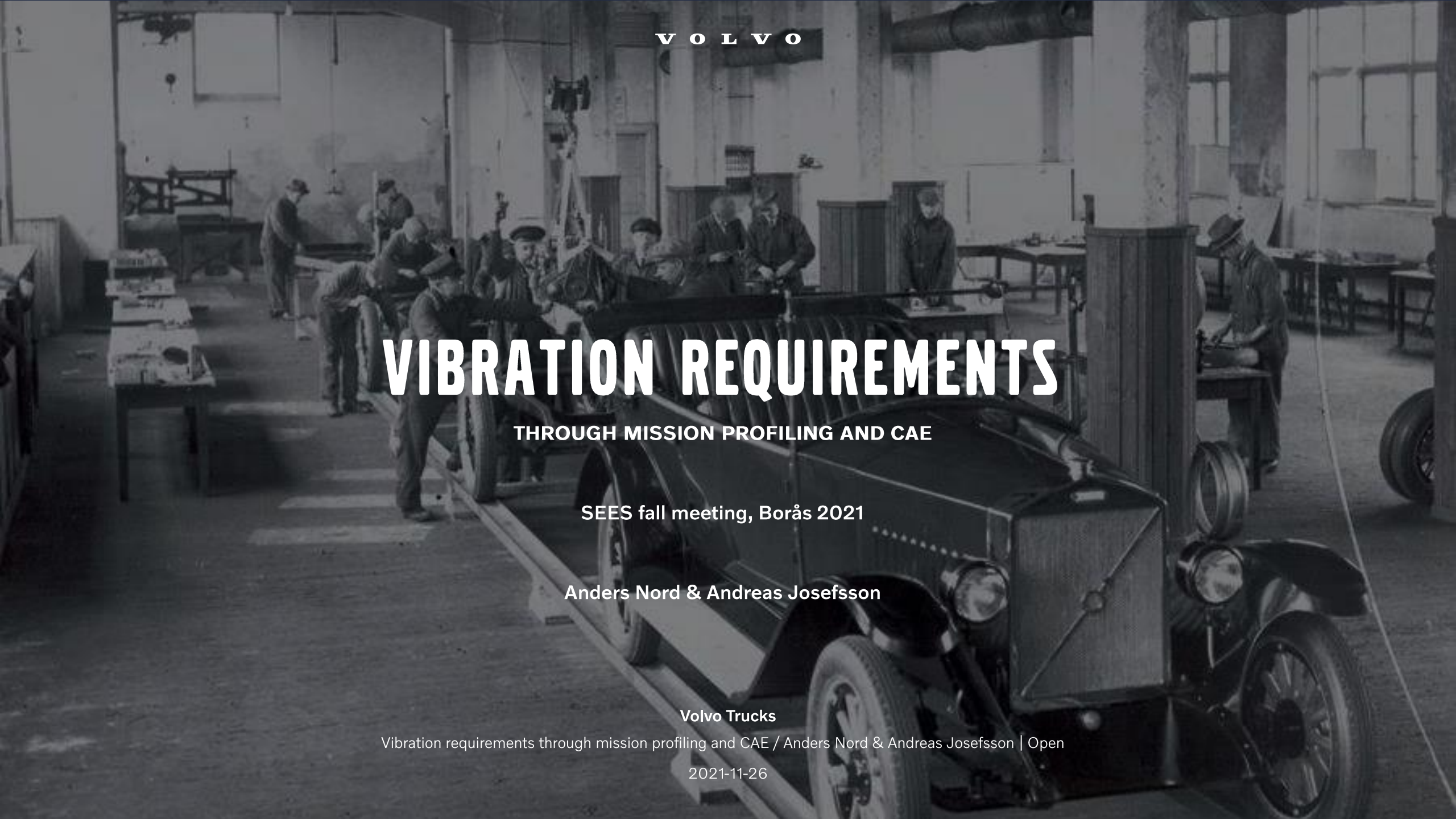


VOLVO

VIBRATION REQUIREMENTS

THROUGH MISSION PROFILING AND CAE

SEES fall meeting, Borås 2021

Anders Nord & Andreas Josefsson

Volvo Trucks

Introduction

Accurate environmental requirements ensuring meaningful early phase component testing is especially important when considering new technologies and competing in a race to the market. A well-connected verification chain needs to be developed to support design decisions and ensure a high-quality product. This talk details the work performed at Volvo Trucks in this direction w r t energy storage systems for battery electric vehicles.

Outline

Outline of presentation

- Introduction
- Outline of presentation

- Outer description of vibration environment through mission profiling
- Internal comparison of stress levels through CAE
- Cascaded test requirements

- Conclusions and sum up

Mission Synthesis

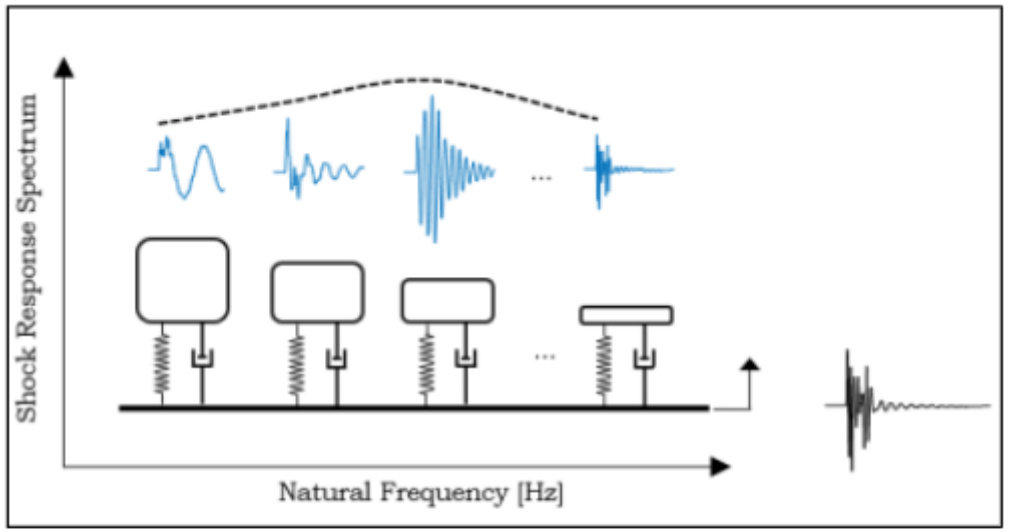
Response spectrum approach to vibration requirement setting

- The Mission Synthesis approach is a method using response spectra of measured (or calculated) events to generate a nominally damage equivalent vibration requirement based on acceleration data only.
- For Volvo Trucks, these events are test program obstacles from our test track. Different types of vehicles behave differently, thus several observations are needed.
- The benefit – and drawback – of the method is that it does not require a detailed model of the subsystem under study.

Maximum Response Spectrum

- Maximum Response Spectrum, Shock Response Spectrum or Extreme Response Spectrum represents extreme amplitude responses witnessed by a single degree of freedom (SDOF) system through base excitation by the signal to be evaluated.
- For a random PSD excitation of duration T seconds, this can be calculated as:

$$MRS(f_n) = \sqrt{\pi \,.\, f_n \,.\, Q \,.\, G_{\ddot{z}}(f_n).\ln(f_n \,.\, T)}$$



Shock Response Spectrum (SRS/MRS)
Shows the damage potential with respect to MAX levels. The extreme values from each SDOF system are plotted.

Fatigue Damage Spectrum

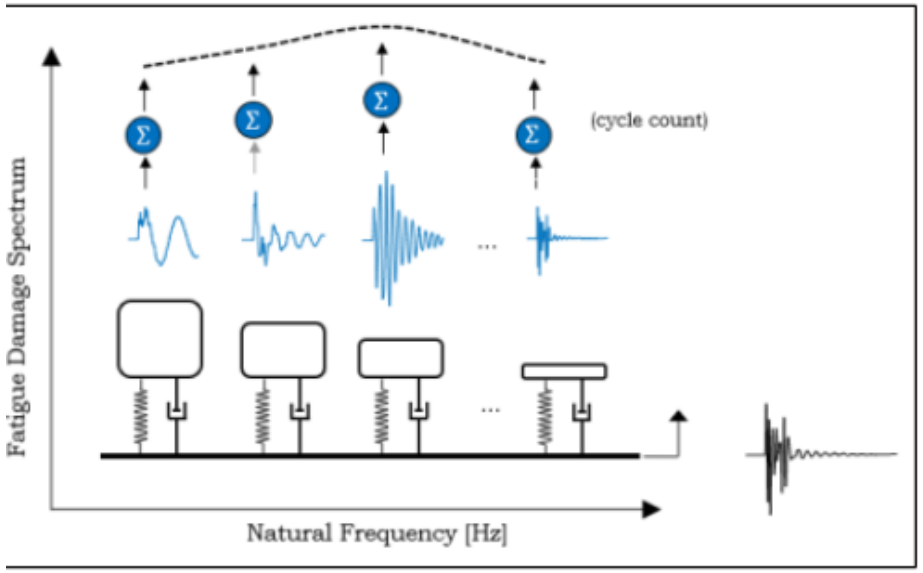
Following initial work by Bendat (1964) and Rice (1954) to determine fatigue damage directly from a PSD of stress, Lalanne (2002) was able to use this concept to create a methodology by considering the acceleration PSD.

$$FDS(f_n) = f_n \,.T\,. \frac{K^b}{C} \,. \left[\frac{Q\,.\,G_{\ddot{z}}(f_n)}{2\,.\,(2\pi\,.\,f_n)^3}\right]^{b/2} .\varphi\left(1+{}^{b}/_{2}\right)$$

K: stiffness of the SDOF system;

$\varphi(\,)$: function defined by $\varphi(g) = \int_0^\infty x^{(g-1)}\,.e^{-x}dx$;

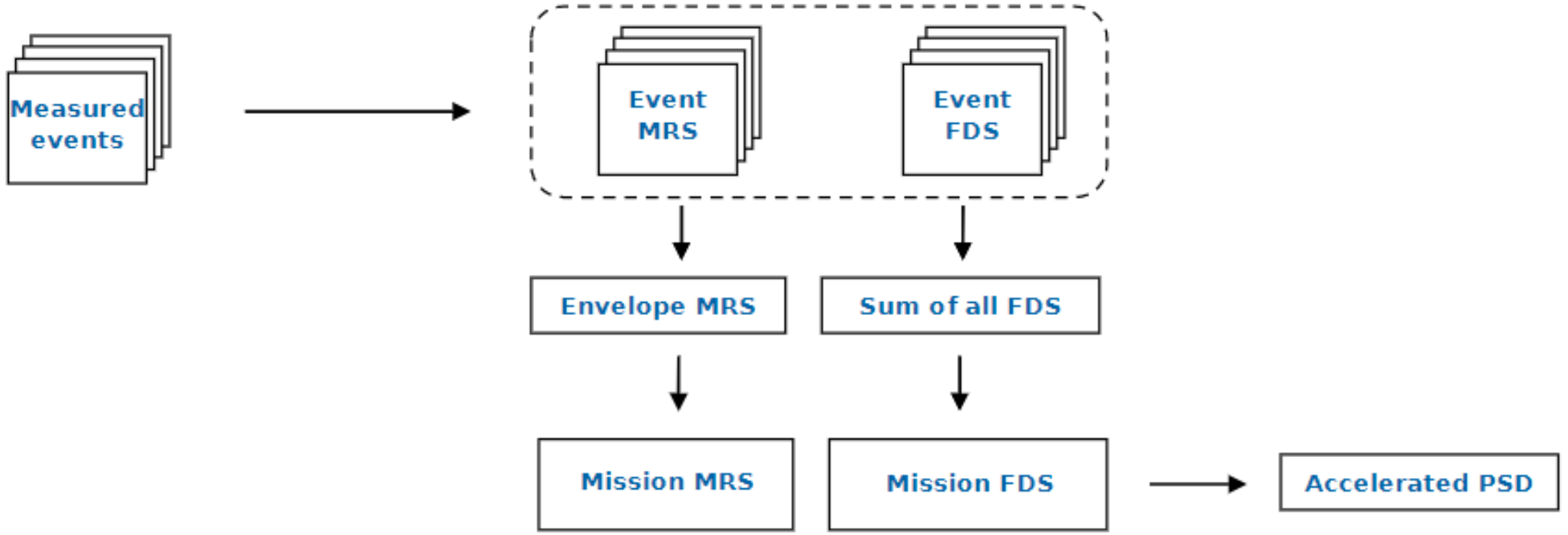
b and C: fatigue parameters describing Wöhler curve, such that $N = C\,.S^{-b}$, Where N is the number of cycles to failure of cyclic stress amplitude S.



Fatigue Damage Spectrum (FDS)
Shows the damage potential with respect to fatigue levels. A cycle count is performed on each SDOF response and a final fatigue value is given at each natural frequency.

Mission Synthesis

Response spectrum approach to vibration requirement setting

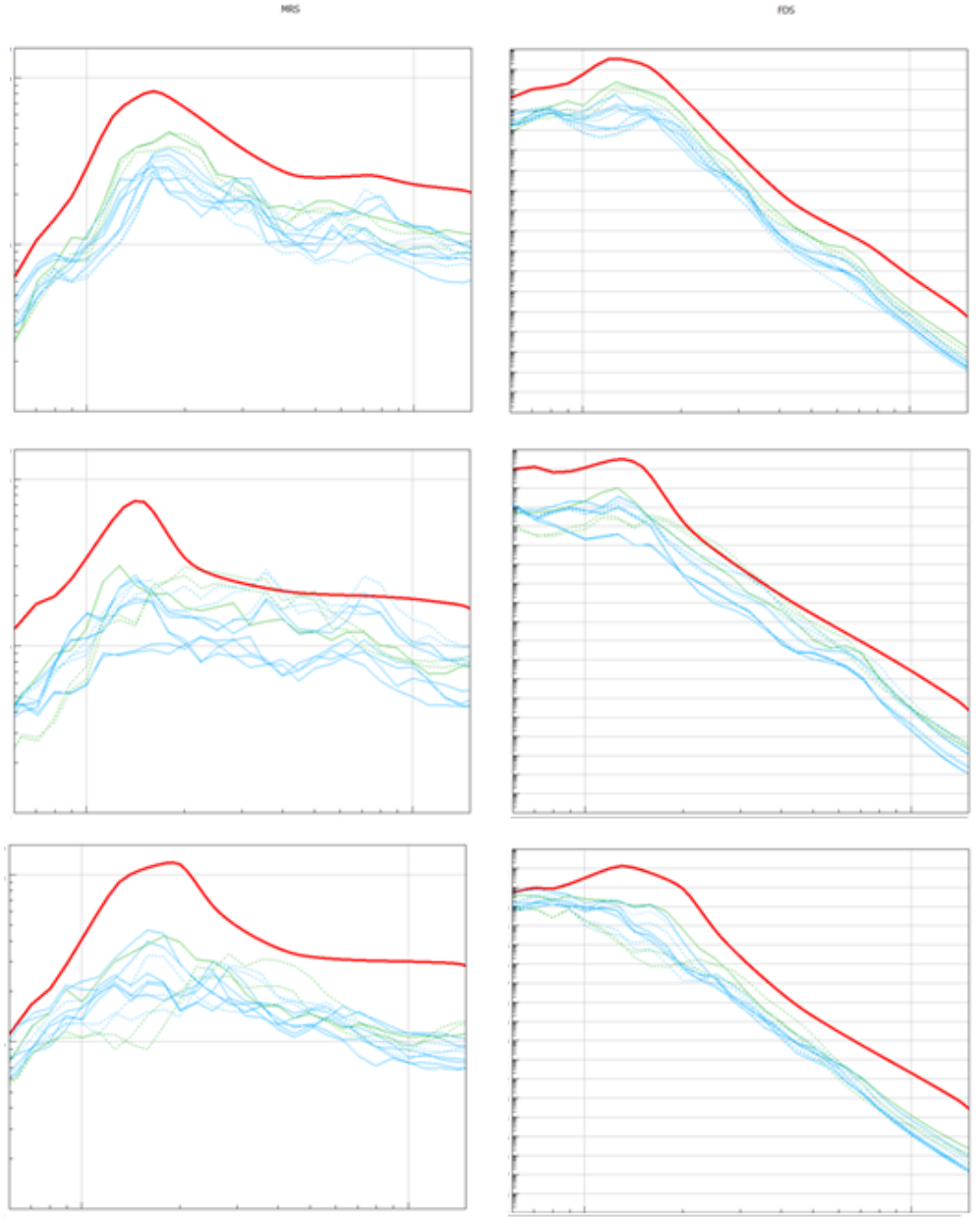


Mission Synthesis

Energy Storage System overview

- PSD requirement built through mission synthesis based on full vehicle dynamics CAE and estimates of vibration isolation effects of suspension
- Calibrated and verified with respect to test program measurements of project vehicle builds
- Requirement coverage (including safety factor) seen in figures to the right

- Well-balanced requirement level with respect to acceleration levels!



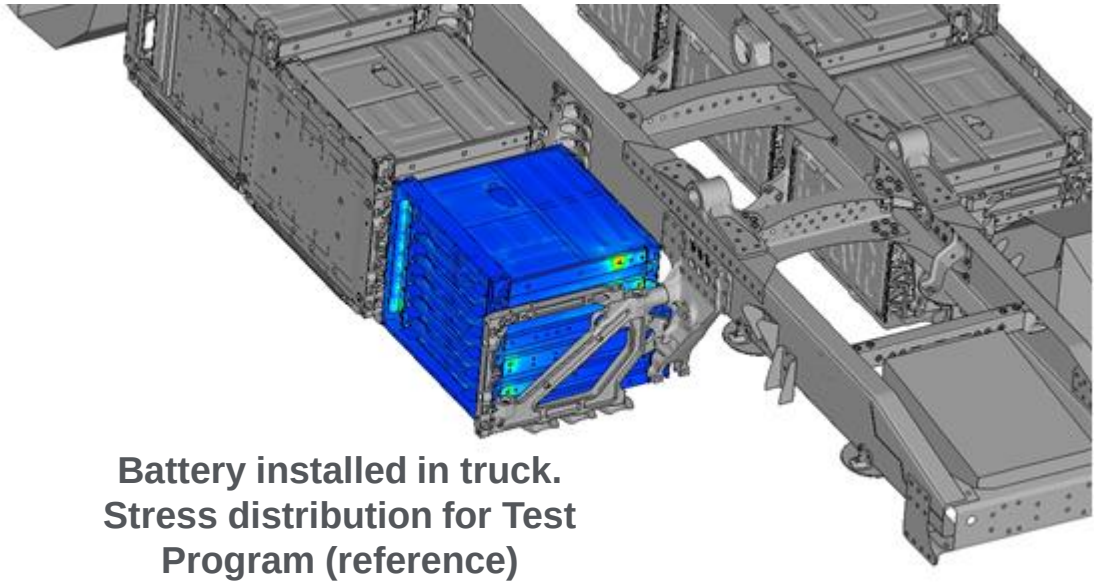
Component testing

Single axis shake test

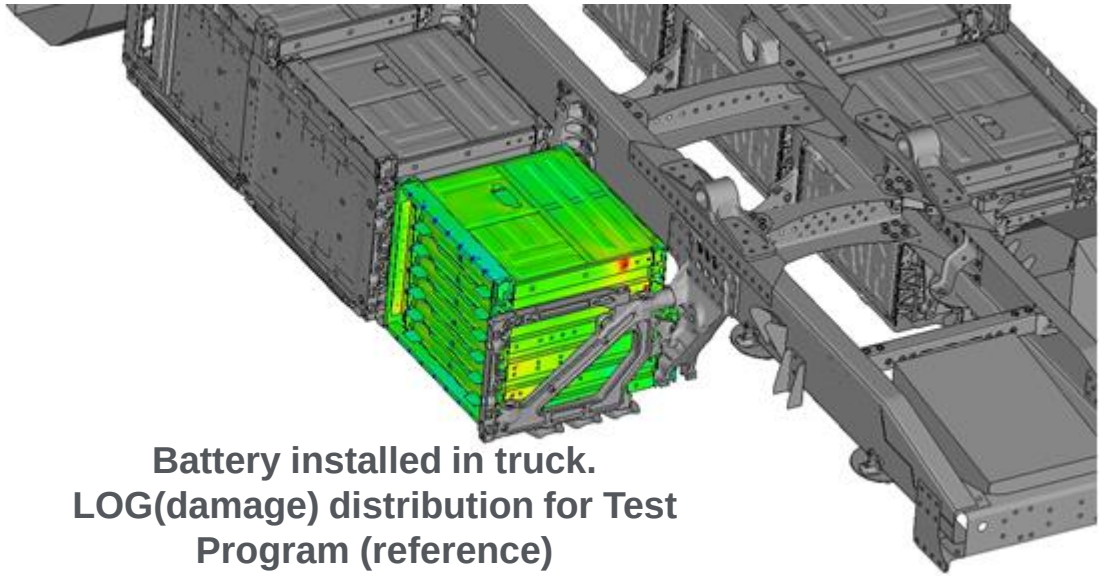
- PSD requirement to be tested on single axis electrodynamic shaker table
- Tests planned on different levels:
  - **cell** – smallest unit of battery, a few centimeters
  - **module** - large plates of cells
  - **pack** – several modules, cooling and control
- Assumptions of base excitation only accurate on cell level
- Relevance of test on higher test levels needs verification

CAE verification

- Reference stress distributions generated from vehicle dynamics model as seen to the right
- To be compared to component testing on module and pack level
- When necessary, augment
  - Boundary conditions
  - Requirement levels
  - Test methods



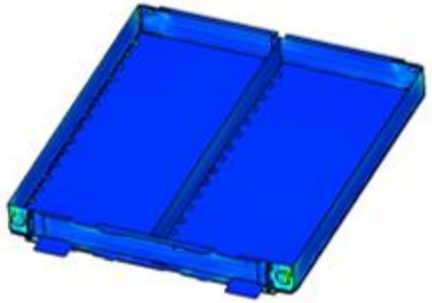
Battery installed in truck. Stress distribution for Test Program (reference)

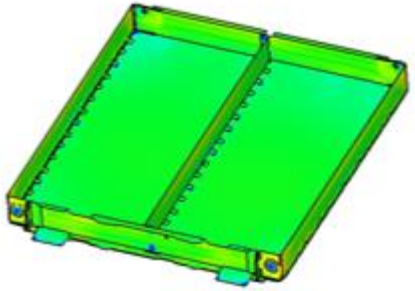


Battery installed in truck. LOG(damage) distribution for Test Program (reference)

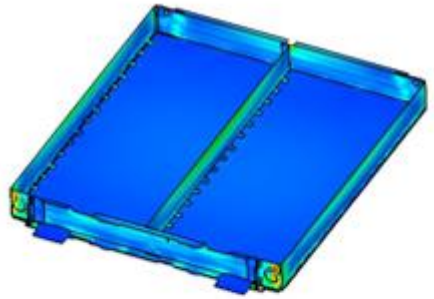
CAE comparison of module test

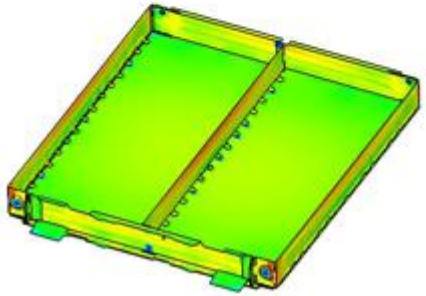
Well balanced requirement, stess distribution essentially correct





Module installed in truck (Test Program)
Stress distribution
LOG(damage) distribution.



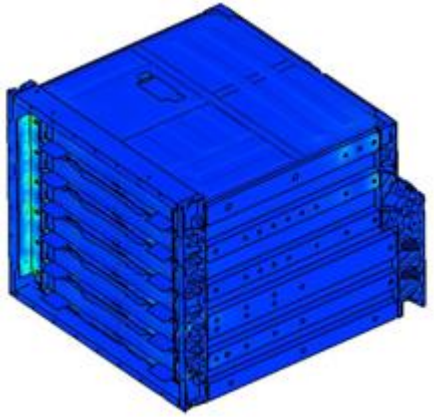


Module on Shaker Table with PSD-input (XYZ)
Peak Stress distribution.
LOG(damage) distribution.

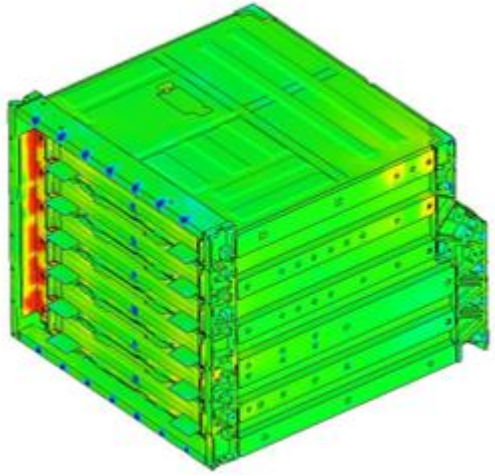
CAE comparison of pack test

Requirement needs modification, stess distribution OK when bushings included

Battery on Shaker Table (Rigid mounts)
PSD-input (XYZ)

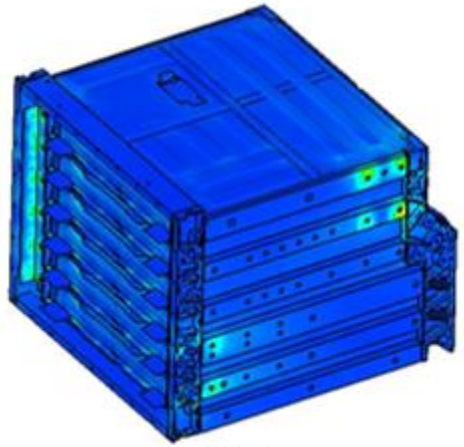


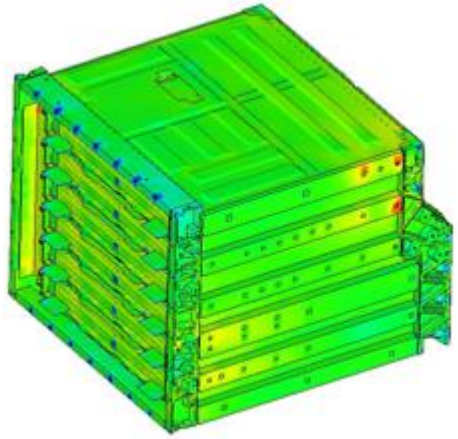
Peak Stress distribution.



LOG(damage) distribution.

Battery on Shaker Table (Bushings)
Rescaled PSD-input (XYZ)





Cascaded requirement

Supplier vibration testing requirements different at different levels

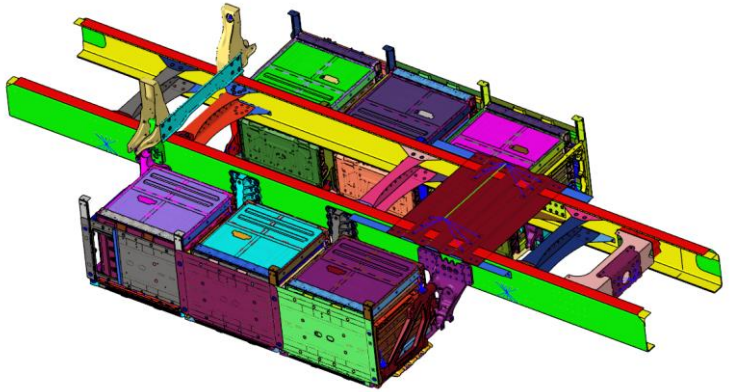
Analysis resulted in the following strategy

- Baseline requirement from mission profiling used for **cell** and **module**
- Rescaled requirement used for **pack** with augmented boundary condition
- Importance if full system test highlighted

System testing

Augmented with CAE

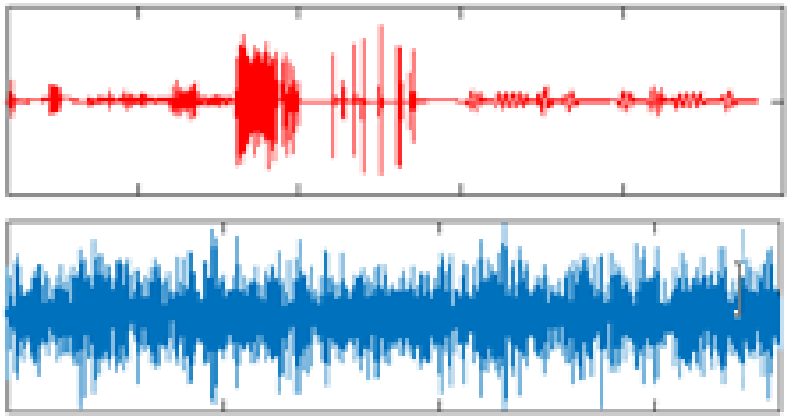
- System test replicating 6 DOF time domain signal from test track
  - Closer to real load paths
  - Includes routing etc, testing coupled system
  - Limited frequency range because of hydraulic actuation
- Rig CAE model used to
  - Verify stress distribution in rig compared to vehicle model
  - Perform virtual testing using measured signal covering full frequency range



Bushing forces

Example of specific usage area for system test model

- Assessment of bushing forces prior to pack electrodynamic test needed to calculate how many extra bushings are needed (will be over-tested in setup)
- Iterative Learning Control rig simulation using the entire frequency range of the electrodynamic test sequence used to estimate bushing forces in vehicle
- Comparison to electrodynamic rig simulation and component test results indicate a handful exchange bushings will be needed



Conclusions

End of presentation, sum up

- Heavy components, exemplified by ESS of Volvo BEV trucks, require special attention when testing using PSD inputs
- CAE analysis can be used to assess boundary condition effects and evaluate possible remedies
- Requires well-correlated models with adequate level of detail
  - Modal, acceleration & force comparisons vehicle <-> vehicle model
  - Modal, acceleration & force comparisons rig <-> rig model
  - Outcome correlation CAE, rig and full vehicle testing