CAE Pipeline for Fatigue of Fiber Based Components

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Fachkongress Composite Simulation 2014

AGENDA

1. Introduction – Autoneum
2. Problem Definition
3. CAE workflow for underbody design
    1. Material model
    2. Load description
    3. Finite Elements Analysis and Stress evaluation
4. Fatigue Pipeline

Introduction – Who is Autoneum?

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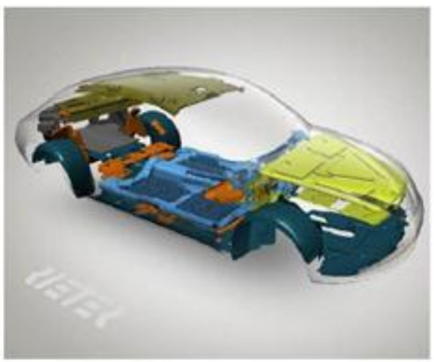


Leading partner for the major light vehicle and heavy truck manufacturers around the world. Unique combination of core competences:

→ Leading acoustics and thermal management

→ Global presence with a broad customer portfolio

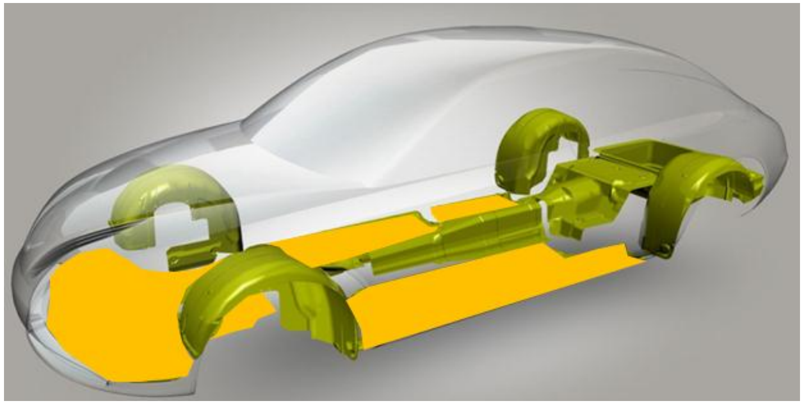
Innovative and cost effective solutions for noise reduction and thermal management to increase vehicle comfort value

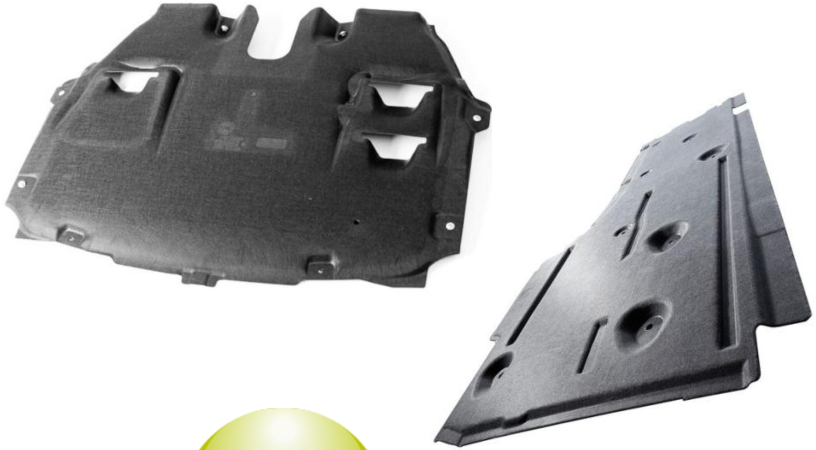
Focus on underbody as exterior acoustic and structural parts; fiber consolidated parts (glass fiber free).

Engine Bay	Interior Floor	Underbody	Body Treatment	Other Products
• Engine Covers • Hoodliners • Outer Dashes • Water Box Shields	• Inner Dashes • Carpets • Tufted Carpets • Floor Insulators • Floor Mats • Crash Pads	• Underbody Shields • Floor Pans • Heatshields • Wheelhouse Outer Liners	• Dampers/ Stiffeners • Sealants • Other Acoustic Parts	• Trunk Side Trims • Trunk Flooring • Other Trunk Trim Parts • Parcel Shelves
				

Our Products & Technologies

Underbody shield - aerodynamic screens





Functions of under body shields:

- Aerodynamic improvement
- Interior and exterior noise reduction
- Protection of BIW

Technologies for under body shields:

- **RUS™ = Unique textile product**
- DLFT = Direct Long Fiber Thermoplastic
- IM = Injection Molding
- GMT = Glass Matt Thermoplastic

Problem Definition

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We know that under engine shields could break around the fixation points because of vibrations.

Target

Understanding of the failure modes of these textile components

Developing a durability test method for fiber based materials (characterization)

Establishing a simulation Workflow for vibration fatigue calculation of underbody parts

Highlight the benefits in terms of durability of a porous glass-free material

Benchmarking Activity

Brand	Supplier	Mileage	Year	Rupture
X1	Y1	117'800 km	2008	No
X1	Y1	84'200 km	2007	Yes
X2	Y2	112'000 km	2008	No
X2	Y2	96'944 km	2008	Yes
X3	Y3	77'957 km	2009	Yes

Example of OEM specification:
*Vibration resistance test: Vertical and laterals acceleration at 30Hz (close to the 1st resonant frequency), 3g acceleration for 5*10^6 cycles.*

Overview of Structural Analysis

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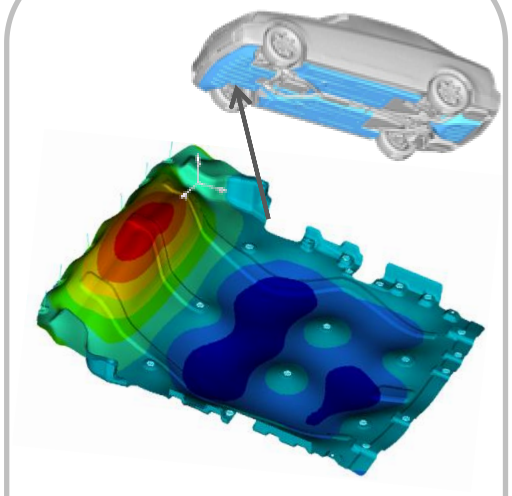
Tools (FE)

- MSC Nastran
- Altair Optistruc
- HBM nCode

Simulation Software

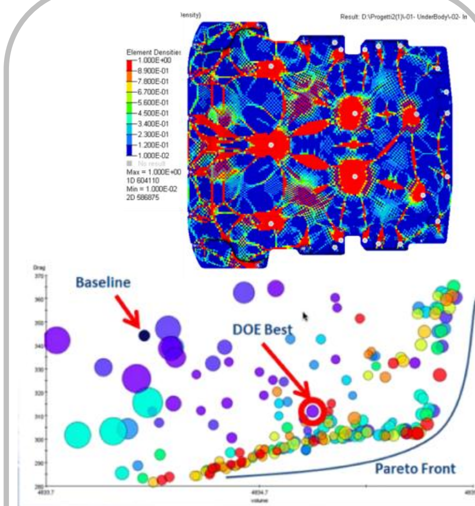
Underbody Application

MSC Software Simulate More



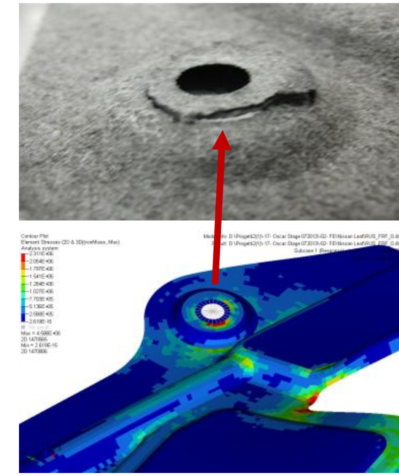
- Part deformation
- Dynamic response
- Strain-Stress level

Altair HyperWorks



Objectives :
- Increase stiffness
- Reduce thickness
- Design by Shape/Ribs/Beads
- Increase durability

nCode ...an HBM brand



- Prediction of crack nucleation areas
- Part Life expectation under a static or dynamic load (vibration)

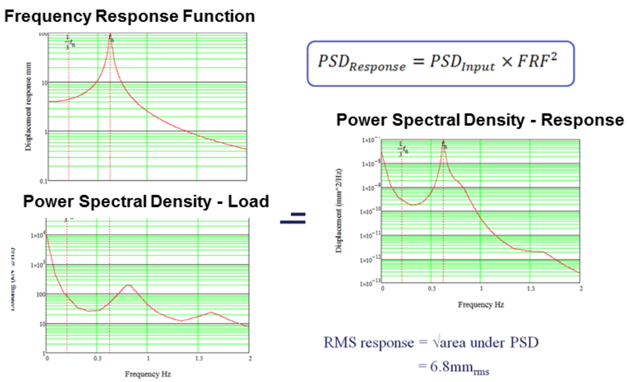
Structural behavior

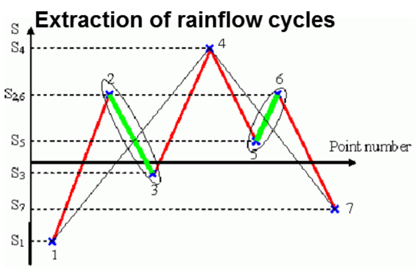
Design Optimization

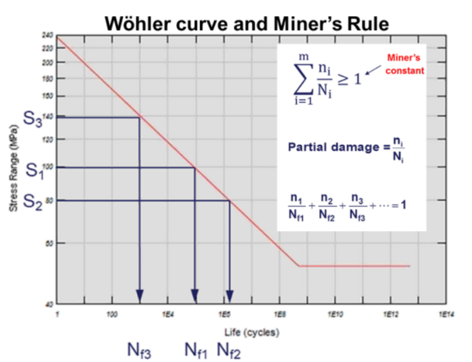
Durability

CAE workflow for underbody design

- nCode Fatigue Simulation -







nCode Simulation Process for vibration fatigue – Life duration

- Determination of the Absolute Maximum Principal stresses composed of the Real and Imaginary eigenvalues from the FRF X*ij*(f) with the largest magnitude.

- For PSD loadings, a local response PSD is calculated as an intermediate step: $G_{AMP}(f) = P(f) * |X_{AMP}(f)|^2$

- Statistical methods used to predict the probability density function (PDF) of stress range, and hence the rainflow count. Using the Lalanne theory, the probability density function N(S) of stress range S is given by:

  $N(S) = G[f] * p(S)$

  $$p(S) = \frac{1}{rms}\left\{\frac{\sqrt{1-\gamma^2}}{\sqrt{2\pi}} e^{\frac{-S^2}{2rms^2(1-\gamma^2)}} + \frac{S\cdot\gamma}{2rms} e^{\frac{-S^2}{2rms^2}}\left[1+erf\left(\frac{S\cdot\gamma}{rms\sqrt{2(1-\gamma^2)}}\right)\right]\right\}$$

- Damage and life calculation based on the Wöhler curve and the Miner's Rule

  $$\sum_{i=1}^{m} \frac{n_i}{N_i} \geq 1$$

  Miner's constant

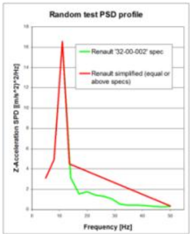
CAE workflow for underbody design

- Fatigue Simulation -

Simulation used with the aim of calculating the right stress distribution according to the material properties, for an accurate *life* prediction.

Loading history

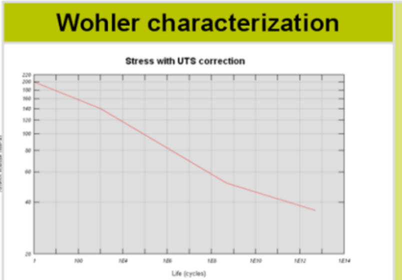
Customer specification
Autoneum Measured Load



Geometry and stress levels
FE calculation

MSC Software Simulate More — Altair HyperWorks

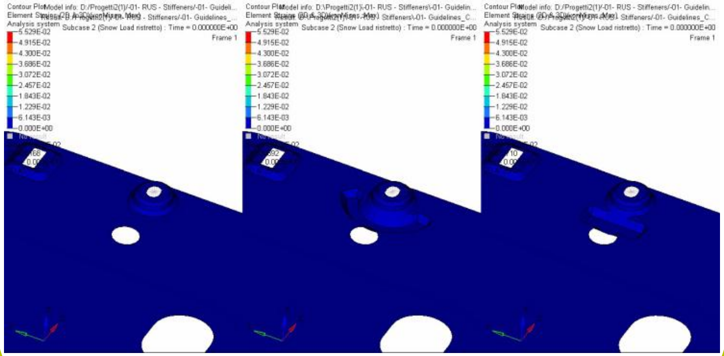
Autoneum Material Database



Cycle by Cycle fatigue analysis

nCode ...an HBM brand

Failure Areas
Life expectation



CAE workflow for underbody design

- Fatigue Simulation -

Loading history

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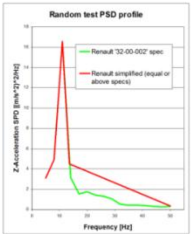
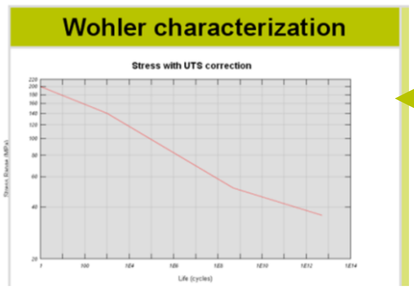


Geometry and stress levels
FE calculation

Autoneum Material Database



Simulation used with the aim of calculating the right stress distribution according to the material properties, for an accurate *life* prediction.

- Relevant load level and profile to apply
- Correct stress distribution and values according to the excitation levels
- Material characterization, addressing the right failure mode relevant for the simulations

CAE workflow for underbody design

- Material Main Characteristics -

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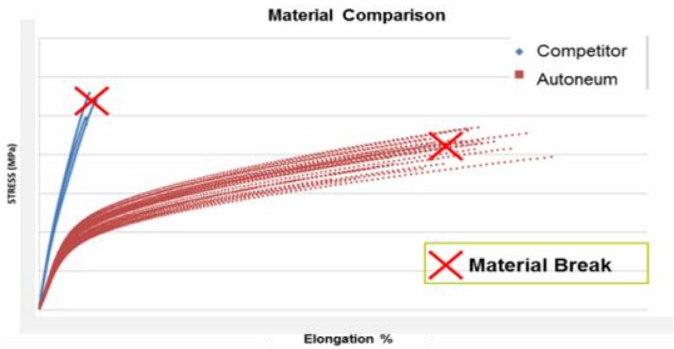
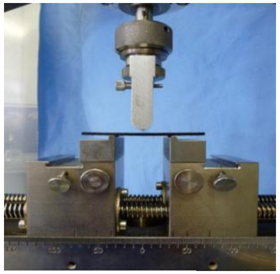
RUS Autoneum material: Lightweight fiber technology

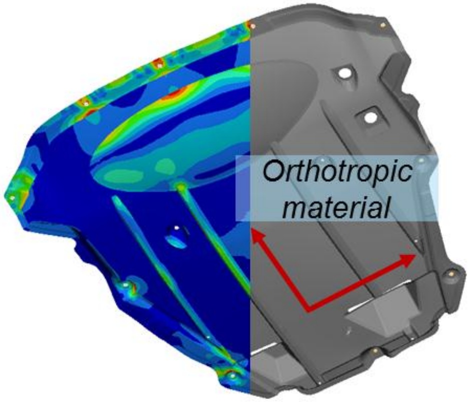
- 100% glass free PET
- 1.5 dB average **Sound Pressure Level (SPL)** improvement of exterior noise compared to plastic solutions
- 45% **lower weight** for a full underbody coverage
- **Higher elongation** before break than other materials



- Porous Material
- **Orthotropic behavior** (2 main fibers' directions)
- Textile material – multi-plies
- Variable density (changing the compression rate)
- Different membrane and bending behavior

	PID	MID1	[T]	MID2	[I12_T3]	MID3
PSHELL	1	1	3.000	2		1

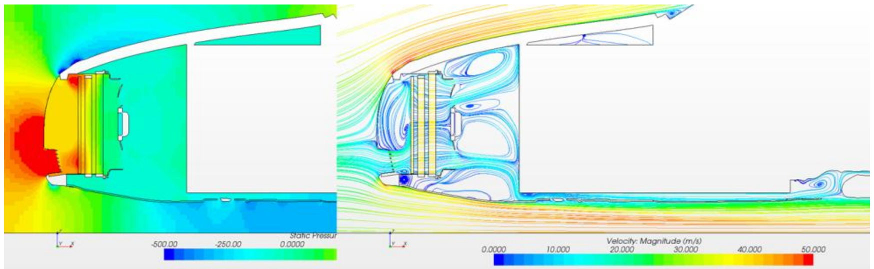




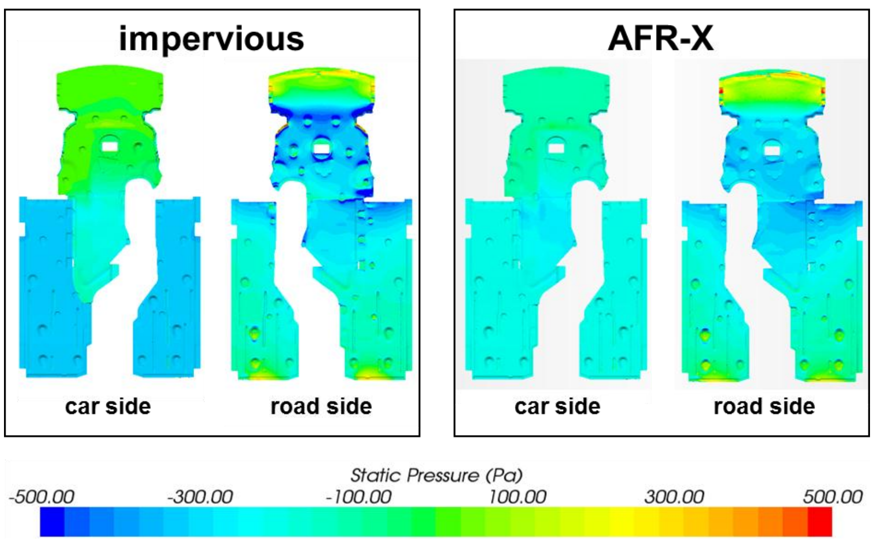
CAE workflow for underbody design

- Porosity effects on structural behavior -

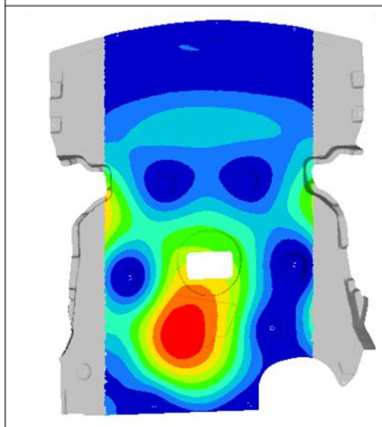
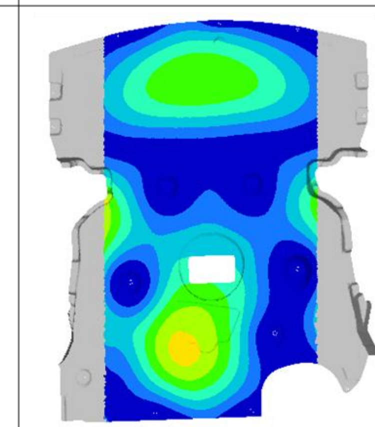
Vehicle aerodynamic model (x km/h)
Aerodynamic model validated through wind tunnel test.

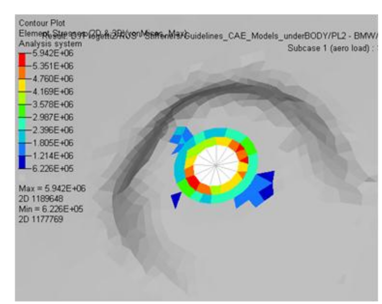


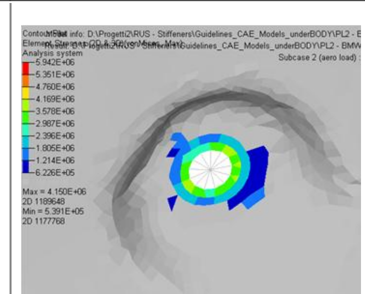
Pressure Distribution



3D part deflection prediction and stress at fixation points

Impervious LWRT part	Porous LWRT part
	
	-27% deformation at peak





CAE workflow for underbody design

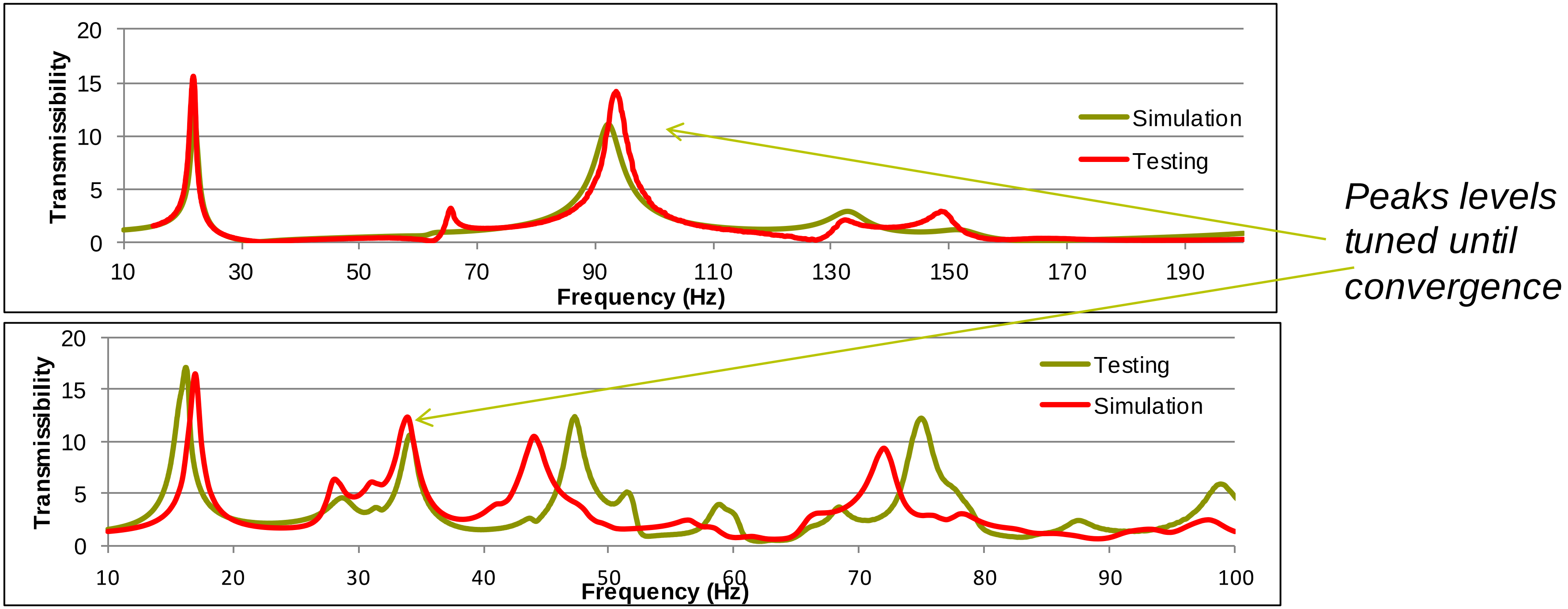
- Simulation Correlation -

Laser measurements: ~30 measurement points

Material validation at low-medium frequencies

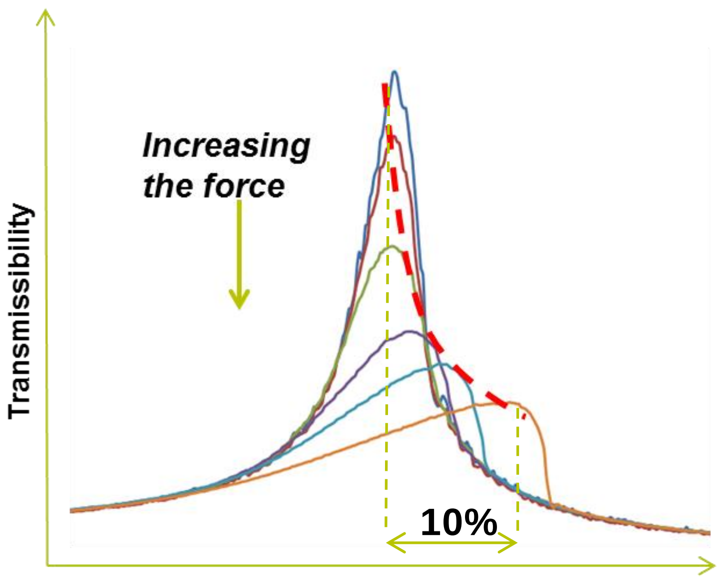
→ Good match of the resonances and dynamic behavior between tests and simulation

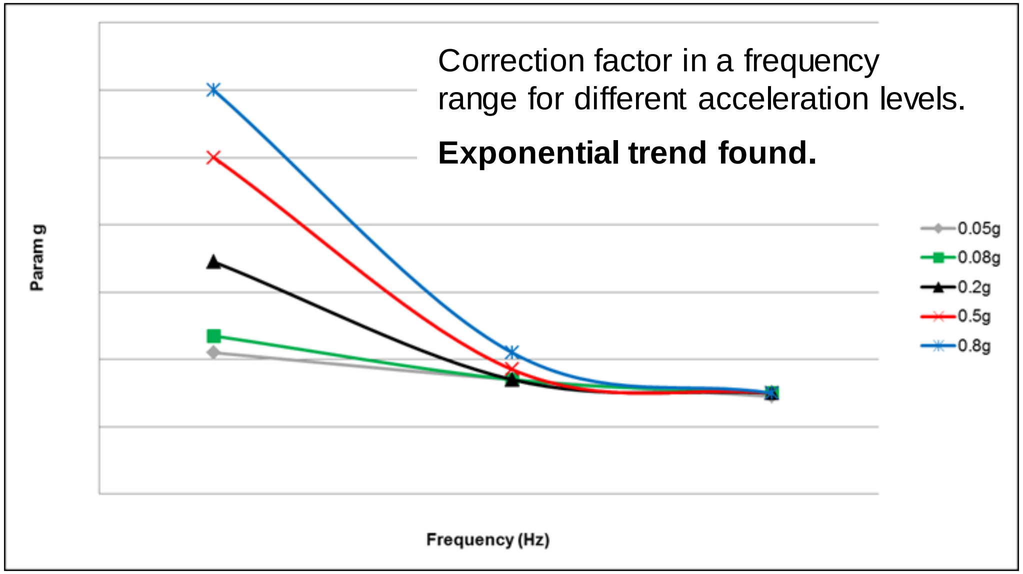
→ “Damping values” extrapolated from the measurements, and tuned until convergence of the acceleration peaks, for different acceleration levels (from 0.01g to 3.5g)



CAE workflow for underbody design

- Simulation Correlation -





FRF for the same parts 20 < f < 250 Hz.

→ Increasing the acceleration the transmissibility decrease.

→ Partially driven by the damping ratio factor at different strain rates

→ Non linear effect at higher excitation levels (system stiffens with increasing excitation)

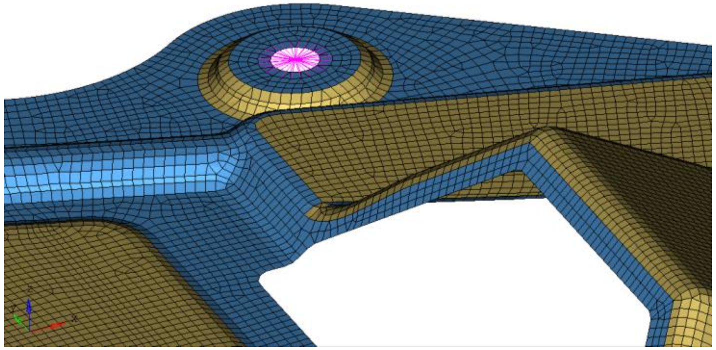
Comparison made for different part geometries and densities.

This estimation is essential, in order to have the right stress values at the critical areas of the part.

CAE workflow for underbody design

- Stress Simulation -

FE model

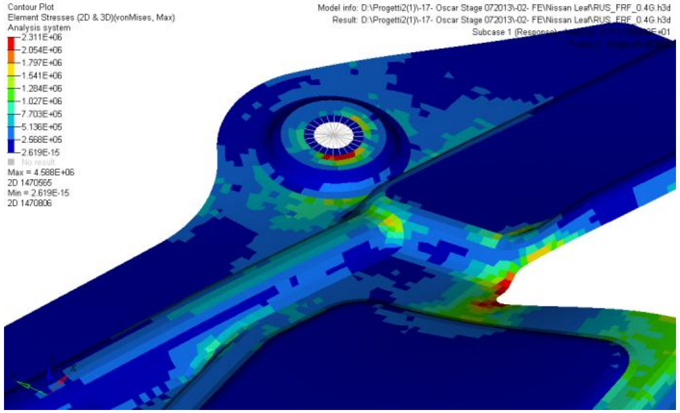


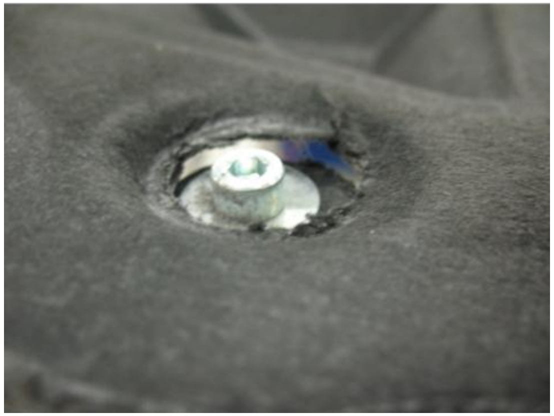
Boundary conditions represented as a rigid clamped connection on the washer area, or with a spring (depending on the connection).

Different PSHELL considering the thickness and density of the material

Membrane and Bending properties

- Simulations confirm the same point with the highest stress level.
- Consistent stress level, based on our previous test/simulation comparison.





CAE workflow for underbody design

- Load description -

Measure acceleration at fixation points → 6 different driving conditions (environments) → Fatigue / Max Stress

Environments

- Highway (130kph)
- Dirth Road (30kph)
- Pavement Stones (30kph)
- Rough Road (30, 50 and 80kph)

(Environments averaged according to the Worldwide harmonized Light vehicles Test Procedures)

Max acceleration loadings (at low-medium frequencies):
Highway → 3 Million cycles, at 4g *(considering a life of 300 000 km)*
Dirth Road → 180 000 cycles, at 3g *(considering a life of 300 000 km)*

Max Static Displacement Highway: 11.5mm

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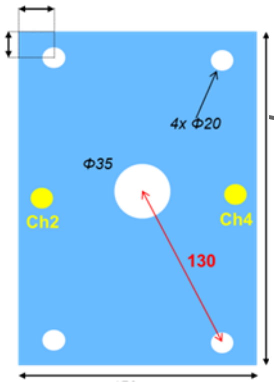
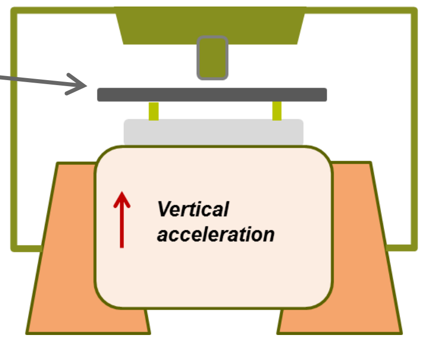
CAE workflow for underbody design

- Wöhler Characterization -

Standard material characterization not adapted to these fibers based materials

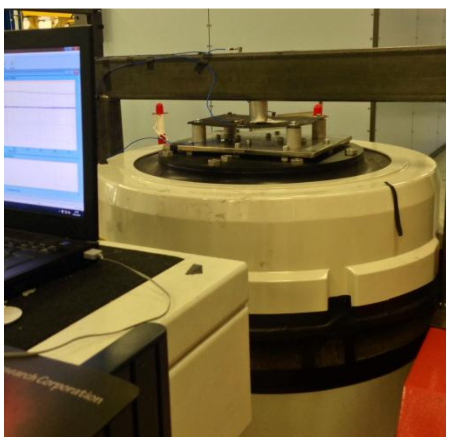




Test performed comparing:
Autoneum RUS 850 gsm *VS* Other Material 1075 gsm.
→ Representative failure mode
→ **Wöhler characterization**

Displacement imposed at a particular frequency at the extremities of the components, while the middle is fixed.

<u>Hypothesis:</u> Results can be extrapolated to the high cycles level.



Factor extrapolated considering the relationship between stress and deformation

	Displacement (mm)	Distance (mm)	b/x^2
Road Measurement	11.5	205	0.27
Testing 1	12.5	130	0.74
Testing 2	10	130	0.59

CAE workflow for underbody design

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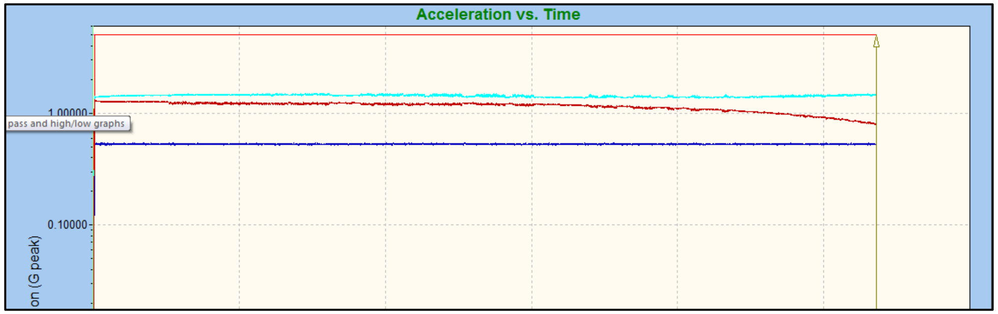
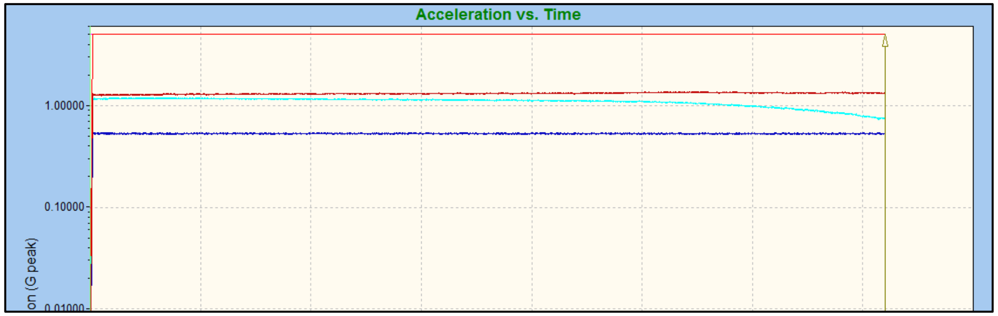
- Wöhler Characterization -

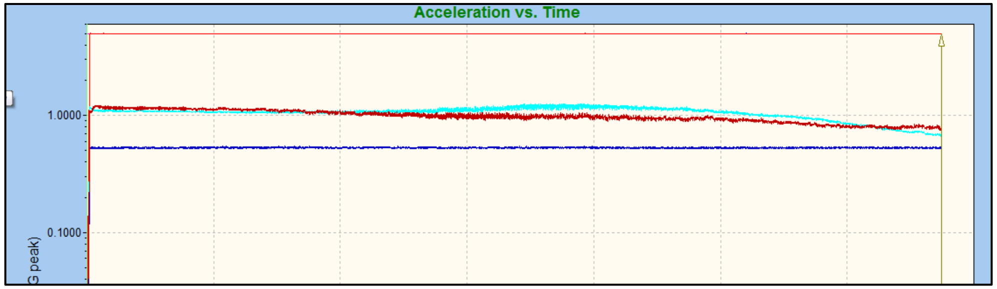
Test 1

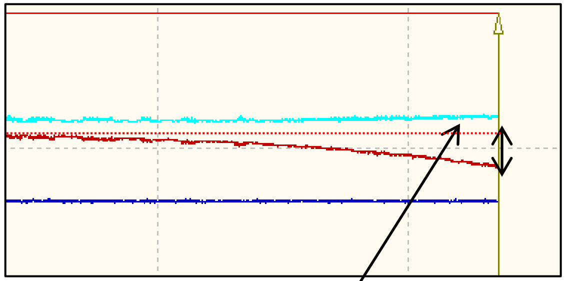


Test 2



Test 3





Criteria to stopping the test:

- %dB reduction in the measured acceleration on the sample
- The accelerometers are placed on at the sides of the sample, at a certain distance from the fixations, to identify the failure point.

CAE workflow for underbody design

- Wöhler Characterization -

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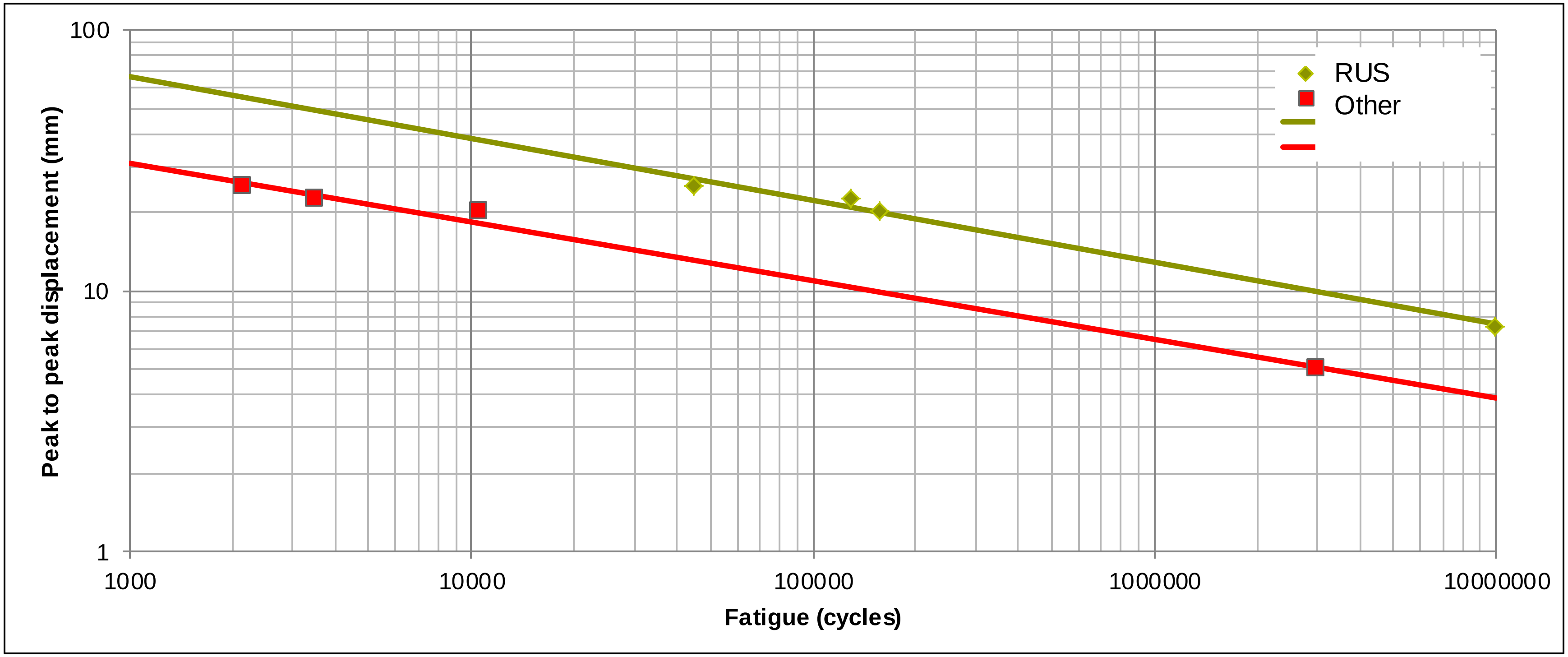

RUS is always showing better durability performances than the other material

(at each deformation level)

Through the simulation is possible to get the S-N curve.

CAE workflow for underbody design

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- Cyclic loads and durability -

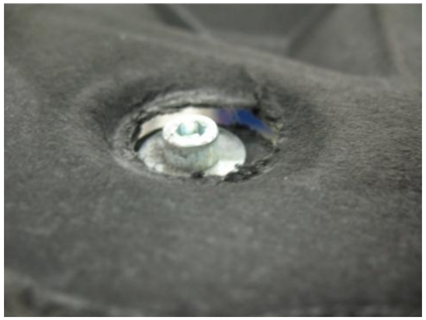
Understanding the durability performance of RUS

Max acceleration loadings (at low-medium frequencies):
Highway → ~3M cycles, at 4g
Dirty Road → ~180K cycles, at 3g
Max Displacement Highway: 11.5mm

	Acceleration level: 4g			
	RUS (850 gsm)		**Other Material (1075 gsm)**	
	1st Sample	**2nd Sample**	**1st Sample**	**2nd Sample**
1st Resonance	22	22	27	27
Millions of cycles until failure	>10	>10	3	2.7

- Both failure modes are similar, the parts break around the washer (same failure modes found on vehicle benchmarked).
- Even with an input acceleration of 6g, RUS will not arrive at failure before 10M cycles.
- CONCLUSION: The other material is stiffer (higher value of 1st resonance), but RUS is clearly more resistant in terms of durability.

RUS



Competitor material

CAE workflow for underbody design

- Cyclic loads and durability -

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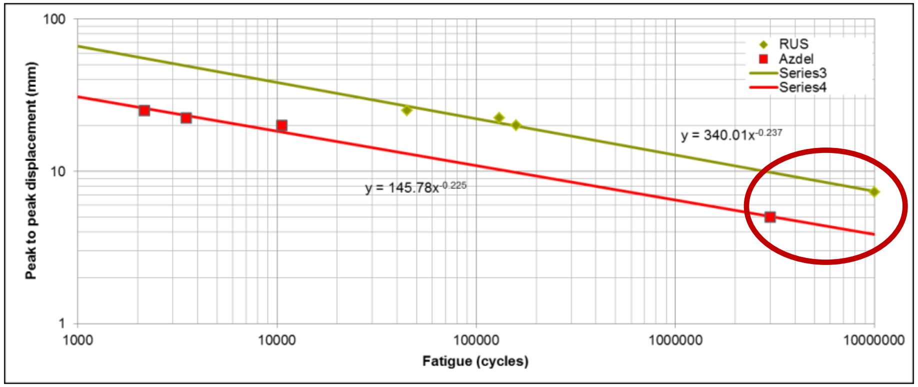
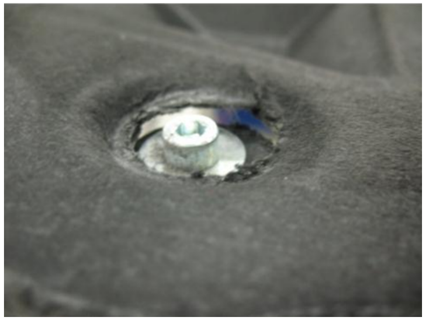


RUS



Competitor material

Fatigue Analysis Pipeline

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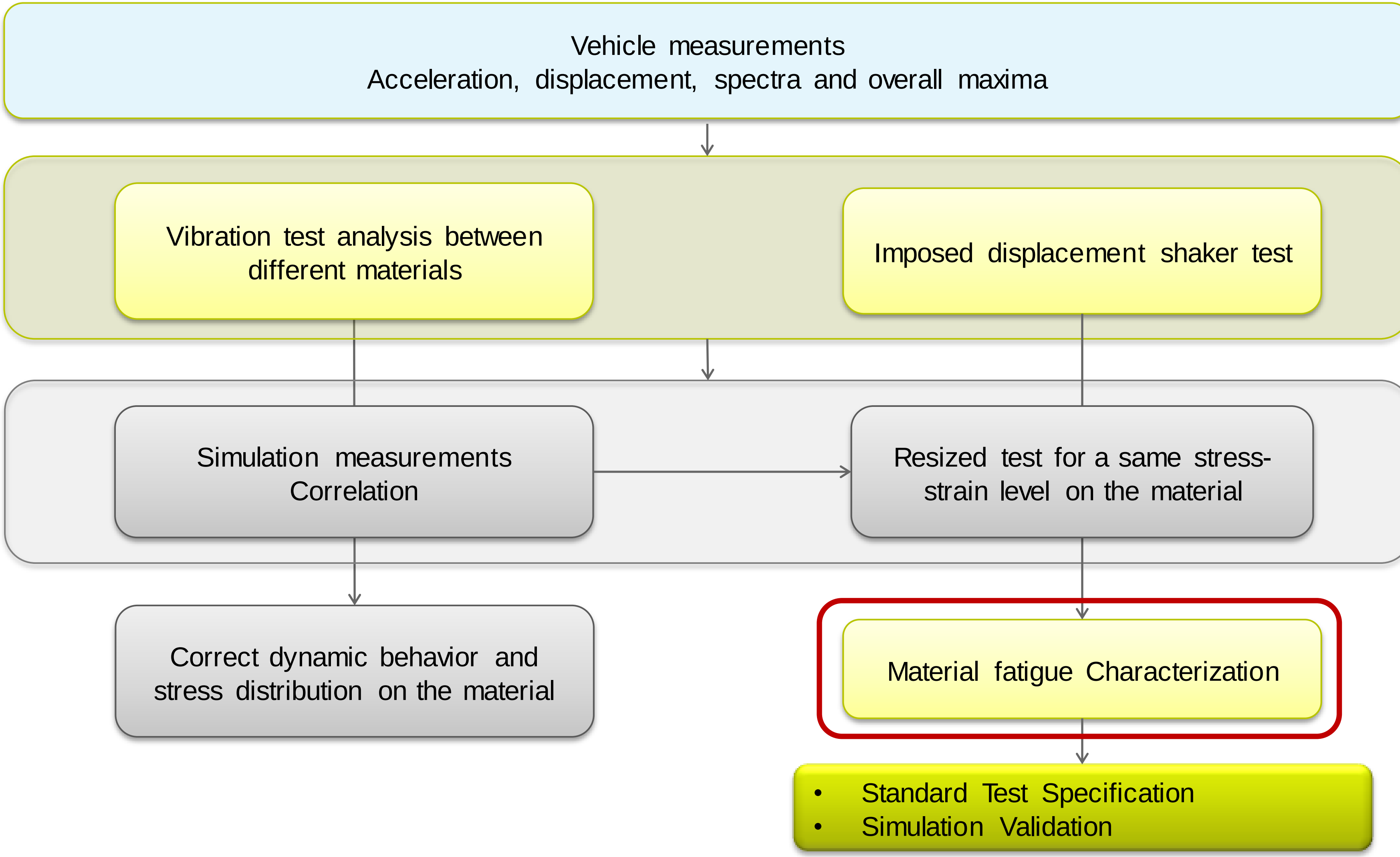

Application on Metallic Component

- Simulation Results -

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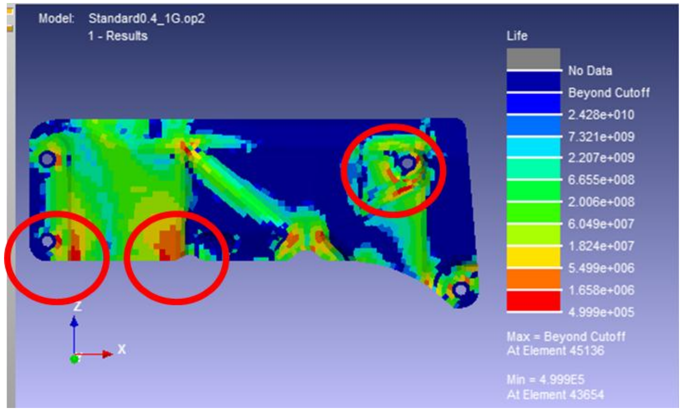


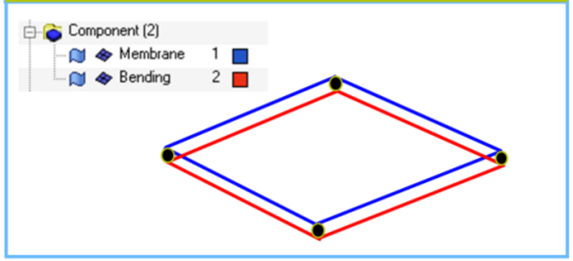
Methodology already applied on metallic components

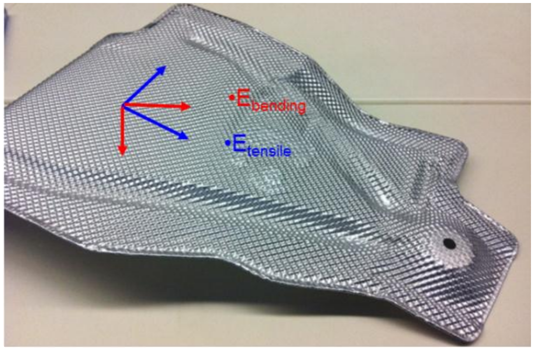
Metallic part with a special 3D shape embossment, changing the material behavior
→ Orthotropic
→ Different membrane and bending bahavior

Plasticization of Al, next failures areas

Failure points

These two shells are used at exactly the same nodes, sharing the same mid-plane





Application on Metallic Component

- Simulation Results -

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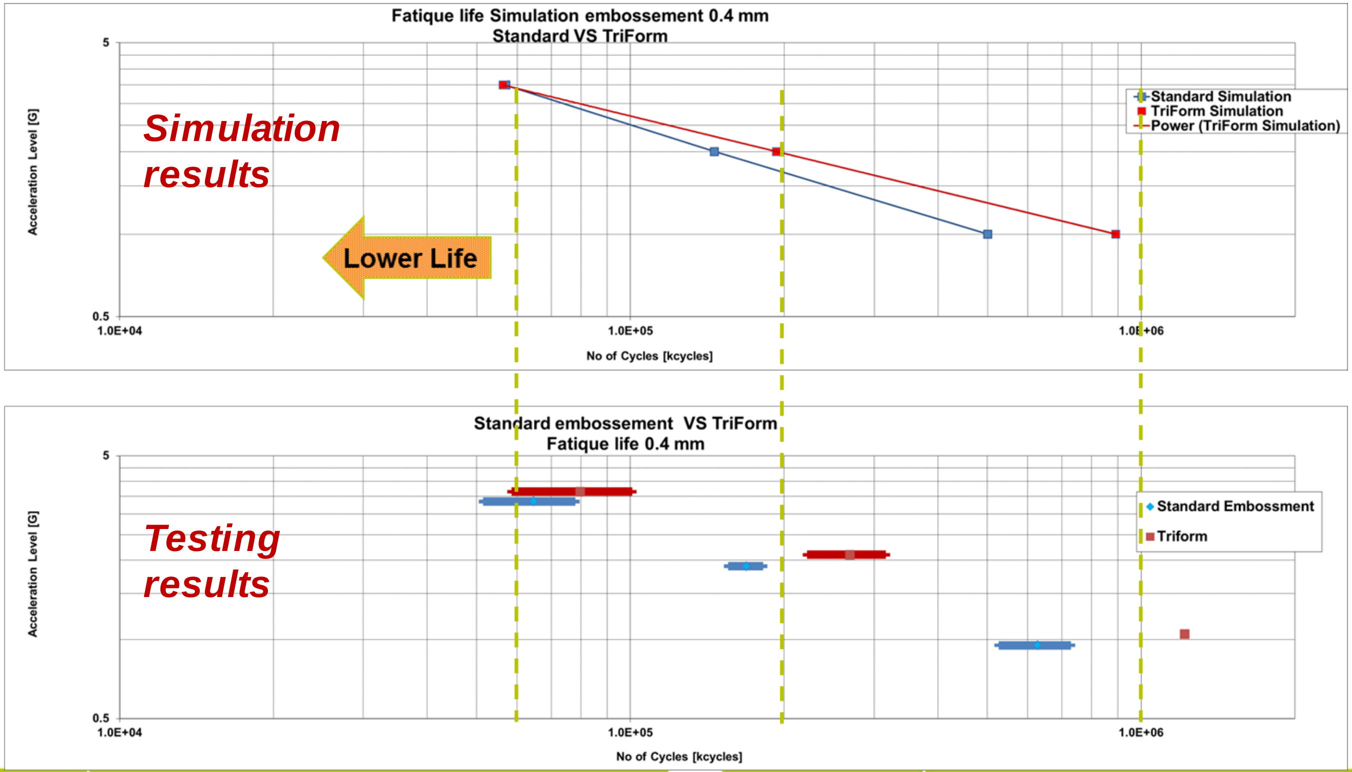


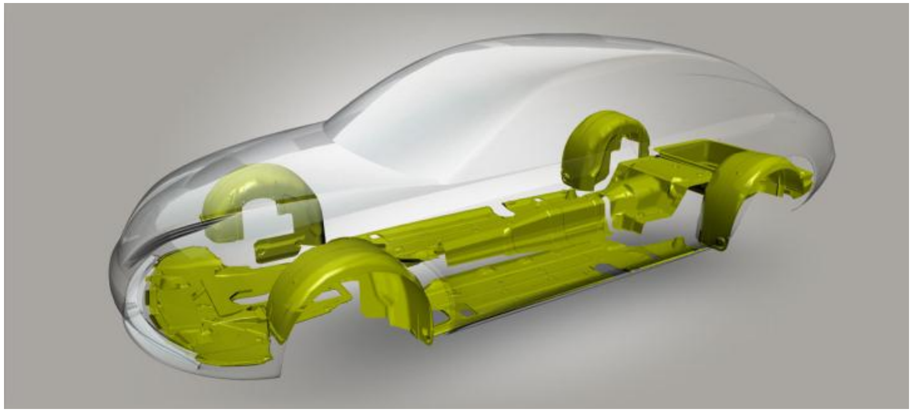
Accel level (g)	Standard embossment life (cycles)	
	Testing	Simulation
3.5	55'000	55'000
2	175'000	150'000
1	600'000	400'000

Accel level (g)	TriForm embossment life (cycles)	
	Testing	Simulation
3.5	70'000	55'000
2	280'000	200'000
1	1'200'000	900'000

Conclusions

- Material Model composed of the membrane and bending behavior validated
- Simulations in accordance with tests results (dynamic response correlation)
- Simulations allow to predict the behavior of the parts for RUS and other materials
- A test method has been developed in order to characterize the durability performances of these fiber based materials (reproducing the right failure mode), and producing a S-N curve
- The CAE process to simulate the durability of such parts is already in place (applied on metallic part), it still needs to be applied and validated on fiber based parts

  → Main risk coming from the material characterization and the non-linear effects at higher excitation



Q&A
THANK YOU FOR YOUR ATTENTION

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