Powering Innovation That Drives Human Advancement

Hybrid Digital Twins: Combining Physics Based and Data Analytics Approaches

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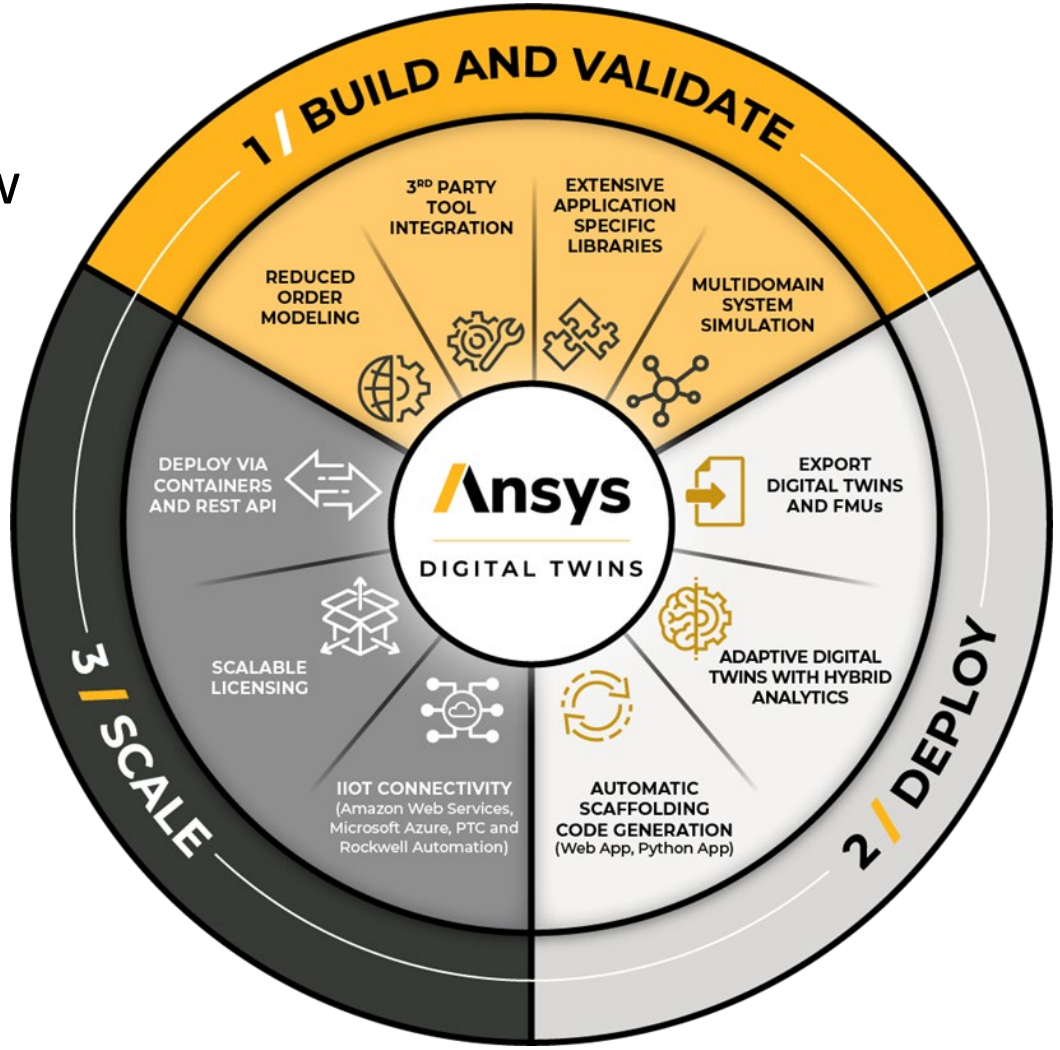
16.10.2024

Agenda

- Digital Twin and Hybrid Analytics Overview
- Example Use Cases
- Hybrid Analytics deep-dive
- Parameter Calibration Workflow
- Fusion Modeling Workflow



Digital Twins will unlock value

digital twin™ CONSORTIUM : "**Virtual representation** of **real-world entities** and **processes**, **synchronized** at a specified **frequency** and **fidelity**"

Digital Twin Concept

Real Asset, Process or System

Operating variables

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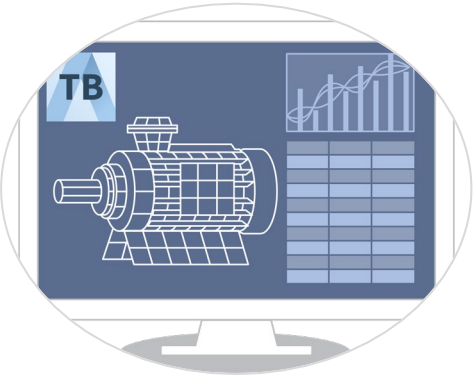
Data/info exchange

Actionable Insights

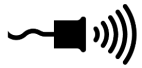
Digital Twin



Virtual Prototyping / Testing / Validation*
What-if's / Optimization*
Virtual Sensing (Monitoring)
Model-based Control
Predictive Maintenance

Customers are putting simulation at the center of their Digital Twin implementations

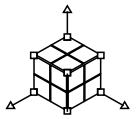
Simulation-based & hybrid analytics



Create virtual sensors to “measure” missing data

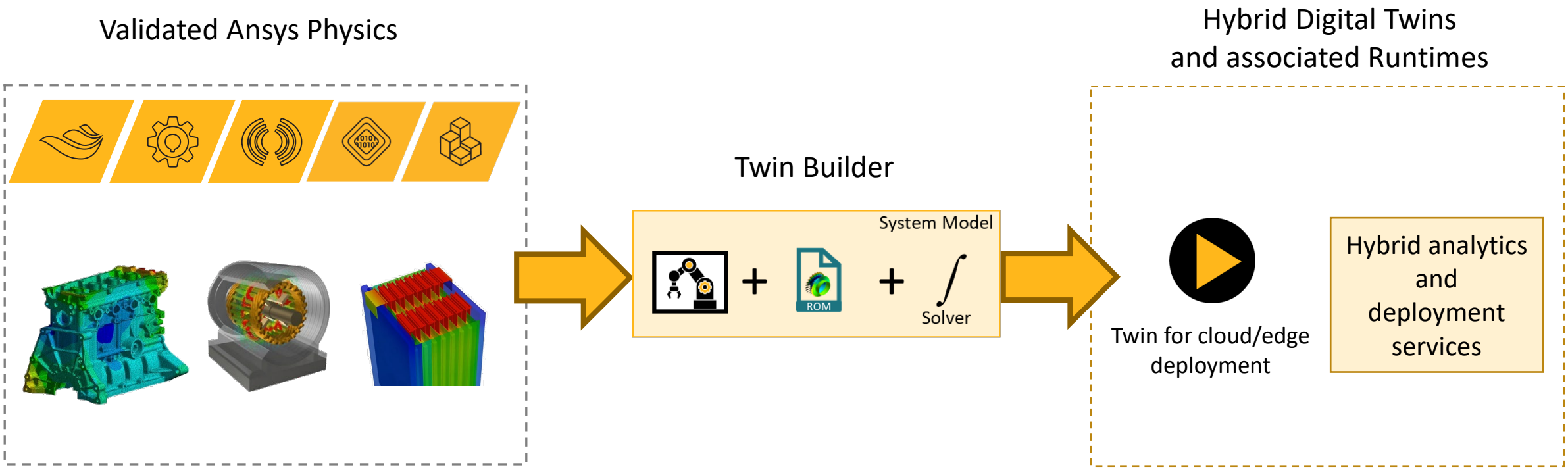
Perform what-ifs before applying a solution

Analyze accurate and deterministic predictions based on physical principles



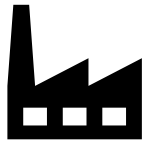
Explore causality and failure modes using physics

Our solution architecture fits seamlessly into our customers' stack



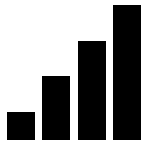
1. Best in class Reduced Order Modeling capabilities → Reuse
2. Hybrid Calibration → Accurate, evolving models
3. Unique runtime model and open architecture → Scalability

Typical use cases for Digital Twins



Virtual commissioning and system configuration

Predictive and prescriptive maintenance



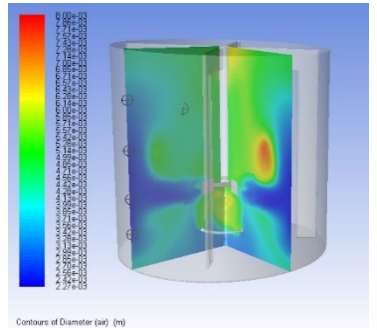
Production optimization

Virtual commissioning of bioreactors at global biopharma company

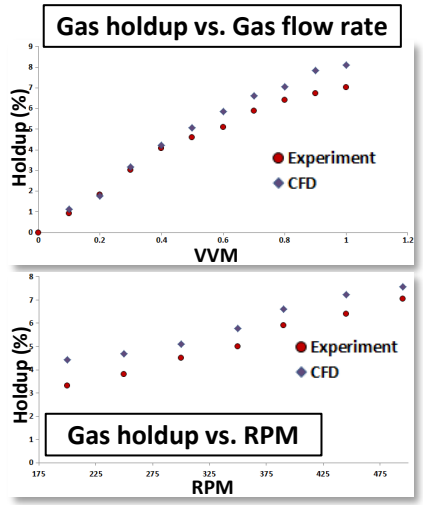
Challenge: Efficient bioreactor operation is dependent on the distribution of oxygen and other nutrients, which in turn depend on the operating conditions of the tank. A trial-and-error approach is very expensive and time consuming, requiring 8-10 calibration studies whenever a new formulation is deployed in a facility.

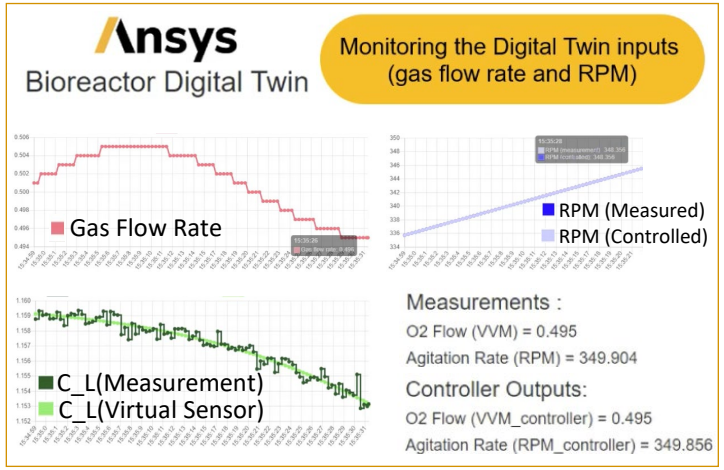
Solution: A bioreactor digital twin that incorporates both fluid dynamics as well as metabolic modeling of biomass, pH, nutrient concentration, the concentration of waste byproducts, as well titer over the course of the cell culture as a function of operating conditions.

Result: An understanding of drug titer over the course of the cell culture to maximize tank performance, expected to lead to savings in the millions of dollars per year.



Validated Bioreactor Process Model





Digital Twin Dashboard

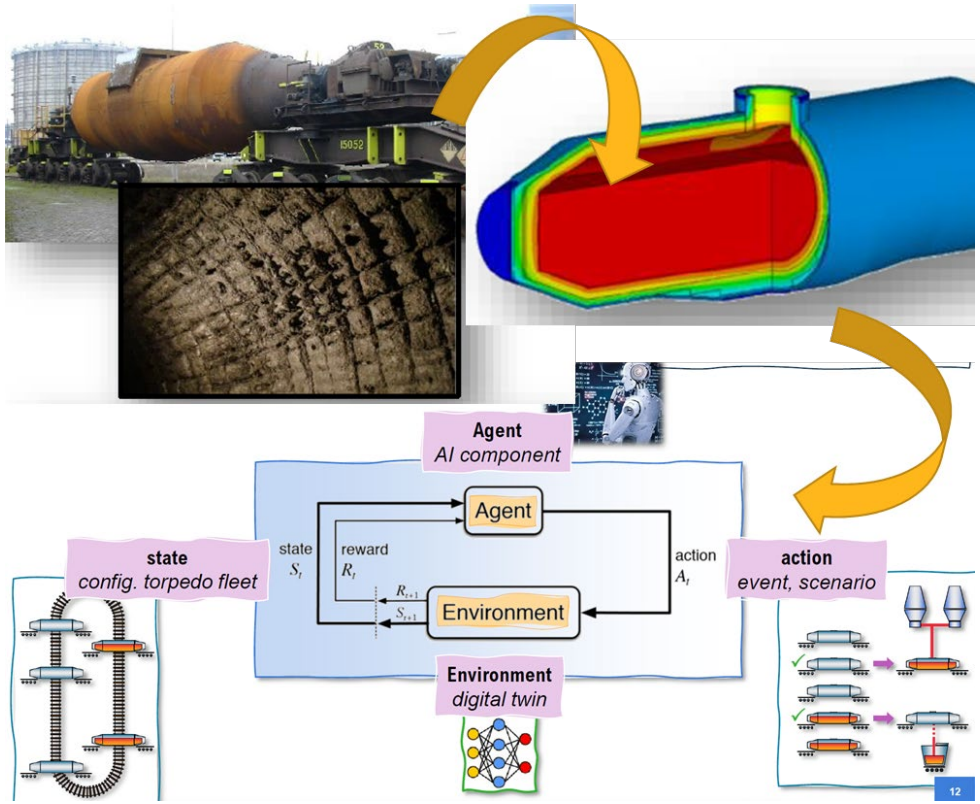
[The Powerful Potential of Digital Twin Technology to Improve Drug Discovery, Development, Manufacturing, and More (pharmasalmanac.com)]

Improving maintenance outcomes at Tata Steel

Challenge: Higher hot metal temperatures help with yield losses and CO_2 emissions but lead to higher wear of insulation of torpedo car linings and higher energy usage. Unplanned torpedo refractory maintenance leads to higher-than-expected downtimes.

Solution: A comprehensive (thermal) digital twin for the entire hot metal (HM) production route. AI based controls to optimize for refractory wear rate and energy consumption.

Result: Facility downtime reduced by 400 hours annually. Additionally, can optimize number of ladles and torpedo cars in use. Finally, in combination with other initiatives, this digital twin is enabling Tata Steel to achieve its target of 30-40% reduction in CO2 emissions by 2030



https://www.ansys.com/blog/simulation-takes-heat-off-tata-steel-during-production

Improving EV range in partnership with global automotive suppliers

Challenge: EV range is a complex function of multiple factors, including several that are comfort and performance related, and user controlled.

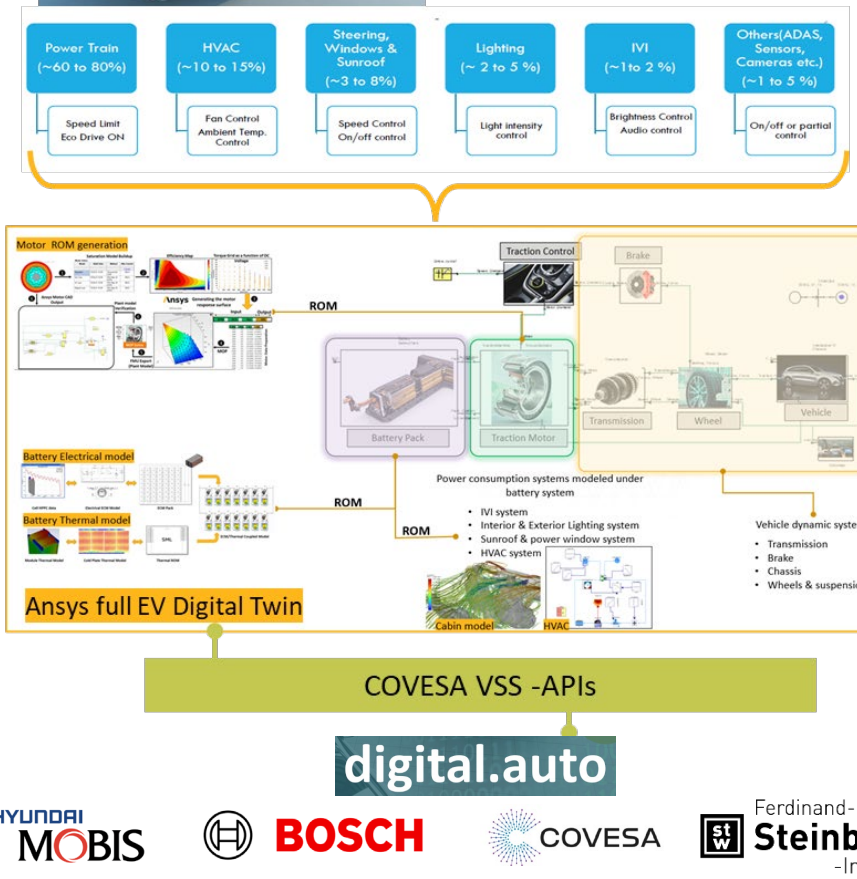
Solution: A detailed simulation-based digital twin model of the EV system is deployed onboard and connected via standard APIs to provide an interactive capability to consumers. The digital twin can accurately predict range based on user selected comfort level policy. Once battery charge drops below a certain level, the customer is presented with several policies that allow for trade-off between comfort/performance and range.

Results: The digital twin helps mitigate customer range anxiety. This is seen as a significant competitive differentiator for automotive suppliers and OEMs such as Hyundai Mobis and Bosch and is currently being deployed in pilot installations.

Whitepaper: Going the extra mile

EV Power consumption systems

- ❑ Power train
- ❑ Chassis
- ❑ Electronic Systems
- ❑ Networking
- ❑ Safety & Control
- ❑ Infotainment
- ❑ Comfort & Control



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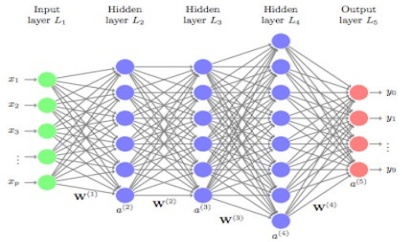
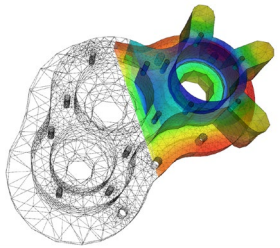
Hybrid Analytics

Digital Twin Challenge: Accuracy, Time & Cost



Data-Driven Modeling

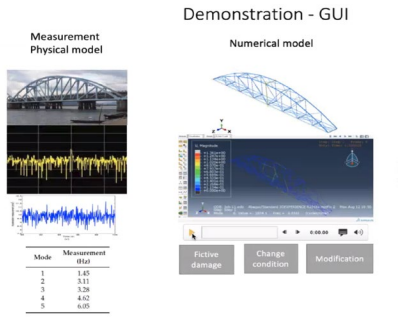


Design & simulation information not readily available / usable

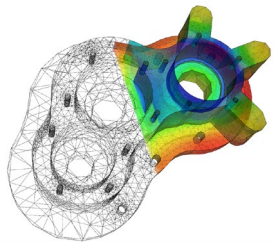
Model Development

Large volumes of process data required for training

Insufficient accuracy, limited by observed data



Simulation-Based Modeling



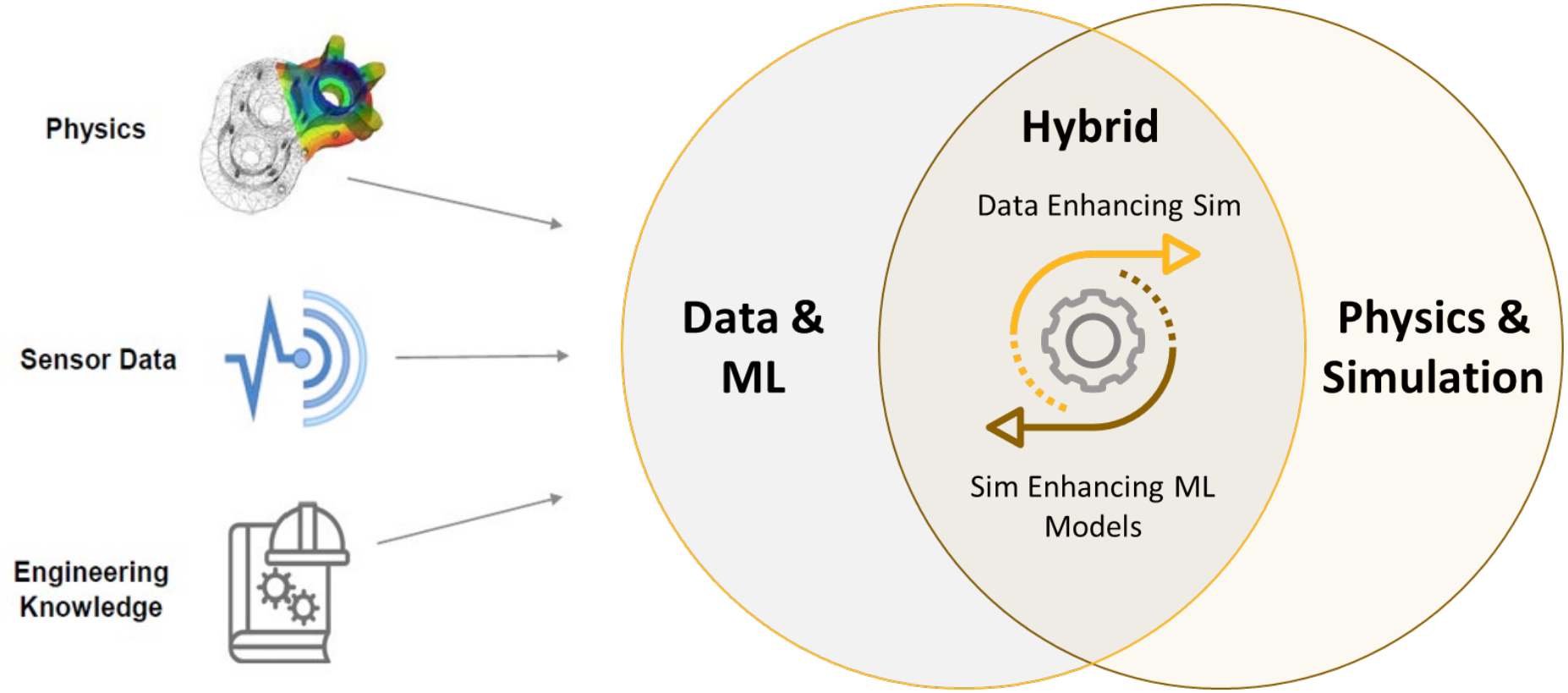
Difficult to accurately model the as-operated performance of equipment

Model Development

Lacking ability to incorporate available data into models

Long, expensive time scales to develop & deploy

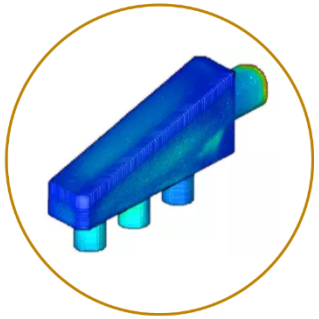
Hybrid Digital Twins: combining simulation and data



Hybrid Analytics combines data and physics to build **Hybrid Digital Twins**

Hybrid Digital Twins Use Cases

- Hybrid approach open new use cases for digital twins useful across many industries:



Virtual Sensor

Virtual sensors provide missing information

Fleet Deployments

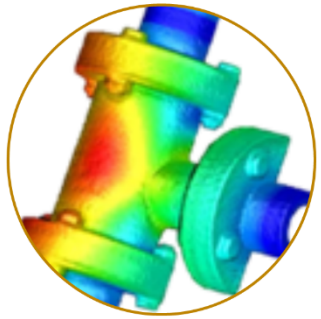
Use data to match the asset's unique behavior and environment

Brownfield Deployments

Learn missing behavior/information my enhancing a model with data

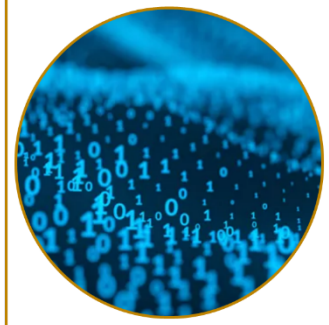
Greenfield Deployments

Decrease cost by replacing physical sensors with virtual sensors



Inverse Problem

Infer what inputs or operating conditions would lead to the desired behavior



Sparse Data

Quantify uncertainty for any amount of data and return meaningful results

Incomplete Physics Modeling

Model the residual between the known/modeled physics behavior and the expected behavior

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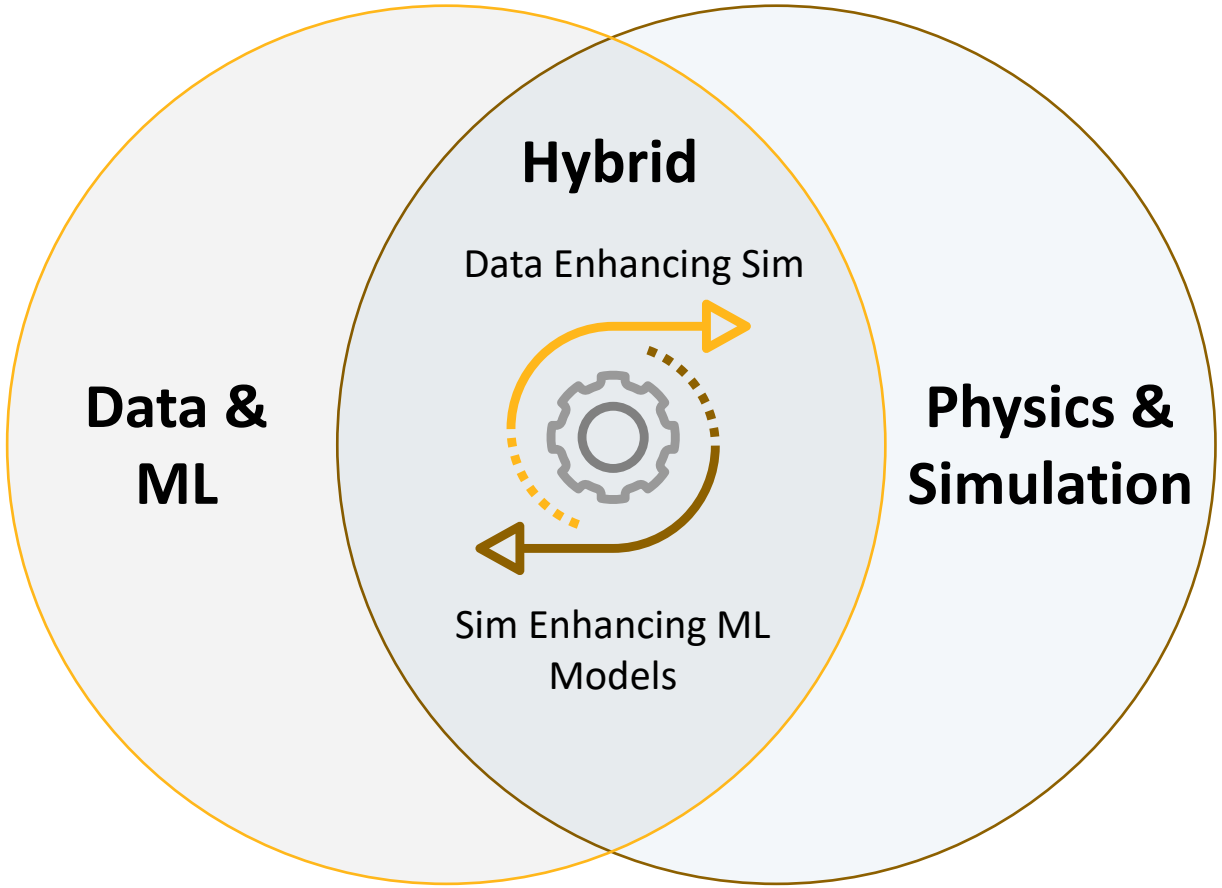
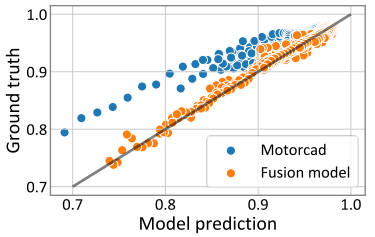
Hybrid Analytics

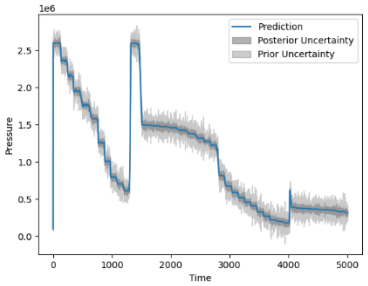


Hybrid Analytics

Fusion Modeling

Model built from at least two different types of data





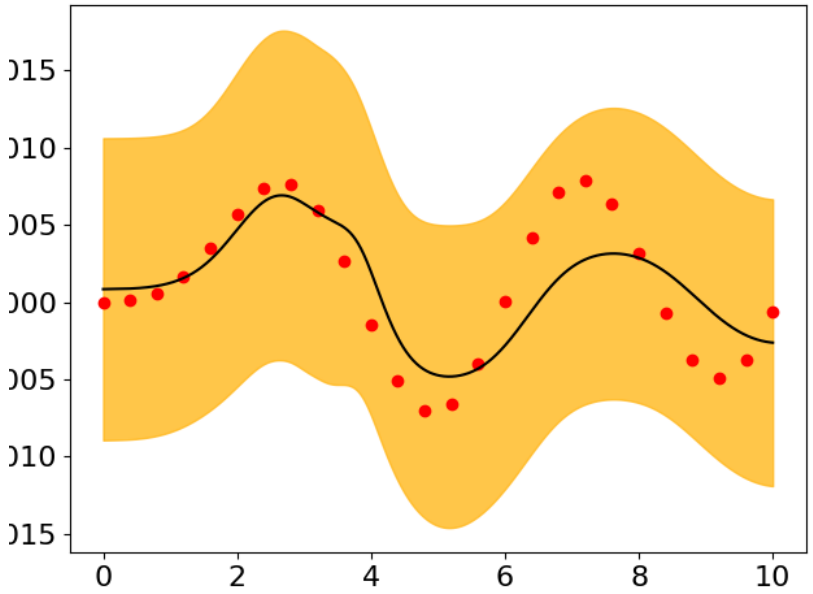
Twin with parameters that can be calibrated online based on sensor data

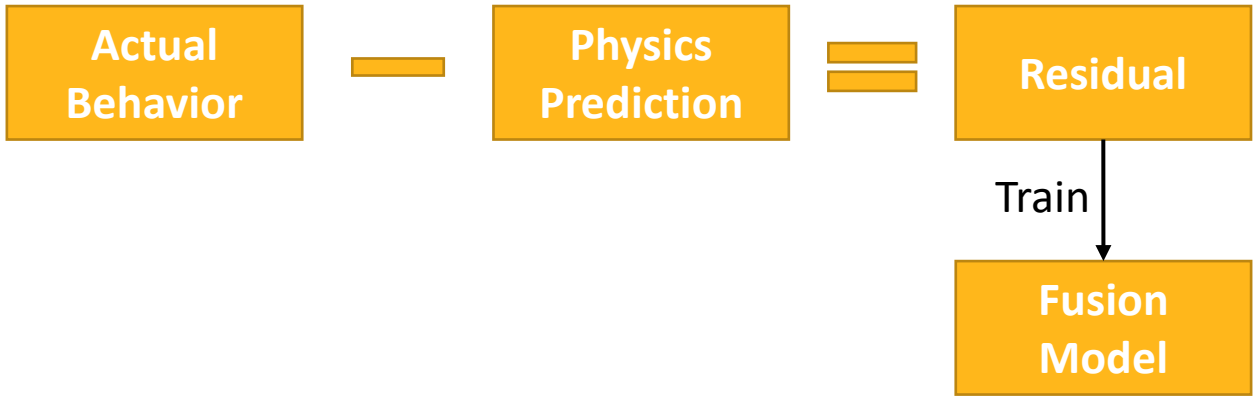
Calibration

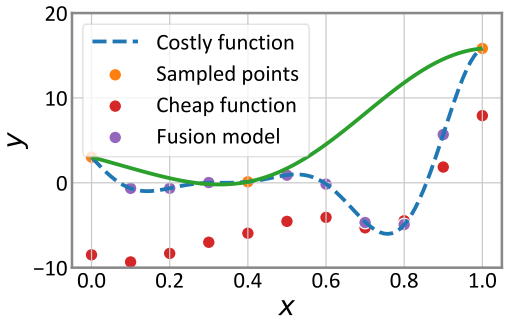
Hybrid Analytics is a toolset for combining data and physics modeling using machine learning techniques

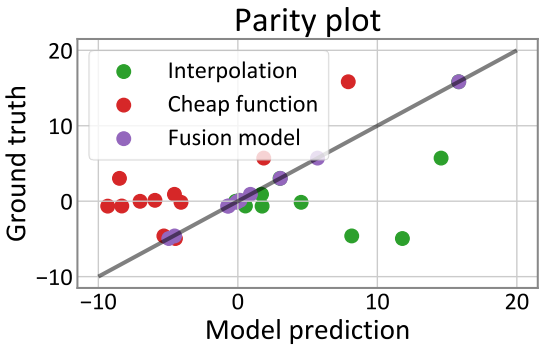
Fusion Modeling

- Build models from two different types of data
  - Simulation and Experimental
  - 3D simulation and 1D simulation
- Returns uncertainty of fit
- Instead of training a full data model, use the most accurate physics model available and train an ML model of the residual









A **Fusion Model** is a machine learning model built from at least two different types of data

Hybrid Digital Twin Example

Traction Motor Design

Traction Motor Simulation Approaches

Concept Design

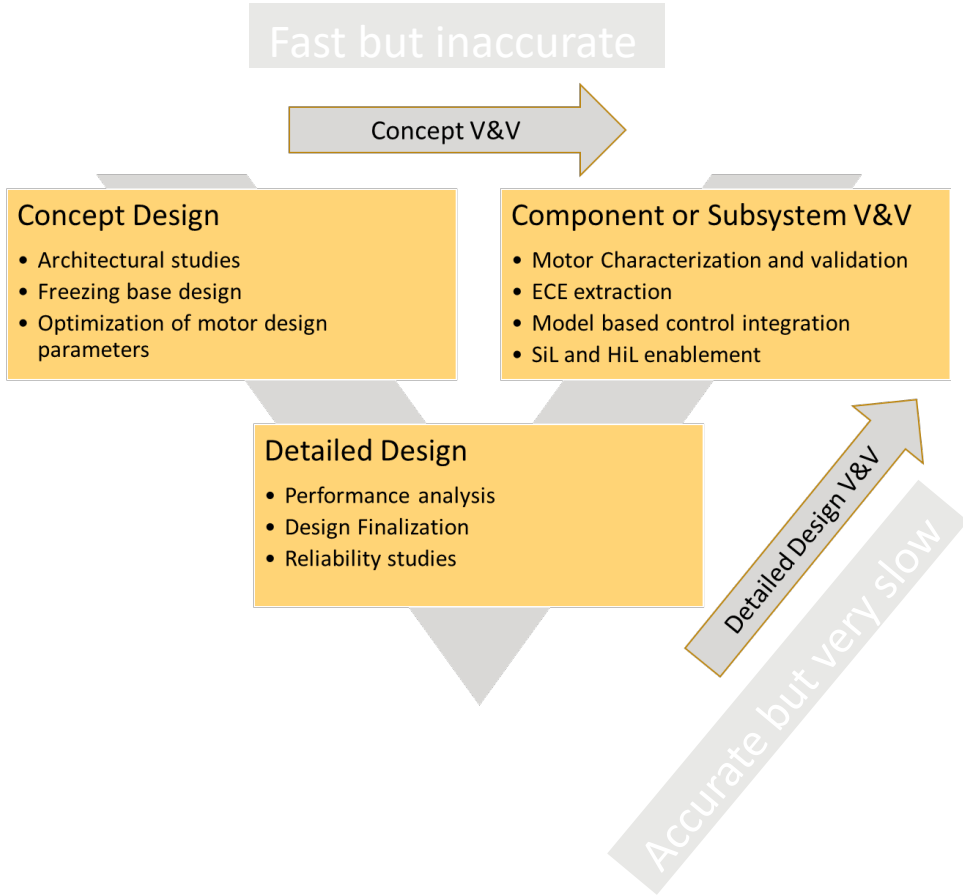
- Template based Multiphysics Design
- Very fast based on 1D assumptions and 2D FEA

Detailed Design and Analysis

- CAD based design for added geometric detail
- Advanced 2D/3D Analysis for 3D effects, switching harmonics, etc.
- Some advanced simulations may incur long run times

Component V&V

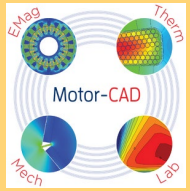
- Concept V&V for design validity
- Detailed design V&V enables performance insights but time expensive
- Some advanced analysis for component V&V not feasible unless ROM technology is employed
- Control held off until design finalization and testing



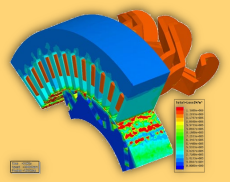
Fusion Model for Motor Characterization

Input Variables
Current
Torque Angle
Speed

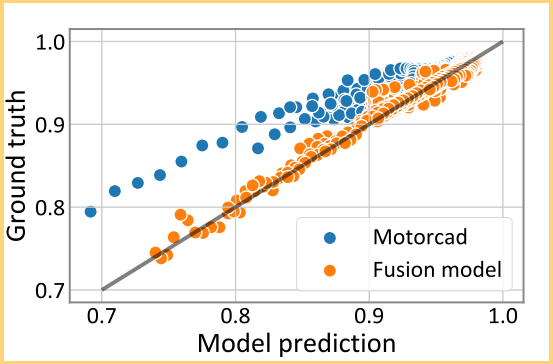
Accurate 2D Assumptions:
Motor-CAD Parametric Sweep:
500-600 Design Points
CPU Hrs: 3

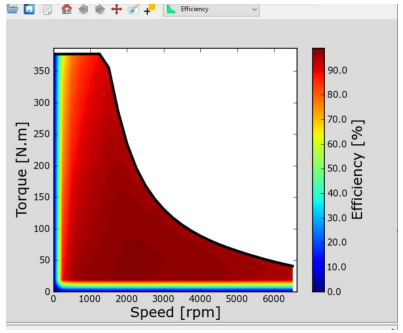


Accurate 3D Features:*
Maxwell Parametric Sweep:
40-50 Design points
CPU Hrs: 456



Fusion Model
Black Box 500-600 Design Points of Fusion + Motor-CAD





Efficiency Map

Response Surface
Torque, Loss, Power, D-Q parameters, Efficiency etc.

Optimization
Operating point extraction and Torque Speed Envelope

Control Strategy
Implementation of Operating points based on MTPA

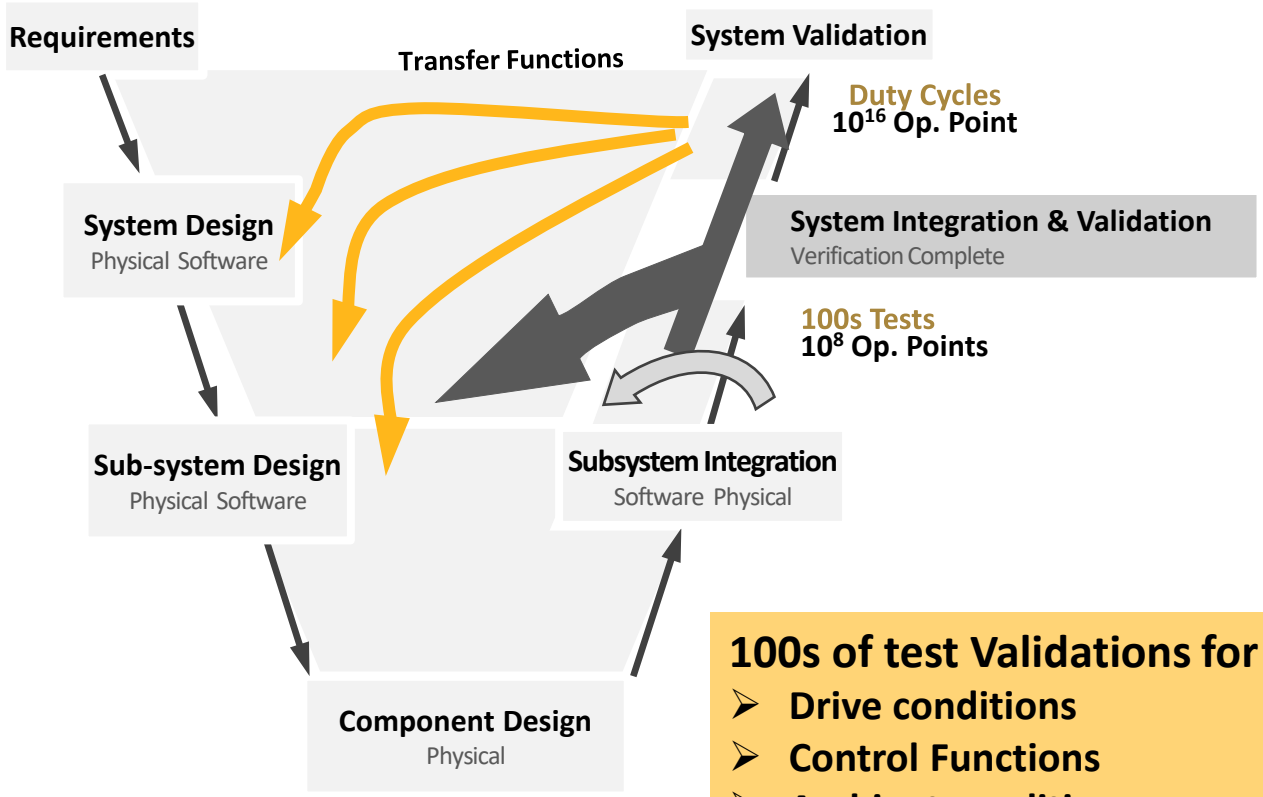
Response Surface
Efficiency Map
Ld Lq Map
Current Map etc

** 3D effects could include end leakage, magnet segmentation, etc.*

Case Study: Prius IPM with Skew

Analysis Type	No of Runs Required	CPU-Hours
Maxwell 3D	480	4352
Motor-CAD	480	3
Fusion of Motor-CAD + Maxwell 3D	Motor-CAD (480) + Maxwell 3D (50)	456

~10X Speed Up per design



100s of test Validations for
- **Drive conditions**
- **Control Functions**
- **Ambient conditions**

~1000X Speed Up over Complete Design Cycle

Model predictions for NOx emissions

Challenge

- Model predictions for NOx emissions are inaccurate which drives significant testing and re-work
- Develop first-time right engine and after-treatment architecture

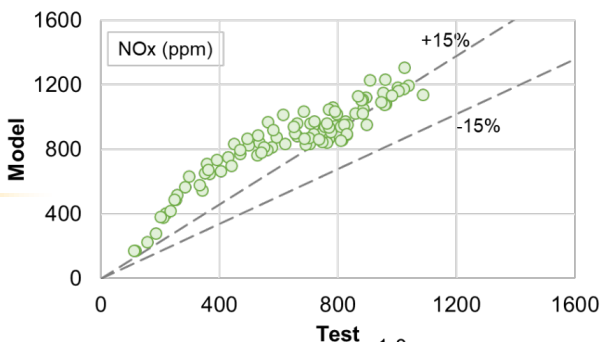
Solution

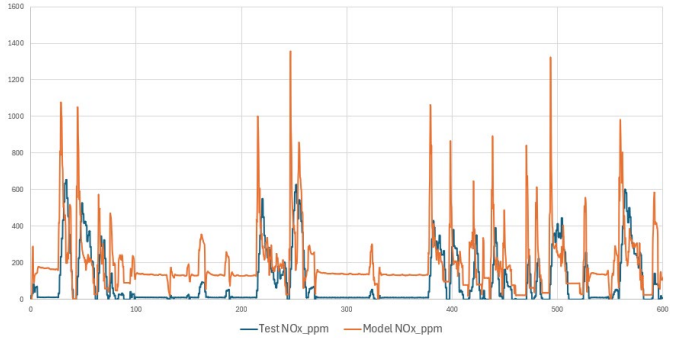
- Developed Fusion model that improves simulation predictions dramatically using model and test data

Benefits

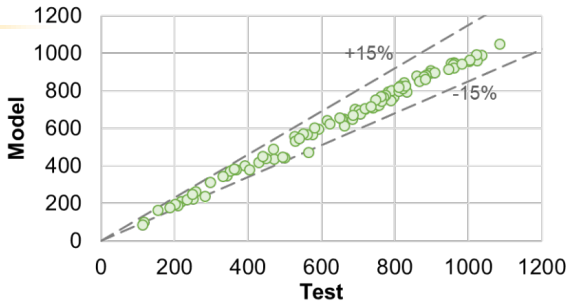
- Accurate Fusion model to predict the NOx emissions
- 6-18 months reduction in development time
- $600K savings per program

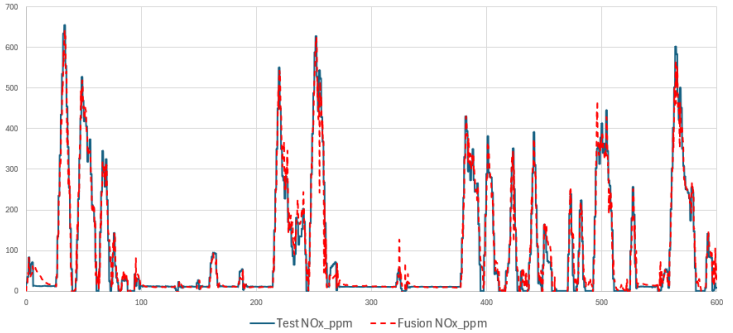
Physics-based Model





Fusion Model





Machine Learning for Physics-Accelerated Design of Mixing Tanks

Challenge

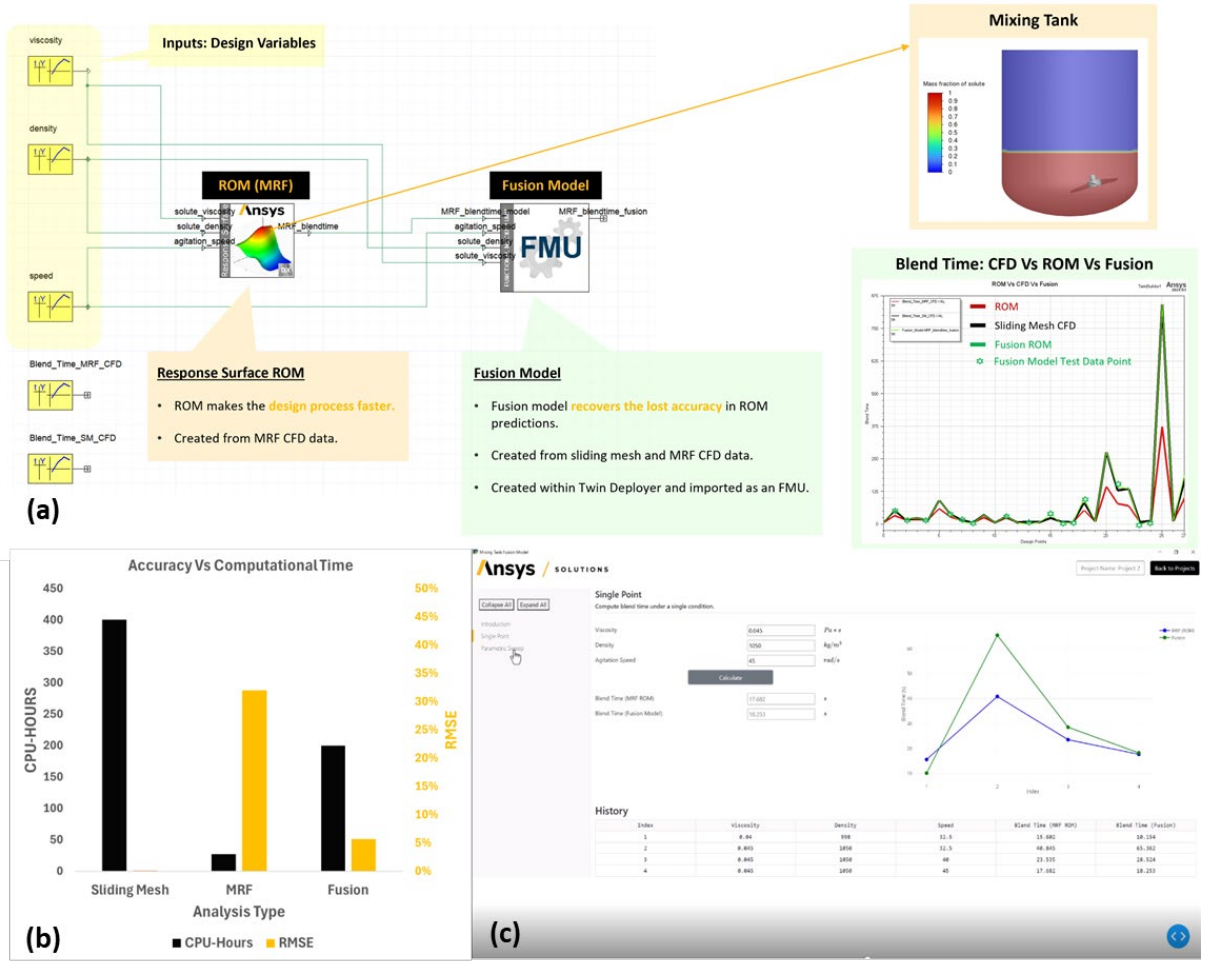
- Need for efficient and accurate blend time prediction in mixing tanks at different agitation speeds and for distinct liquid properties (distinct density and viscosity).
- Multiple Reference Frame (MRF) CFD approach is computationally efficient but has low accuracy in comparison to the sliding mesh approach.

Solution

- Applied machine learning approach (Fusion model) to improve the MRF model accuracy by learning from few sliding mesh simulation data.
- Created a Fusion-Reduced Order Model (Fusion-ROM) for quick and accurate blend time prediction.
- Integration of the system-level model into an interactive custom App.

Benefits

- Error reduction in MRF model predications from 32% to 1.5%-5.7%.
- Reduction of CPU hours required to construct the design space by ~50% versus the purely sliding mesh approach.
- Building an interactive easy-to-use custom App for non-expert users.



Summary

- Ansys TwinAI streamlines the validation process of a Twin Model
- Additional capabilities such as Hybrid Analytics are also available to enhance the Twin predictions with data
- Hybrid Digital Twins solve many problems facing operators today
- Combining different types of data opens new digital twin use cases and increases digital twin accuracy
- Ansys TwinAI 20224R2 contains the Hybrid Analytics package to start building Hybrid Digital Twins

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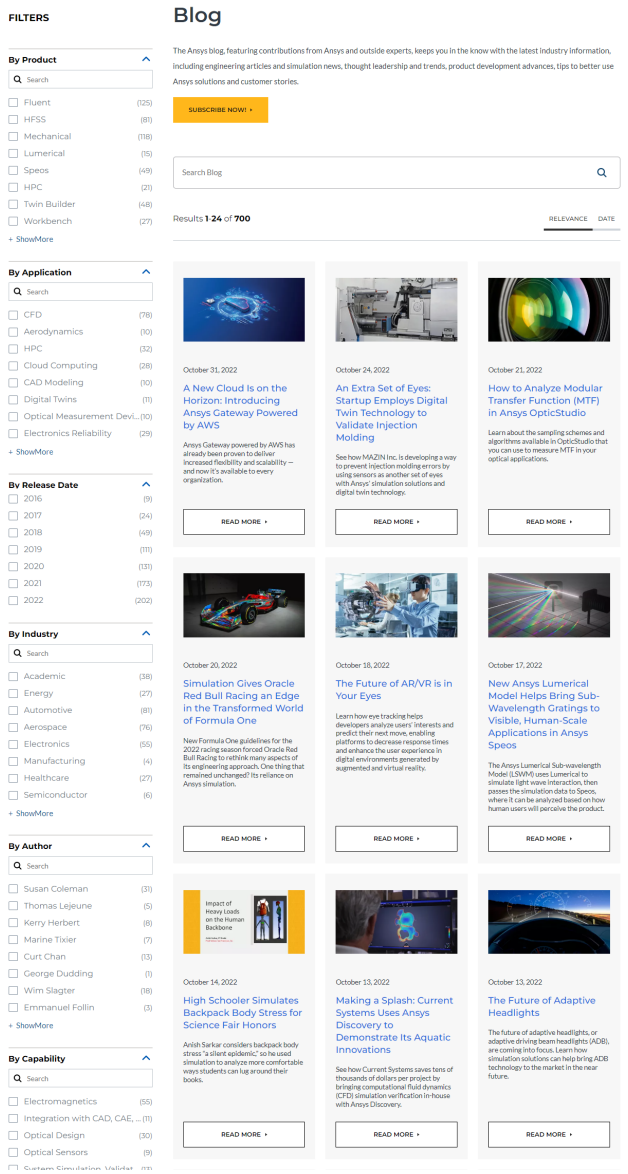

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