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WORKSHOP 2022

Non-linear transient reduced Order Model with Mechanical and optiSLang

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Agenda

- Why are **Reduced** **Order** **Models** required?
- Reduced Order Overview
- Focus:
  - Physical ROMs (linear, transient)
  - Data Based ROM (non-linear, steady)
  - Combining Data Based and Physical ROM
- Model implementation and validation
- Summary

Motivation for Reduced Order Model (ROM)

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- Many Applications (Power Electronics, Combustion Machines…) underly transient load cycles
- Different transient load Scenarios and combinations may be possible and may be unknown in the Design Process, i.e. many transient, computational expensive simulations are required
- Challenge: accurate and fast solving Reduced Order Model (ROM) is required to simulate many load scenarios in short time, with high accuracy
- Vision:
  - Simulation of system by ROM in real time for any load scenario
  - Installation of ROM as Digital Twins for real time monitoring of connected assets

Reduced Order Model - Overview

- Reduced Order Modelling is a huge research area!
  - many different approaches even for same application area
- Focus on this presentation:
  - Physical ROM by projection method, linear and transient
    - Work with the underlying conservation equations
      - Deliver “tailored” ROM for certain physics
      - Implementation for each physic is required
    - Examples: Modal-Superposition, Component Mode Synthesis, Krylov-Reduction in FEM
  - Data Based ROM, non-linear and steady
    - Work with black-box approach, one implementation fits all physics
    - ROM is generated as output=function(input)
    - Example: optiSlang’s Meta Model of Optimal Prognosis
- Objective: combine advantages of Physical- and Data-Based ROMs

Projection Method for Reduced Order Modelling

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Large 3D FEM Equation System:

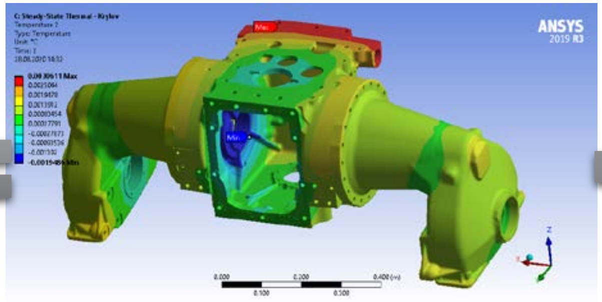
$$C \cdot \dot{x} + G \cdot x = B \cdot u(t)$$

$$x = T \, q$$

Large Vector with Degree of Freedom is assumed as a linear combination of n T-Vectors

$$x = T_1 \cdot q_1 + T_2 \cdot q_2 + T_3 \cdot q_3 + \dots$$

x =



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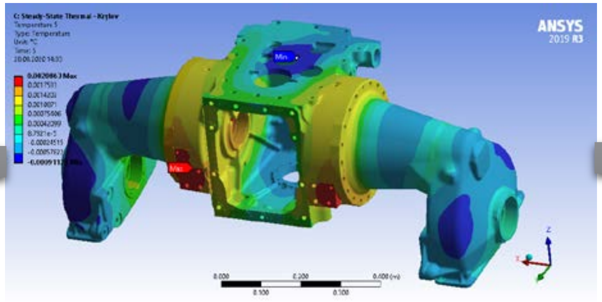

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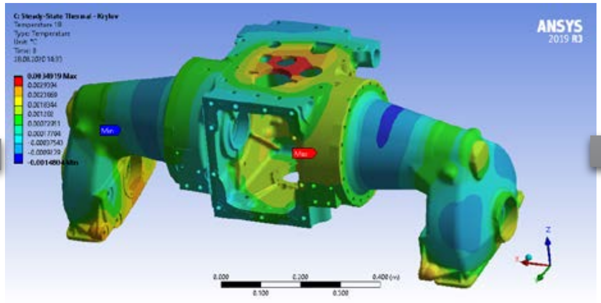


+ …

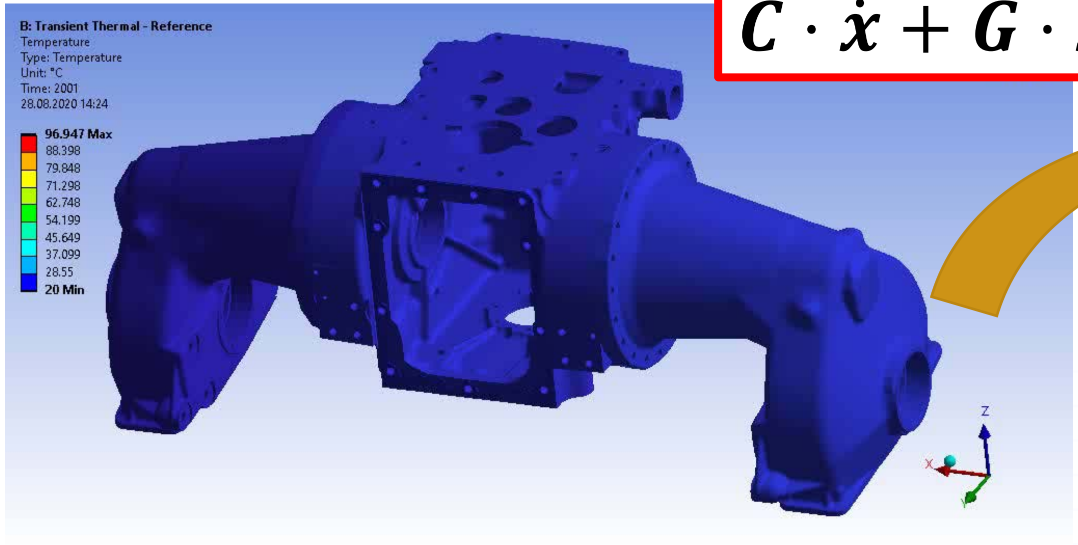
Large Equation System is projected to small Modal-Subspace

$$T^T \; [C,G] \; T = [\;]$$

$$C_{sub} \cdot \dot{q} + G_{sub} \cdot q = B_{Sub} \cdot u(t)$$

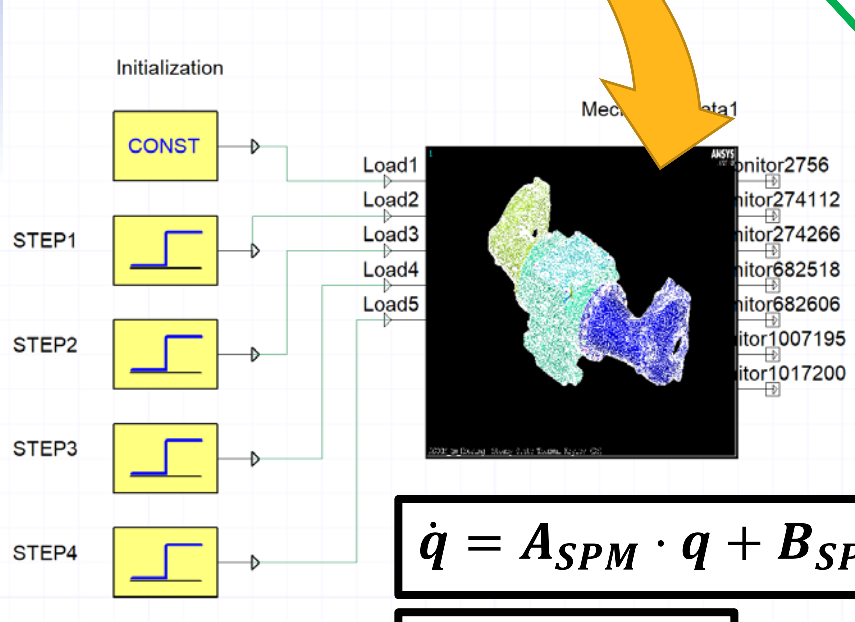
From 3D FEM to System Level

$$C \cdot \dot{x} + G \cdot x = B \cdot u(t)$$ 1



Huge FEM Model is projected to Sub-Space Model by T-Vectors

$$C_{sub} \cdot \dot{q} + G_{sub} \cdot q = B_{sub} \cdot u(t)$$ 2



Sub-Space Equation is transformed to State-Space

$$\dot{q} = A_{SPM} \cdot q + B_{SPM} \cdot u(t)$$ 3

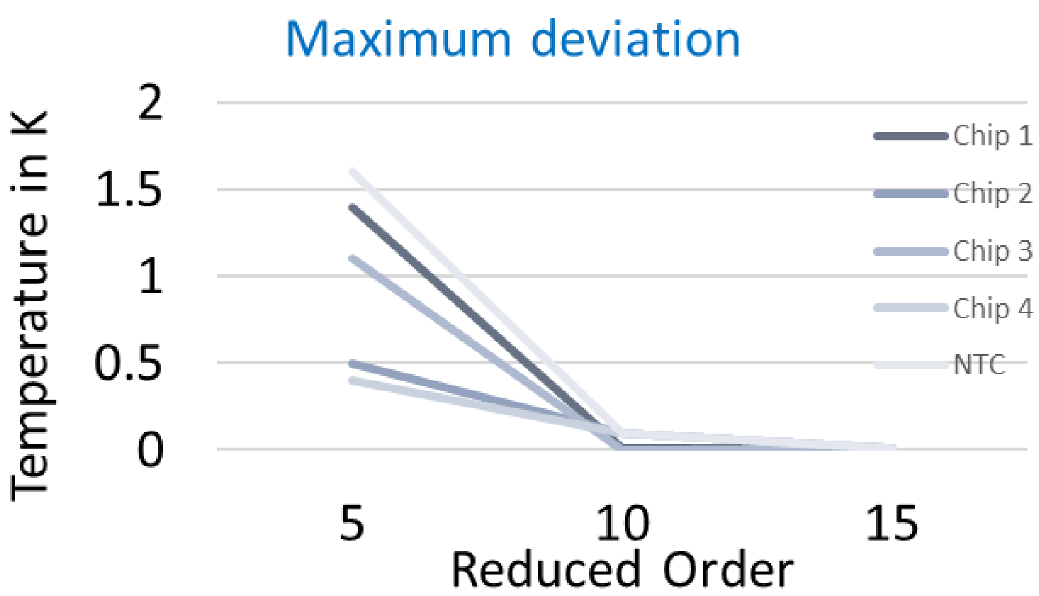
$$y = C_{SPM} \cdot q$$

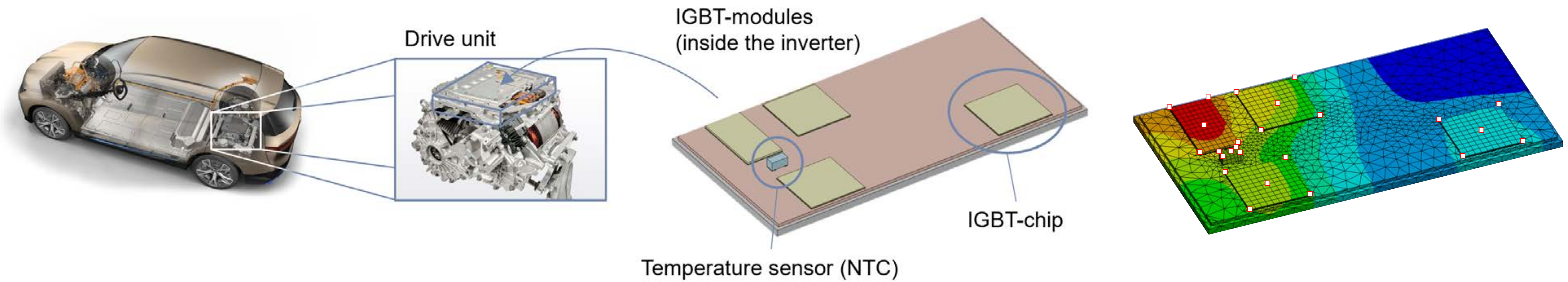
C_{SPM} = lines of T-Vectors, wrt to Monitor DOF-ID

Challenge:

- How should we compute the T-Vectors?
- How many do we need?
- How accurate will the ROM be?

Sim-World 2021





Data Based ROM

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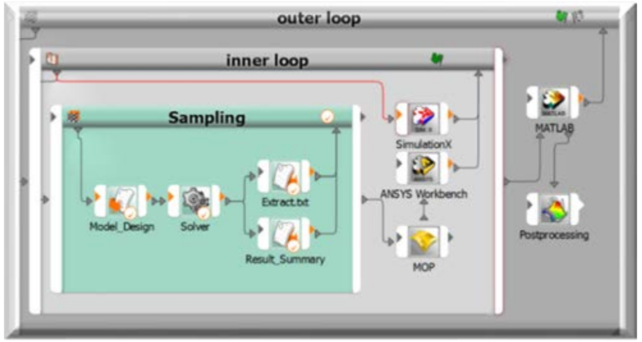
ROM Generation Pass: Fully automatic Workflow for any Physic

Input 1

Input 2

Input …

Workflow-Management



with Process Integration and for Automatization

Output 1

Output 2

Output …

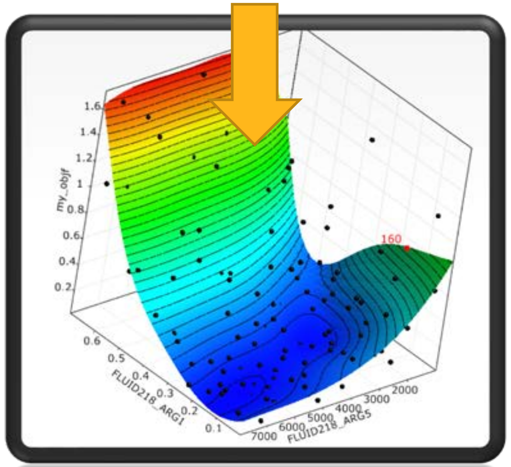
Excel Add-In

ANSYS Solver

3rd Party Solver

Data Based ROM

Input



Output=f_{MOP}(Input)

Combining Physical and Data based ROM

Multiple Physical ROMs are generated, each with different Input Parameter p_i

Output: State Space Model, where each Coefficient is represented by an individual MOP

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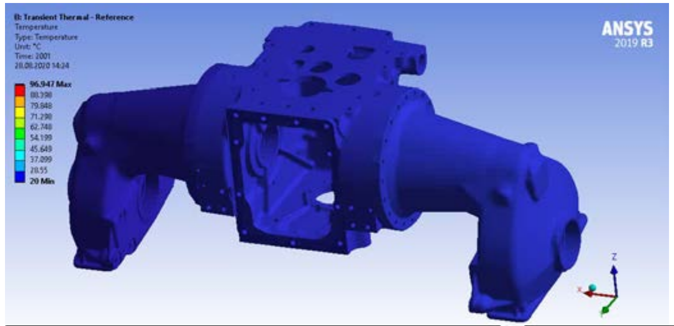
ROM Generation Pass:

Input p_1

Input p_2

Input …



linear Physical ROM, with fixed Input Parameters p_i
Output: State Space Matrices A, B, C

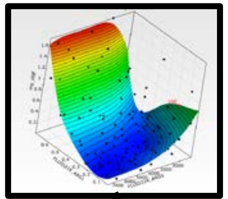
$$\dot{q} = A \cdot q + B \cdot u(t)$$

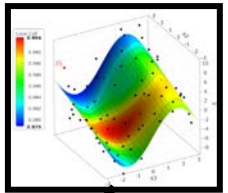
$$y = C \cdot q$$

Output A

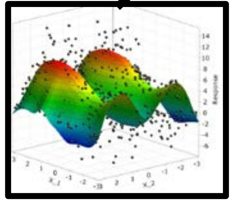
Output B

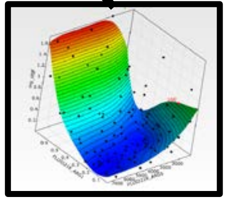
Output C





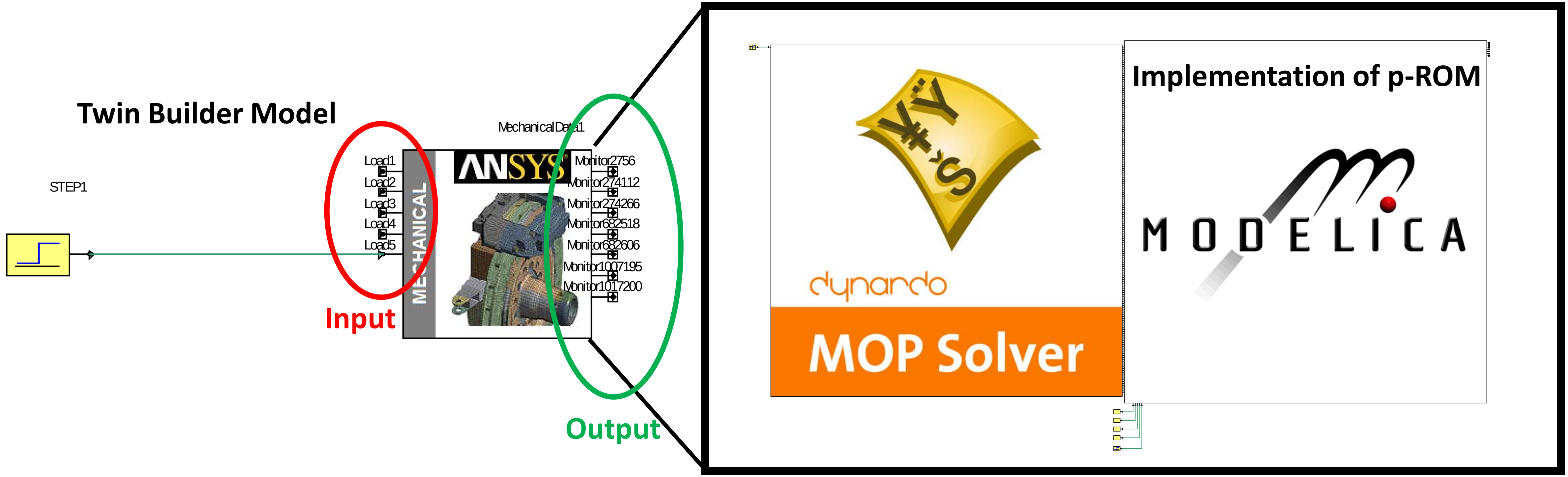
$$A = \begin{pmatrix} a_{11}(p_i) & \dots & a_{1n}(p_i) \\ \dots & \dots & \dots \\ a_{n1}(p_i) & \dots & a_{nn}(p_i) \end{pmatrix}$$





Validation: single linear ROM vs parametrized ROM

- ROM was generated with varying HTC at 5th input
- To validate the model implementation, we can compare the results from individual linear ROM with respect the new parameterized ROM evaluated at equivalent operating conditions
- Unit load is applied on the 5th input of ROM (other inputs kept to zero)

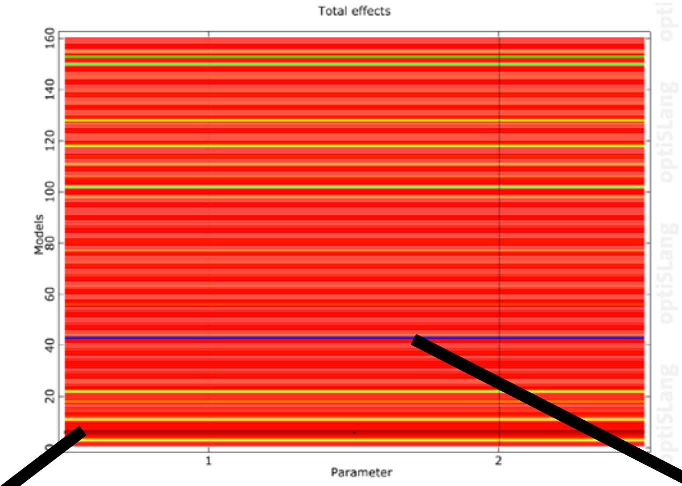


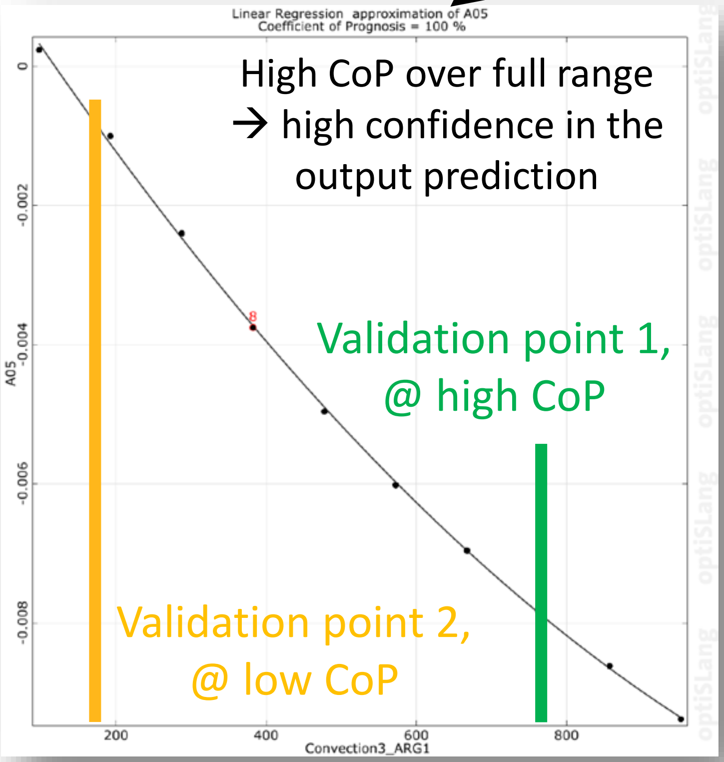
Quality Assurance: COP-Matrix

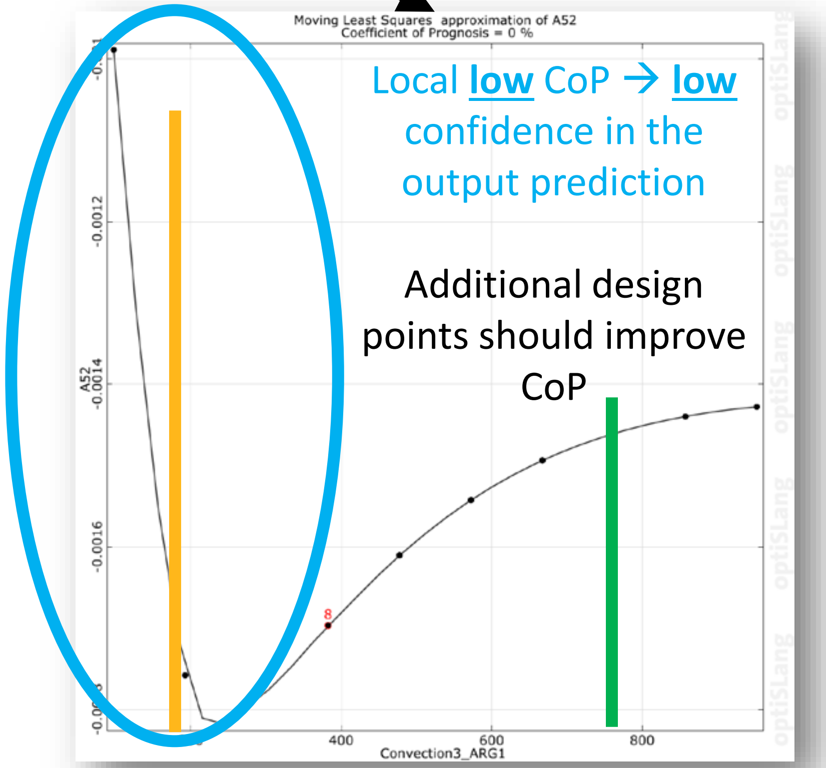
MOP interpolation error can be analyzed in optiSLang by COP

additional design points can be added to improve the MOP prediction

~160 Matrix coefficients, i.e. Output parameters







Validation: single linear ROM vs parametrized ROM (1)

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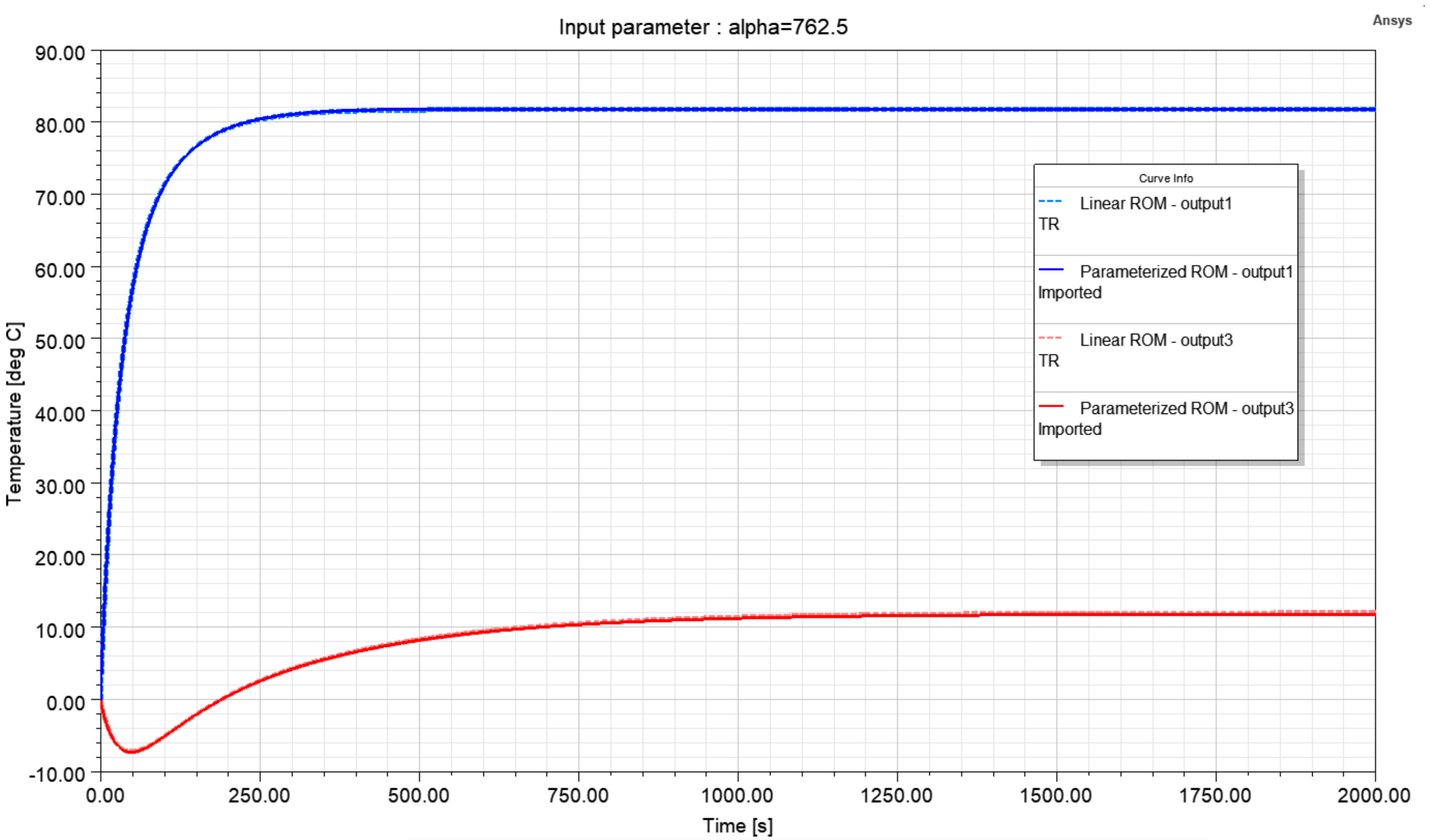
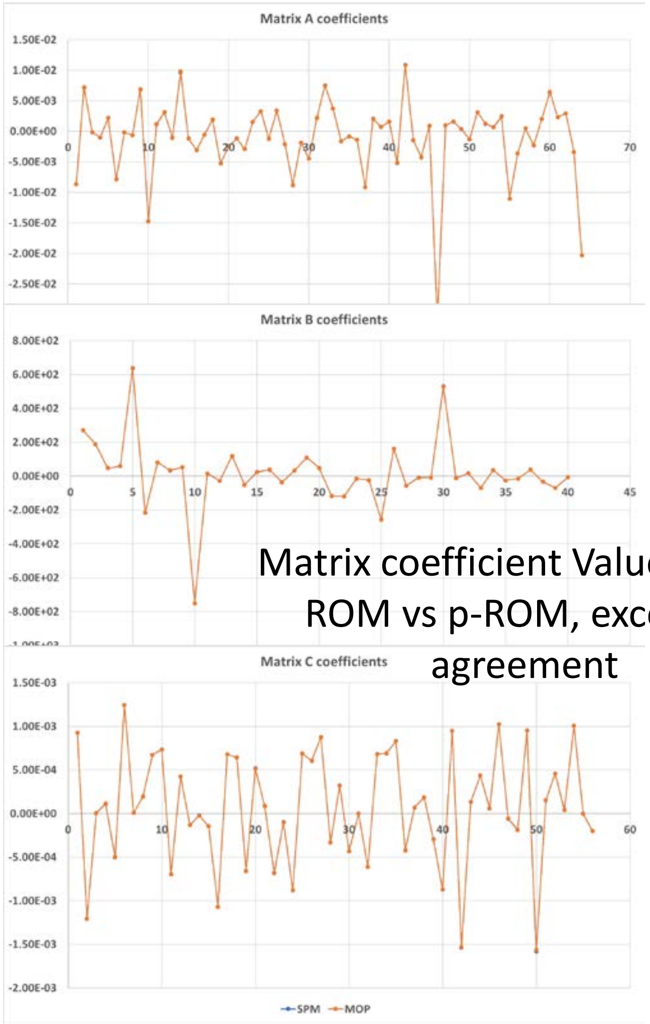
Validation point 1 : input parameter/HTC = 762.5



Hight COP → Excellent agreement



Matrix coefficient Values linear ROM vs p-ROM, excellent agreement

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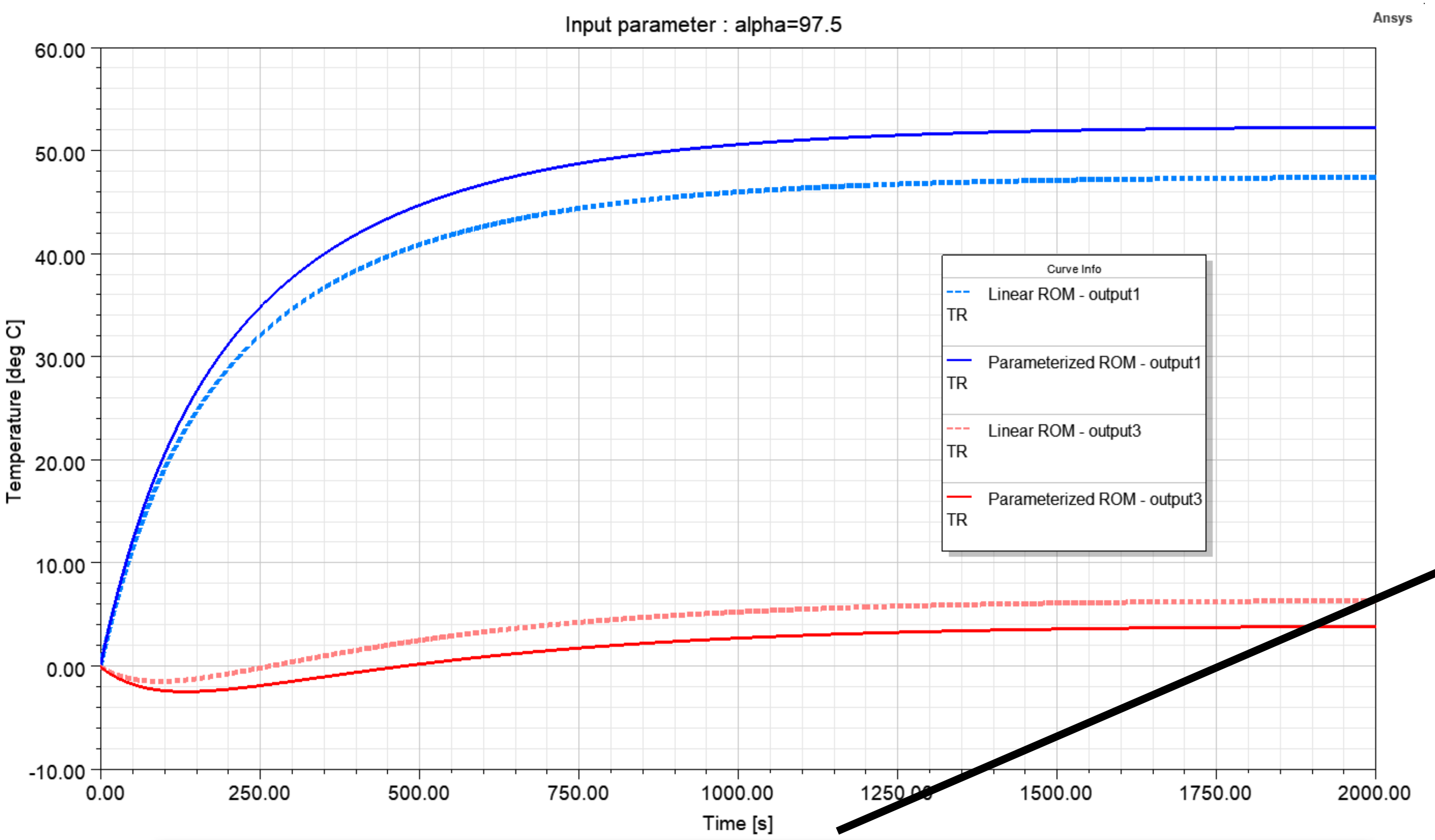
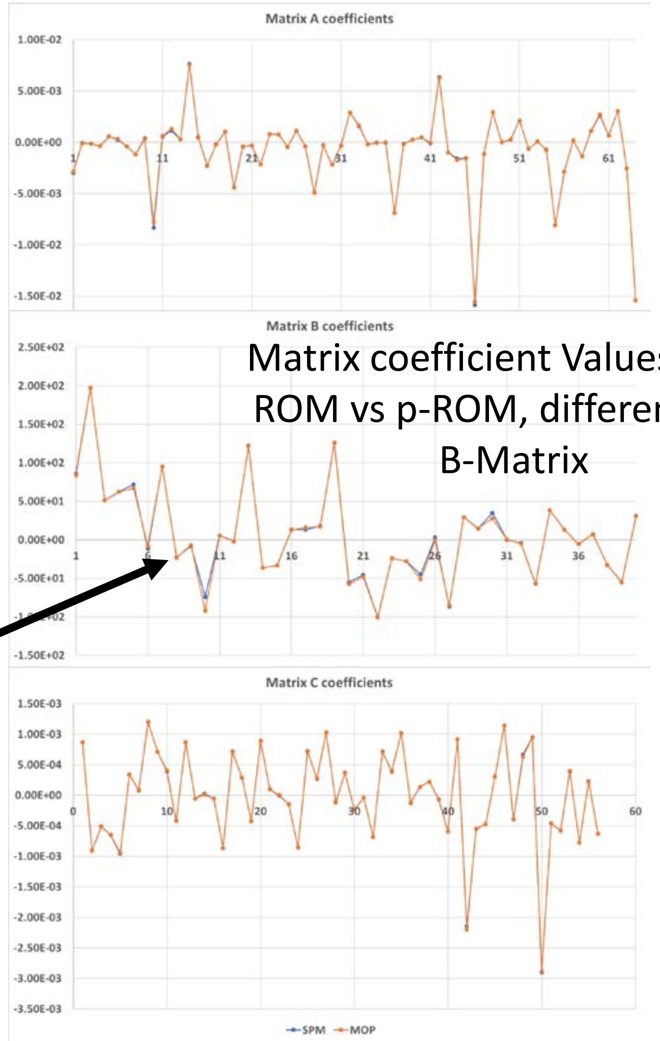
Validation: single linear ROM vs parametrized ROM (2)

Validation point 2 : input parameter/HTC = 97.5



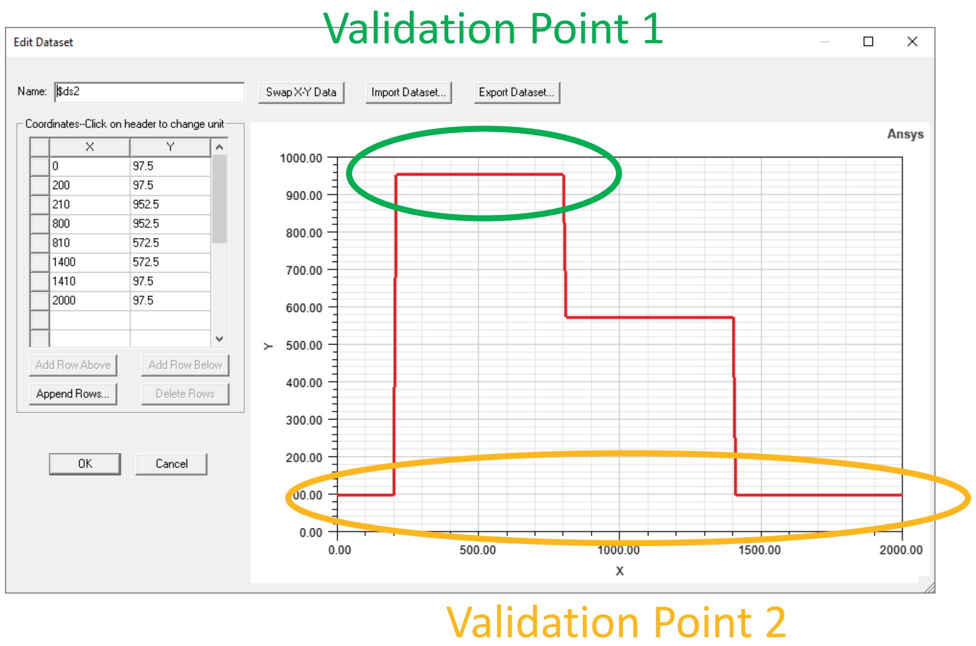


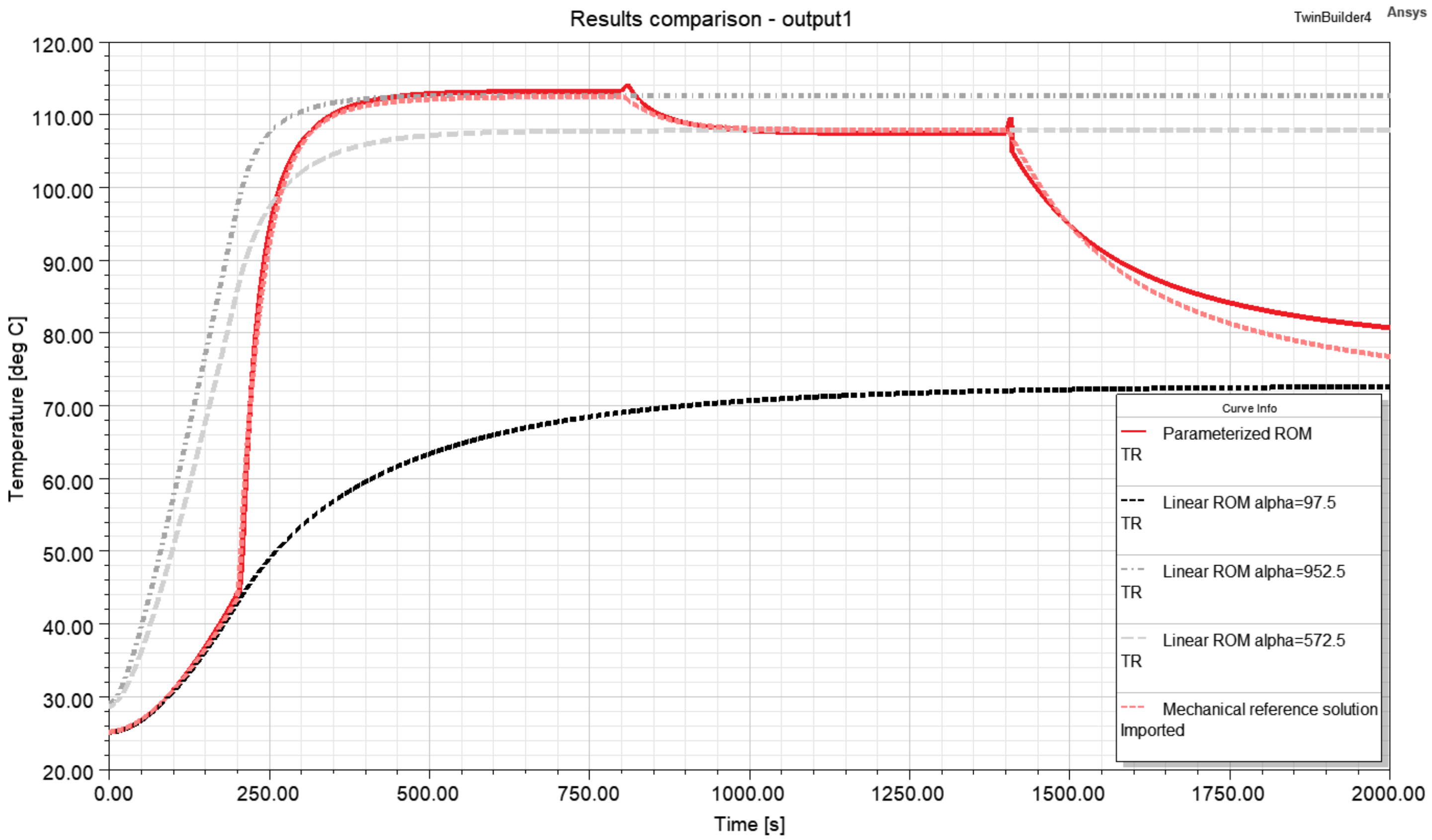
Matrix coefficient Values linear ROM vs p-ROM, differences at B-Matrix

Low COP → error in MOP prediction → differences in results

Validation: non-linear transient Mechanical vs p-ROM

- Unit load is applied on the 5th input of ROM
- Time varying input parameter alpha

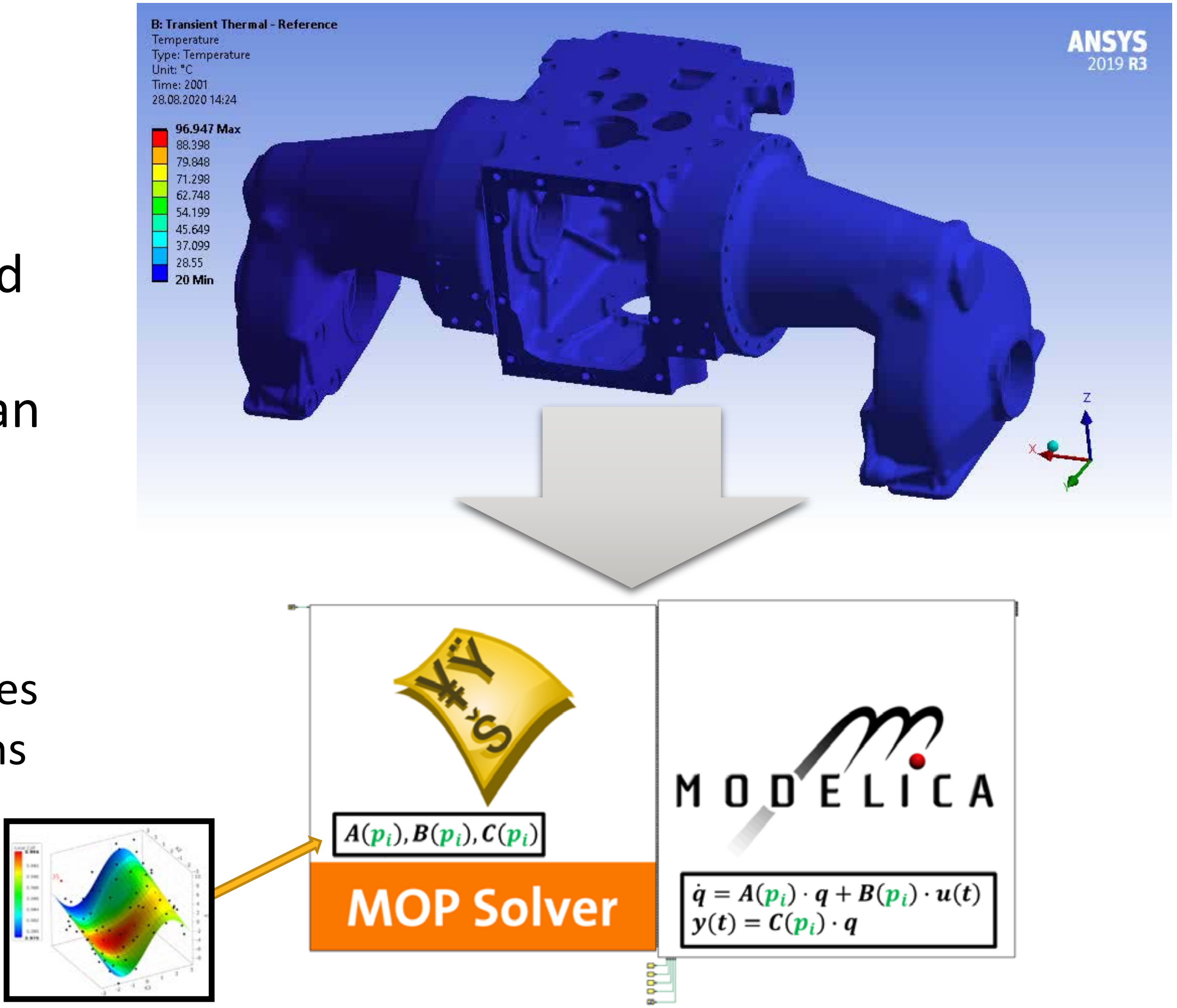




Mechanical solution runtime : ~15340 sec ~4 hours
Twin Builder solution runtime : ~30 sec (>500 faster)

Summary

- Multiple ***Physical Reduced Order Models*** are available for different Physics (Krylov, Modal Superposition, Component Mode Synthesis)
- ***optiSLang*** can generate ***Data Based ROMs***
- Physical and Data based ROMs can be combined on ***System Level***
- System Simulation with ROM is much ***faster*** than 3D FEM with very good ***accuracy*** (wrt to COP)
- ROM as enabler for ***Digital-Twin***
- Perspectives :
  - Improve the modeling to better handle discontinuities
  - Validate the approach on more customer applications
  - Include more parameters in the model



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