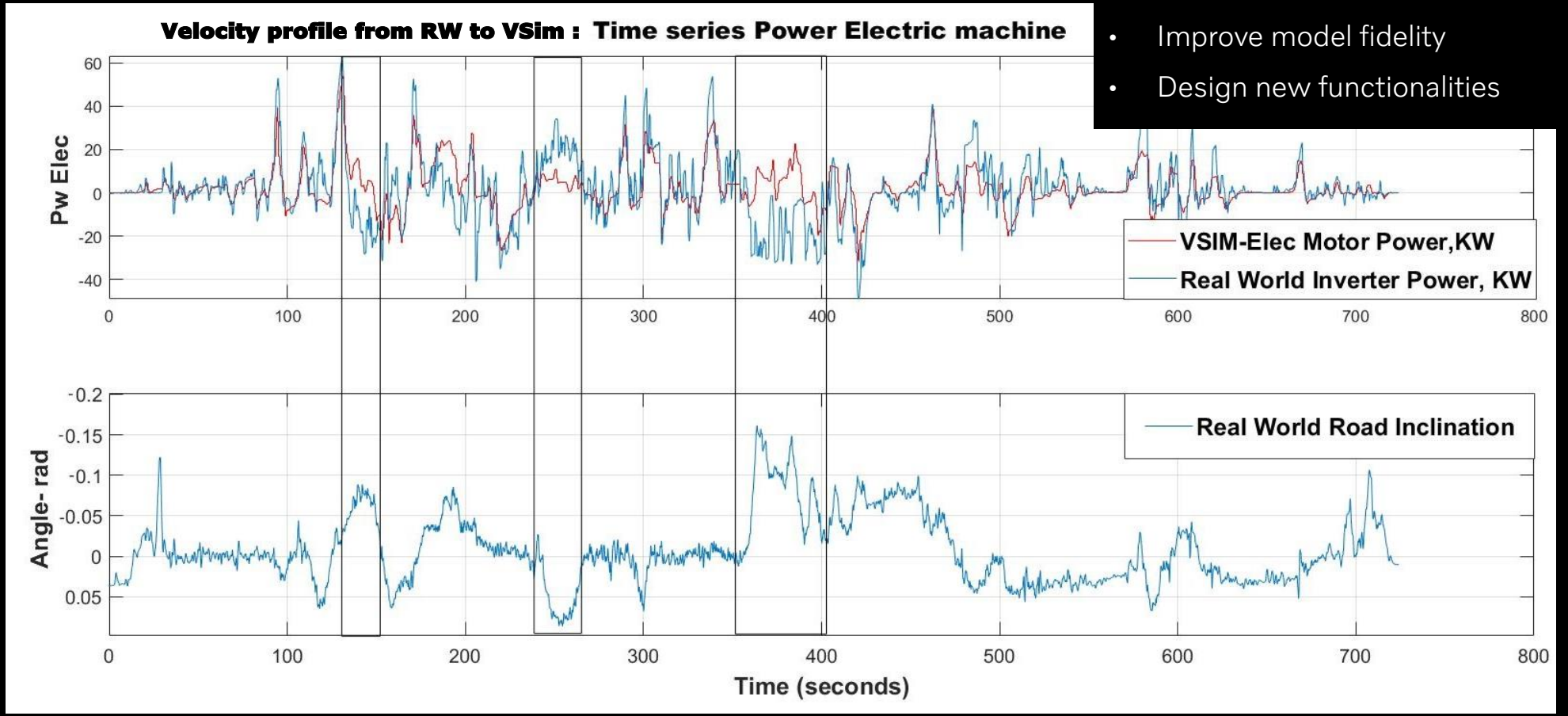
Validation on a standard radiator



Validation on a standard electric machine



Comparison with Real-World data



Utilize the Real-World data

- Improve model fidelity
- Design new functionalities

Final remarks

VOLVO

VSim is :

- built to improving vehicle energy efficiency and performance
- component-based and has modular model architecture
- based on physical system modeling of domains (electrical, thermal, mechanical)
- an enabler to build virtual fleets
- not only a simulation platform but also a community within VCC (Volvo Legacy)

VOLVO