

um
2026

Accelerate blast resistance optimization coupling process automation, variability analysis and AI-based metamodels

Christopher GEORGE
CAE Engineer
CIMES France



Agenda

Introduction

CIMES company / Impetus / Protection of armored vehicles

Case study description

Model description / Blast simulation / Process automation

Data pre-processing

Statistical analysis / Material database / Variability on threat

Accelerate simulation with AI

Methodology / RSM / Failure prediction

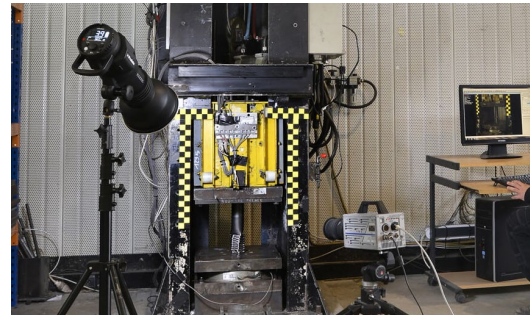
Conclusion

Current status / Perspectives

Introduction



Company presentation



TEST FACILITIES
Valenciennes, France

Integration of laboratories & testing services

1989

2010

DATA ENGINEERING
Process automation, DoE, optimization & surrogate models



modeFRONTIER

2021

OFFICIAL PARTNERSHIP WITH IMPETUS
Impetus Conference – Paris, France



Distribution & integration in France and Belgium

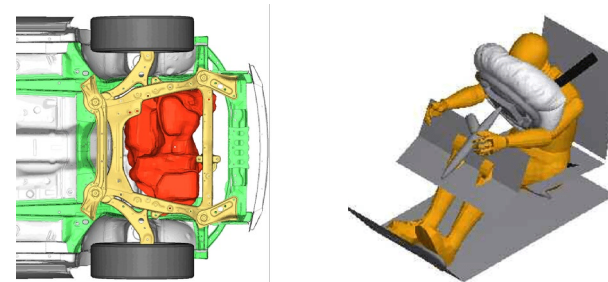
1995

CIMES CREATION
Valenciennes, France

Engineering expertise in numerical simulation



2019

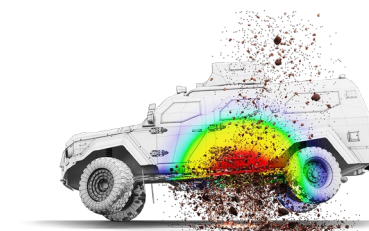


CRASH & SAFETY TEAM
Lyon, France

Automotive, railway & defense applications

2025

IMPETUS INTEGRATION
Simulations for military land vehicles



IMPETUS



Impetus solver

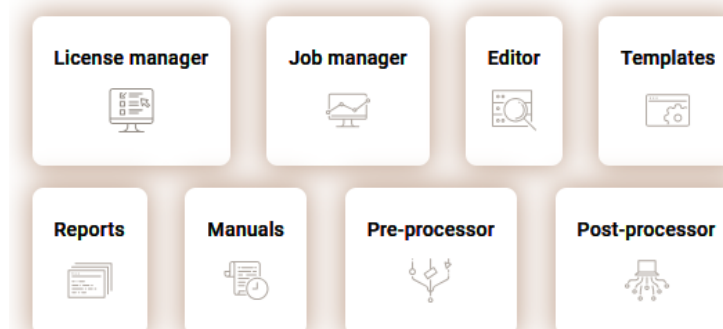
Impetus Solver is a versatile solution designed to meet the needs of both **weapons and protective structures** developers.

At its core, Impetus Solver utilises an explicit Lagrangian **Finite Element** solver. This powerful foundation is further enhanced by seamless integration with discrete particle (**DP**), smoothed particle hydrodynamics (**SPH**), and computational fluid dynamics (**CFD**) modules.

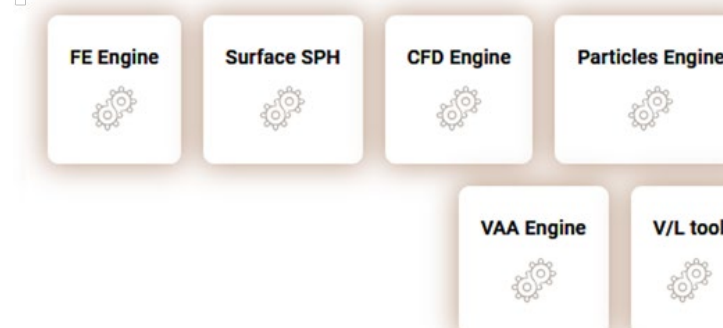
Thanks to **GPU acceleration**, the Impetus suite can be run efficiently on a regular stand-alone desktop computer.



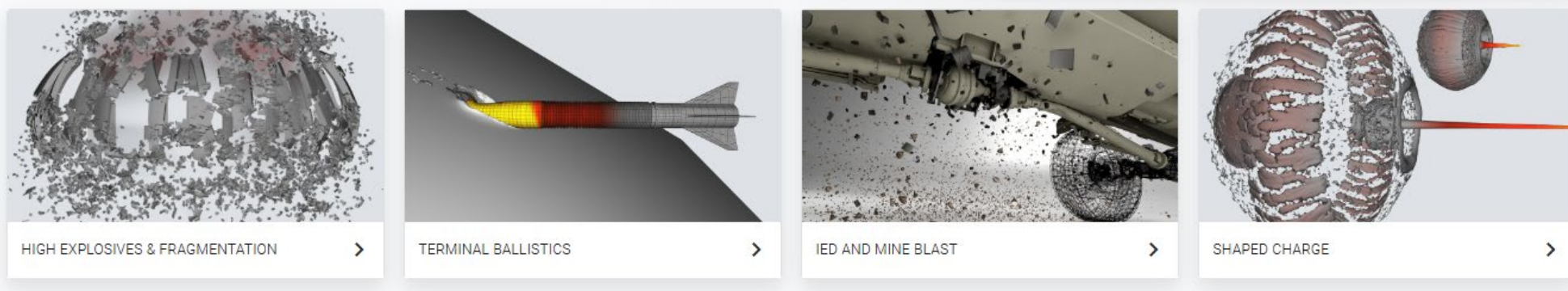
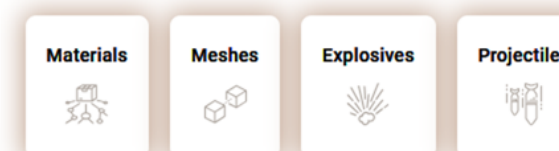
Graphical User Interface



Computational modules



MARKET Assets Library

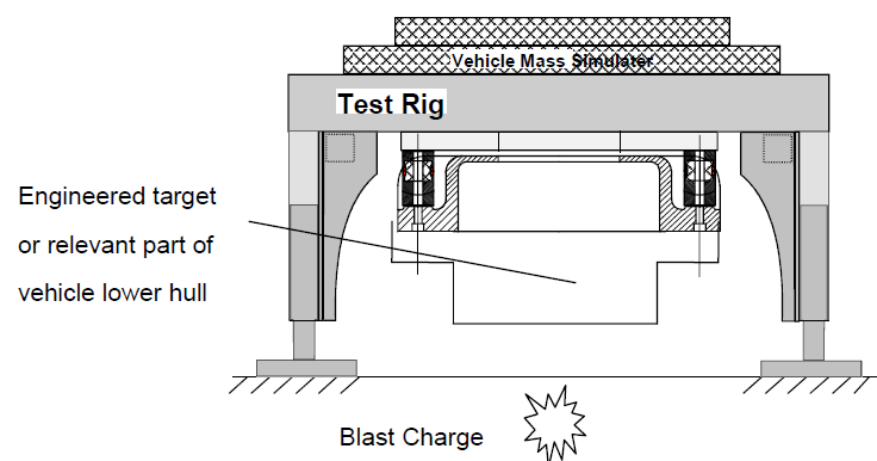


Protection of armored vehicles

STANAG 4569

A NATO military standard that defines protection levels for occupants of armored vehicles.

		Location	Explosive
Level-1		Anywhere under the vehicle	Hand grenades, unexploded artillery fragmenting submunitions, and other small anti personnel explosive devices
Level-2	2a	Under any wheel or track location	6 kg (explosive mass) Blast AT Mine
	2b	Under belly	6 kg (explosive mass) Blast AT Mine
Level-3	3a	Under any wheel or track location	8 kg (explosive mass) Blast AT Mine
	3b	Under belly	8 kg (explosive mass) Blast AT Mine
Level-4	4a	Under any wheel or track location	10 kg (explosive mass) Blast AT Mine
	4b	Under belly	10 kg (explosive mass) Blast AT Mine

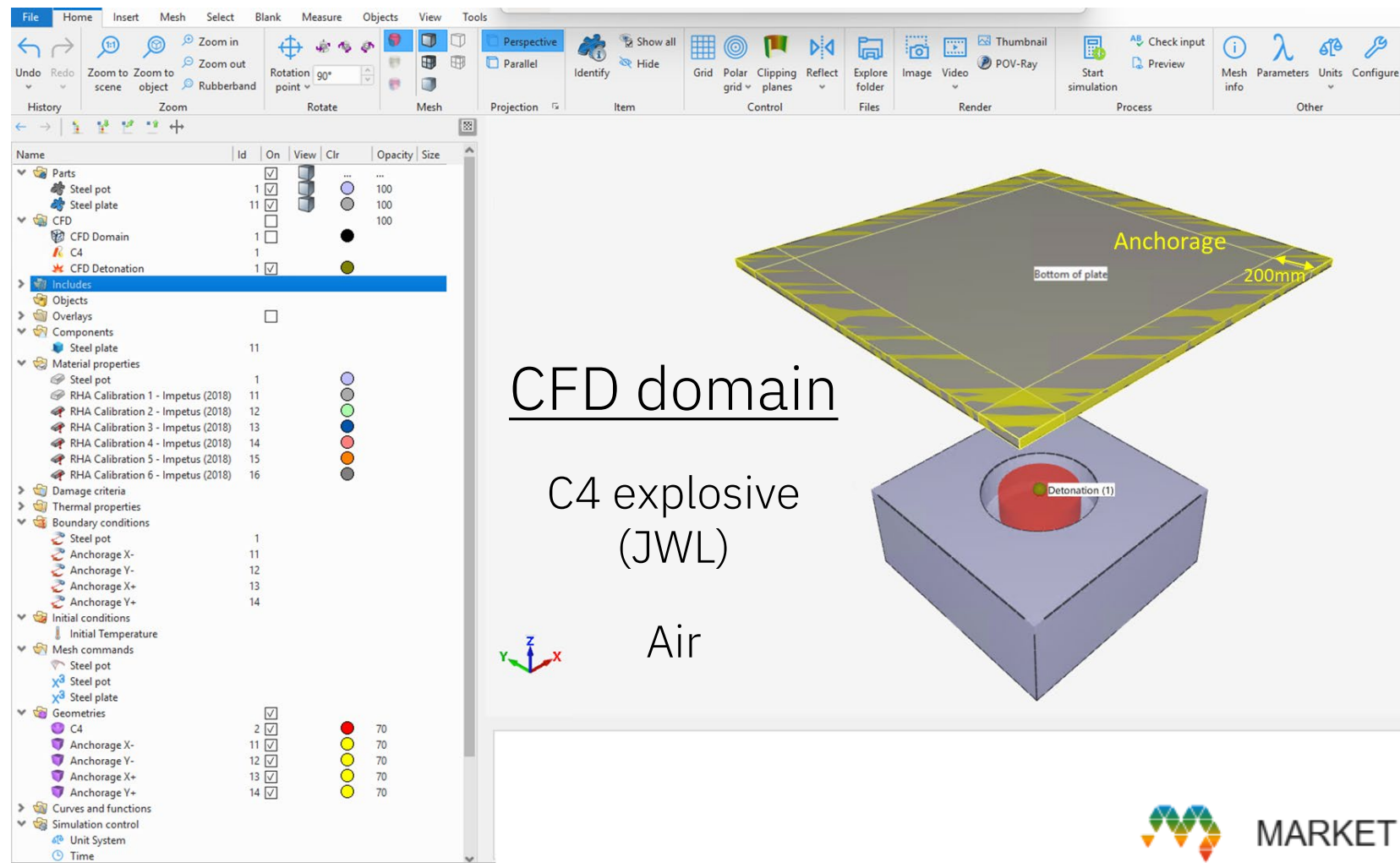


Case study



Model description

Surrogate mine in steel pot



CFD domain

C4 explosive (JWL)

Air



Threat

Level 3 +0%

Standoff distance = 0.7m

Scaled distance = $0.35\text{m/kg}^{1/3}$

Target plate

Material: RHA #1

(Roller homogeneous armor)

Thickness: 20mm (157kg/m^2)

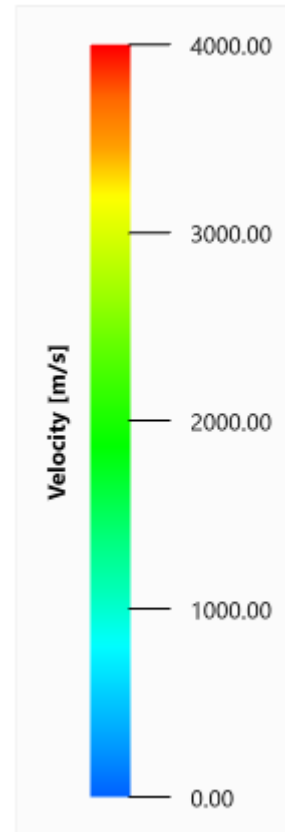
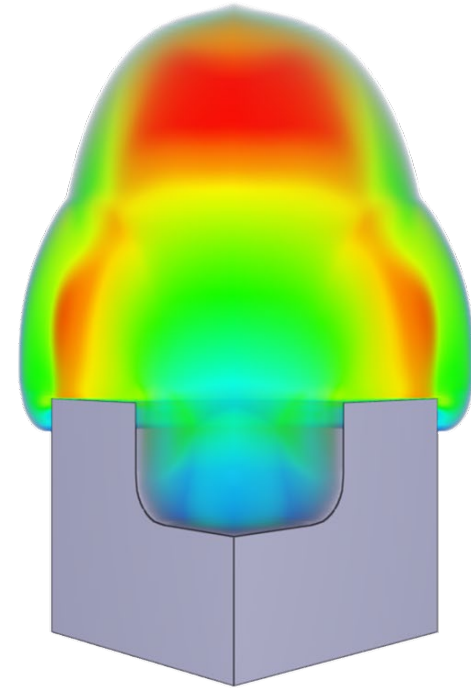
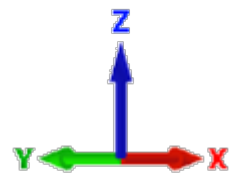
Parameters: initial values

Parameter	Expression	Value	Description
tend	3.0e-3	0.003	Termination time
dcell	10e-3	0.01	CFD: cell size
geo_update	1	1	CFD: coupling geometry update interval (number of iterations)
level	3	3	Threat level
sf	1	1	Scale factor applied on charge
rho_c4	1601	1601	Density of C4
det_p	0.3	0.3	Top of charge
sod	700*1e-3	0.7	Stand-off distance
mid	11	11	Material ID of plate
tp	20*1e-3	0.02	Thickness of plate
lp	1.0	1	Side length of plate
Z0	%sod+ %det_p	1	Z-coord of bottom of plate
dx	20e-3	0.02	Element size of plate
erode	2	2	Element erosion flag: = 0, 1, 2 or 3 (see object documentation)
reg	1	1	Regularized damage accumulation: = 0 -> Exclude
T_ref	293.0	293	Reference temperature for thermal expansion [K]
m_TNT	8	8	Mass of TNT
hd_c4	0.3634040865072634	0.363404086507263	Height-to-diameter ratio of C4 charge
m_c4	%m_TNT*%sf*0.84	6.72	Mass of C4 including scale factor
r_c4	(%m_c4/(2*pi*%hd_c4*%rho_c4))^(1/3)	0.1225	Radius of C4 charge
h_c4	%hd_c4*2*%r_c4	0.0890340011942795	Height of C4 charge
Z	%sod/(%m_TNT*%sf)^(1/3)	0.35	Reduced distance

Blast simulation

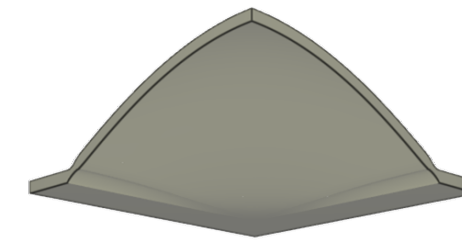
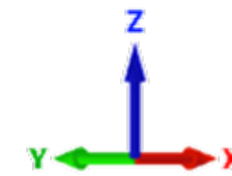
Restart and mapping from fine to coarse grid

Step 1: Detonation & initial blast wave formation

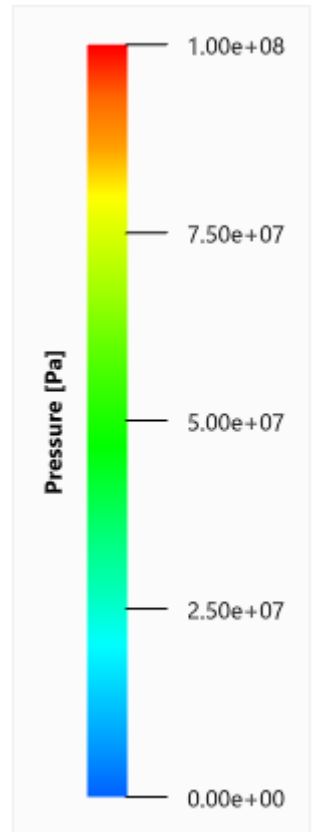
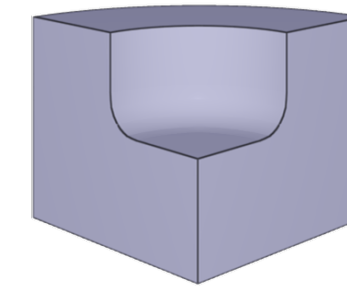


Simulation time: 0.1ms
 CPU time: **51min** (GPU)
 Quarter symmetry
 CFD cell size: 2.5mm

Step 2: Blast wave propagation



No failure
 Max Dz: 143.06mm
 Max Vz: 216.74m/s



Simulation time: 3ms
 CPU time: **4min30s** (GPU)
 Quarter symmetry
 CFD cell size: 10mm

Process automation

Workflow

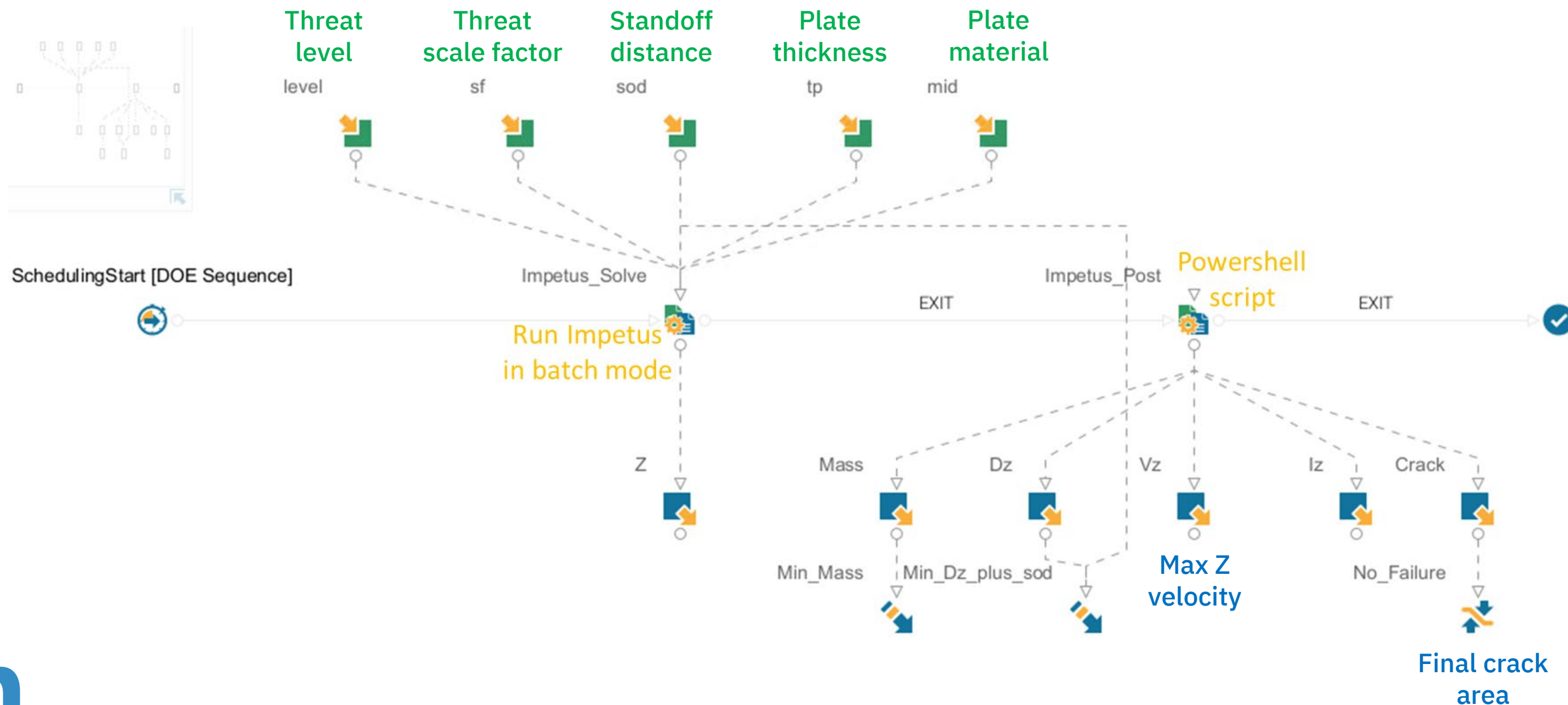


Plate material



IMPETUS
RHA - Impetus (2018)

Material

Data pre-processing



Statistical analysis

Correlation matrix

Failure
No failure

Threat level
Plate material
Threat scale factor
Standoff distance
Plate thickness
Final crack area
Max Z velocity

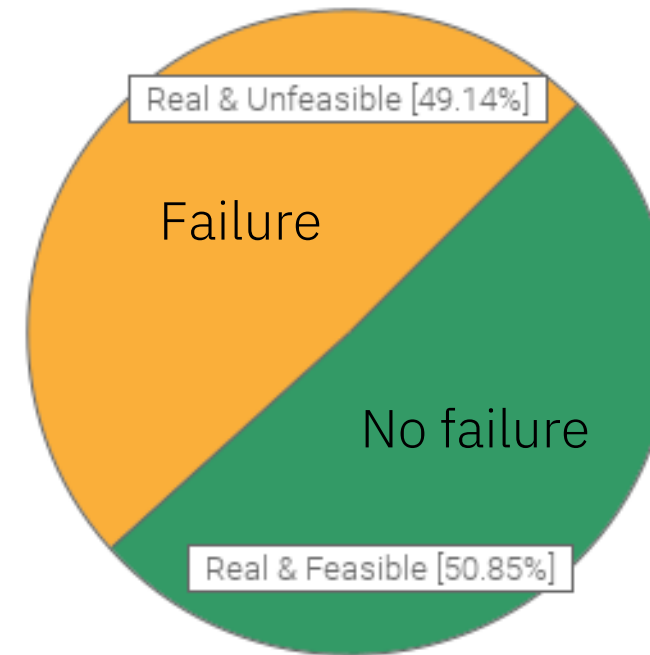


Full factorial DoE: 1050 simulations

No correlation between inputs

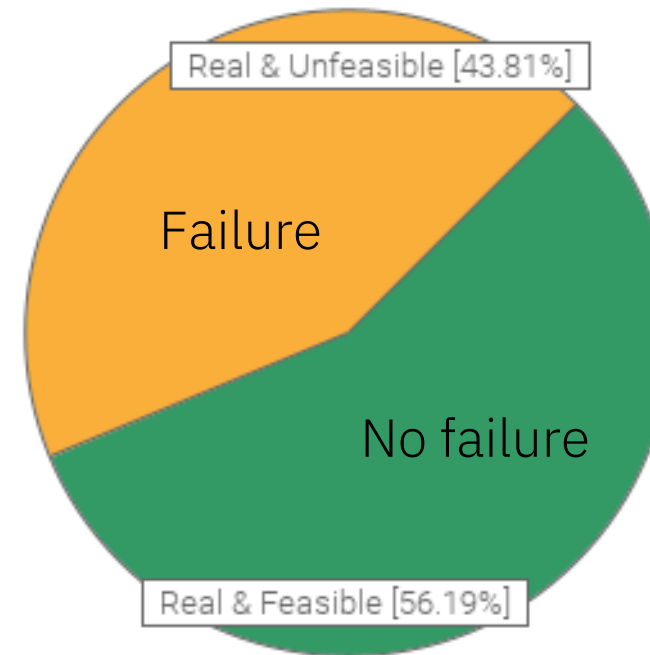
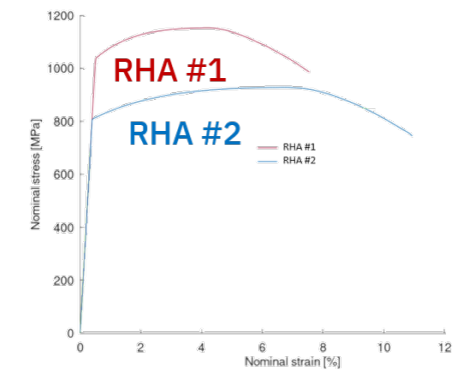
High correlation between crack area and Vz

Design summary



Material RHA #1

Designs Summary
 Real & Feasible
 Real & Unfeasible
 Virtual & Feasible
 Virtual & Unfeasible
 Real Error
 Virtual Error



Material RHA #2

Designs Summary
 Real & Feasible
 Real & Unfeasible
 Virtual & Feasible
 Virtual & Unfeasible
 Real Error
 Virtual Error

Less failure: softer material grade

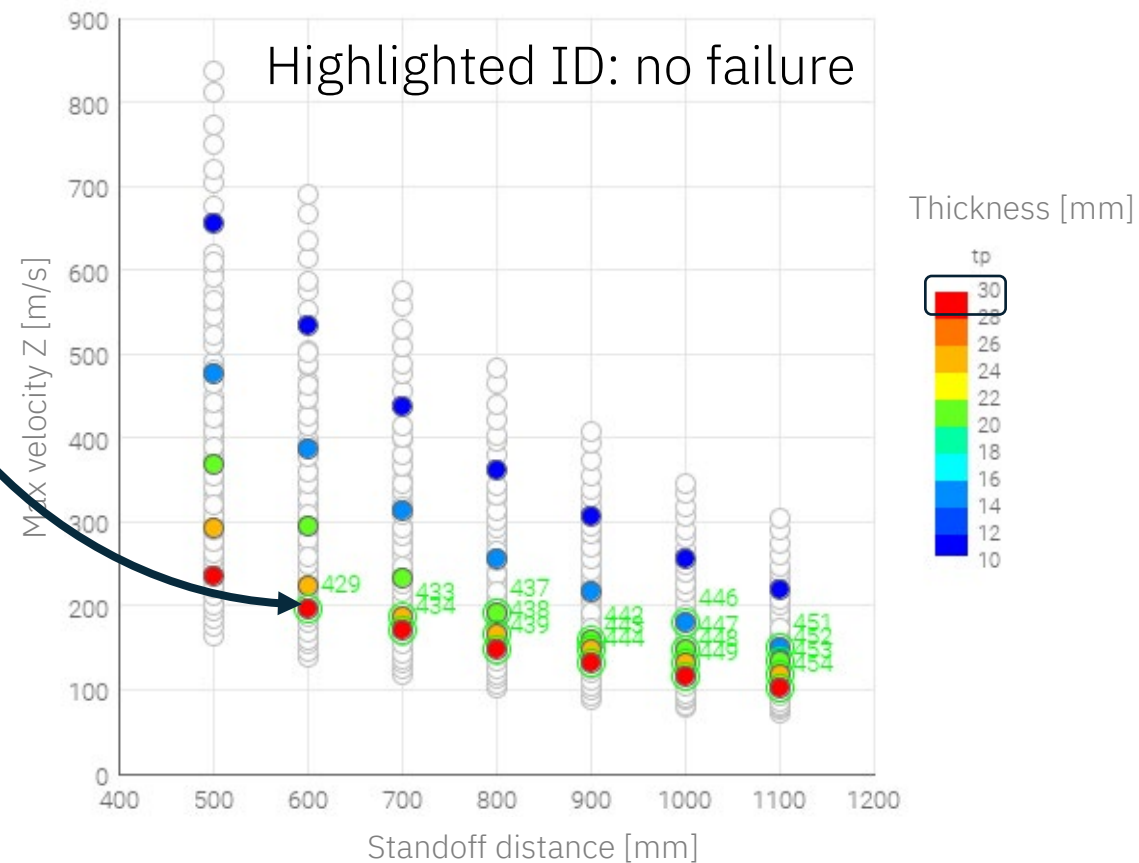
Material database

Material RHA #1

Critical thickness to ensure no failure

Threat level	Standoff distance [m]						
	0.5	0.6	0.7	0.8	0.9	1	1.1
2	25	20	20	15	15	15	10
3	>30	30	25	20	20	15	15
4	>30	>30	30	25	20	20	20

Threat level 3

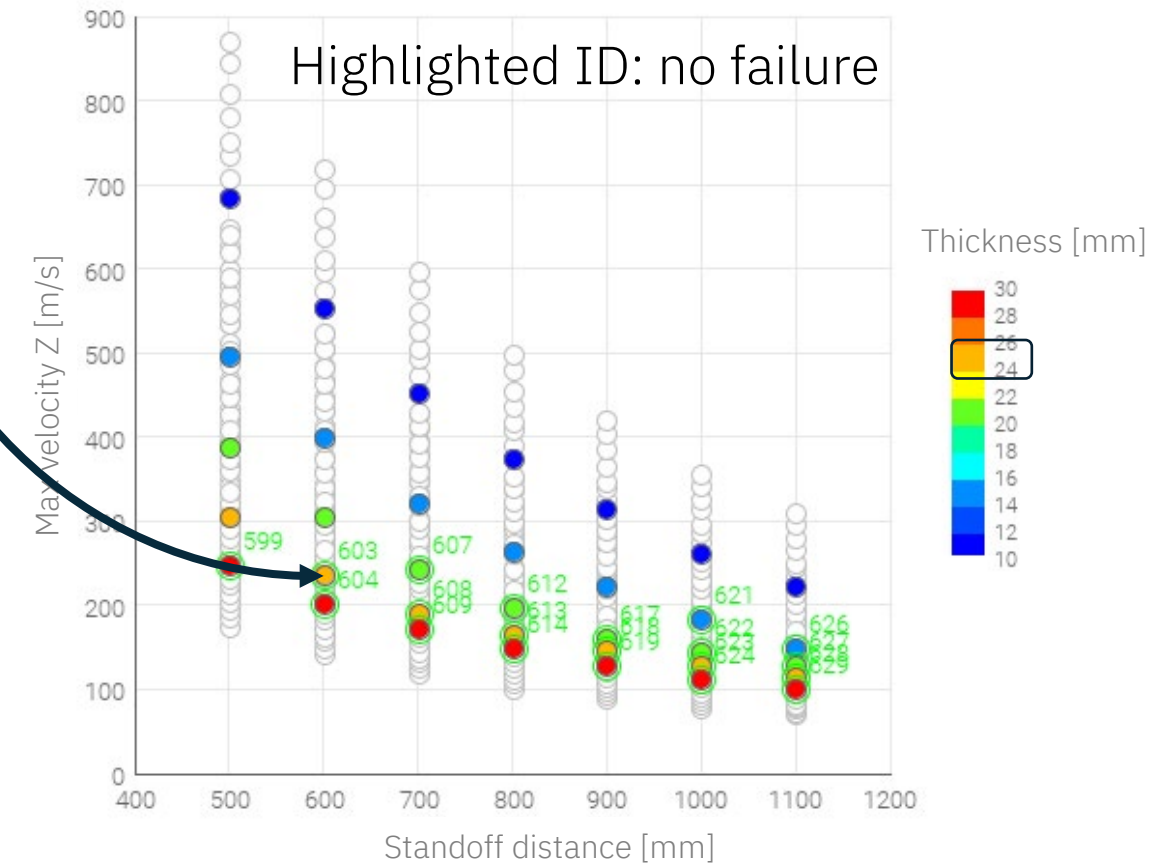


Material RHA #2

Critical thickness to ensure no failure

Threat level	Standoff distance [m]						
	0.5	0.6	0.7	0.8	0.9	1	1.1
2	20	20	20	15	15	15	10
3	30	25	20	20	20	15	15
4	>30	>30	30	25	20	20	15

Threat level 3

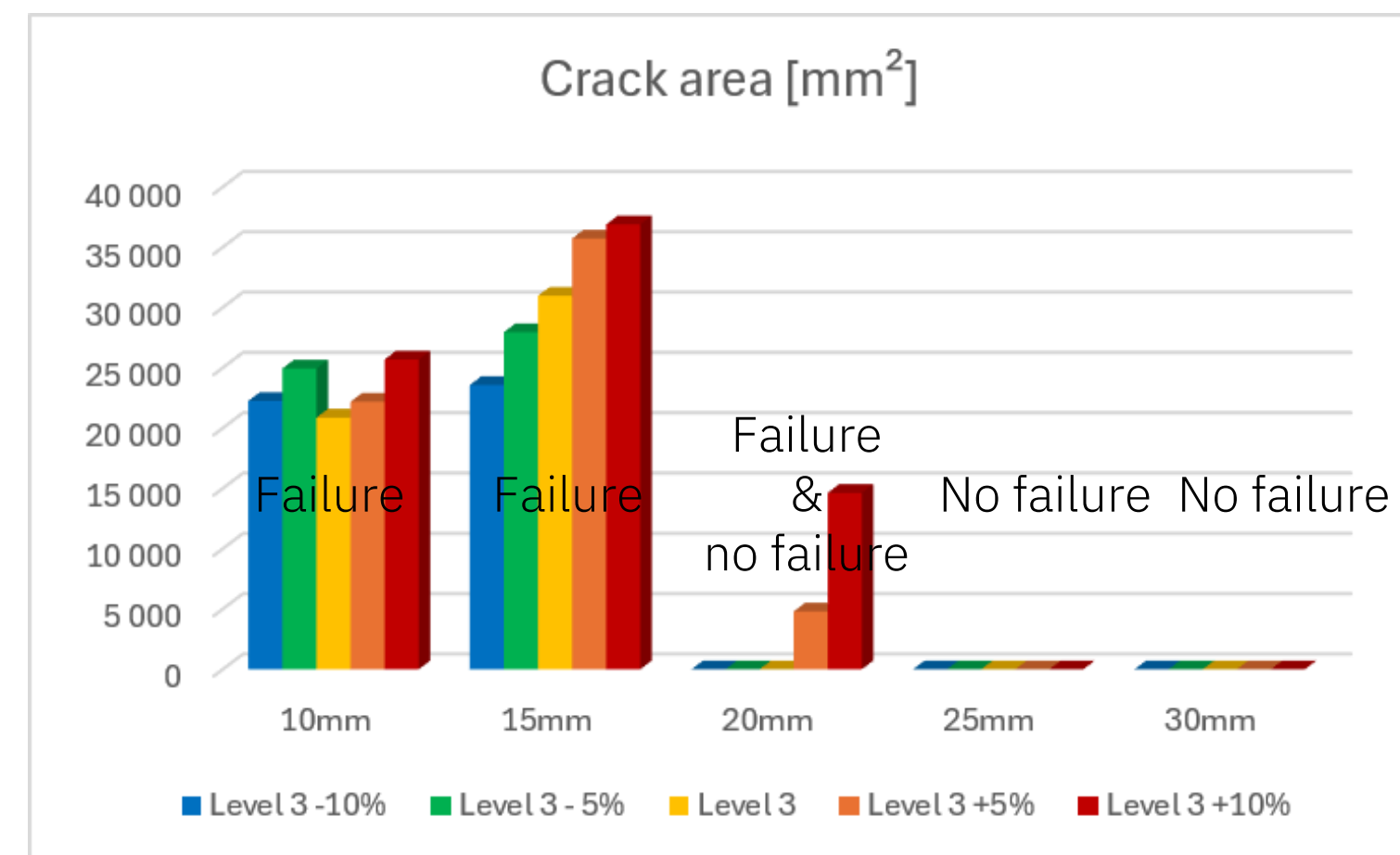
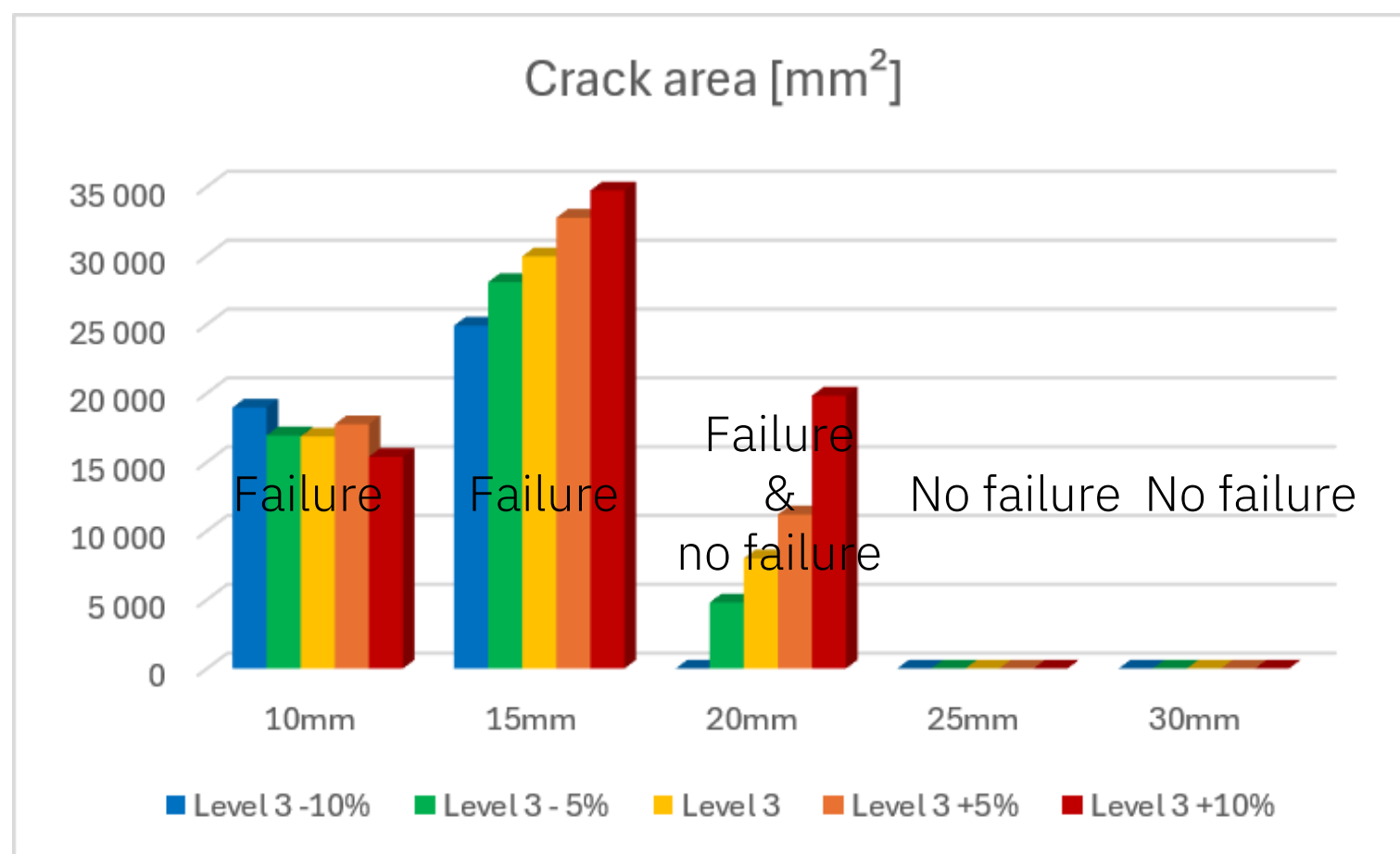


Variability on threat

Threat level 3 +/- 10%
Standoff distance 0.7m

Material RHA #1

Material RHA #2



20mm-thick plate: non robust configuration

20mm-thick plate: non robust configuration

Level 3 -10%: no failure

Level 3: no failure

Level 3 -5%: failure

Level 3 +5%: failure

Accelerate simulation with AI



Methodology

Step-by-step procedure

Step 1: Training dataset (~82 hours)

DoE: Full Factorial (1050 simulations)

Step 2: Validation dataset (~23 hours)

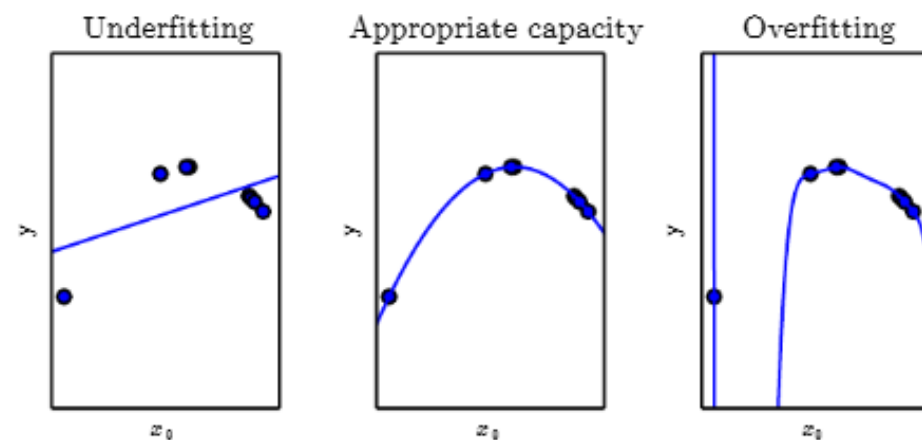
DoE: Uniform Latin Hypercube (250 simulations)

Step 3: RSM creation (~2 minutes)

RSM algorithm: Neural Networks

Step 4: RSM validation (**few seconds**)

How to trust RSM predictions? (validation tools, performance index)



RSM Tool

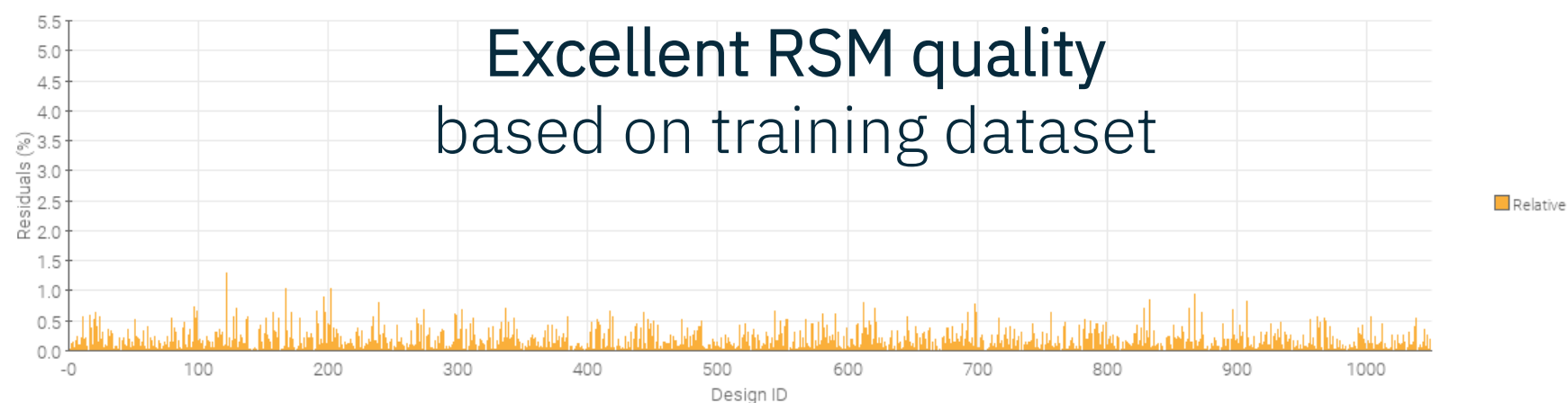
The screenshot shows the RSM Tool interface with the following components:

- Workflow:** A three-step process: 1. SELECT TRAINING TABLE, 2. DEFINE VALIDATION TABLE, 3. CREATE AND CONFIGURE RSM MODELS.
- Summary Panel:** Shows training and validation table names: Training table: DOE_FF_1050_Results, Validation table: DOE_ULH_250_Results.
- Model Configuration:**
 - Outputs:** A list of outputs including Crack, Dz, Iz, Mass, Vz, and Z.
 - Selected output:** Crack.
 - Inputs:** A list of input variables: level, mid, sf, sod, and tp.
 - Models:** A list of model types including Classical (User Model, Polynomial SVD, Stepwise Regression, Parametric Surfaces), Statistical (Shepard - K-Nearest, Kriging, Anisotropic Kriging, DACE-Kriging, Gaussian Processes, Smoothing Spline AN...), and Advanced (Radial Basis Functions, **Neural Networks**, Evolutionary Design).
- Diagram:** A neural network diagram showing inputs x_1, x_2, \dots, x_n with weights w_1, w_2, \dots, w_n being summed (Σ) and added to a bias b . The result is passed through an activation function f to produce the output y . The equation $y = f(\mathbf{w}^T \mathbf{x} + b)$ is shown below the diagram.

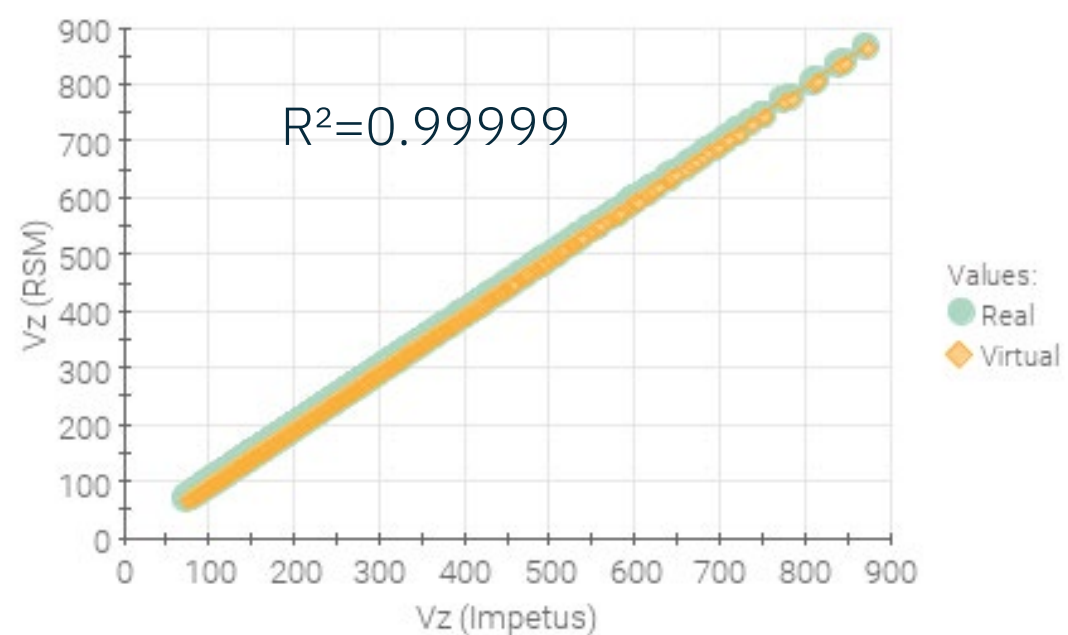
RSM - Maximal Z velocity

Training

Max Abs. Error	2.1	Max Rel. Error	1.3	Max Norm. Error	0.3
Mean Abs. Error	0.4	Mean Rel. Error [%]	0.2	Mean Norm. Error [%]	0.0
Regression	1.0	Error Mean	0.0		

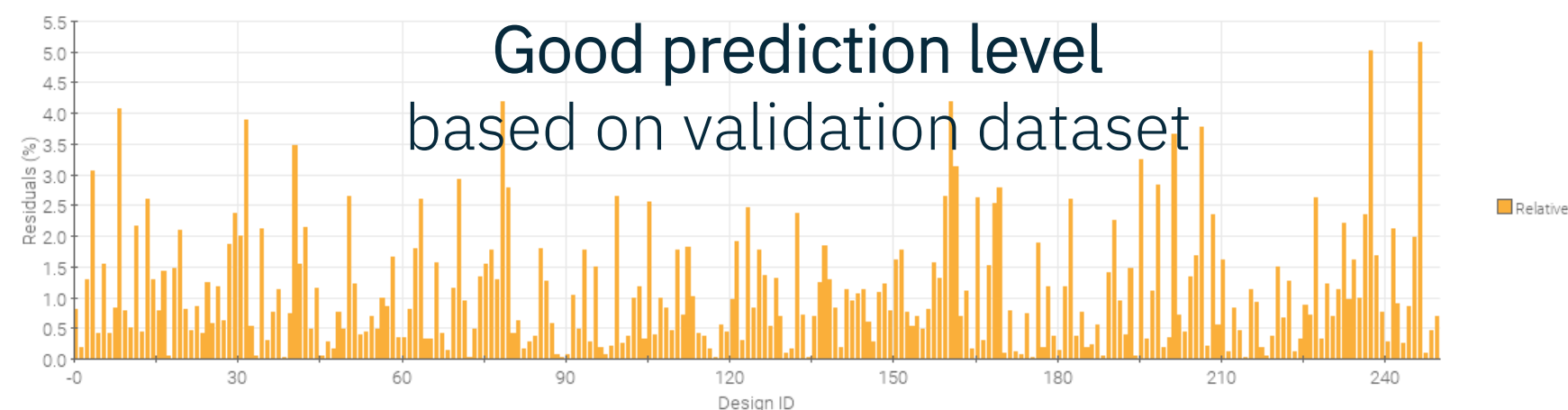


Excellent RSM quality based on training dataset

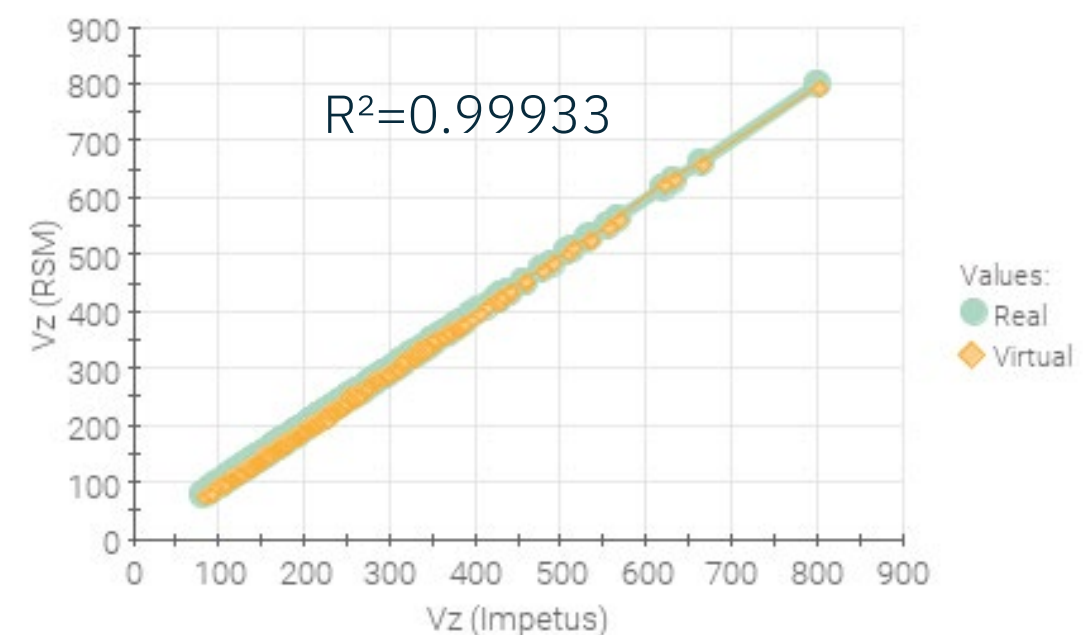


Validation

Max Abs. Error	11.0	Max Rel. Error	5.2	Max Norm. Error	1.5
Mean Abs. Error	2.3	Mean Rel. Error [%]	1.1	Mean Norm. Error [%]	0.3
Regression	1.0	Error Mean	0.4		

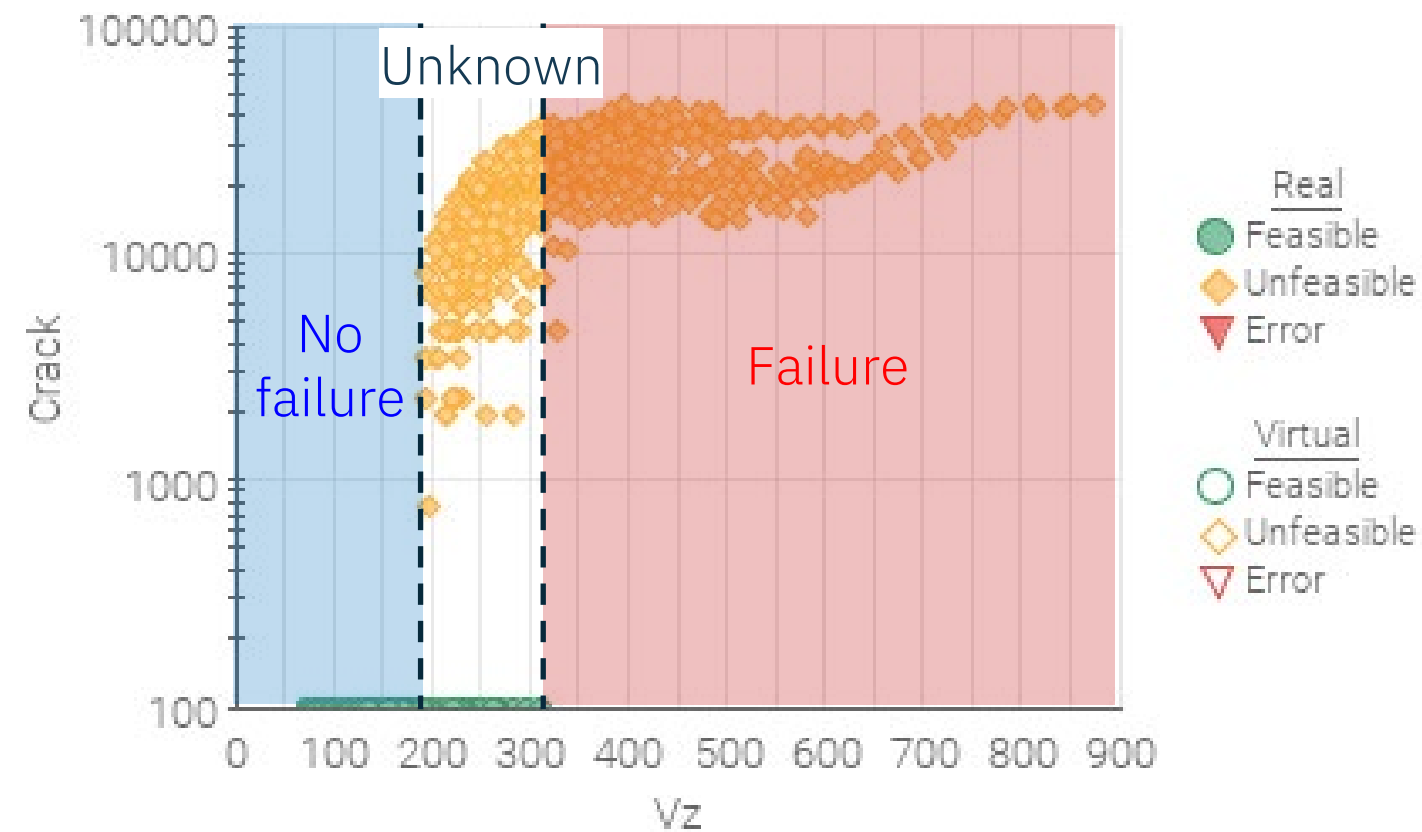


Good prediction level based on validation dataset

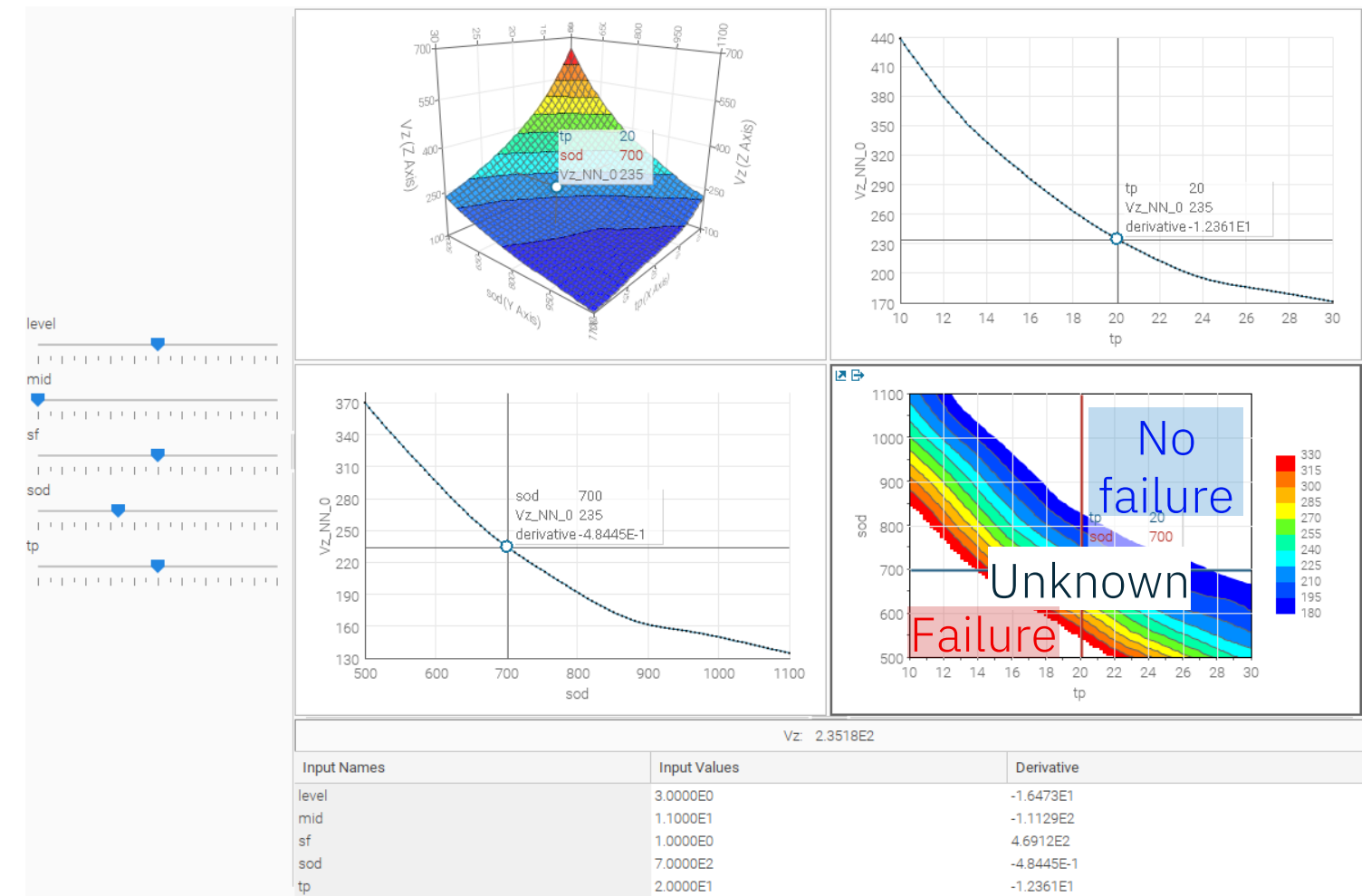


Failure prediction

Failure criteria from Impetus velocity



Failure prediction from RSM velocity

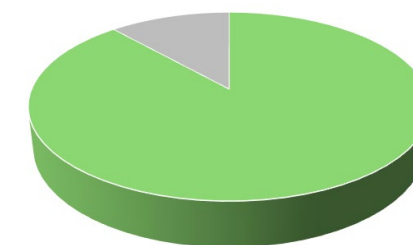


Status

90% good predictions (221/250)

10% no prediction (29/250)

0% bad prediction (0/250)



Good prediction Bad prediction No prediction

Conclusion



PoC – Current status

Step 1: Accurate numerical model

→ IMPETUS solver has demonstrated its good performances for blast simulations with **advanced coupling between finite elements and CFD domain**.

Step 2: Process automation & data generation

→ modeFRONTIER offers to CAE engineers a **user-friendly platform to automate complex workflows** which avoid repetitive manual tasks.

Step 3: Data pre-processing

→ A lot of charts are available to pre-processing data and **highlight valuable information**.

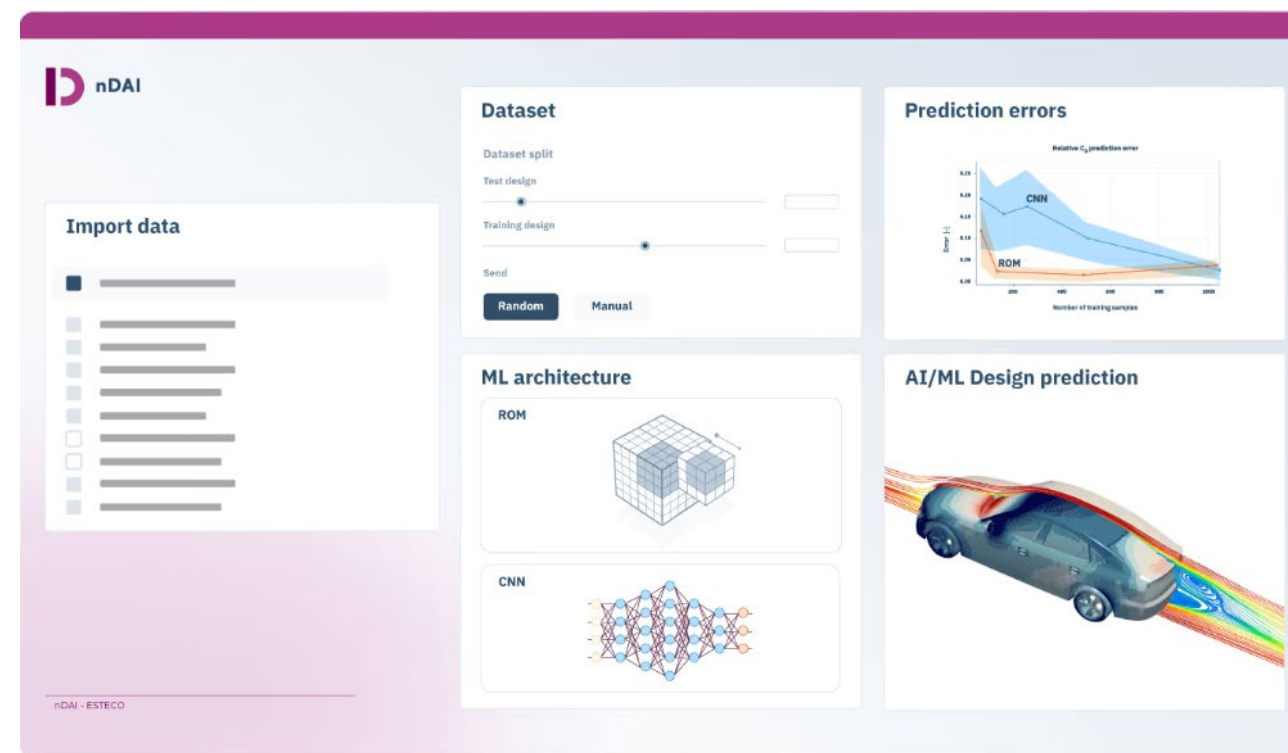
Step 4: Surrogate models

→ RSM tool is a convenient way to produce **simple surrogate models**, but sometimes the prediction capability is not at the expected level.

Perspectives

To go further

- Reduce number of simulations of the training dataset to be applied this method in industrial applications.
- Create metamodels for **other outputs** (displacement, crack area).
- Integrate **physical test data** to increase **confidence level** and also integrate **variability**.
- Use the new module nDAI from ESTECO for metamodel creation. It allows to produce **Reduced Order Model (ROM)** which attempts to model **scalar** (0D variable) but also **signal** (1D variable).



Thank you

esteco.com



Let's discuss
your challenges!

CIMES



03 27 41 62 71



christopher.george@cimesfrance.fr



www.cimesfrance.com