



HEXAGON



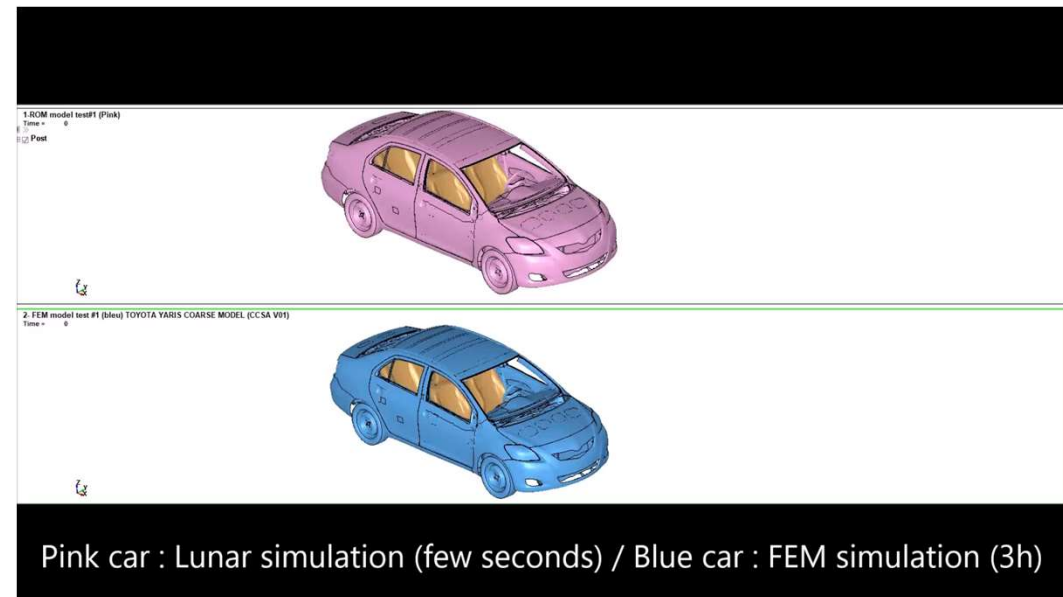
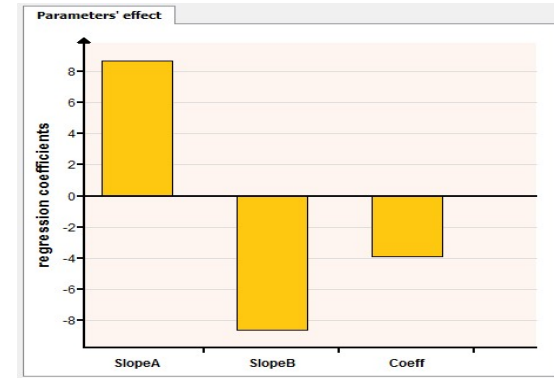
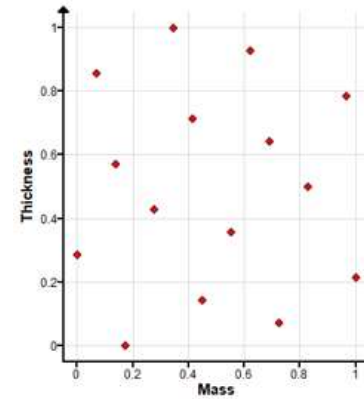
# Machine Learning im CAE

Cornelia Thieme, Lars Oelgeschläger  
MSC Software / Hexagon

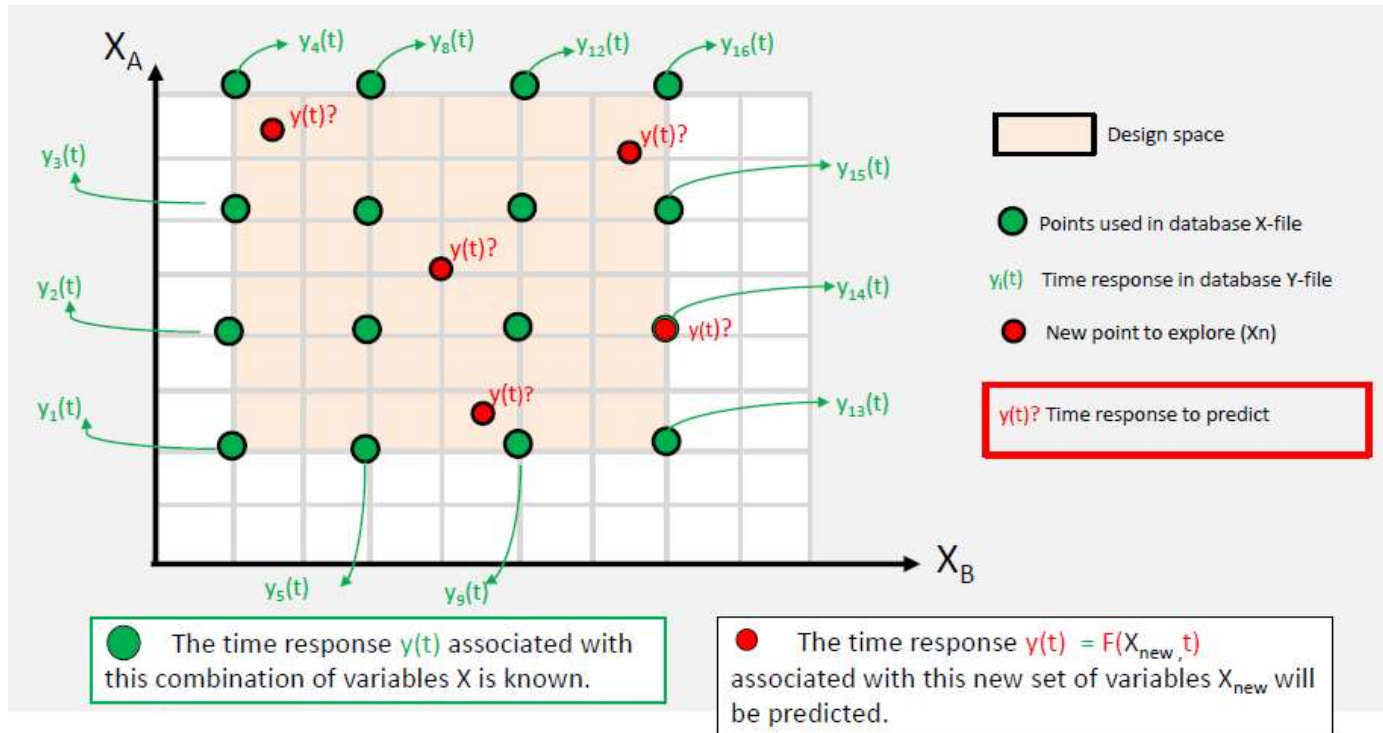
**Bayreuther 3D-Konstrukteurstag  
15.9.2021**

# ODYSSEE Overview

- Machine learning for FEM, CFD and other data
- From available analysis or test results, predict responses for further parameter combinations
- Interesting e.g. for highly nonlinear analyses which take long time
- Predict and view time-histories
- Predict and view animations (write and view hdf5, d3plot etc.)
- Image handling
- Generate, improve, reduce DOE
- Understand the influence of model parameters
- Optimization, e.g. adapt analysis model to test result curve



# Formulation of the Problem

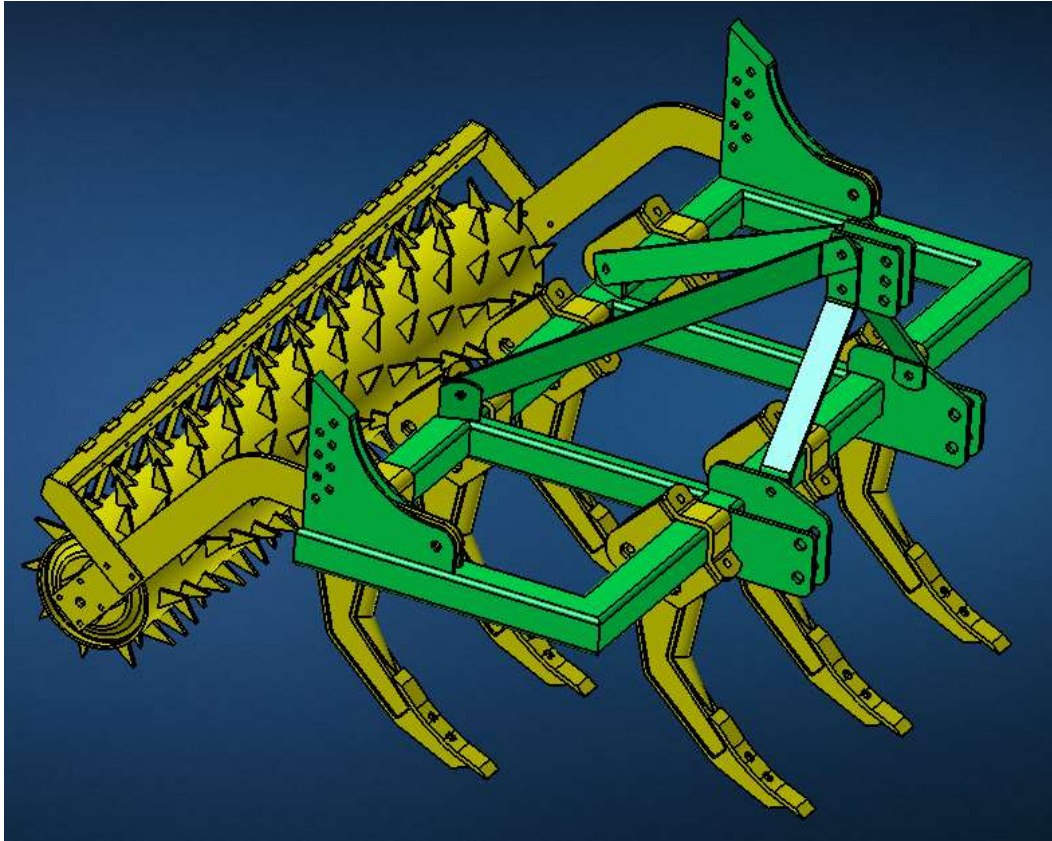


Input: Learning base  $F(x) = Y$   
(Existing analysis or test data)

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

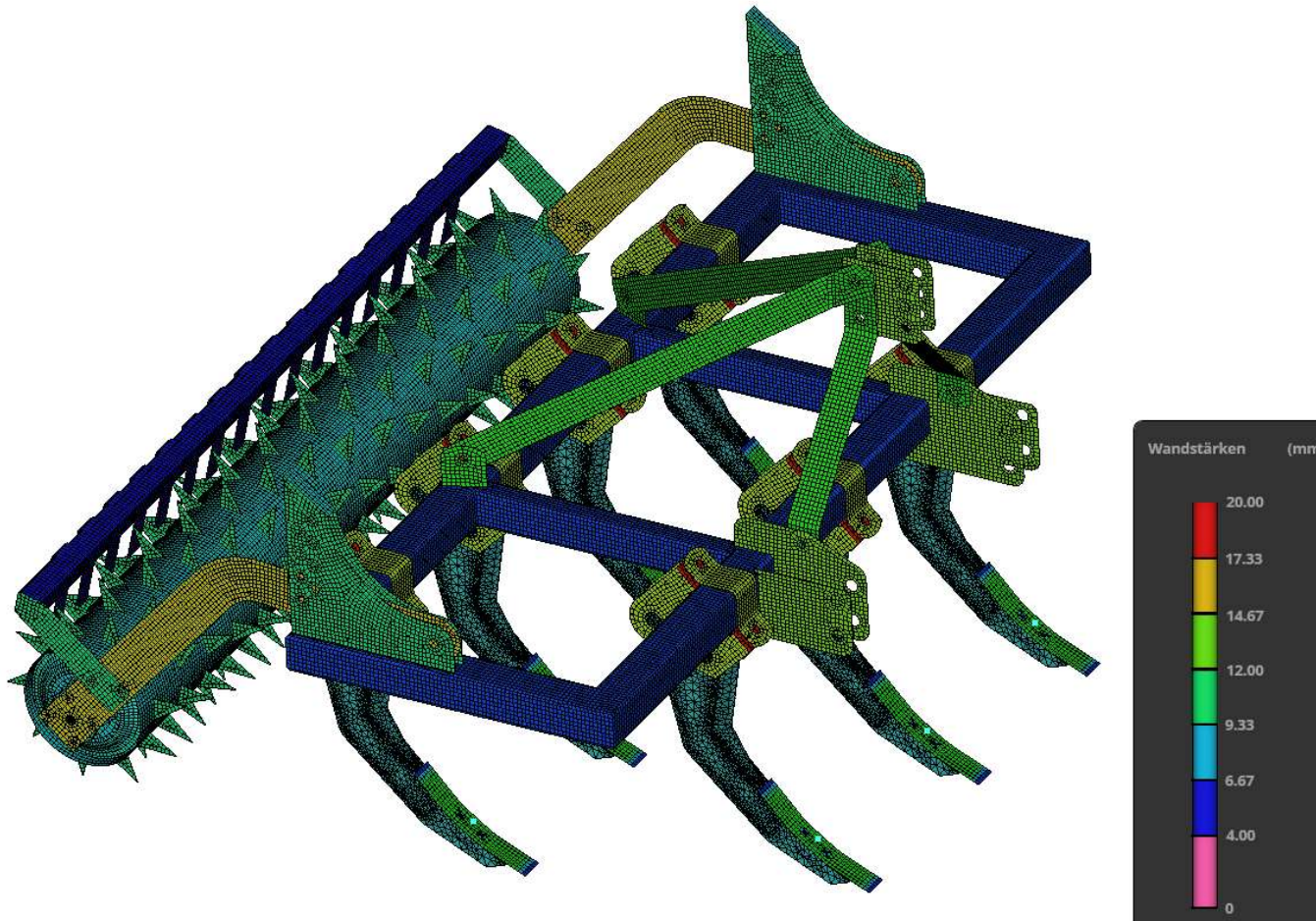
$Y$  can be a curve  $Y(t)$

## Example Model: Geometry



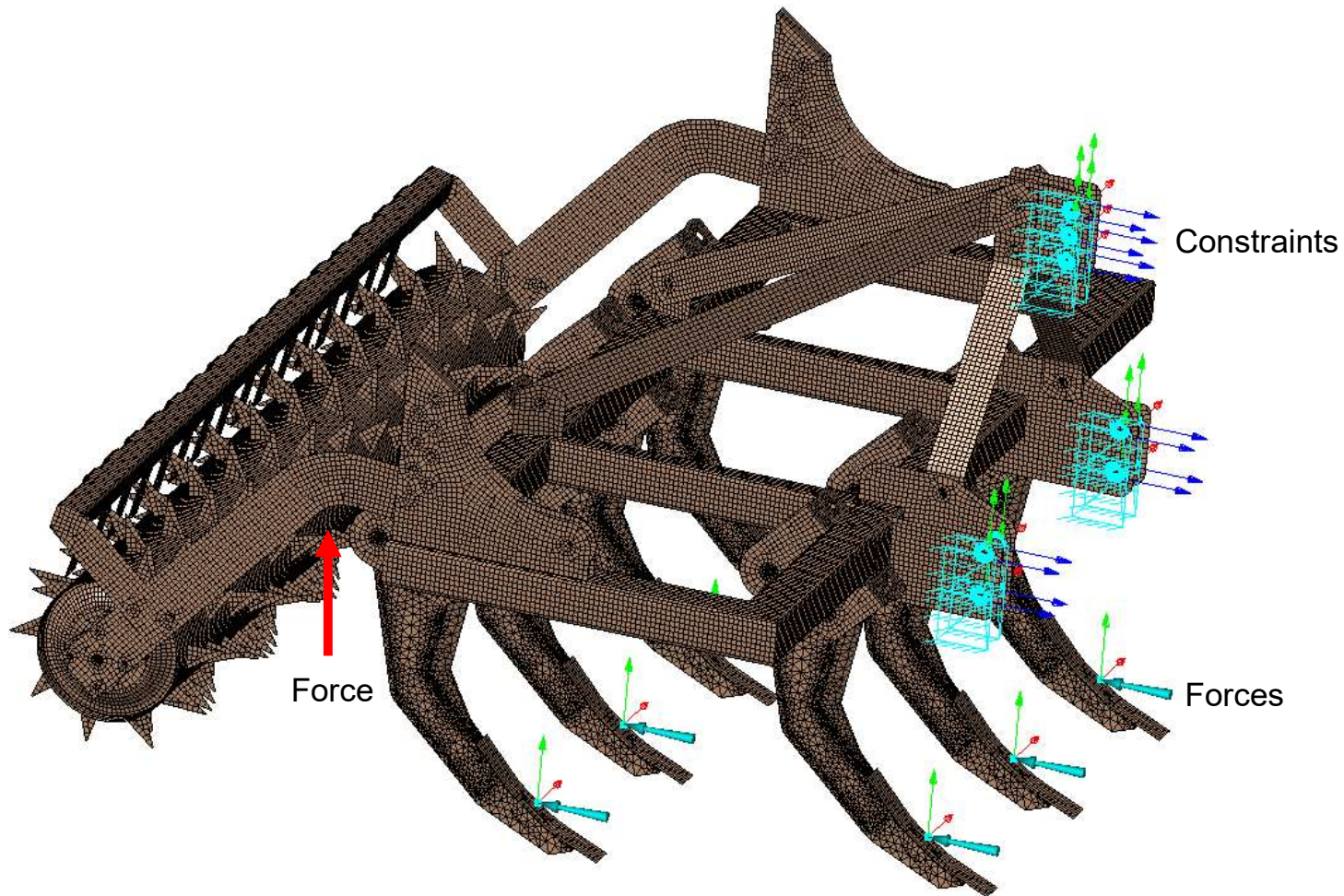
CAD model from Javad Valaei (Grabcad)

## Example Model: FEM Model with Wall Thicknesses





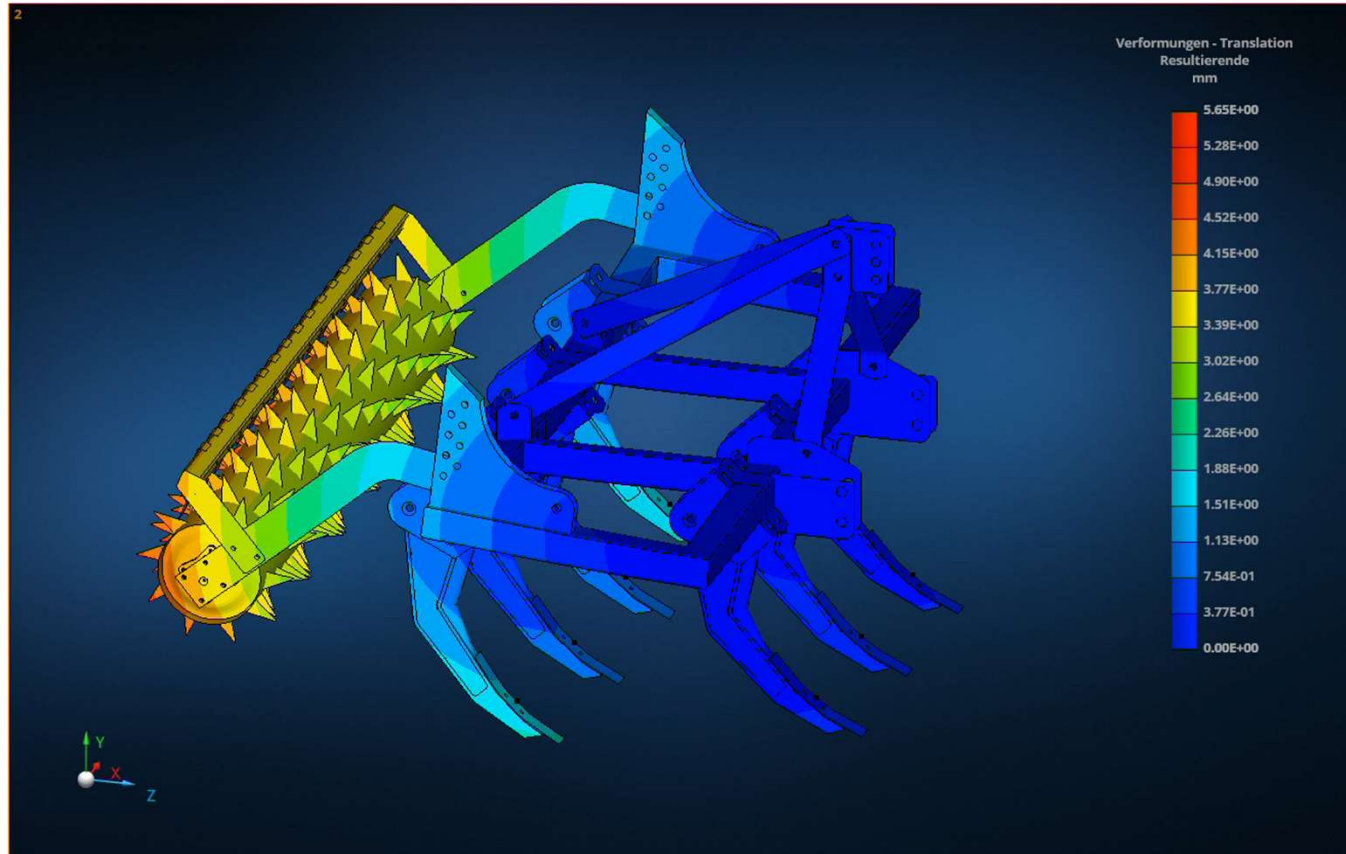
## Example Model: FEM Model with Loads and Boundary Conditions



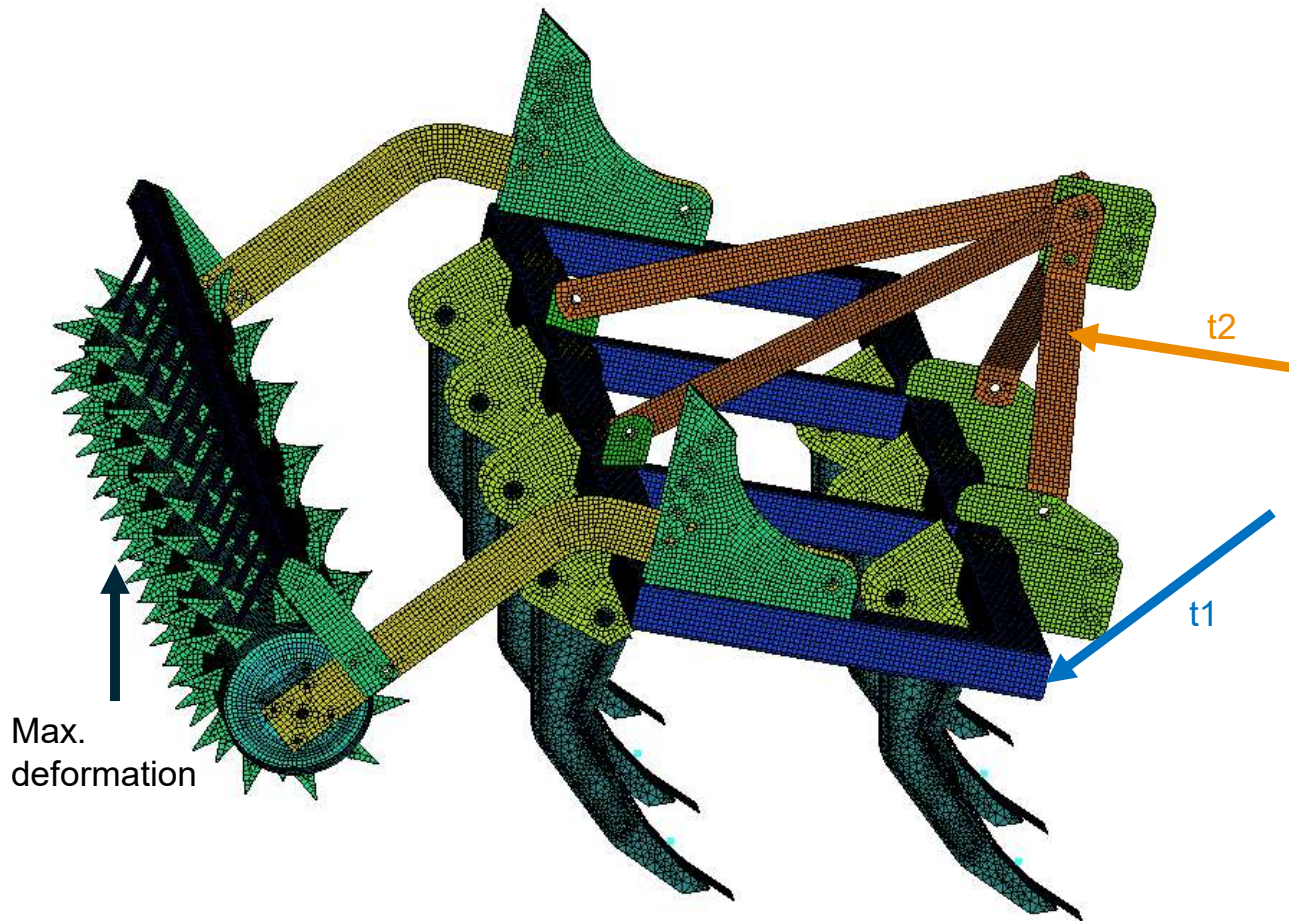
HEXAGON

MSC Software

## Example Model: Deformation Results



## Formulation of the Problem



From these two wall thicknesses predict the max. deformation (and the complete result file)



## Learning Base

X		Y				
t1	t2					
3	16.7692	1.77565	3.55814	5.34747	7.1403	8.90885
3.45455	10.6154	1.55555	3.11633	4.67978	6.23097	7.80816
3.90909	15.5385	1.33615	2.67394	4.00489	5.35077	6.69965
4.36364	13.0769	1.203	2.40726	3.60741	4.81806	6.03117
4.81818	18	1.07084	2.13906	3.2144	4.29146	5.37043
5.27273	10	1.01514	2.02857	3.0481	4.06947	5.09287
5.72727	14.9231	0.917384	1.8336	2.75421	3.6761	4.59934
6.18182	12.4615	0.866509	1.73224	2.60171	3.47238	4.34432
6.63636	17.3846	0.798641	1.59672	2.3977	3.19963	4.00252
7.09091	11.2308	0.777377	1.55444	2.33428	3.11514	3.89708
7.54545	16.1538	0.721435	1.44262	2.16601	2.89019	3.61518
8	13.6923	0.697431	1.39473	2.09408	2.79421	3.49514

12 combinations  
of the 2 wall  
thicknesses

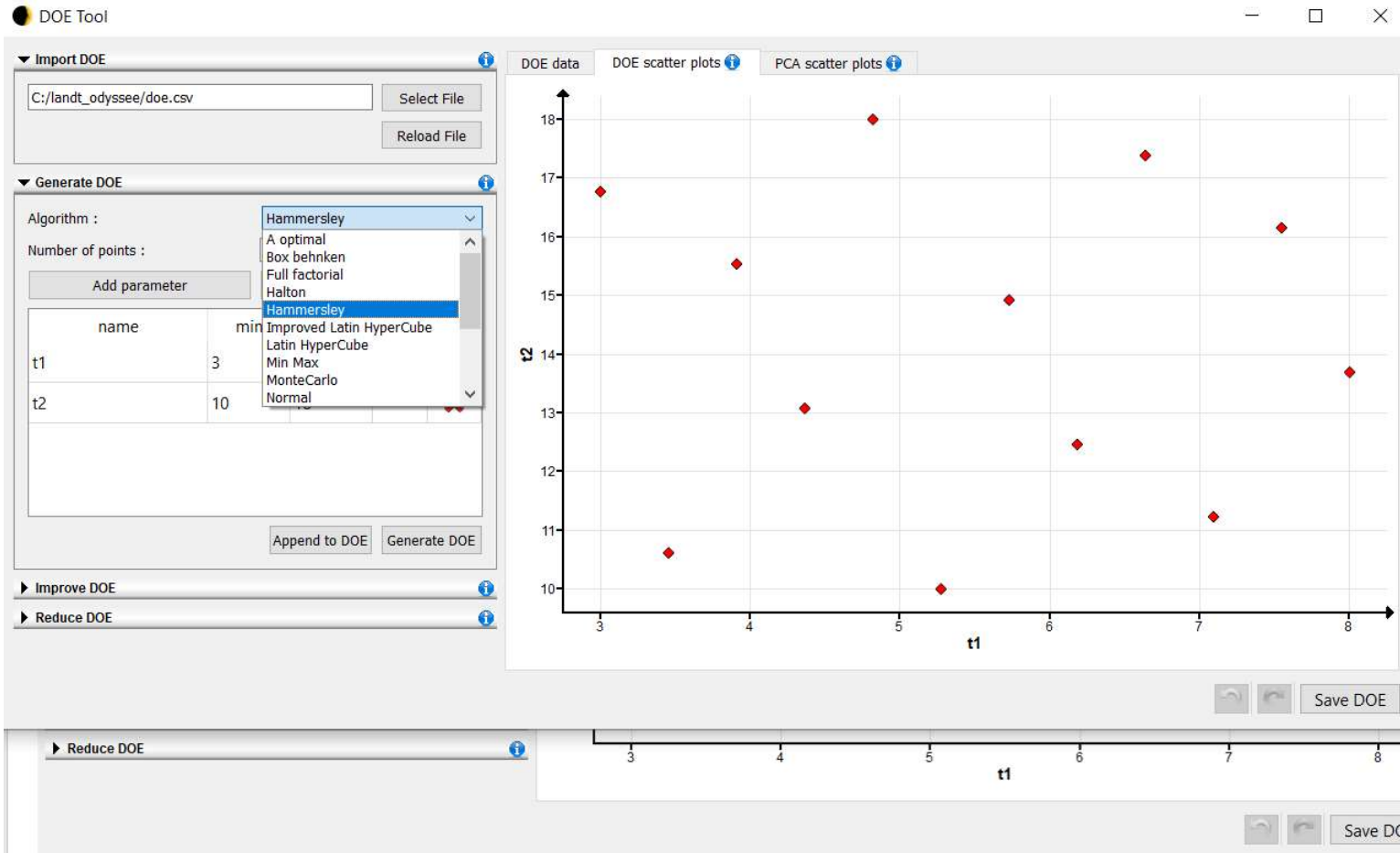
Result for the 12 FEM analyses  
(5 steps in nonlinear analysis)

## Requested Output

Xn		Yn
t1	t2	
7	15	?

Predict displacements for a new  
combination of the 2 wall thicknesses

# How to Create the DOE (Design of Experiments)



In the DOE Tool, enter the parameters with desired range and number of points.

ODYSSEE will create the DOE

Can also import an existing DOE file and improve it

Export DOE as csv file

## Input X-Files: Minimum number of sampling points

The number of sample is depending of the budget available to run simulations.  
Usually we propose to use a polynomial formula to estimate the number of sampling point. But if  $n$  is high, we suggest a full factorial formula.

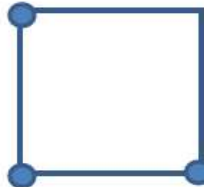
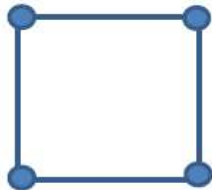
$n$  = variables  
 $d$  = order

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

Full factorial formula

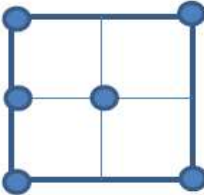
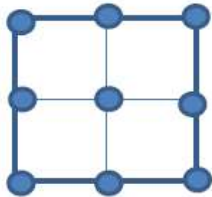
Polynomial formula

$d=1$  (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

$$(2+3)! / (2! 3!) = 5! / (3! 2!)$$

# Create the Learning Base (Run the FEM Analyses for all Combinations in the DOE)

Project setup

Working directory

C:/landt\_odyssee

Main model file

Chisel\_Plow\_sol400.bdf

DoE file

C:/landt\_odyssee/doe.csv

Configure solver

Nastran solver/batch (C:/Program Files/MSC.Software/MSC\_Nastran/2019fp1/bin/nastran.exe)

Substitution step

Config by table

Config by script

On

	DoE label	File	Keyword	ID label	ID value	Parameter	
1	t1	Chisel_Plow_sc	PSHELL	PID	16	T	✖
2	t2	Chisel_Plow_sc	PSHELL	PID	11	T	✖

Extraction step

Config by table

Config by script

On

	Output file	Output group	Output dataset	ID	Start time/step	End time/step	
1	Chisel_Plow_sol400	Nodal displace	Y	4410	0	1	✖

Post-processing configuration

Script path

Off

Open working path

Save project

Run

Script content

Chisel\_Plow\_sol400.bdf

```
1 SOL 400
CEND
$
$ Output Requests
$
$ Displacement
DISP(PLOT) = ALL
$ Element Stress
STRESS(PLOT,VONMISES,CORNER) = ALL
$ Applied Loads
PARAM,AUTOSPC,YES
$ Automatic Stiffness Singularity Constraints
AUTOSPC(NOPRINT) = YES
$ Activate mesh independent ties (Segment to segment permanent glue)
BCONTRACT = 1
PARAM,PRTHAXIN,YES
$ Event name: Event 1
$ Event description:
SUBCASE 1
SUBTITLE=Event 1
SPC = 15
LOAD = 9
nliststep,1
BEGIN BULK
nliststep,1
,fixcd,5
param,lgdisp,1
$ HDF5 Results file
MDLPRM,HDF5,1
$
PSHELL 12 1 14. 1 1
PSHELL 13 1 12. 1 1
PSHELL 14 1 10. 1 1
CQUAD4 48590 16 83021 83020 83156 83022 0.
CQUAD4 48591 16 83020 83089 83091 83156 0.
CQUAD4 48592 16 83022 83156 83157 83023 0.
CQUAD4 48593 16 83156 83091 83092 83157 0.
CQUAD4 48594 16 83023 83157 83158 83024 0.
CQUAD4 48595 16 83157 83092 83093 83158 0.
CQUAD4 48596 16 83024 83158 83159 83025 0.
CQUAD4 48597 16 83158 83093 83094 83159 0.
```

Log

```
12.09.2021 10:25:39 Lunar parser started
12.09.2021 10:25:47 Working path: C:/landt_odyssee
12.09.2021 10:25:49 Parsed file : Chisel_Plow_sol400.bdf
12.09.2021 10:25:53 DoE file selected: C:/landt_odyssee/doe.csv
12.09.2021 10:25:55 Model file and DoE file are parsed.
```

Parsers exist for different solver input / output formats or generic txt files

Select the DOE file and one solver input file

ODYSSEE creates the different variants, starts the solver jobs and extracts the results

This PC > Local Disk (C:) > landt\_odyssee

Name

M1

M2

M3

M4

M5

M6

M7

M8

M9

M10

M11

M12

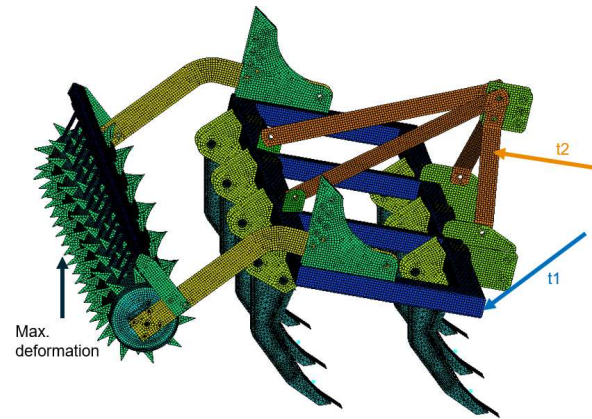
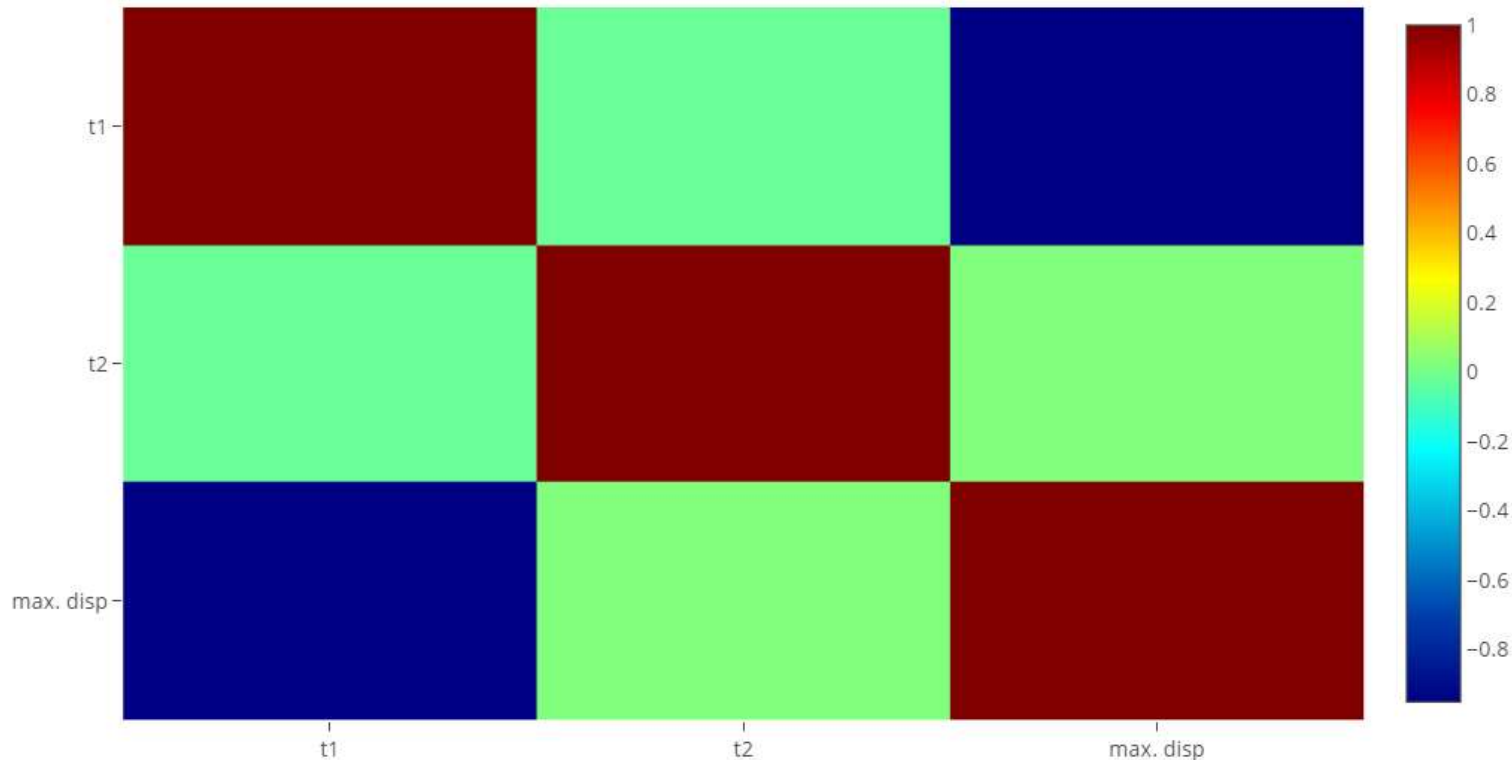




# Correlation Plot

Get a first overview of the correlations: which parameters have high influence on the results?

1: 100% correlation; 0: no correlation; -1: 100% negative correlation

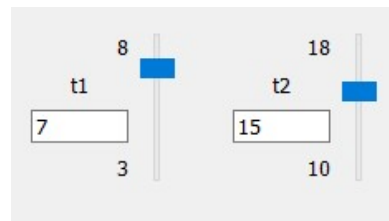
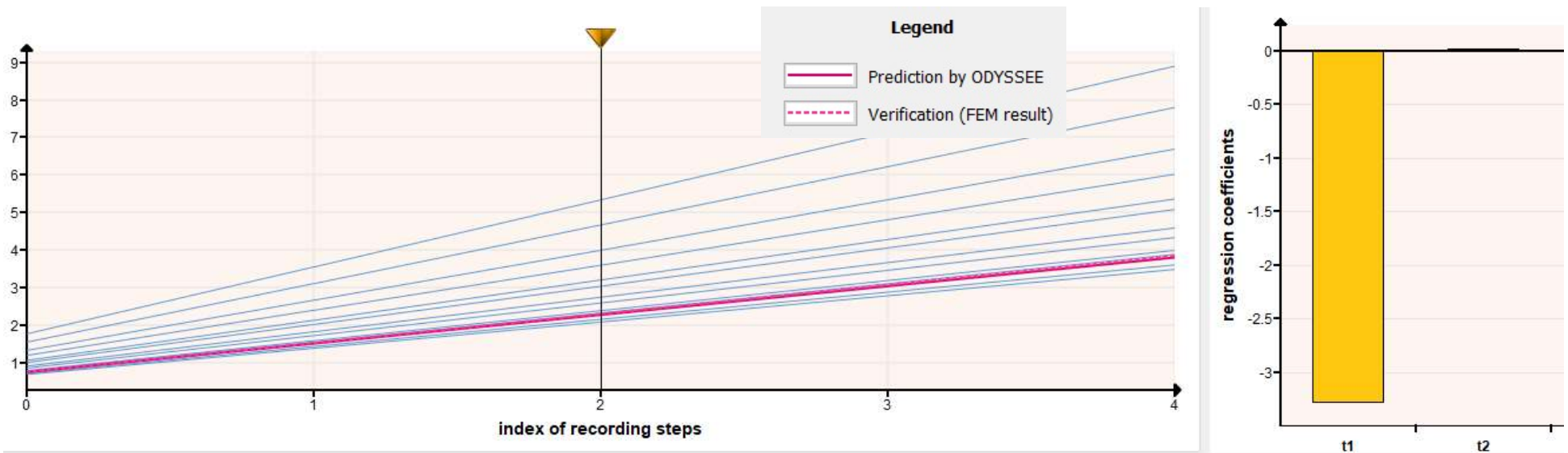


Interpretation:

- t1-t2 very low correlation: good DOE
- t1 – max disp: very high negative correlation
- t2 – max disp: very low correlation
- to influence max disp, t1 is the suitable parameter



## Prediction of Max. Displacement for New Parameter Combination

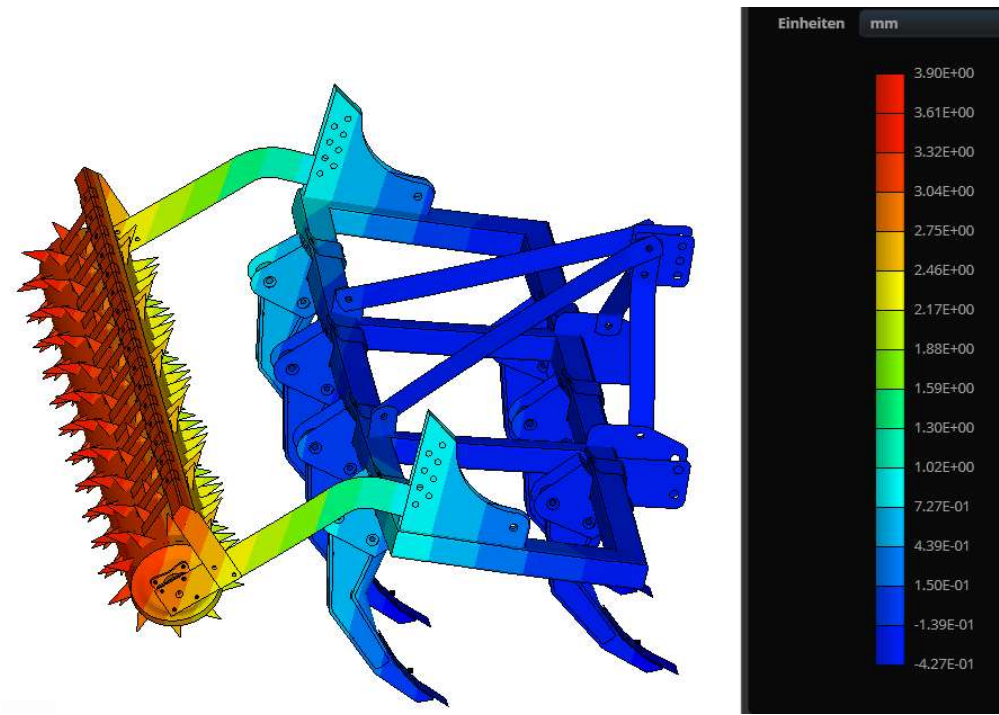


Blue curves: learning base, the results of the 12 Nastran runs

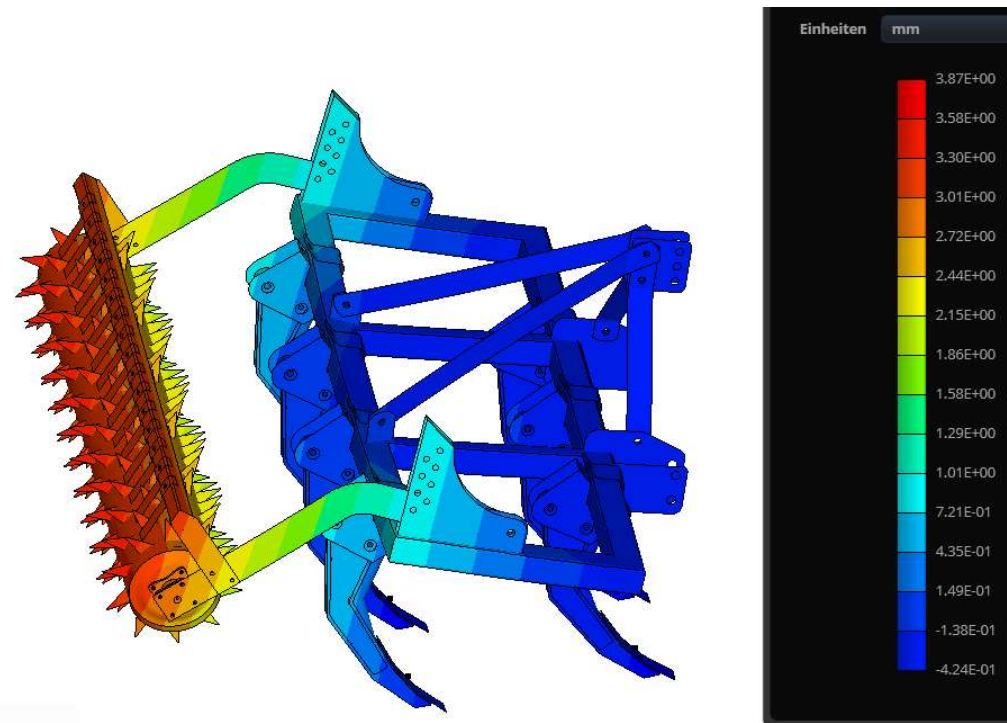
From this learning base, predict the results for a new parameter combination (thicknesses  $t1 = 7$ ,  $t2 = 15$ )

The regression coefficients show again the high influence of  $t1$

# Displacements for Full Model

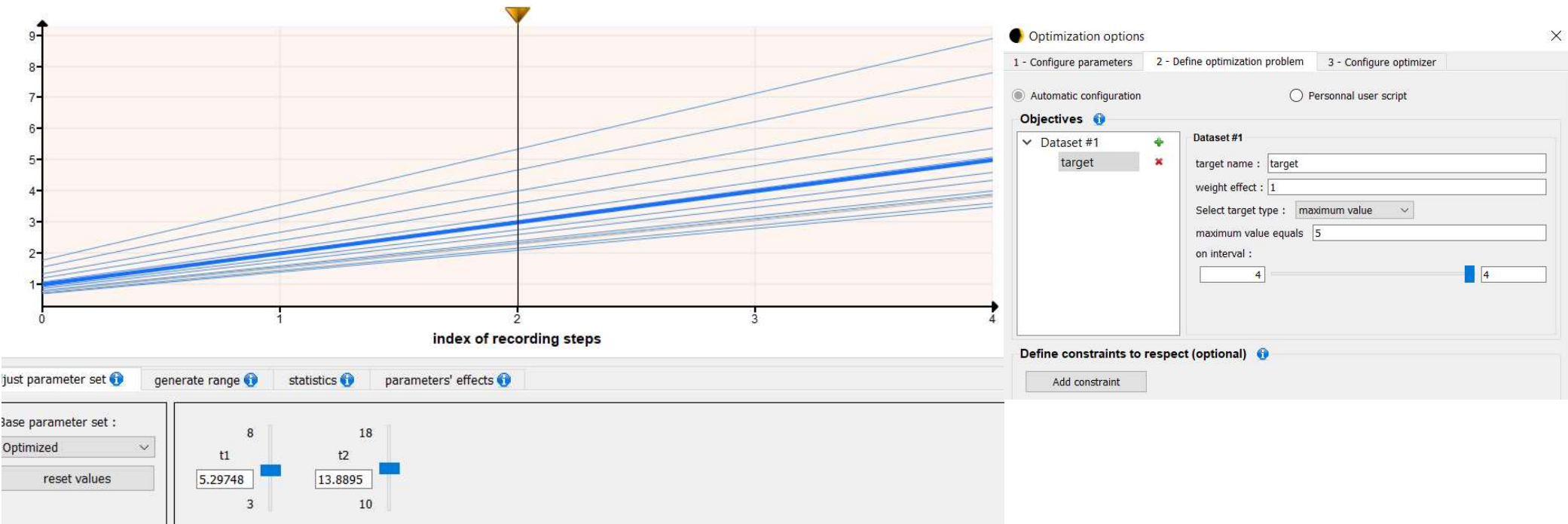


Prediction by ODYSSEE



Verification by FEM

# Optimization



Which thicknesses should be used to reach a displacement of max. 5mm?



# Video

Lunar v4.1.5.5

File Export Tools Preferences Help

1-Project

2-Data

3-Sensitivity

4-Interpolation

5-Optimization

6-Animation

User script

configure

Display log file

configure

Display log file

configure

Display log file

configure

Display log file

**Lunar**  
Data fusion & model reduction

Interpolation

Animation

Solver : POD (all modes)  
with ARBF

open model

open animation output directory

speed : 60 fps

0 / 0

time : 0

Parts

configure legend

Type here to search



3:41 PM  
9/12/2021  
ENG  
Software

## Other Examples

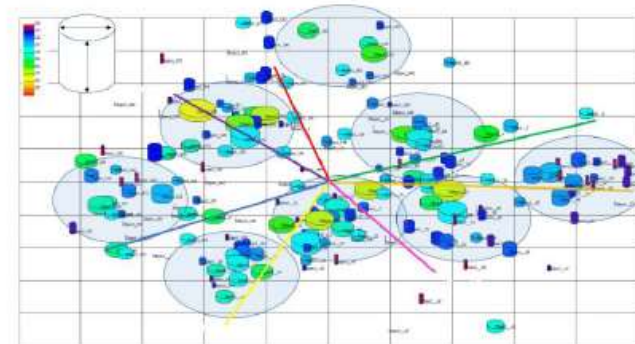
Understanding origin of defects in casting process



**Analysis** of acquired on-board data  
**Cost saving** by finding links between process parameters and defects

- **Data Analysis** using physical sensor data
- **Correlation table and multi-plots** using ODYSSEE.

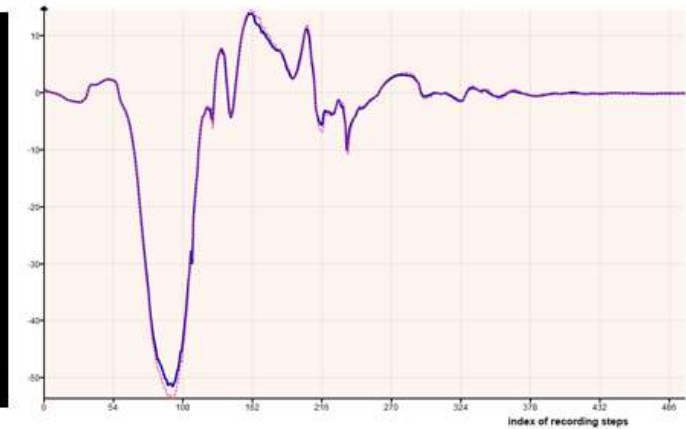
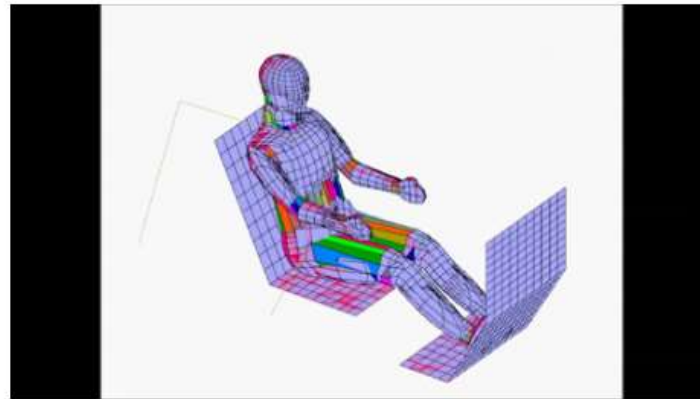
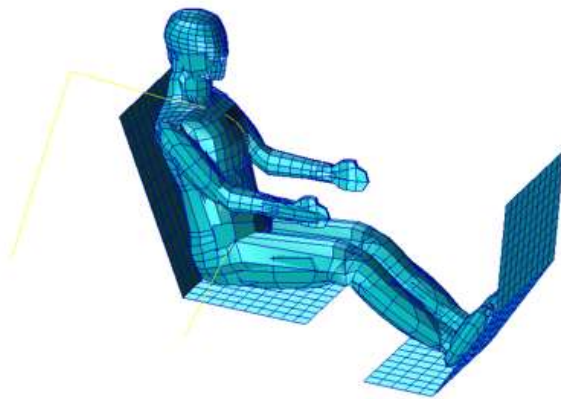
*dedicated application to prevent defects before they appear!*



Input: a table of process parameter settings over a time period (X) and all reports of system failure or product deficiency (Y).  
ODYSSEE identifies source of problem (this is a probability function) by relating Y to X.

# Nastran Sol 700 – sled test

*Courtesy of Raoul Spote (MSC)*



## 10 runs, 2 parameters

Sled acceleration => X1

Pretension force => X2

## Output Channel

X-acceleration of

Dummy Head => Y1

## Elapsed Time

LUNAR = 8 sec

Saved to this PC

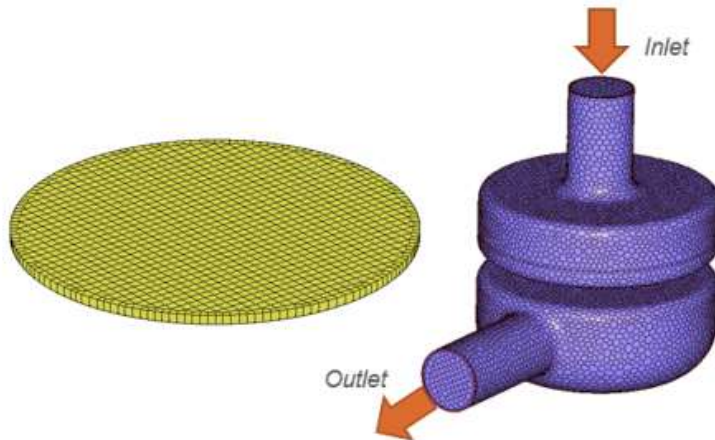


# Pump membrane optimization with multi-physics interaction

## Design of experiments

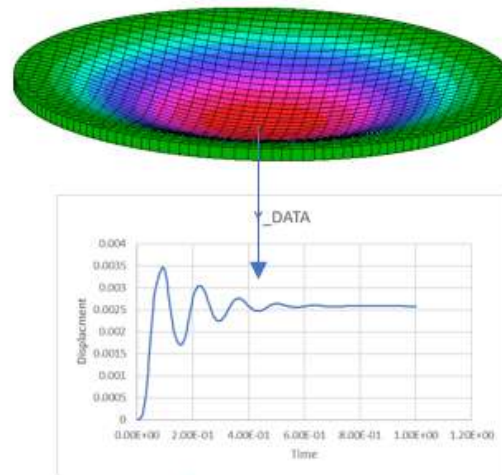
### X: (2 variables)

1. Inlet Fluid Speed
2. Membrane Stiffness

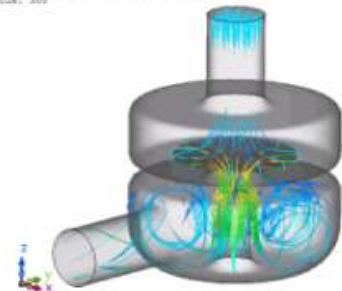


### Y:

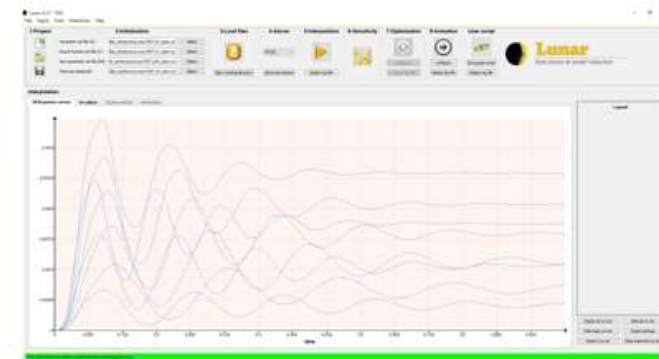
1. Displacement center of membrane



File : flexible\_membrane\_scflow\_500.fgh  
cycle: 500



x 8

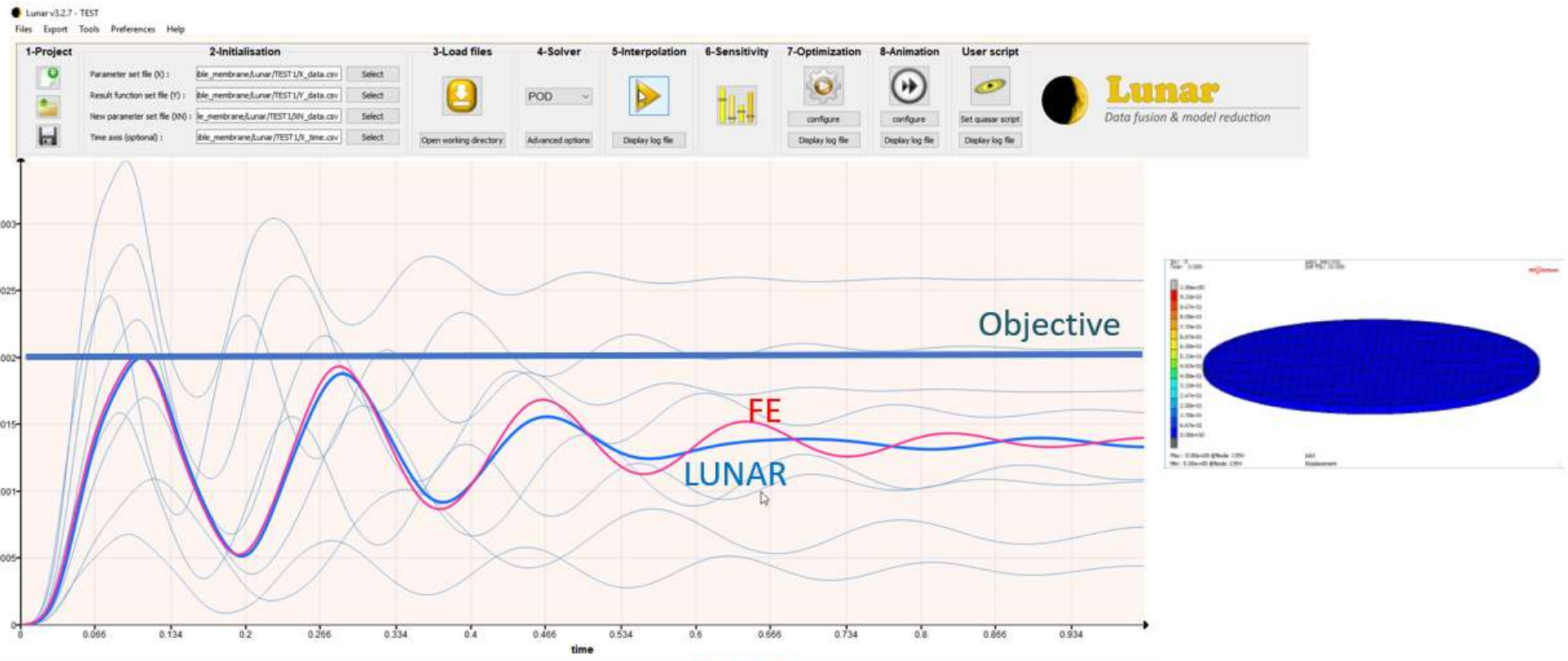




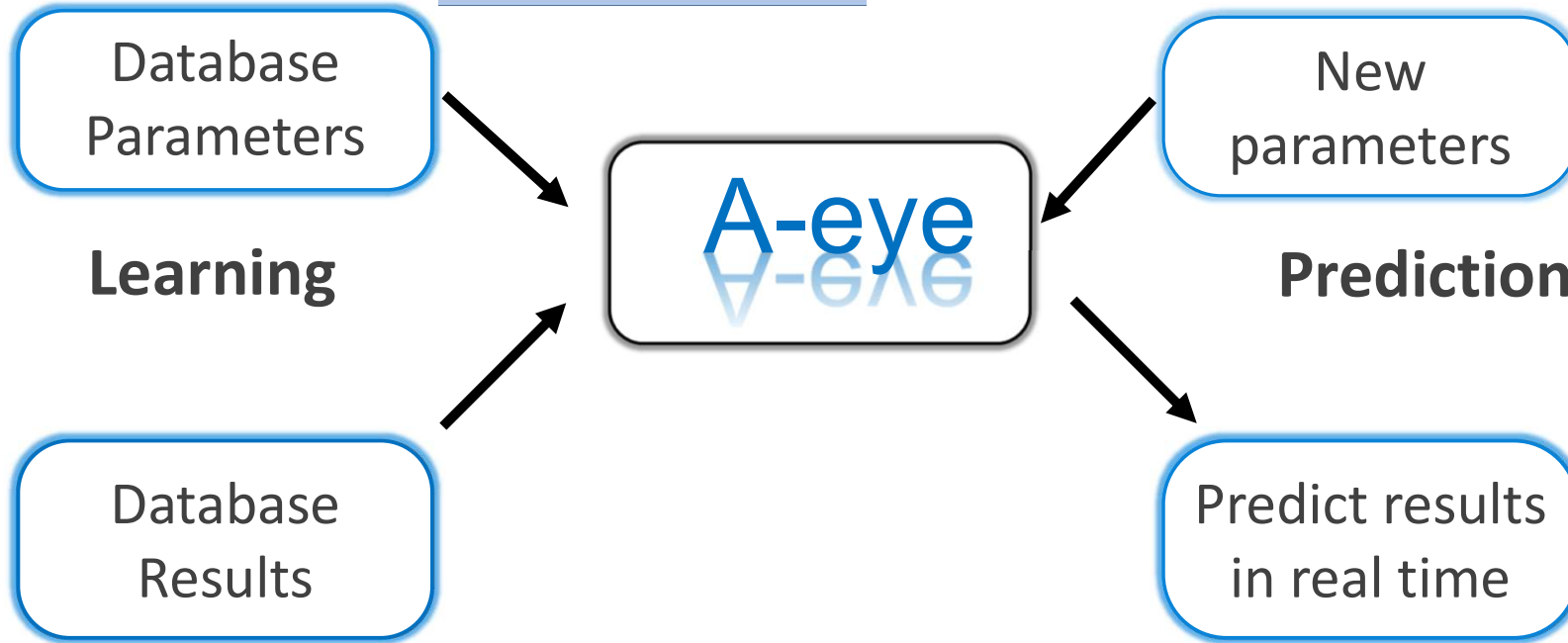
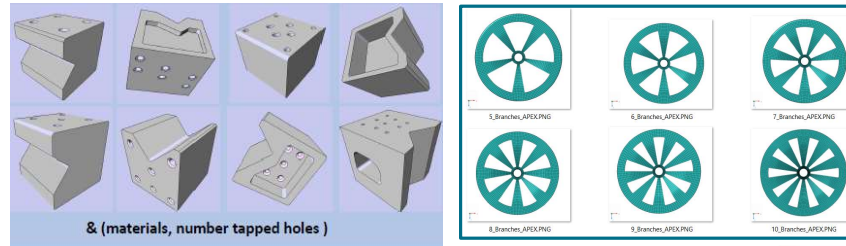
Explore new industrial horizons

# LUNAR versus Co-simulation (Marc/scFlow)

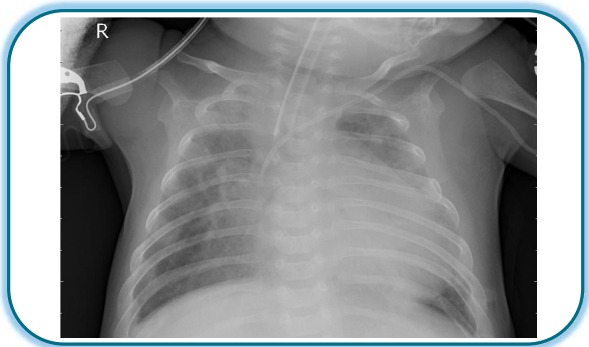
## Result Verification



# Machine Learning for Images and Production



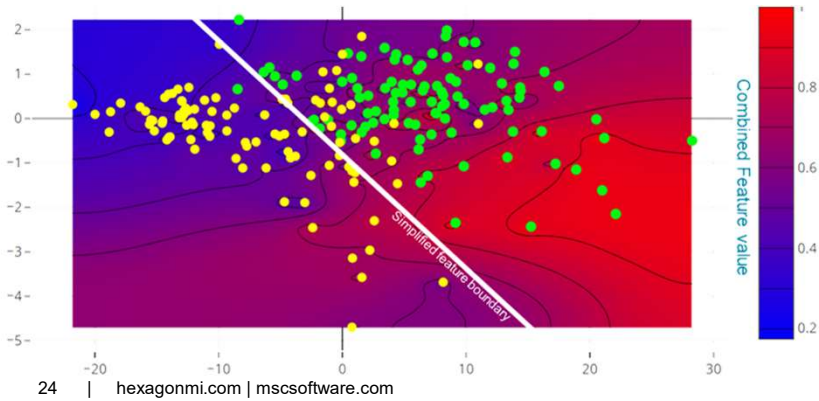
# Prediction Based on CT Scan



Learning



Prediction  
based on 200  
cases  
(Error 12%)

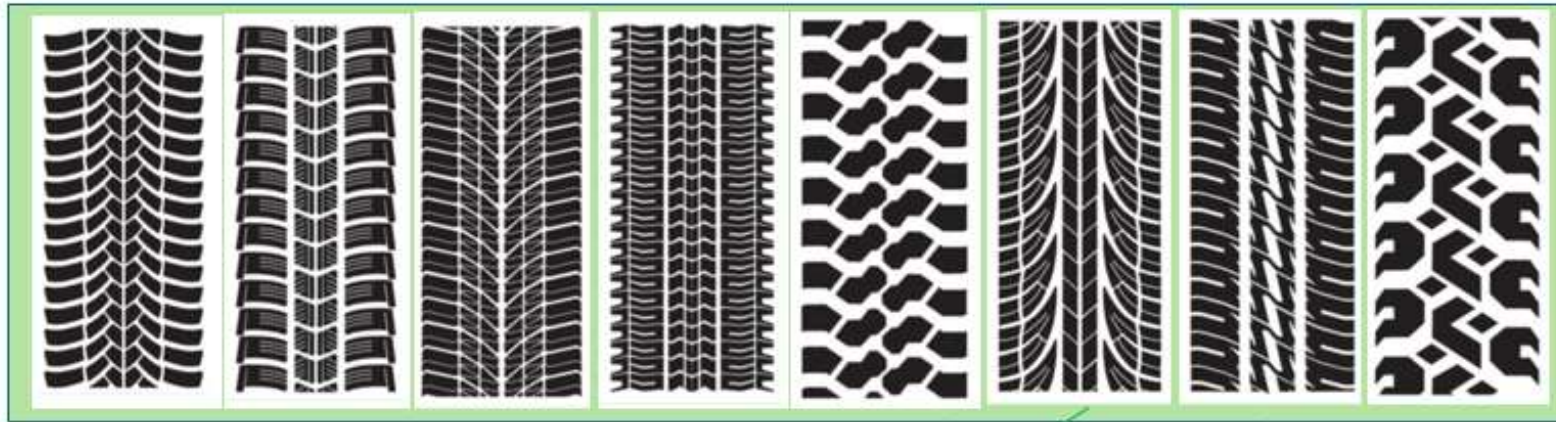


- Pneumonia
- Normal

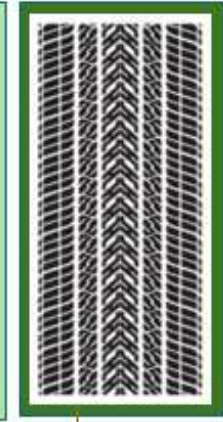


# Predict Sound Spectrum Curves from Tire Pattern Images

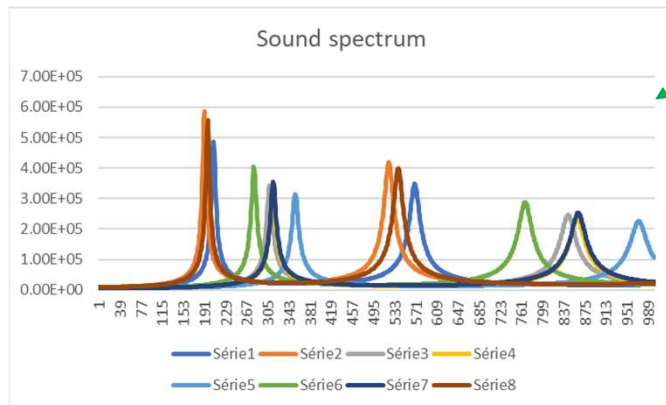
Known database: Parameters (Images)



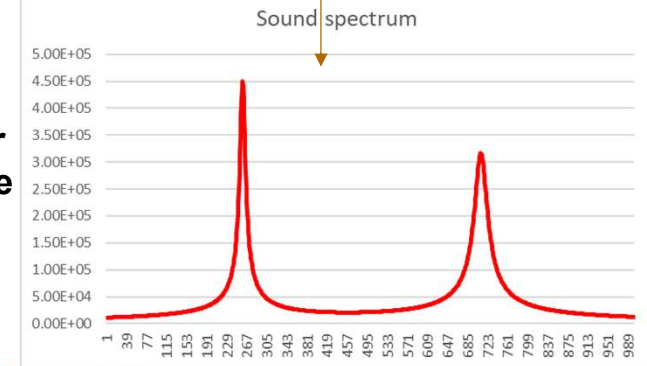
New parameters  
(new image)



Known  
database:  
Results



Predicted  
results for  
new image





**Vielen Dank fürs Zuhören!**

**Kontakt:  
cornelia.thieme@hexagon.com**