HEXAGON

Reliable Design of Reinforced Plastics

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Agenda

1 **Introduction**
Pain points & objectives

2 **Workflow**
Methodology & solution

3 **Outcomes**
Examples & results

4 **Conclusion**
Perspectives & next steps

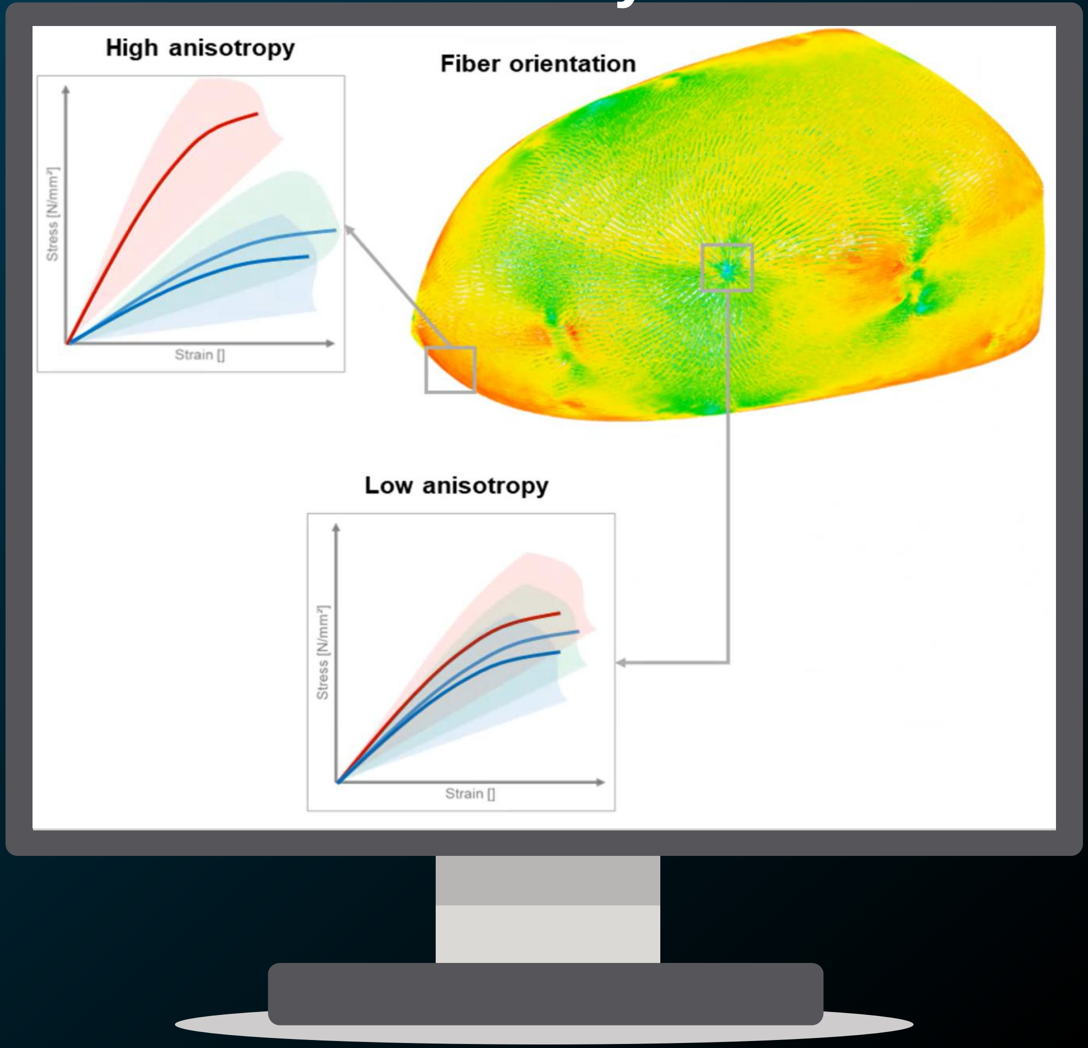
Introduction

Pain points & objectives

Introduction

Pain points – Material

Reality



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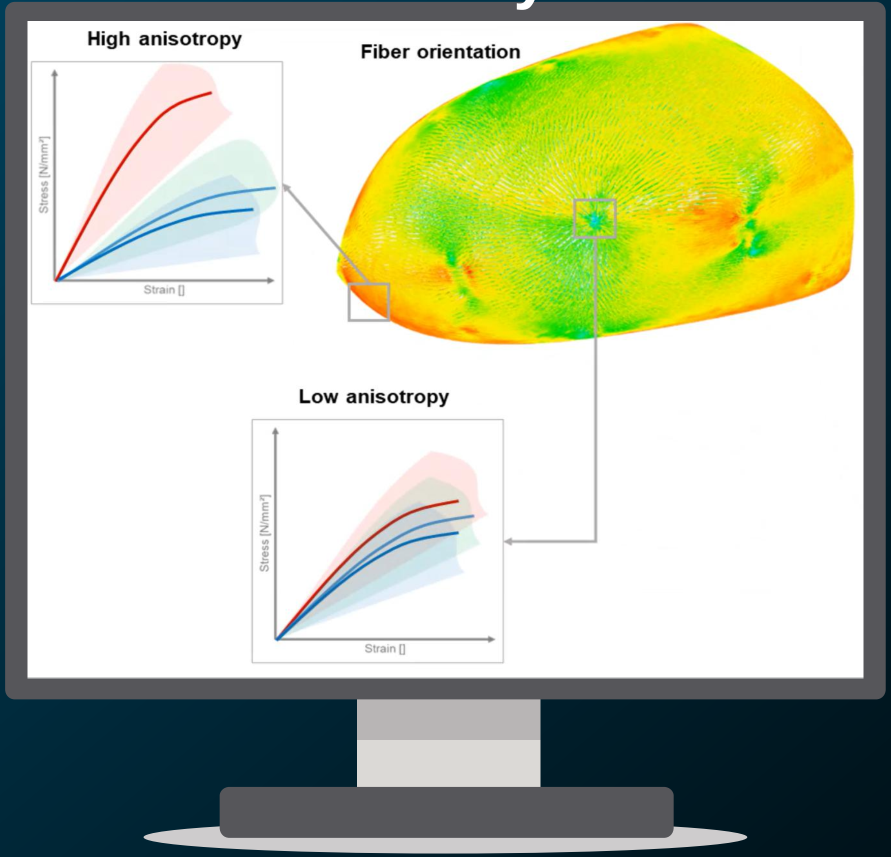
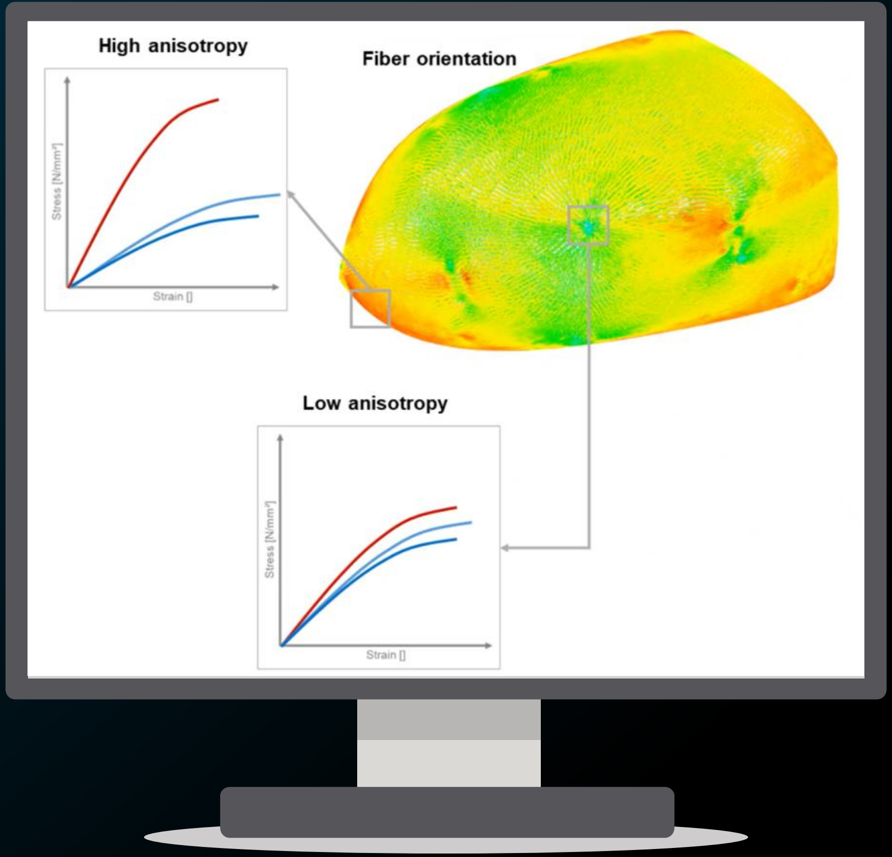
Introduction

Pain points – Material

Reality

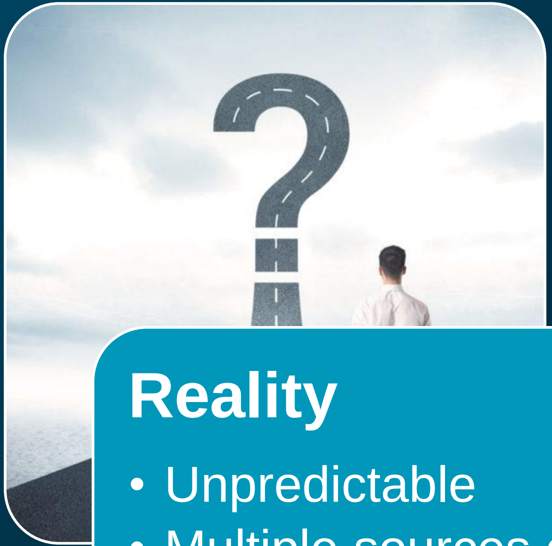


Conventional Simulation



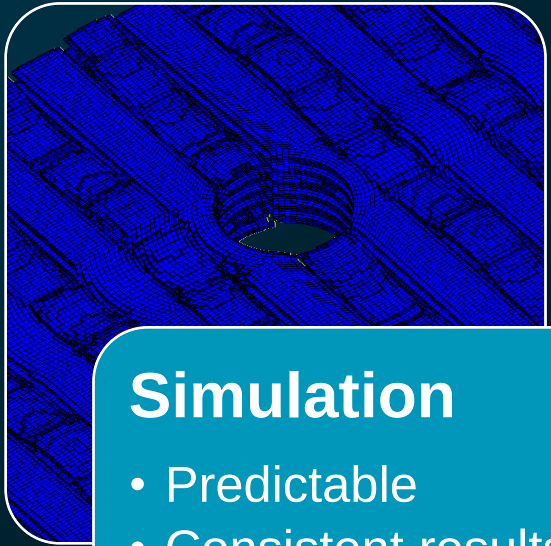
Introduction

Pain points – Overall



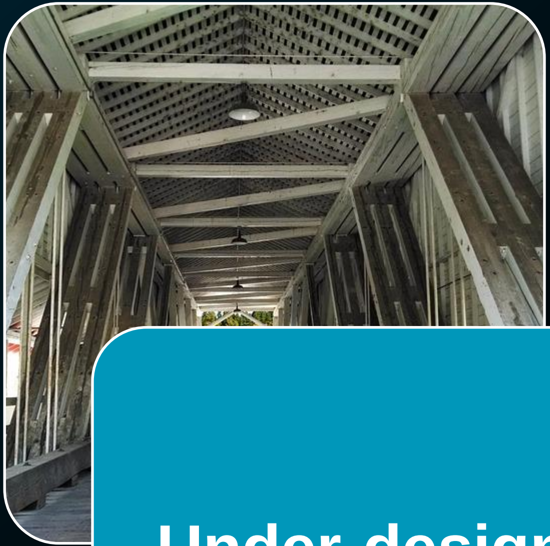
Reality

- Unpredictable
- Multiple sources of uncertainty
- Cannot always be accounted for



Simulation

- Predictable
- Consistent results based on inputs
- Sources of uncertainty neglected



Under-design

Over-design

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Probabilistic based design

Sources of uncertainties

Physical Uncertainty

- Issues from material processing & testing
- Unexpected defects in part

Numerical Uncertainty

- Averaging errors in structural analysis results
- Inaccurate process simulation results

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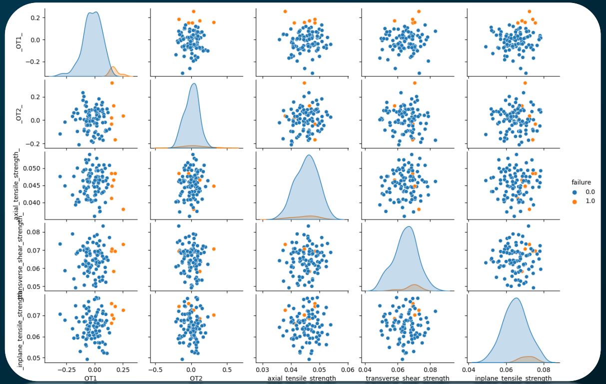
Introduction

Objectives

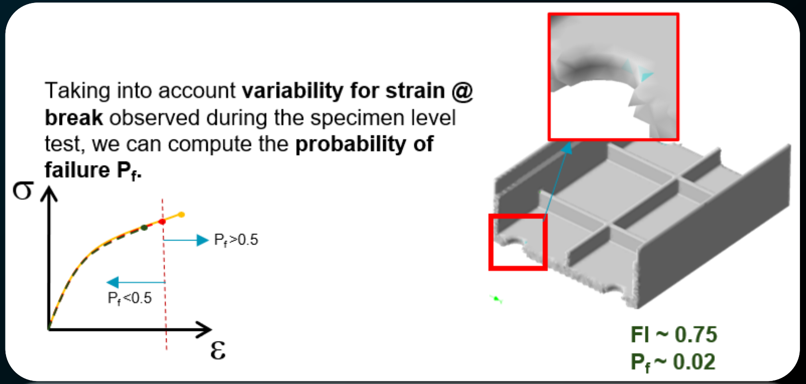
Reliable Design of Reinforced Plastics

Uncertainty Quantification	**Variability**



All sources from material card

Marc, Dassault Systèmes



Only material failure limit

Marc, Dassault Systèmes, Ansys

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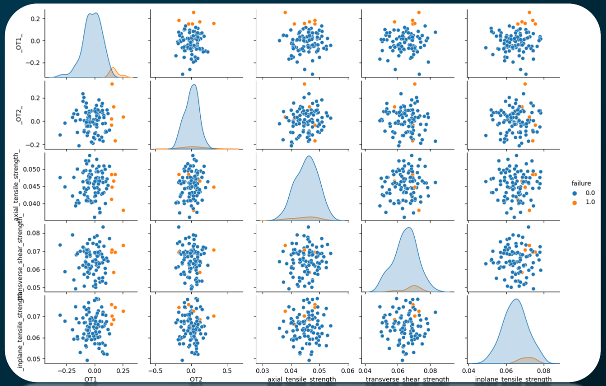
Introduction

Objectives

Reliable Design of Reinforced Plastics

Uncertainty Quantification

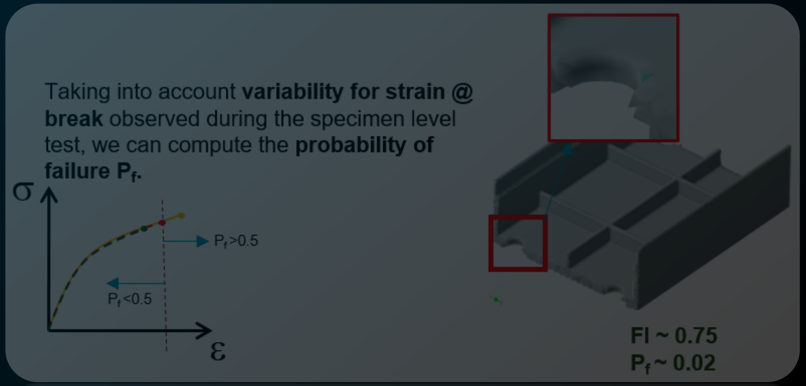
Variability



All sources from material card

Marc

Focus of presentation



Only material failure limit

Marc

Workflow

Methodology & solution

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Workflow

Methodology – Five main steps

1. Prepare input files
2. Define & execute Design of Experiments (DoE)
3. Train & evaluate Reduced Order Model (ROM)
4. Define & compute design limit
5. Perform Uncertainty Quantification (UQ) analysis

Digimat

ODYSSEE

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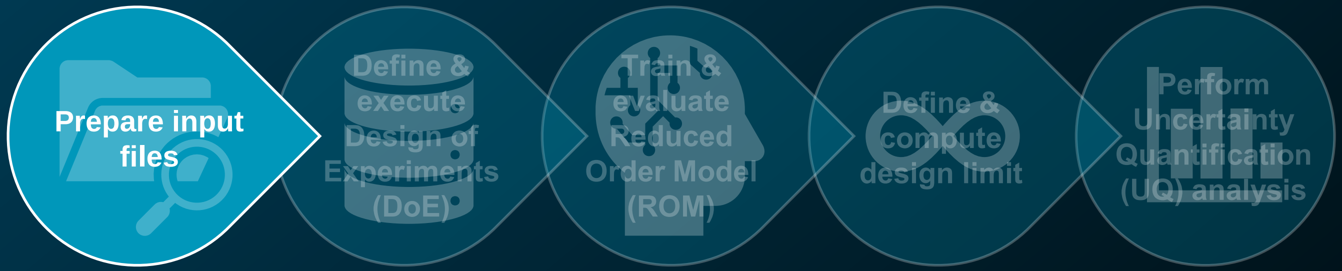
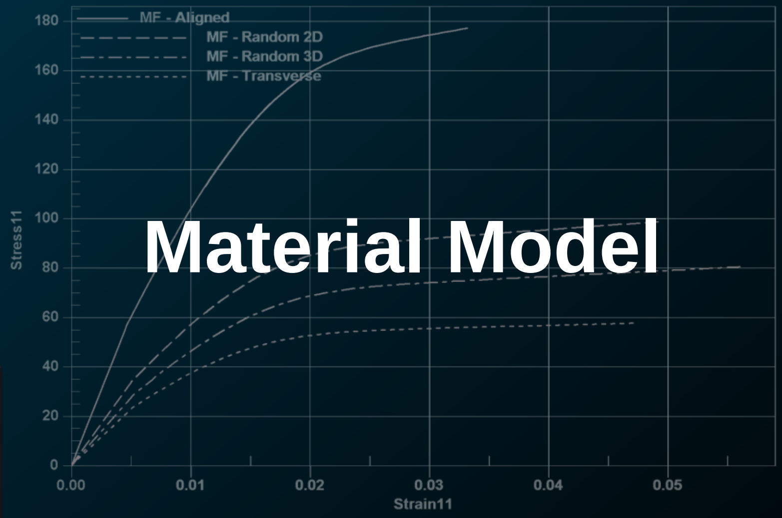
Workflow

Methodology



User inputs

FEA Model



Material Model

Orientation File

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Workflow

Methodology

Prepare input files

Define & execute Design of Experiments (DoE)

Train & evaluate Reduced Order Model (ROM)

Define & compute design limit

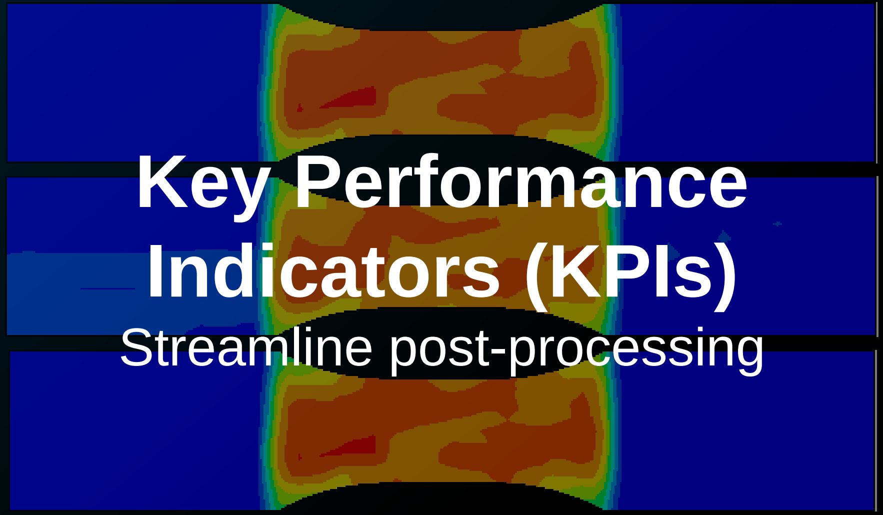
Perform Uncertainty Quantification (UQ) analysis

User inputs

Range of uncertainty

Uniform distribution

Number of simulations



Key Performance Indicators (KPIs)

Streamline post-processing

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Workflow

Methodology

User inputs

High-Fidelity DoE

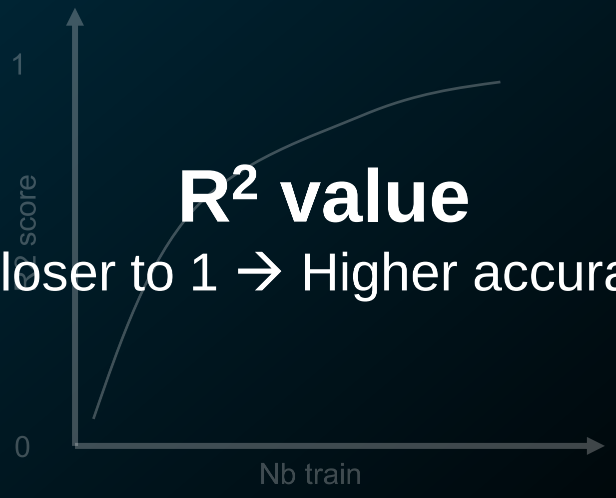
Number of simulations used for ROM training

Recommendation:
80% → Train
20% → Test

Train
Test

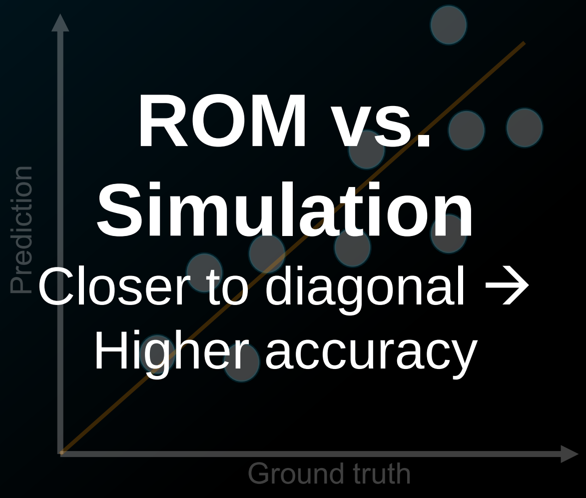
Performance Assessment

Based on KPIs identified



R^2 value

Closer to 1 → Higher accuracy



ROM vs. Simulation

Closer to diagonal → Higher accuracy

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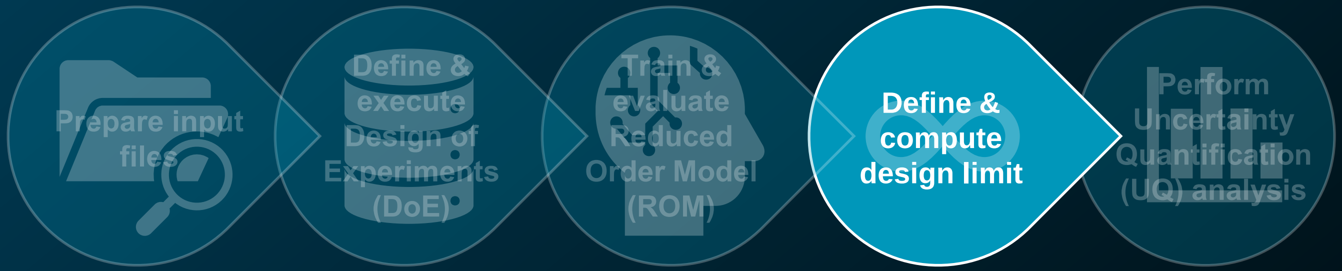
Workflow

Methodology



Design limit

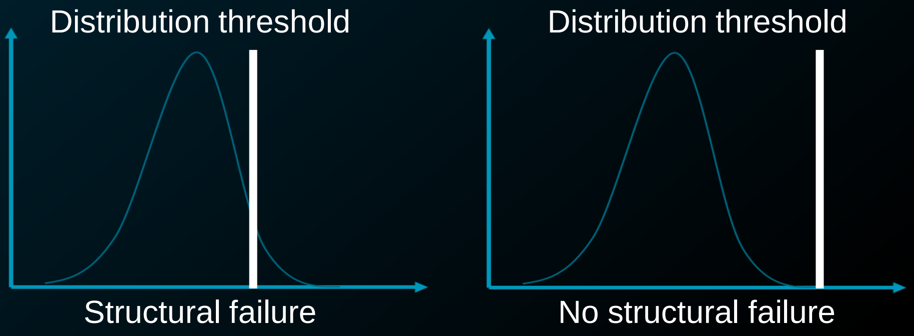
Criteria used to determine if design is robust or not

Example: Part failure

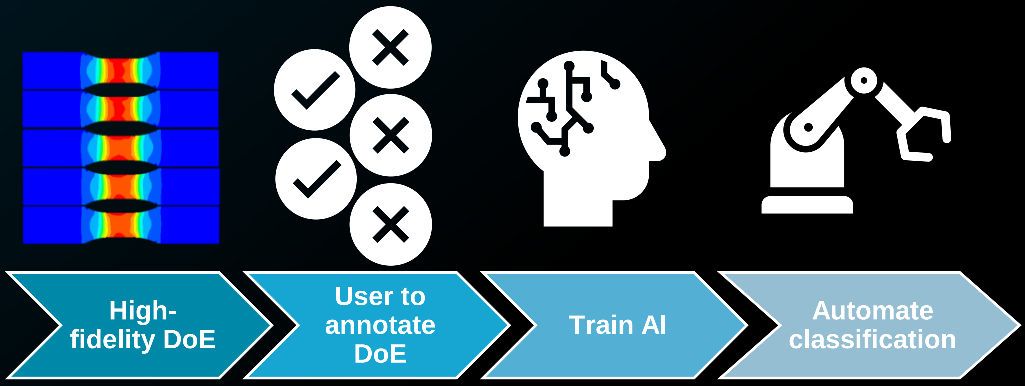
Failure limit determined by:

- Criteria at each integration point
- Evolution of force/displacement curve (Not yet available)

Distribution method
Part breaks if x% of distribution exceeds critical index



Artificial Intelligence method
Train model to learn to determine if part breaks



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Workflow

Methodology

Prepare input files

Define & execute Design of Experiments (DoE)

Train & evaluate Reduced Order Model (ROM)

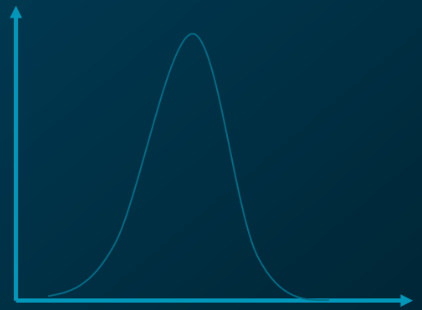
Define & compute design limit

Perform Uncertainty Quantification (UQ) analysis

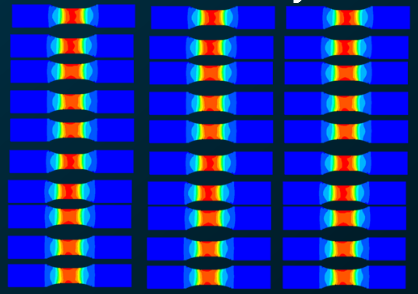
Uncertainty

Scatter expected on input of interest

Gaussian distribution of error



N random configuration generation based on uncertainty



n broken cases determined by design limit

Probability of failure: $P_f = \frac{n}{N}$

Reliability: $1 - P_f$

Define uncertainty → **Predict N cases with ROM** → **Predict n broken cases** → **Deduce reliability**

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Example 1

Specimen

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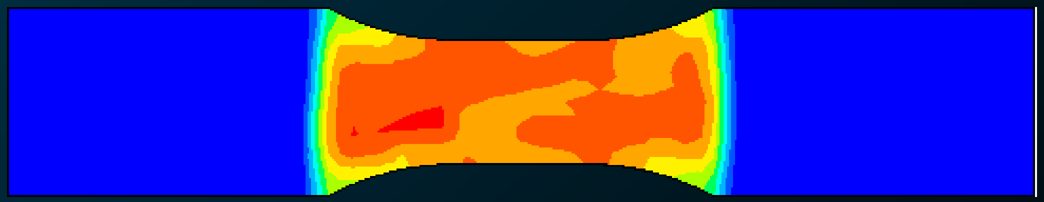
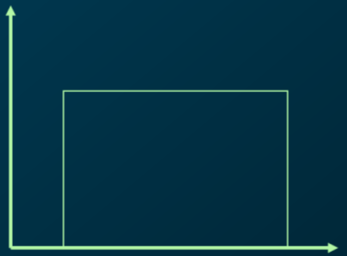
Results

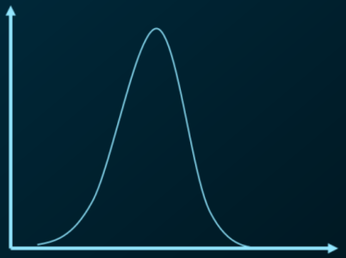
Design of Experiments (DoE) validation

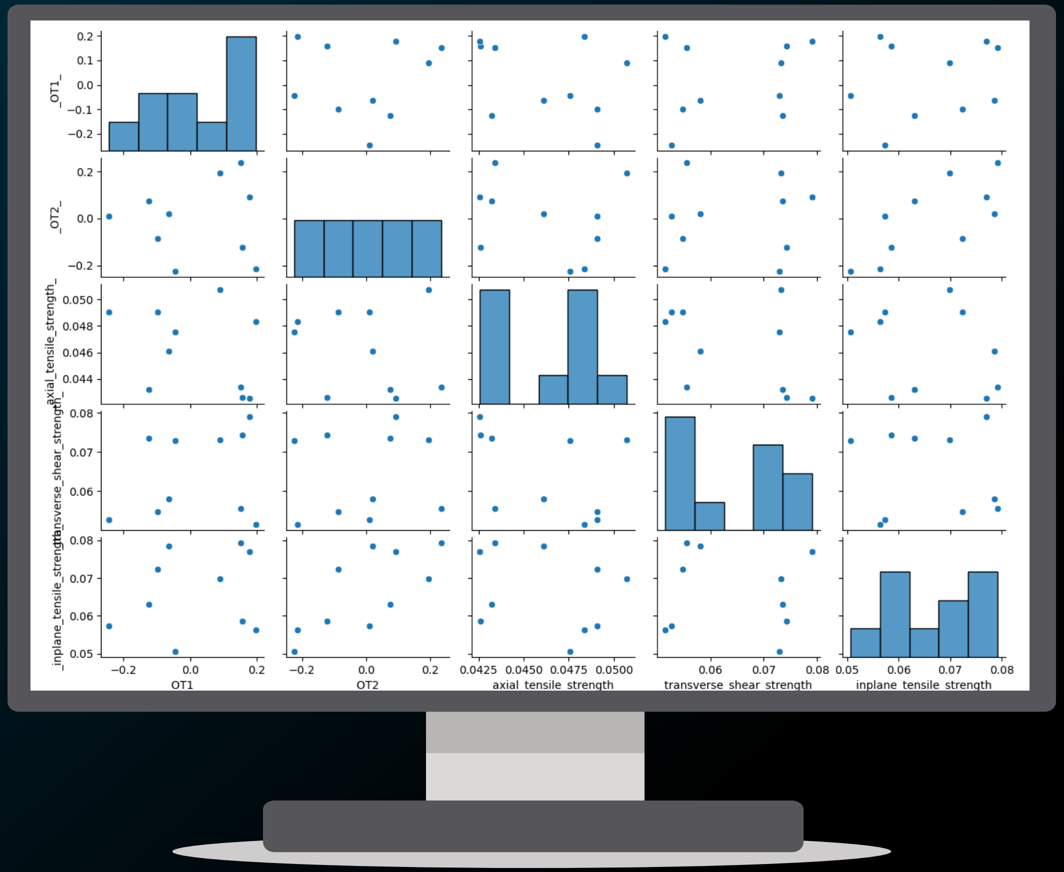


DoE variables → Uniform distribution



Reliability evaluation → Gaussian distribution



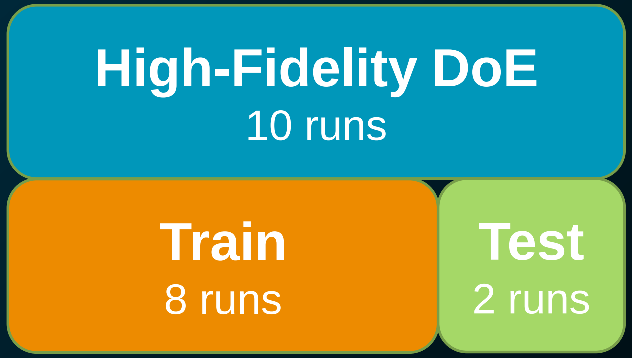


Two sources of uncertainty:

1. **Injection simulation results; i.e., orientation tensor**
   2 parameters
2. **Failure limits of material**
   3 parameters

Results

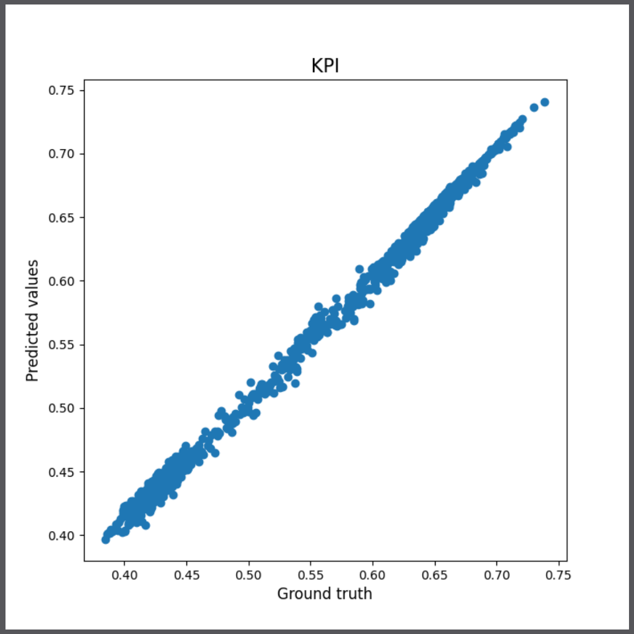
Validation of Reduced Order Model (ROM)



Failure indicator at each integration point compared

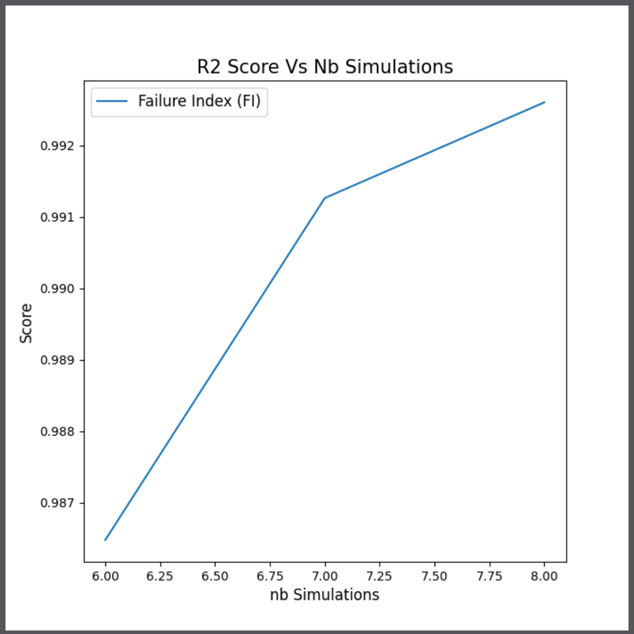
ROM vs. Simulation

Near perfect match between ROM & ground truth



R^2 value

Between 98.6-99.3% accuracy



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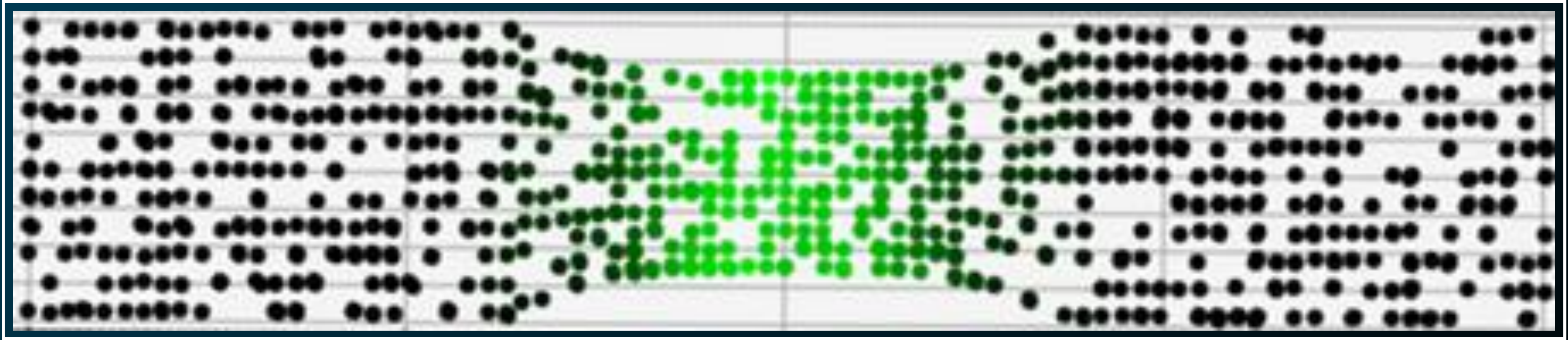
Results

What-if analysis



Predict & display full field of failure indicator using trained ROM

- Real time testing of different configurations
- Assess how model responds to various sources of uncertainty

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Results

UQ/Reliability analysis

Probability of failure: $P_f = \frac{n}{N}$

Reliability: $1 - P_f$

No failure   Failure

100 calls to trained Reduced Order Model (ROM)

- Failure : 6/100
- P_f : 6%
- Reliability : 94%

First component of orientation tensor

- Greatest impact on design reliability
- Failed runs show clear trend as function of OT1

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Example 2

EV battery enclosure

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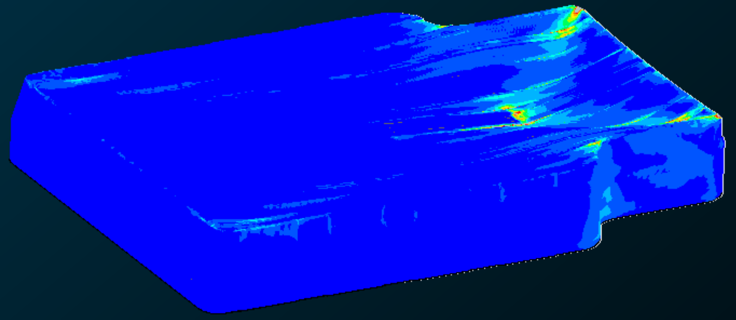
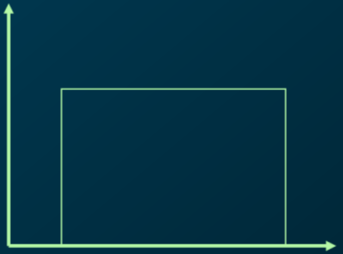
Results

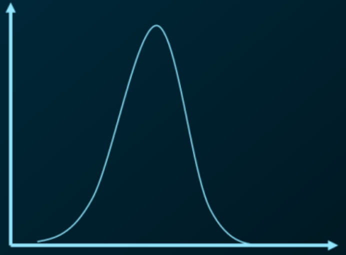
Design of Experiments (DoE) validation



DoE variables → Uniform distribution



Reliability evaluation → Gaussian distribution



Two sources of uncertainty:

1. **Injection simulation results; i.e., orientation tensor**
   2 parameters
2. **Failure limits of material**
   3 parameters

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Results

Validation of Reduced Order Model (ROM)

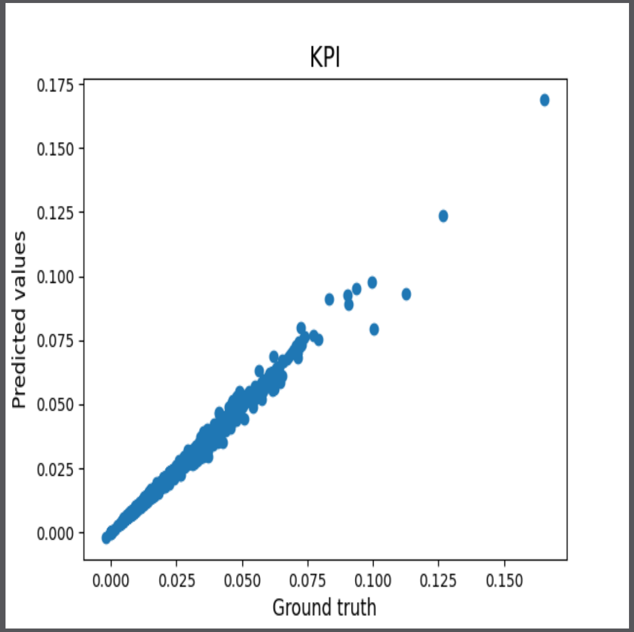
High-Fidelity DoE
10 runs

Train
8 runs

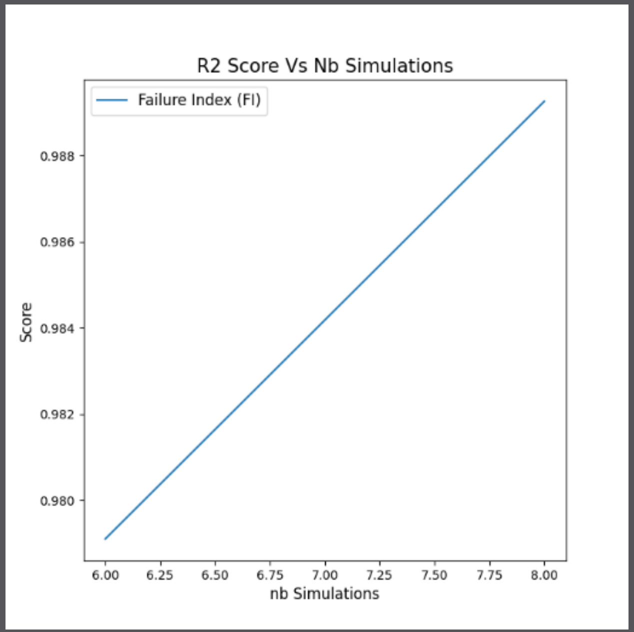
Test
2 runs

Failure indicator at each integration point compared

ROM vs. Simulation
Near perfect match between ROM & ground truth



R^2 value
Between 97.9-98.9% accuracy



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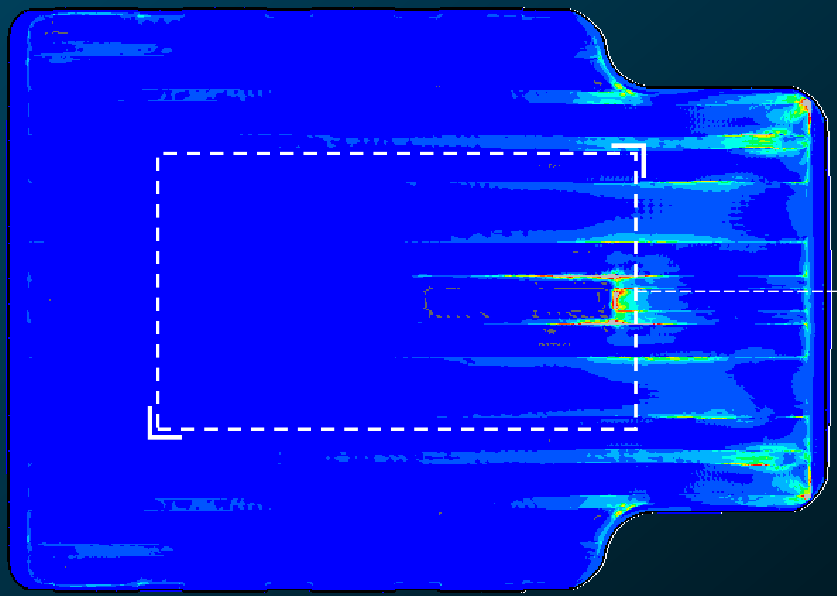
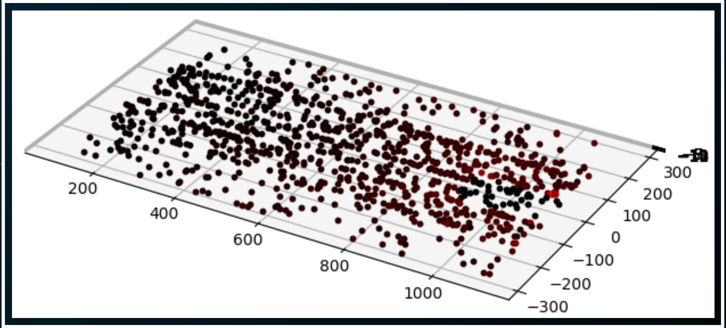
Results

What-if analysis





Predict & display full field of failure indicator using trained ROM

- Real time testing of different configurations
- Assess how model responds to various sources of uncertainty

Results

UQ/Reliability analysis

Probability of failure: $P_f = \frac{n}{N}$

Reliability: $1 - P_f$

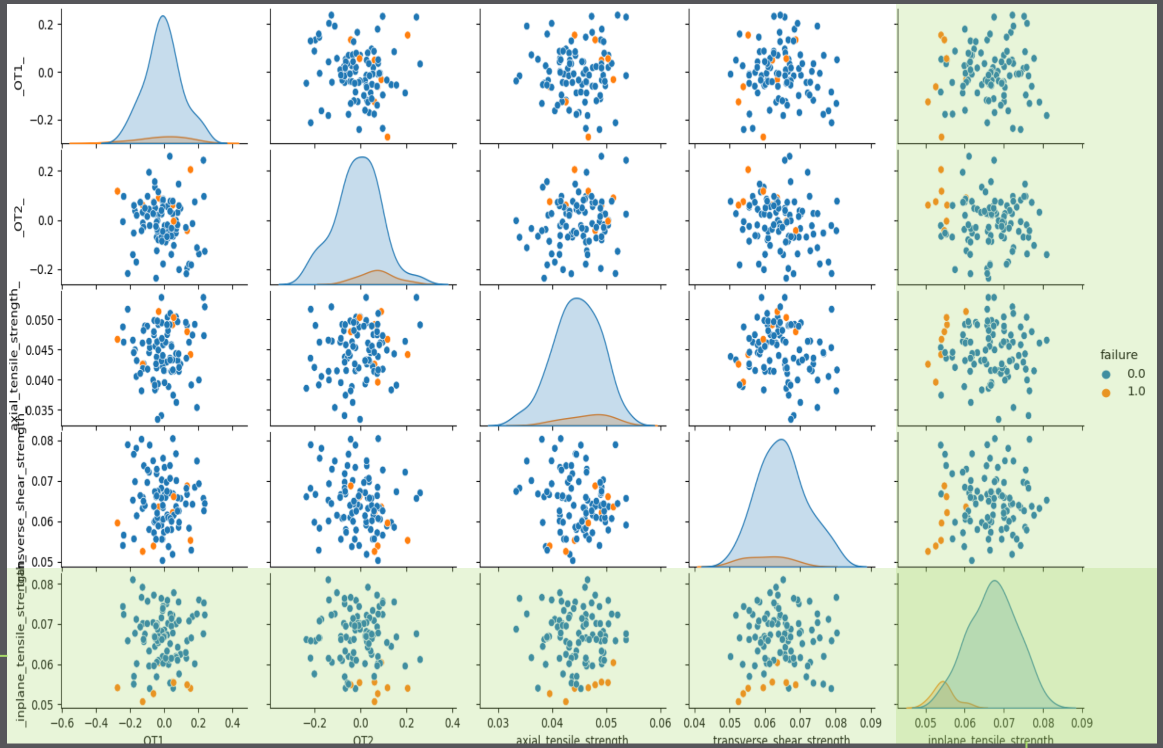
No failure Failure

100 calls to trained Reduced Order Model (ROM)

- Failure : 8/100
- P_f : 8%
- Reliability : 92%

In-plane tensile strength

- Greatest impact on design reliability
- Failed runs show clear trend as function of inplane_tensile_strength



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BOSCH

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UQ based design for reinforced plastics

Hexagon's products and services provide excellent support to our daily business with innovative simulation methods for holistic virtual engineering of plastic components. It's great to collaborate with such a professional and knowledgeable team. ***Jan-Martin Kaiser***

Challenge

- Numerous sources of uncertainty present in reality
- Simulation ignores uncertainty
- Uncertainty must be accounted for to obtain robust designs

Solution

- Simplified workflow, available through Digimat, that performs multiscale material modeling from manufacturing process to structural analysis
- Integration of Artificial Intelligence (AI) & Uncertainty Quantification (UQ) to account for material property uncertainties also available

Benefits

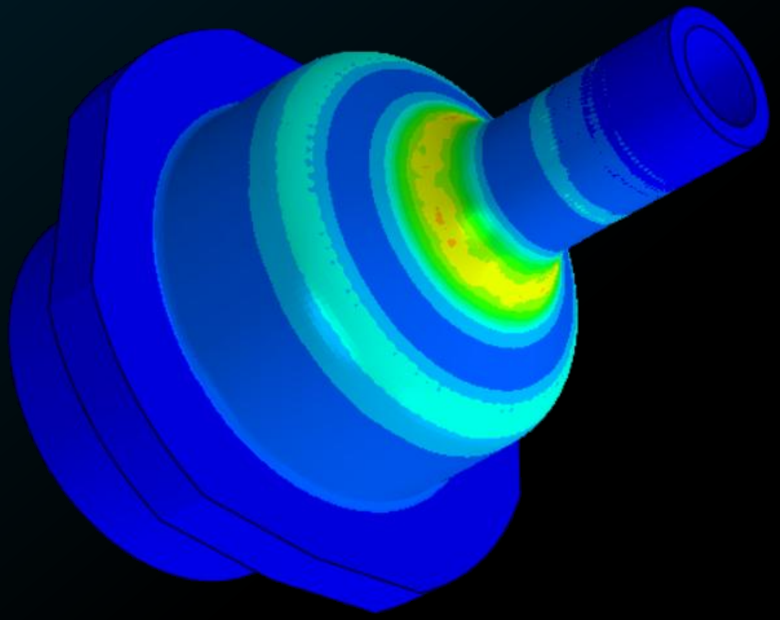
- Embedding of material science, AI & UQ, into automated workflow allows for efficient and accurate design qualification
- Reliability of studied structural analysis can be evaluated
- Enhancement of product quality

DASSAULT SYSTEMES

Marc

Digimat

ODYSSEE



Conclusion

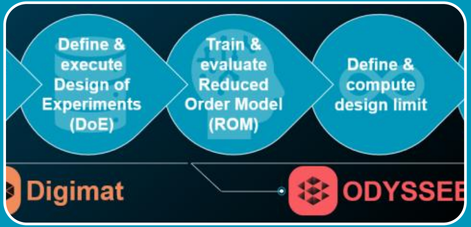
Perspectives & next steps

Conclusion

Perspectives

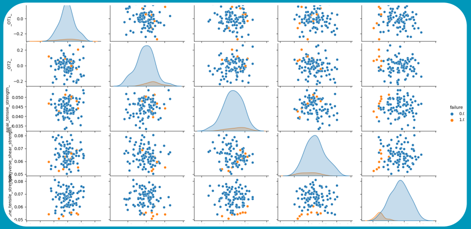
Uncertainty

- Present in physical world
- Conventional simulation ignores uncertainty
- Uncertainty Quantification (UQ) necessary to prevent over/under-design



Digimat & ODYSSEE

- Users can perform UQ based design studies
- Any input within material card or processing can be considered source of uncertainty
- Seamless integration of both solutions into existing workflow



Results

- Assess probability of failure based on 100s of tests through trained ROM
- Determine reliability of designed structural part
- Understand which parameters influence desired performance most greatly

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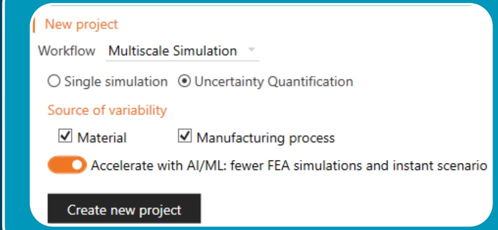
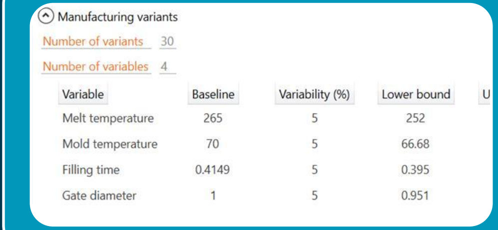
Conclusion

Next steps



Implementation

- Digimat 2025.1 includes seamless, user-friendly interface for UQ analyses
- Ability to select material or manufacturing process as source of variability
- Option to select AI/ML to accelerate studies



Assessment

- New and expanding plot library, like parallel coordinates, for reliability assessment
- Any predicted manufacturing process variability can be assessed:
    - Melt/mold temperature, filling time, pressure etc.

Expansion

- Gather customer feedback on existing capabilities & future needs
- Improve existing workflows to be more seamless & user-friendly
- Gating position optimization based on structural KPIs

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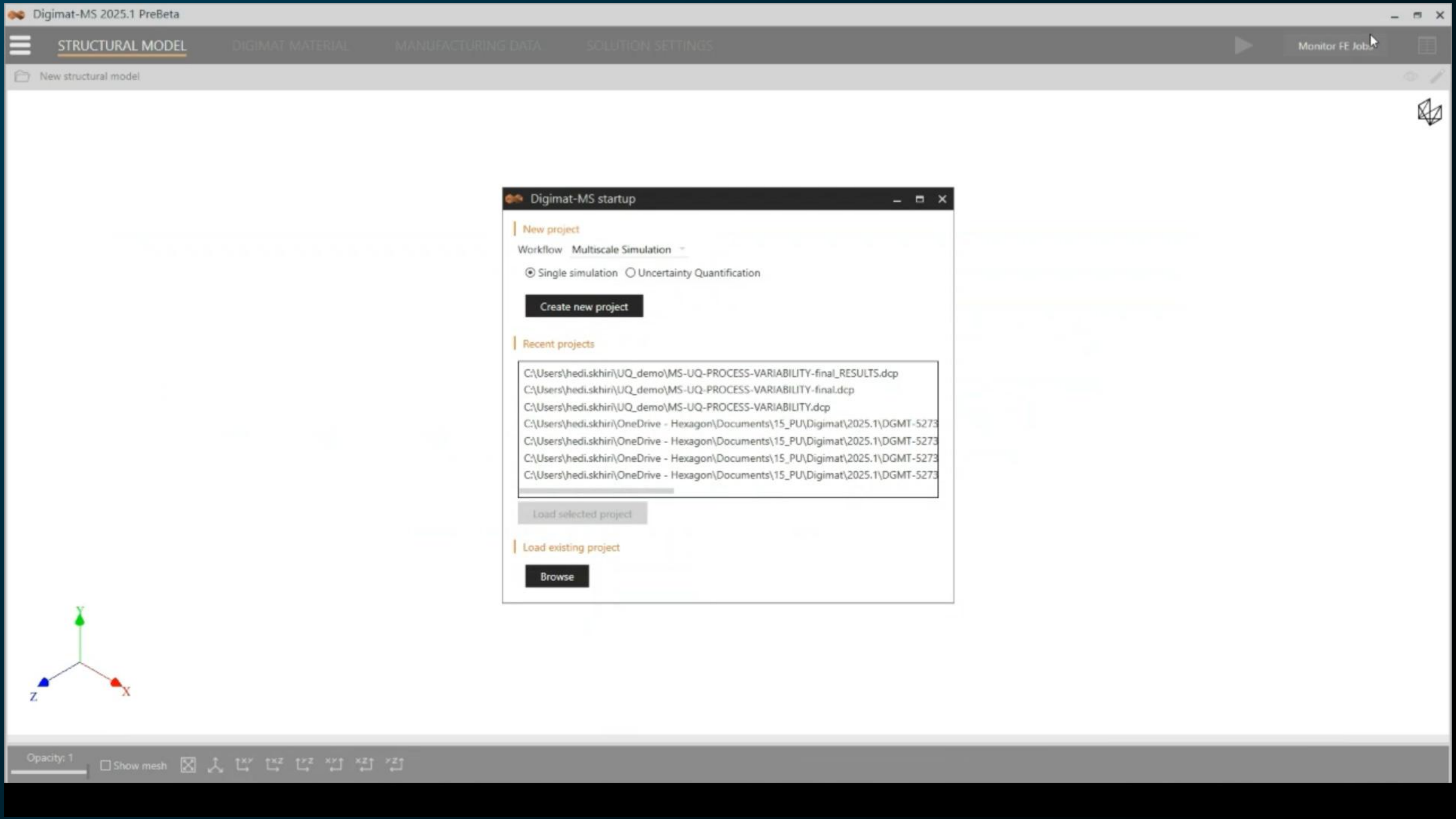
Conclusion

Next steps



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Thank You!

Questions?

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