Fatigue Estimations with Contact for Long Load-Time Histories

A Short Review of two alternative approaches

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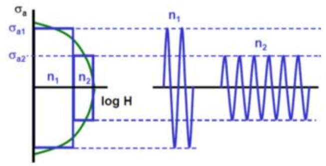
Overview

1. Introduction
2. Approach 1: Damage Equivalent Block Loads (DCP)
3. Approach 2: Approximation of Load Space (ELASTOLOADS)
4. Correlation
5. Pro’s & Con’s
6. Conclusion

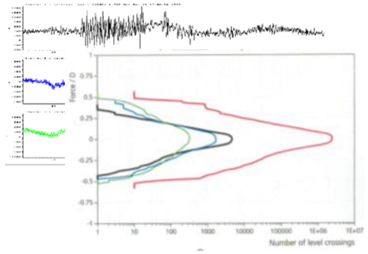
Introduction – Base Fatigue Estimation processes

Loads

Block Loads



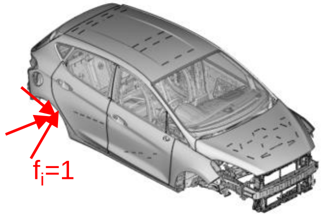
Standardized Spectra



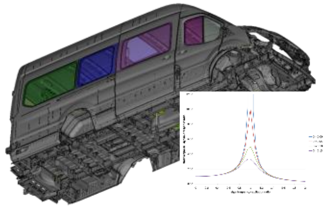
Full Vehicle PG Loads

FE Calculation

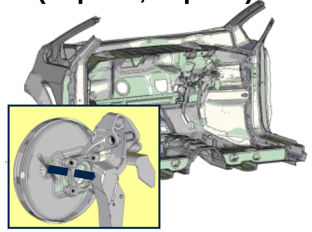
Linear Static Analysis



Linear Dynamic Analysis



nonlinear static/dynamic (implicit, explicit)



Stress Function

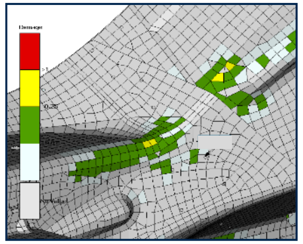
Static Superposition (Stress-Time History)

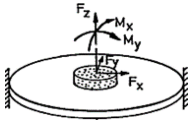
Modal Superposition (Stress-Time History)

No Superposition (Stress-Time History)

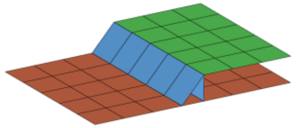
Frequency Domain (PSD Function)

Fatigue Models





(RUPP, FAT-Ber. 111)



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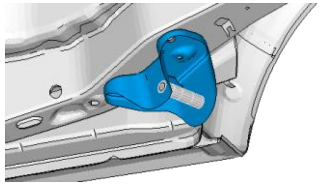
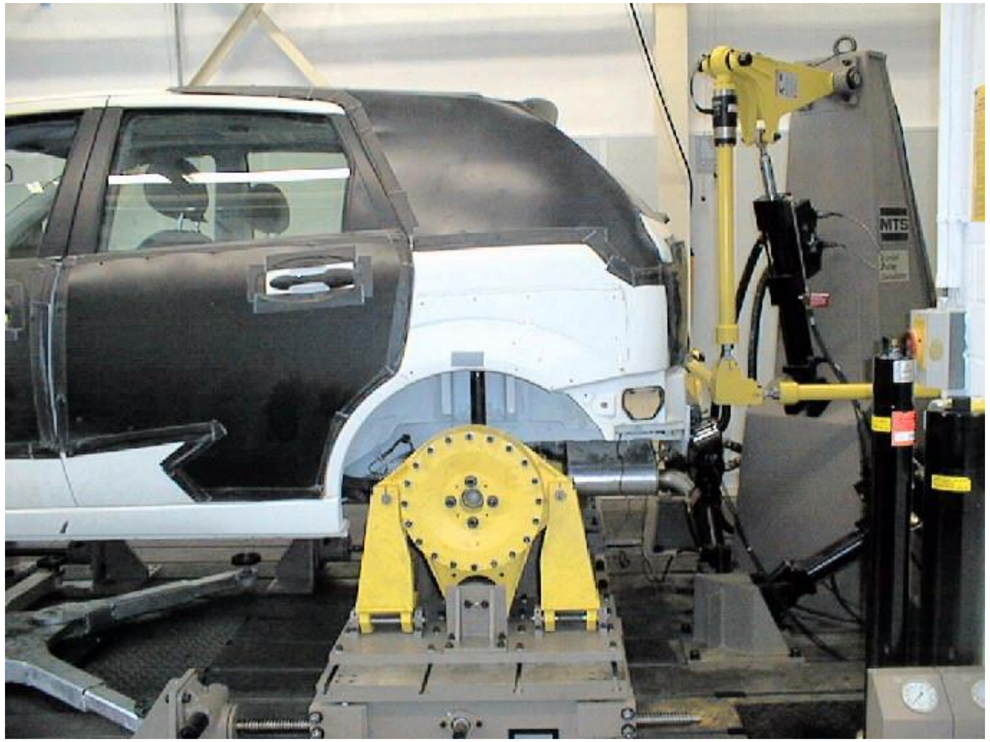


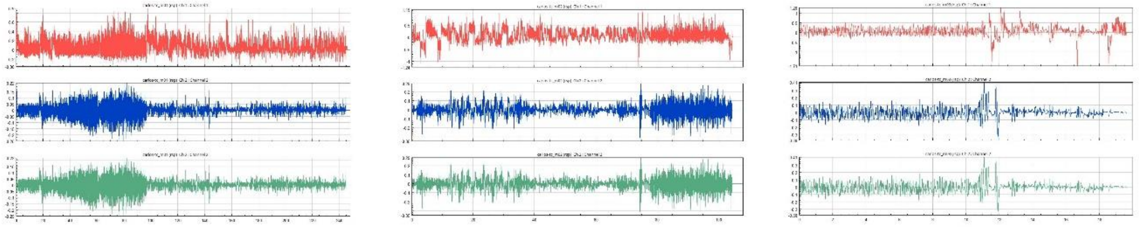
Introduction – Problem Nonlinearity

- **Nonlinear effects are important for fatigue assessments of some structural design features**
- **Here, we considers contact at a bolt connections; the material remains linear elastic**
- **Two approximation concepts are shown and discussed here:**

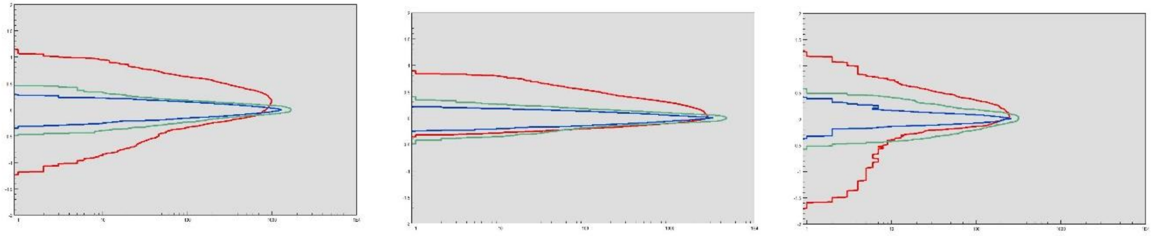
1. **A process based on damage equivalent load blocks (Ford In-House)**
2. **A process based on Load Approximation / Interpolation (FEMFAT - ELASTOLOADS)**

Example Loadcase (CARLOS-TC)





Module M1 | Module M2 | Module M3



Spectra Combination

CARLOS-TC = 10*(5*(10*M1 + M2)+M3)

Load Scaling

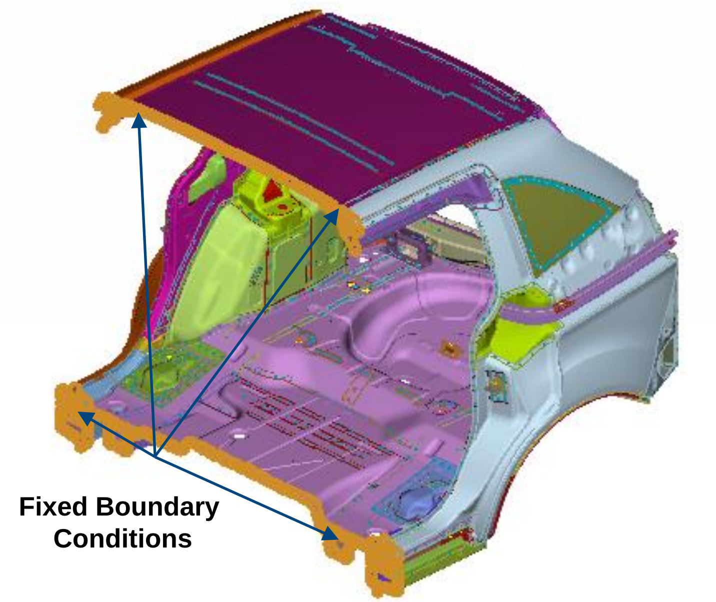
$$D = g \cdot \frac{m_V \cdot m_T}{(m_V + m_T)}$$

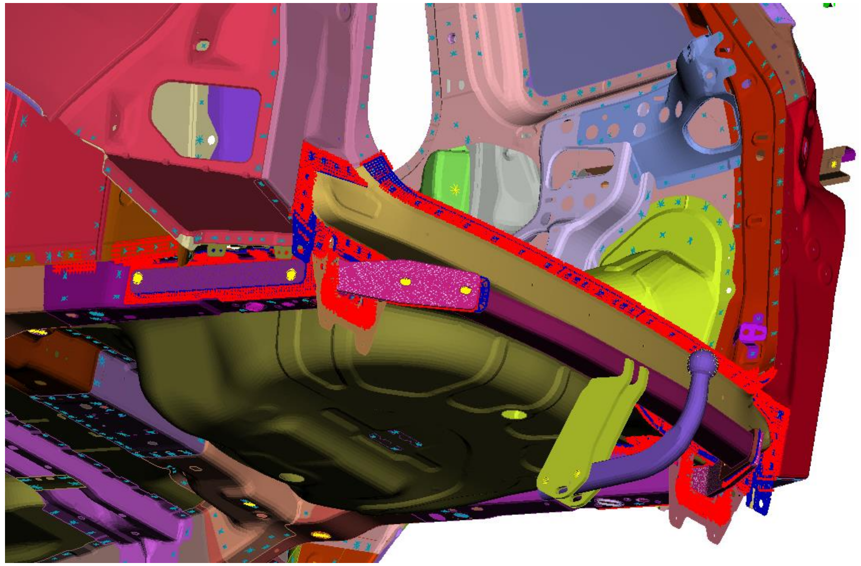
Standard Spectrum to verify Trailer Tow Devices (now included in 94/20 EC Regulation)

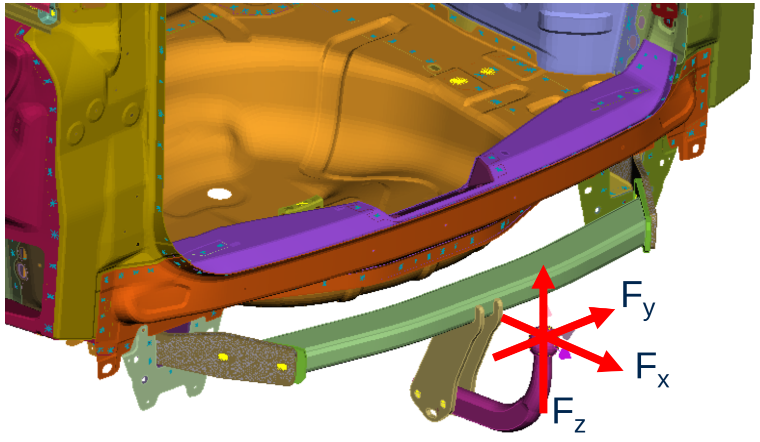
X-OEM Project led by Fraunhofer LBF 2000-2003

(Klätschke, H., Bruder, T.: Standardisierte Lastkollektive und Lastfolgen für PKW-Anhängevorrischtungen als Ergänzung zur EU-Richtlinie 94/20/EG – CARLOS TC; Unveröffentlichter LBF-Bericht Nr. 110833 (d), Fraunhofer Institut für Betriebsfestigkeit LBF, Darmstadt, 2003)

CAE Model

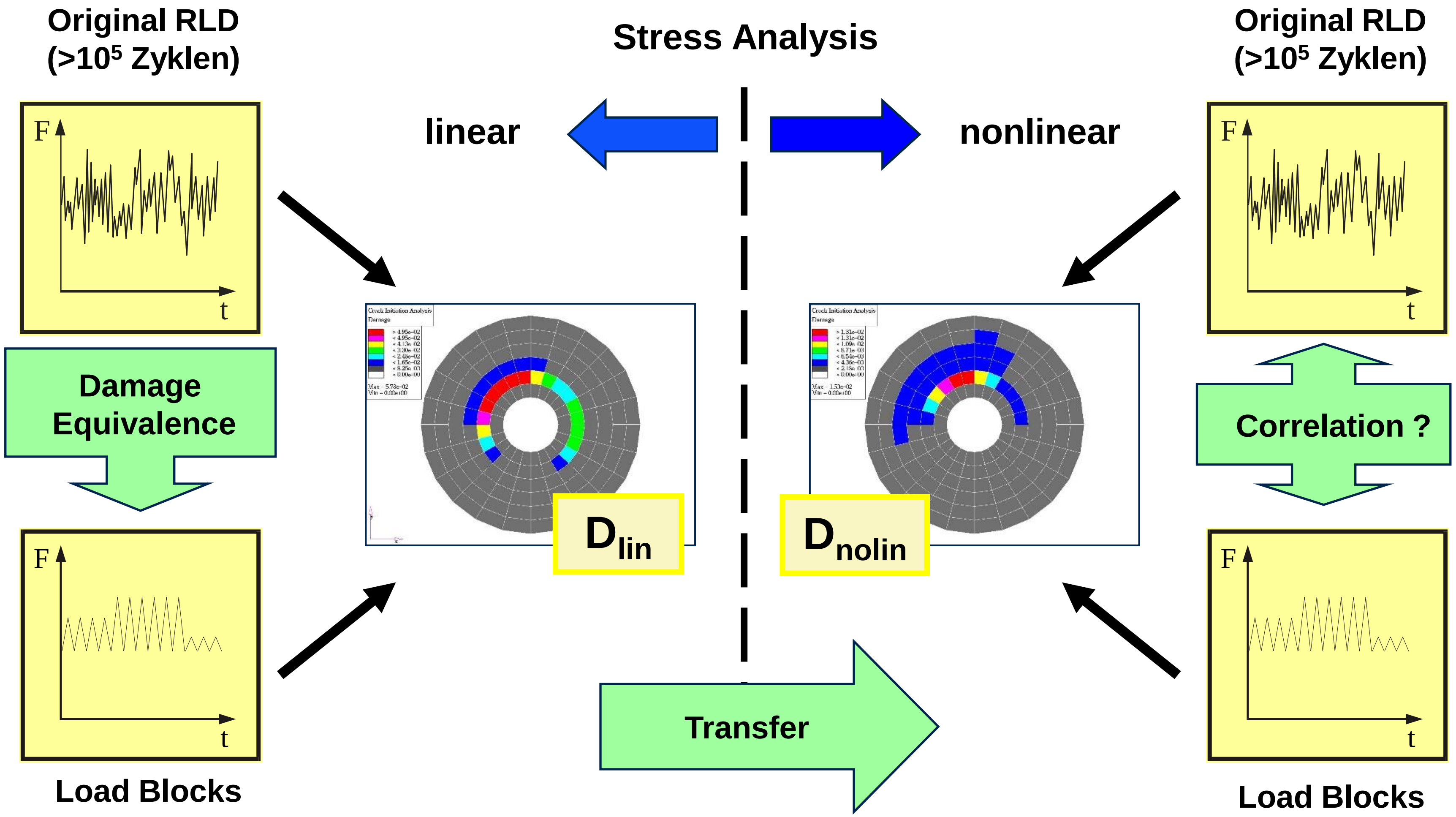




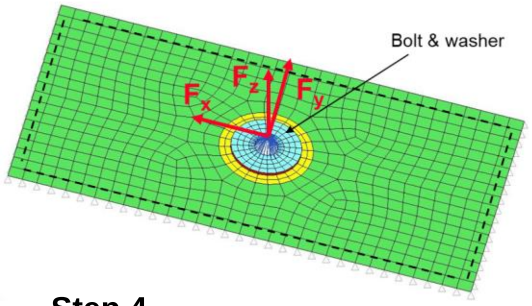


- **Nonlinear ABAQUS model w/ elastic material; contacts in all critical areas**
- **Bolt Pre-Tension & small tolerance gaps between tow bar sword, spreader plate & side rail considered**
- **Additionally, a linear Nastran model derived for one of the methods**

Approach 1 – DCP Overview



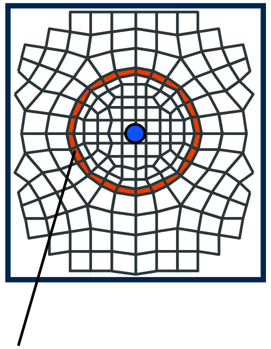
Approach 1 – Load Reduction Algorithm



Problem: Determine a set of load blocks that generate the equivalent damage pattern as the full load time history

Step 1

Select elements for approximation

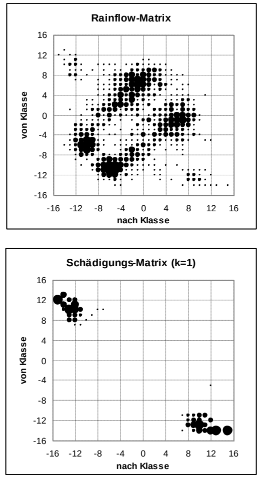


Criteria:

- spatially distributed
- highly damaged
- models with surrogate contact also possible
- # elems = max # load blocks

Step 2

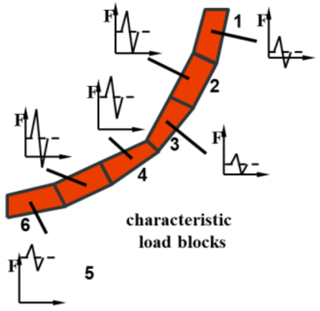
Select charact. load cycles / elem

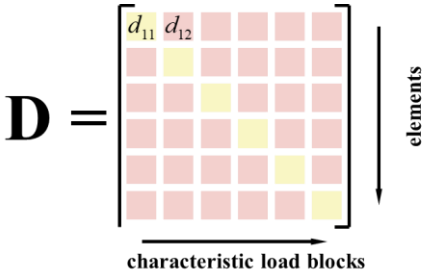


$$[DM]_{ij} = \left[d^{RM}\right]_{ij} \cdot \left[n^{RM}\right]_{ij}^{k}$$

Step 3

Build eq system for least square





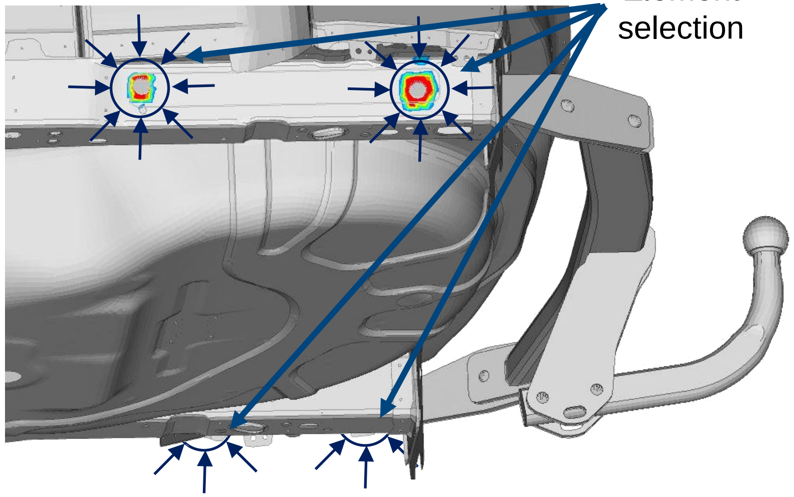
Step 4

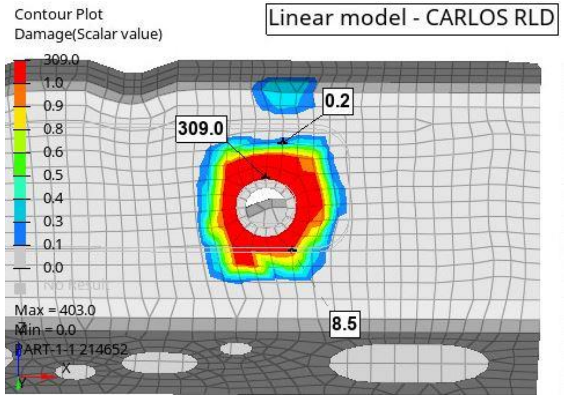
Solve optimization problem

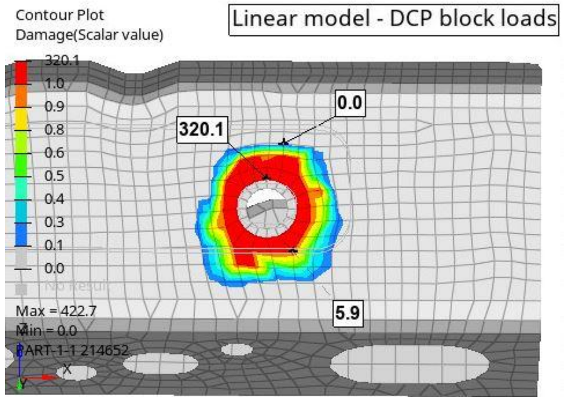
$$\min_{n \in R_{0+}} \{ \| \mathbf{D} \cdot \mathbf{n} - \mathbf{d}^{total} \|^2 \}$$

- optimization problem w/ non-negativity constraint necessary
- special robust NNLS-Algorithm
- redundant cycles eliminated
- approximation errors in all known cases small (typical: <10%)

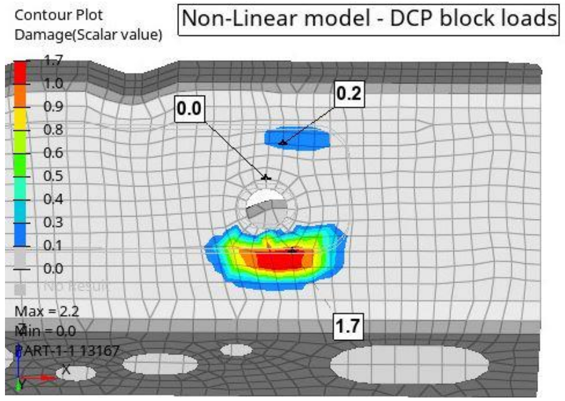
Approach 1 – DCP - Results





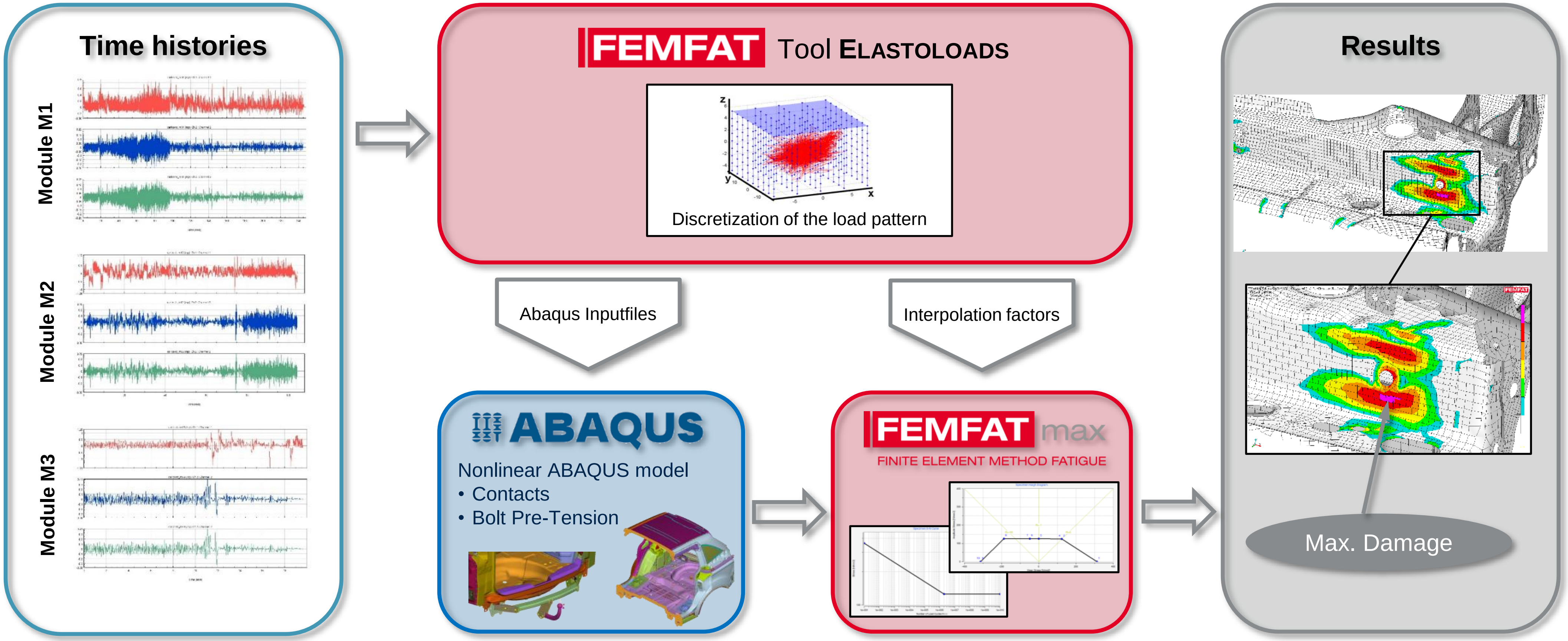


- Linear model w/o contact & pre-tension
- Elements selected around all 4 attachment points (~100)
- Results: 11 load blocks (i.e. 11 ABAQUS analyses)
- Linear approximation error (3-4%)
- Nonlinear model:
  - damage around bolt hole disappearing
  - Realistic damage level at plate edge



Approach 2 - ELASTOLOADS

- ELASTOLOADS Workflow



Approach 2 - ELASTOLOADS

- **Discretization for all modules of the CARLOS signals is based on the maximum forces in each direction, which occur in module M3:**

	No of sampling points	Min. [kN]	Max. [kN]
x-direction	15	-15.2	11.4
y-direction	5	-3.4	3.7
z-direction	5	-6.0	4.3

- **The main direction (simulation direction) is the x-direction**
- **25 Abaqus simulations (5x5) provide the result basis for all following FEMFAT analyzes (only 21 of them are needed)**
- **The Abaqus simulations are defined as restart on assembly load case**
- **The FEMFAT analyses are done separately for the different CARLOS signals (M1, M2, M3)**
- **Reduction of signal lengths by removing intermediate points**
- **The total damage is determined by linear combination considering the number of repetitions for each signal.**

Simulation parameters

ABAQUS:

21 analyses

Duration: ~16h (4 CPUs, 2 GPUs)

FEMFAT:

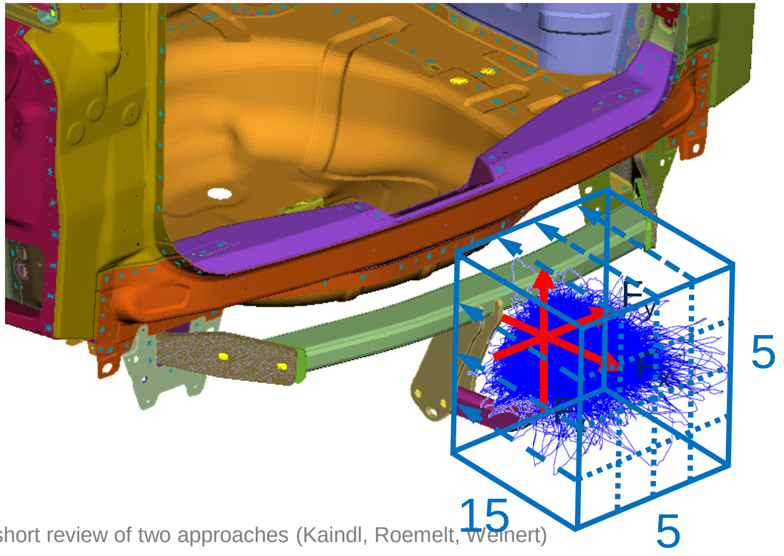
M1: 115 channels, ~33000 time points

M2: 191 channels, ~9000 time points

M3: 165 channels, ~1600 time points

Duration: ~3h (1 CPU)

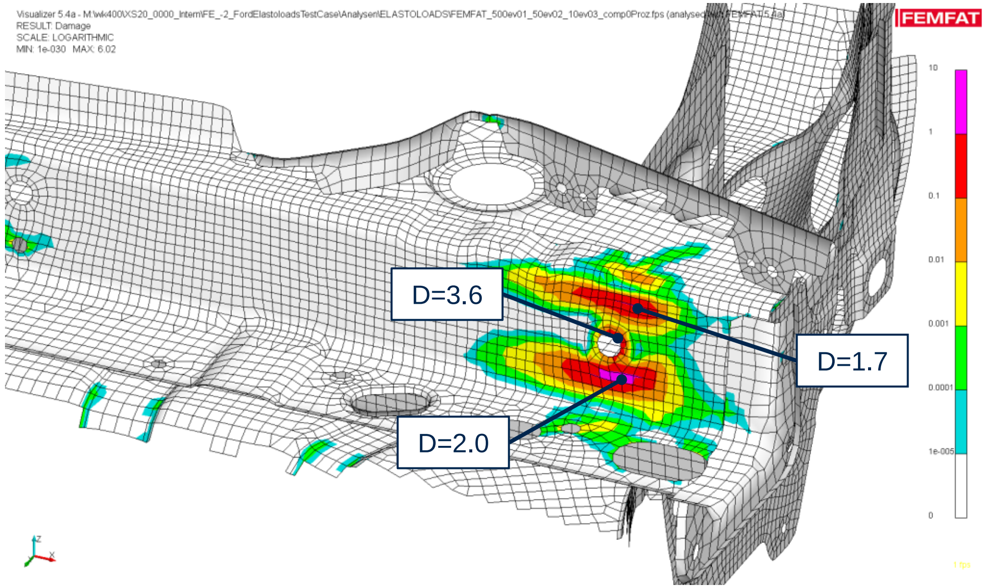
Total analysis time: ~19h



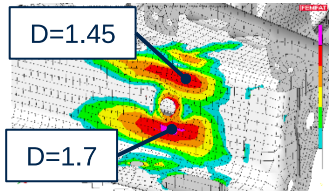
Approach 2 - ELASTOLOADS

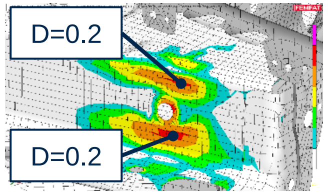
- **Results**

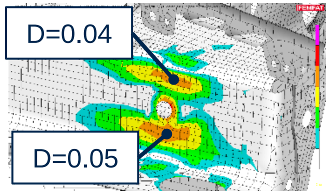
Total Damage left side – CARLOS-TC = 10*(5*(10*M1 + M2)+M3)



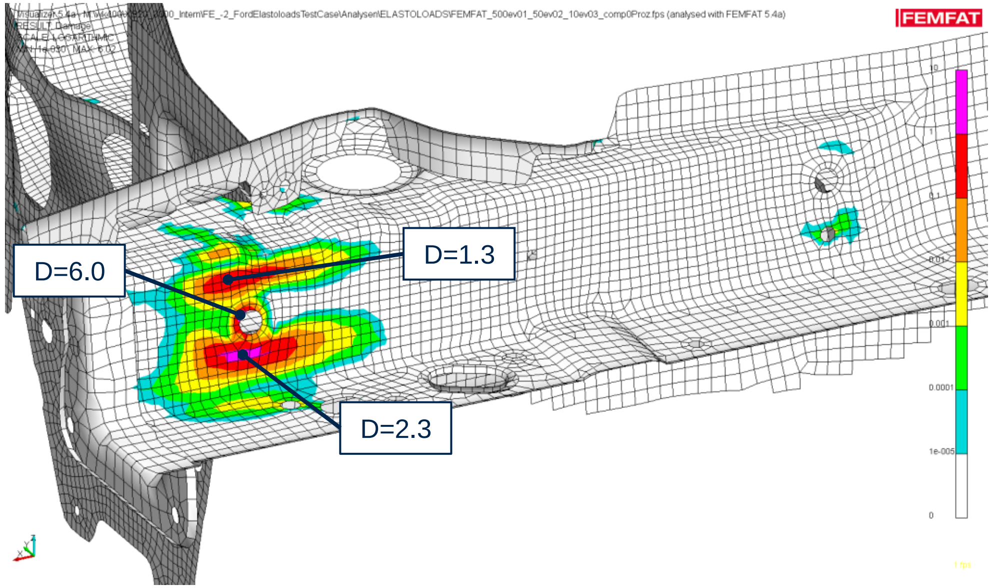
Damage – 500*M1	**Damage –** 50*M2	**Damage –** 10*M3



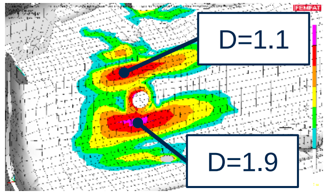


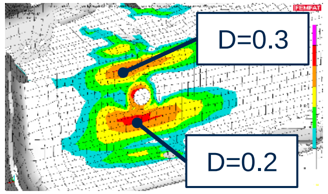


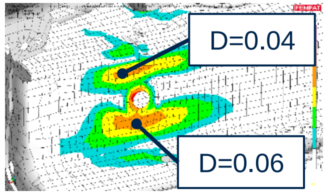
Total Damage right side – CARLOS-TC = 10*(5*(10*M1 + M2)+M3)



Damage – 500*M1	**Damage –** 50*M2	**Damage –** 10*M3

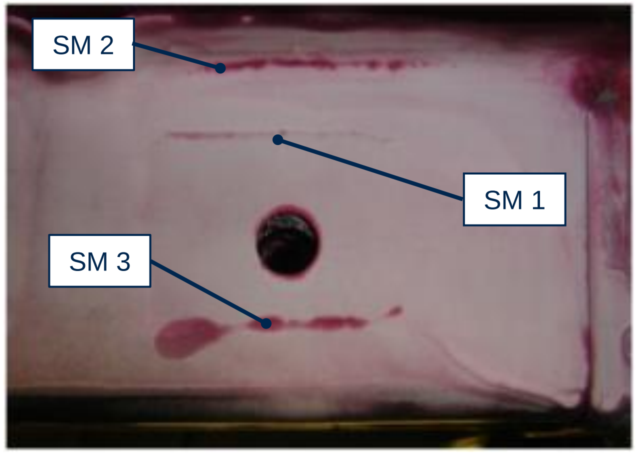




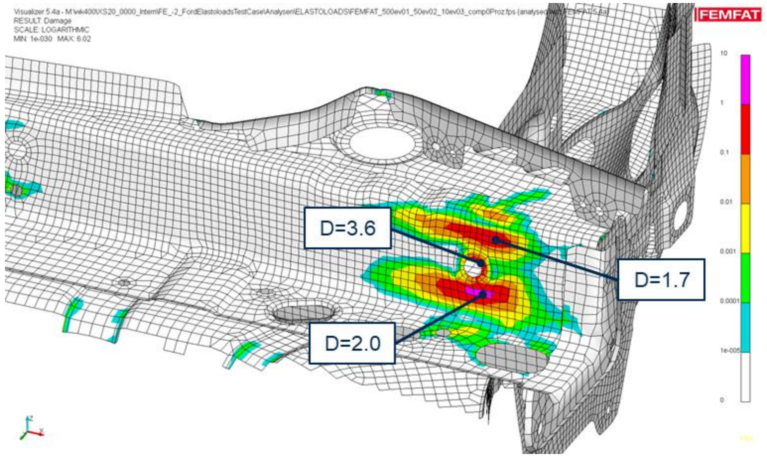


Correlation

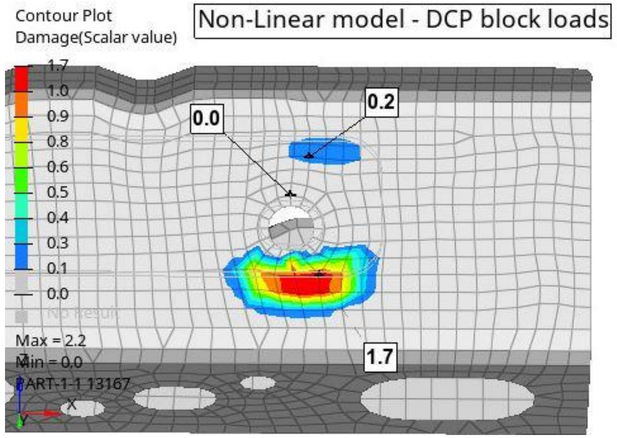
Physical test results



ElastoLoads Result



DCP Result



- **Both methods show a good correlation to the physical test failure**
- **Compared to linear analyses both methods give significantly more realistic damage level & location**
- **The upper two hotspots are somewhat better articulated by ELASTOLOADS compared to DCP**
- **Bolt pretension creates an (easily detectable) artifact around the bolt hole**

Comparison / Pro’s & Con’s

- **Correlation:**
  - Both methods show a good correlation to the actual physical test result
  - ELASTOLOADS shows a bit more articulation of the hotspots especially for the 2nd hotspot
  - 3rd hotspot not identified by neither of the tools
- **Effort / efficiency / User friendliness**
  - Manual effort is lower in ELASTOLOADS (fully automated single step analysis)
  - DCP is a multistep analysis with required intermediate quality checks
  - Numerical effort higher in ELASTOLOADS vs DCP (in FEA analyses & Fatigue Postprocessing)
- **Application bandwidth**
  - ELASTOLOADS can be used for any nonlinearity; DCP is mainly intended for contact investigations
  - ELASTOLOADS uses approximated (interpolated) loads directly; DCP creates damage equivalent load blocks
  - ELASTOLOADS is practicable for up to 4-5 channels; DCP is less sensitive to the number of channels

Thank you!