LS-OPT Status: Enhancing Surrogate Accuracy in Automotive Crash Analysis

Anirban Basudhar, Katharina Liebold, Lars Gräning, Nielen Stander

LS-DYNA Forum, Stuttgart, Germany *2024-10-16*

Ansys

Overview

- Metamodel integration
- Reduced Order Modeling

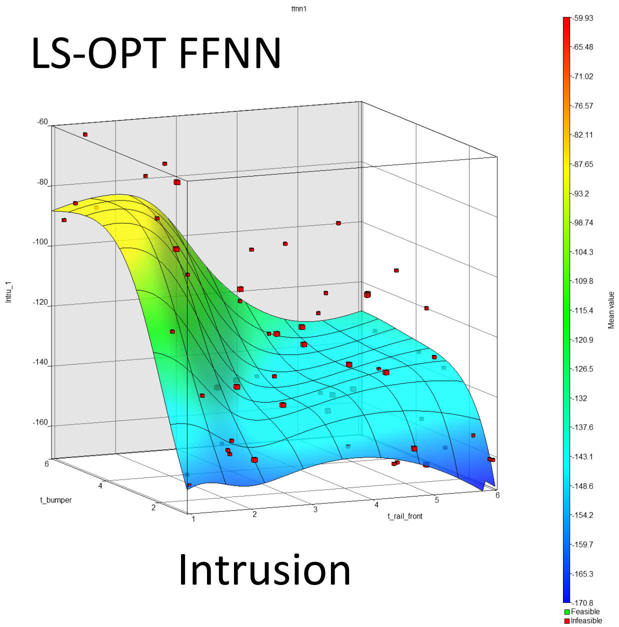
Improving prediction accuracy: *Metamodel of Optimal Prognosis* (MOP)

- Normalized cross-validation error
- Automatically selects the best of ***LS-OPT*** and ***optiSLang*** metamodels:
  - FFNN, RBF, Kriging, Polynomials, MLS, OS-Kriging, OS-RBF

$$\text{Criterion: } CoP = 1 - \frac{SS_E^{pred}}{SS_T}$$

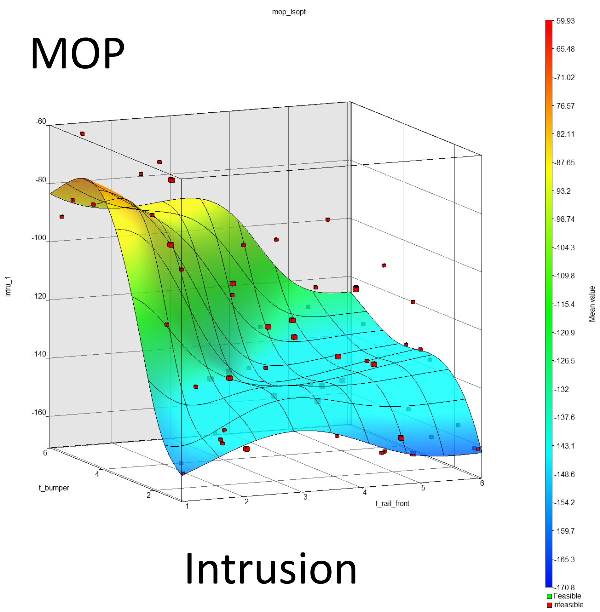
- SS_E^{pred} is the sum of squared prediction errors based on cross validation
- SS_T is the total variance in the observed data

LS-OPT FFNN

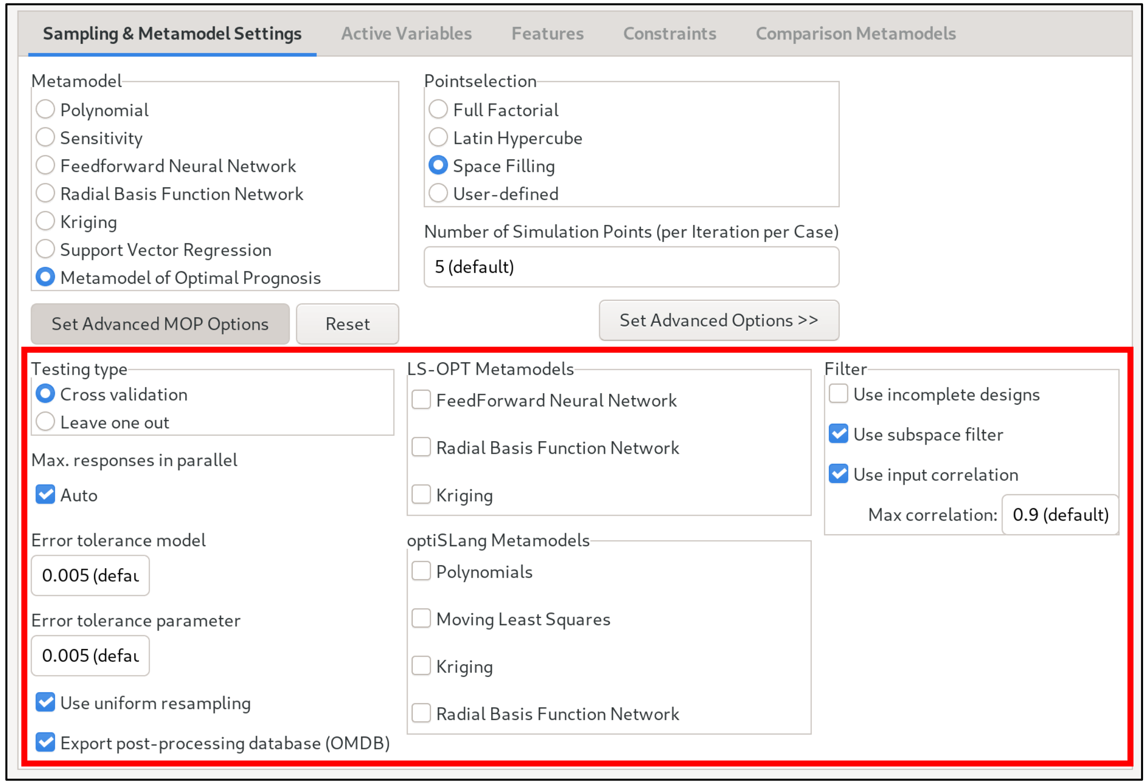


Intrusion

MOP



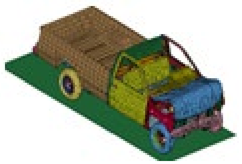
Intrusion

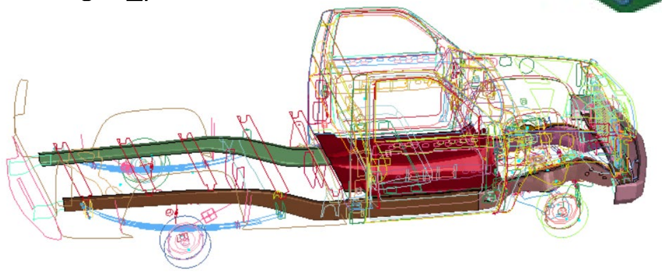


Metamodel integration

Quality of new, unseen data

min *mass (11 parts, 22 variables)*
s.t. *displacement ≤ 1*
stage1_pulse ≤ 1
stage2_pulse ≤ 1





Design Parts (Thickness variables)

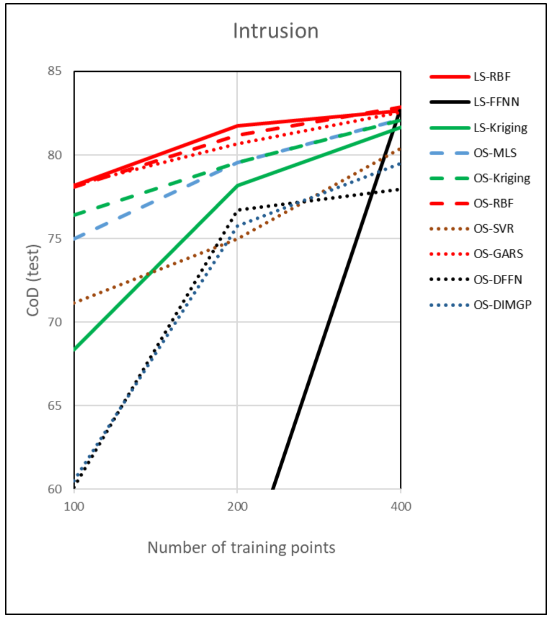
Adjusted Coefficient of Determination

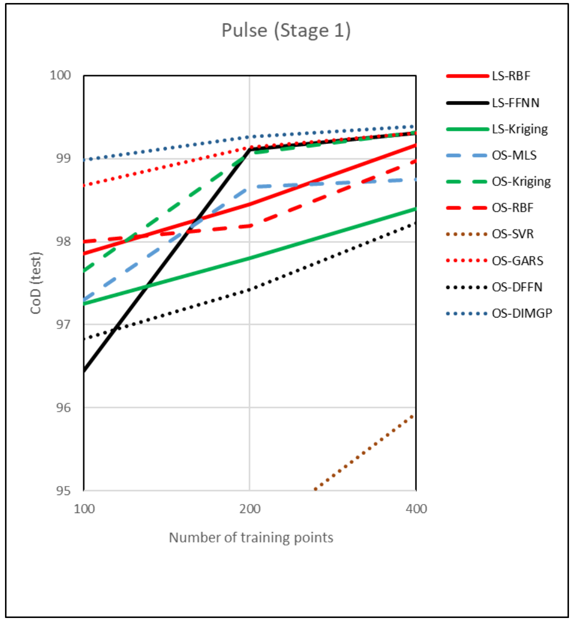
$$R^2_{adj} = 1 - \frac{N-1}{N-p}(1 - R^2)$$

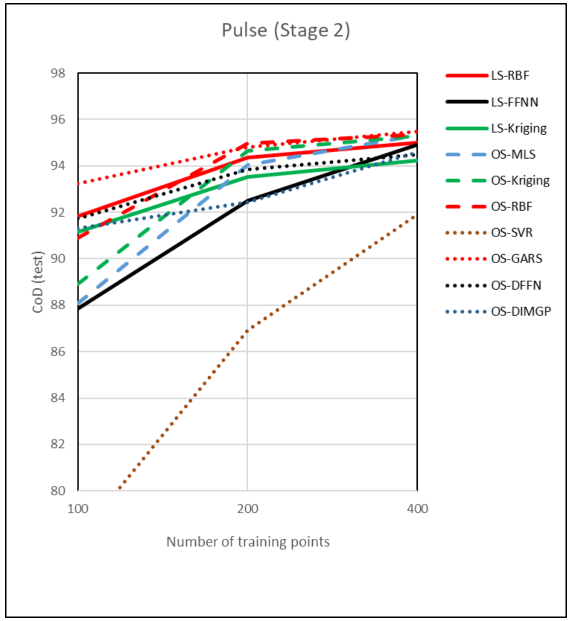
$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T} \qquad 0 \leq R^2 \leq 1$$

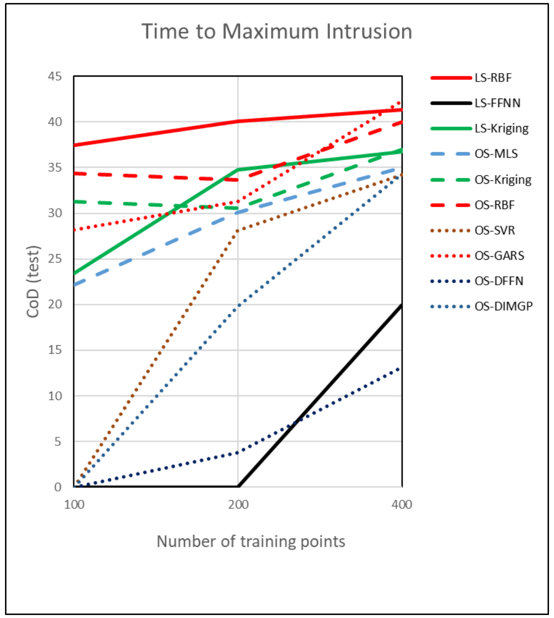
$$SS_T = \sum_{i=1}^{N}(y_i - \mu_Y)^2$$

$$SS_E = \sum_{i=1}^{N}(y_i - \hat{y}_i)^2$$









MOP3: Metamodel of Optimal Prognosis: automatically selects the *best method.*

——— : LS-OPT 7
– – – – : shared OSL
·········· : OSL only

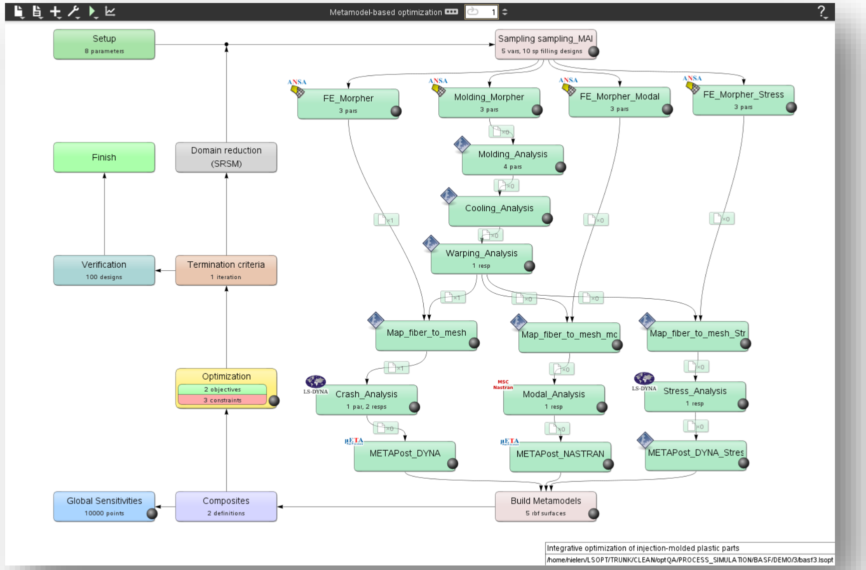
22 variables (thickness and material)
Metamodel training points from ***800*** pts available
CoD evaluated using ***1200*** test points

Full-field modeling
(Twin Builder)

Ansys *Twin Builder and LS-OPT:* Full-field approximation

LS-OPT

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



LS-OPT Process Integration

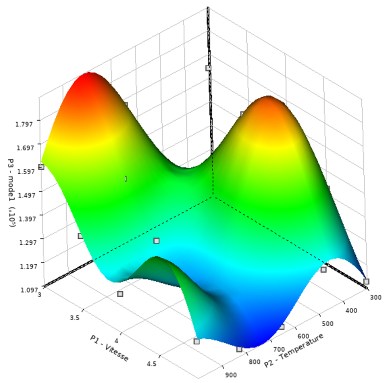
Twin Builder

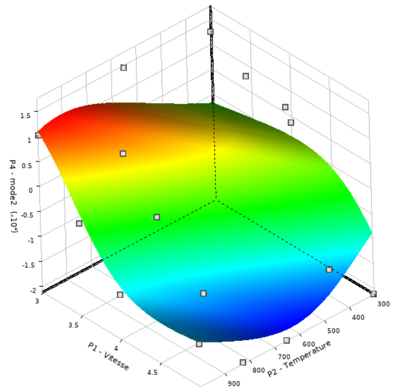
Uses blackbox solver agnostic techniques for creating ***Reduced Order Models*** as *fast early design* tools for Non-Linear Dynamic Systems

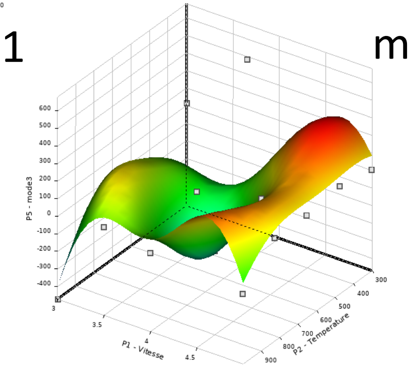
- Reduction :
  - Projection methods (eigen solution): SVD/POD.
  - Limited number of eigenvalues automatically selected: *removes response noise*
- Machine learning:
  - Advanced Interpolation of modal coefficients using metamodels (Polynomial, Kriging, SVR, GARS (aggregation)) → Static ROM Builder

How Twin Builder works: SVD → modal coefficients → interpolation

Every modal coefficient is interpolated using a response surface

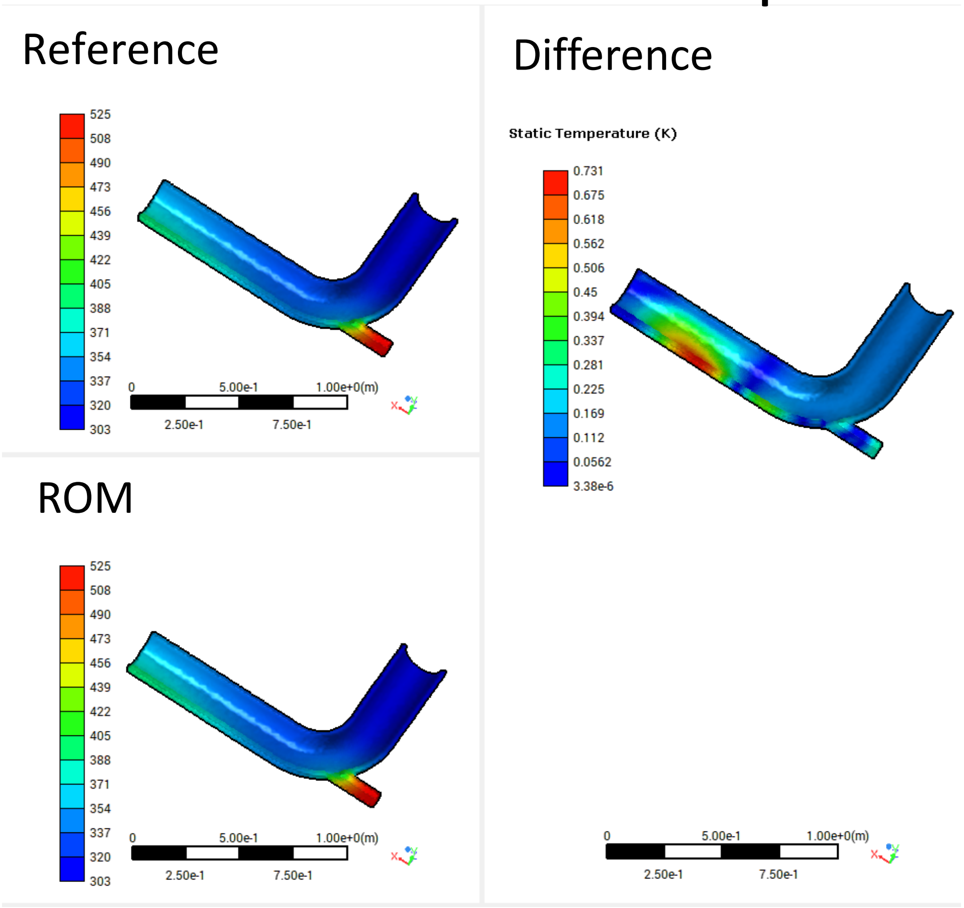

mode1


mode2


mode3

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

Validation at the Verification points



Ansys

Seat design (frontal crash): ROM with part selection

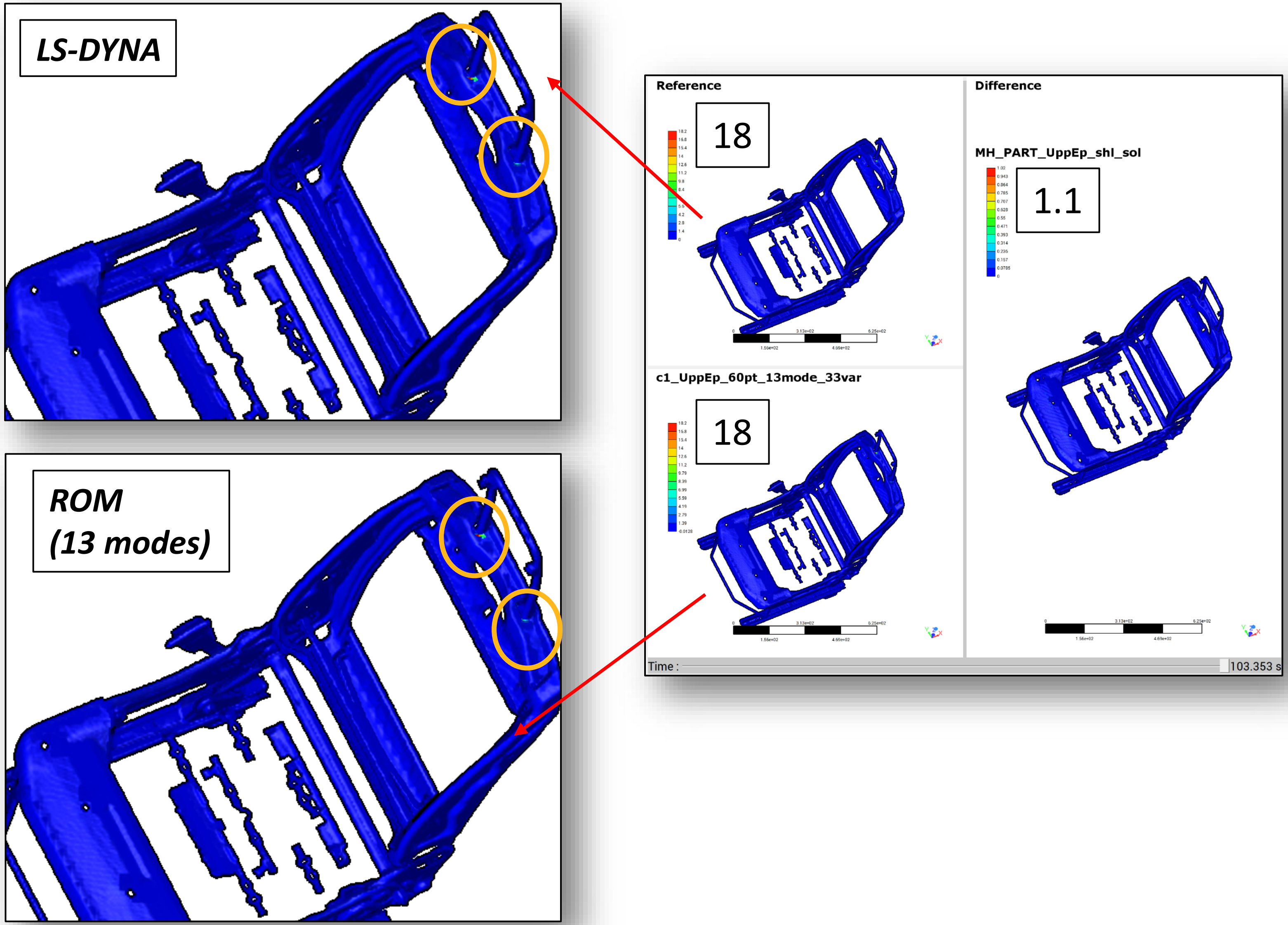
- **22** time states
- **33** variables
- **63** simulations, 60 training + 3 validation

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

Seat: ROM with part selection: *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

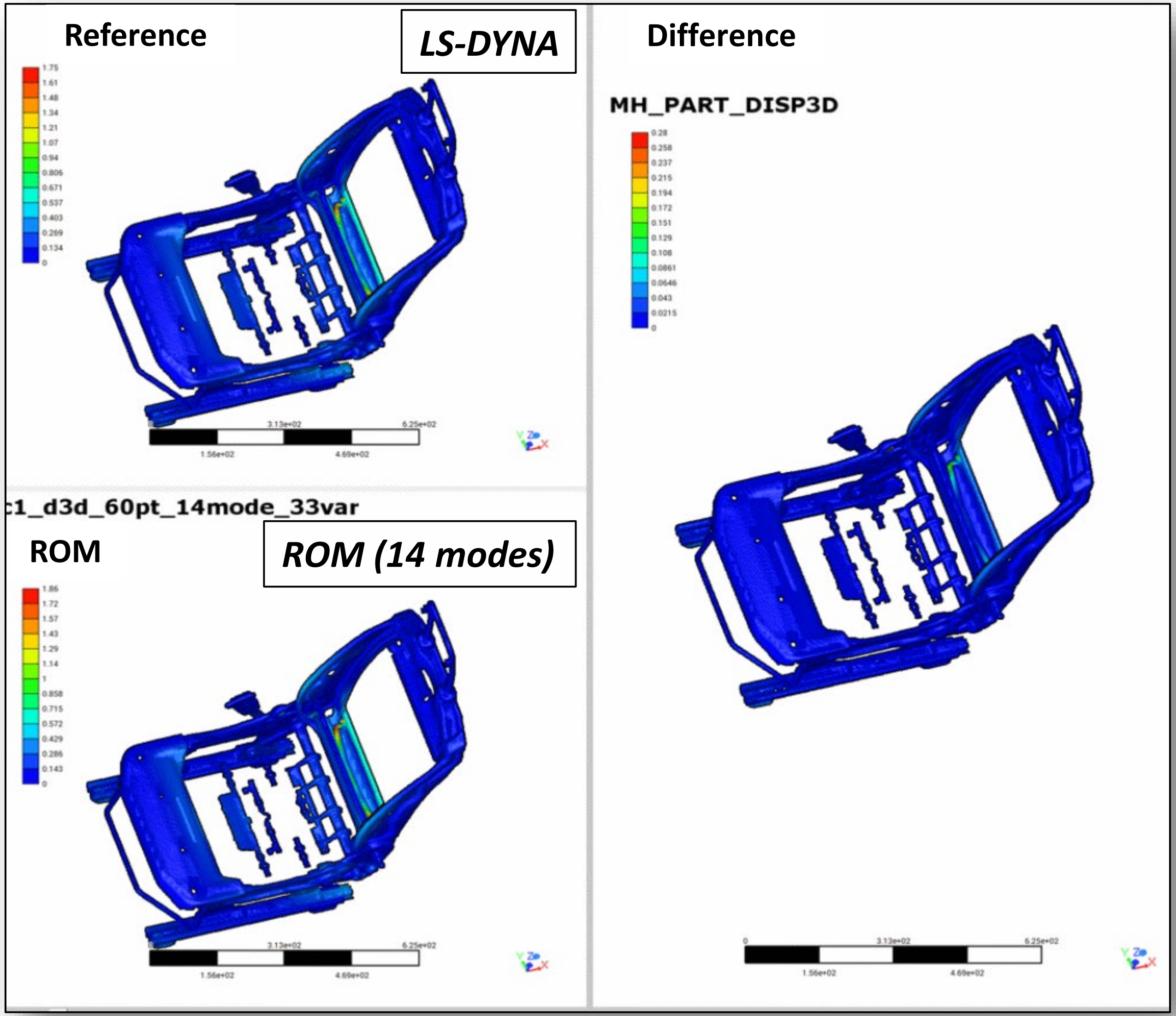
- ***Prediction accuracy:***
  - *Relative Error =* ***2.2%***
  - *Max. error =* ***1.1***



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

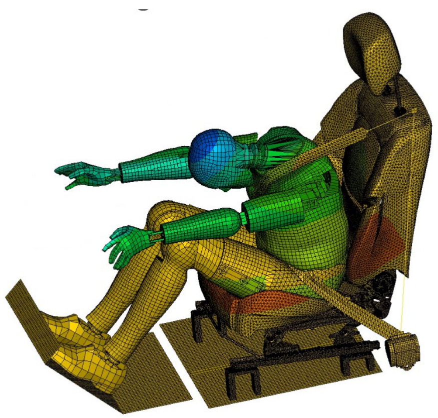
- ***Prediction accuracy:***
  - *Relative Error = **0.16%***
  - *Max. error = **6.2mm** (Resultant)*

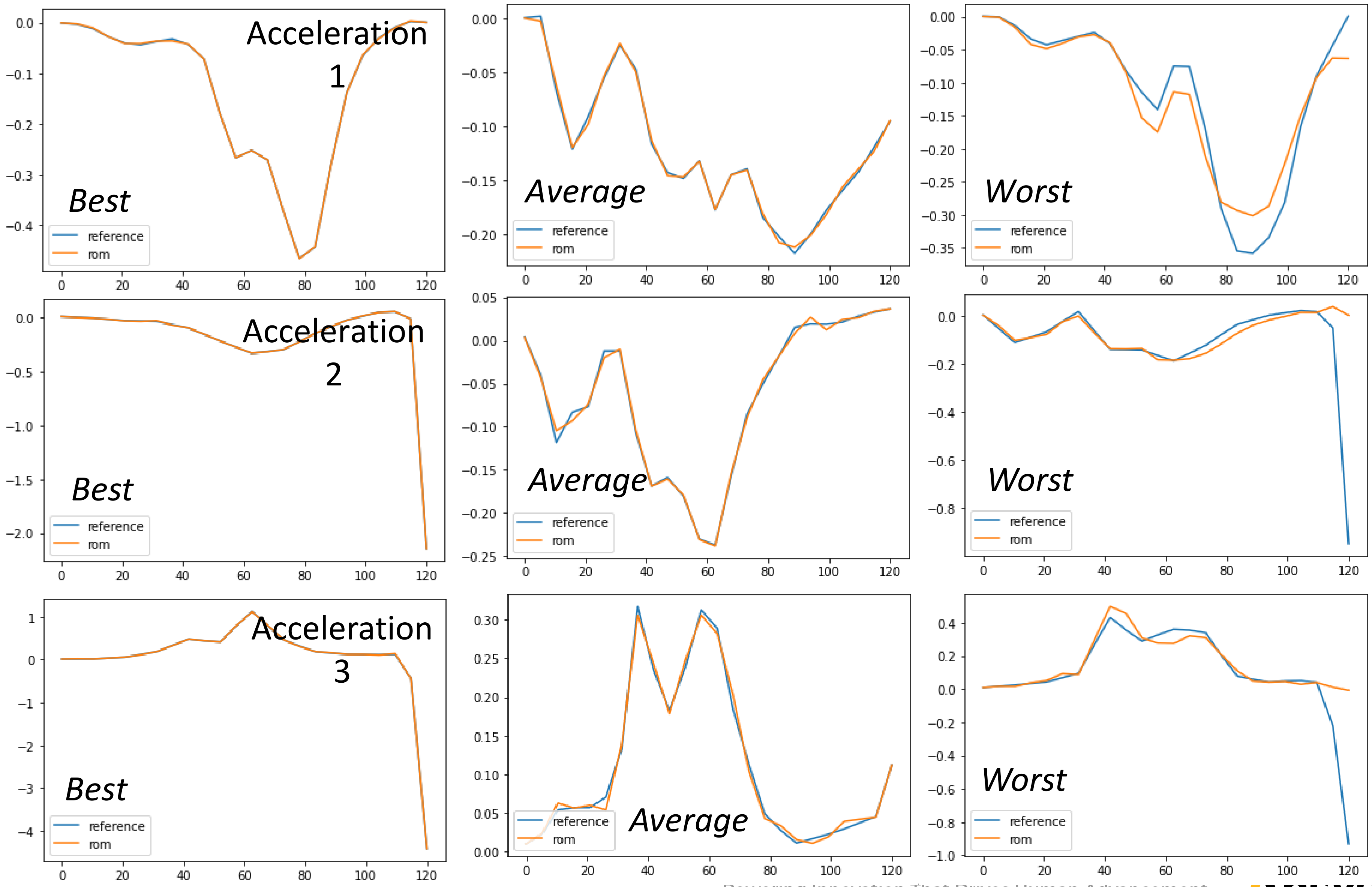


Ansys

Twin Builder: ROM vs FE acceleration histories at dummy locations

- Dummy
  - **8 Variables**
  - **240 Outputs**
  - **101 runs**
  - **90% training points**





LS-OPT® features: full-field extraction and ROM export (2025R1)

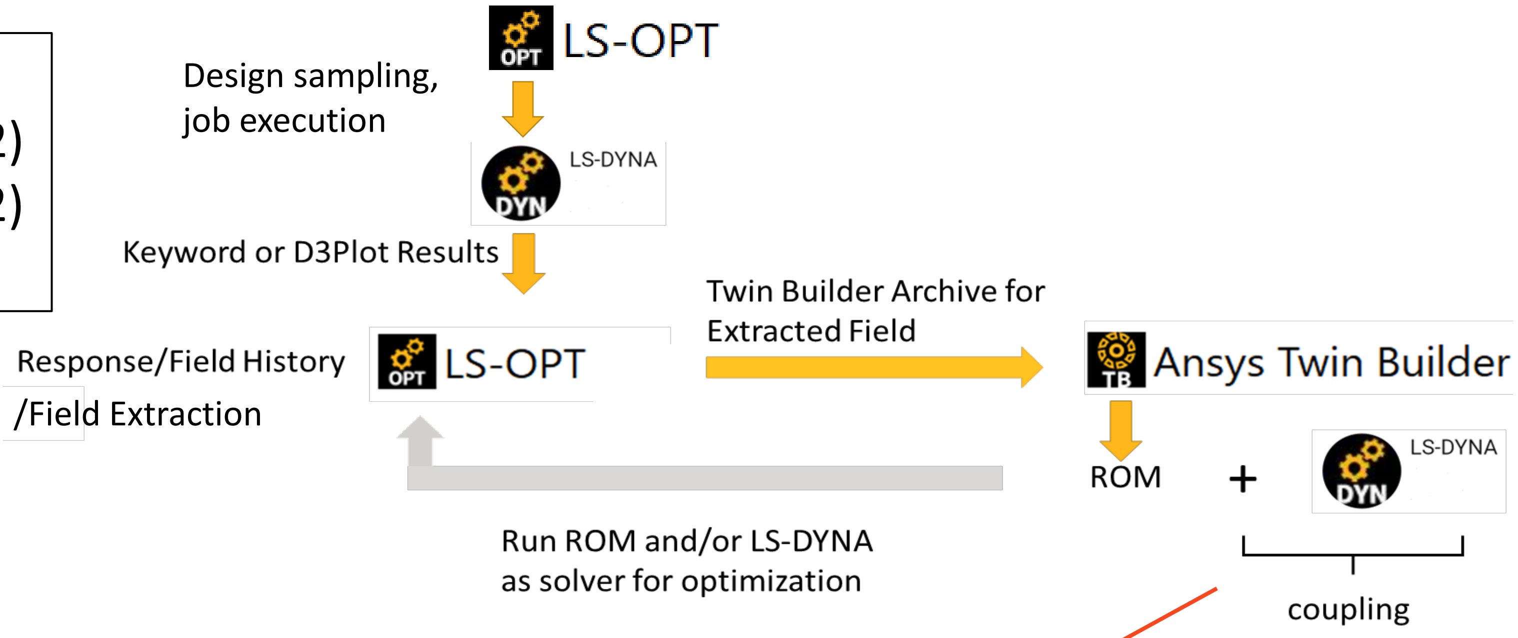
- Utilizes the full-field dynamic output of *LS-DYNA*
  - *D3plot and Binout (displacement, nodout, nodfor, rcforc, …) (4D)*
- Histories, Fields and Field-histories
  - Full-field quantities *(displacement, stress, strain, …)*
  - *Solids* and *shells*
  - Element-based quantities (stress, strain) are *mapped* to nodes (averaging). (Same as LS-PrePost)
- *LS-DYNA Parts* or *Part sets*
- *Node sets* (using LS-DYNA setid).
  - For ROM coupling
- Account for element failure – truncate/interpolate as needed

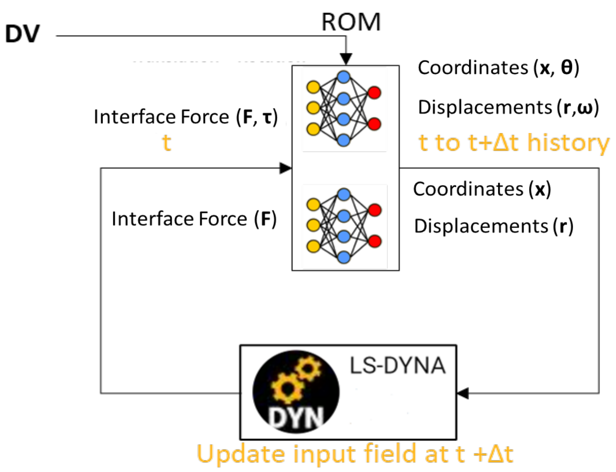
- ROM data export (Twin Builder)
  - Part sets, Node sets
  - Histories (signals)
  - Fields, Field-histories
  - *Vector fields* (e.g. 3D displacement)
  - *Tensor fields* (e.g. 6D strain)
  - Synchronizes time steps across designs for ROM data export
  - Database files directly consumed by Twin Builder
  - LS-DYNA *user-defined IDs* for identification
- Special *Field-based* functions
  - *FieldSelect, FieldHistSelect.* Min, Max, Ave of fields or field-histories
  - *FieldHistEuclidean.* Field-history similarity measure

LS-OPT - Twin Builder tool chain overview (2025R2)

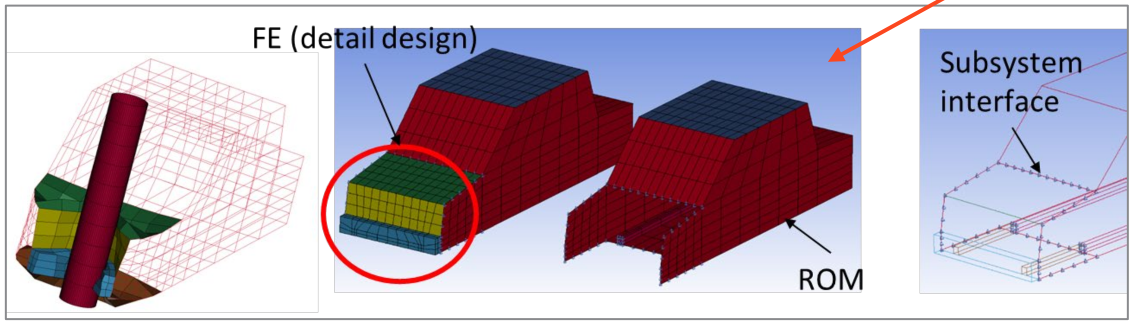
- *D3plot export* to Twin Builder ✓
- *Optimization* process flow (✓25.2)
- ROM *LS-DYNA* coupling (✓25.2)
- *LS-PrePost* ROM rendering (?)

Design optimization process flow with ROM (with/without LS-DYNA ROM coupling)

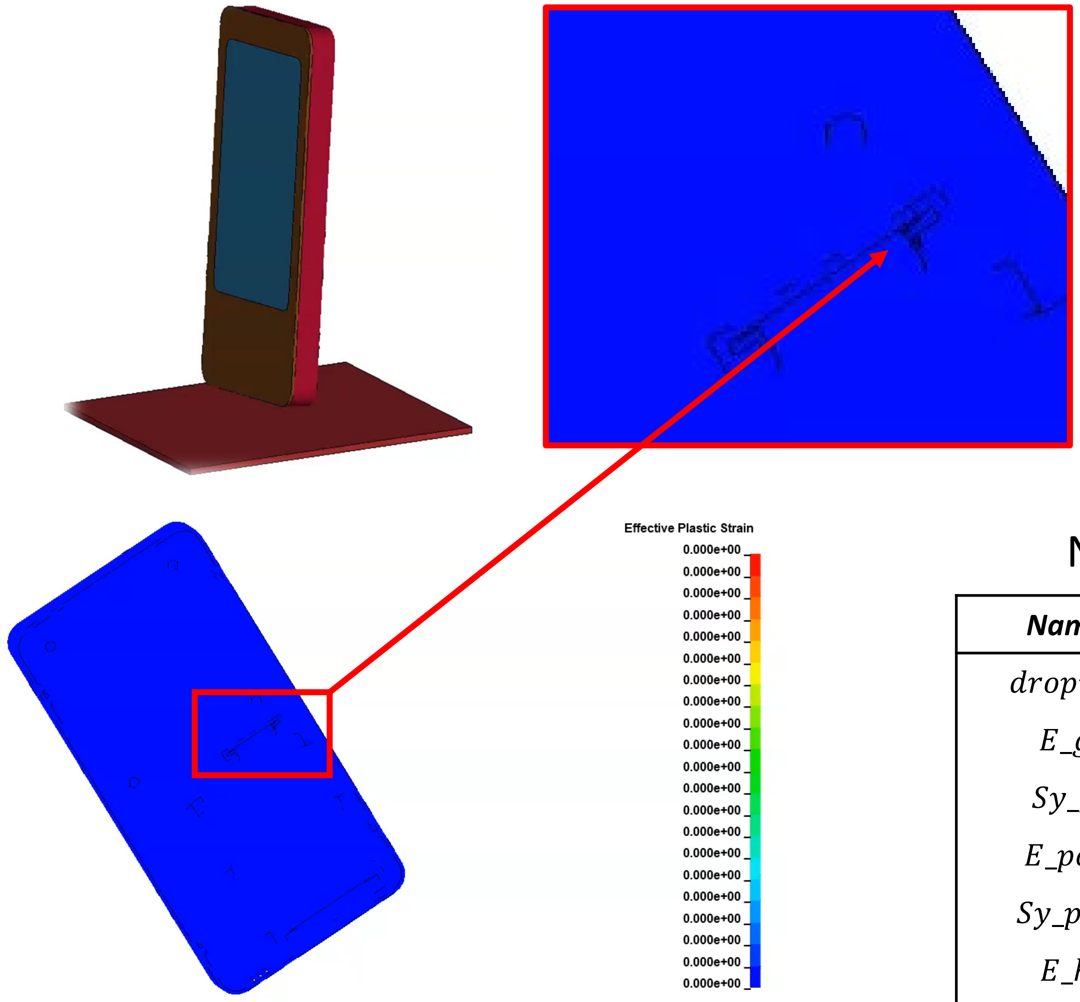




LS-DYNA coupling



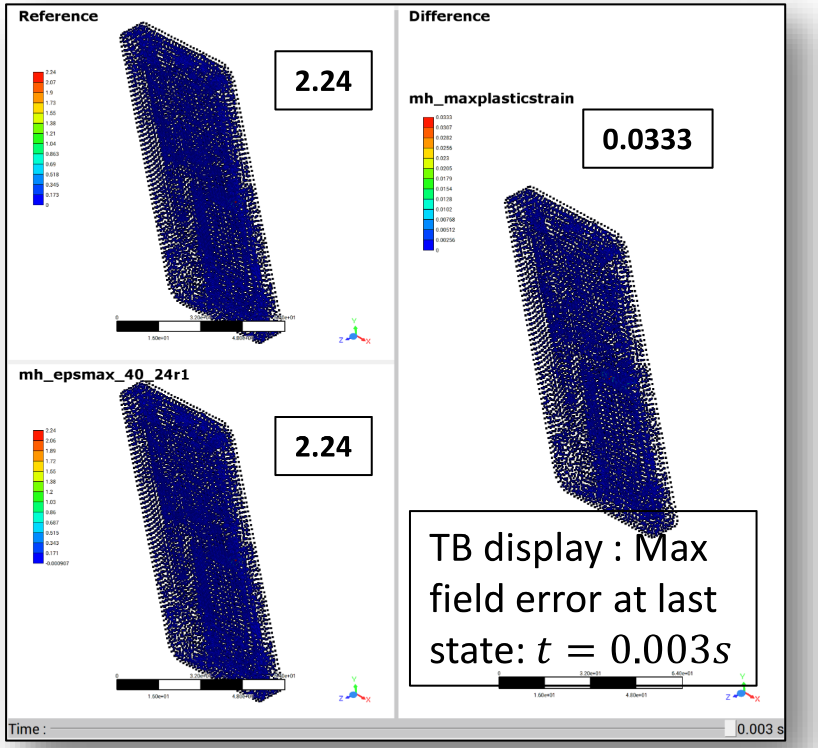
Phone Drop Test: Effective Plastic Strain – TB-ROM Error



- Full-field Effective Plastic Strain ε^{pl}
  - Highly localized
- 8 Noise variables including velocity
- ROM built using **40** training samples

Noise variables

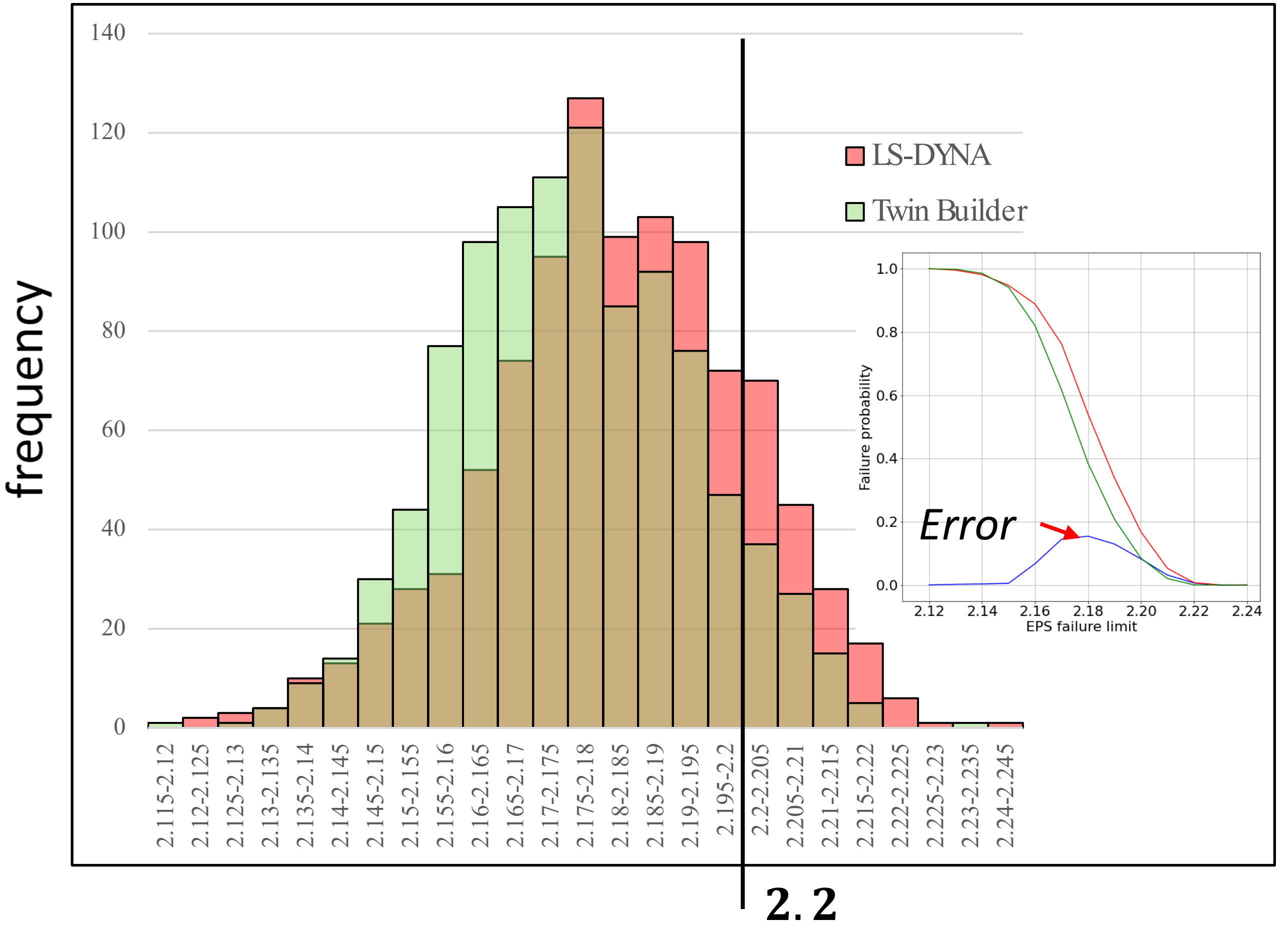
Name	***Distribution***
$dropvel$	$U(-5000,-4000)$
E_g	$N(3100,30)$
Sy_g	$N(65,0.5)$
E_pcb	$N(4000,40)$
Sy_pcb	$N(62,0.5)$
E_h	$N(4000,40)$
Sy_h	$N(62,0.5)$
t_pole	$N(1.1,0.025)$



Phone Drop Test: Reliability/Robustness Analysis – TB-ROM vs. LS-DYNA

	LS-DYNA	TB-ROM
Simulations	1,000	40
Sampling size	1,000	1,000
Mean	2.182	2.176
Standard Deviation	0.0182	0.0168
$P\left(\varepsilon_{max}^{pl} > 2.2\right)$	0.168	0.085
Comp. Time*	~8h	<1h

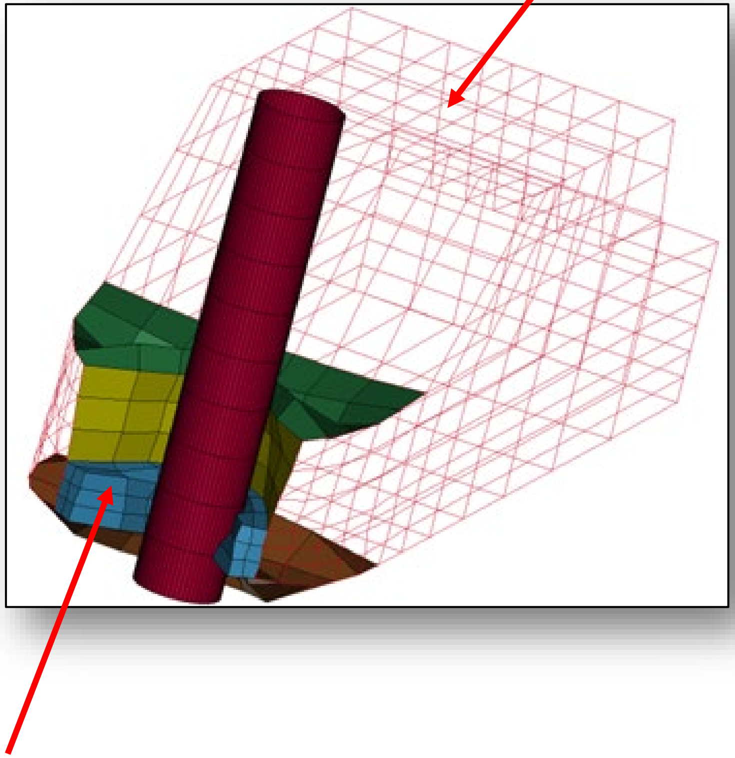
**estimate: different job scheduling, in/out-core*



Frequency distribution of ε_{max}^{pl}
Inset: Failure probability and approximation error (blue)

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

- Further integration of Twin Builder as a low fidelity LS-OPT solver:
  - *TB-ROM generation as an LS-OPT library* for seamless optimization and reliability studies (2025R2)
  - Example: ROM-based Digital Image Correlation (DIC)
- *LS-DYNA* ROM coupling
  - Similar to the current **QUASAR* interface
  - Application: *Seat recliner mechanism* – in progress



Ansys