Digital Design Validation Using Probabilistic Fatigue Analysis

Smart Prototype Symposium
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Overview and Outline

- Product validation in modern automotive framework
- Correlated FEA structural simulation
- Stochastic simulation
- Use Cases
- Conclusions

Product Development - Tier 1 perspective

What is Reliability

- The engineering discipline that safeguards your product's sales margin.

Front-End: avoid (or lower the cost of) warranty returns

Back-End: Streamlined & effective product design and validation

Product Development - Timeline

Structural Simulation + Validation Tests

Design | Design Validation | Product Validation | Production

Prototype (DV) | *Pre-serial (PV)*

TEMPORA
PRECISION IN MOTION

From project kick-off to vehicle-to-market : **15 months**

Final vehicle prototyping: 12 months

Valeo
Driving Change Together

Product Design Validation Phase: 6 months

Design → Validation → Pre-serial

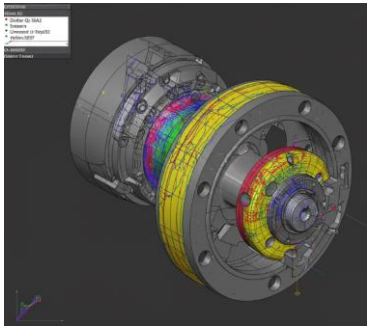
Zero Prototype
Skip DV phase (test)
Rely only on FEA simulation
...
Correlation?

Smart Prototype
⇒ Right 1st time
⇒ Empowered by correlated FEA simulations
...with correlation activities

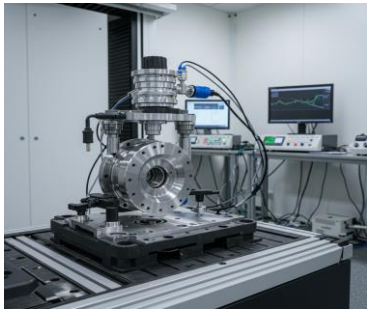
Why Stochastic Simulation in Fatigue

What is a correlated Simulation?

FEA Simulation



Physical tests?



Three principles for effective and generalizable correlated simulations

Statistics-based correlation

Relating Reliability criteria

Performed on real components

Statistical Analysis and Correlation

Weibull, W., 1939. *The Statistical Theory of the Strength of Materials*

$$p(x) = \frac{\beta}{\eta}\left(\frac{x-\gamma}{\eta}\right)^{\beta-1} * e^{-\frac{(x-\gamma)^{\beta}}{\eta}}$$

Probability density function ☑

Failure rate ☑

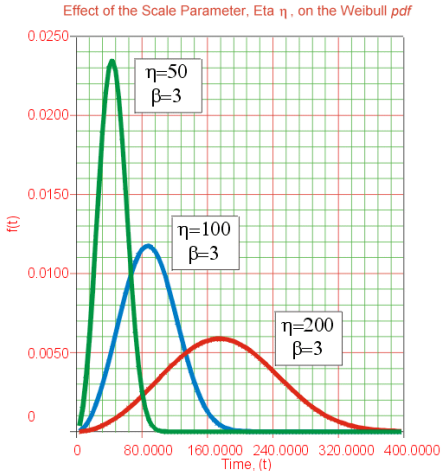
Reliability function R(t) ☑

x : time to failure

ß : shape parameter ☑

η : scale parameter

γ = 0 (Weibull 2-parameter)



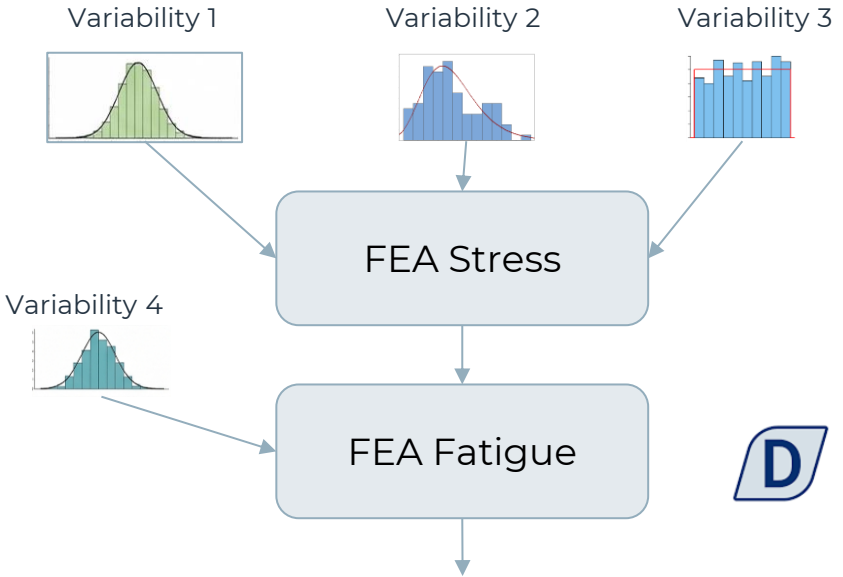
FEA Stochastic Fatigue

Probabilistic Approach

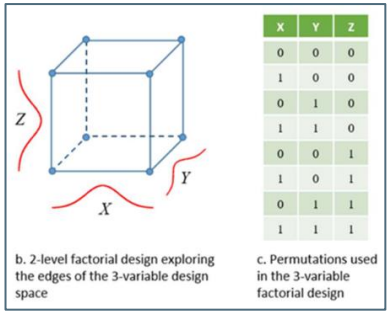
Variability of the FEA model

1) Selection of the parameters
   a) Failure fatigue mechanism

1) Quantification of the scatter
   a) Based on **experimental data**
   b) Defined by a representative statistical distribution
      i) Normal
      ii) Lognormal
      iii) Uniform
      iv) etc.



Simulation Sampling



b. 2-level factorial design exploring the edges of the 3-variable design space

X	Y	Z
0	0	0
1	0	0
0	1	0
1	1	0
0	0	1
1	0	1
0	1	1
1	1	1

c. Permutations used in the 3-variable factorial design

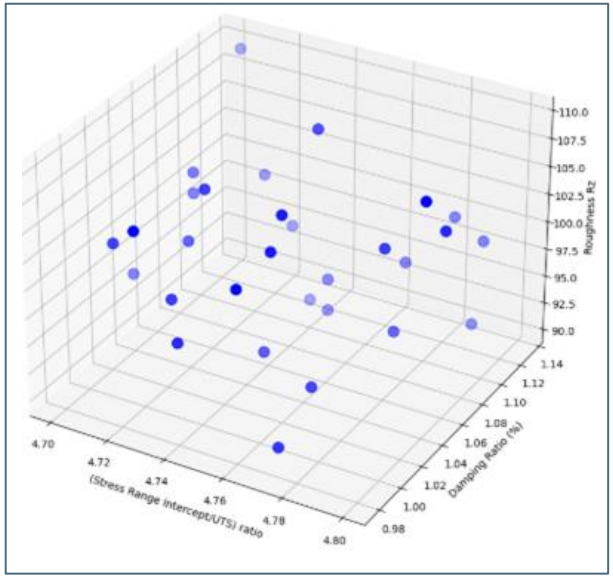
Halfpenny at al., *Probabilistic Fatigue and Reliability Simulations*, Procedia Structural Integrity, Volume 19, 2019, Pages 150-167

Example: Latin Hypercube Sampling

a) 3 simulation parameters

a) 30 runs

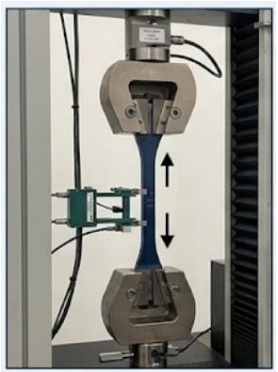
- Geometry: uniform
- Material: normal
- Load: uniform

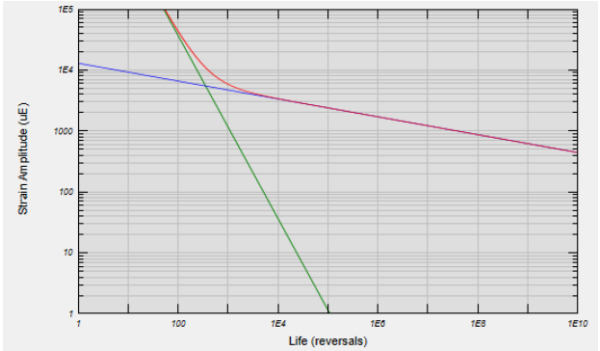


Main Limitations

The Material Cards

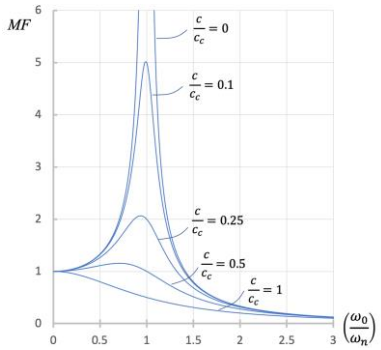
a) Fatigue life curve
b) On real components (material, loads, failure mode)

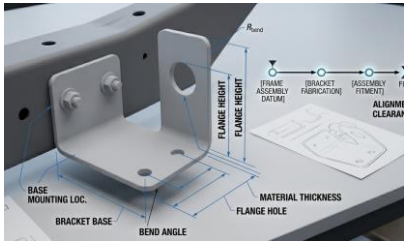




The input parameters for Uncertainty Qualifications

a) How many factors
b) What is their statistical distribution
   i) Eg vibration: the damping, the geometries etc.





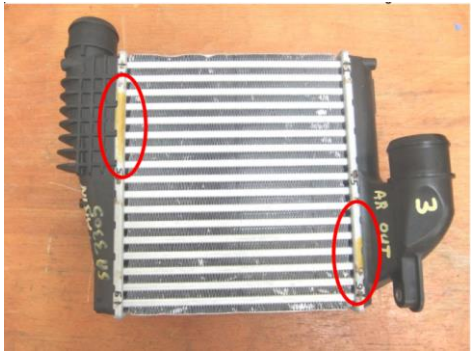
Correlation of the results

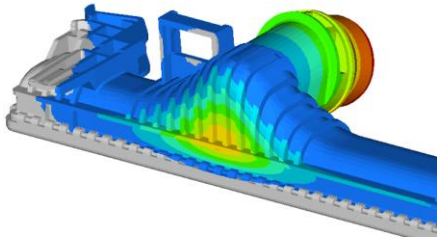
a) Statistically significant samples tested to failure
b) Time-to-failure detection
   i) Test monitoring strategy
c) Censored data

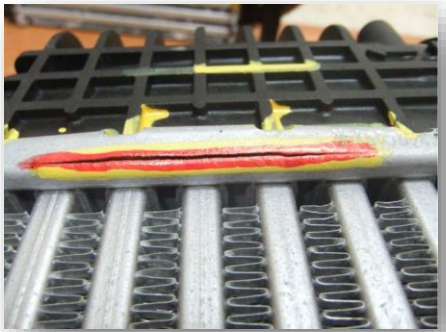
Heat Exchanger (Intercooler)

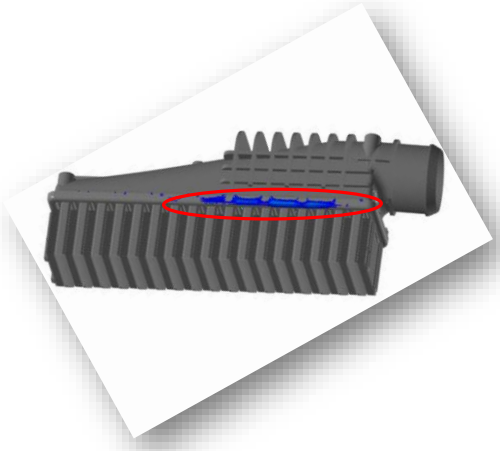
Pressure Cycling fatigue

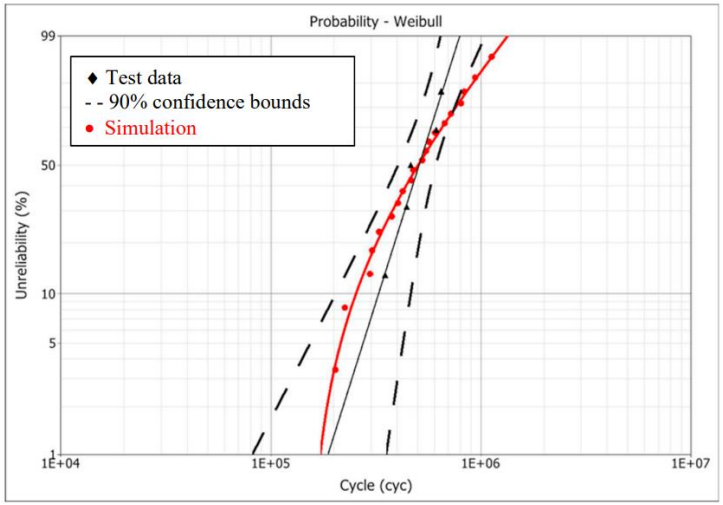
UQ: FEA loads + Material variability

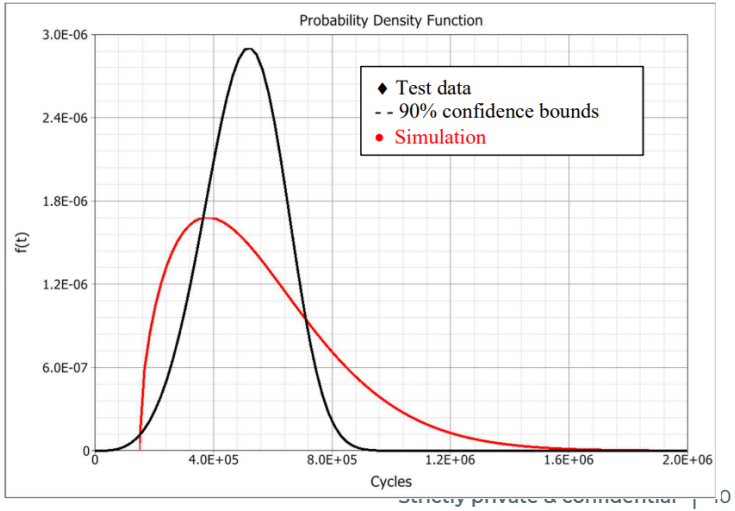






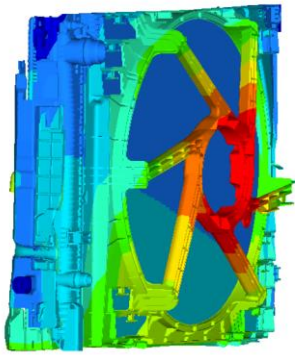


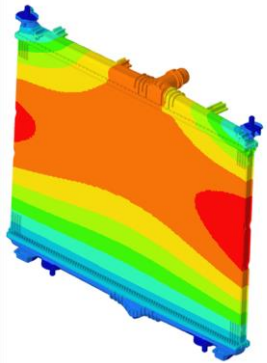


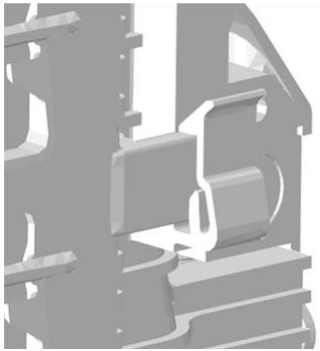


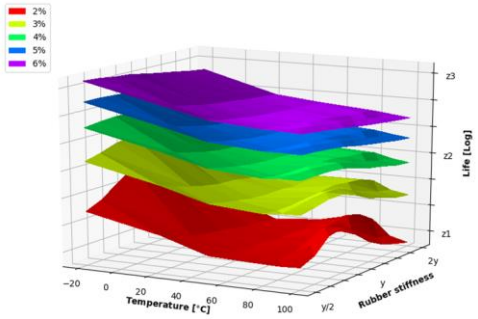
Engine Cooling Module

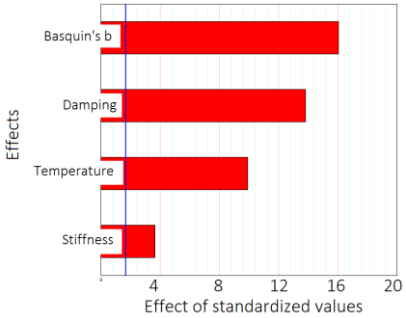
Structural Component - vibration tests.
The FEA validates the “high level of assembly” of the **engine cooling radiator** (the module carrier)











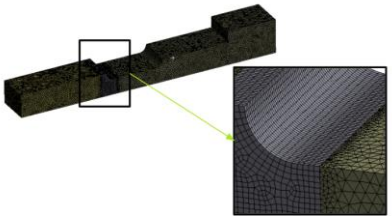
ECM - anisotropic parts, decoupling, clips

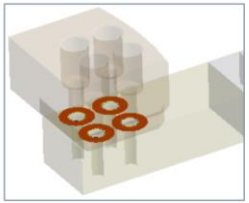
No suitable for Stochastic FEA with Correlation

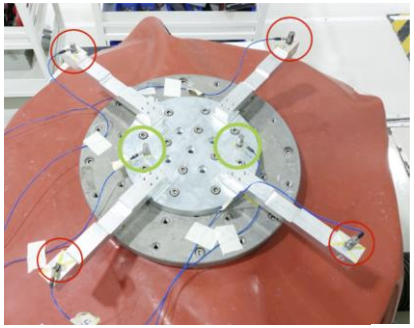
Better idea: factorial analysis (30 000 MC runs)

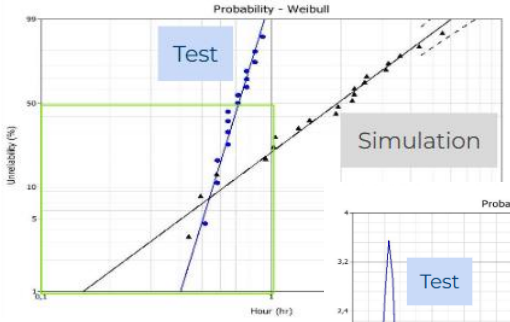
Automotive bracket mock-up

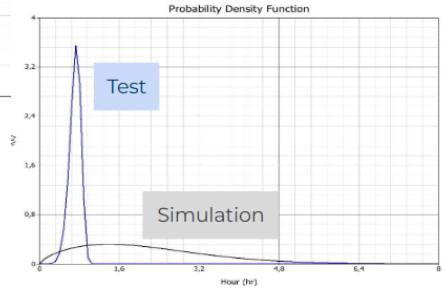
Simple geometry - vibration fatigue.



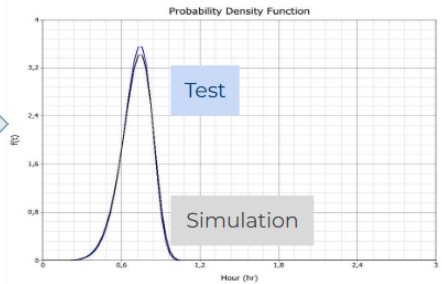


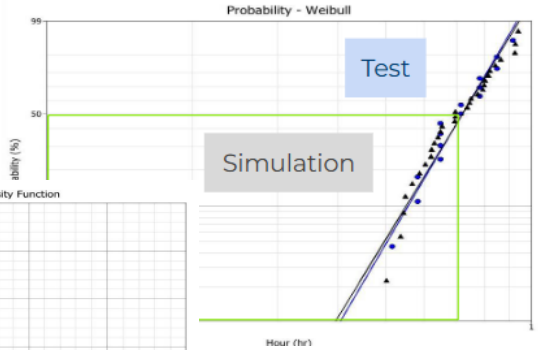






UQ: Damping variability
& Material variability





Generic input,
Generic data

Bad correlation

Tailored input,
Experimental data

Excellent Correlation

Next Steps

1) Use case on real component (an eAxle) under <u>vibration loads</u>

Automatized **Parametric Analysis** of the input factors

Uncertainty Qualifications: Experimental measurements

Correlation based on stochastic FEA *vs* test to failure

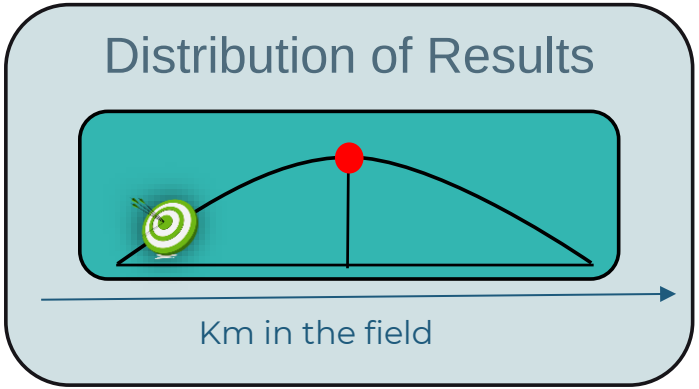
2) Deployment of the methodology

FEA fatigue “transfer function”

- Library of fatigue life scatter
- Update FEA criteria with reliability targets

New material suppliers

- Method for material card generation
  - Component level
  - Die-caster parts



Conclusions

Reliable Predictions

Statistics-based correlation is essential – **empowered simulations**

Data Accuracy

Experimental data drives accuracy – **Improved correlation**

Systematic Approach

Deployment requires systematic approach – **Transversalizacion of the method**

Smart Prototyping

Stochastic FEA enables Smart Prototyping – **Right First time**

Valeo

Driving Change Together

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