Full-field Dynamic ROM generation with LS-OPT, LS-DYNA and Twin Builder

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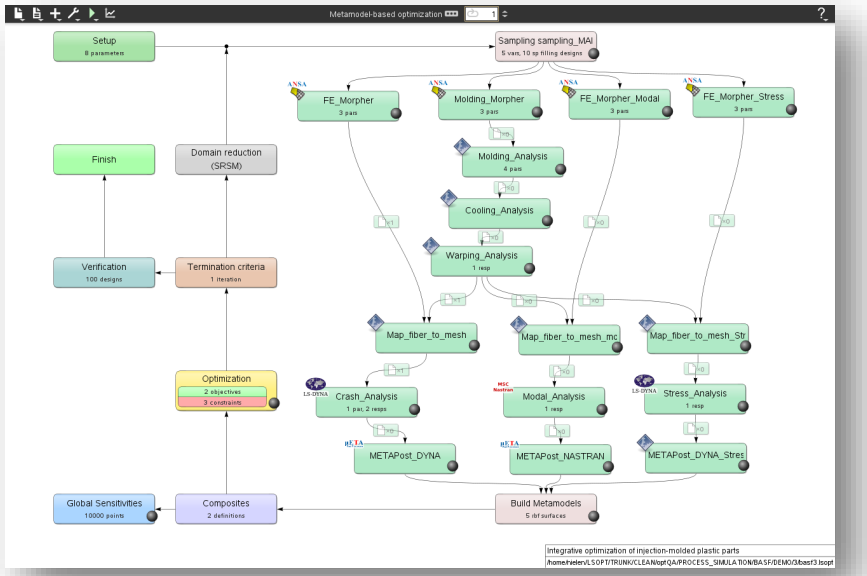
Overview

- Reduced Order Modeling
- Metamodel integration

Ansys *Twin Builder and LS-OPT*

LS-OPT

- Optimization (Direct, Metamodel-based)
- Reliability and Robustness
- Material calibration



LS-OPT Process Integration

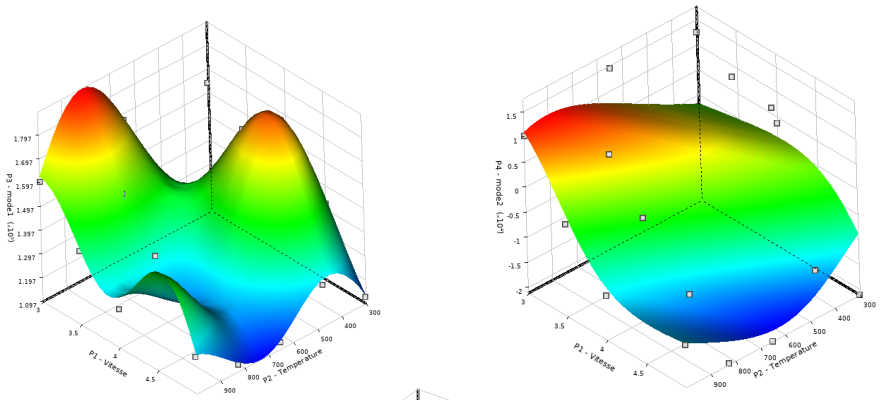
Twin Builder

Uses blackbox solver agnostic techniques for creating ***Reduced Order Models*** as *fast early design* tools for Non-Linear Dynamic Systems

- Reduction :
  - Projection methods (eigen solution): SVD and POD.
  - Limited number of eigenvalues automatically selected: *removes response noise*
- Machine learning:
  - Advanced Interpolation of modal coefficients using metamodels (Polynomial, Kriging, SVR, GARS (aggregation)) → Static ROM Builder

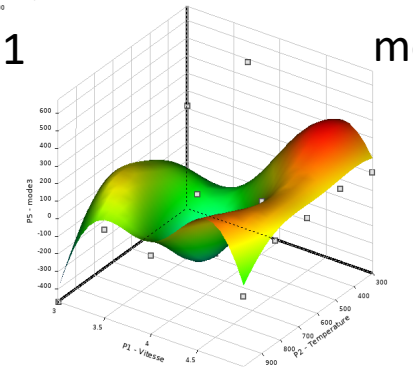
Modal Coefficients Interpolation

Every modal coefficient is interpolated using a proper response surface



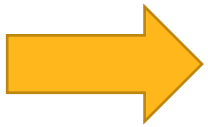
mode1

mode2



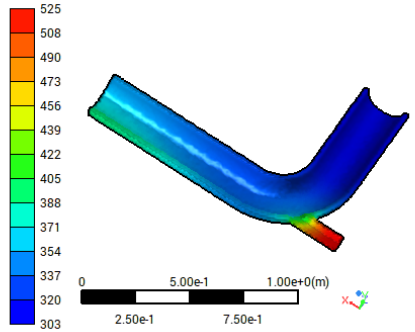
mode3

A Static ROM is thus a combination of an SVD compression and mode coefficient interpolations

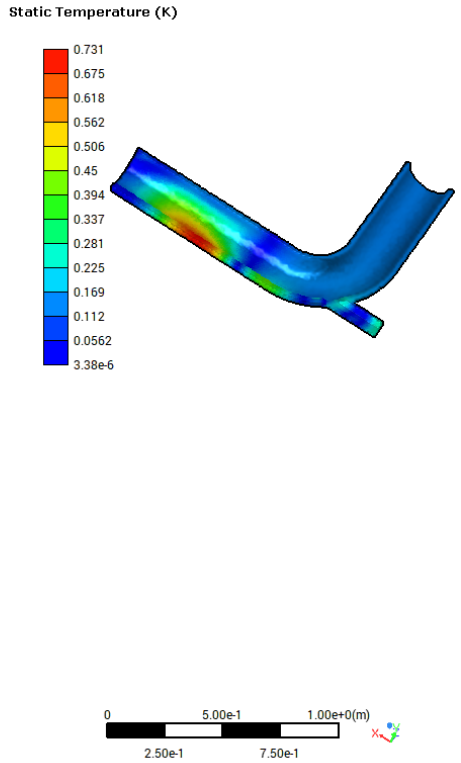


Validation at the Verification points

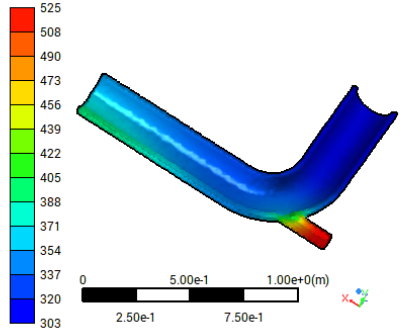
Reference



Difference

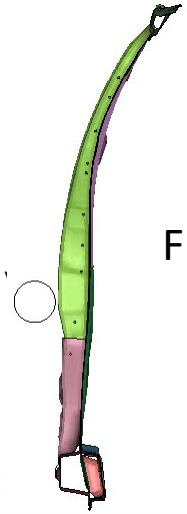


ROM

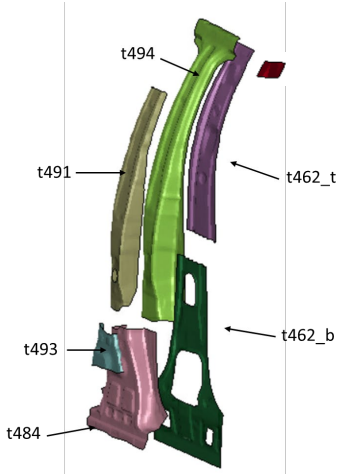


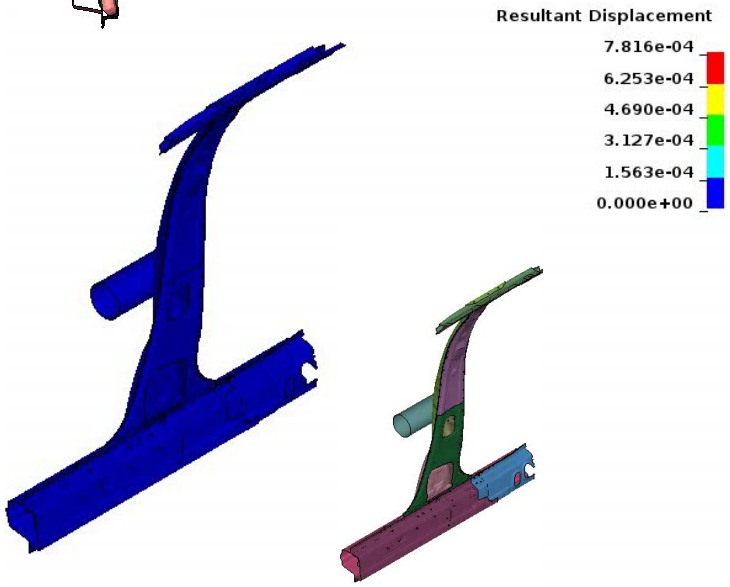
LS-OPT®/Twin Builder Full-field Dynamic *Reduced Order Model*

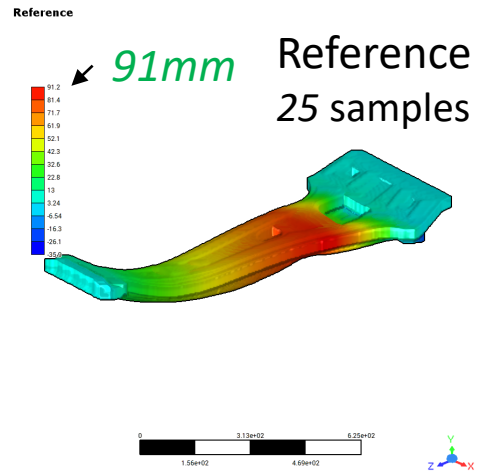
Side impact B-Pillar Displacement (7 thickness parameters)



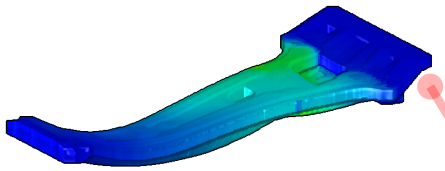
FE model

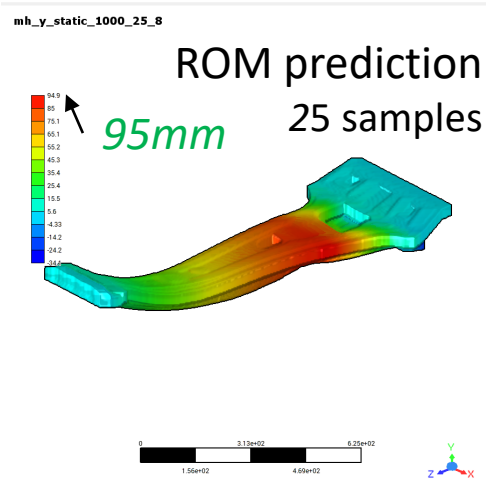


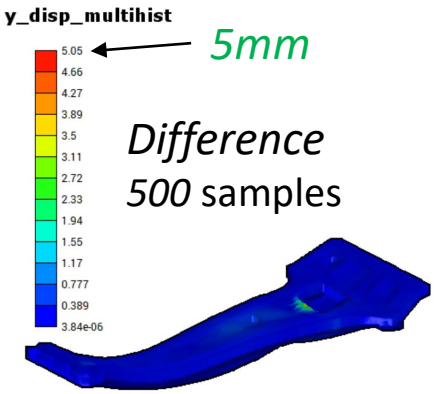




Difference
25 samples

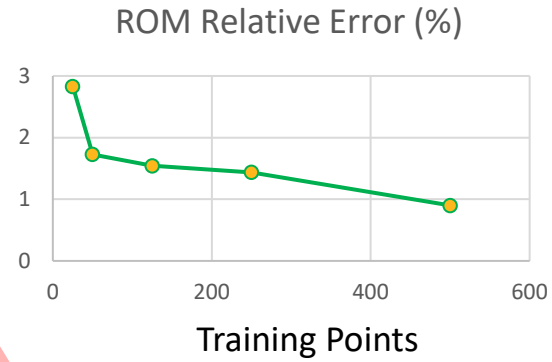


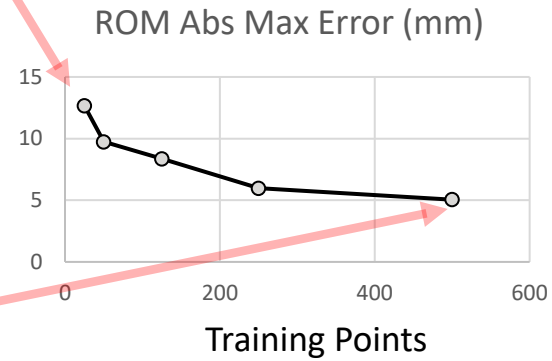




Difference
500 samples

Reduced Order Models



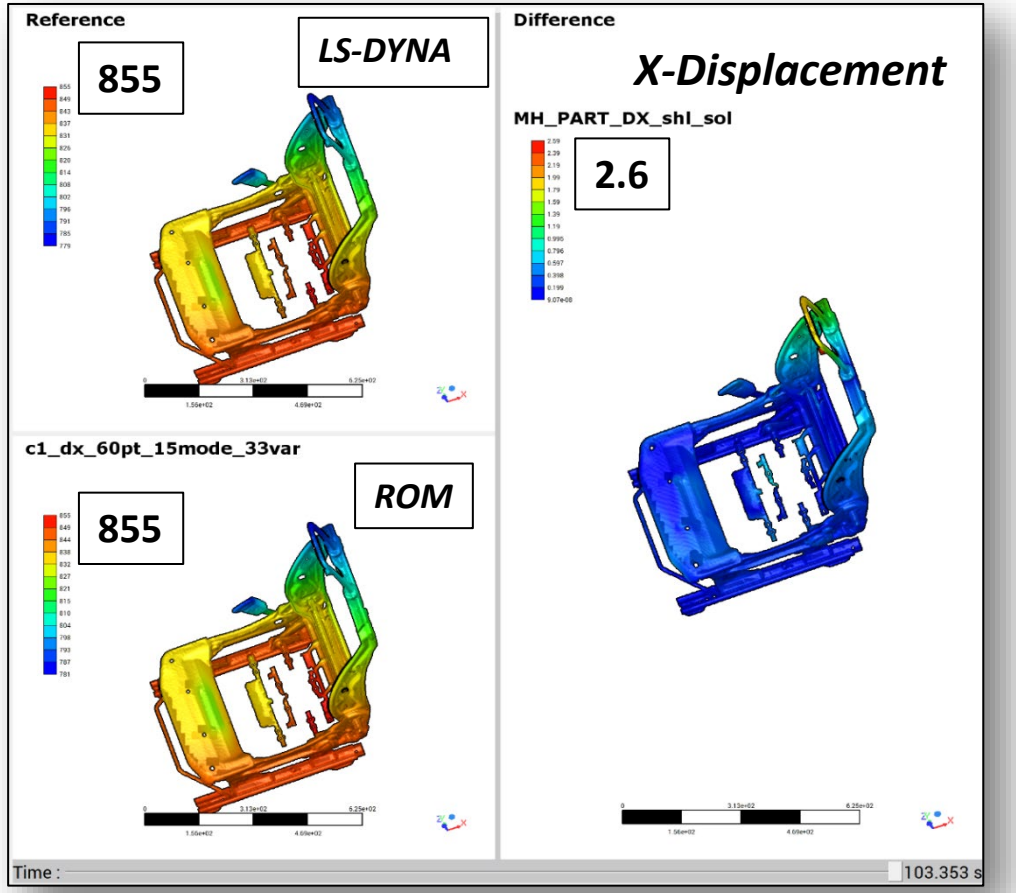


Seat design (frontal crash): ROM with part selection

- **22** time states
- **33** variables
- **63** simulations, 60 training + 3 validation

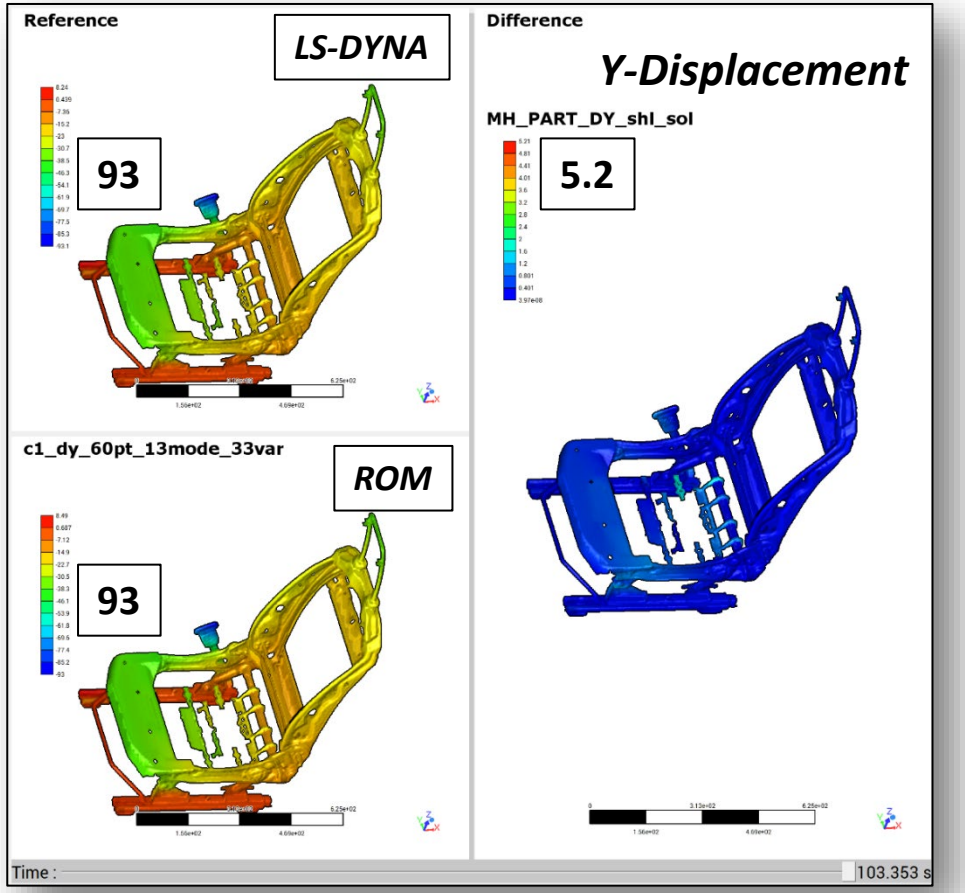
- User-specified part set
  - **191** structural parts selected
  - **271,048** nodes

Seat: ROM with part selection: *X- and Y-displacements*



Prediction accuracy:

Relative Error = ***0.12%*** *Max. error =* ***6.4mm***
15 *modes*



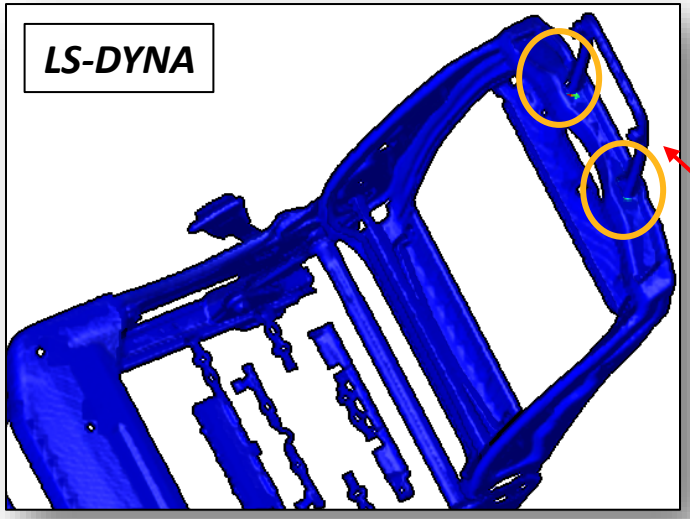
Prediction accuracy:

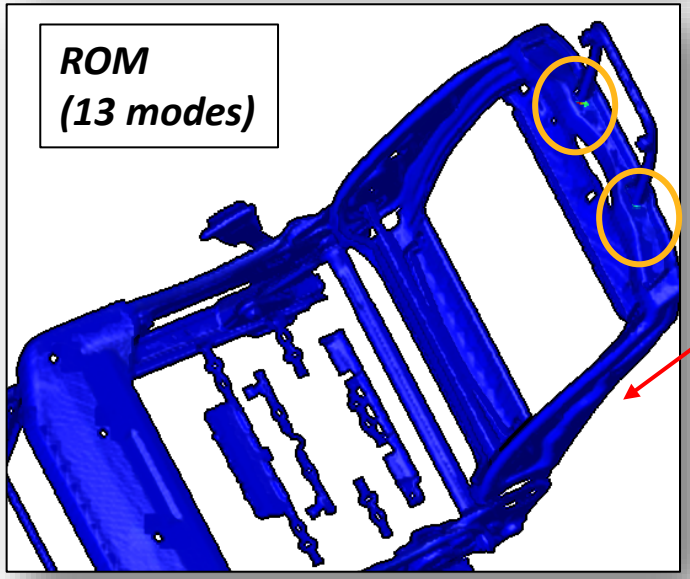
Relative Error = ***3.8%*** *Max. error =* ***5.7mm***
13 *modes*

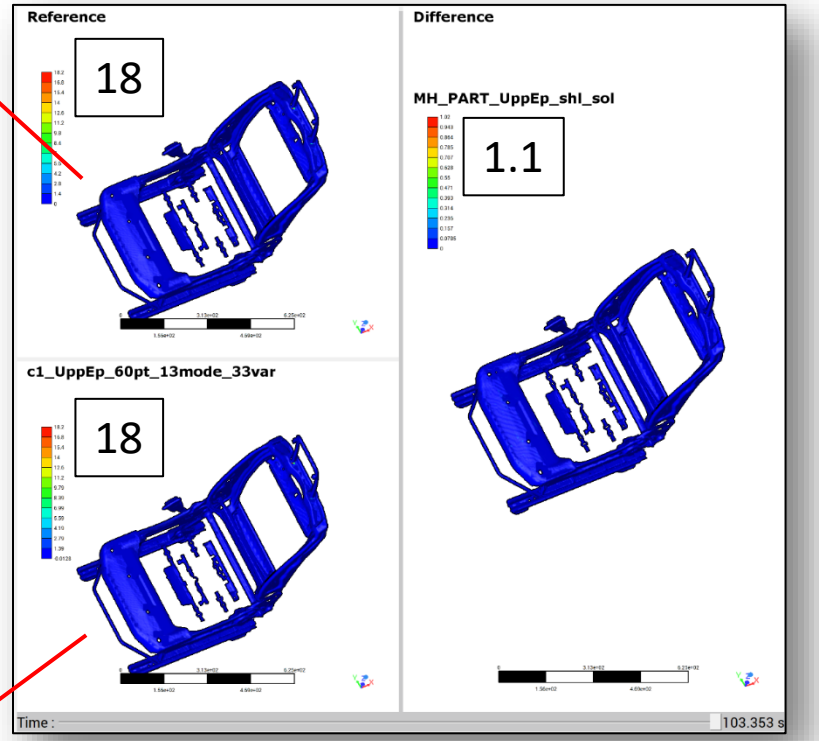
Seat: ROM with part selection: *Plastic strain*

- LS-DYNA dynamic case (crash)
  - 22 time states
  - 271,048 nodes
  - 191 parts
- **63** simulations (d3plot)
  - 60 training + 3 validation
- **33** variables
- Part set specification

- ***Prediction accuracy:***
  - *Relative Error = **2.2%***
  - *Max. error = **1.1***



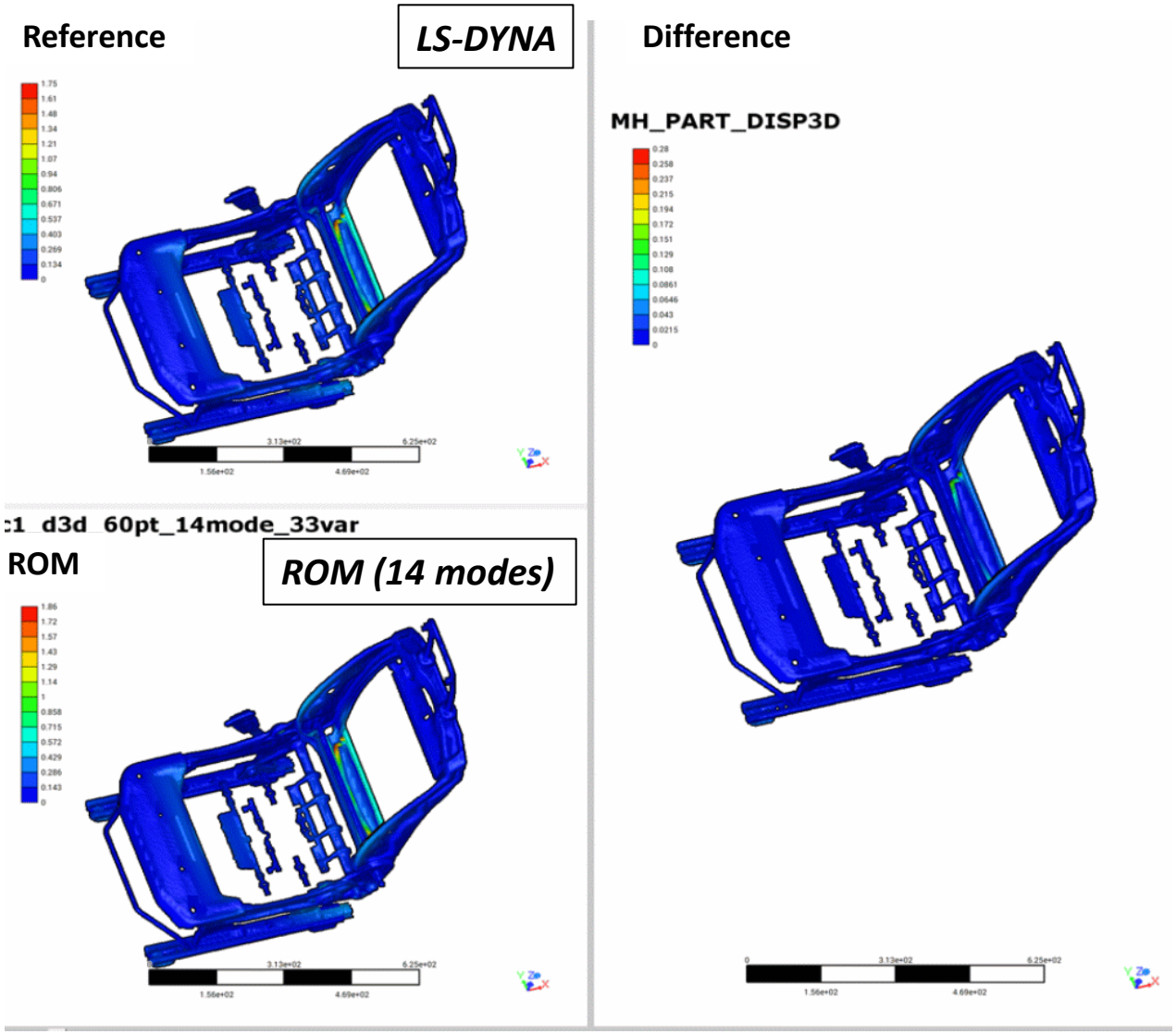




Seat: ROM with part selection: *Displacement vector field (u,v,w)*

- LS-DYNA dynamic case (crash)
  - 22 time states
  - 271,048 nodes
  - 191 parts
- **63** simulations (d3plot, d3plot.fz)
  - 60 training + 3 validation
- **33** variables
- Part set specification

- ***Prediction accuracy:***
  - *Relative Error =* ***0.16%***
  - *Max. error =* ***6.2mm*** *(Resultant)*



Case 1 Summary: Relative and Maximum Absolute ROM Errors

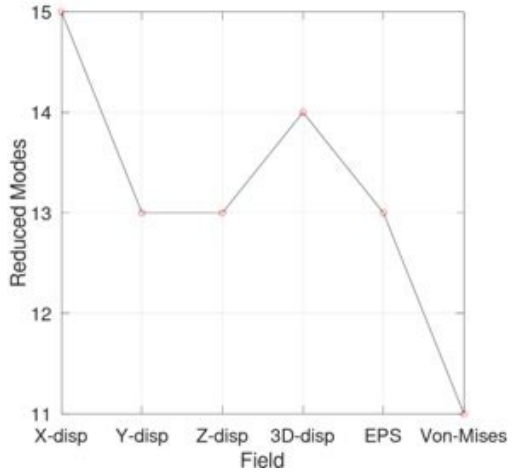
	Worst Des.	2nd Worst	3rd Worst
X Disp	0.12%	0.10%	0.08%
Y Disp	3.75%	3.61%	1.66%
Z Disp	4.41%	3.08%	2.94%
3D Disp (Resultant)	0.16%	0.13%	0.11%
Plastic strain	2.16%	1.76%	1.72%
Von Mises	6.49%	6.15%	5.89%

Relative error

	Worst Des.	2nd Worst	3rd Worst
X Disp	6.4mm	3.5mm	3.1mm
Y Disp	5.7mm	4.9mm	3.8mm
Z Disp	5.1mm	4.4mm	4.3mm
3D Disp (Resultant)	6.2mm	5.8mm	4.9mm
Plastic strain	1.1	0.9	0.6
Von Mises	0.27MPa	0.24MPa	0.24MPa

Maximum Absolute error

Number of modes used

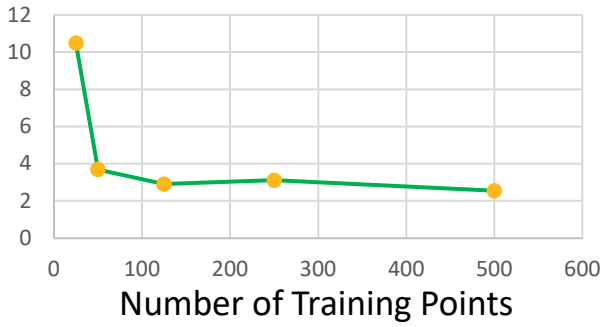


LS-OPT®/Twin Builder Full-field Dynamic Reduced Order Model

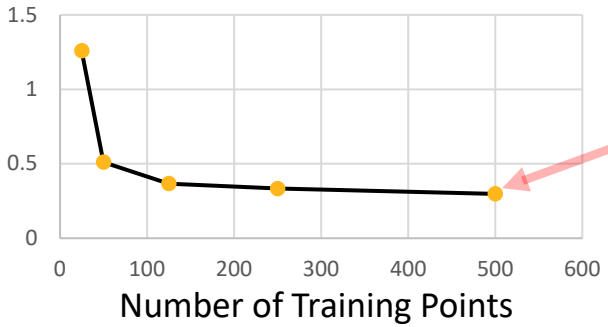
Left Ventricle Displacement Vector Field (10 material parameters)

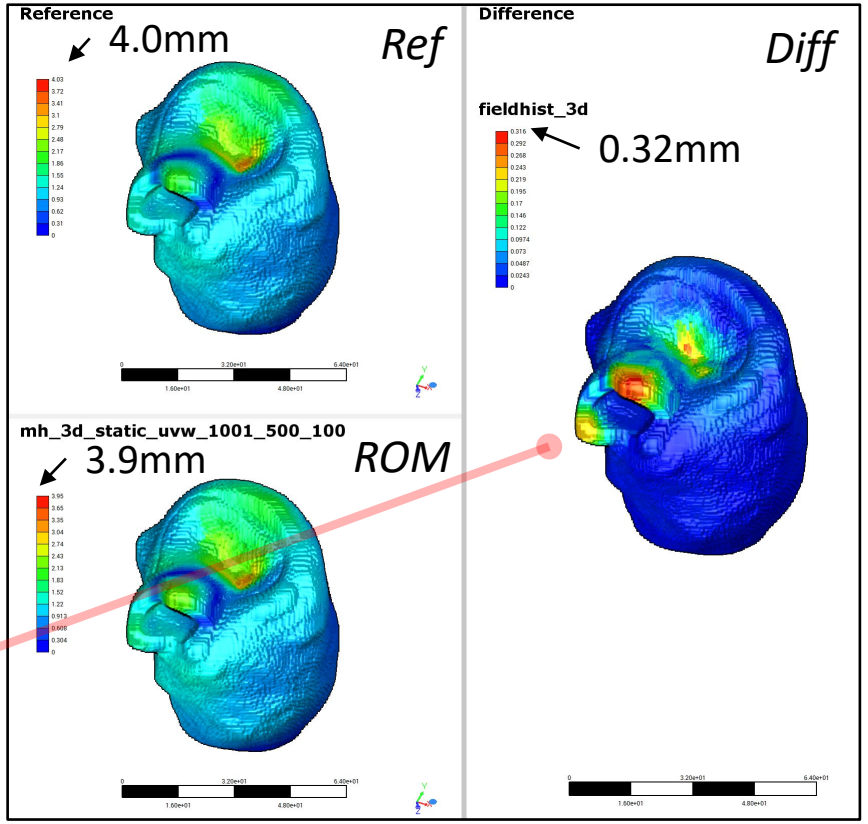
ROM Accuracy

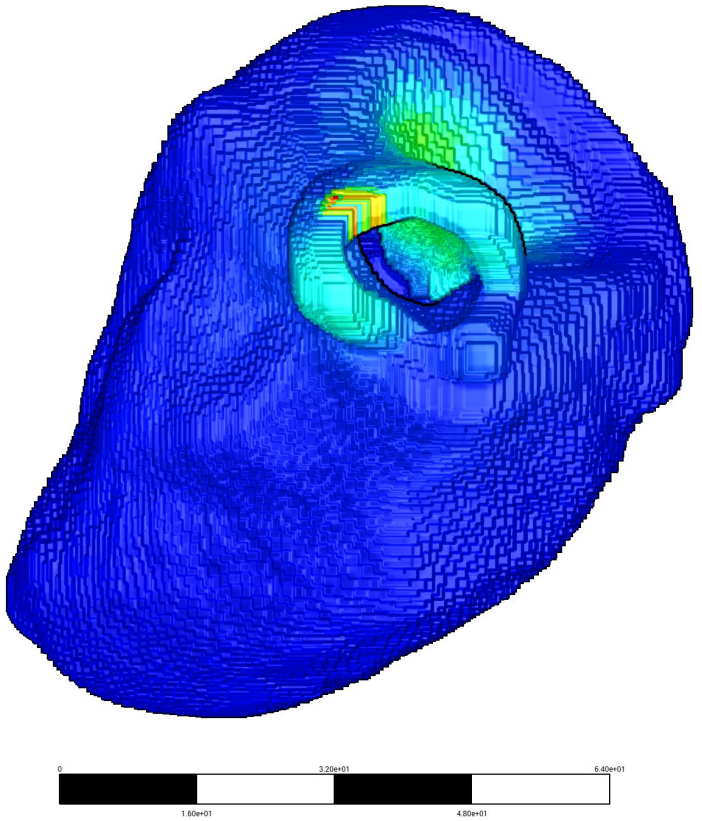
Relative Error (%)



Abs Max Error (mm)







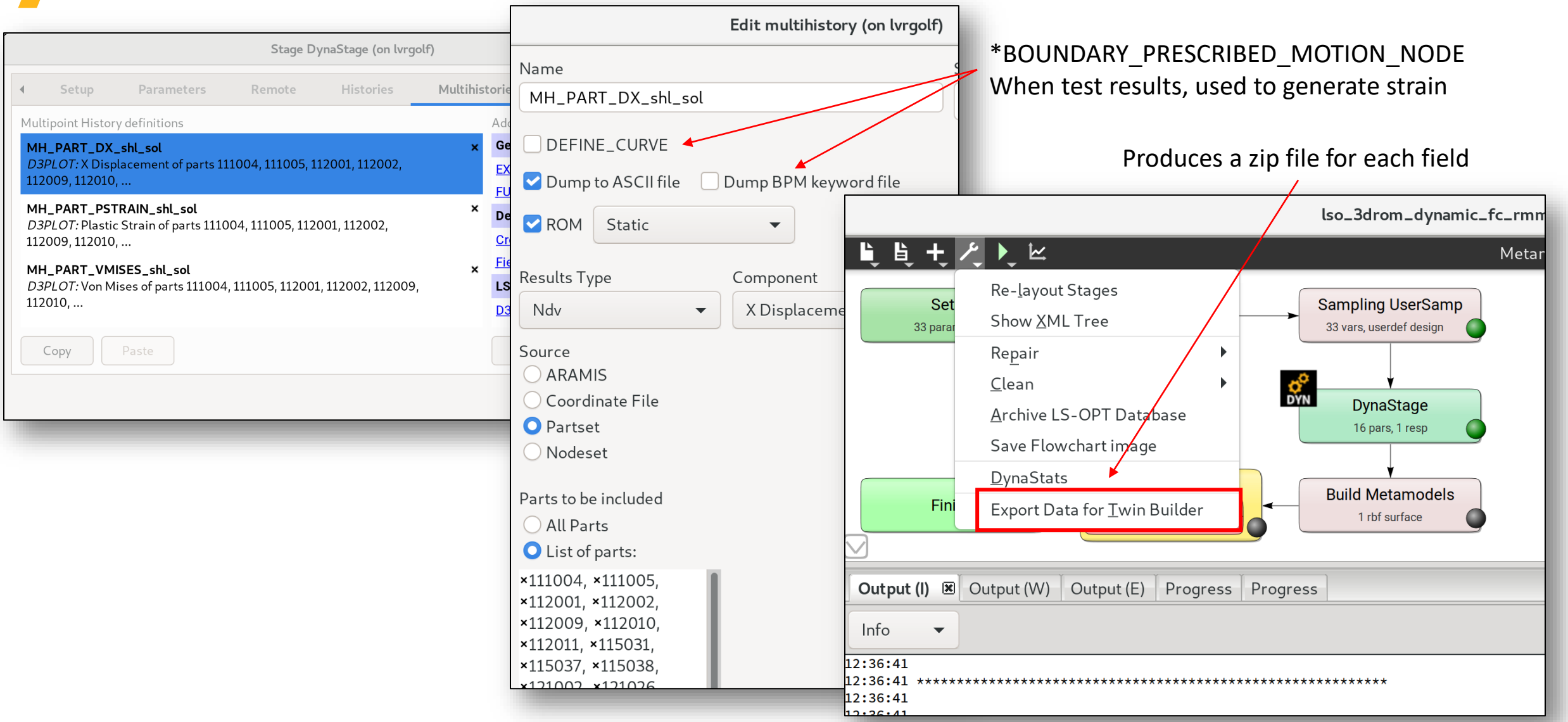
Heart model courtesy of and in collaboration with Synopsys. Automated mesh generation with Simpleware software from CT scans.

Reduced Order Model: Displacement vector field at $t = 200\text{ms}$

LS-OPT® features: full-field extraction and ROM export (2024R1)

- Utilizes the full-field dynamic output of *LS-DYNA*
  - *D3plot* (*4D*)
- Histories, Fields and Field-histories
  - Full-field quantities *(displacement, stress, strain, …)*
  - *Solids* and *shells*
  - Element-based quantities (stress, strain) are *mapped* to nodes (averaging). (Same as LS-PrePost)
- *Parts* or *Part sets*
- Node sets (using LS-DYNA setid).
  - For ROM coupling
- Synchronizes time steps across designs for ROM data export
- ROM data export (Twin Builder)
  - Histories (signals)
  - Fields, Field-histories
  - Part sets, Node sets
  - Vector fields (e.g. 3D displacement)
  - Tensor fields (e.g. 6D strain)
- Standard field interfaces: points mapped to the FE model. Used for calibration.
  - GOM (Digital image system for materials testing)
  - GenEx (in-house parser)
  - Fixed Format (LSPP text format)
  - DYNA *NODE format (at time steps)
    - Simpleware interface (CT Scan)
    - 3D Geometry and displacement

LS-OPT interface



LS-OPT/LS-DYNA/Ansys Twin Builder – Current development

- Twin Builder as low fidelity solver for LS-OPT tasks. Will implement TB as a library for seamless optimization and reliability studies
- LS-DYNA ROM coupling
  - Similar to *CADLM Odyssee* coupling using the *QUASAR interface
- Mapping to LS-PrePost
  - Animate ROM model
- More complex models
  - Bi-ventricular cardiac model

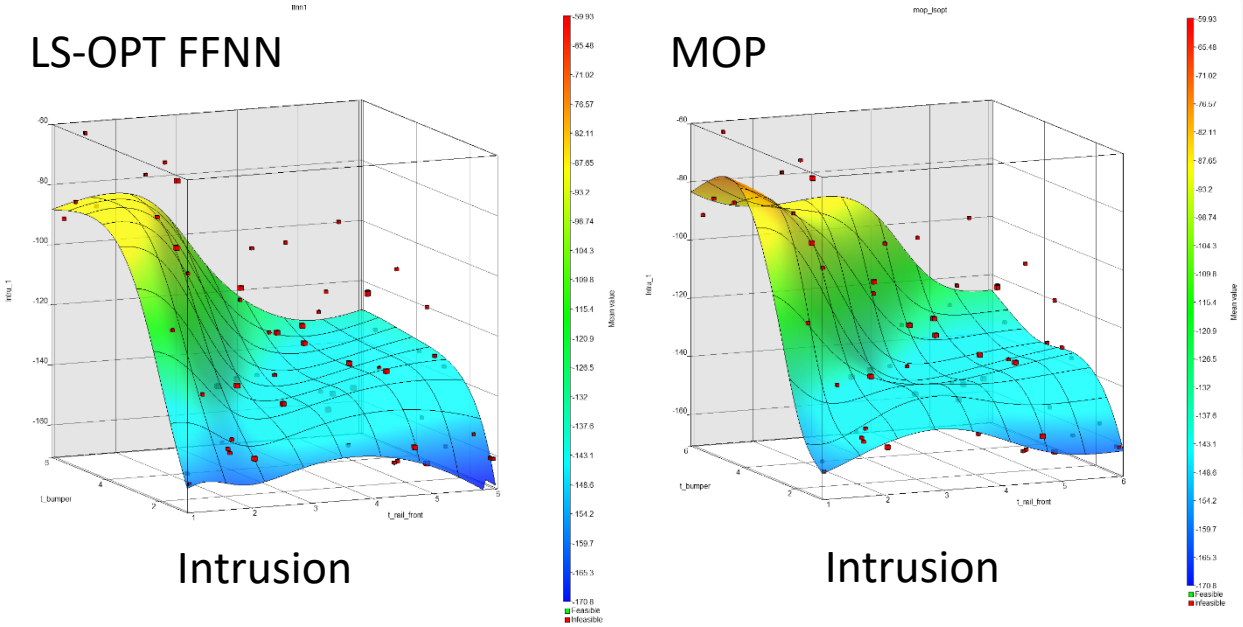
Integration: Metamodels

Integrating LS-OPT features into Ansys products: Metamodels

MOP (Method of Optimal Prognosis)

- Automatically selects the best metamodel from *competing* LS-OPT and oSL metamodels:
  - FFNN, RBF, Kriging, SVR, Polynomials, MLS

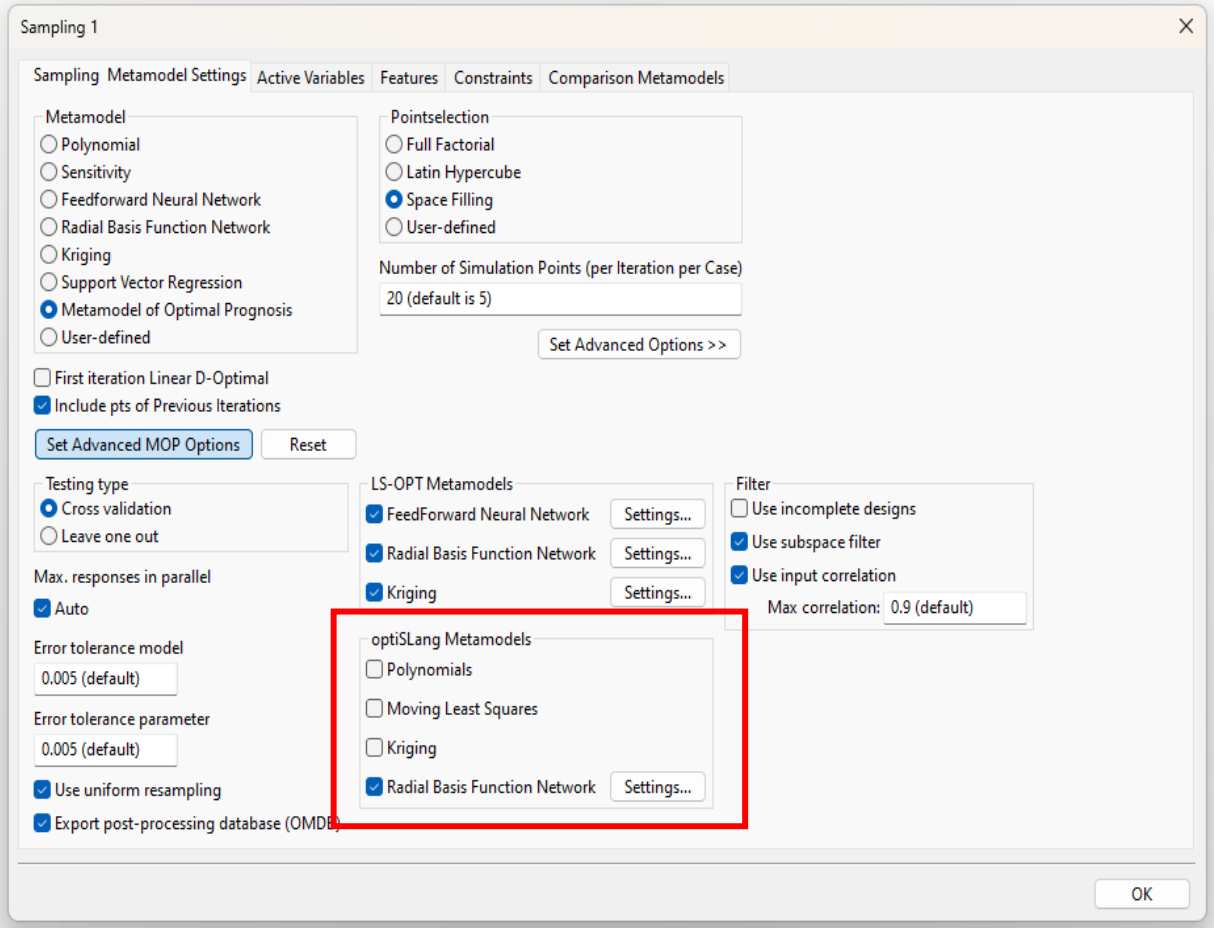
LS-OPT FFNN



Intrusion

MOP

Intrusion




Ansys

Reduced Order Model (ROM)

Reduced Order Model (ROM)

Model Order Reduction (MOR) is a technique for reducing the computational complexity of mathematical models in numerical simulations.

The output of this technique is a **Reduced Order Model** (ROM)**.**

Benefits of ROM

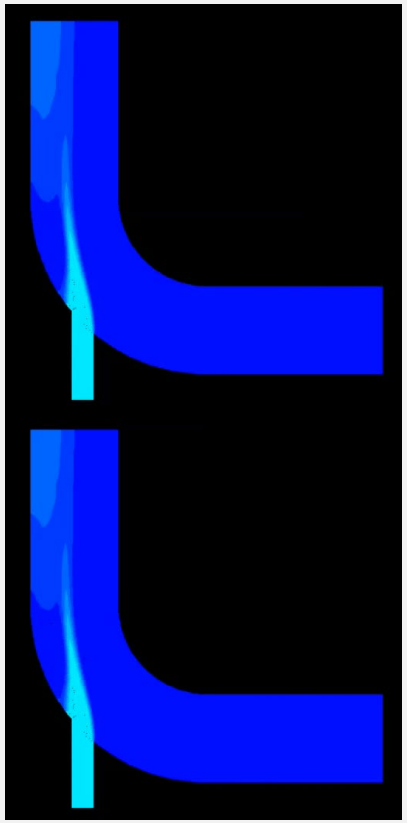
Reduced simulation time
- Runtime generation for near real-time applications

Improved Stability
- Stability is enforced by construction

Reduced storage size
- Reduce the required storage size dramatically

Reuse 3D model
- Utilize validated 3D physics in system model
- Help increase the 3D solver footprint

Fluent CFD Simulation:
3 hours on 12 cores

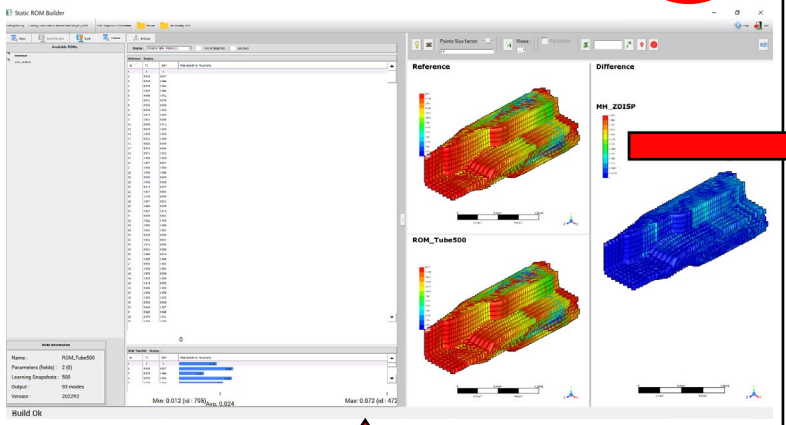


ROM Simulation
Realtime

Process flow: LS-OPT – Twin Builder

TwinBuilder ROM Builder

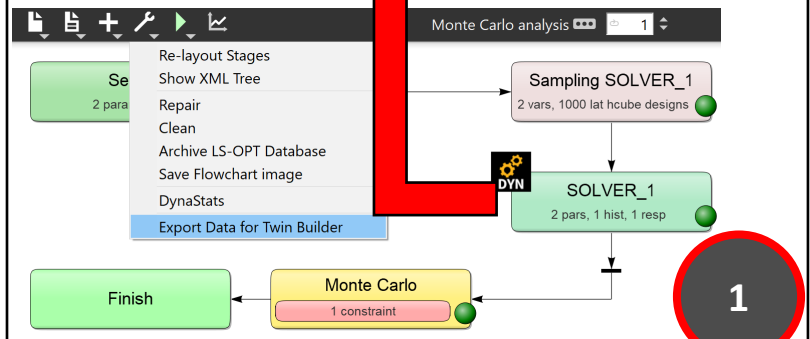
2



twinPackStatic.MR_Zdisp.zip

Saved ROM

Field snapshot archive

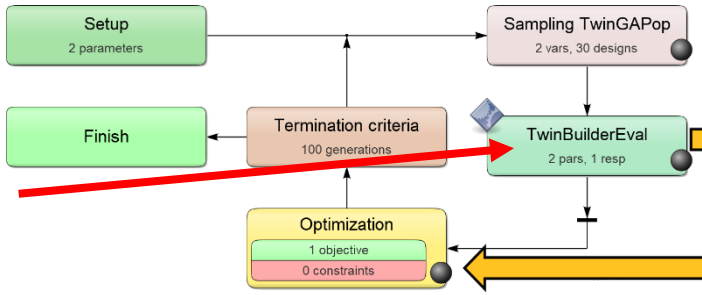


1

LS-OPT: LS-DYNA simulation + field result archiving for TwinBuilder

A. Basudhar

LS-OPT: ROM-based optimization/calibration



3a

DOE evaluation
TwinBuilder Solver

SVDTools.exe
SROMevaluate

predicted_snapshot.bin (for each sample)

Scalar field	3D field
n	$3n$
α_1	α_1
α_2	β_1
⋮	γ_1
α_n	α_2
	⋮
	γ_n

3b

LS-OPT:
predicted field extraction
+
optional d3plot mapping

ROM result mapped to d3plot (LS-PrePost)

Current Status:
Variable detection is user-defined (<< >>)
Extraction is TwinBuilder specific