

um
2026

Fast AI-driven simulation of the pantograph-catenary interaction using Reduced Order Models (ROM)

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Technical Director
CIMES France



Agenda

Introduction

CIMES / Pantograph-catenary / Virtual certification

Case study

Rolling stock / Catenary / Dynamic simulation

Data generation with modeFRONTIER

Process integration / DoE definition

Reduced order models with nDAI 2026R1

Uplift / Contact force

Conclusion

Conclusions & Perspectives



Introduction



Company presentation

CREATION

1989

EXPERTISES

**SIMULATIONS
& TESTS**

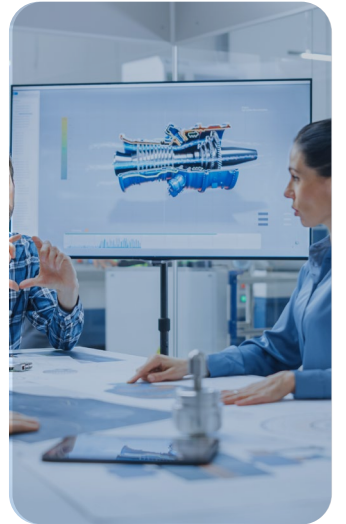


SUPERVISION 4.0

IoT sensors
Infrastructure &
transport monitoring

**MULTIPHYSICS
SIMULATIONS**

Implicit & explicit
Multibody dynamics
CFD

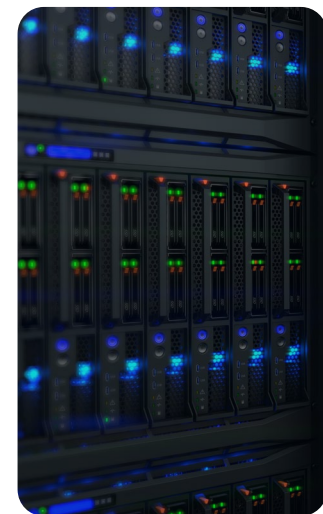


STAFF

20 CAE engineers

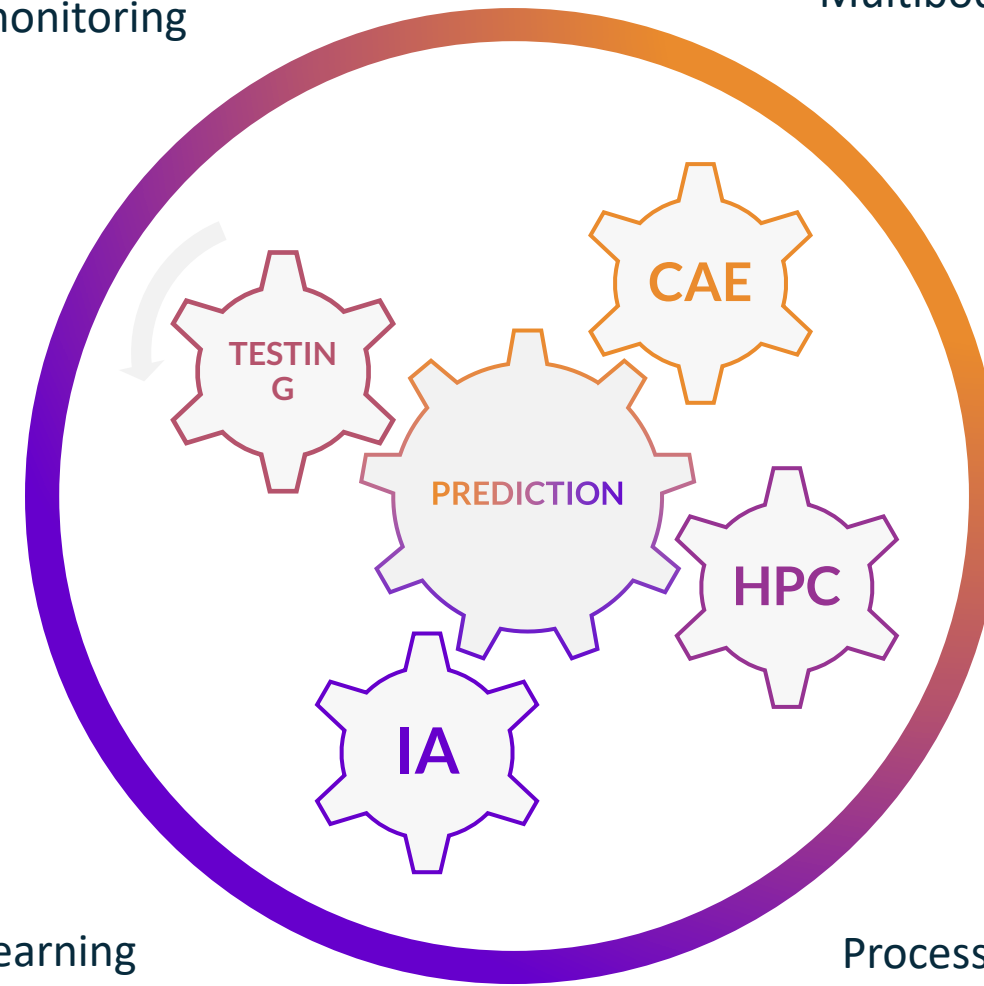
HARDWARE

**Internal HPC
Cluster** 🇫🇷



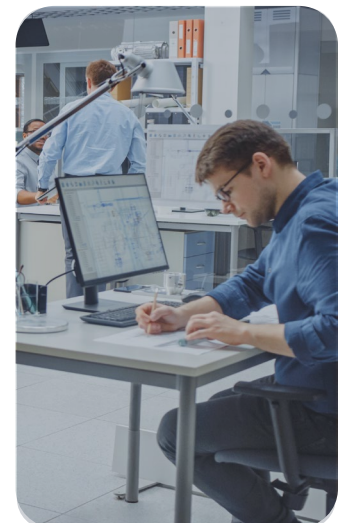
Machine learning
Reduced order model
Variability analysis

**AI-POWERED
ENGINEERING**

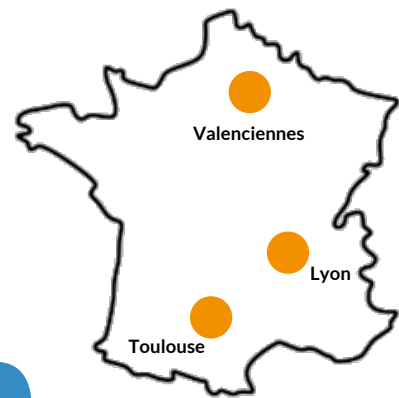


Process integration
Workflow automation
Design of experiments

**EXPLORATION
DESIGN**

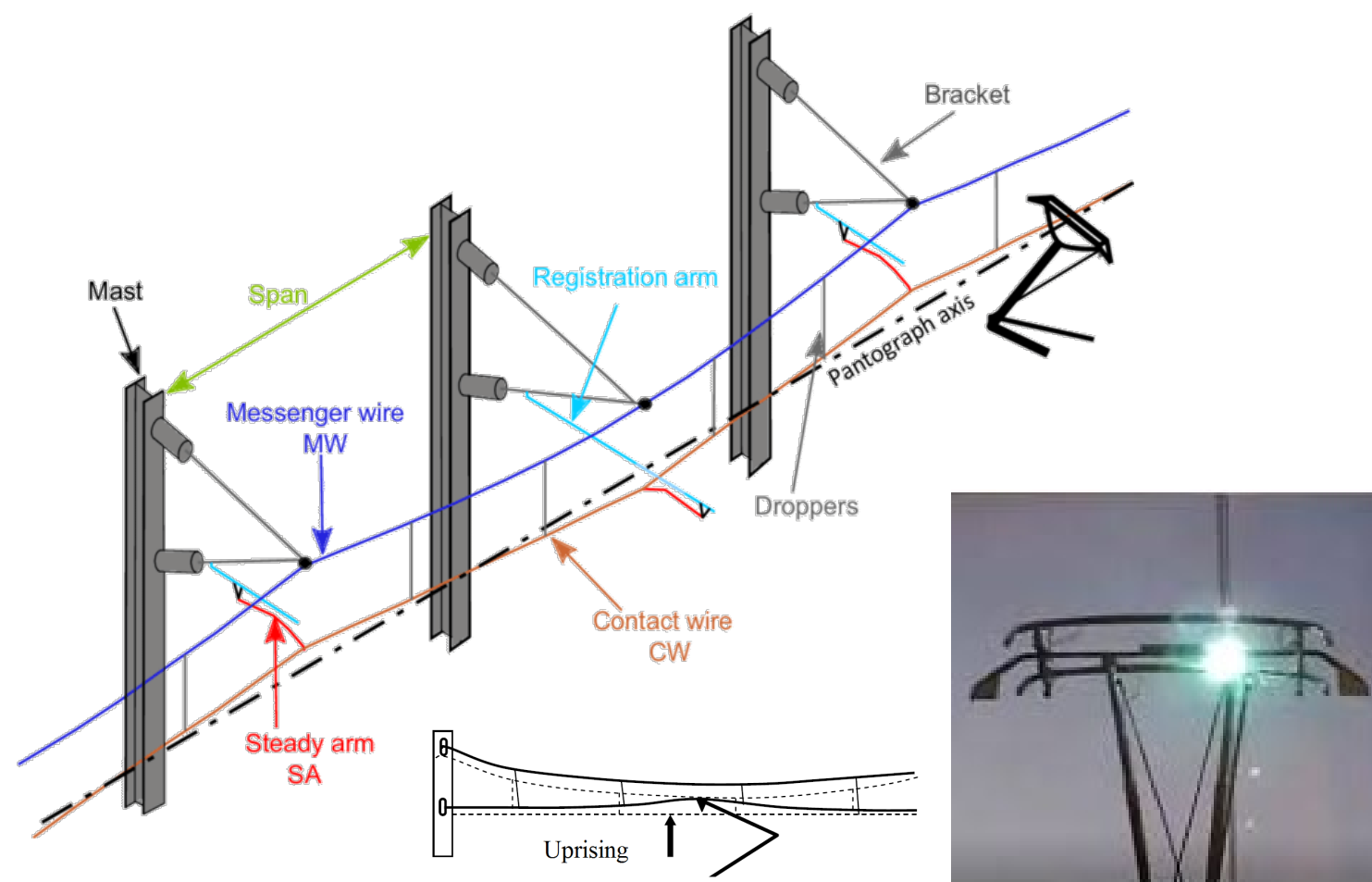


APPROVALS



Pantograph-catenary interaction

Current collection quality



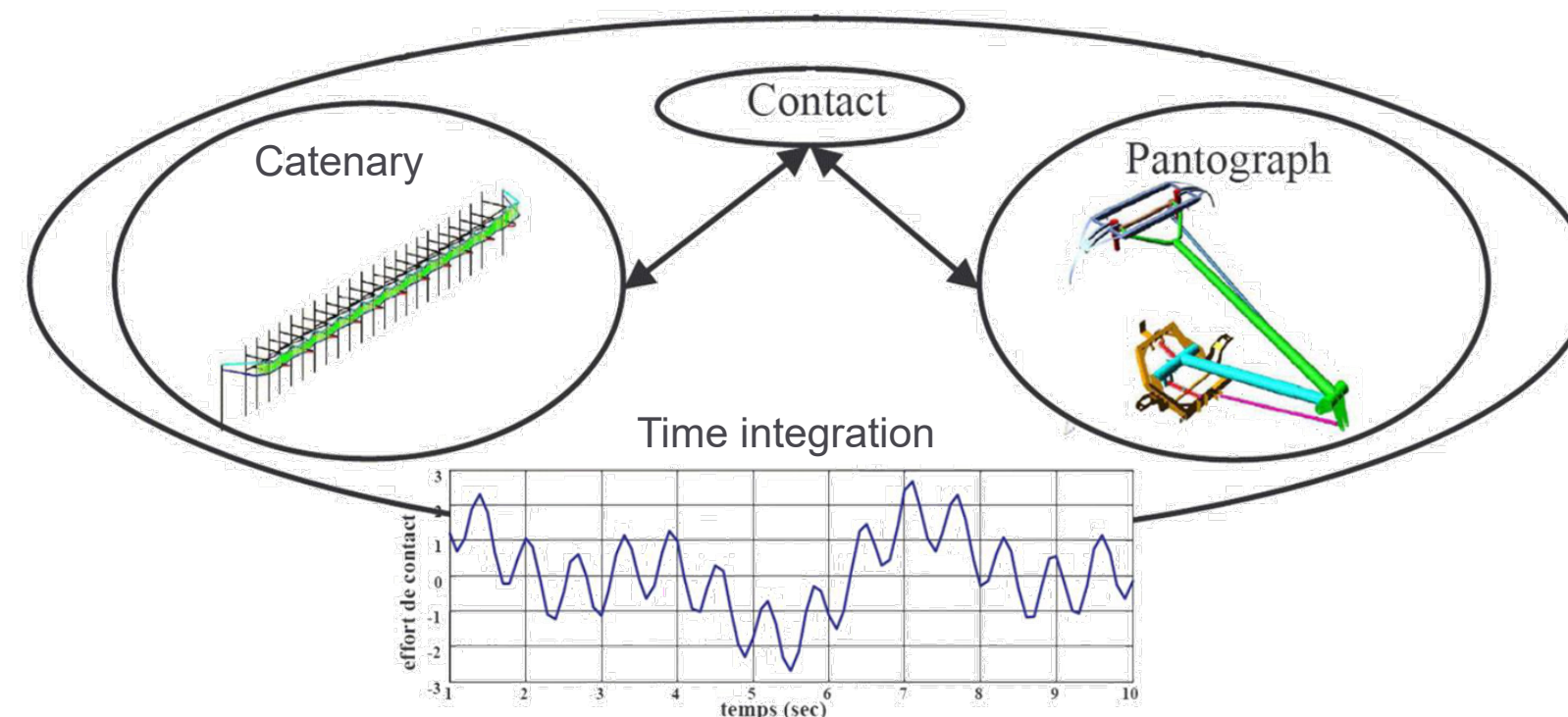
EN 50367

A European railway standard that specifies the technical criteria for ensuring good current collection quality between pantographs and overhead contact lines.

Simulation

OSCAR
Principes

MATLAB environment



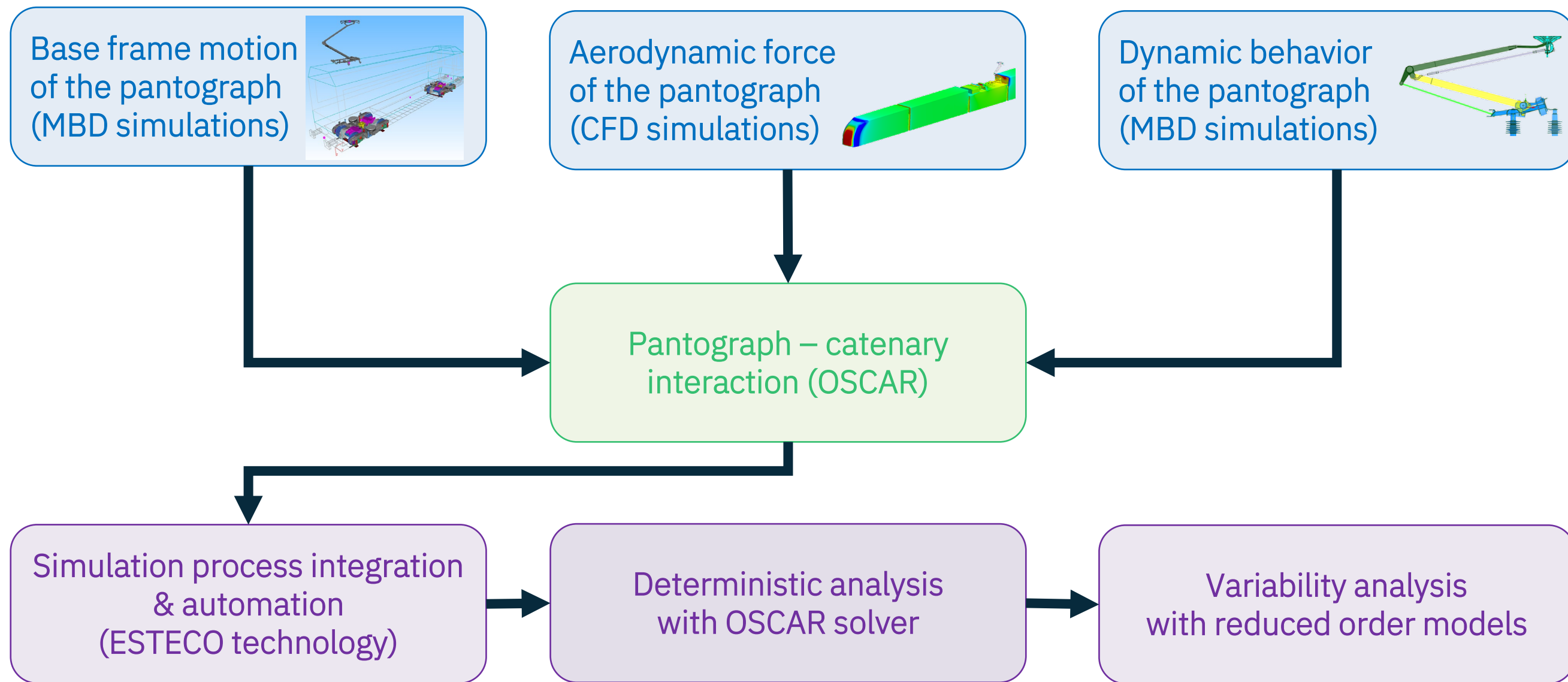
EN 50318

A European railway standard that specifies the validation of numerical models used to assess the dynamic interaction between pantographs and overhead contact lines.



Virtual certification in railway industry

Research & Innovation program in collaboration with SNCF Réseau



Task 1: Integrate multiphysics aspects to obtain high fidelity models with a strong predictive accuracy.

Task 2: Automate the workflow, generate data and develop ROMs to facilitate design space exploration and accelerate simulations.

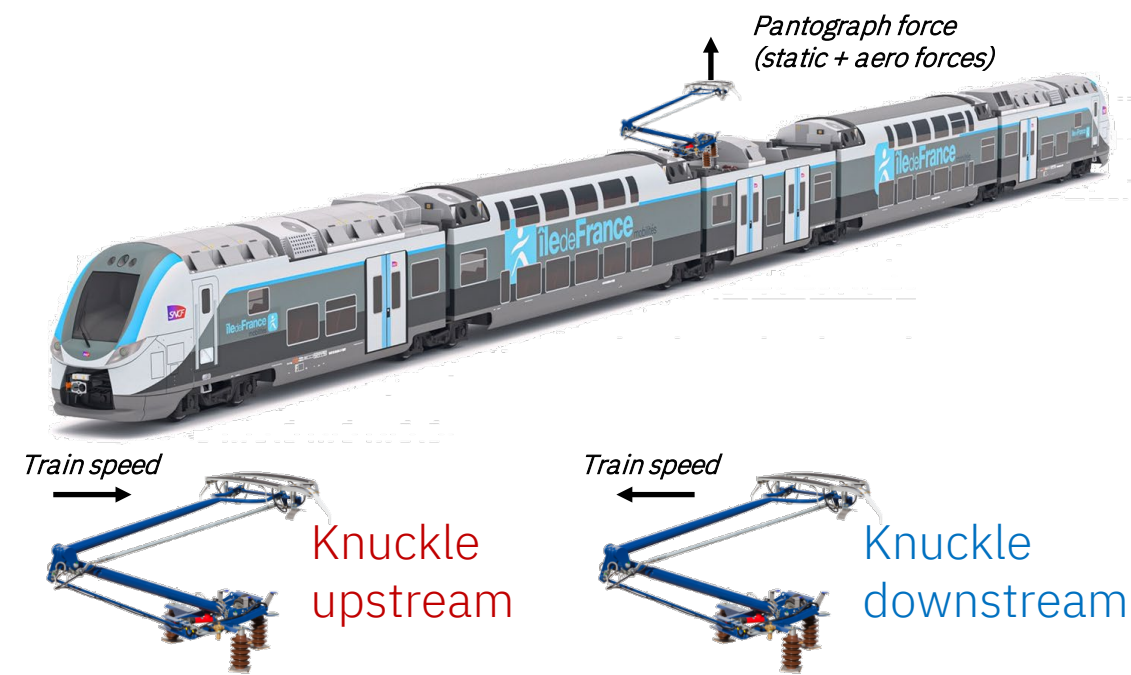
Case study

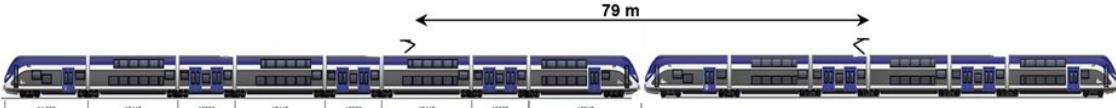
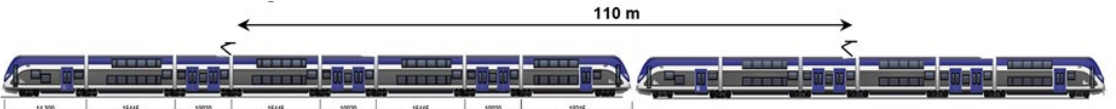
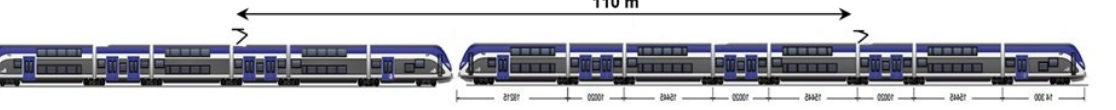
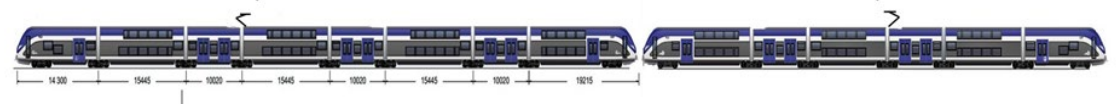


Rolling stock

REGIO 2N

The Regio 2N is family of a double-deck, dual-voltage electric multiple unit trainsets built for French rail operator SNCF to serve its regional rail routes (TER, Transilien, and RER).

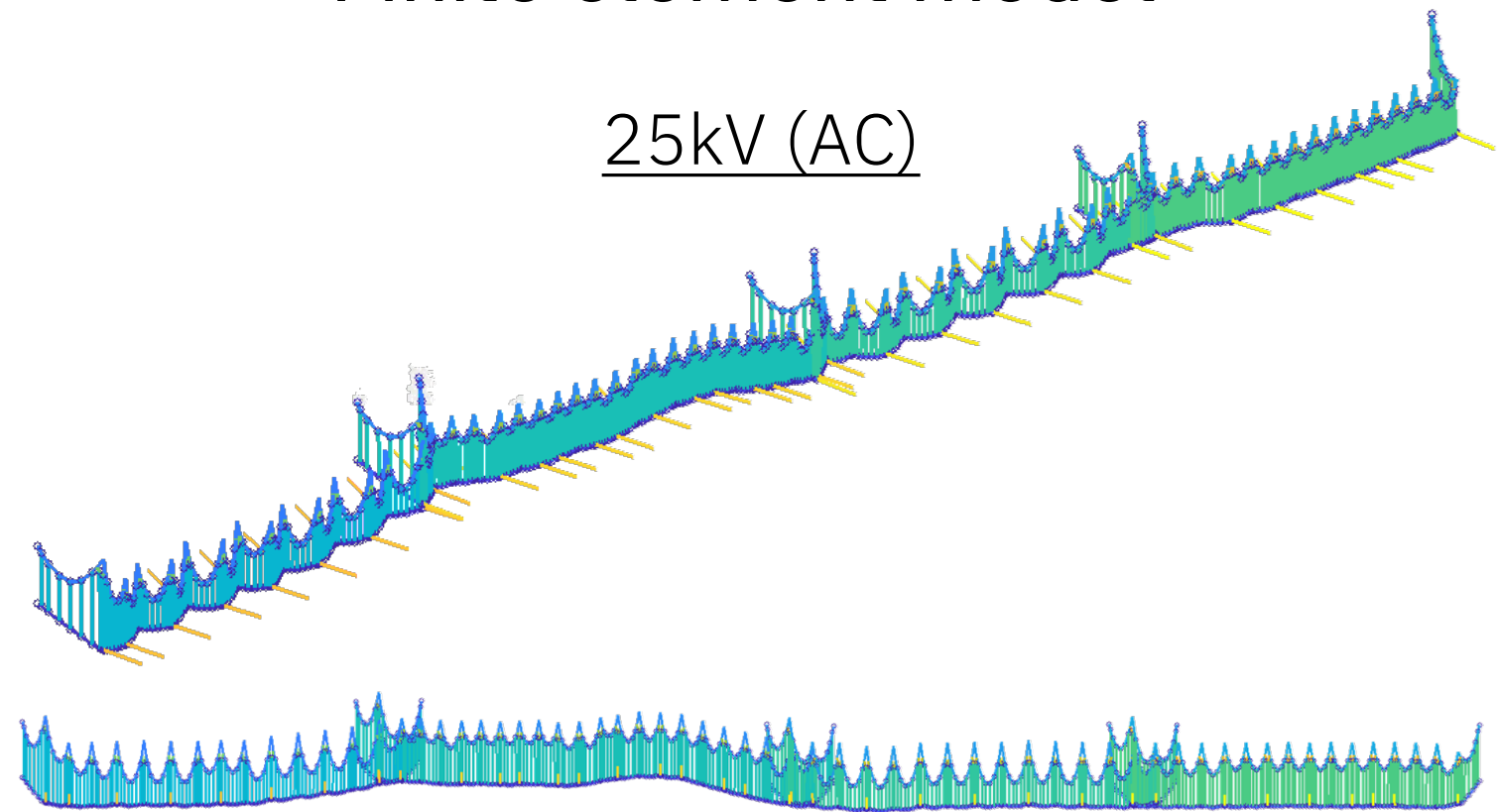


	Multiple Unit configuration	dPto	Pto 1	Pto 2
1		79 m	Faero = 2.6 N <i>Knuckle downstream</i>	Faero = 12.8 N <i>Knuckle upstream</i>
2		110 m	Faero = 12.8 N <i>Knuckle upstream</i>	Faero = 12.8 N <i>Knuckle upstream</i>
3		110 m	Faero = 2.6 N <i>Knuckle downstream</i>	Faero = 2.6 N <i>Knuckle downstream</i>
4		113 m	Faero = 12.8 N <i>Knuckle upstream</i>	Faero = 2.6 N <i>Knuckle downstream</i>

Train speed = 160 km/h (44.444 m/s)

Catenary

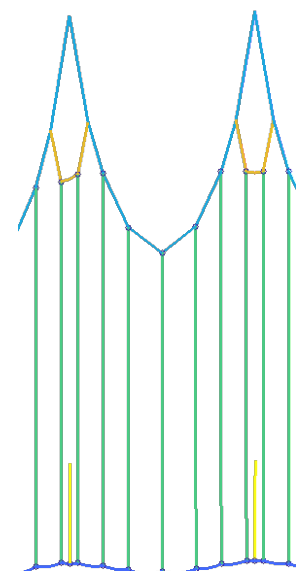
Finite element model



Span 60m

Stitch wire (SW)

Steady arm (SA)

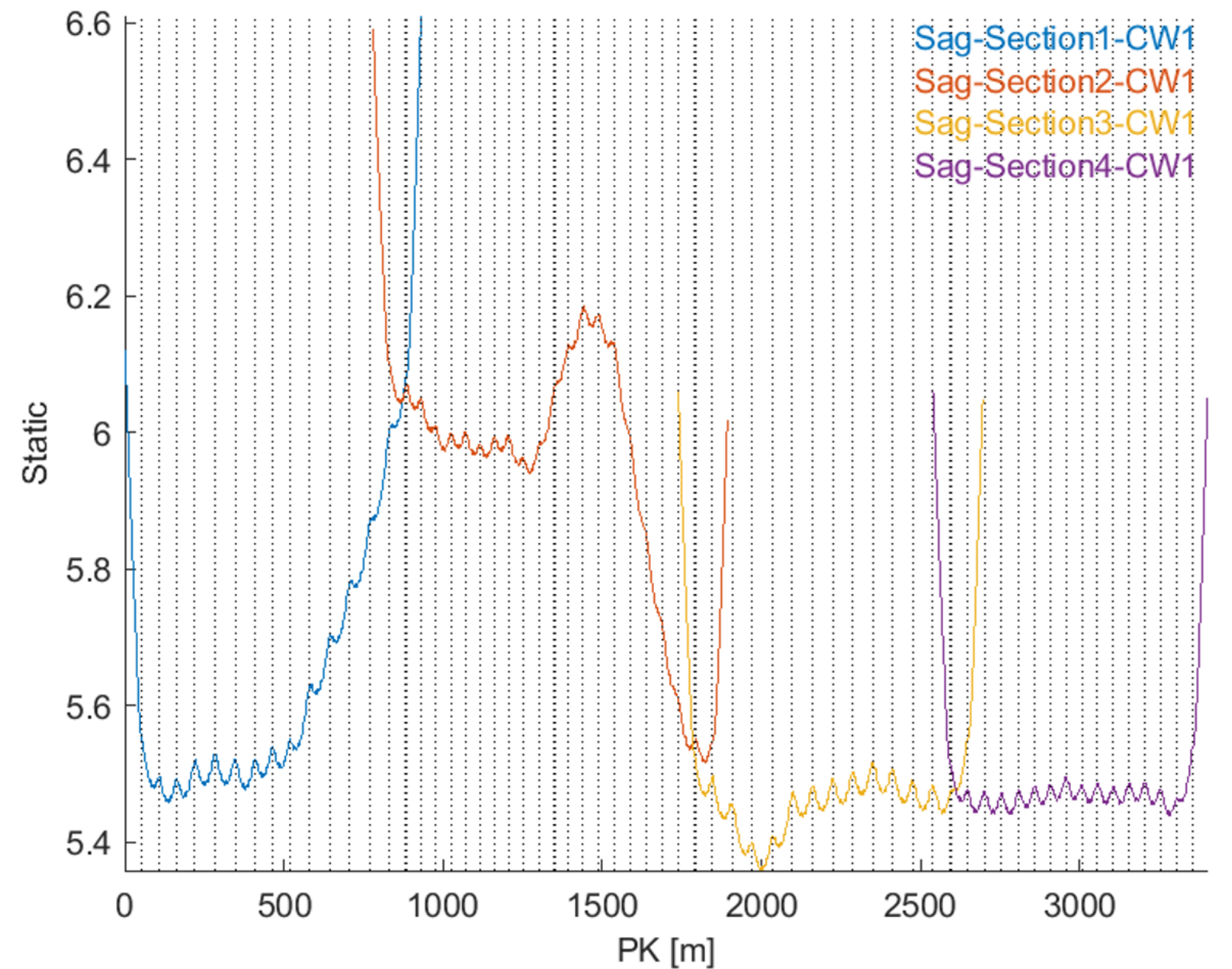


Messenger wire (MW)

Dropper

Contact wire (CW)

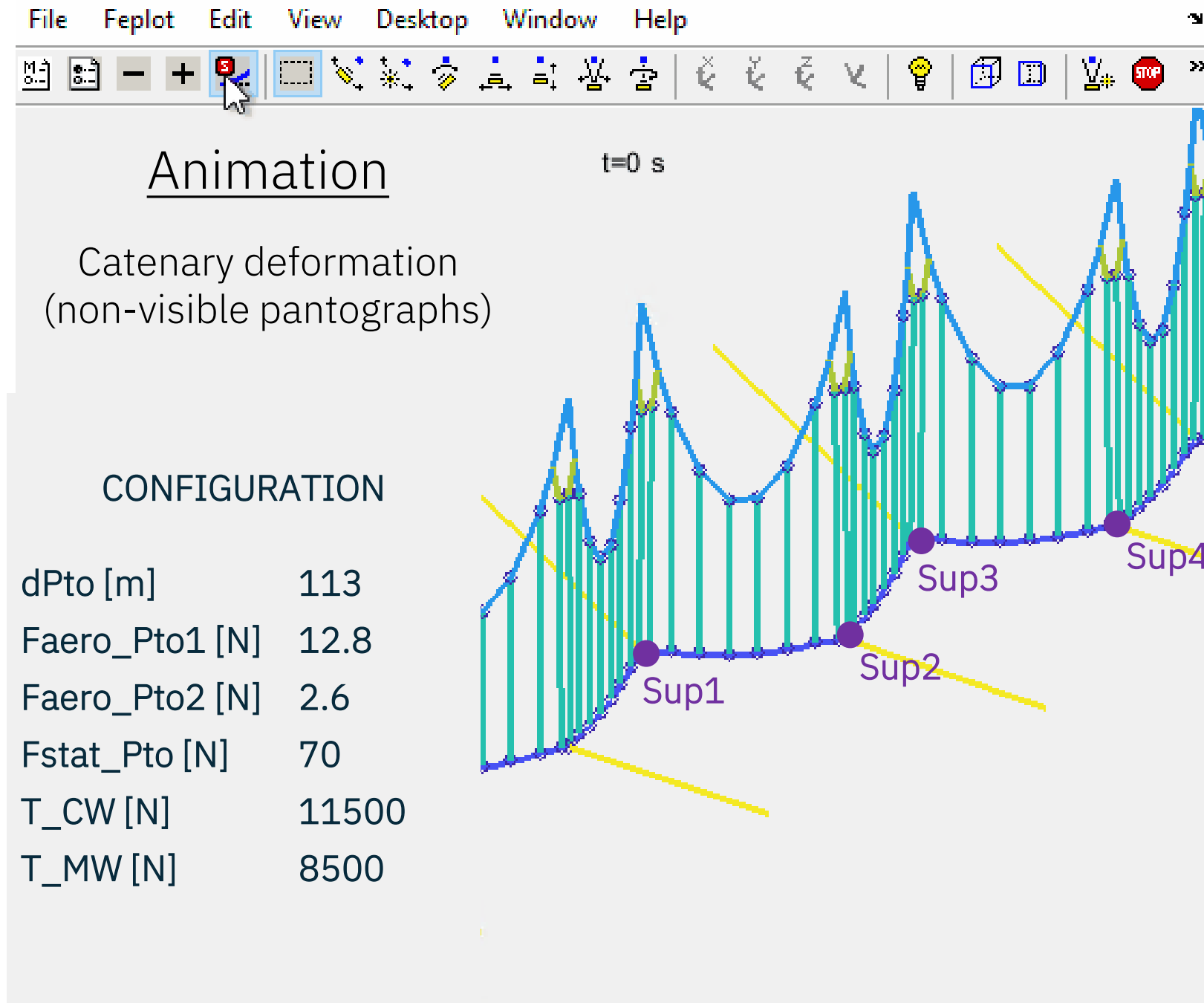
Static equilibrium



Load: gravity + wire tensions

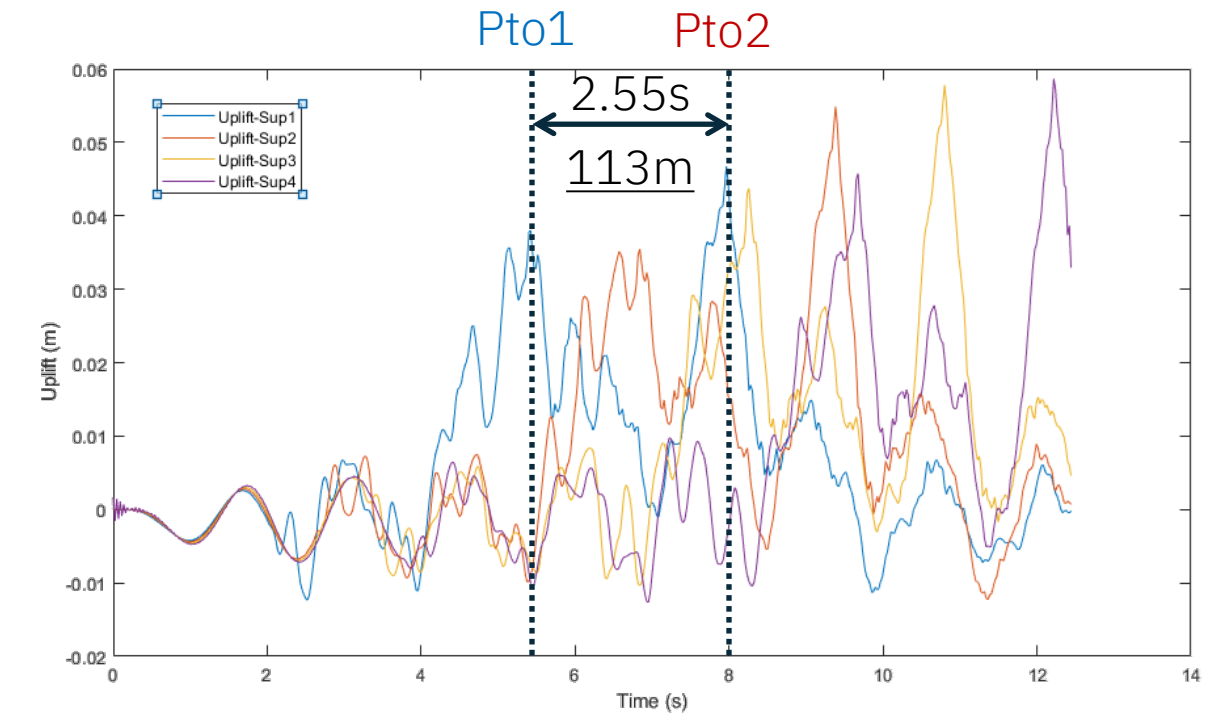
→ Result: sag wire (static contact wire height)

Dynamic simulation



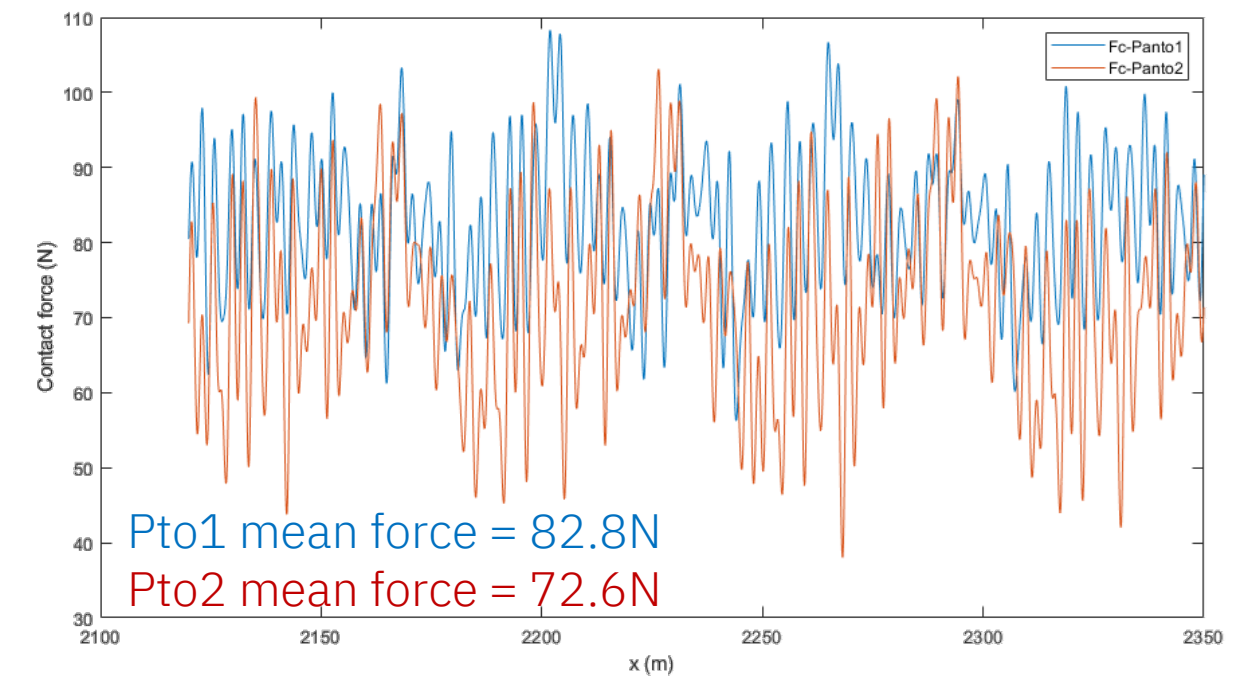
Contact wire uplift

Sampling: 550 points



Contact force

Sampling: 51 750 points

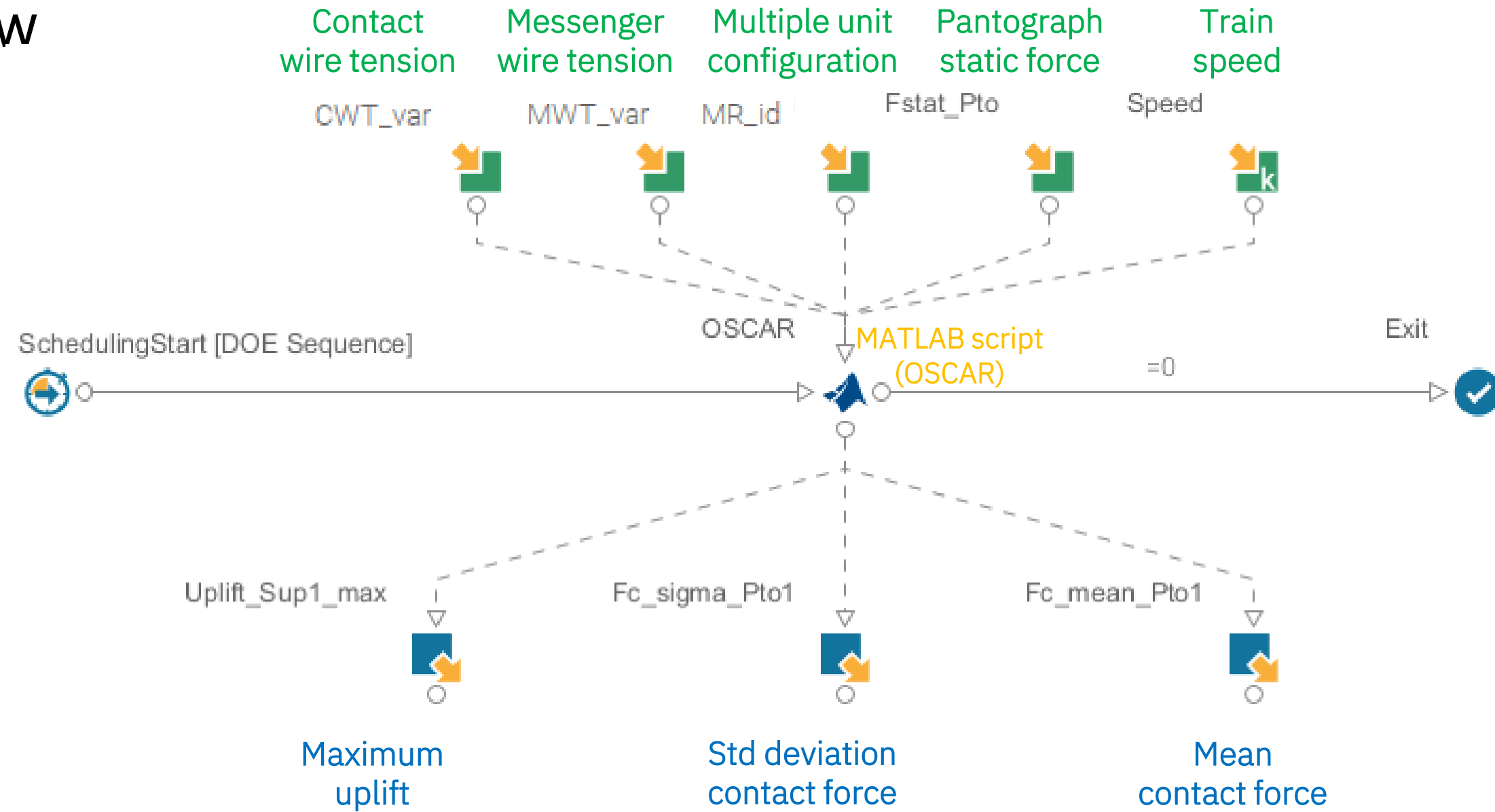


Data generation with modeFRONTIER

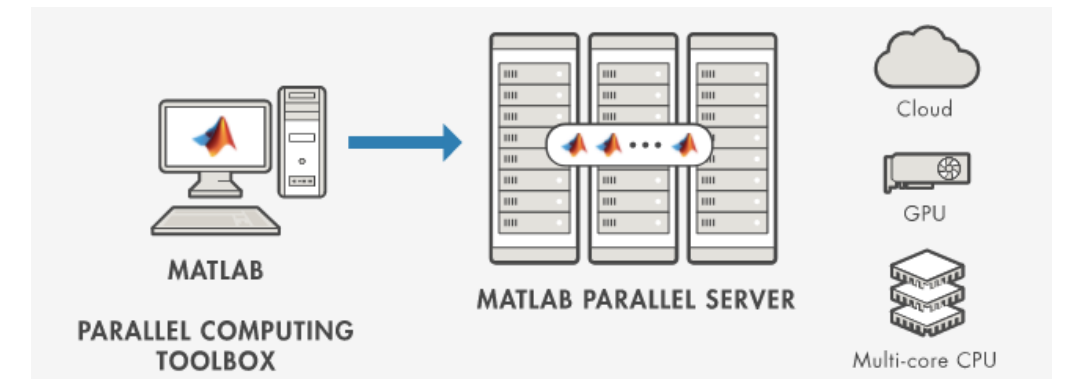


Process integration

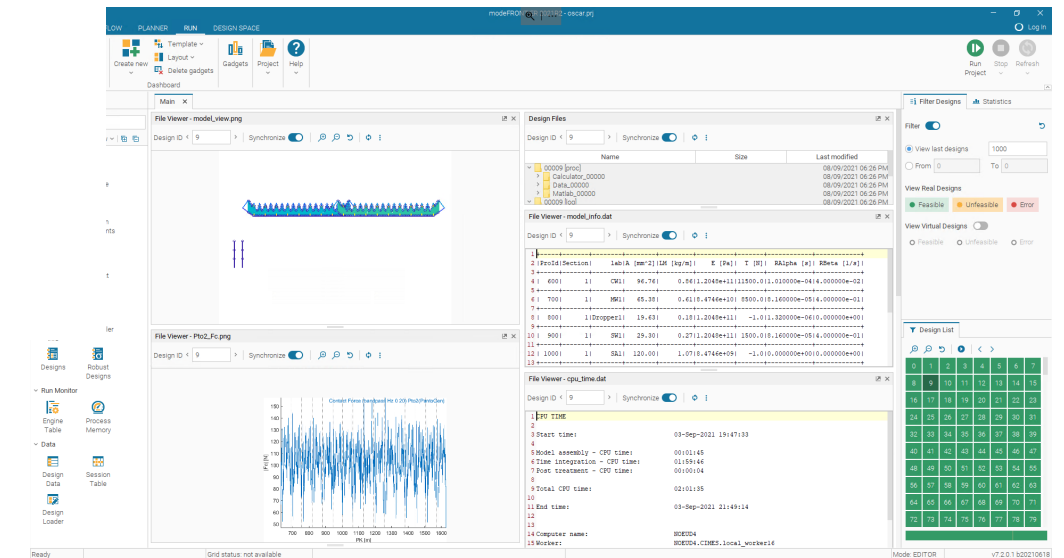
Workflow



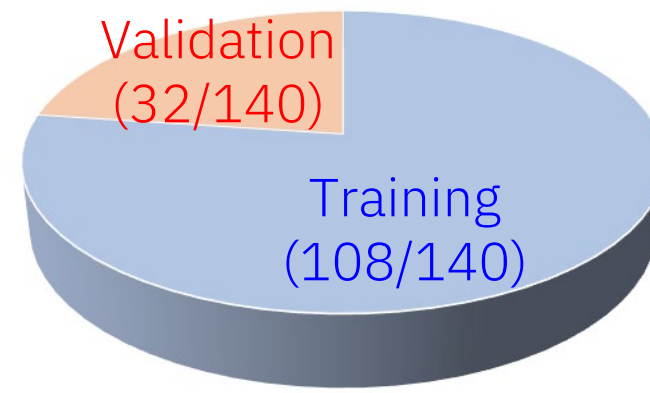
HPC cluster configuration



Run modeFRONTIER

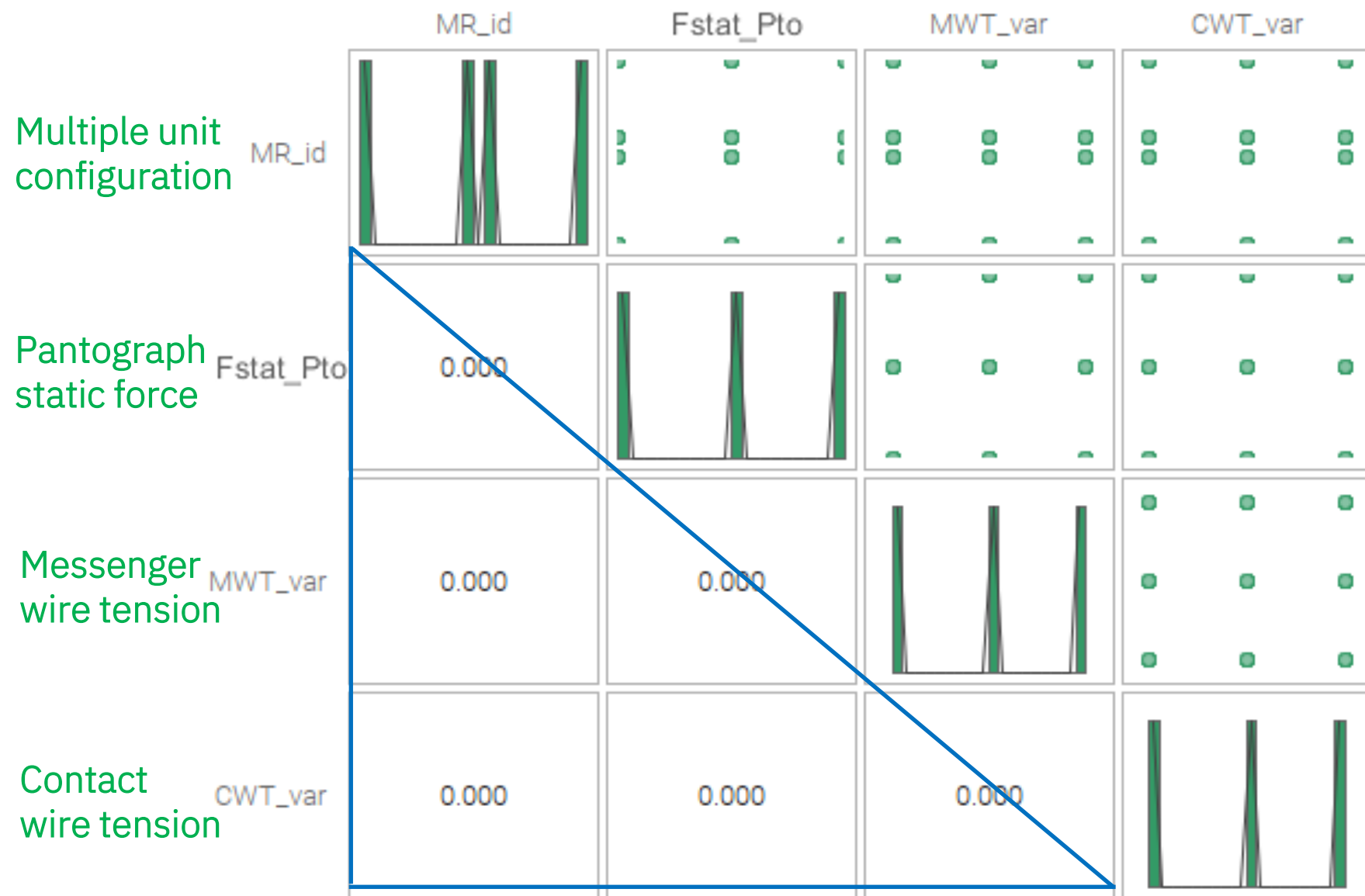


DoE definition



CPU time: around 1 hour for each simulation

Training dataset

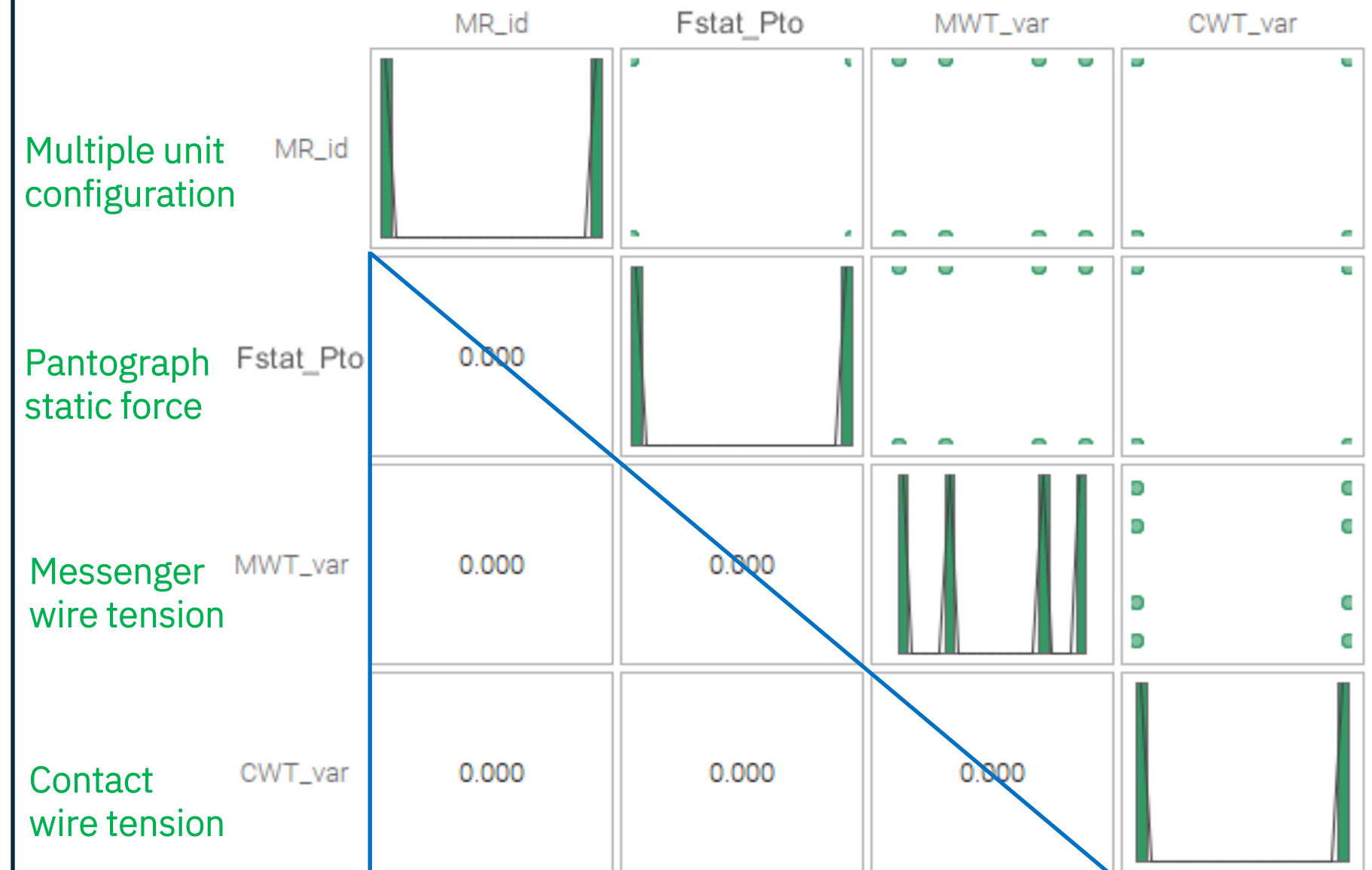


108 simulations

Full factorial DoE

→ no correlation between inputs

Validation dataset



32 new simulations

Full factorial DoE with different bounds

→ no correlation between inputs

Reduced order models with nDAI 2026R1



Uplift: ROM creation with nDAI

nD Modeler

Uplift_Sup1_m_1_1

Encodings (1)

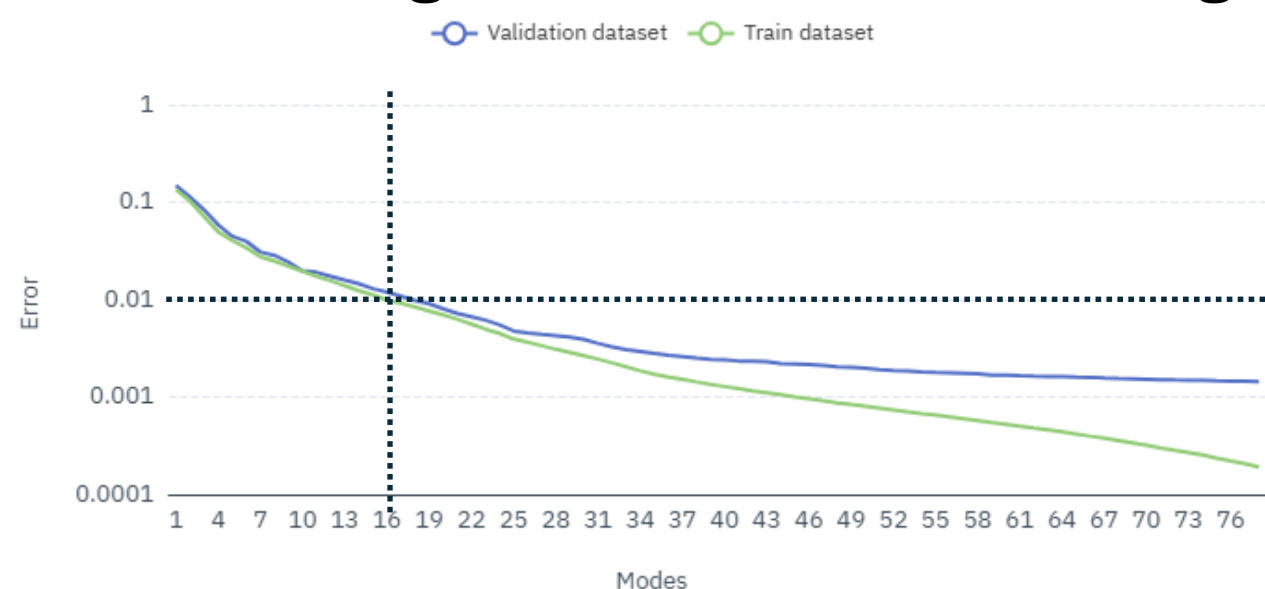
DATA: Uplift_Sup1_m_1_1D

ENCODER: 16/78 - modes POD

Regressors: RBF

POD

Compromise between low training error & risk of overfitting



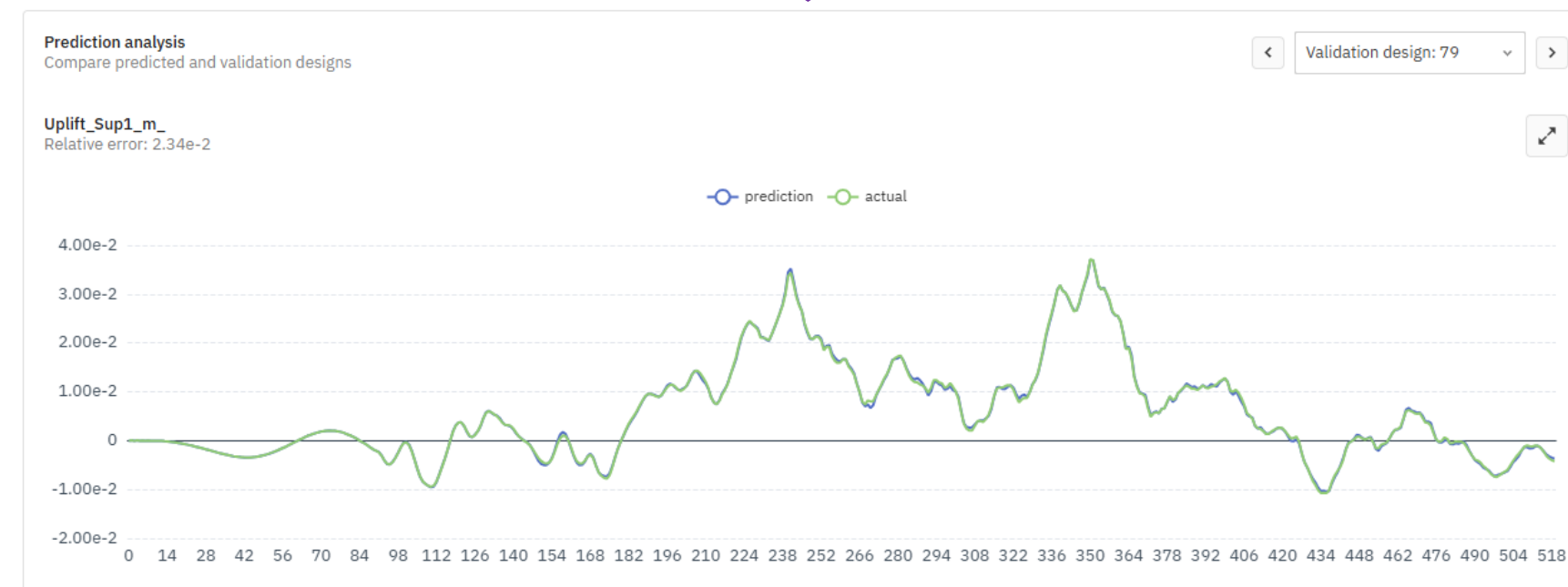
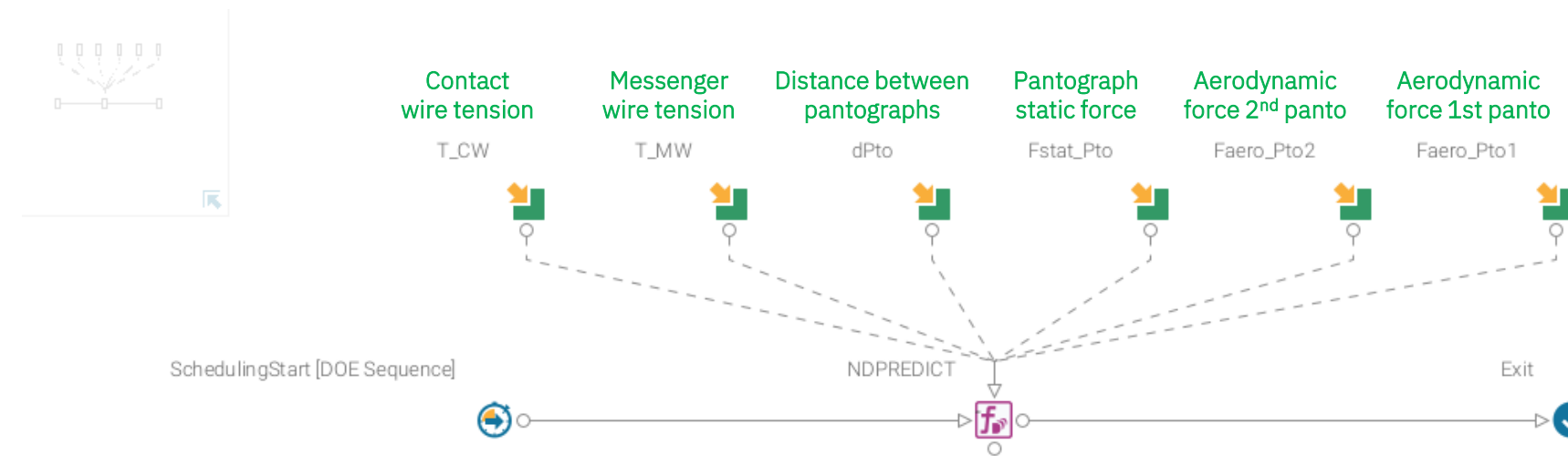
Number of modes: 16

Error on validation data for chosen modes: 1.19e-2

Error on training data for chosen modes: 9.92e-3



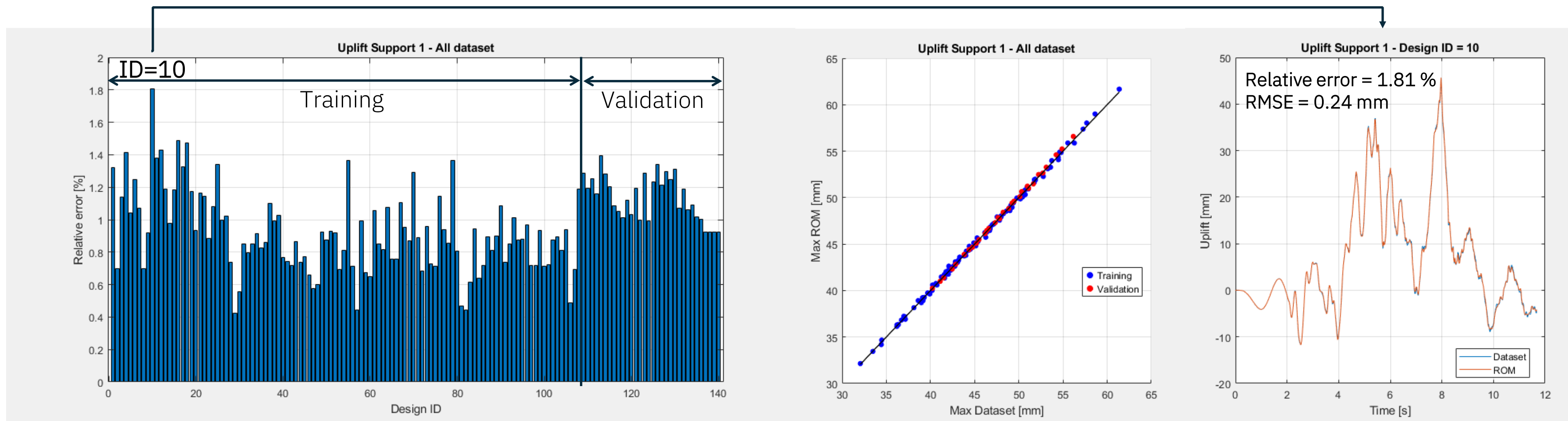
nD Predict



Fast prediction (few seconds)



Contact wire uplift: Results



Dataset: max = 45.28 mm
ROM: max = 45.66 mm (+0.84%)

	Coeff R ²	RMSE [mm]	Max relative error [%]	Mean relative error [%]	Min relative error [%]
All dataset	0.9987	0.1421	1.8075	0.9670	0.4229
Training	0.9987	0.1365	1.8075	0.9172	0.4229
Validation	0.9982	0.1596	1.3952	1.1348	0.9230

Contact force: ROM creation with nDAI

nD Modeler

Fc_Pto1_N_1_1

Encodings (1)

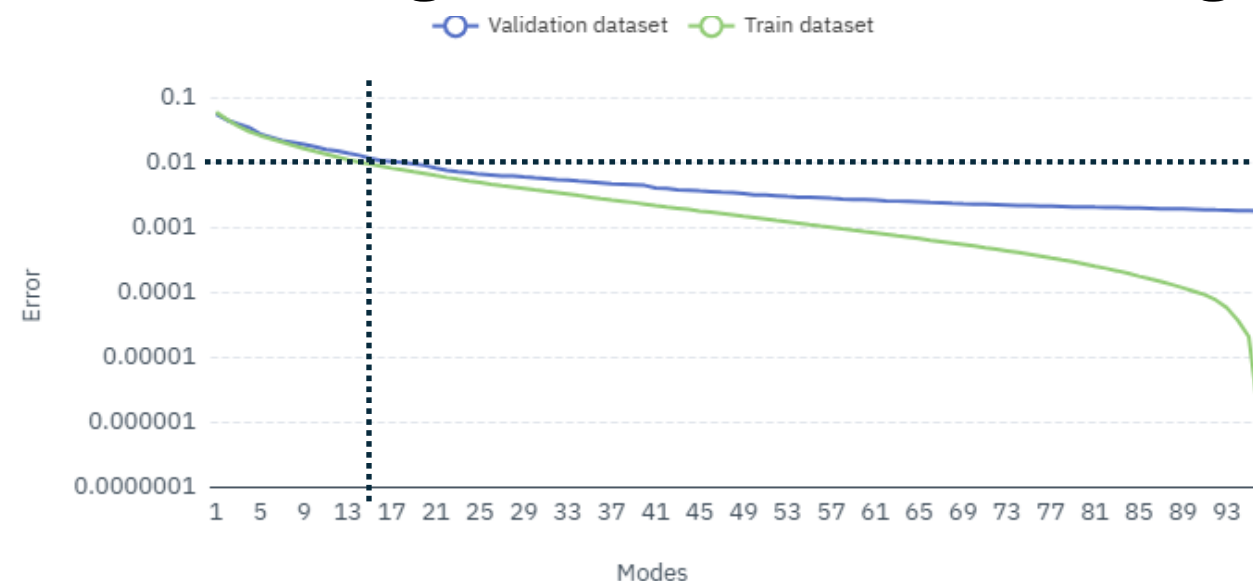
DATA: Fc_Pto1_N_1_1

ENCODER: 15/96 - modes POD

Regressors: RBF

POD

Compromise between low training error & risk of overfitting

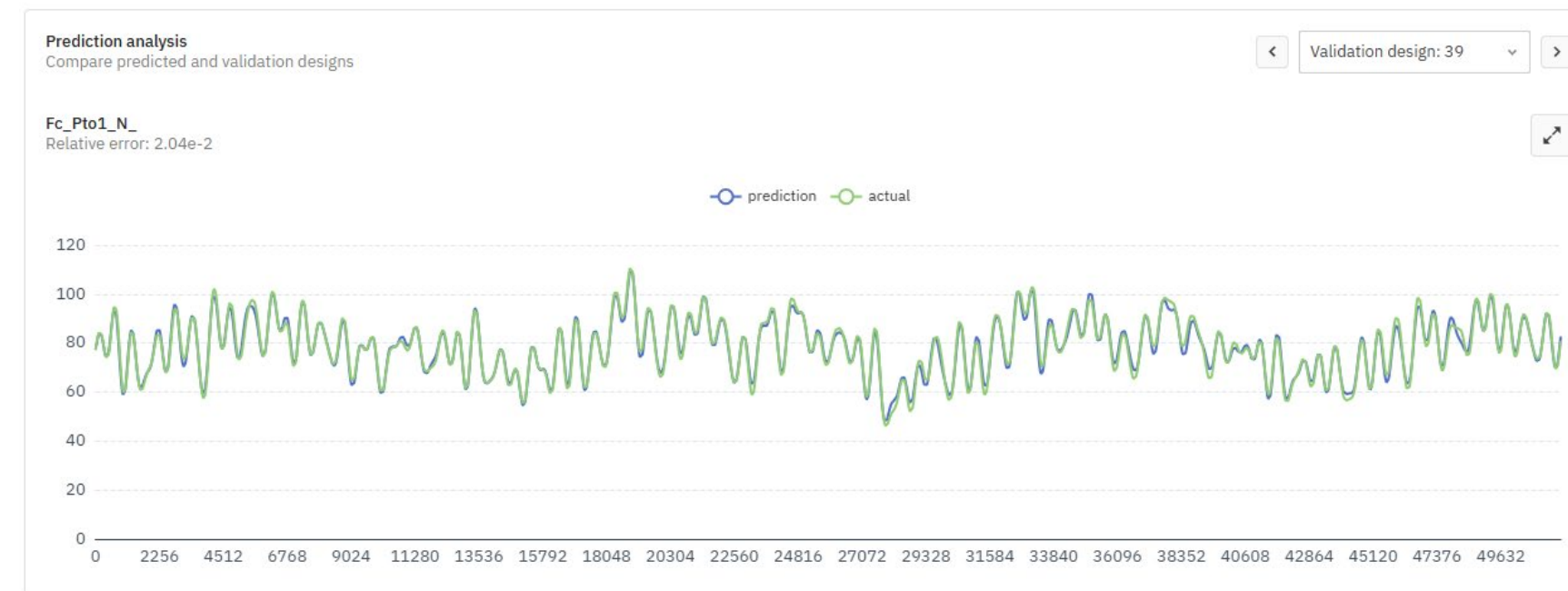
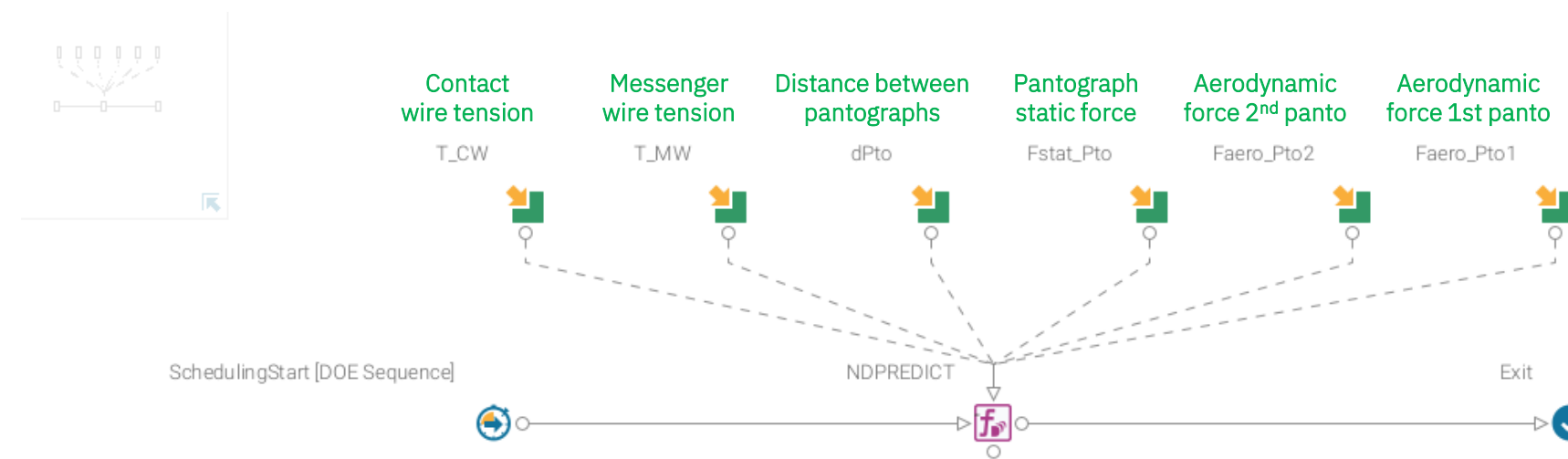


Number of modes: 15

Error on validation data for chosen modes: 1.14e-2

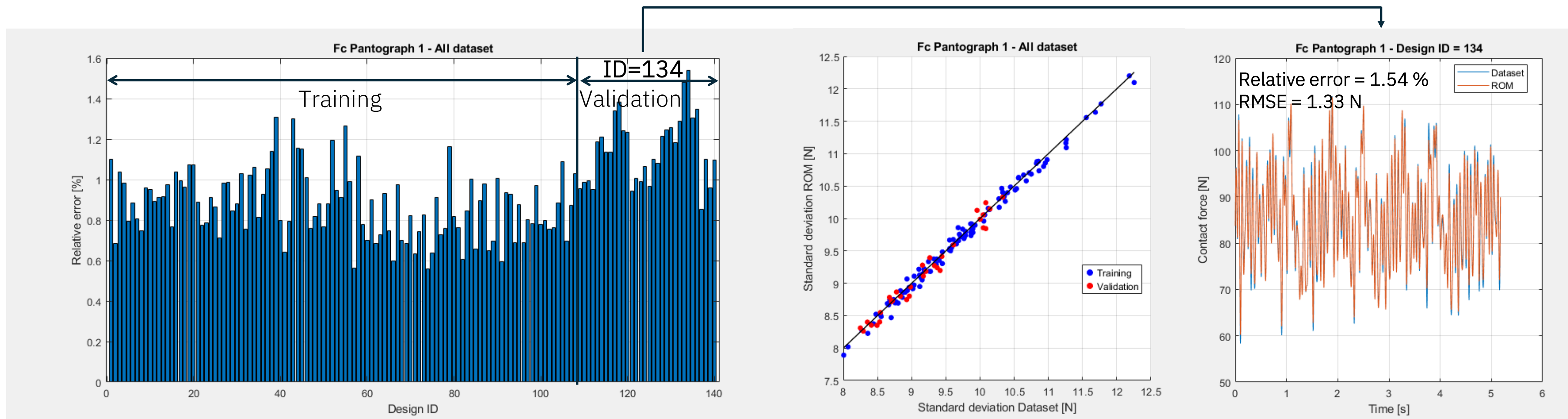
Error on training data for chosen modes: 9.28e-3

nD Predict



Fast prediction (few seconds)

Contact force: Results



Dataset: $\sigma = 10.08$ N
 ROM: $\sigma = 9.84$ N (-2.39%)

	Coeff R ²	RMSE [N]	Max relative error [%]	Mean relative error [%]	Min relative error [%]
All dataset	0.9904	0.7498	1.5402	0.9360	0.5593
Training	0.9926	0.6939	1.3092	0.8730	0.5593
Validation	0.9691	0.9134	1.5402	1.1488	0.8510

Conclusion



Conclusion & Perspectives

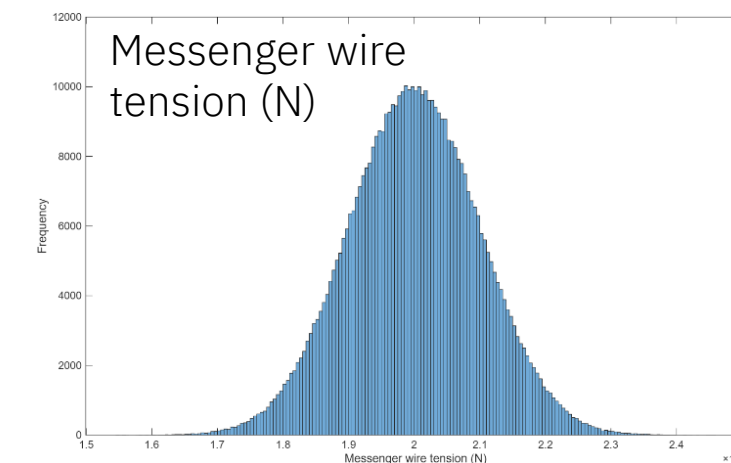
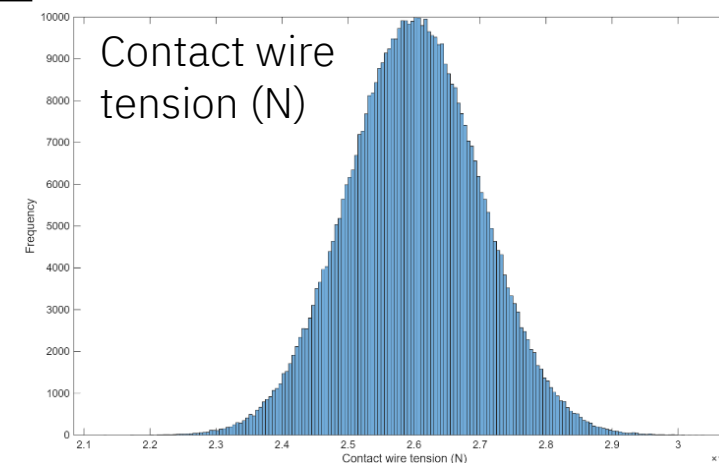
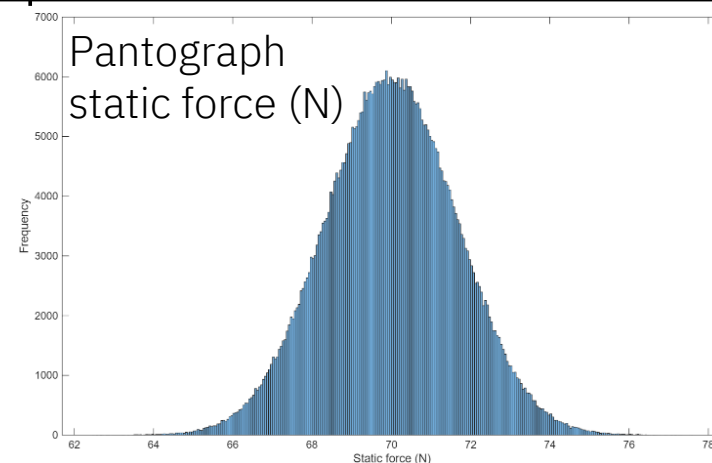
Current status

- ✓ Successful ROM creation with the new module nDAI (nD Modeler + nD Predict).
- ✓ Excellent prediction level for contact wire uplift and contact force (max relative error < 2%).
- ✓ Reduce calculation times from one hour (OSCAR) to seconds (ROM).

What to do:

- Add more input variables (different catenary geometries, different rolling stocks, train speed, ...)
- Create ROM for more outputs (uplift in different locations, contact force for each pantograph, ...)
- Perform complex stochastic studies (a new opportunity enabled by AI-metamodels)

Example of 500 000 random draws :



Thank you

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Let's discuss
your challenges!

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