Machine Learning im CAE

Saxsim 2023

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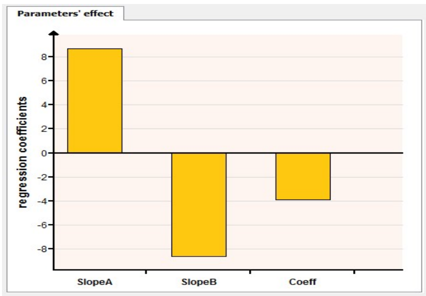
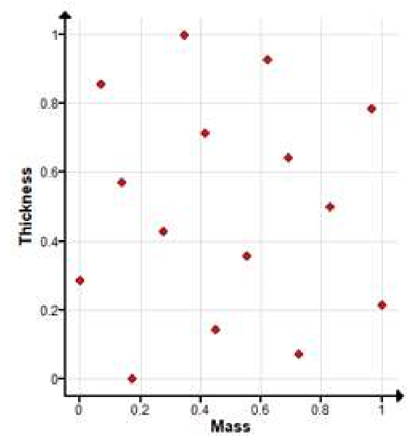
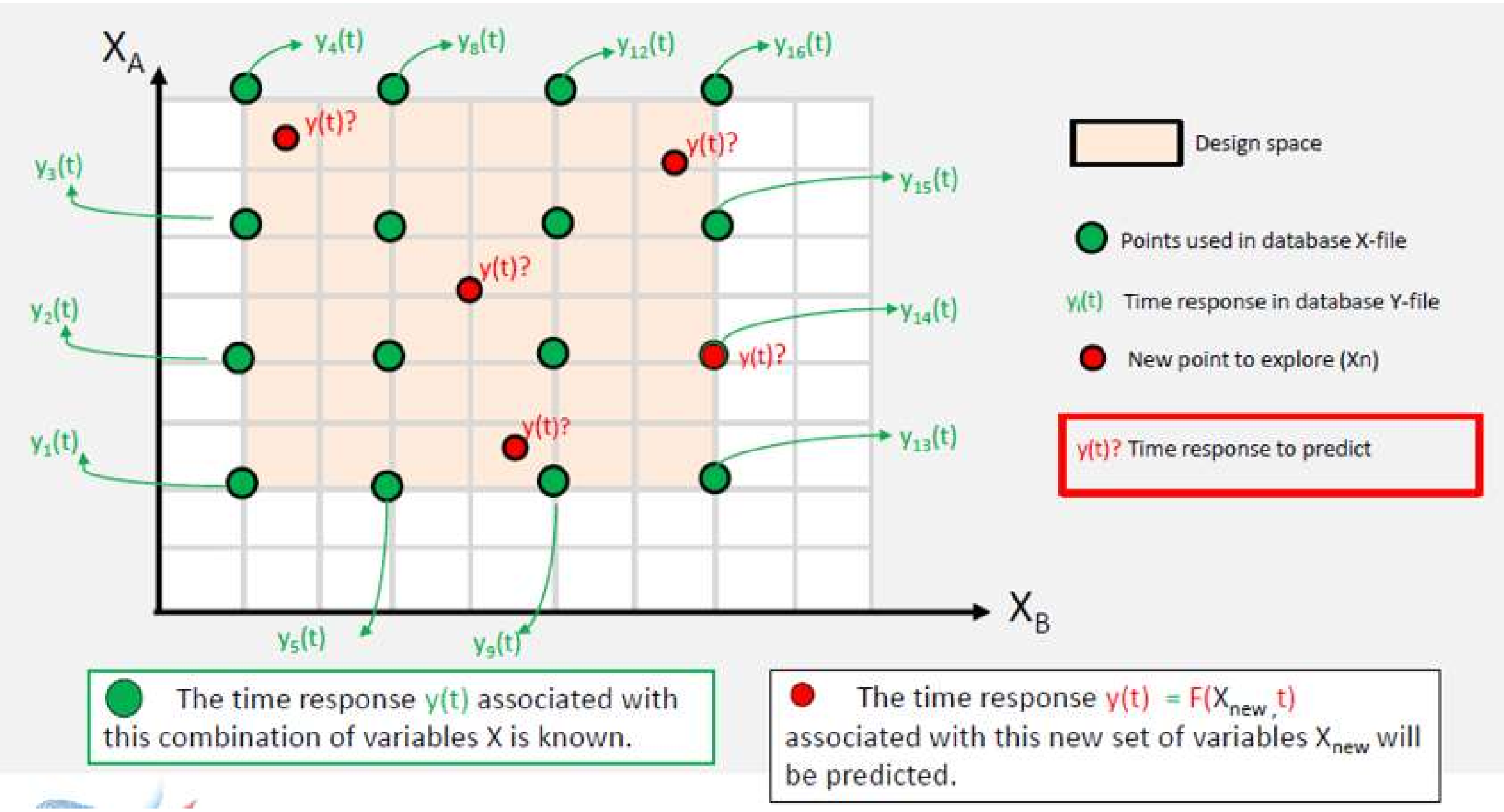
ODYSSEE – Overview

- From available analysis, test results or measurements, predict responses for further data points
- ODYSSEE delivers the response in seconds
- Predict results values, curves and animations
- Improve parameters of manufacturing processes
- Input: csv files
- Can use images instead of parameters
- Easy-to-use GUI
- Scripting possible
- Create and improve DOE
- Plot tool for correlation, PCA, heat map, etc.
- Optimization, e.g. adapt analysis model to test result curve





Task Formulation



Input: Learning base
F(x) = Y
(Existing analysis or test data)

Output: $F(x_{new}) = ?$

Y can be a curve Y(t)

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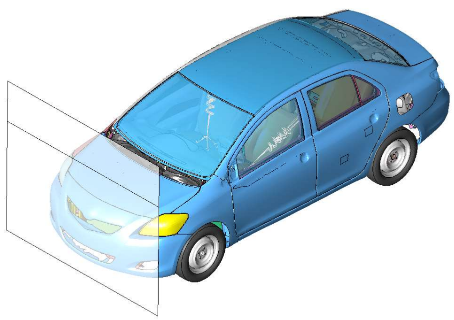
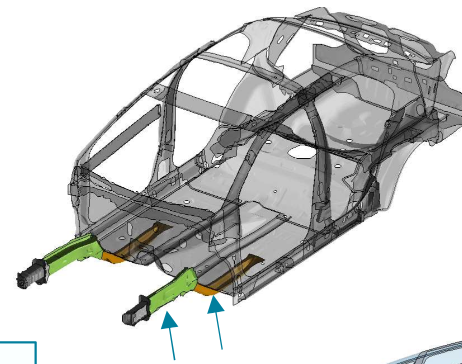
Example – ‘Yaris Front crash’

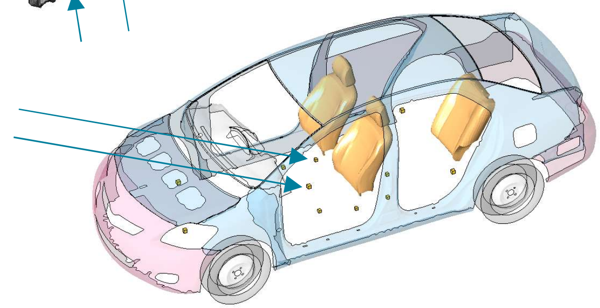


Source Model : https://www.ccsa.gmu.edu/models/2010-toyota-yaris/

3 Model parameters:
Rail inner thickness => X1
Floor support thickness => X2
Velocity => X3



Output channels:
Driver seat acceleration=> Y1
Rigid wall Force => Y2
Gravity center acceleration => Y3

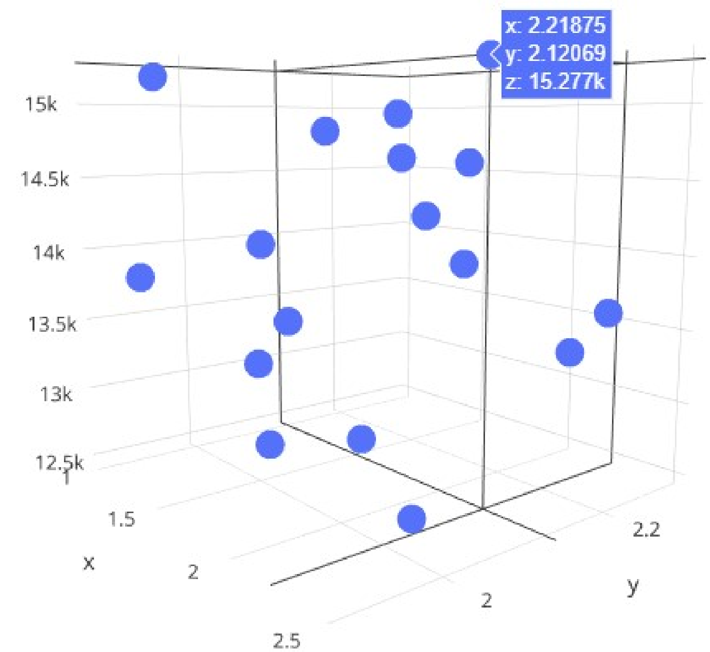


DOE of 17 runs

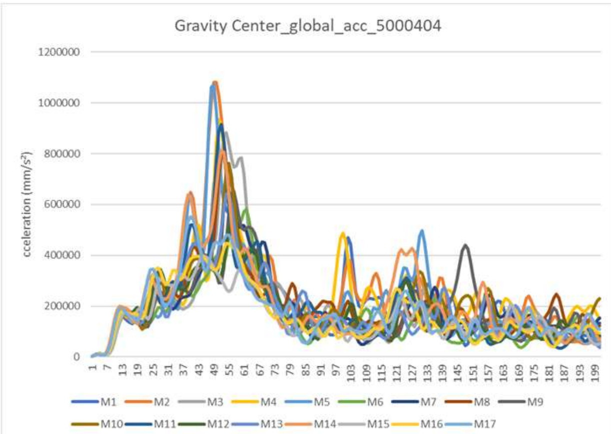
Finite Elements	Lunar
3h per simulation	2 seconds

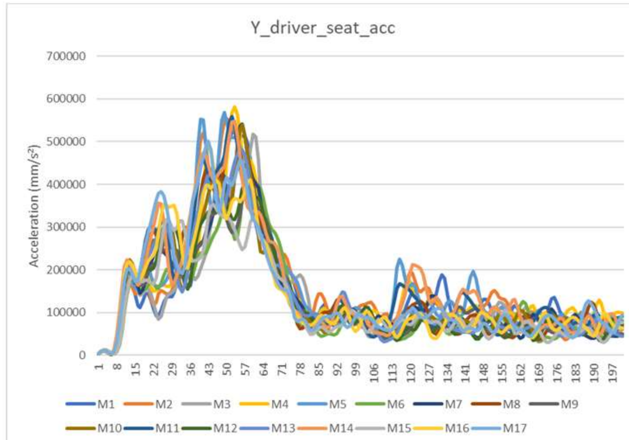
Example – 'Yaris Front crash'

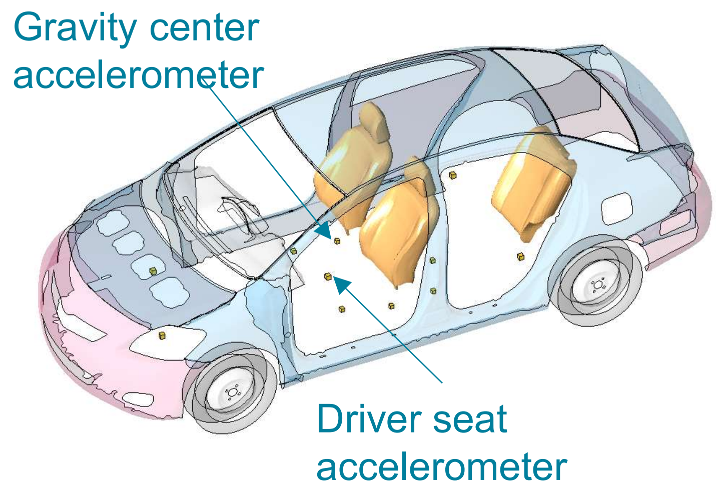
	Rail inner thickness (mm)	Floor support thickness (mm)	Velocity (mm/s)
M1	1,00	1,94	13772,80
M2	1,09	2,16	14814,20
M3	1,19	2,05	13078,50
M4	1,28	2,27	14119,90
M5	1,38	1,91	15161,30
M6	1,47	2,13	12500,00
M7	1,56	2,02	13541,40
M8	1,66	2,24	14582,80
M9	1,75	1,97	12847,10
M10	1,84	2,19	13888,50
M11	1,94	2,08	14929,90
M12	2,03	2,30	13194,20
M13	2,13	1,90	14235,60
M14	2,22	2,12	15277,00
M15	2,31	2,01	12615,70
M16	2,41	2,23	13657,10
M17	2,50	1,96	14698,50

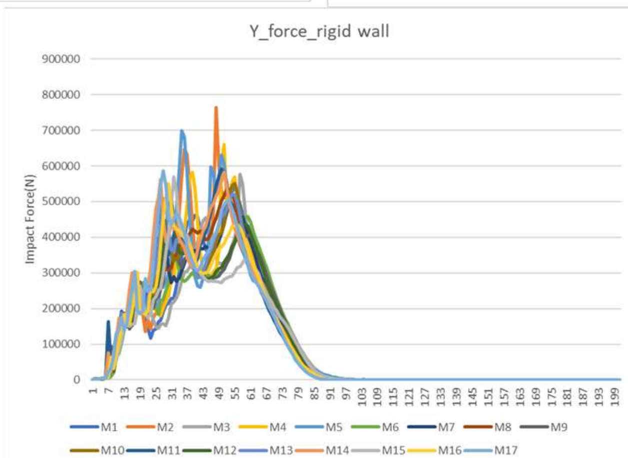


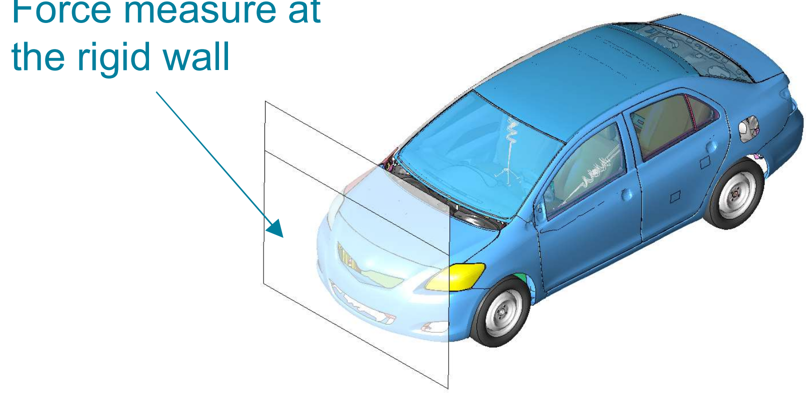
Example – 'Yaris Front crash'







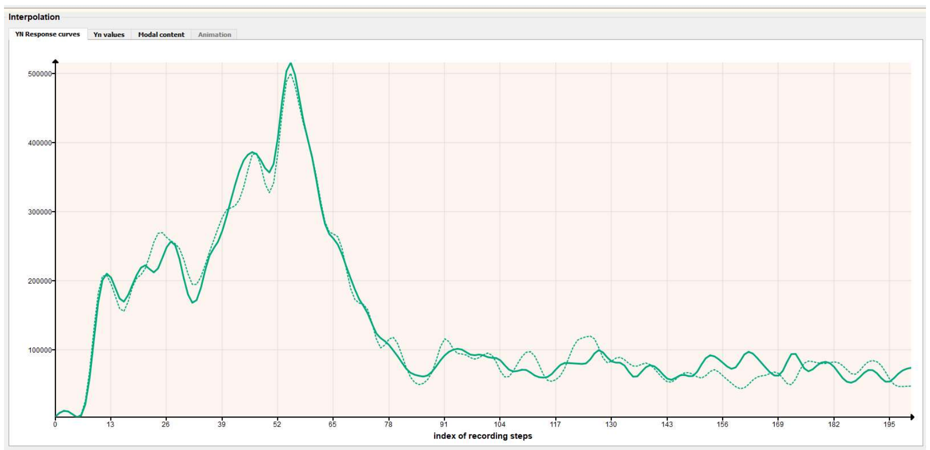


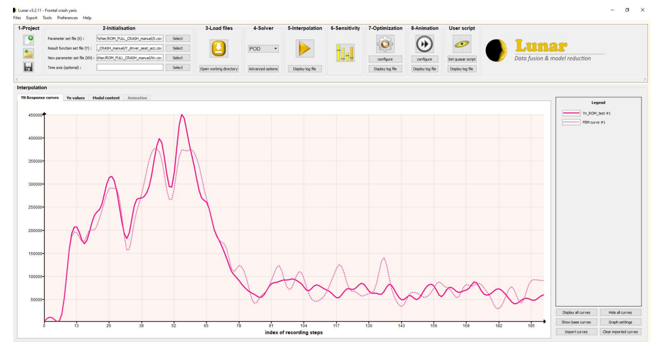


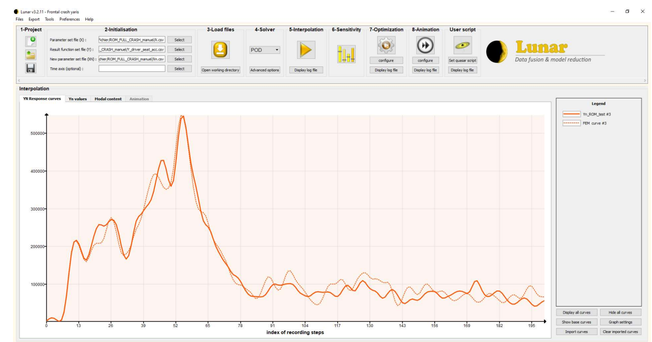
Example – ‘Yaris Front crash’

Driver seat acceleration

POD KRG quadratic h1





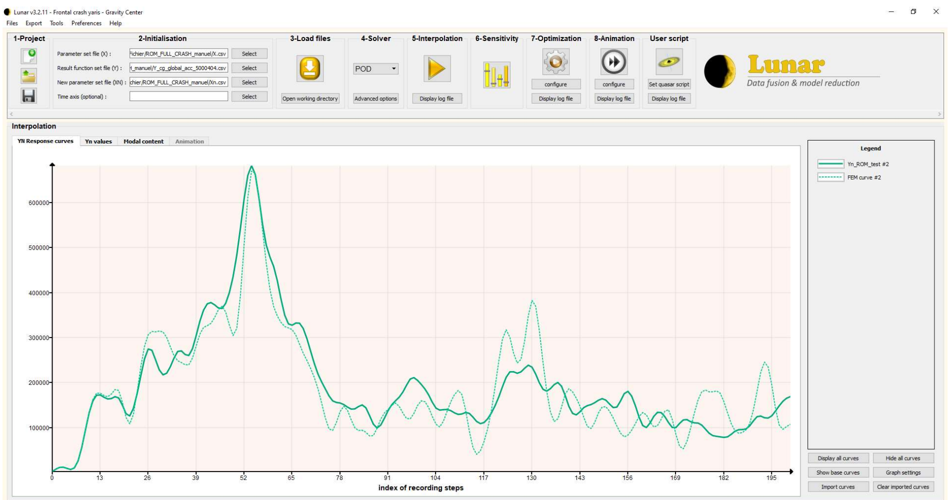


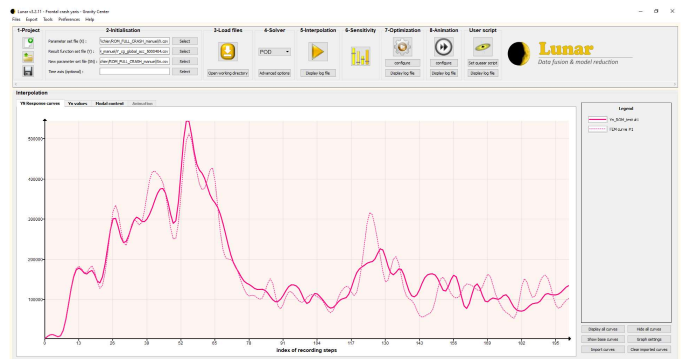
Lunar: 1 s   FEM : 3h

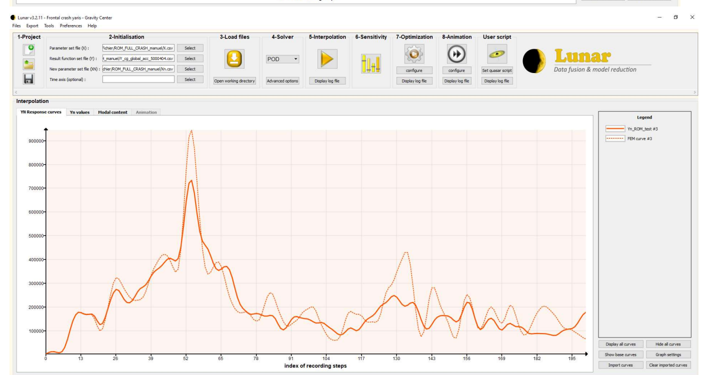
Example – 'Yaris Front crash'

Gravity centre acceleration

POD ARBF







Lunar
Data fusion & model reduction

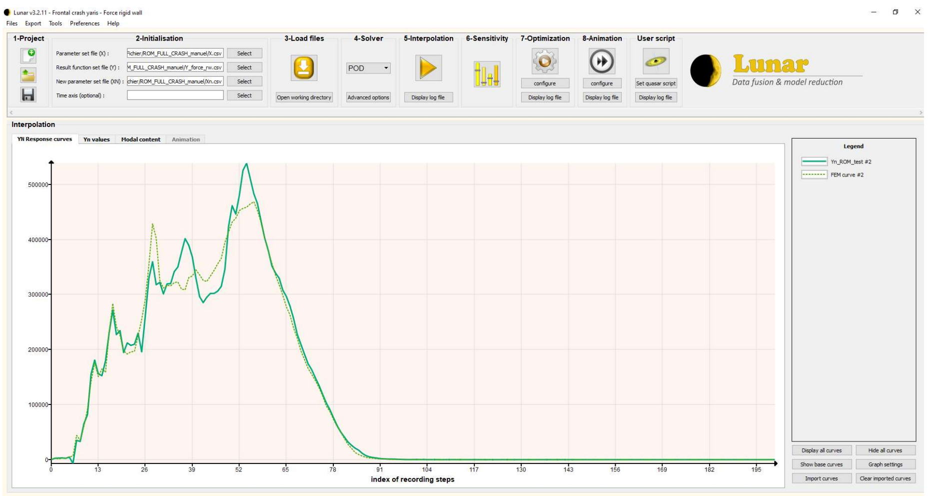
Lunar: 1 s

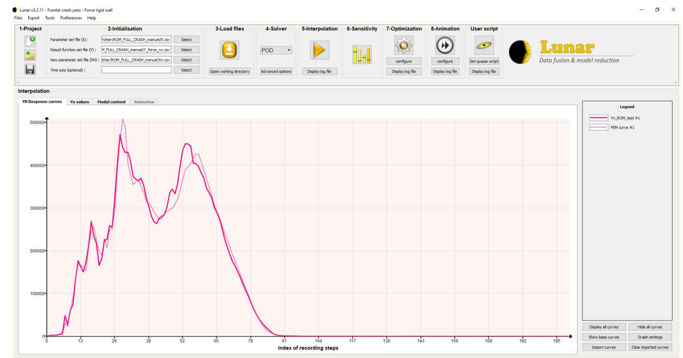
FEM : 3h

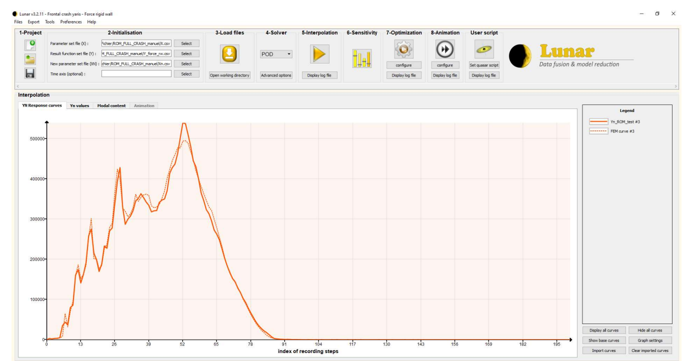
Example – 'Yaris Front crash'

Rigid Wall force

POD ARBF





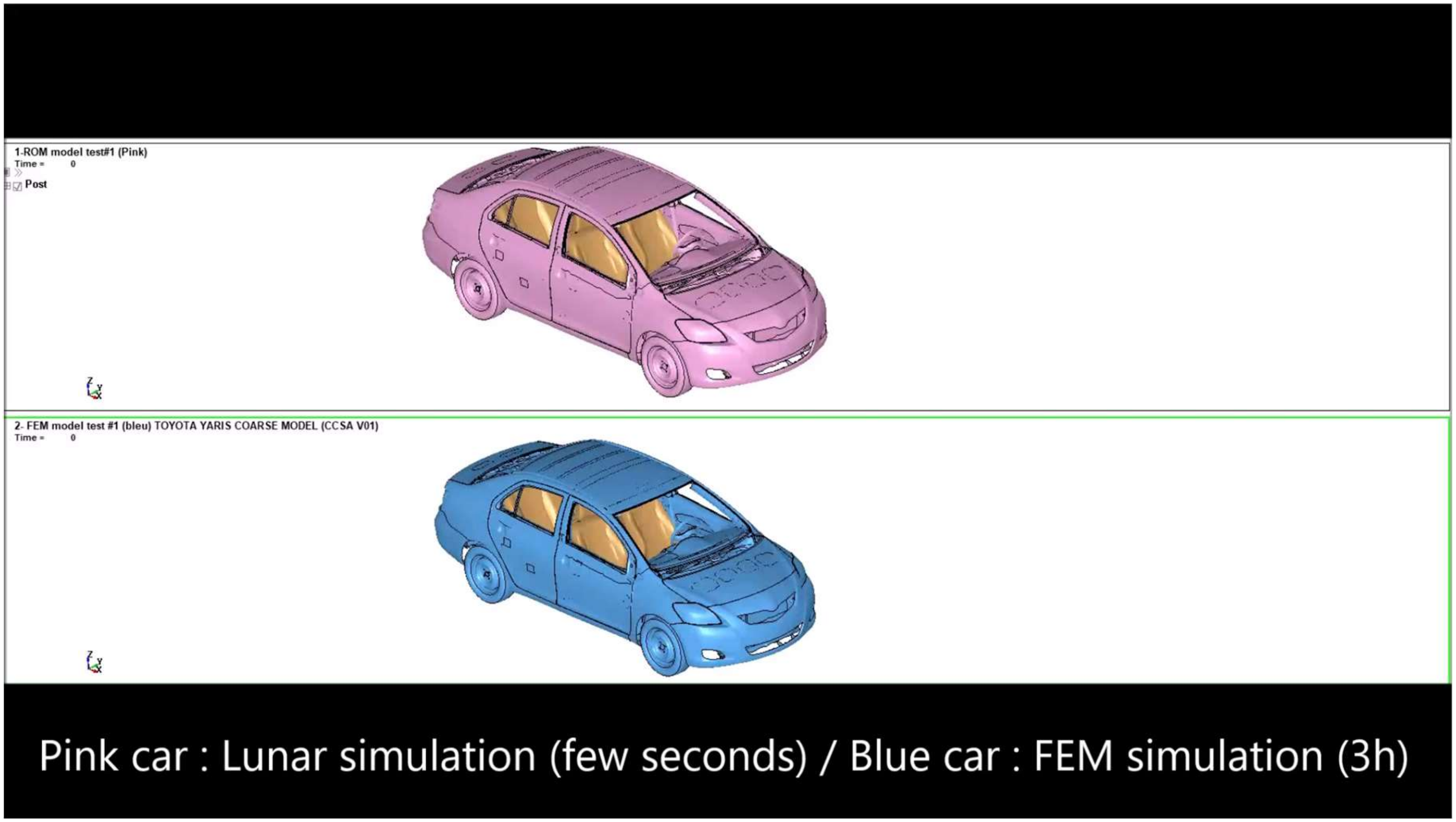


Lunar
Data fusion & model reduction

Lunar: 1 s

FEM : 3h

Example – 'Yaris Front crash'



Source Model: https://www.ccsa.gmu.edu/models/2010-toyota-yaris/

Romax-Odyssee Example

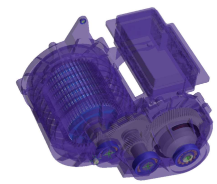
Prediction of contact stress on tooth gear of input Gear set of electric vehicle powertrain GBTE

Parameters (surface modifications) :

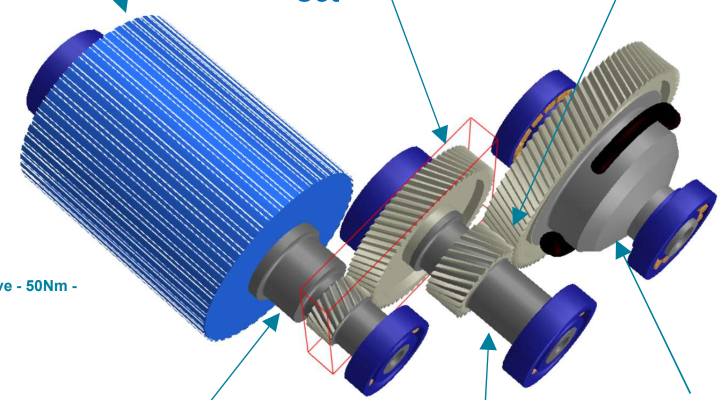
- Lead slope modification (µm)
- Involute slope modification (µm)

Outputs:

- Contact Stress max (Mpa)
- Khbeta (design parameter)
- Repartition of contact stress over tooth surface



Electrical vehicle powertrain



Requires 2000 runs and about 10h-15h of computation time !

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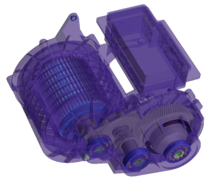
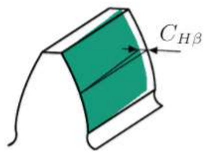
Romax-Odyssee Example



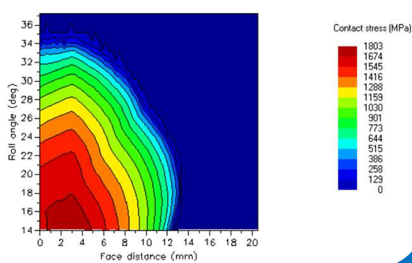
Prediction of contact stress on tooth gear of input Gear set of electric vehicle powertrain GBTE

- INPUTS:
  - ➢ Lead slope modification (µm)
  - ➢ Involute slope modification (µm)



- OUTPUTS:
  - ➢ Contact Stress max (Mpa) (**scalar**)
  - ➢ 1st Harmonic (**scalar**)
  - ➢ Khbeta (**scalar**)
  - ➢ Repartition of contact stress over tooth surface (Matrix)
    - Is a **matrix 24*64**

TE 1st Harmonic GBTE	Contact Stress GBTE	Khbeta GBTE ()
2.15	1606.19	3.80
3.01	1729.55	4.12
2.61	1980.78	5.61
2.03	2124.66	3.56
1.42	1712.18	4.20
2.41	1788.34	3.43
0.98	1127.00	1.65
6.64	2792.24	3.89
1.46	2370.46	4.56
3.59	2457.38	4.44
3.96	1934.18	5.01



- Validation :
  - ➢ 5 cases out of the 200 of the design space

200 runs and about 1h of computation!

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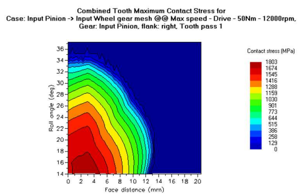
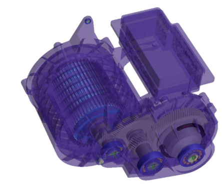
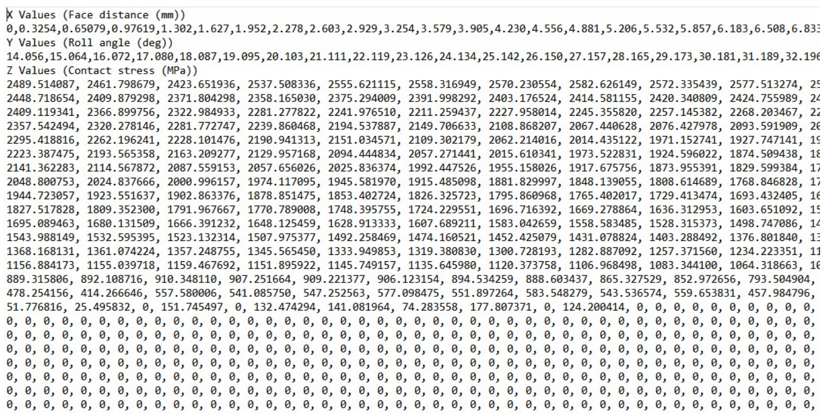
Romax-Odyssee Example

Contact stress repartition







```
X Values (Face distance (mm))
0,0.3254,0.65079,0.97619,1.302,1.627,1.952,2.278,2.603,2.929,3.254,3.579,3.905,4.230,4.556,4.881,5.206,5.532,5.857,6.183,6.508,6.83
Y Values (Roll angle (deg))
14.056,15.064,16.072,17.080,18.087,19.095,20.103,21.111,22.119,23.126,24.134,25.142,26.150,27.157,28.165,29.173,30.181,31.189,32.19
Z Values (Contact stress (MPa))
2489.514087, 2461.798679, 2423.651936, 2537.508336, 2555.621115, 2558.316949, 2570.230554, 2582.626149, 2572.335439, 2577.513274, 2
2448.718654, 2409.879298, 2371.804298, 2358.165030, 2375.294009, 2391.998292, 2403.176524, 2414.581155, 2420.340809, 2424.755989, 2
2409.119341, 2366.899756, 2322.984933, 2281.277822, 2241.976510, 2211.259437, 2227.958014, 2245.355820, 2257.145382, 2268.203467, 2
2357.542494, 2320.278146, 2281.772747, 2239.860468, 2194.537887, 2149.706633, 2108.868207, 2067.440628, 2076.427978, 2093.591909, 2
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1368.168131, 1361.074224, 1357.248755, 1345.565450, 1333.949853, 1319.380830, 1300.728193, 1282.887092, 1257.371560, 1234.223351, 1
1156.884173, 1155.039718, 1159.467692, 1151.895922, 1145.749157, 1135.645980, 1120.373758, 1106.968498, 1083.344100, 1064.318663, 1
889.315806, 892.108716, 910.348110, 907.251664, 909.221377, 906.123154, 894.534259, 888.603437, 865.327529, 852.972656, 793.504904,
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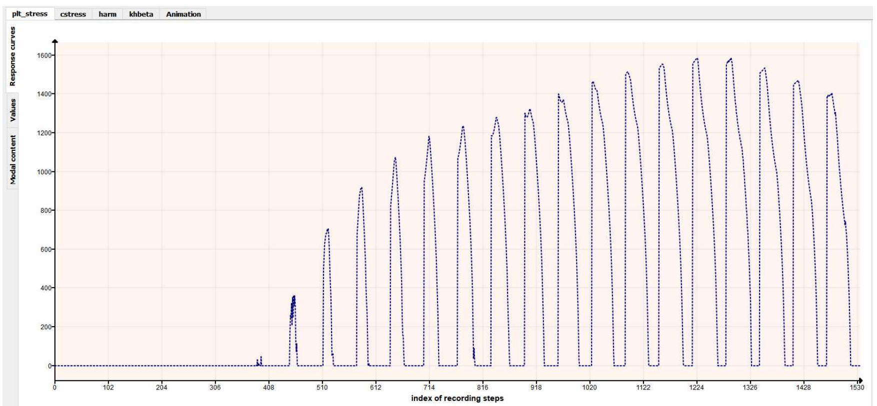
flatten



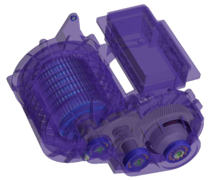
A matrix 24*64

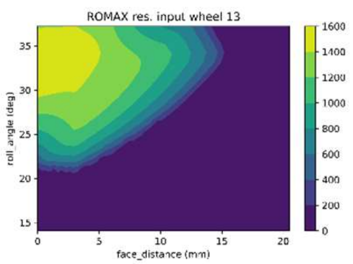
A vector 1*1536

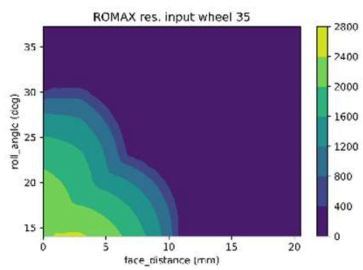
Repartition of contact stress over tooth surface

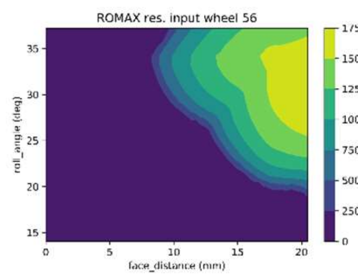
Romax-Odyssee Example

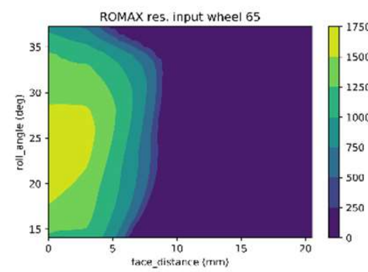
Validation: Comparison of stress distribution results between Romax and Odyssee results

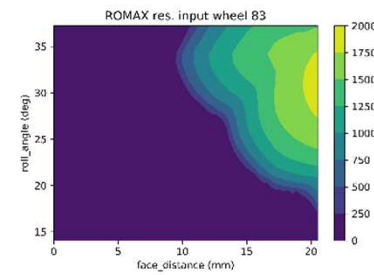




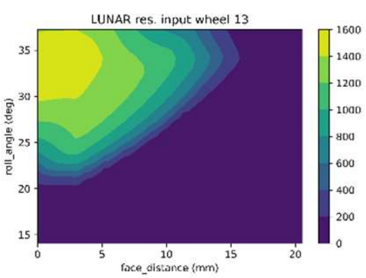


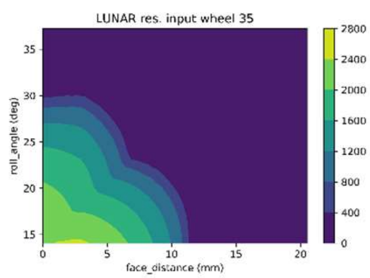


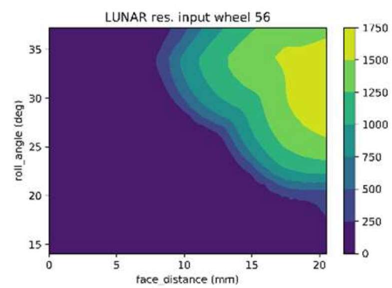


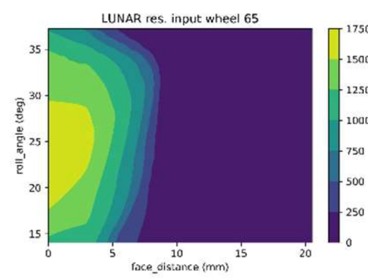


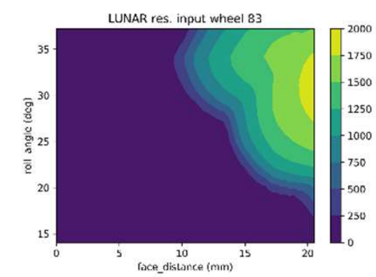
Romax results











Odyssee results

VERY GOOD RESULTS !

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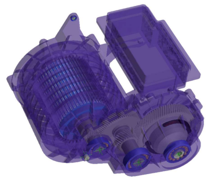
Romax-Odyssee Example

Comparison between Romax and Odyssee



	1st Harmonic		
	ROMAX result	LUNAR prediction	Error
cas 13	1.8905	1.8909	0.02%
cas 35	4	3.9956	-0.11%
cas 56	2.0804	2.1348	2.61%
cas 65	2.2009	2.1655	-1.61%
cas 83	3.014	3.011	-0.10%
	Max contact stress		
	ROMAX result	LUNAR prediction	Error
cas 13	1587.71	1585.84	-0.12%
cas 35	2458.11	2458.42	0.01%
cas 56	1723.15	1724.84	0.10%
cas 65	1676.21	1675.7	-0.03%
cas 83	1837.91	1838.7	0.04%
	Khbeta		
	ROMAX result	LUNAR prediction	Error
cas 13	3.4819	3.477	-0.14%
cas 35	4.682	4.672	-0.21%
cas 56	4.2957	4.3091	0.31%
cas 65	3.6167	3.6436	0.74%
cas 83	4.6959	4.6994	0.07%

VERY GOOD RESULTS !

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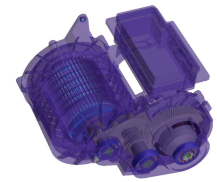
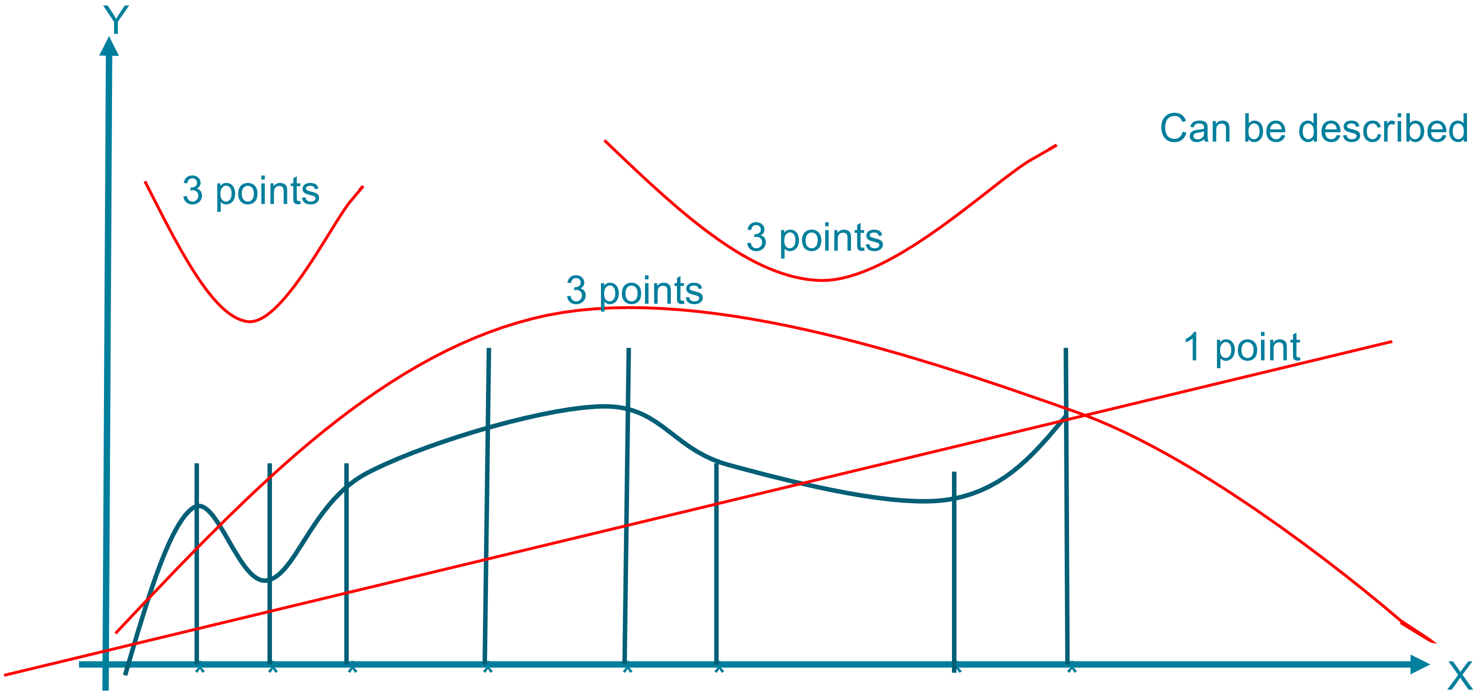
Romax-Odyssee Example

Conclusion:



- Lunar gives very good prediction of ROMAX results with a maximum error of 2% in this case with less runs and less calculation time (10h vs 1h).
- With the help of Lunar it's now possible to reduce the design time and calculation without losing the precision of the calculus
- The process is very simple and can be in ROMAX to build a databases of gearbox configuration. Because with the time available for the results of one configuration it's possible to explore 10-15 configurations.

Why does the Modal Method Require Less Data Points?



Can be described by few modes

Other methods use either a high polynomial Polynom degree (overfitting?) or piecewise linear (many points)

Odyssee uses reduced order models and typically represents the model by its Eigenmodes.

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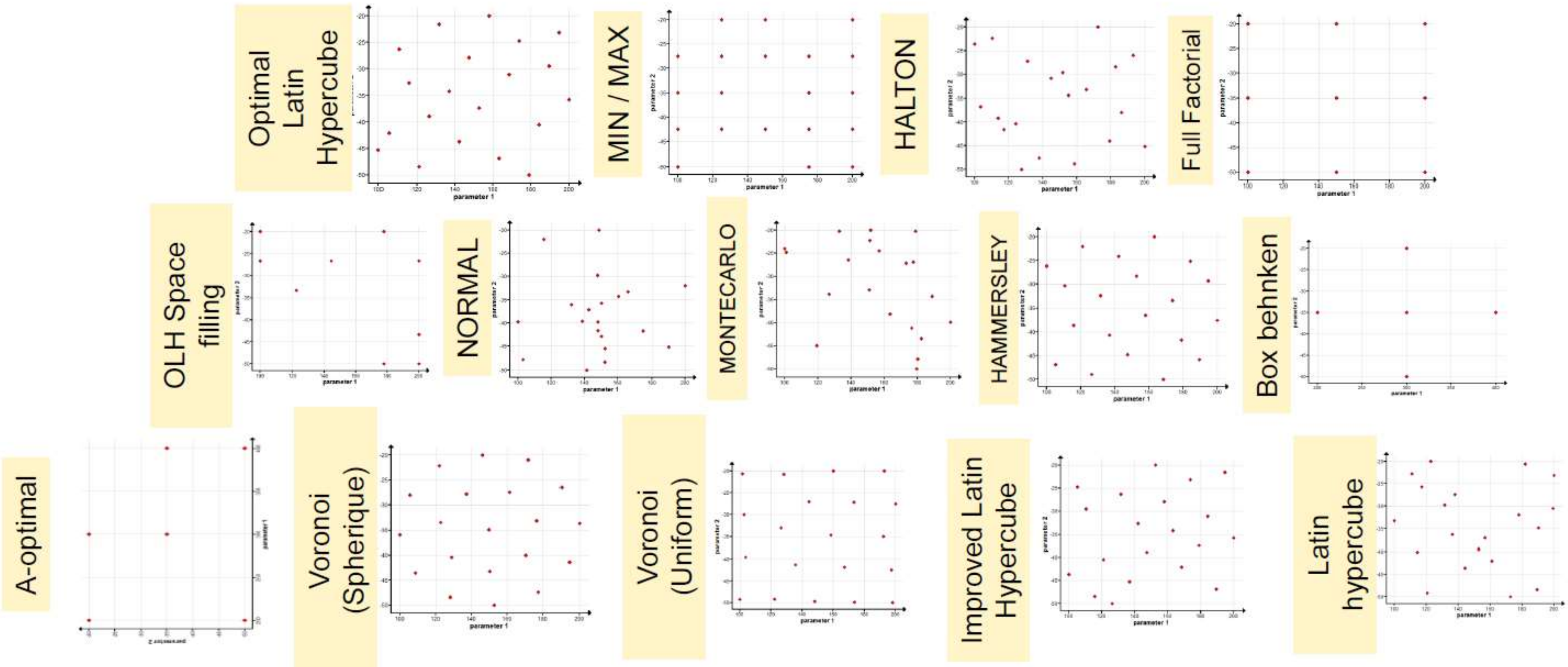
DOE examples with the different methods



DOE tool: Minimum number of sampling points

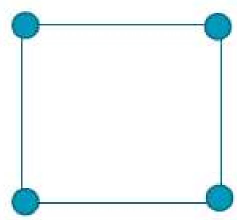
The number of sample depends on the budget available to run simulations. We recommend you to use a polynomial formula (order d=2) to estimate the number of sampling point. But if the number of variables **n** is high, we suggest a full factorial formula.

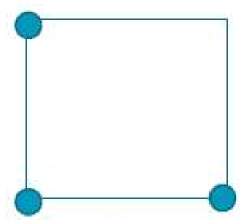
n = variables
d* = order

$$(d+1)^n \gg C_d^{n+d} = (n+d)!/(d!\,n!)$$

Full factorial formula — *Polynomial formula*

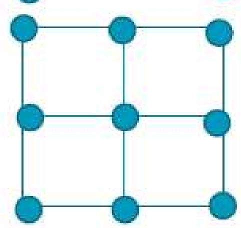
d=1 (linear)
n=2

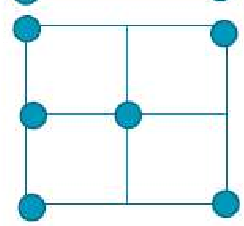




$(2+1)!\,/\,(1!\,2!) = 3$

d=2 (parabolic)
n=2





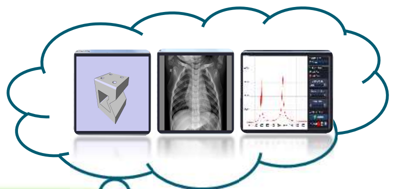
$(2+2)!\,/\,(2!\,2!) = 6$

… e.g. with d=2, n=3 variables we suggest 10 points

Image Based

Use of Past Experience to Predict New Outcomes

1 Learning Phase



Images, 3D files,
Curves data, Signals, etc.

Inputs / Features (X)

Outcomes, Time-Dependent Responses etc…

Associated Results (Y)

AI ODS

2 Predictions

New descriptive **inputs**

Predicted data
in **real time**

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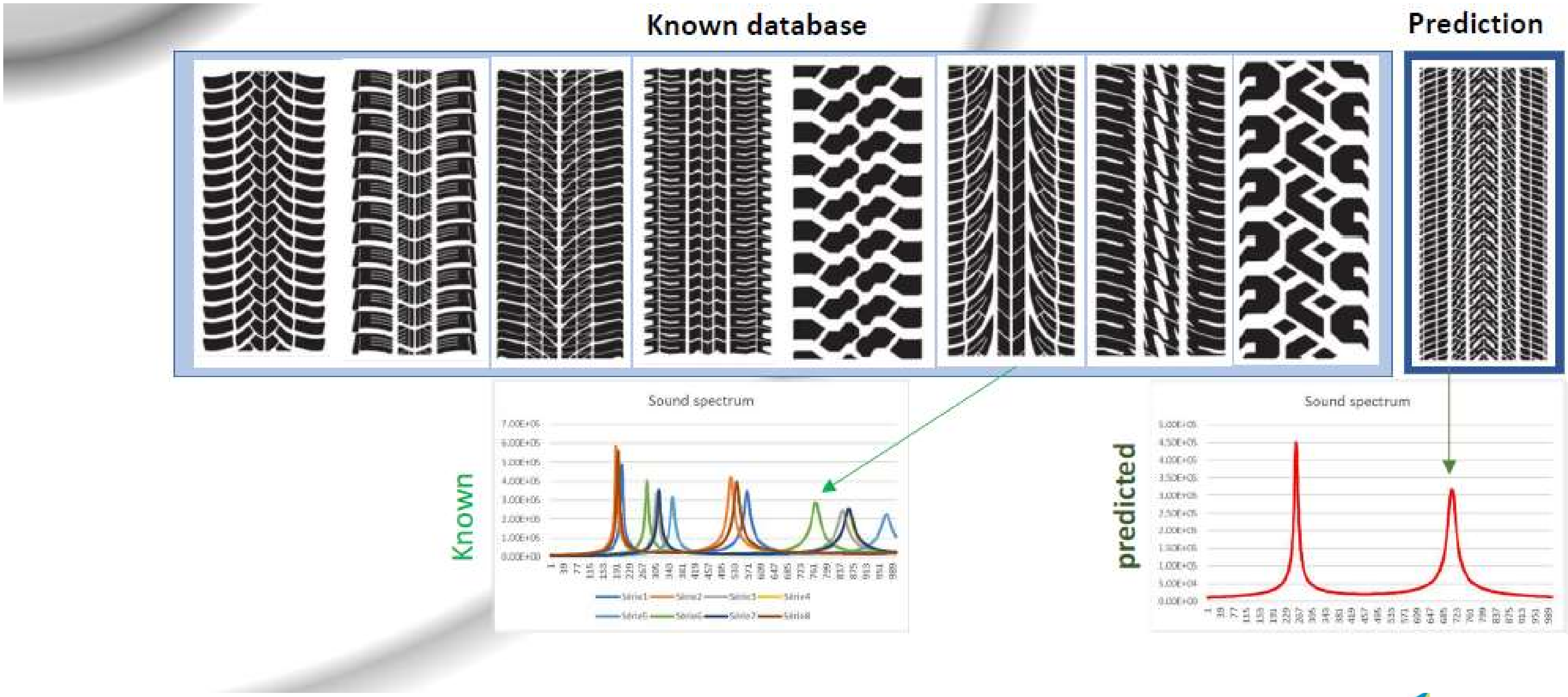
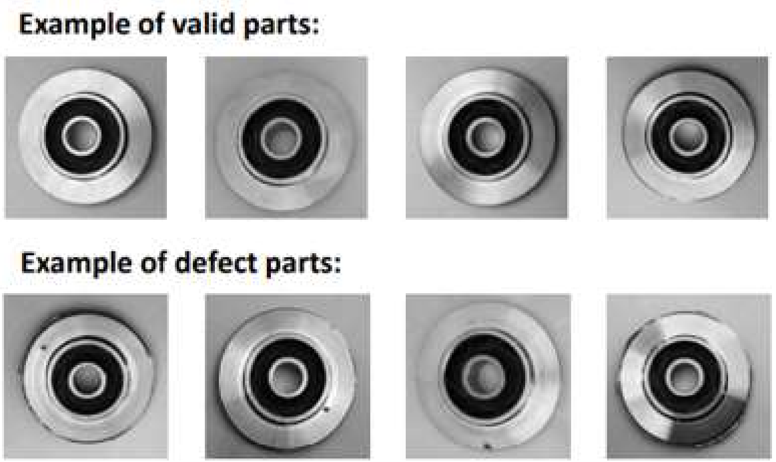
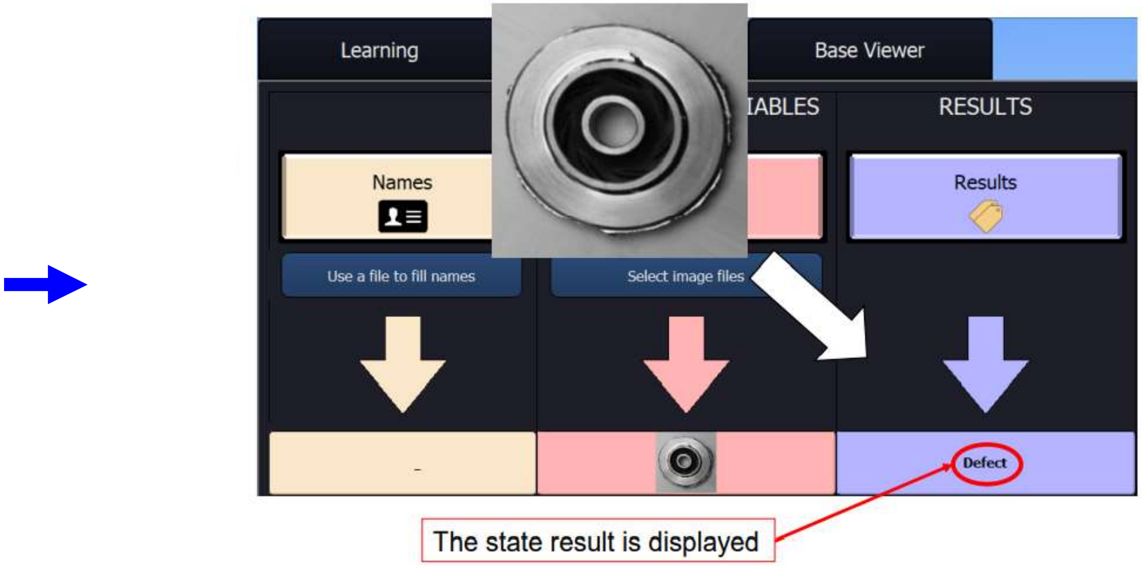
Image Based Learning: Predict Sound Pressure for Tire Profile



Real-Time Product Quality Inspection

A-Eye is not only used for CAE, but also many other applications





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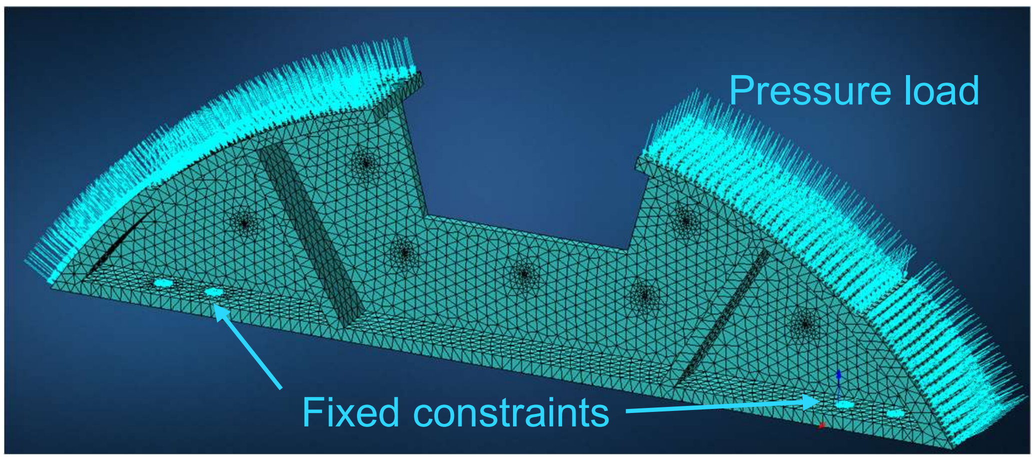
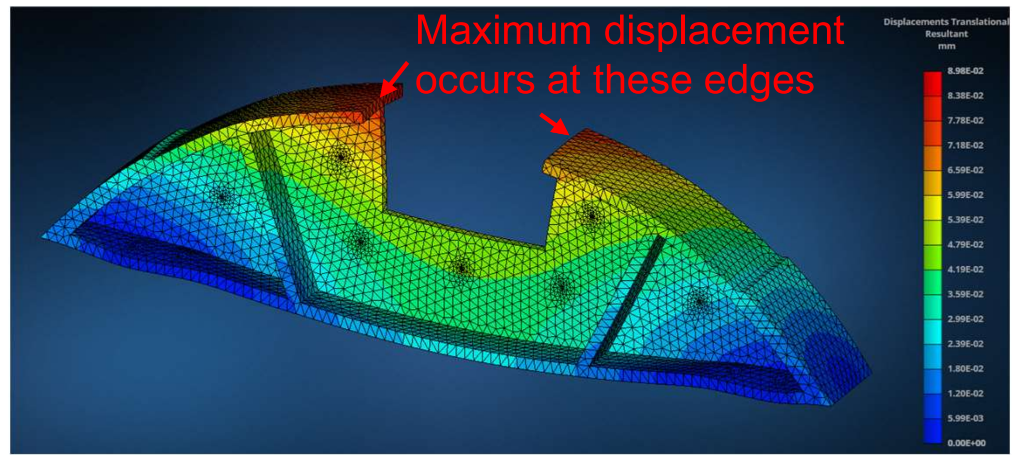
Bracket with Holes – Predict Maximum Displacement from Numbers or Images

- The diameter of the holes is variable
- Predict the maximum displacement for different hole diameters





Bracket with Holes – Predict Maximum Displacement from Numbers or Images

Learning base: Images and corresponding max. displacement values


image1.png


image2.png

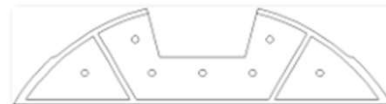


image3.png


image4.png


image5.png


image7.png


image8.png


image9.png


image10.png

0.0898
0.0901
0.0903
0.0906
0.0916
0.0952
0.0966
0.101
0.104

Prediction: Predict max. displacement value for new image


image6.png

0.093

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Thank you for listening!
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