SIMULATION, HPC AND AI TO ACCELERATE THE ELECTRIFICATION OF POWERTRAINS

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To transform enterprise decision-making by leveraging the *convergence* of simulation, high-performance computing, and artificial intelligence.

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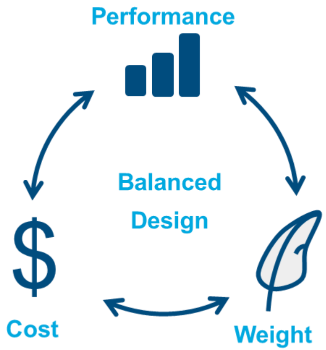
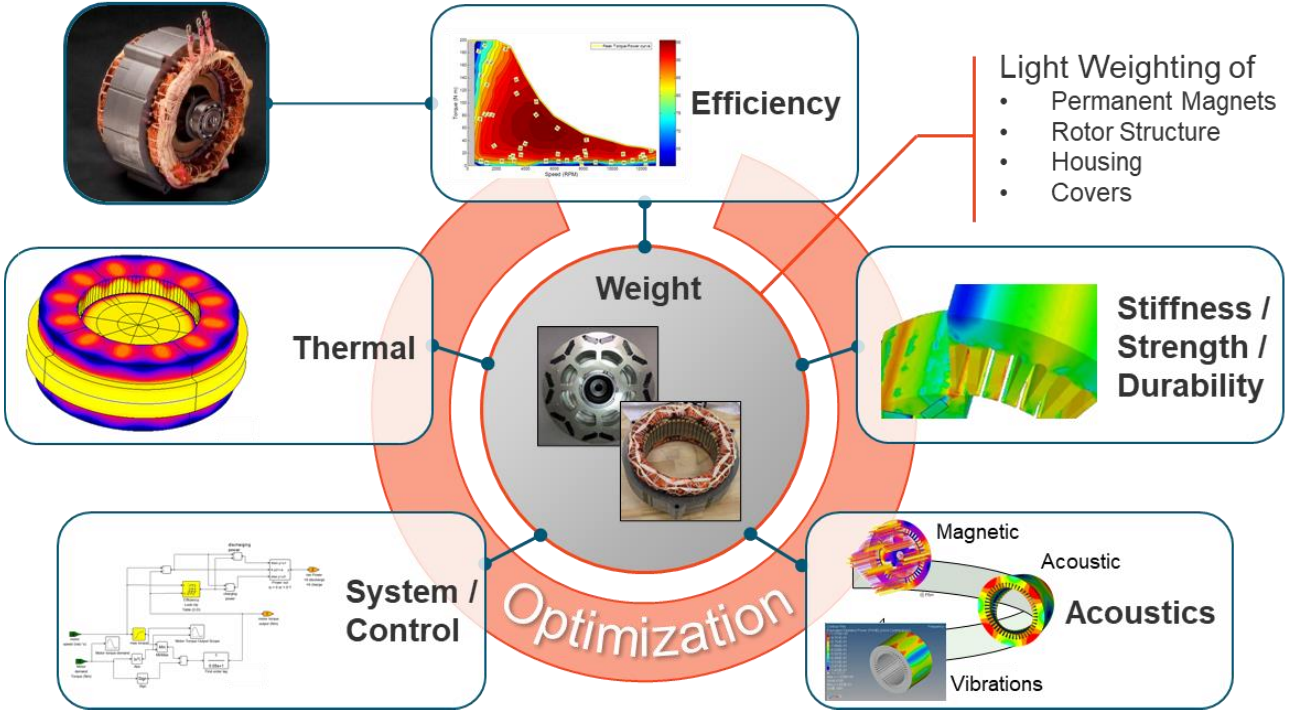
Building a More Sustainable Mobility

- Fierce competition to create electrified drivetrains
- Speed in Technology Development
- Stringent performance requirements
- Maximize efficiency throughout duty cycles
- Multiphysics design and constraints

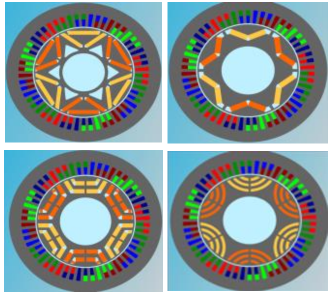


E-Motor Multiphysics Optimization



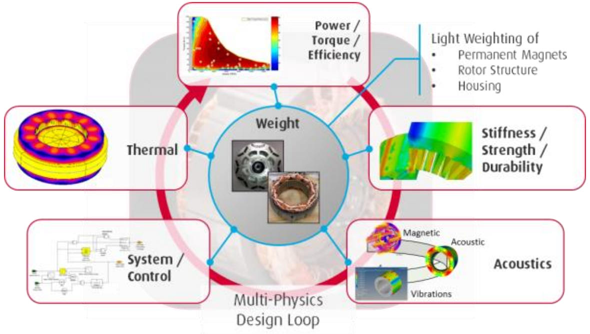
The e-Motor Design Process

Concept Design



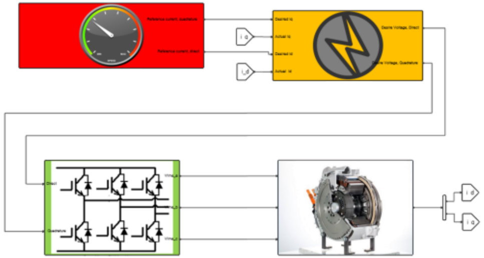
Rapid Design Exploration and Ranking

Detailed Design



Advanced multiphysics analysis

System Integration

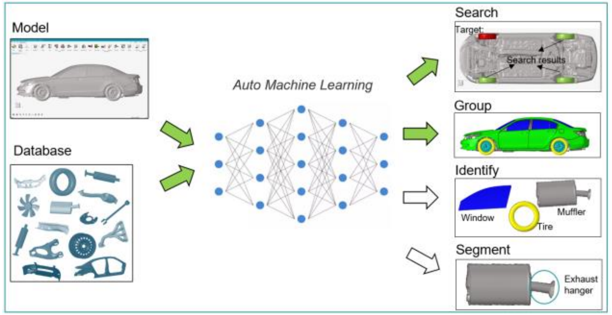


System Simulation – Control Design – Embedded software

Use of AI for Design

Shape

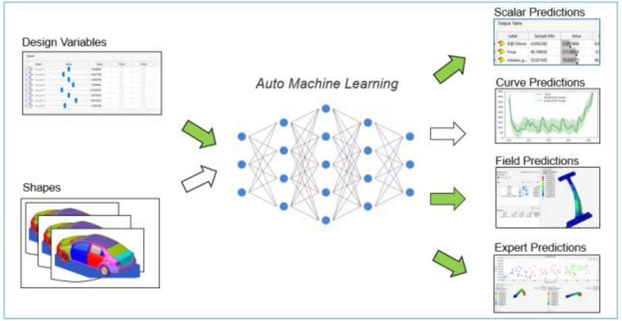
ML Augmented CAE



Modelling
- Part search
- Part clustering
- Model segmentation
- Part and feature labelling
- Part and feature identification
- Model build automation

Physics

AI-Powered Design



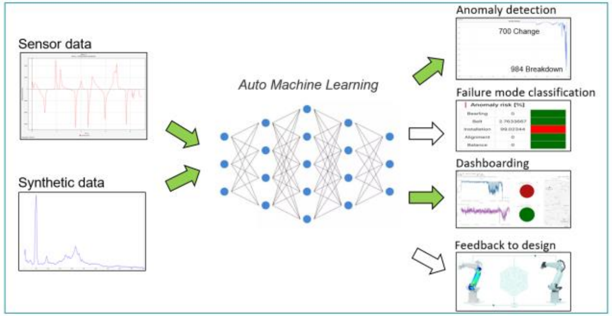
Real-time predictions
- Real-time KPI/curve/field predictions

Expert emulation
- Clustering / Labelling / Classification

Historical data
- Treating unstructured data

Signal

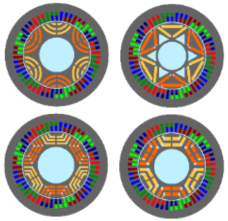
Predictive Analytics



Test/Field data
- Synthetic anomalous data creation
- Anomaly detection
- Failure mode classification
- Data streaming
- Notifications
- Feedback to product designs

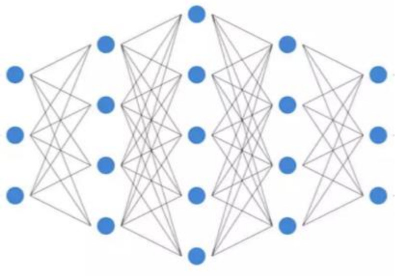
Machine Learning Models for Real-Time Predictions

Train a predictive model on CAE results **from any source**. Use the model for **real-time predictions** and optimizations. Update the model after each new solver run – **model improves over time.**

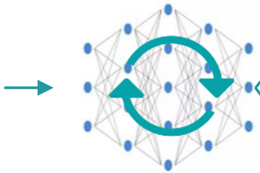


Design of Experiments

Historical data



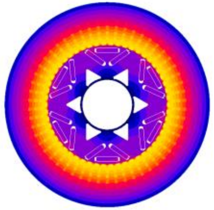
Deep learning on the Cloud.



ML-based prediction/ optimization in seconds

- Magnet Mass
- Efficiency
- Torque Ripples
- Losses
- etc……

KPIs



Field Predictions

A SMALL EXERCISE

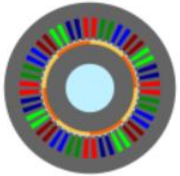
E-Motor Performance Prediction

Input Parameters

- Power supply
- Volume
- Poles
- Airgap
- Cooling system

Motor dimensions calculations

(Basic equations)



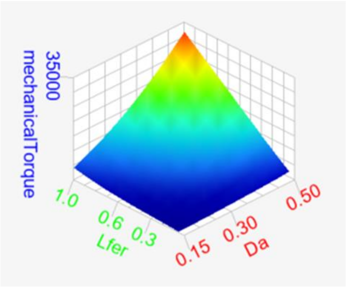
Finite Elements

Outputs

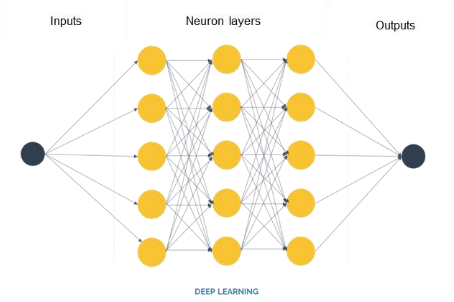
- Torque
- Power
- Speed
- Losses
- Efficiency

Database of Motors

Response surfaces

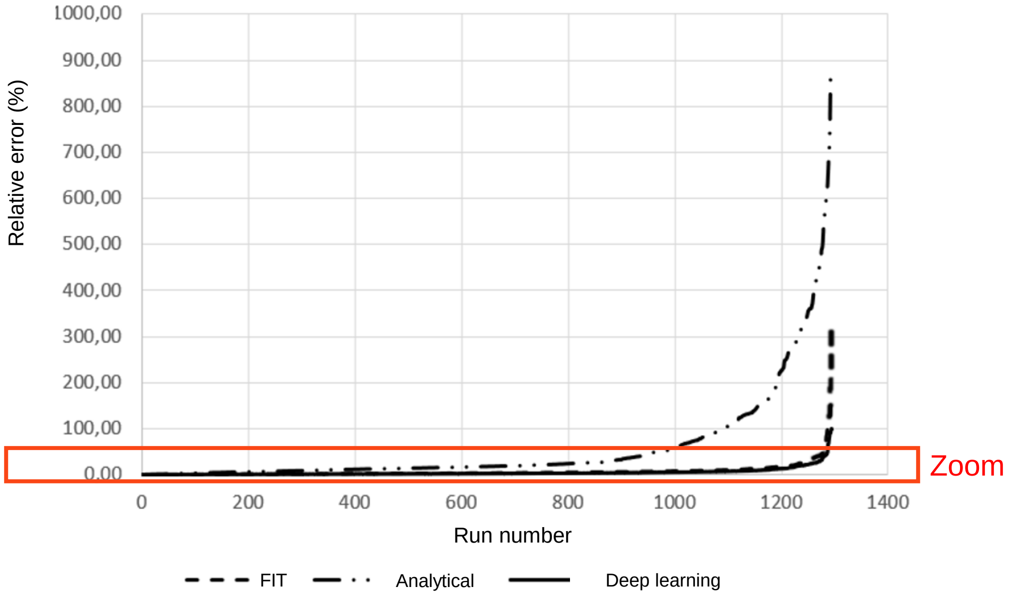


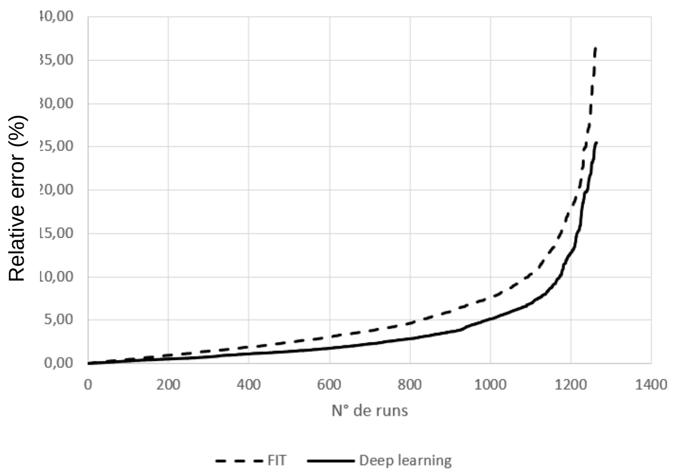
Neural network



Comparison of Predictive Algorithms Performances

Relative error on the torque for different predictive methods with normalized torque





Find the Best Motor for Given Requirements

Required torque: 5000 Nm
Required power: 200 kW
Efficiency : > 92 %

	Torque	Speed	Electromagnetic power	Efficiency	Torque relative error	Power relative error
N°1	4822 Nm	372 RPM	188 kW	94.5 %	3.56 %	6 %
N°2	4851 Nm	351 RPM	180 kW	94.2 %	2.98 %	10 %

Required torque : 300 Nm
Required power : 130 kW
Efficiency : > 92 %

	Torque	Speed	Electromagnetic power	Efficiency	Torque relative error	Power relative error
N°1	277 Nm	2685 RPM	78 kW	92.5 %	7.6 %	40 %
N°2	283 Nm	4441 RPM	132 kW	95 %	5.7 %	1.5 %

THE ZF USECASE

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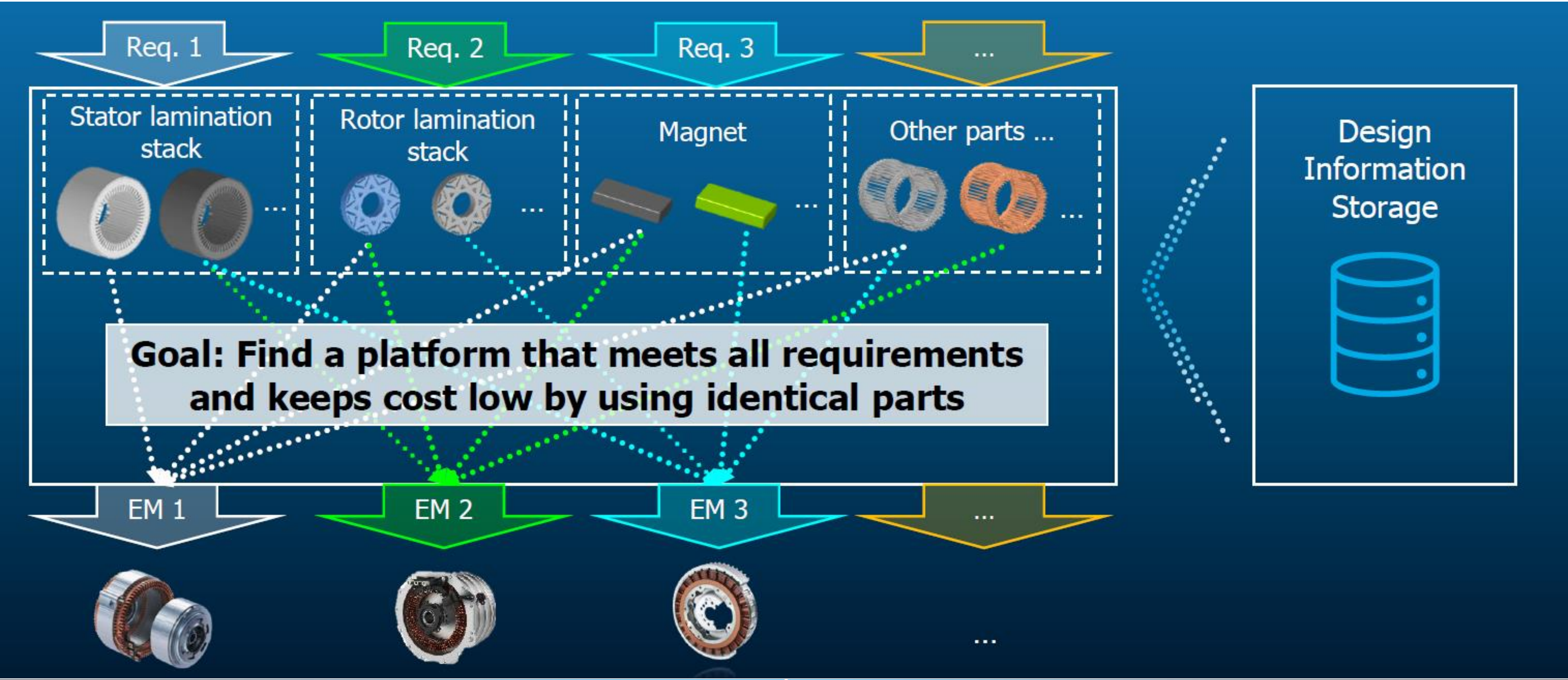
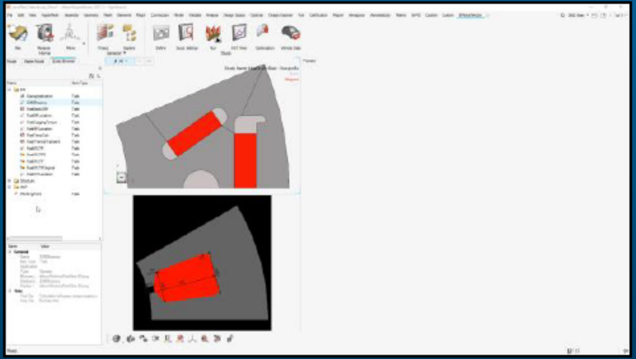
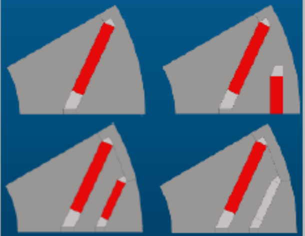
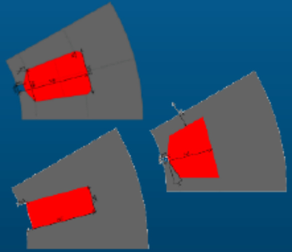
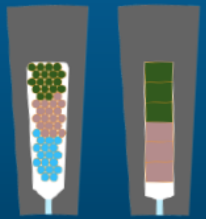
Originally presented at CWIEME Berlin 2022

Modular EMotor Platform Development



EMotor Database Creation



	E-Motor	Rotor	Stator	Winding
Coverage through different DoEs	E-Motor types	Rotor configurations	Slot configurations	Winding configurations
In DoE design variables	Voltage level Max current Length	Magnet sizes Magnet positions Magnet orientations	Slot length Slot width	No wires in hand No turns Fill factor Wire diameter/size

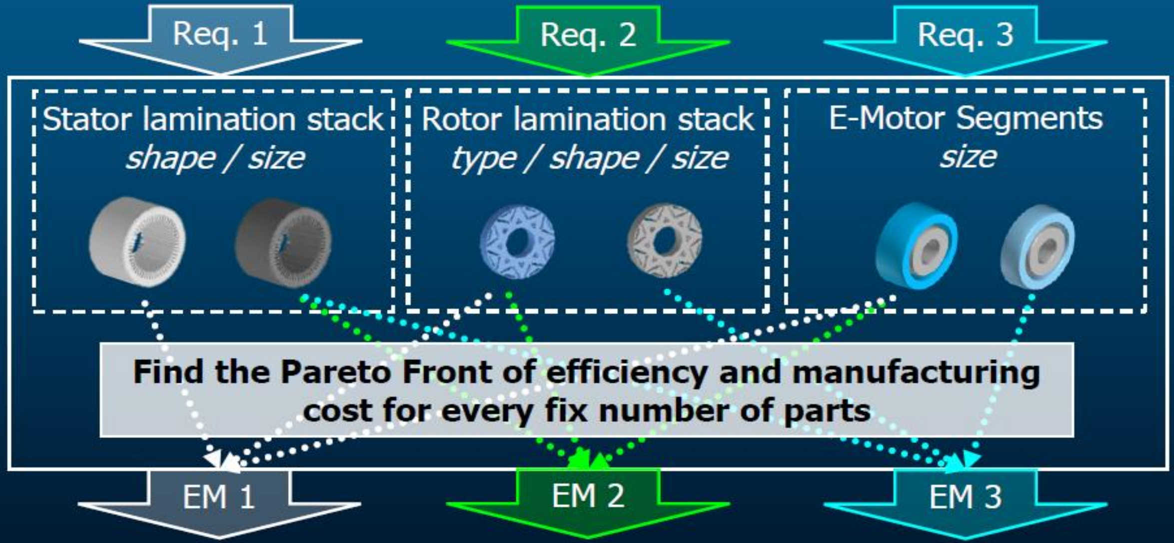
Example Usecase

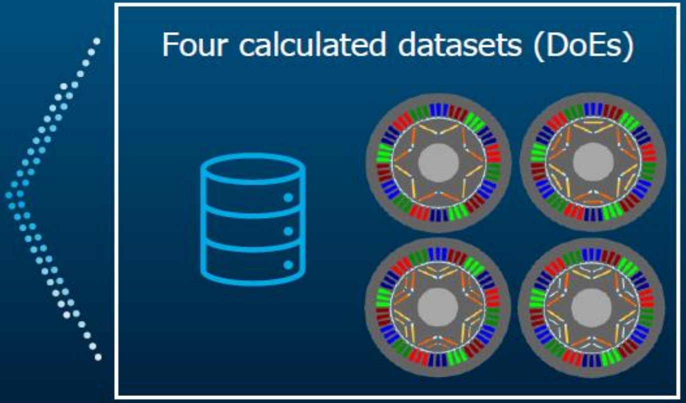
Parameter	Req.1*	Req.2*	Req.3*	Unit
Max E-Motor Torque	160	220	280	[Nm]
Efficiency Measure	Maximize	Maximize	Maximize	[%]
Manufacturing Costs	Minimize	Minimize	Minimize	[]

(*) Additional Constraints to further constrain solution space

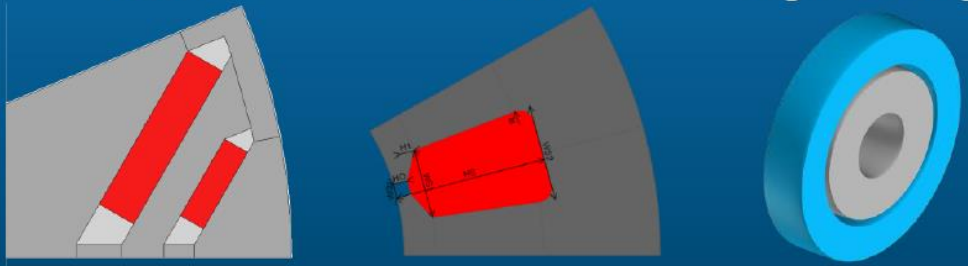
Design / Optimization Task

- 3 e-motors to be found using a set of 4 DoEs representing different rotor lamination sheet configurations
- 3 possible common parts defined



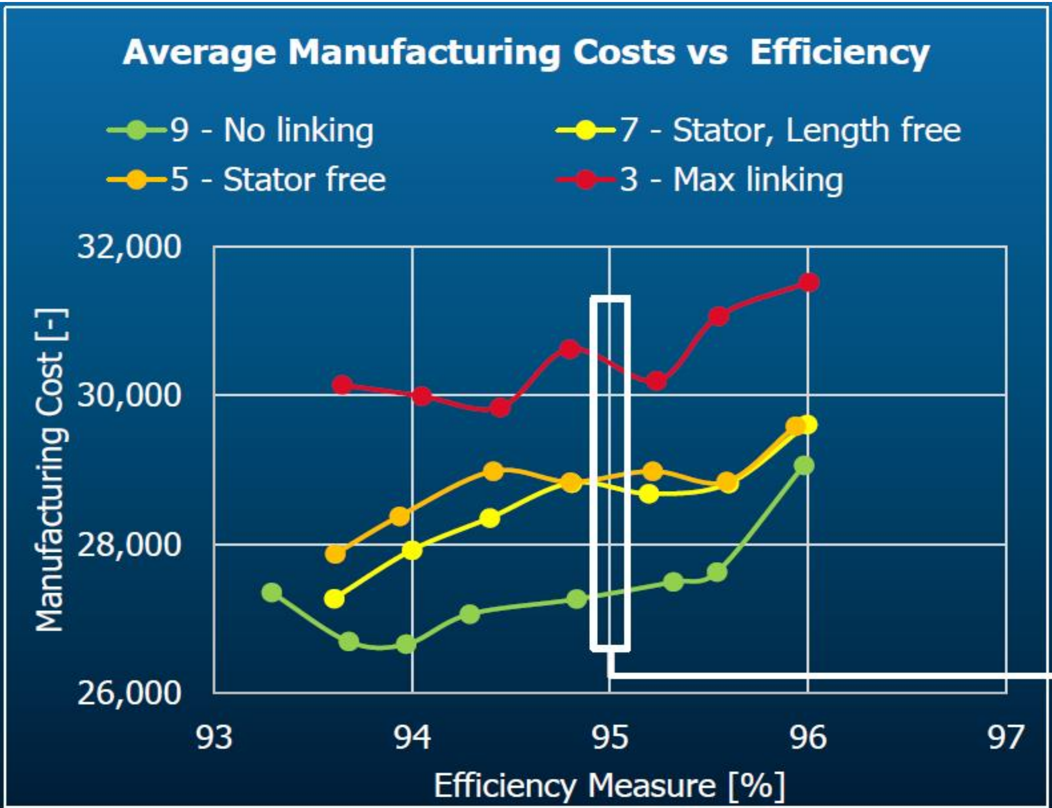


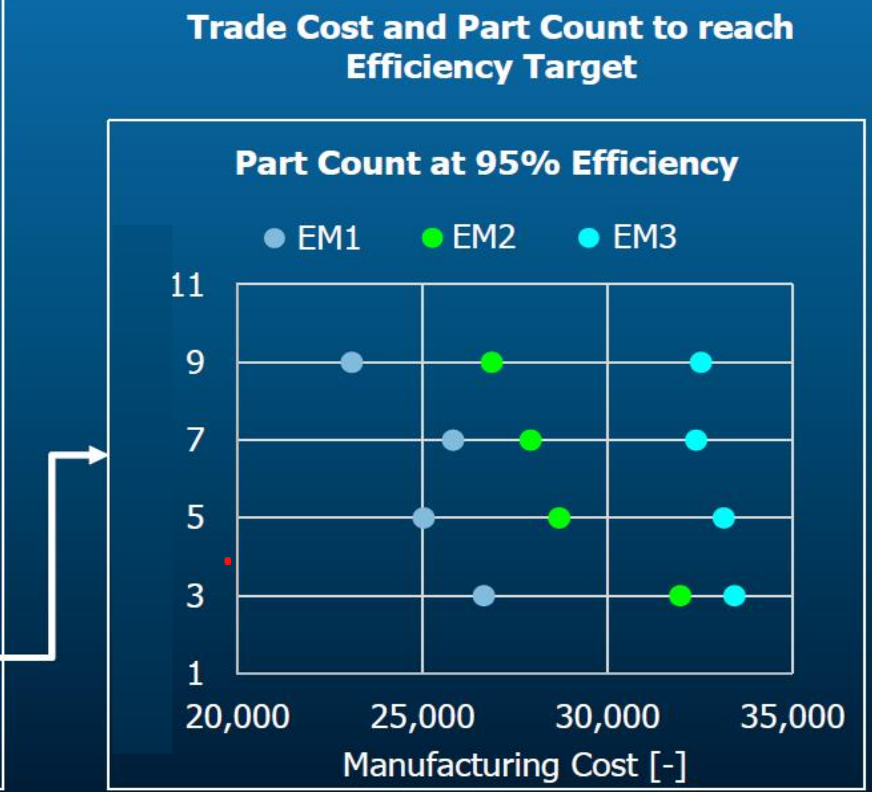
Considering Multiple Scenarios



	Rotor	Stator	Segment Length	Part Count
Maximum Common Parts (Maximum linking)	☑ ☑ ☑	☑ ☑ ☑	☑ ☑ ☑	3
	⋮	⋮	⋮	⋮
	☑ ☑ ☑	☒ ☒ ☒	☑ ☑ ☑	5
	⋮	⋮	⋮	⋮
	☑ ☑ ☑	☒ ☒ ☒	☒ ☒ ☒	7
	⋮	⋮	⋮	⋮
No Common Parts (No linking)	☒ ☒ ☒	☒ ☒ ☒	☒ ☒ ☒	9

Optimization Results

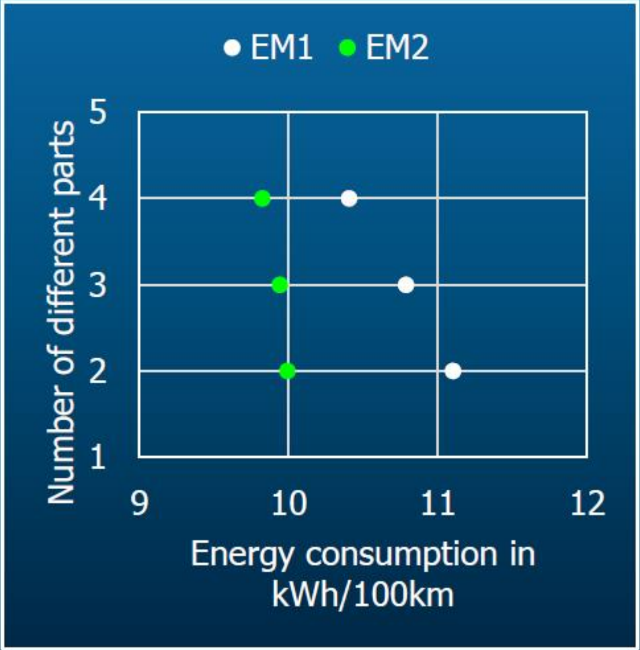




ZF Usecase Summary

The benefit of synergies between individual projects can be directly identified

Identical parts reduce development cost



Identical parts reduce development time

Helps ZF as a basis for decision making process in the projects

USING AI FOR REDUCED ORDER MODELLING

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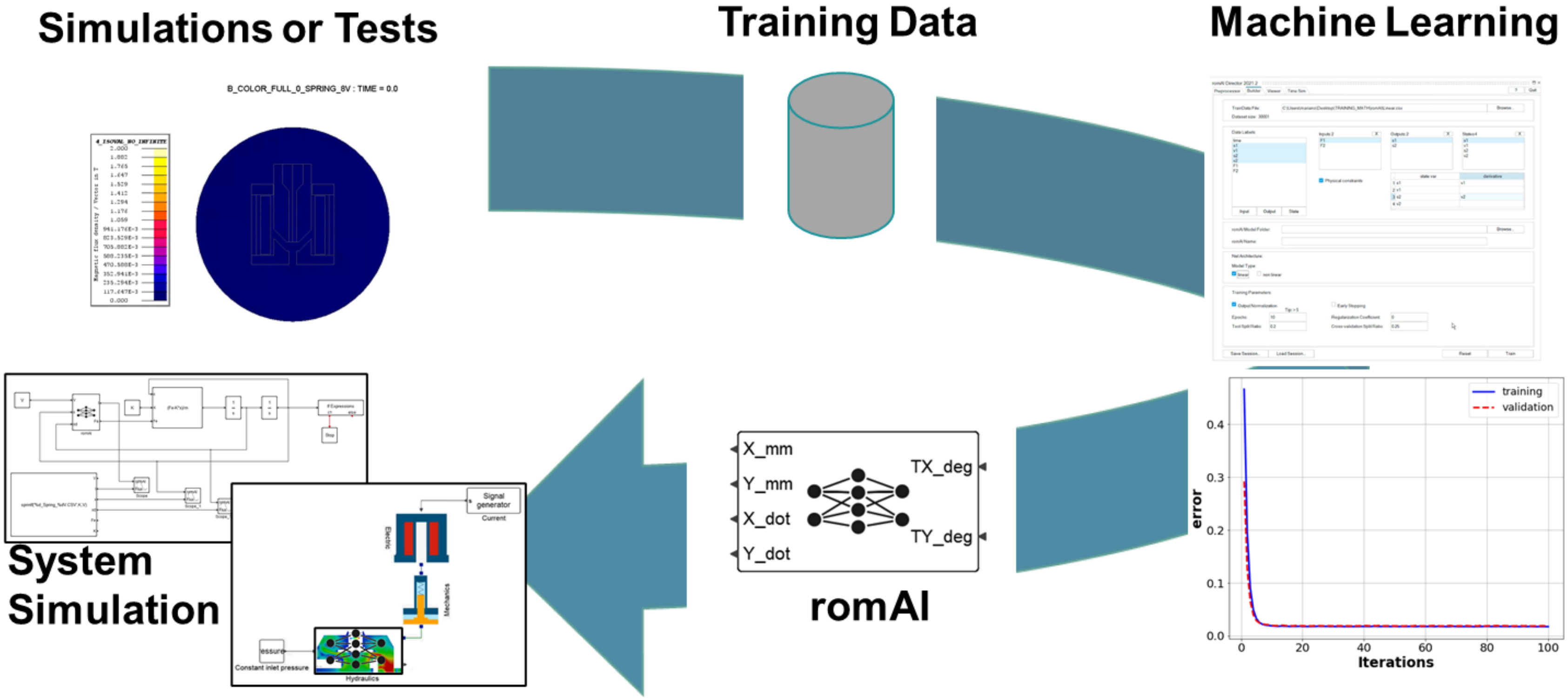
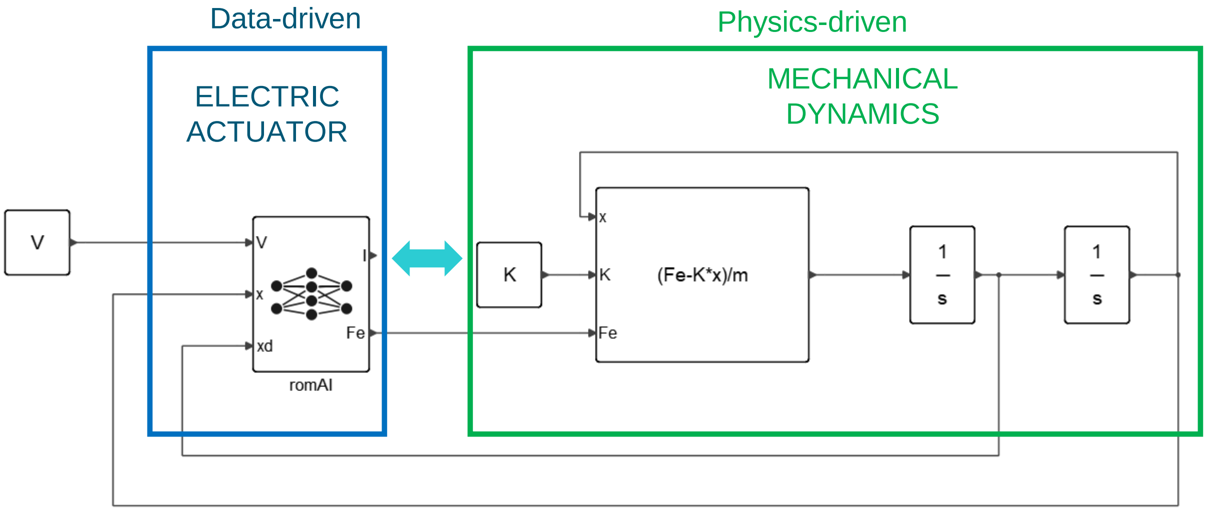
Reduced Order Modeling Based on AI

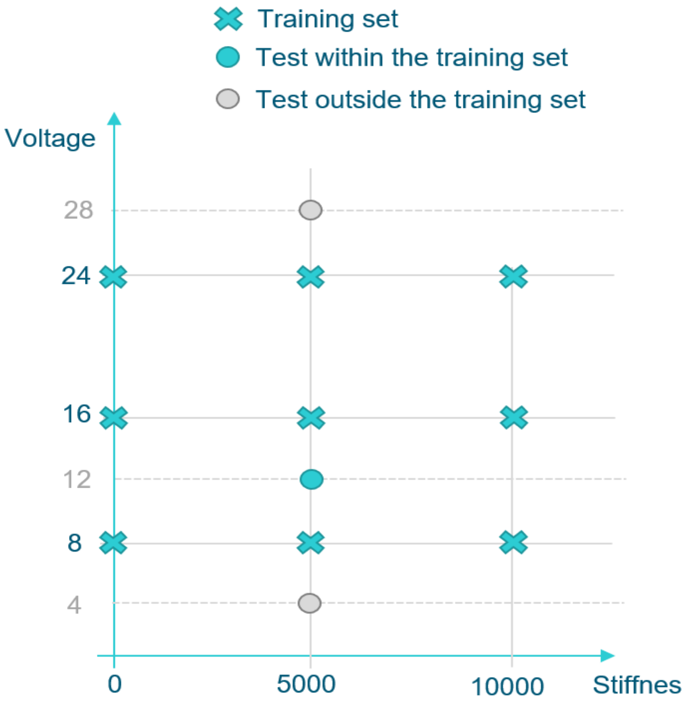


Electromechanical Actuator Example

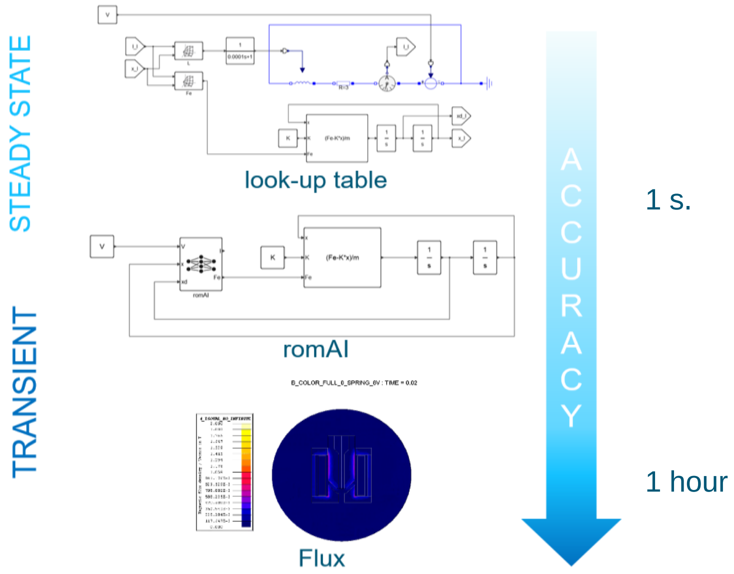


- Data created based on transient finite element electromagnetic computations
- All dynamics effects captured (non-linearities, eddy currents)

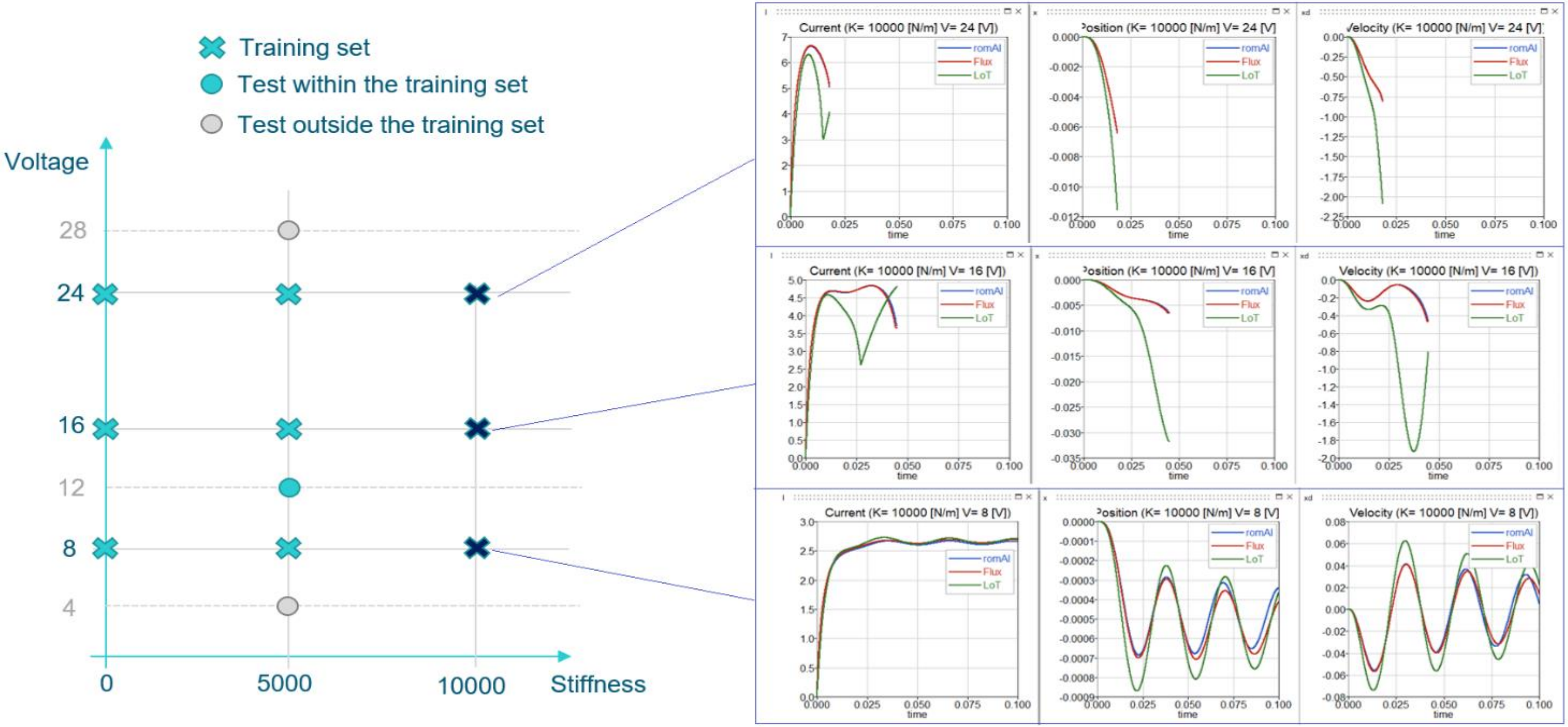
Electromechanical Actuator Example



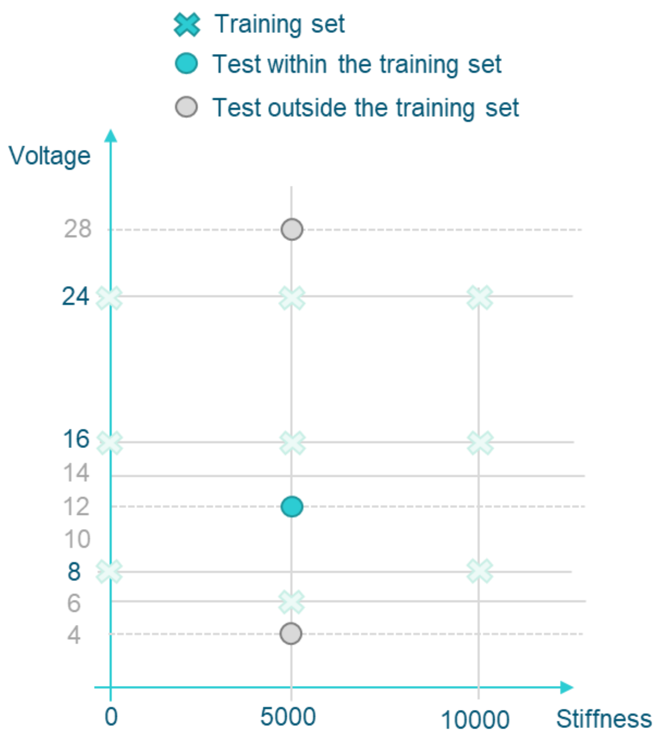
Modeling options

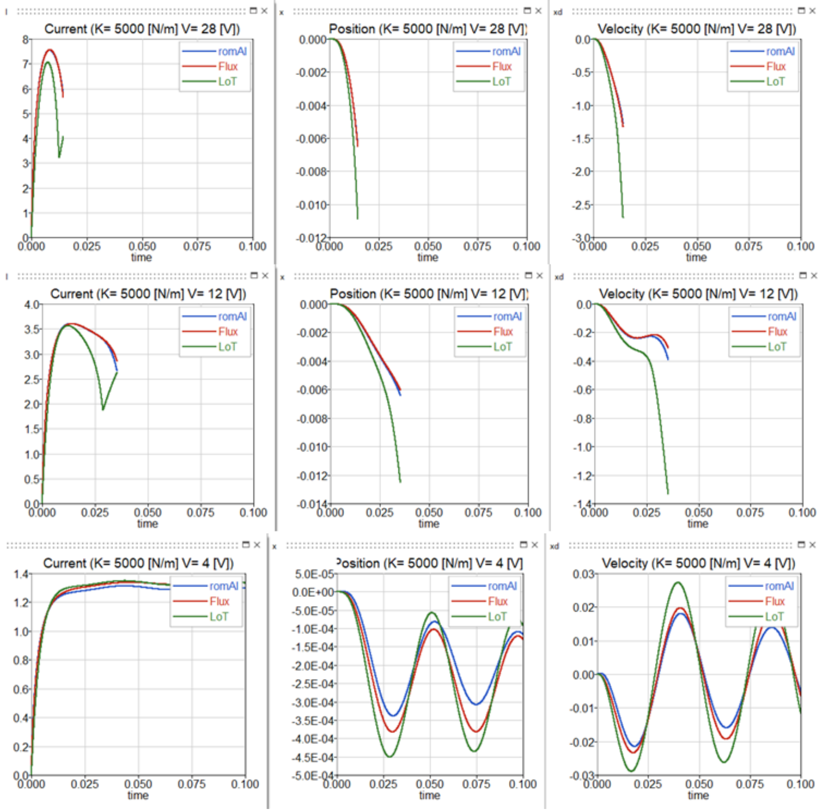


Electromechanical Actuator Results

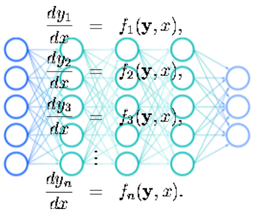


Electromechanical Actuator Results





romAI benefits



Unique combination of machine learning and system modeling techniques:

- **Less training data** with respect to pure data-driven approaches → Fewer 3D simulations run or tests
- **No** influence of **time discretization** → Very robust; works with any solver
- Possibility to **set the state variables** and consider **physical dependencies** → Allow to leverage the knowledge on the underlying physics involved
- **Satisfactory generalization properties** → Great accuracy when interpolating; Adequate accuracy when extrapolating

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SUMMARY & OUTLOOK

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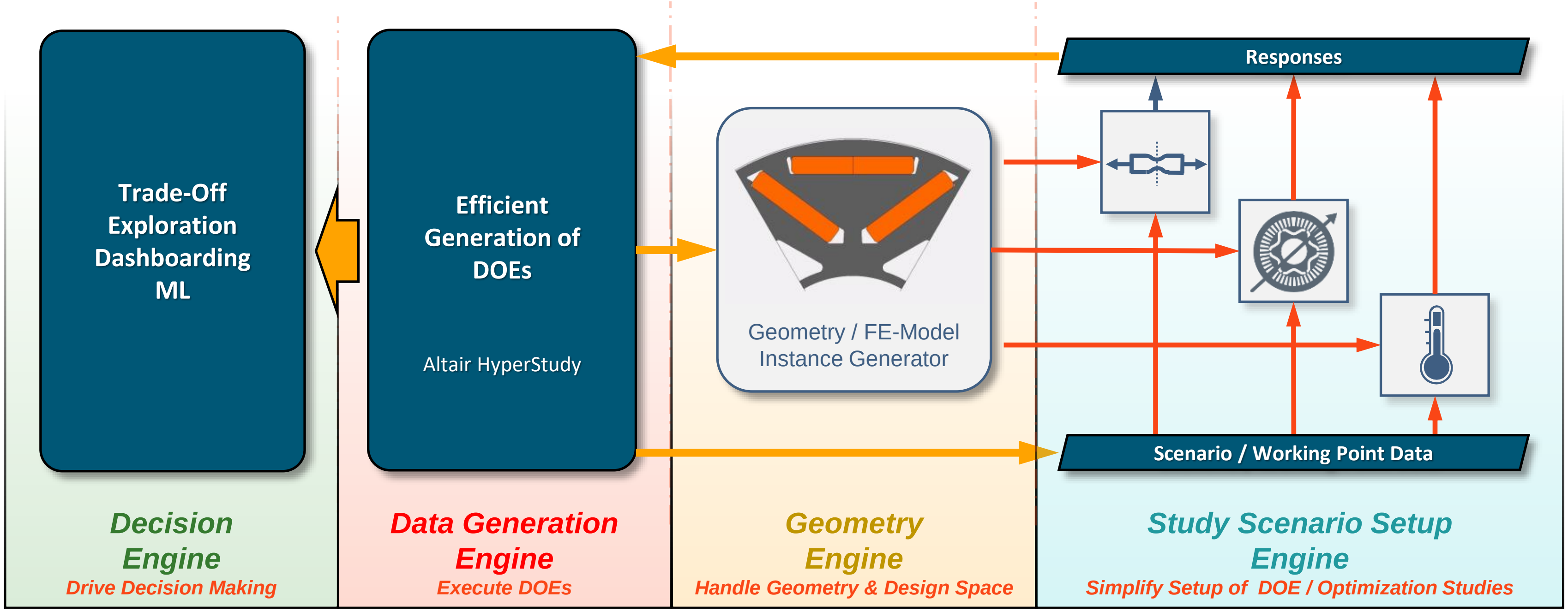
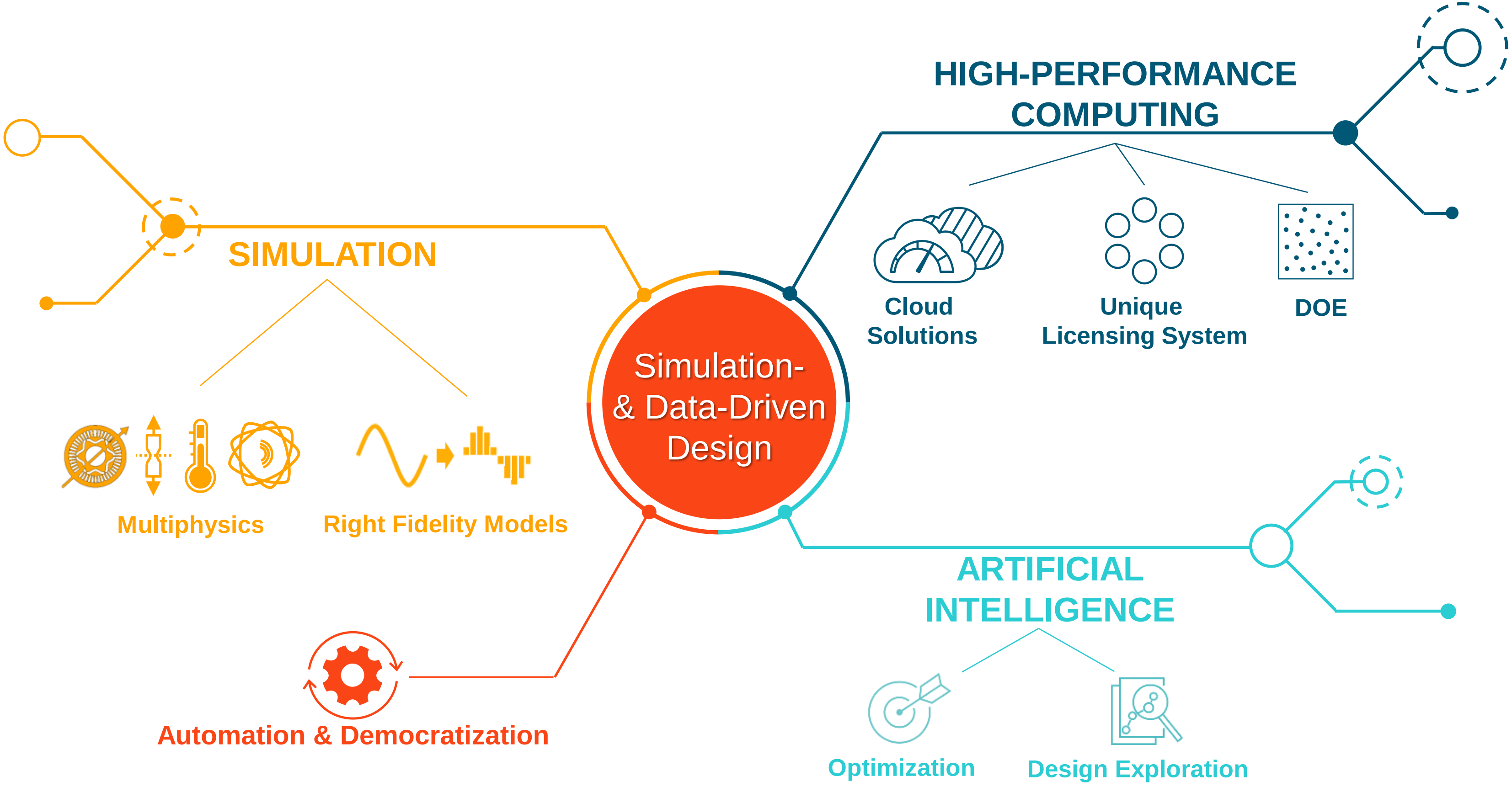
A Tool to Automate EMotor Design Explorations

- Define designable Geometry – Create Test Scenario – Run DOE – Explore and create Decision Material




SIMULATION
Multiphysics
Right Fidelity Models
Simulation-
& Data-Driven
Design
HIGH-PERFORMANCE
COMPUTING
Cloud
Solutions
Unique
Licensing System
DOE
ARTIFICIAL
INTELLIGENCE
Optimization
Design Exploration
Automation & Democratization

The Future of Data-Driven Design

- Massive design exploration and optimization in **real-time to drive decision making**
- Synthesize engineering data to enrich the historical simulation & in-service data
- Automation to **democratize AI** in product design & engineering