Virtual vibration fatigue testing of a battery pack

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Hexagon Design and Engineering

Hexagon AB in brief

Swedish stock market

€500mn (2000) to €5.2bn (2022)

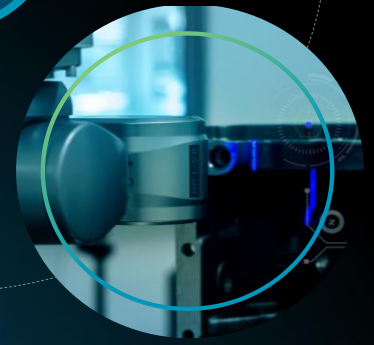
More than 24,000 employees across 50 countries

- Agriculture
- Asset Lifecycle Intelligence
- Autonomy & Positioning
- Geosystems
- Manufacturing Intelligence
- Mining
- Safety, Infrastructure & Geospatial
- Xalt Solutions

Manufacturing Intelligence

Production

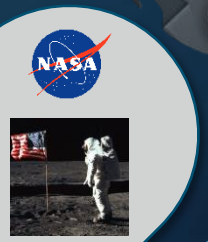
Design and engineering



Metrology and inspection

HEXAGON

Design & Engineering Business Unit



1965 - 1990

Founded and Pioneered FEA for the NASA moon landings

1990 - 2000

Setting the Gold Standard for FEA

2000 - 2009

Diversified into multibody dynamics

2009 - 2017

Expanded to Multiphysics solutions and first steps toward CAE for manufacturing

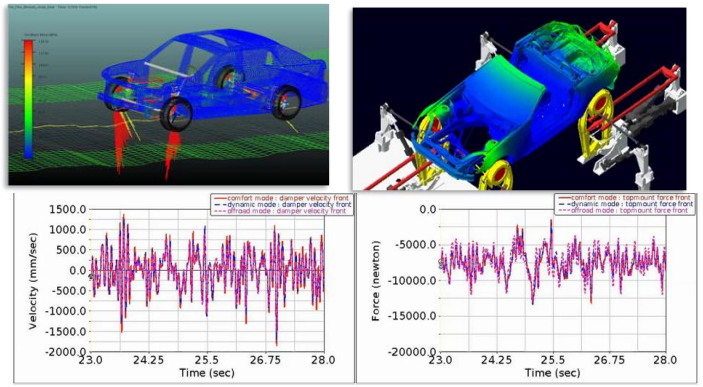
2017 onwards

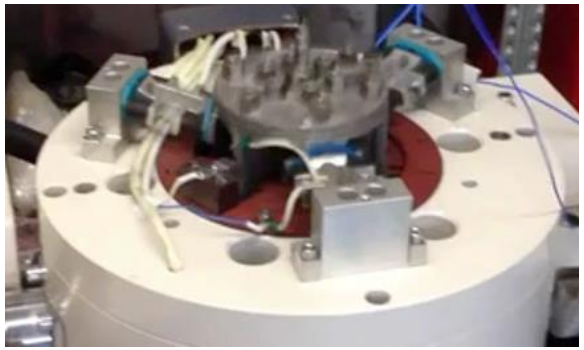
Acquired by Hexagon AB to be part of Hexagon's Manufacturing Intelligence division

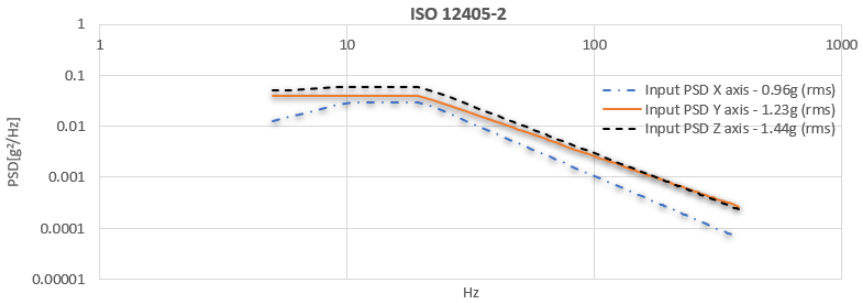
HEXAGON
Design & Engineering

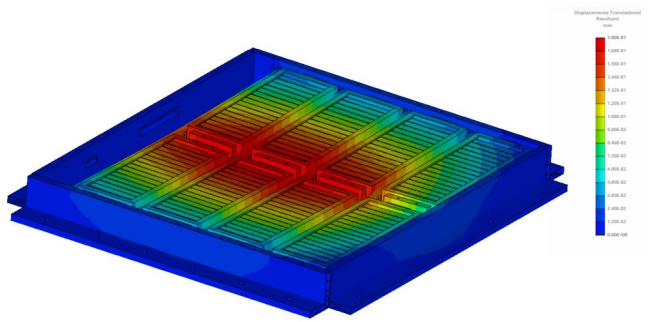
HEXAGON

1. Replicate lab conditions (shaker test)
2. From roads to loads (digitized roads) for full vehicle durability
3. Define and optimize vibration test (surrogate loads)



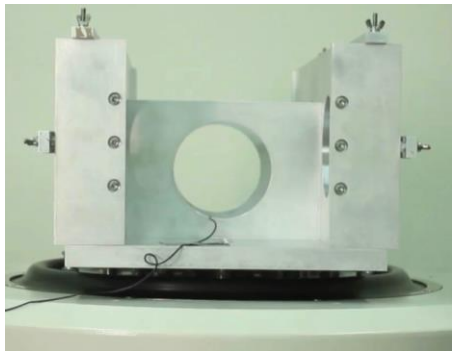




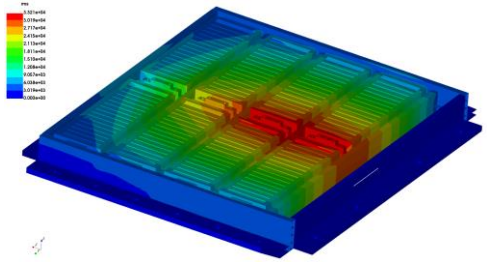


Some of the benefit of simulated test

- The frequency-based approach natively fits the vibrational certification requirements, from sine sweep analysis to random PSD profiles (as in IEC 62660-2, ISO 12405 SAE J2380, USABC, ECE R100, UN 38.3)
- Early Insights on damaging conditions and critical components, rapidly assessing multiple variants and what-if studies
- simulating other environmental effects (hard to represent in test) affecting fatigue material response, such as extreme high or low temperatures



Single Input Base



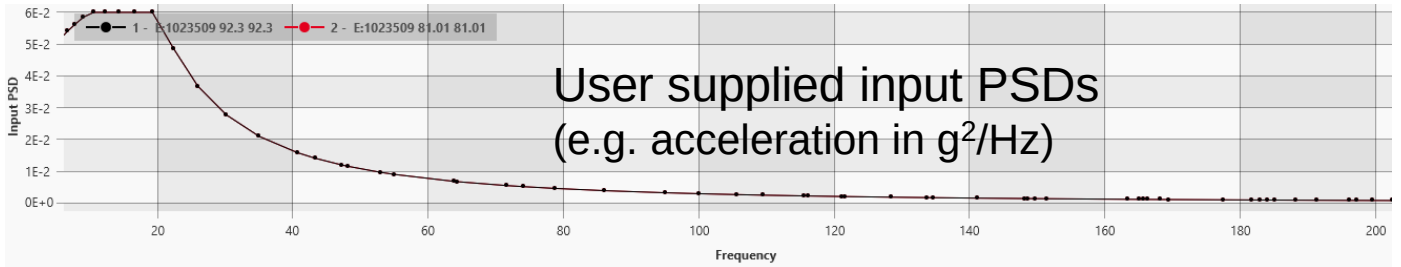
Input Loads (PSDs)

multiplied by

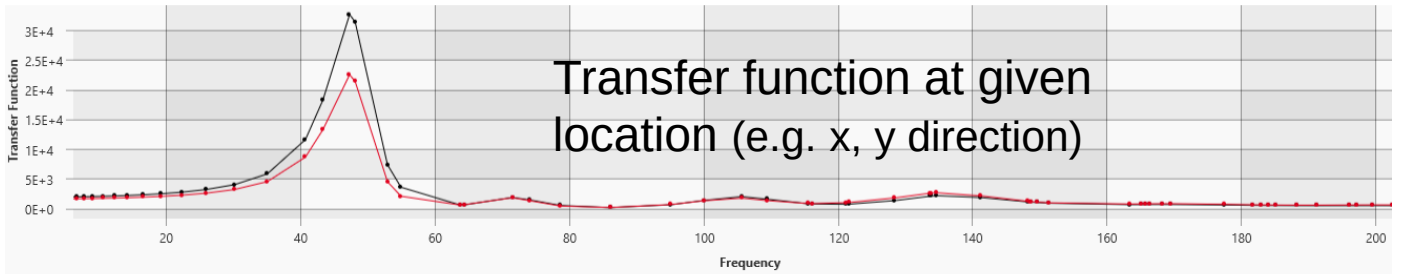
System Properties (Transfer Functions)

gives

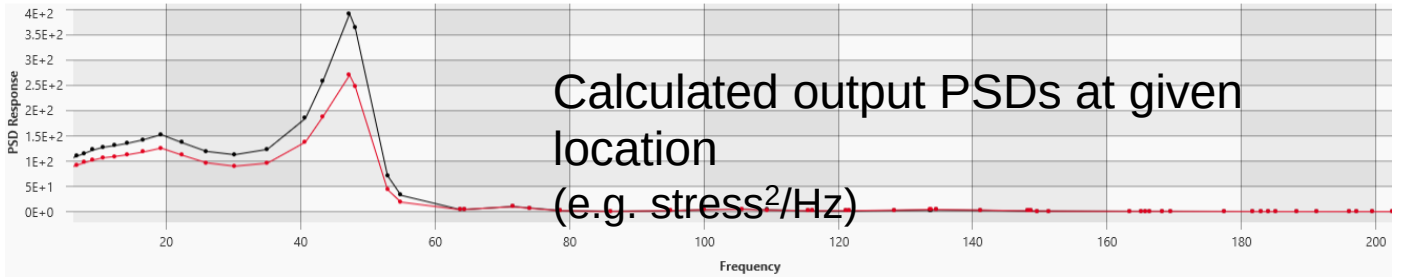
Response PSDs



User supplied input PSDs (e.g. acceleration in g^2/Hz)



Transfer function at given location (e.g. x, y direction)



Calculated output PSDs at given location (e.g. $stress^2/Hz$)

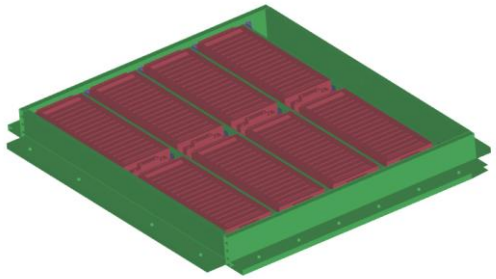
Focusing on the fatigue vibration simulation of a HV battery, in this presentation we are addressing loading and computation challenges, including

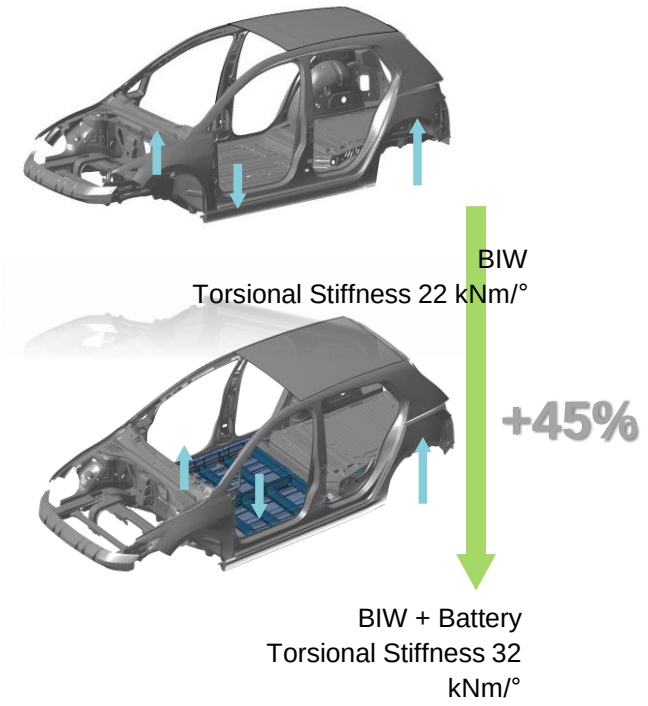
- The automation of key functions in conditioning acquired loads and in the generation of ready to use inputs for the frequency domain
- The use of structured and integrated workflows, shareable and repeatable, also for the benefit of non-specialist workforce
- A modern «native» frequency domain architecture leading to high computational efficiency

Hexagon EV model development roadmap

Design and Optimize the Battery Pack

- Load transfer paths
- Protect battery modules
- Durability





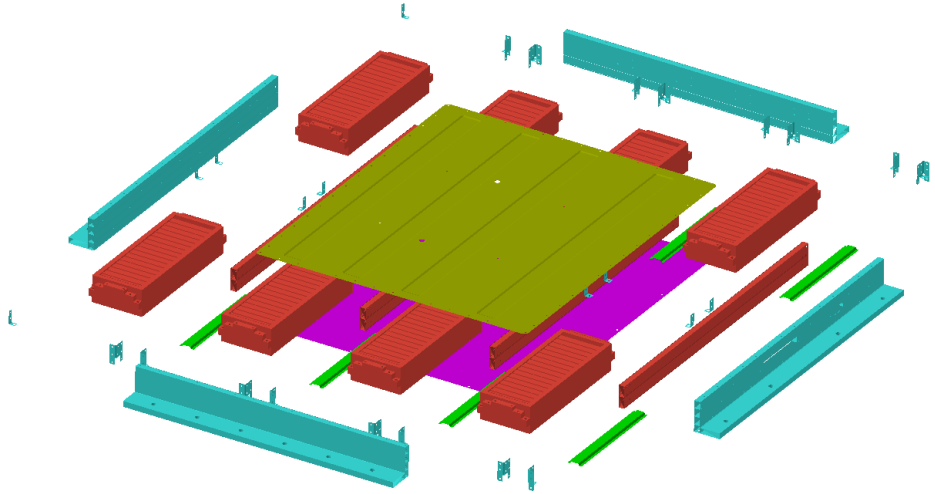
Integrate the Battery Tray into the EV BiW

- Leverage to improve global stiffness
- Define attach point requirements

Analyze Full-Vehicle Behavior

- Impacts
- Vehicle dynamics
- Durability

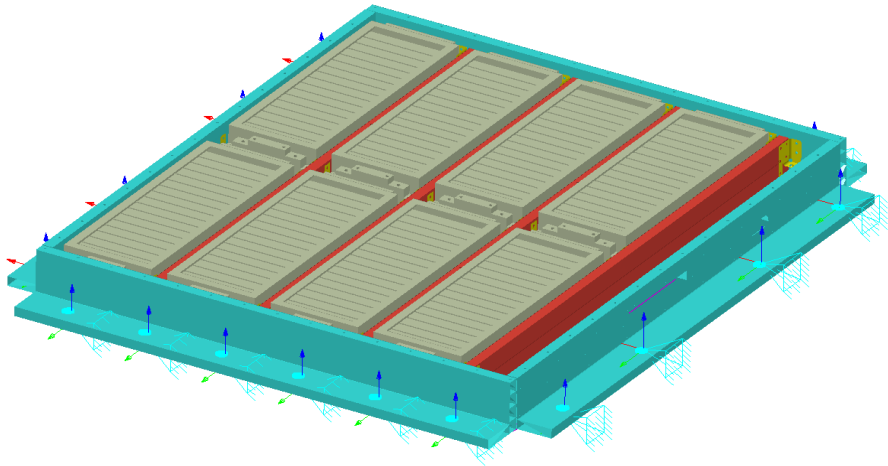
Hexagon HV Battery pack virtual test model

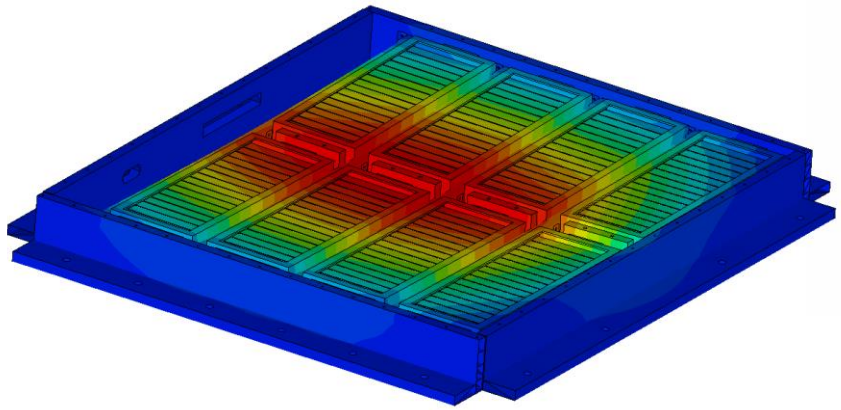


Model	Hexagon-CsBP
Energy	60 kWh
Capacity	150 Ah
Voltage	400 V
Cooling	Water-glycol
Mass	375 kg
Number of modules	8
Number of cells per module	17
Number of cells per battery	136
Cell type	Prismatic

FE model

- 767808 nodes
- 1M+ elements
- 15 properties
- 6 materials

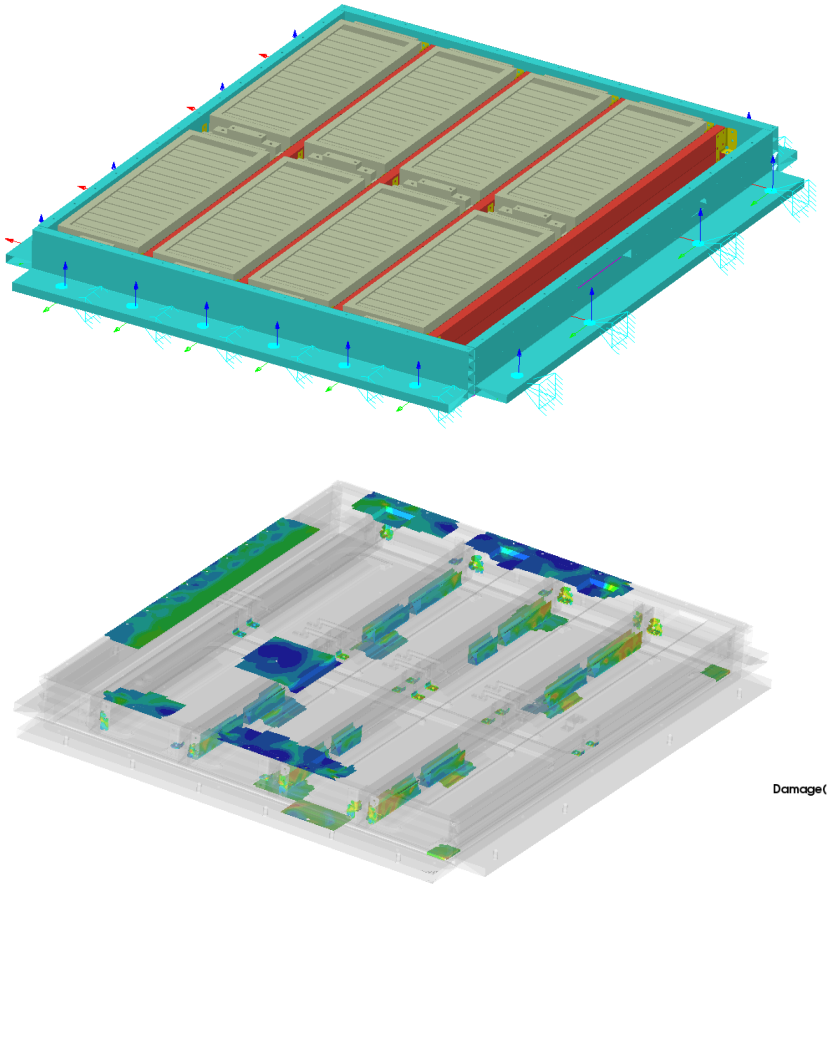




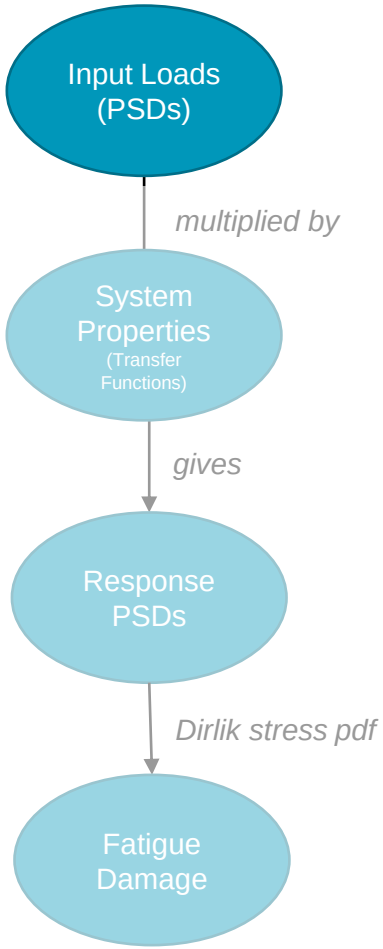
Vertical 1G load deformation

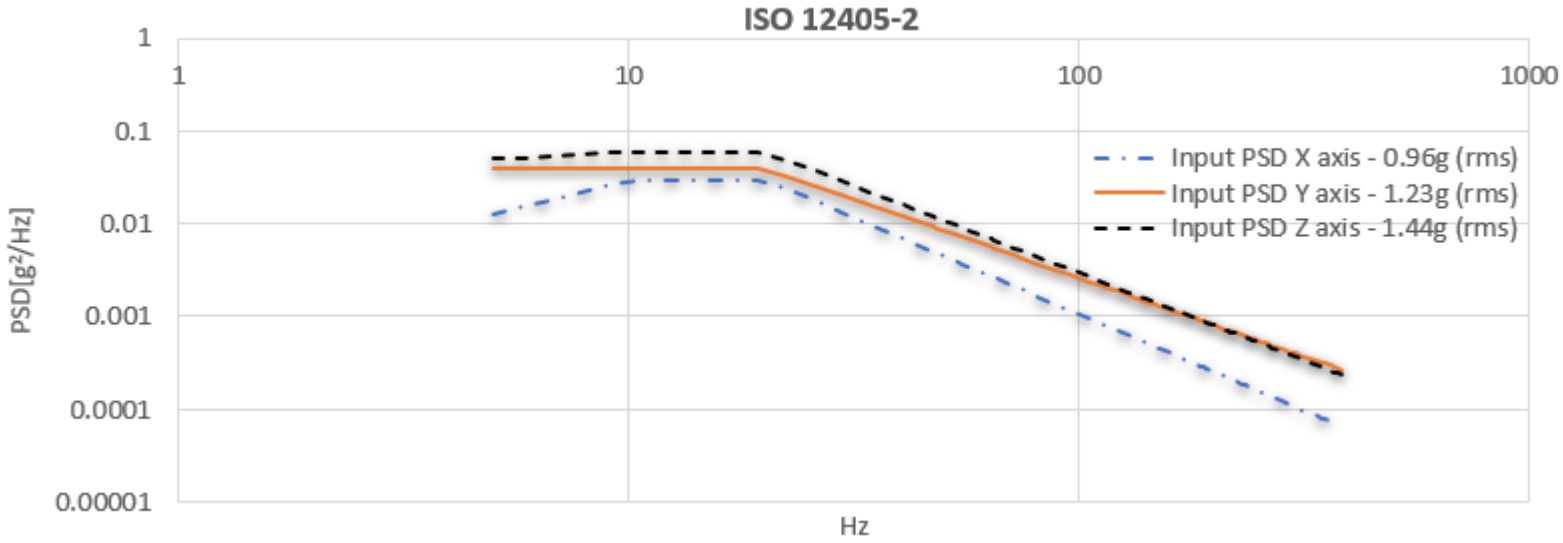
A simulation roadmap encompassing

- Obtaining FE transfer functions (x, y, z directions)
- Computing damage according to applicable standard
- Computing damage according to proving ground events



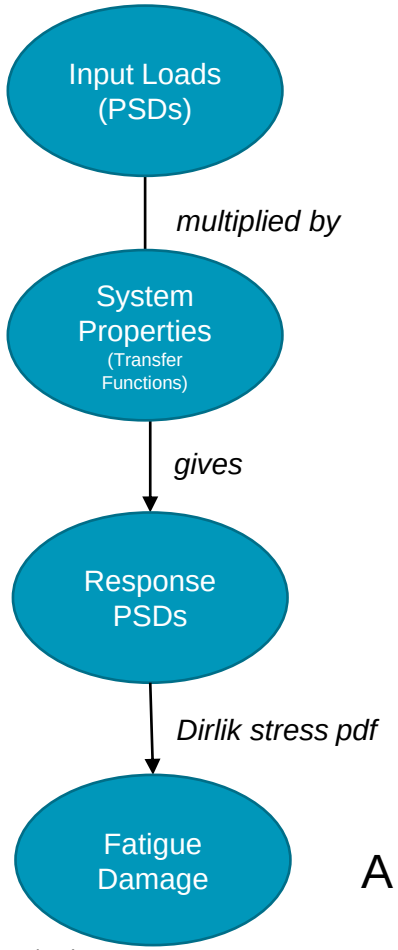
Individual Single Input Base (longitudinal X, lateral Y, vertical Z)

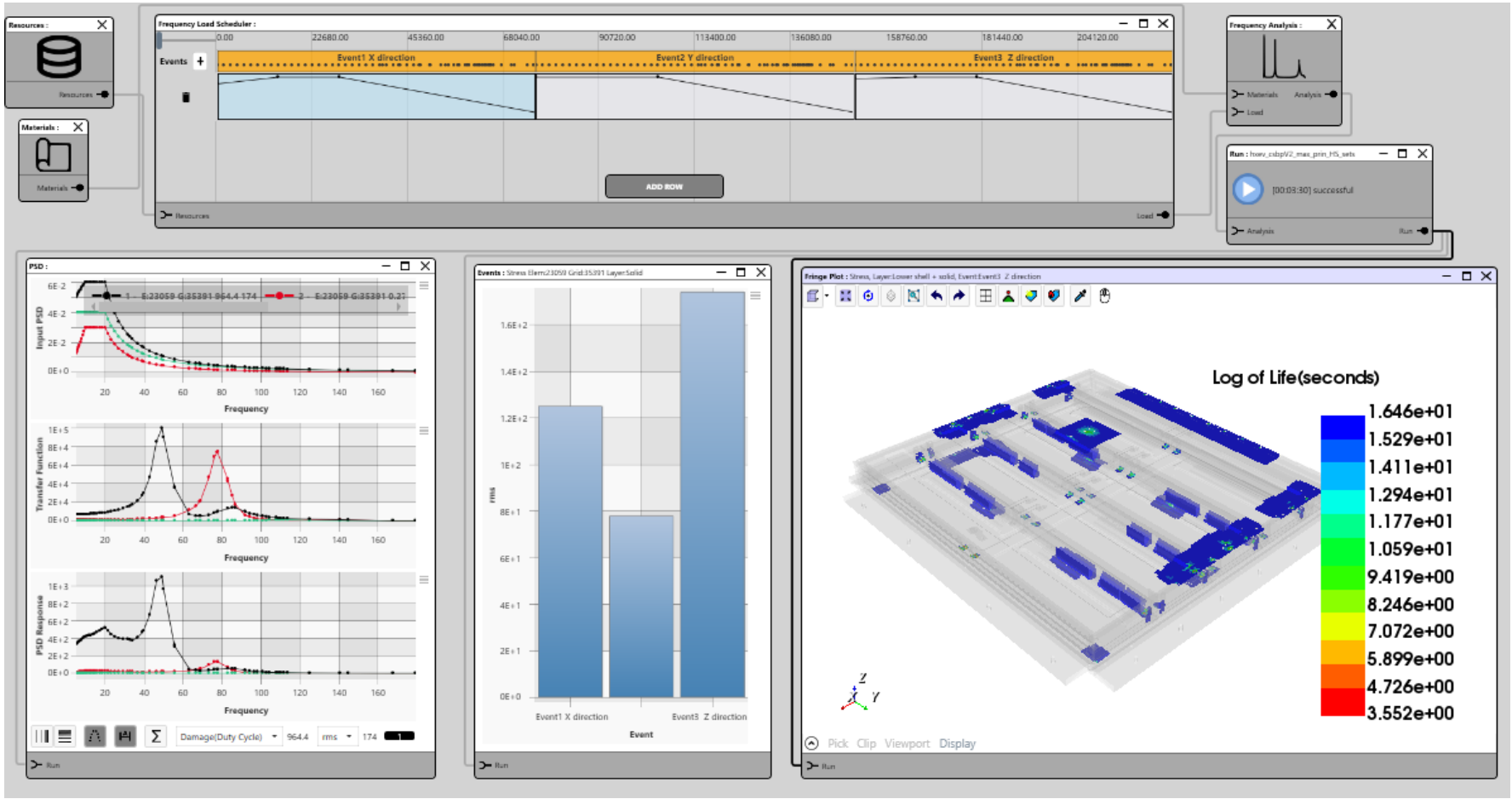




- Long. X (0.96g rms), Lat. Y (1.23g rms), Vert. Z (1.44g rms)
- 21 hours per axis

Individual Single Input Base (longitudinal X, lateral Y, vertical Z)

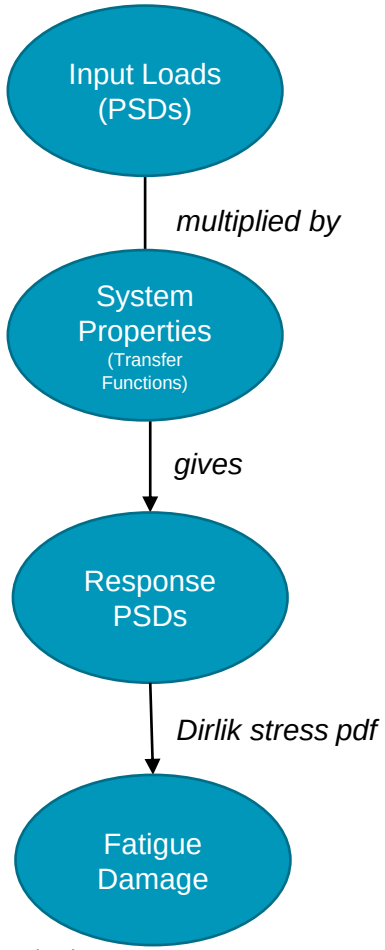




A two-pass approach for automatic hotspot detection

- output reduced from 30GB to 5GB in this case
- Adjust/increase frequency solution point distribution

Individual Single Input Base (longitudinal X, lateral Y, vertical Z)




```
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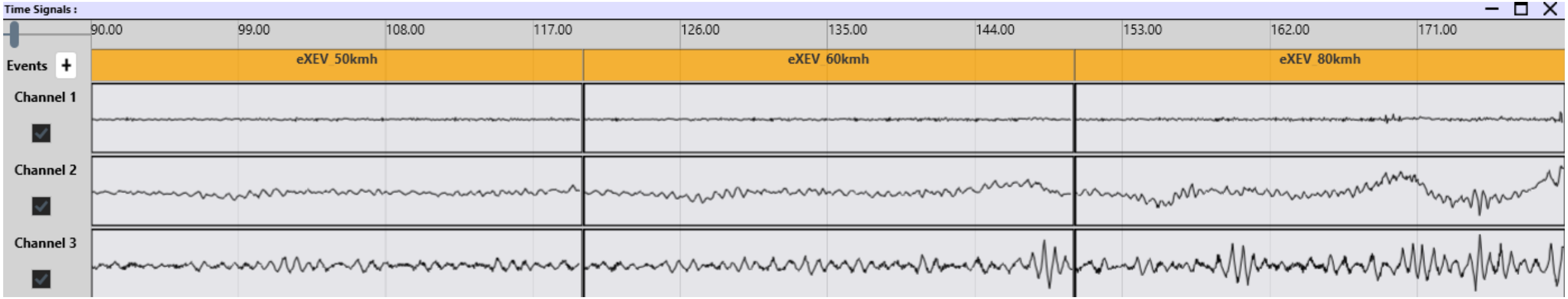
$
vibfat  777     csv     nasth5  corner  0       hxev_csbpV2_max_prin_HS_sets
vmatftg 60      MPa     range
        file    60      en      ID=ALUMINUM 6061-T6 (314) ParentID=
vudname 60
        C:\MSC.Software\CAEfatigue\2021.3\Windows\Resources\Materials\cfv_material_db.xml
fe_units777     MPA     1       B       N       mm
vftgdef 777     dirlik  100     60
vftgparm777
        stress  MAXPRESTNone    naver   None    1E-05
vftgseq 777     1       seconds         1       no
        101     75600   102     75600   103     75600
vftgevnt101     401
        name    Event1 X direction
vrandps 501     1       1       1       0       60
vftgevnt102     402
        name    Event2 Y direction
vrandps 502     2       2       1       0       61
vftgevnt103     403
        name    Event3  Z direction
vrandps 503     3       3       1       0       62
casemap E:\scratch\Battery_Pack\hxev_csbp_frespxyz_29septv1_hs_sets.h5
        1       1
        2       2
        3       3
vftgload401     psd     501     1
 1
vftgload402     psd     502     1
 2
vftgload403     psd     503     1
 3
vtabrnd 60      log     log
        4.9     0       5       0.0125  10      0.03    20      0.03
        200     0.00025 201     0       500     0       endt
vtabrnd 61      log     log
        4.9     0       5       0.04    20      0.04    200     0.0008
        201     0       500     0       endt
vtabrnd 62      log     log
        4.9     0       5       0.05    10      0.06    20      0.06
        200     0.0008  201     0       500     0       endt
```

- The visual workflow is bidirectionally linked to the (Nastran “inspired”) input txt file
- Simple editing leads to quick repeated analysis
- used interactively or in batch mode
- Fast restarts (no change of system properties)

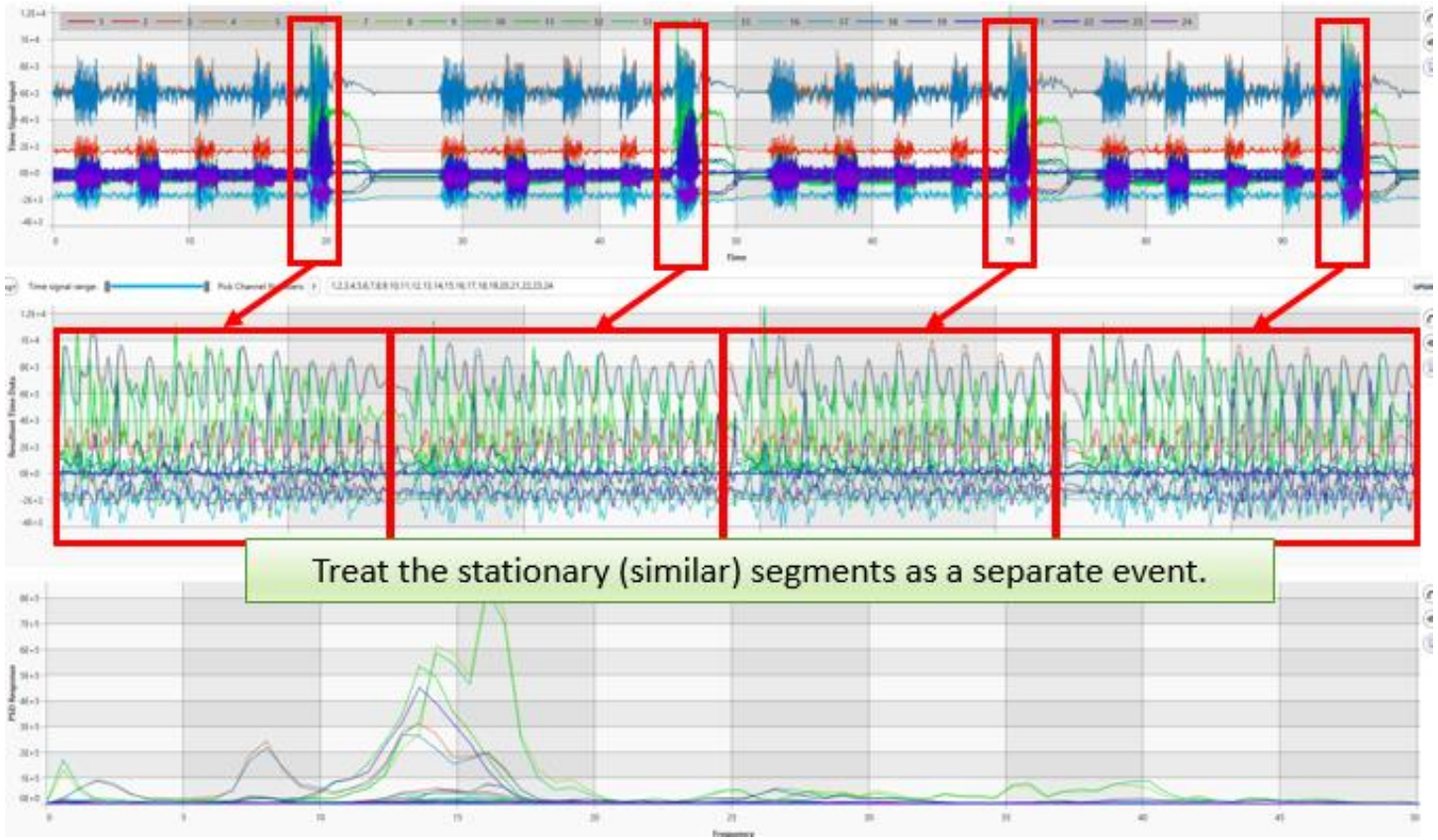
Vibration Fatigue Analysis with loads from virtual proving ground

- MBD provides X,Y,Z time loading at the Battery location for increasing constant speeds and/or for different configurations
- The time load needs to be converted to the frequency domain



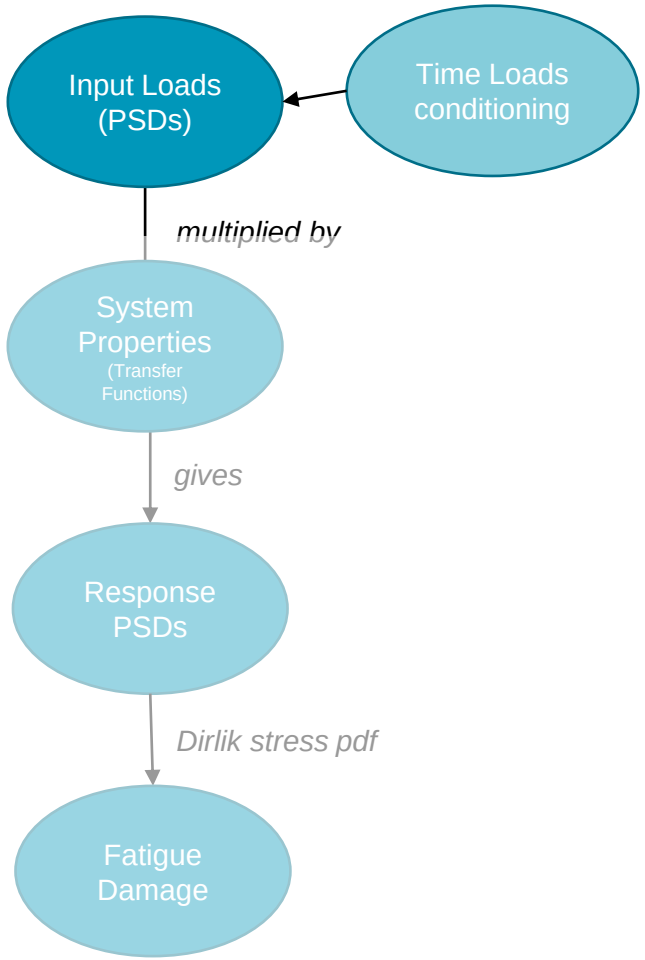
time domain loads conditioning and PSD generation -“Time2PSD”

- Editing the signals and generating readily available frequency domain input
  - Mean stress removal
  - Stationarity checks
  - Collate statistically similar sections
  - Auto choice of FFT buffer length (T) for all events simultaneously
  - Generate correlated input PSD matrix (accounting for phase relationship between channels)

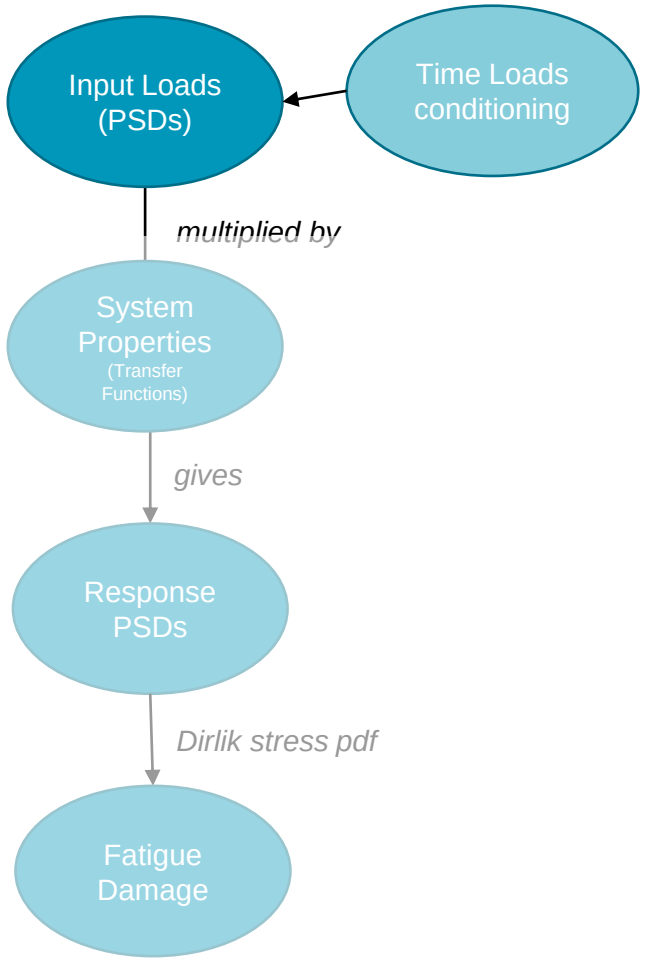


Direct PSD 1-1	Cross PSD 1-2	Cross PSD 1-3	Cross PSD 1-4
Cross PSD 1-2	Direct PSD 2-2	Cross PSD 2-3	Cross PSD 2-4
Cross PSD 1-3	Cross PSD 2-3	Direct PSD 3-3	Cross PSD 3-4
Cross PSD 1-4	Cross PSD 2-4	Cross PSD 3-4	Direct PSD 4-4

Individual Single Input Base (longitudinal X, lateral Y, vertical Z)



Individual Single Input Base (longitudinal X, lateral Y, vertical Z)

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vibfat  777                             1       time2psd_battery_pack
time2psd200     1       9001    6       hanning csv
        mapping 1       3               2       3       4
        autoT   0.5     200     2       50      5
        autoD   0.5     50      1
        ev_opts 1
        D:\CAEFatigue\USE_CASES\Batteries\CARHS_conf\MBD_Signals\time2psd_battery_pack_cfjob\time2psd_battery_pack_timedata_baseline_50kmh.csv
        ev_opts 2
        D:\CAEFatigue\USE_CASES\Batteries\CARHS_conf\MBD_Signals\time2psd_battery_pack_cfjob\time2psd_battery_pack_timedata_baseline_60kmh.csv
        ev_opts 3
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        ev_opts 4
        D:\CAEFatigue\USE_CASES\Batteries\CARHS_conf\MBD_Signals\time2psd_battery_pack_cfjob\time2psd_battery_pack_timedata_eXEV_50kmh.csv
        ev_opts 5
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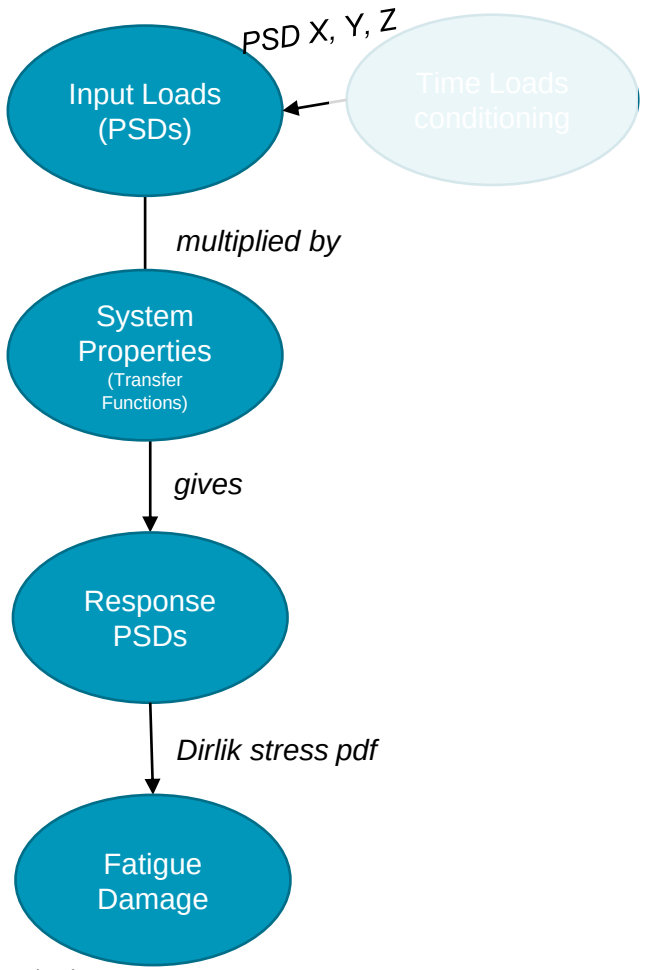
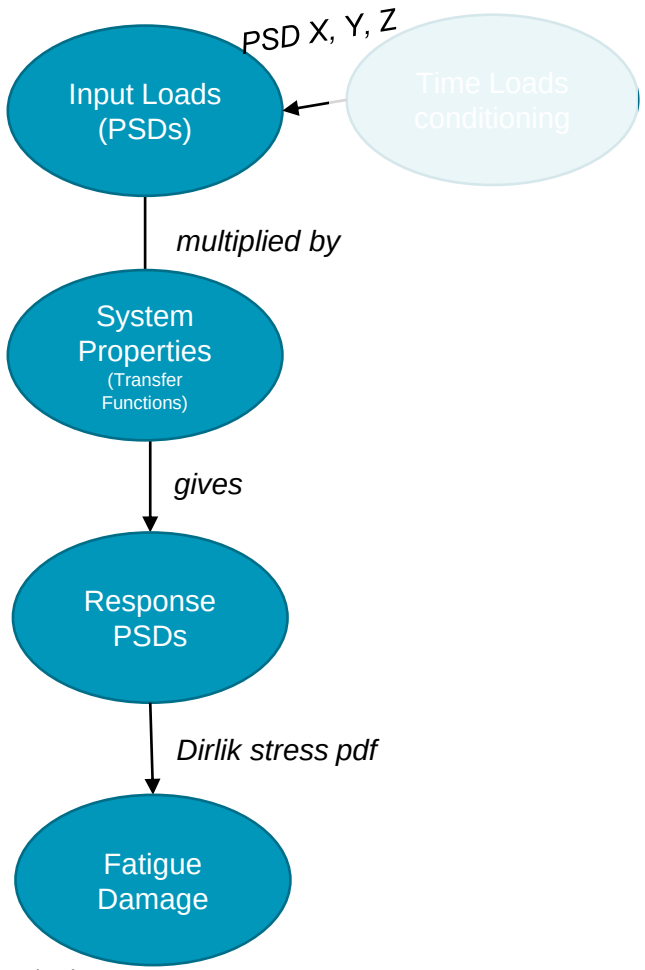
```

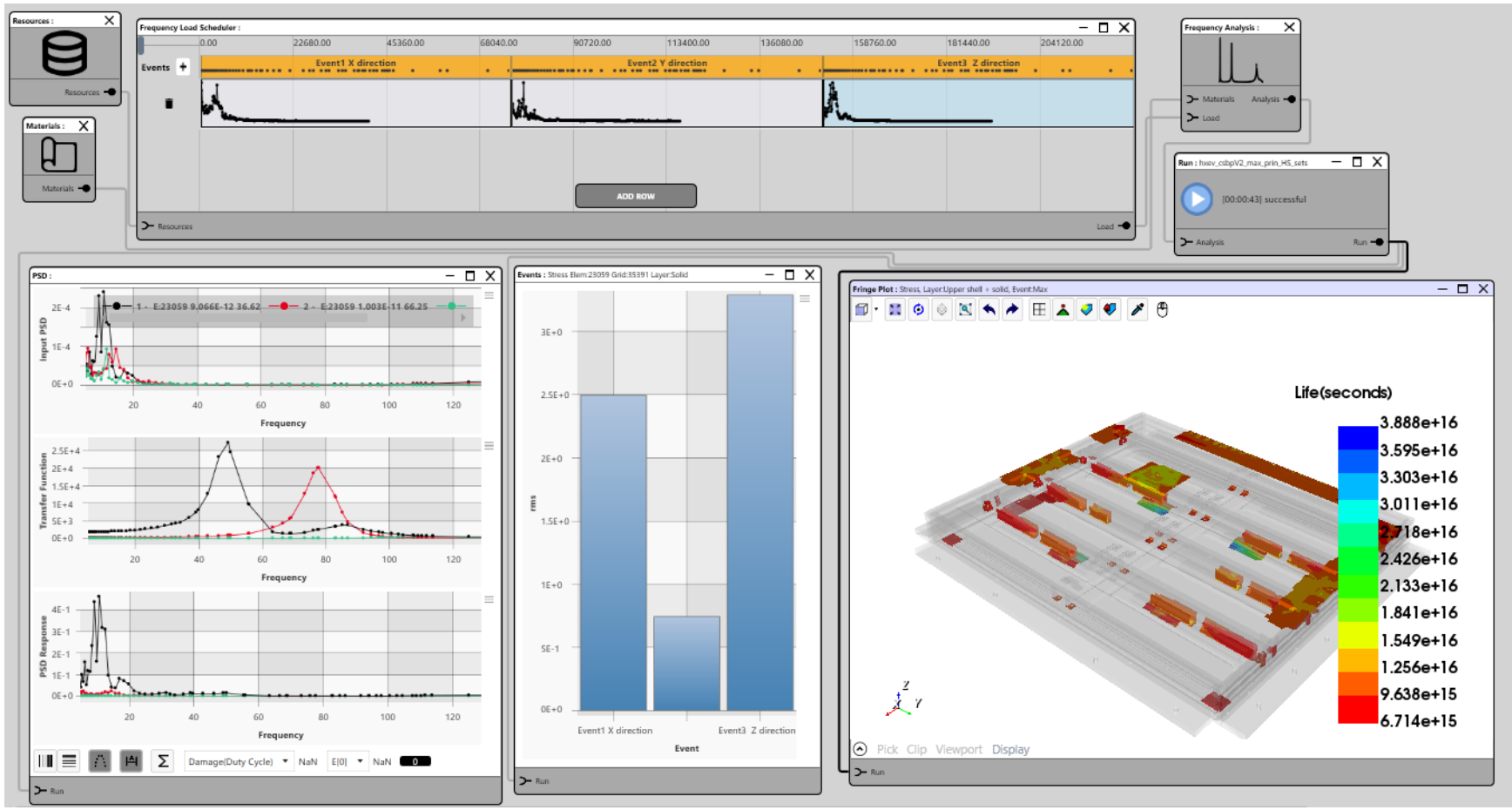
- Again, the piped workflow is bidirectionally linked to the “control file” for batch/ scripted mode operation
- Simple editing leads to quick repeated analysis on multiple events

Individual Single Input Base (longitudinal X, lateral Y, vertical Z)

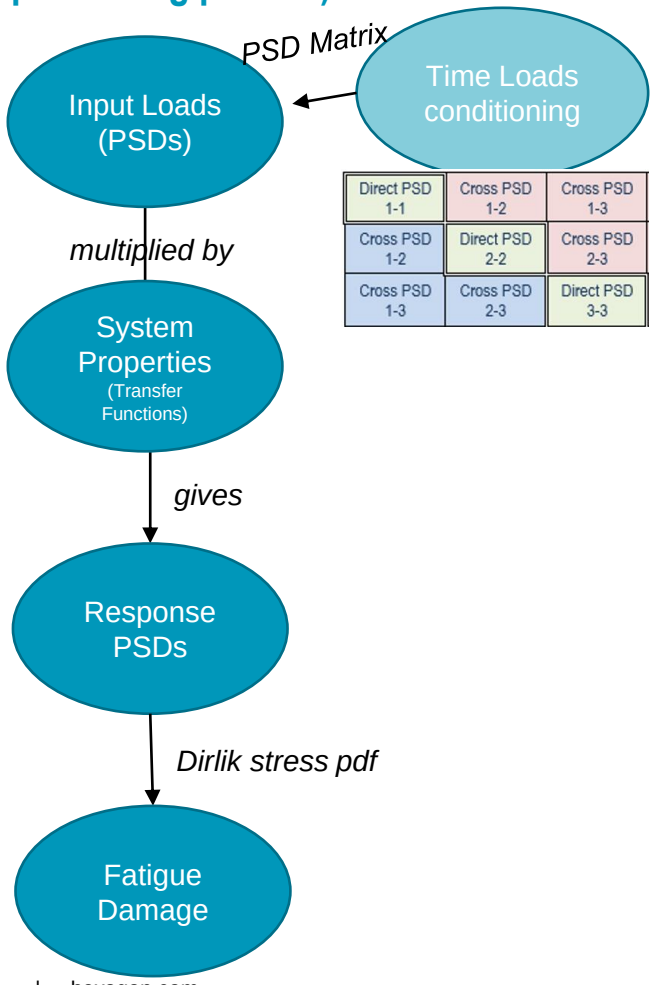


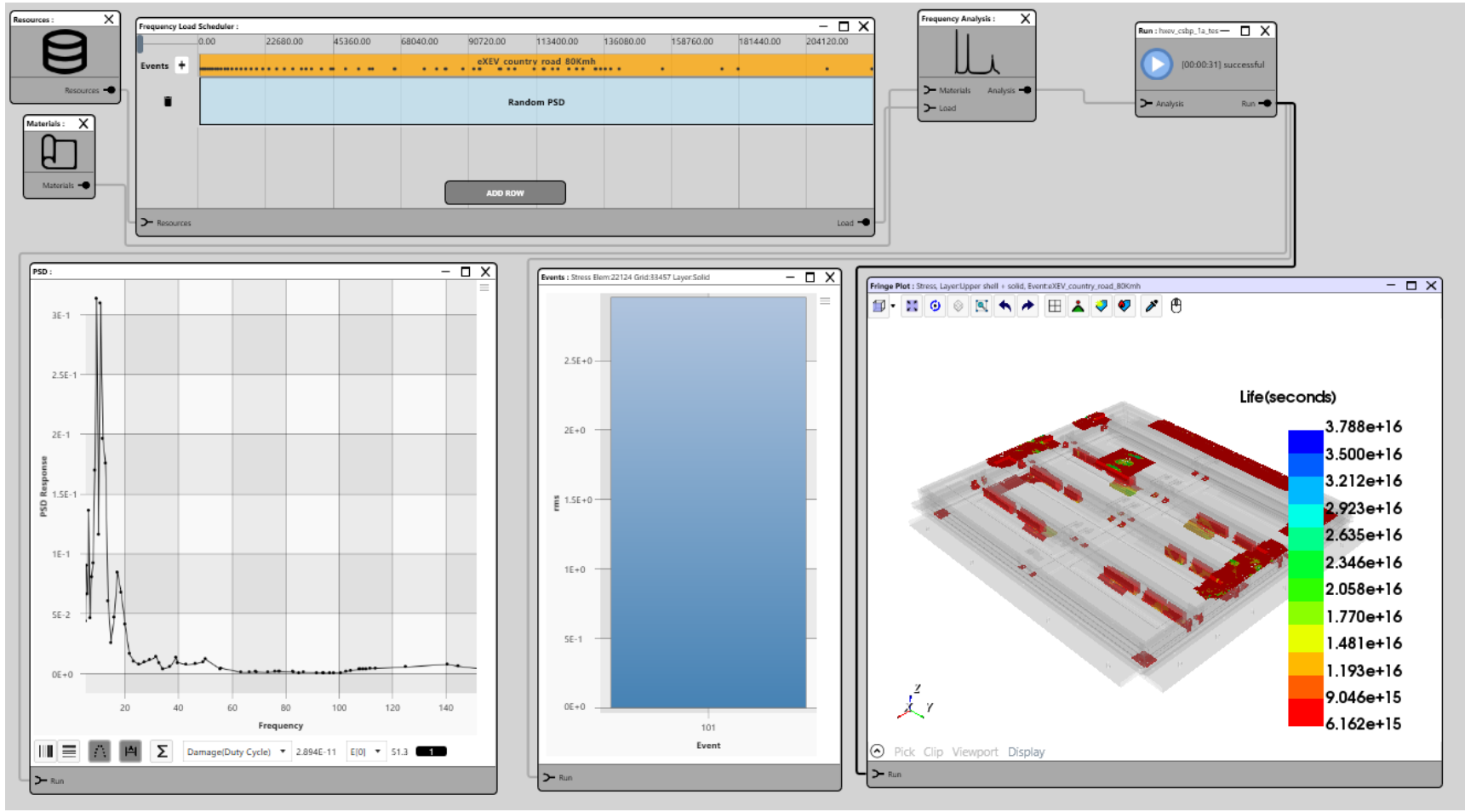
Individual Single Input Base (longitudinal X, lateral Y, vertical Z)

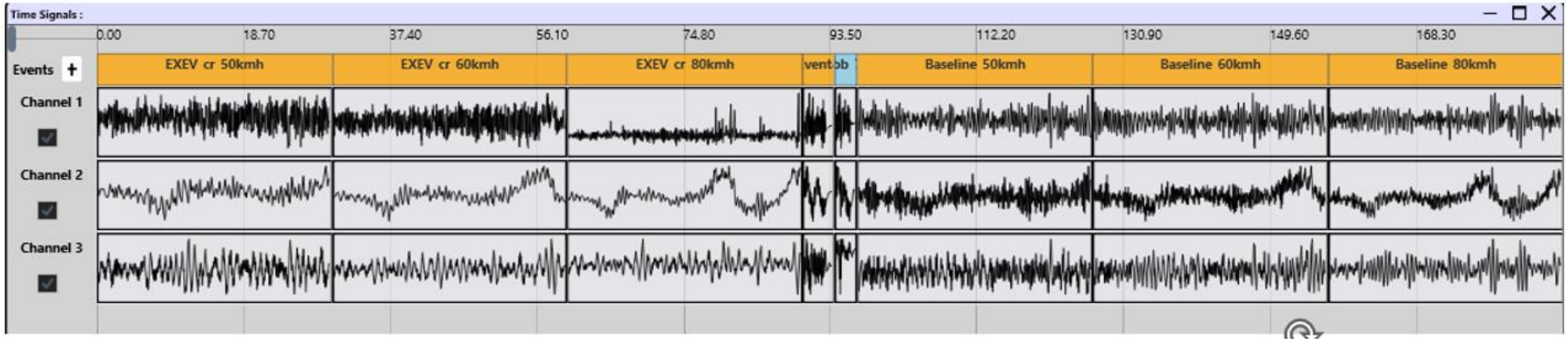


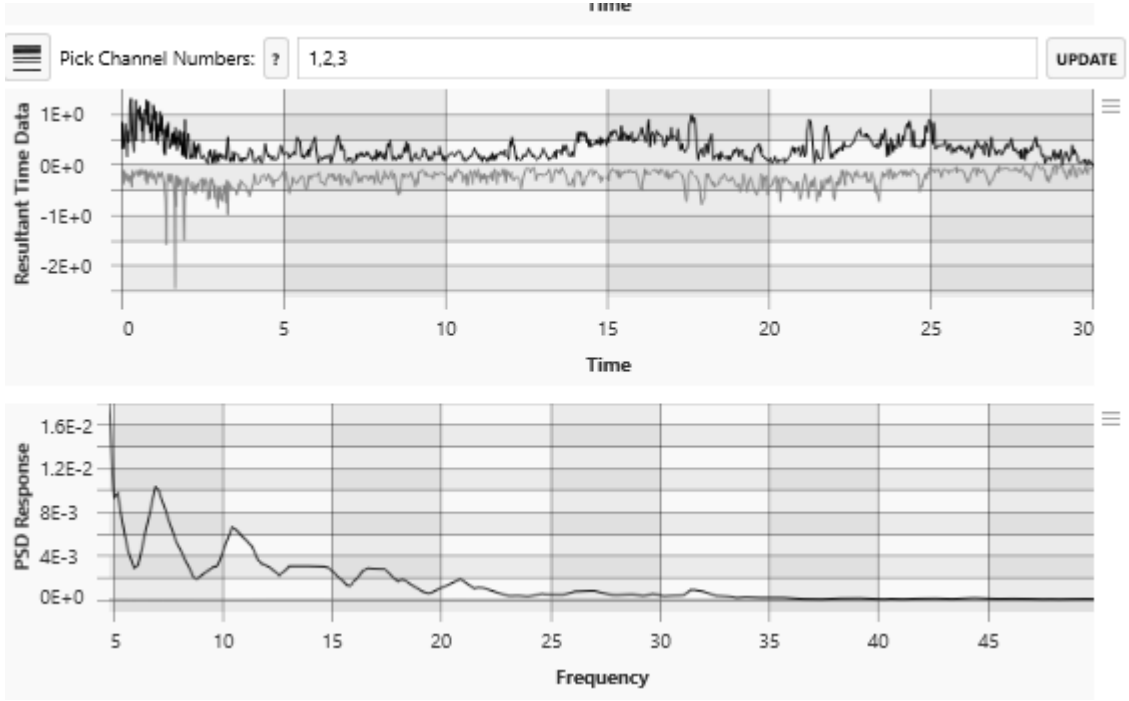


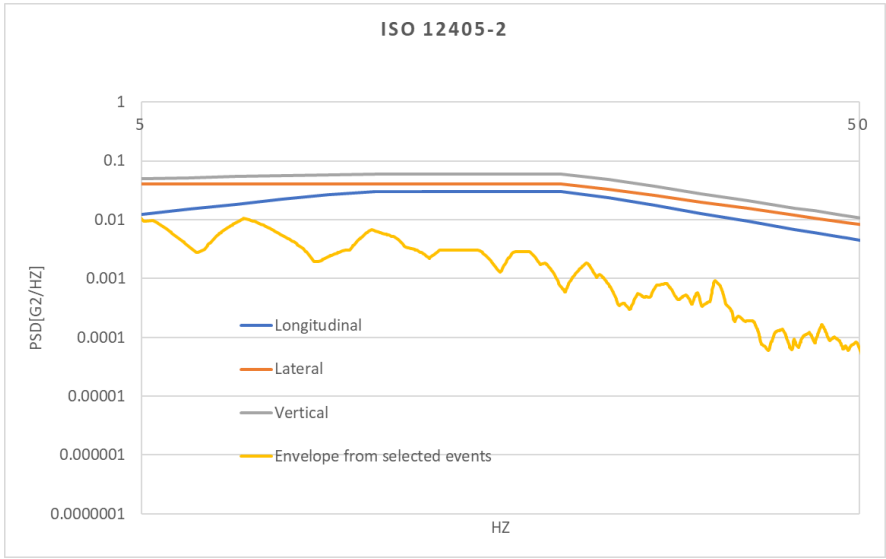
PSD Matrix (correlated multi channel, preserving phases)






Time Signals :
0.00
18.70
37.40
56.10
74.80
93.50
112.20
130.90
149.60
168.30
Events
EXEV cr 50kmh
EXEV cr 60kmh
EXEV cr 80kmh
ventob
Baseline 50kmh
Baseline 60kmh
Baseline 80kmh
Channel 1
Channel 2
Channel 3


Pick Channel Numbers:
1,2,3
UPDATE
Resultant Time Data
1E+0
0E+0
-1E+0
-2E+0
0
5
10
15
20
25
30
Time
PSD Response
1.6E-2
1.2E-2
8E-3
4E-3
0E+0
5
10
15
20
25
30
35
40
45
Frequency


ISO 12405-2
PSD[G2/HZ]
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
5
50
HZ
Longitudinal
Lateral
Vertical
Envelope from selected events

Examples of FE-MBS integrated vibration fatigue workflows have been shown on a reference HV battery pack

- Visual and graphically driven workflows with nested frequency domain load conditioning
    - Enhance our capability to understand, interpret, modify/react and repeat (early)
    - Are easily shareable and repeatable across a team, including non-specialists
    - help abridging simulation with testing as well as OEMs with suppliers

- The nature of the frequency domain combined with modern algorithm efficiency enables processing of very large problems with limited computational resources (home office laptop), as well as working in batch (e.g. Linux sever or cloud)

A team of Hexagon senior simulation specialists have contributed to this presentation:

- Fatigue modelling: Dr **Marco Veltri**, Dr **Neil Bishop, Benjamin Grozdanic,**
- Battery Design: Dr **Luca Castignani**
- FE modelling: **Richard White**
- Multibody Dynamics: **Mauro Vesco**, **Manuel Chene**

Thank you for your attention!