Hybrid Digital Twin
Technology for Predictive Maintenance

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Dr. Reni Raju
Director, Business Development

Dr. Matt Adams
Lead Product Specialist, Digital Twin

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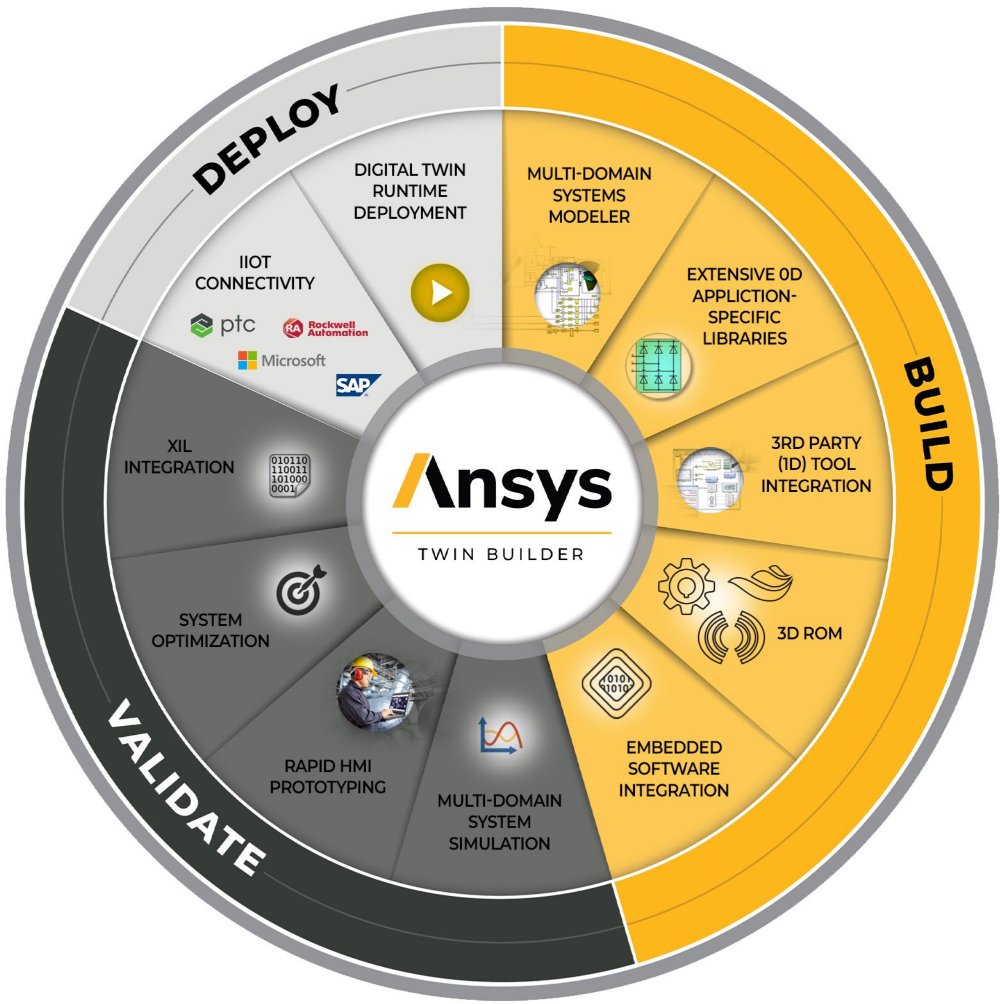
Overview

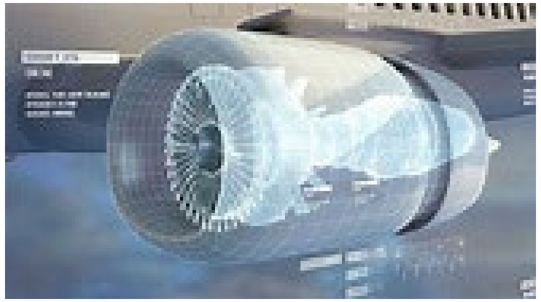
- Intro
- Digital Twin Challenges
- Hybrid Solution
- Hybrid Analytics Capabilities

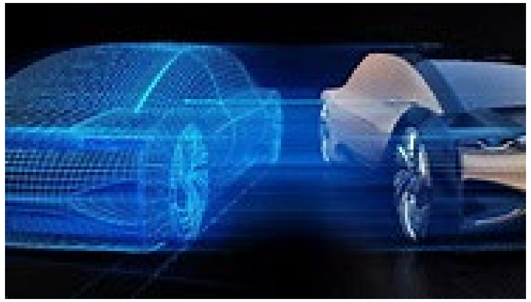


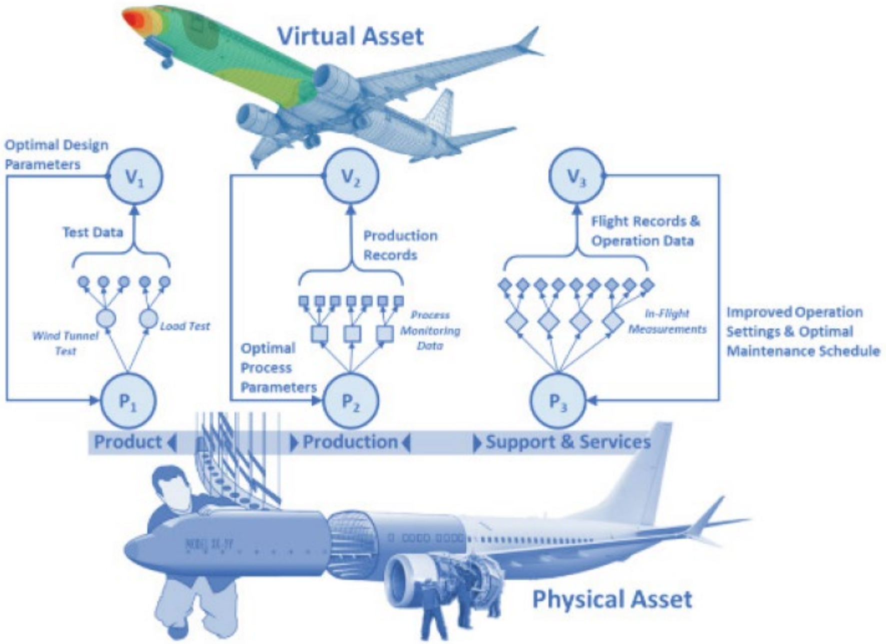
Digital Twins

A Digital Twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

A Digital Twin is a **Virtual Representation** of a **connected Physical Asset**







Digital Twin : Definition & Value, AIAA & AIA, December 2020

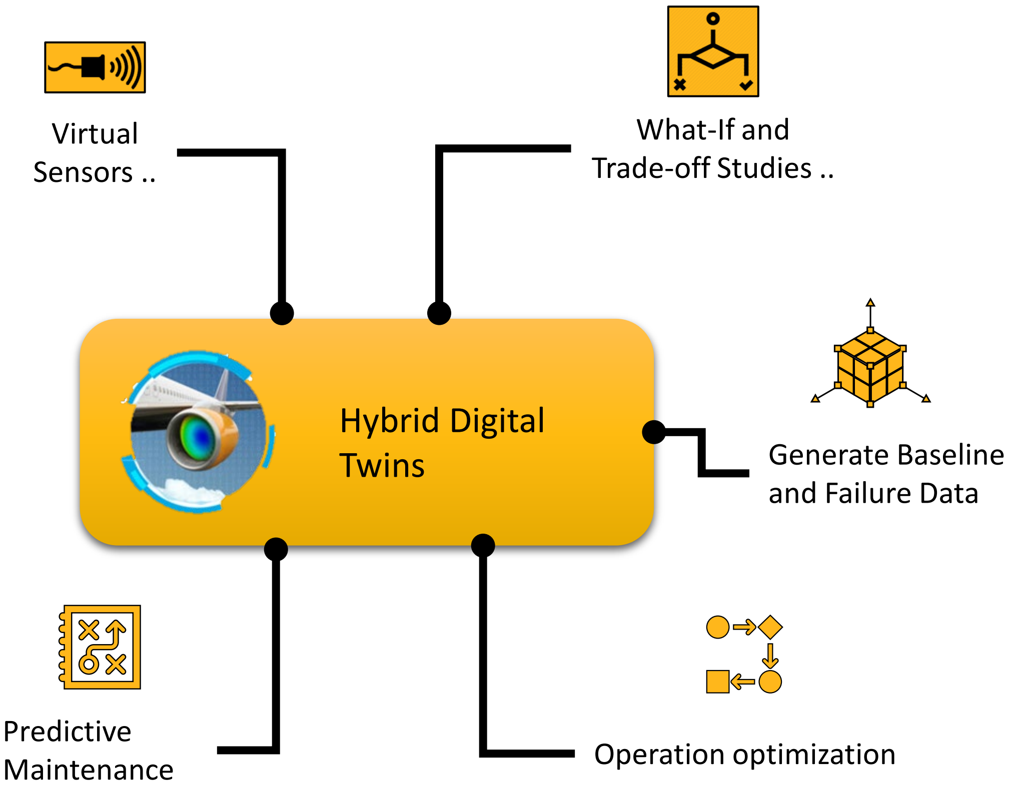
Value of Digital Twins

Detect, prevent, predict, and optimize through real time analytics to deliver business value

Virtual Commissioning, Trouble Shooting and System Configuration

Predictive and Prescriptive Maintenance

Production Optimization and Yield-as-a-service



Challenges in Creating a Digital Twin

Accuracy

Adhere as closely as possible to physical behavior

Adaptability

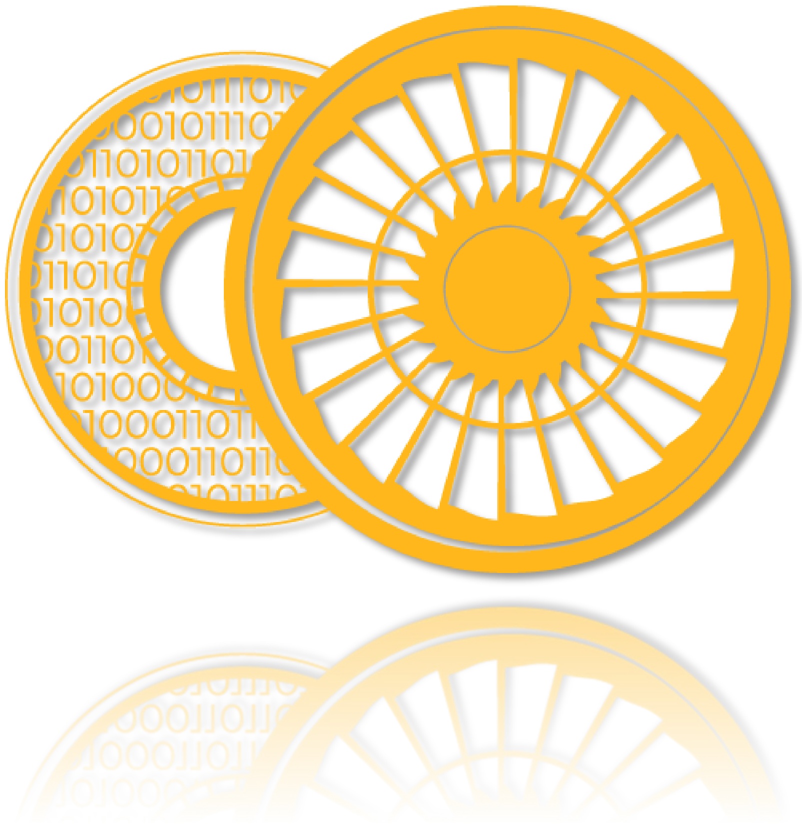
Adapt to changing environments and conditions

Flexibility

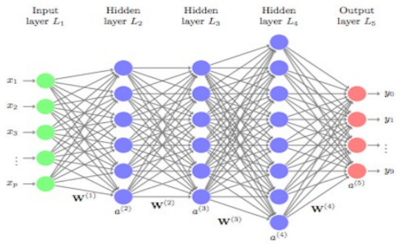
Model multiple scenarios without overfitting to any one

Scalability

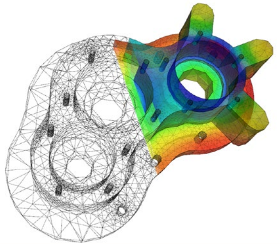
Rapidly build and deploy adaptable Digital Twins



Digital Twin Challenge: Accuracy, Time & Cost



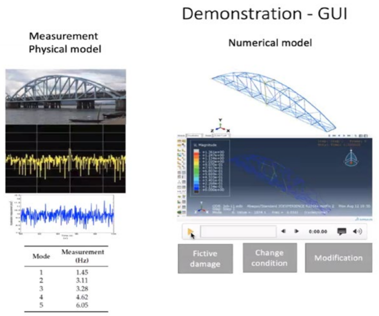
Data-Driven Modeling



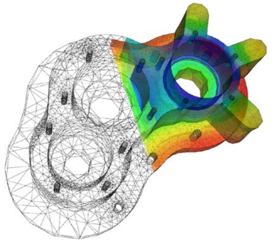
Design & simulation information not readily available / usable

Model Development

Large volumes of process data required for training

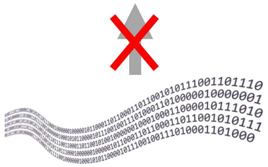


Simulation-Based Modeling



Difficult to accurately model the as-operated performance of equipment

Model Development

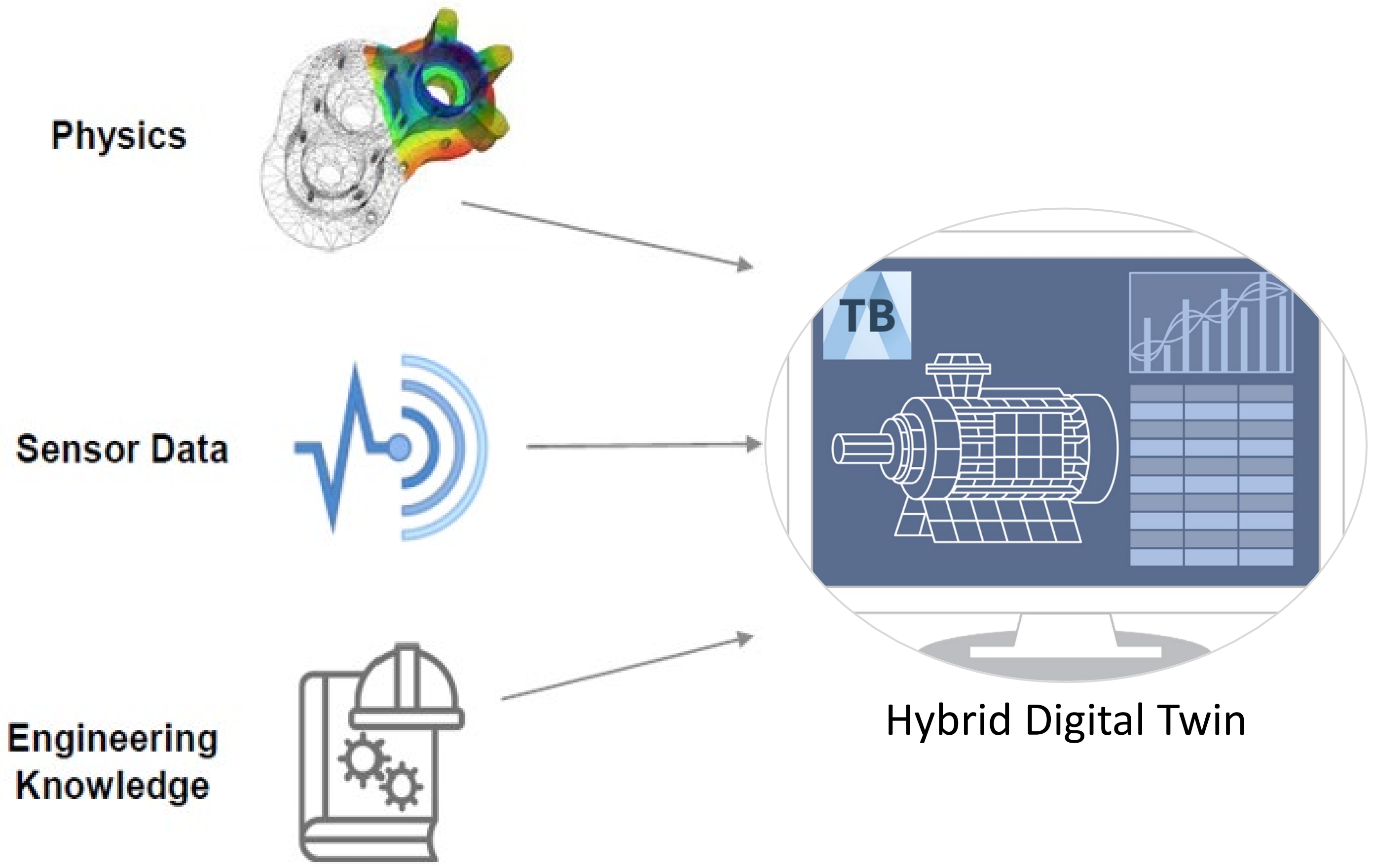


Lacking ability to incorporate available data into models

Insufficient accuracy, limited by observed data

Long, expensive time scales to develop & deploy

Solution = Hybrid Digital Twin

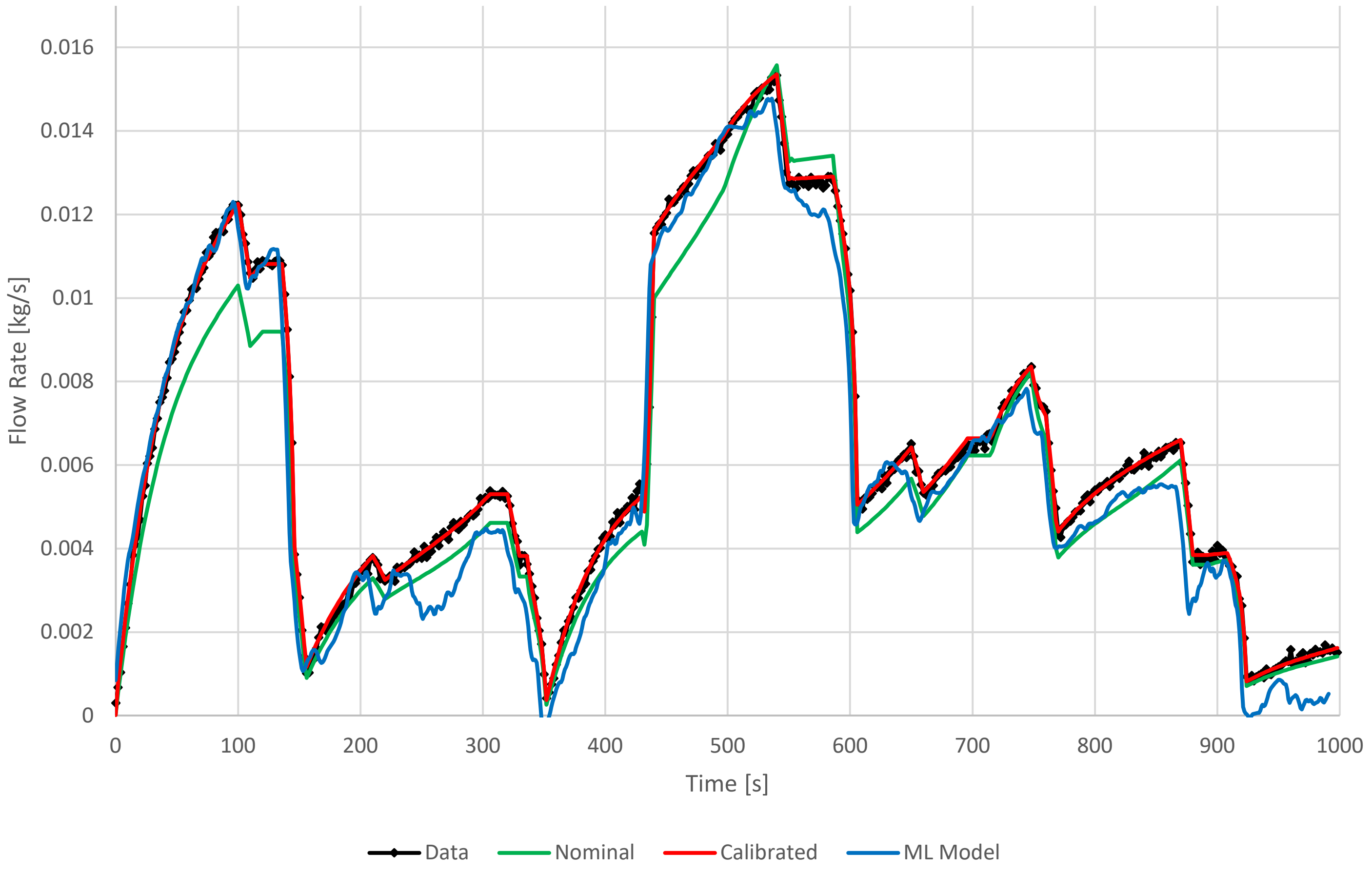


- Combine the best of both approaches
- Use all available information from engineering, physics, and data
- Integrate into a Hybrid Digital Twin

The Hybrid Approach

- Data and Simulation approaches each make reasonable predictions, but also both face limitations

- Using the same data and the same physics model, the Hybrid Approach resents a better, more efficient solution.



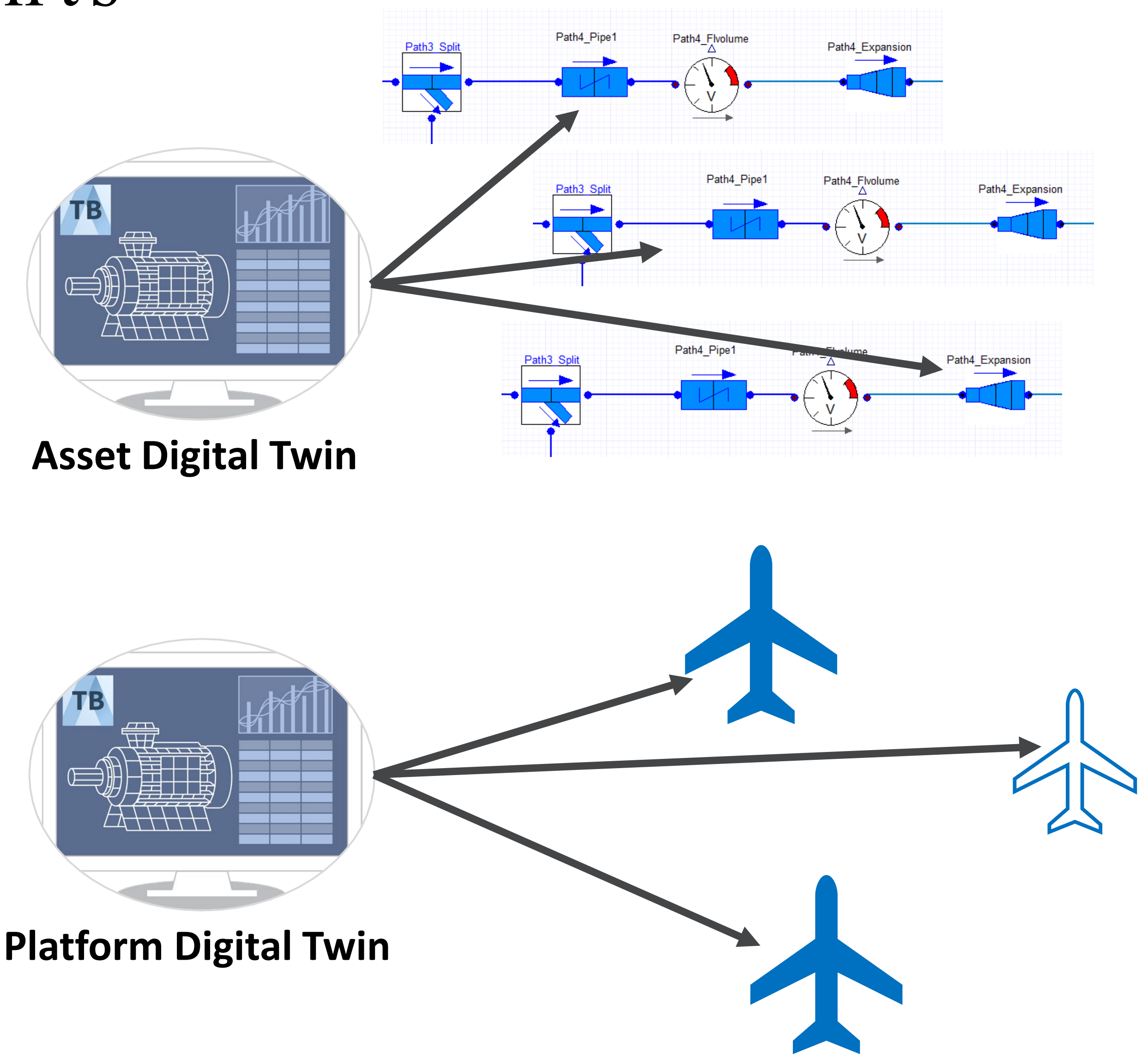
Use Case – Fleet Deployments

Challenges

- Deploy the same Digital Twin to multiple assets in a fleet
- Adapt the twin behavior to each asset as it evolves independently of others in the fleet

Solution

- Use data from each asset to update and adjust the twin to match the asset's unique behavior and environment



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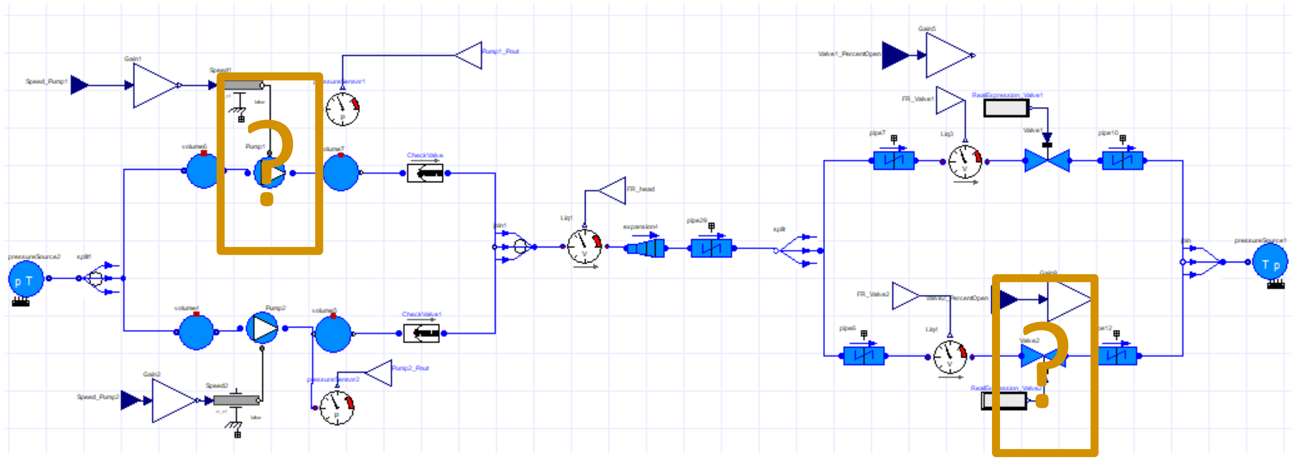
Use Case – Brownfield Deployments

Challenges

- Operators have incomplete information for their system
  - Missing specs or drawings
  - OEM protected IP
- Asset behavior may have changed over time



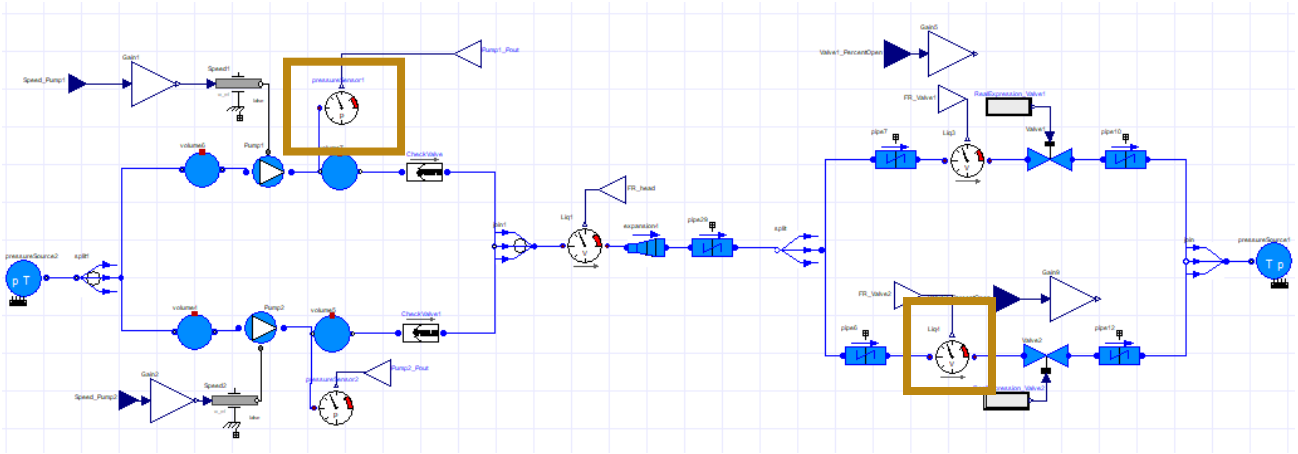
Solution

- Learn missing behavior/information my enhancing a model with data

Use Case – Greenfield Deployments

Challenges

- Physical sensors are expensive



Solution

- Decrease cost by replacing physical sensors with virtual sensors
- Optimize where to place sensors

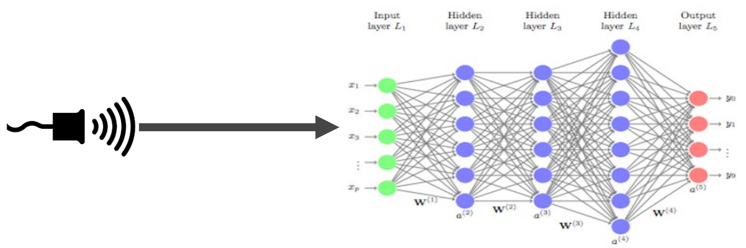
Use Case – Virtual Sensors

Challenges

- Missing information for data models
- Inability to collect with physical sensors either due to cost or because there is not sensor for desired information

Solution

- Virtual sensors provide missing information
- Validate Digital Twin with some physics sensors and predict other missing quantities



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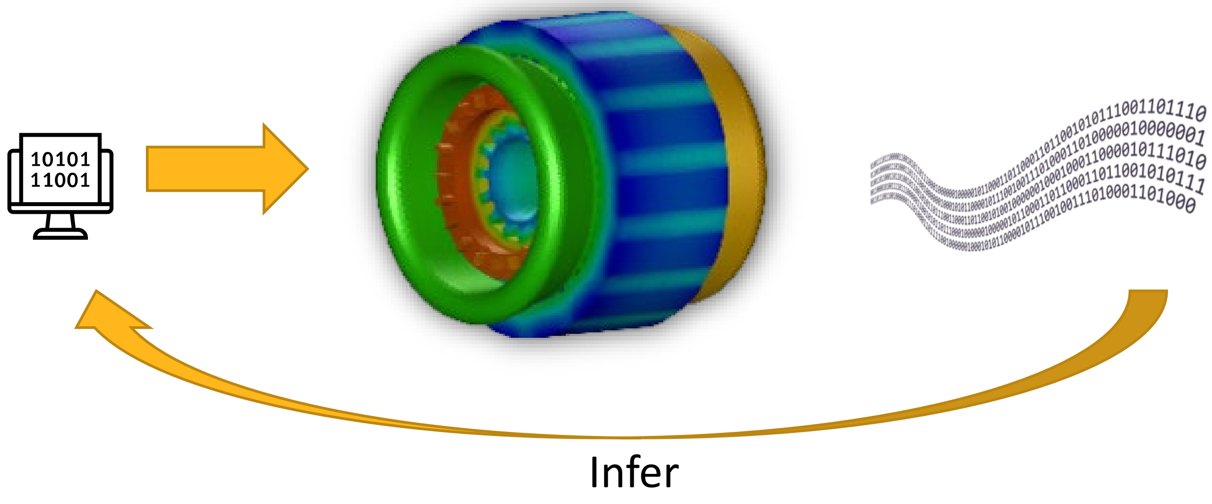
Use Case – Inverse Problem

Challenges

- Understand how to change operation when asset behavior doesn't match desired outcomes

Solution

- Use data and a Hybrid Digital Twin to infer what inputs or operating conditions would lead to the desired behavior



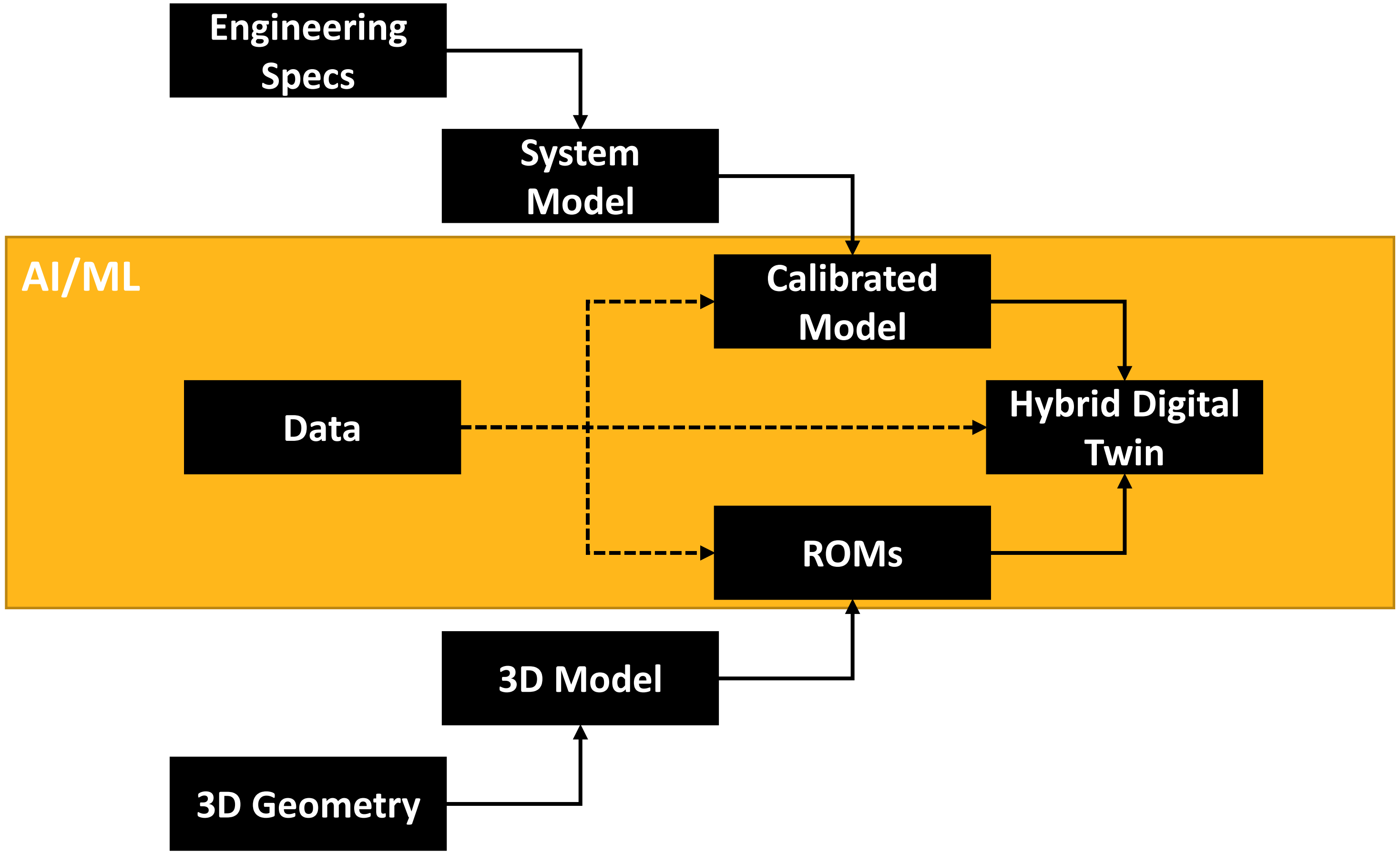
Building a Hybrid Digital Twin – Two Approaches

Top Down

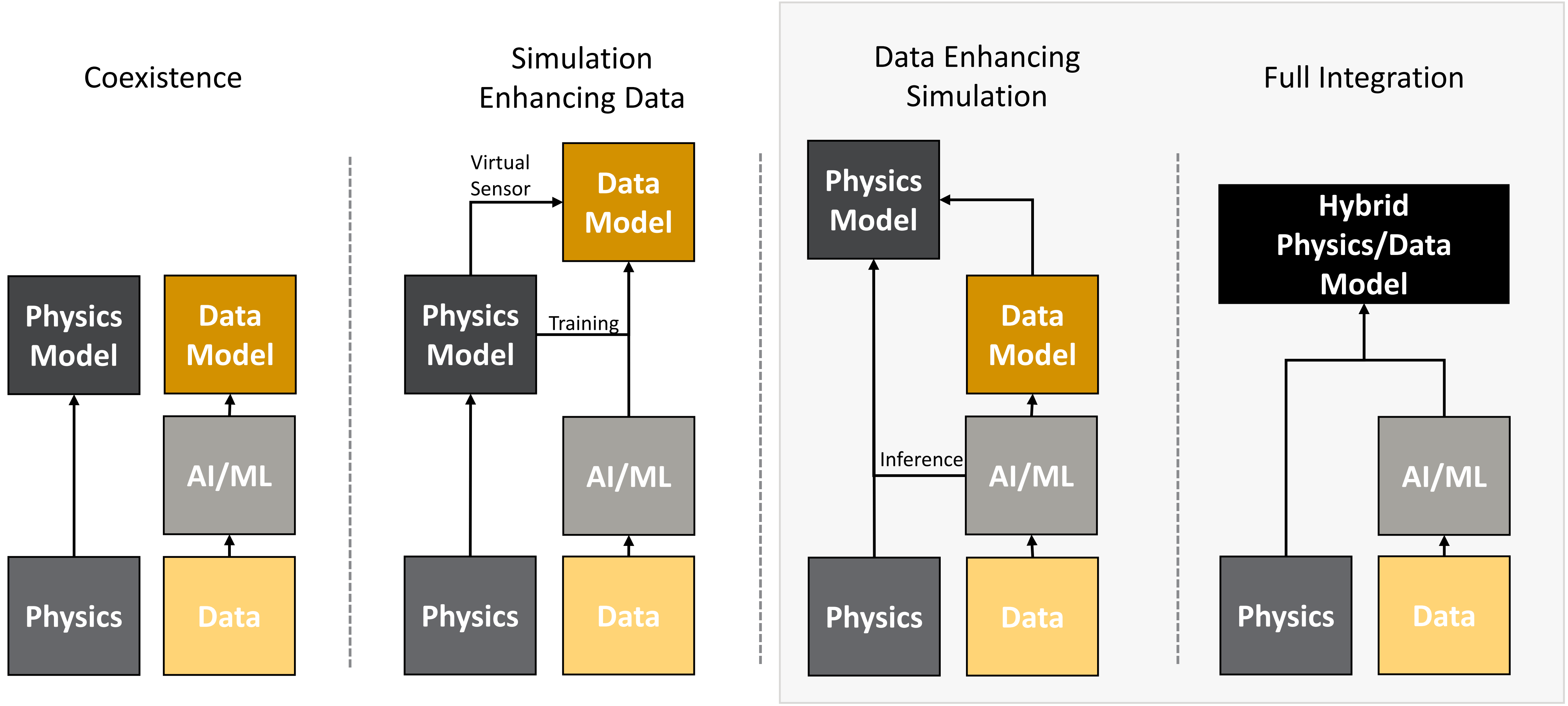
- Accuracy is achieved through model calibration based on experimental data
- Real-time simulation achieved through light-weight system models

Bottom Up

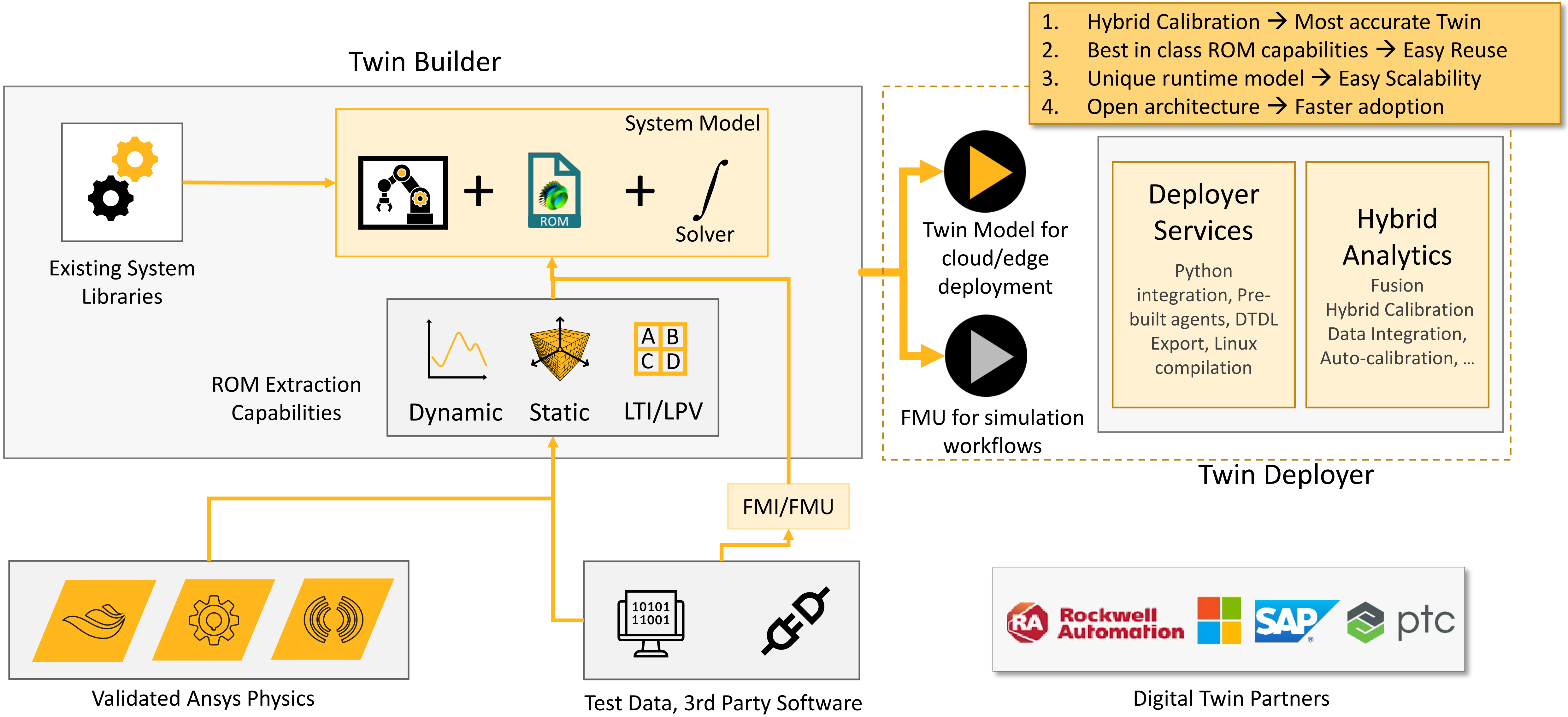
- Accuracy is based on high-fidelity modeling of full physics equation and accurate geometry
- Real-time simulation achieved through ROMs



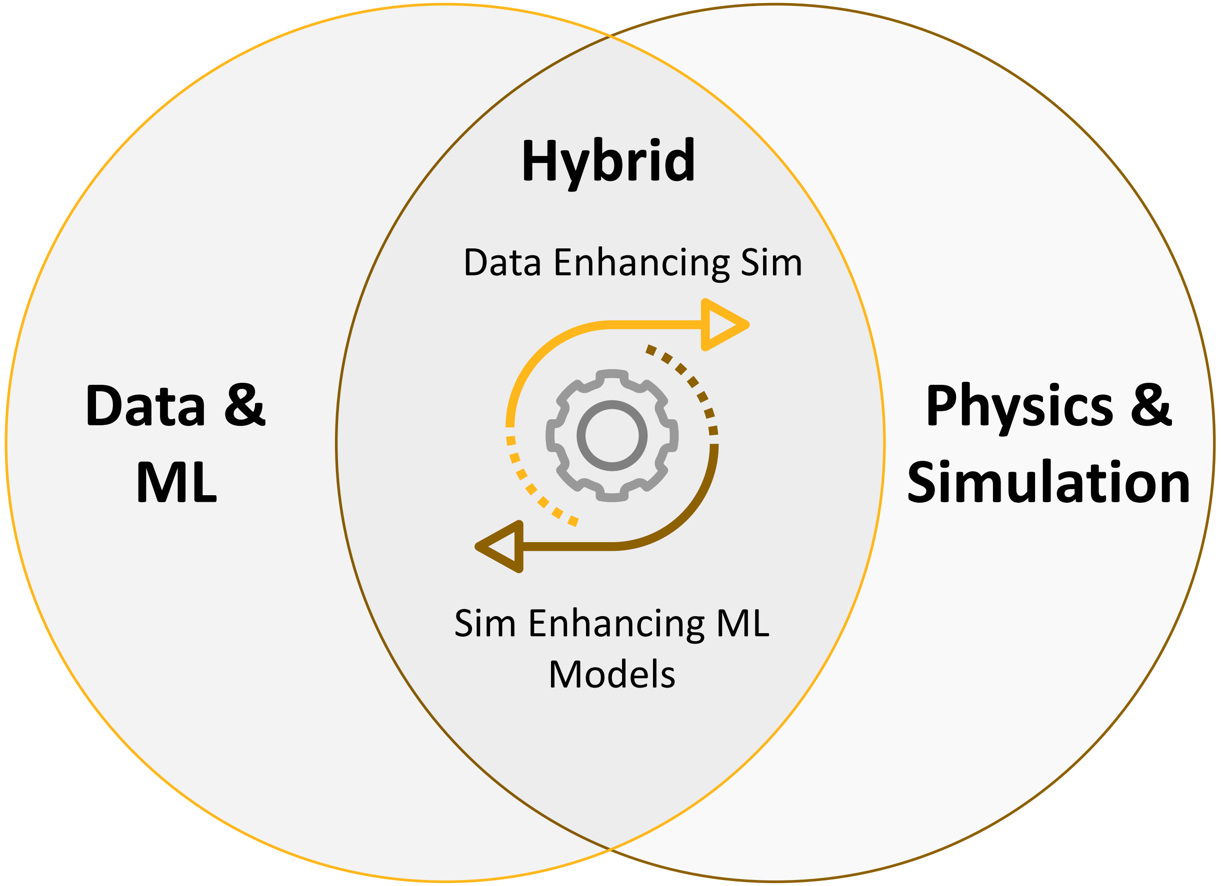
The Hybrid Framework



Digital Twin Solution Architecture



Hybrid Analytics



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

Hybrid Analytics – Combining Data and Physics

Unparalleled Accuracy

Robust Algorithms to cover diverse use cases

Uncertainty Quantification for confidence in fit

Easy Online recalibration

~ **80% accuracy** - Purely ML-based analytics

~ **90% accuracy** - Physics-Based Simulation Digital Twin

~ 98% accuracy - Hybrid Digital Twin

(ML-based analytics combination with the physics-based approach)

Hybrid Analytics – Calibration

What is Hybrid Calibration?

- Parameter Estimation
- Uncertainty Quantification on parameters
- Uncertainty Propagation to outputs

- Key use-case is virtual sensors

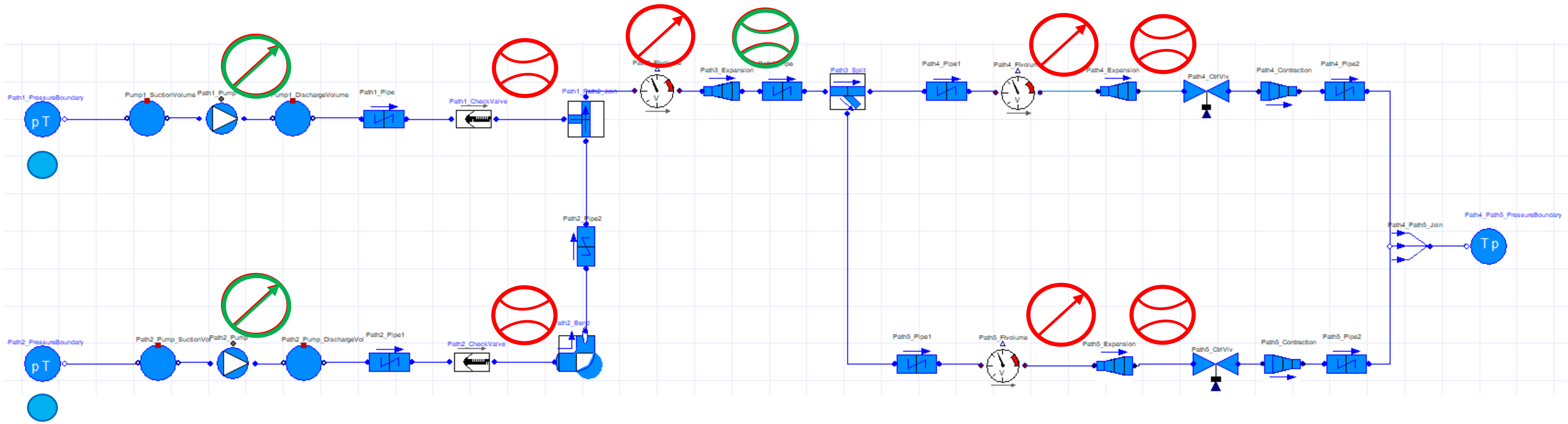
Learn simulation model parameters from data

Parameter Estimation

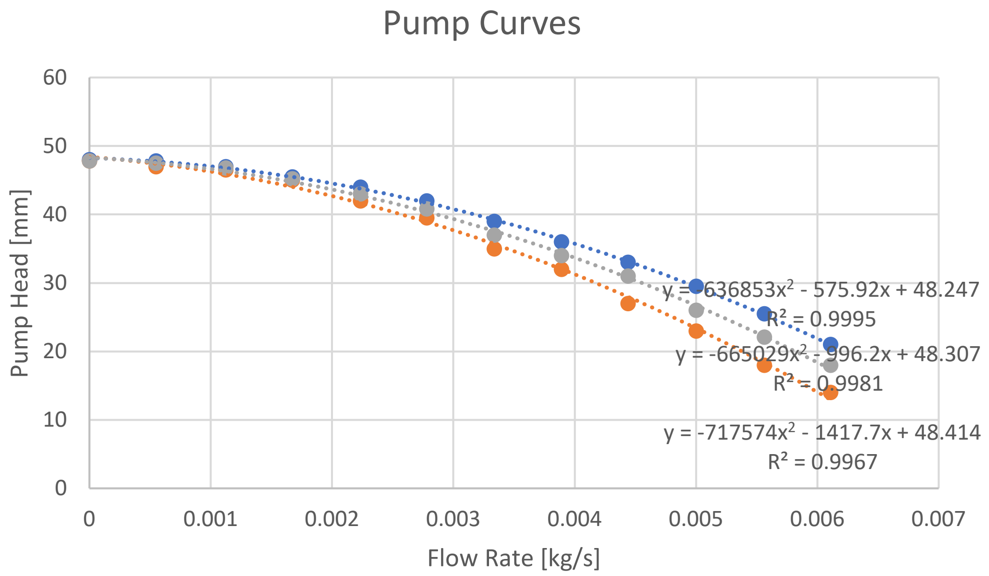
Create virtual sensors to "measure" missing data

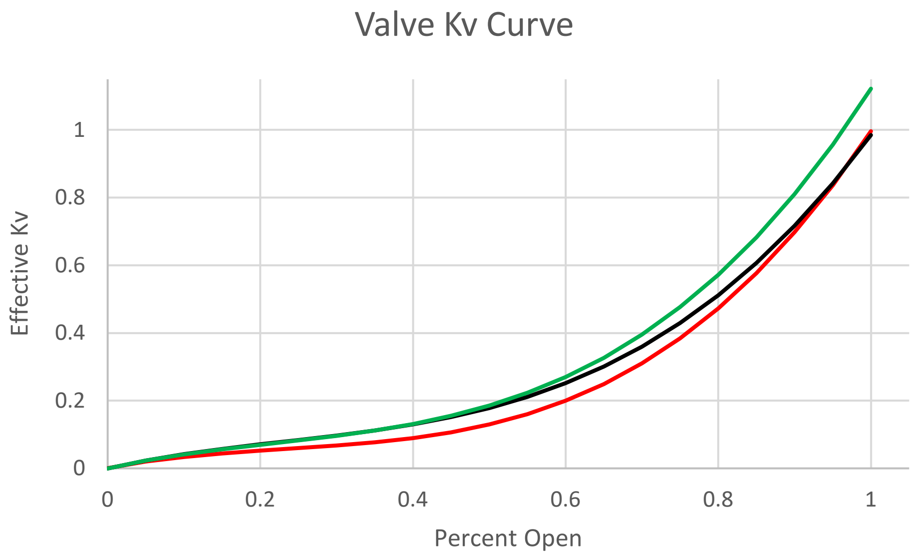
Model Diagram

Challenge: Determine the flow and pressure on each branch with a minimal number of physical sensors



Component Models and Parameters





$$H = b_0 + b_1 q + b_3 q^2$$

$$K_v = a_0 + a_1 D + a_2 D^2 + a_3 D^3$$

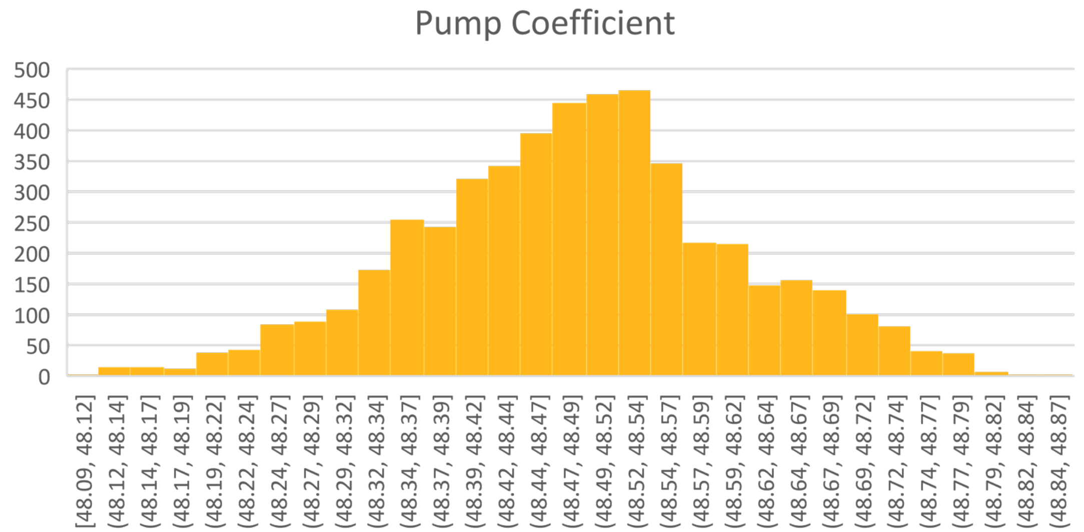
Three polynomial coefficients as parameters

Four polynomial coefficients as parameters

Results – Model Parameter Distributions

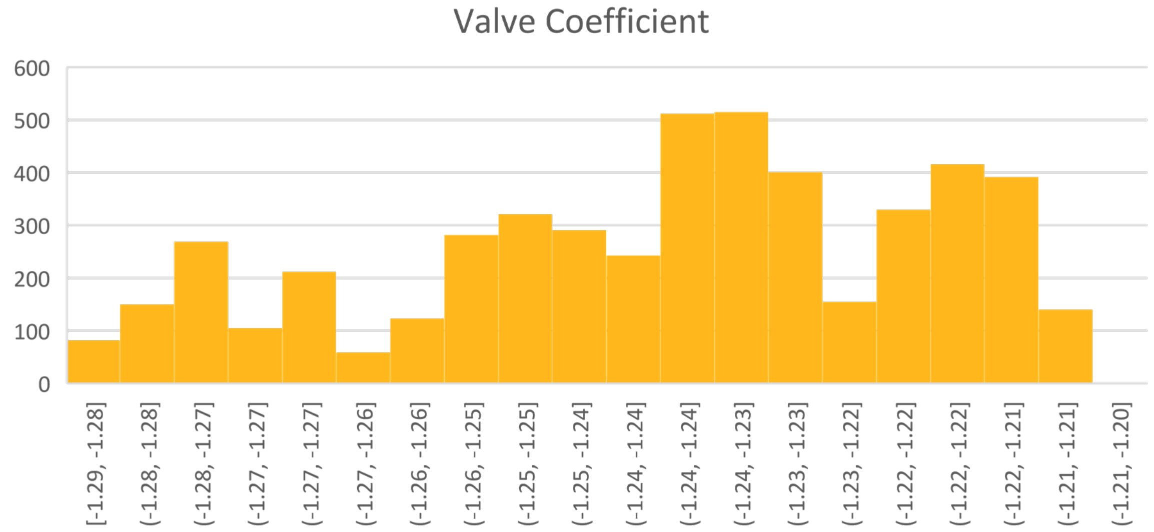
Pump Coefficient b_0

- Peaked distribution shows confidence in prediction
- Range gives uncertainty on measurement



Valve Coefficient a_2

- Dispersed distribution shows that system behavior is insensitive to this parameter
- The parameter can take a wide range of values without significantly affecting the system behavior



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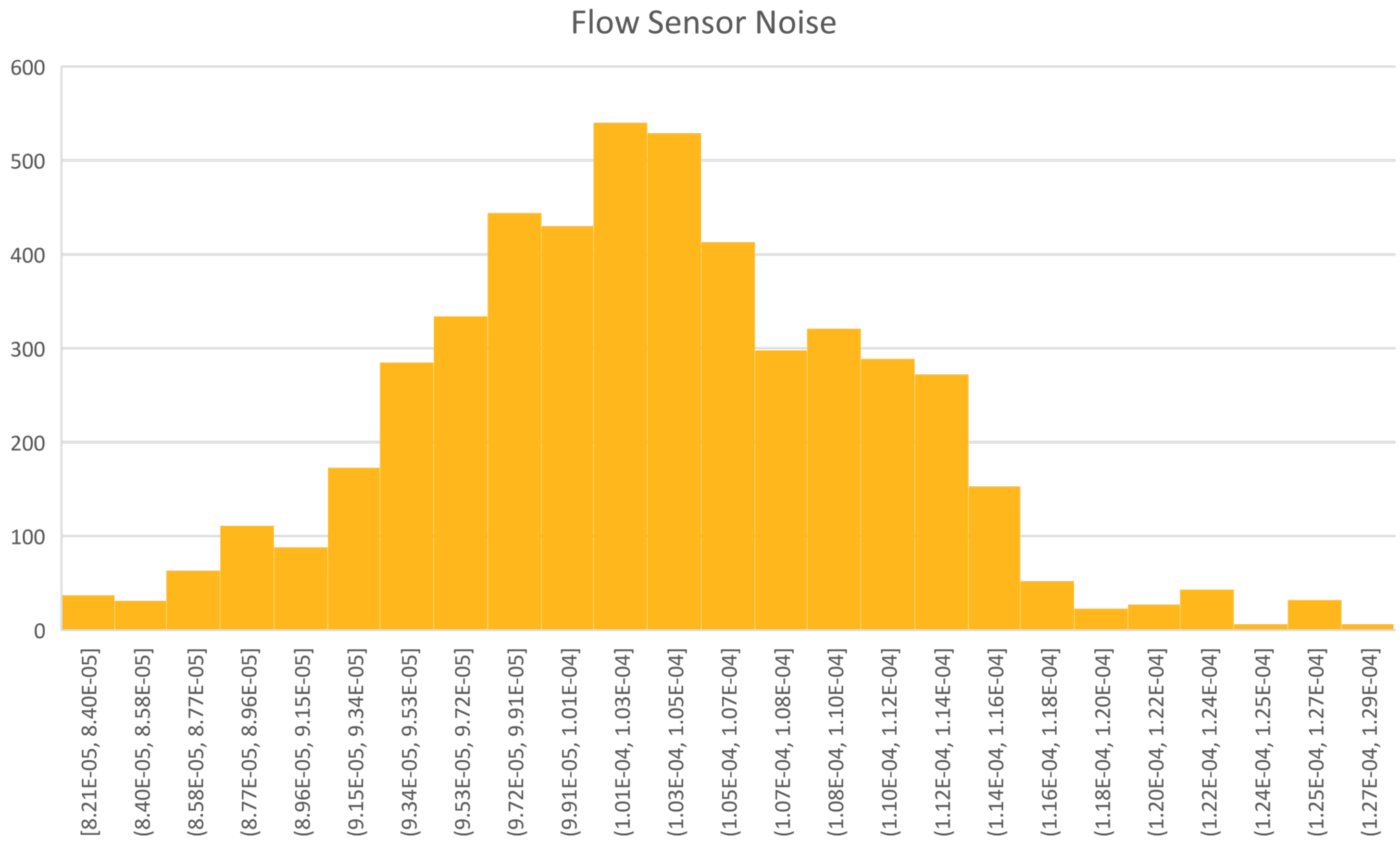
Results – Noise Parameter Distributions

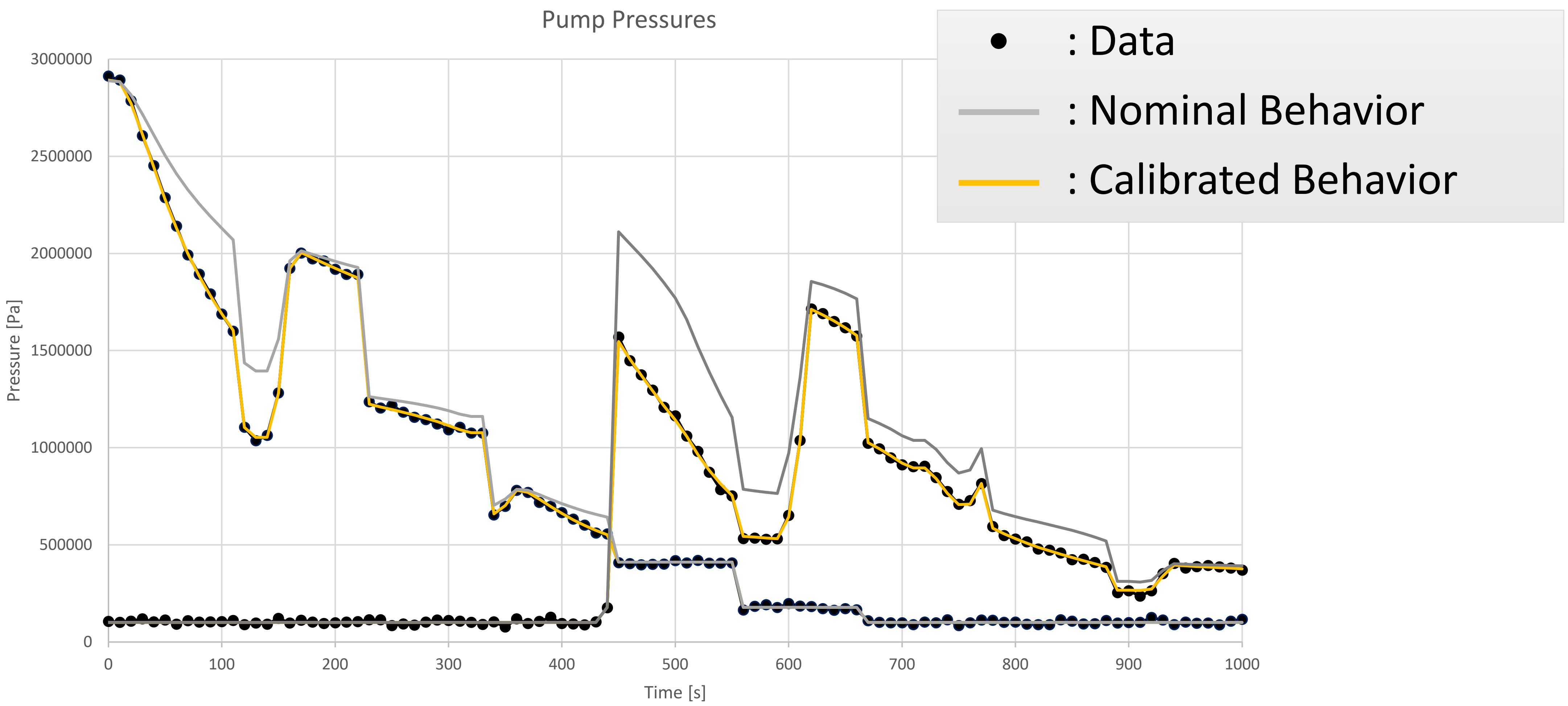
- Manufacturer Spec = 0.1 g/s
- Most Probable = 0.102 g/s

- Accurate virtual sensor value and uncertainty

- Simultaneously fit physical model and noise



Results – Before and After For Physical Sensors

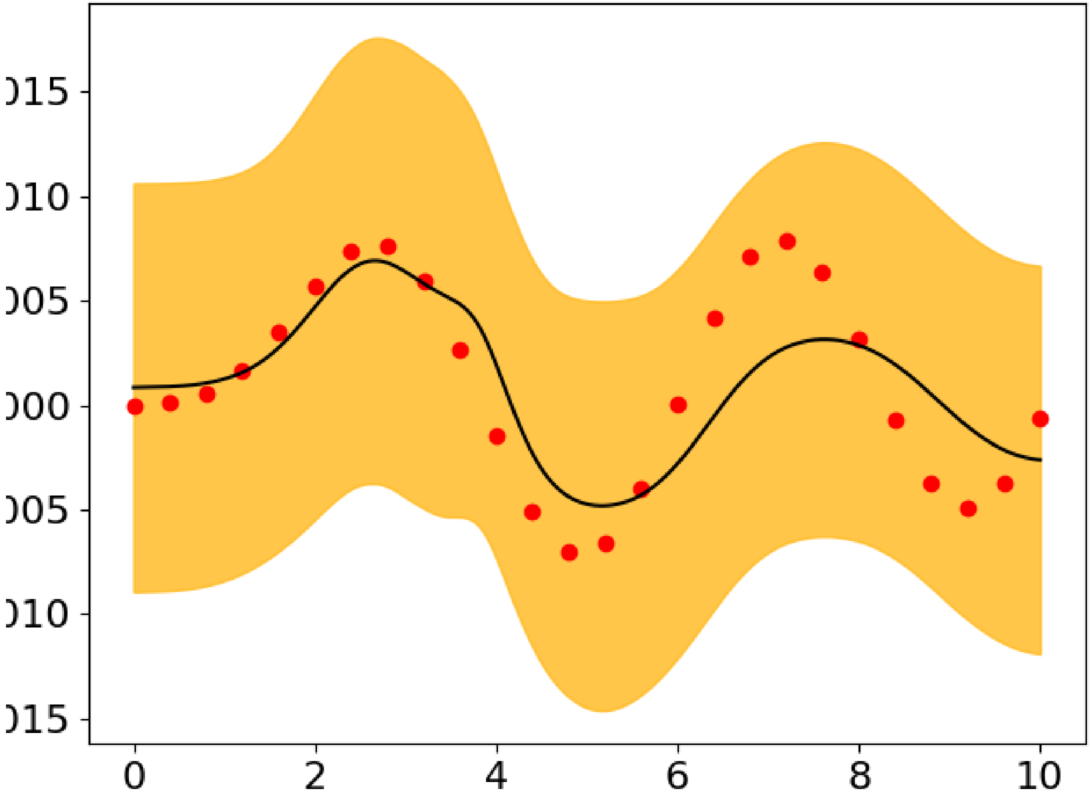


- Updated behavior matches performance much better than nominal manufacturer specs

Hybrid Analytics – Fusion Modeling

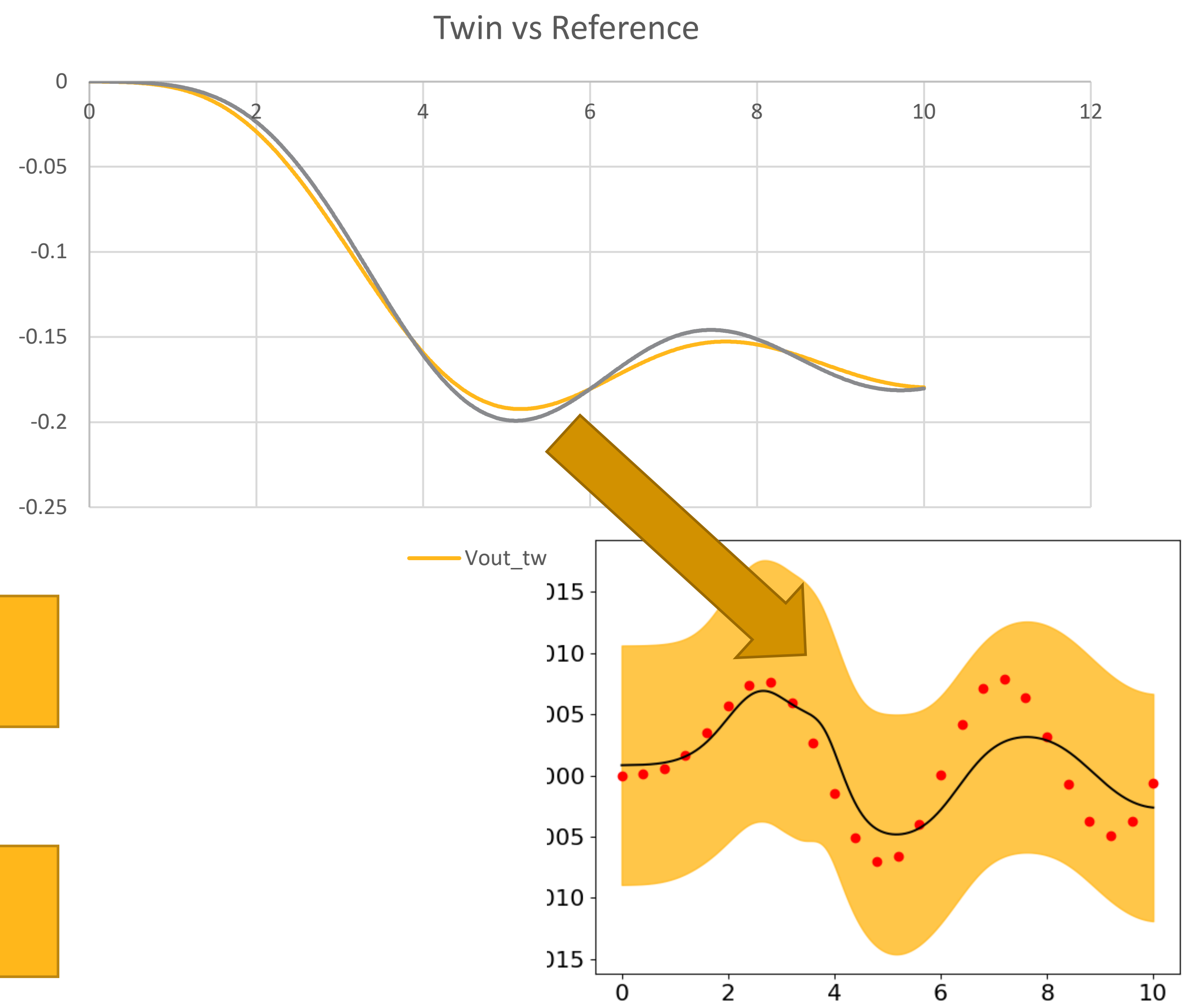
Fusion Models

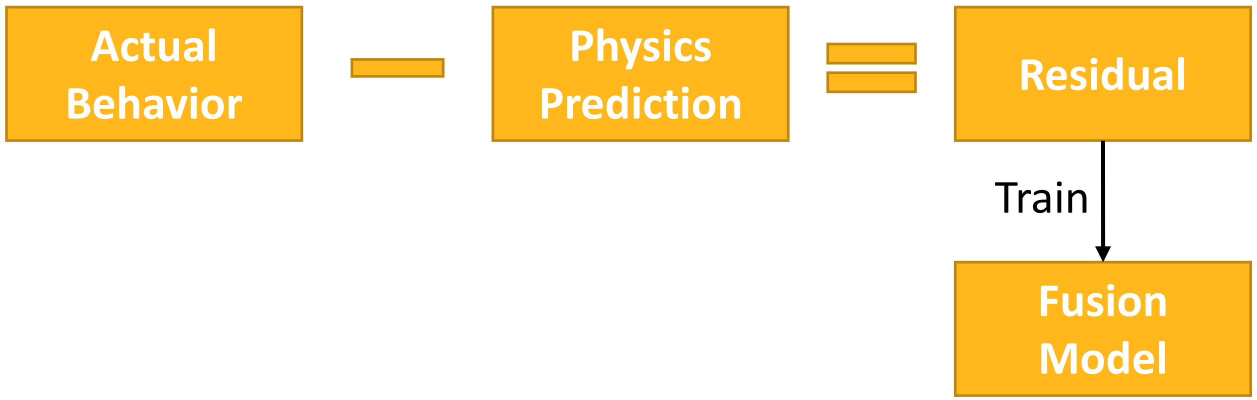
- Multiple machine learning techniques for creating models from data sources
- For some use cases:
  - Automatically search over available techniques and choose the best model
  - Return uncertainty of fit



Fusion Use Case: Residual Modeling

- Often even the best simulations don’t perfectly match sensor data
- Instead of training a full data model, use the most accurate physics model available and train an ML model of the residual
- The results of the physics model + the residual model correction give a better outcome.

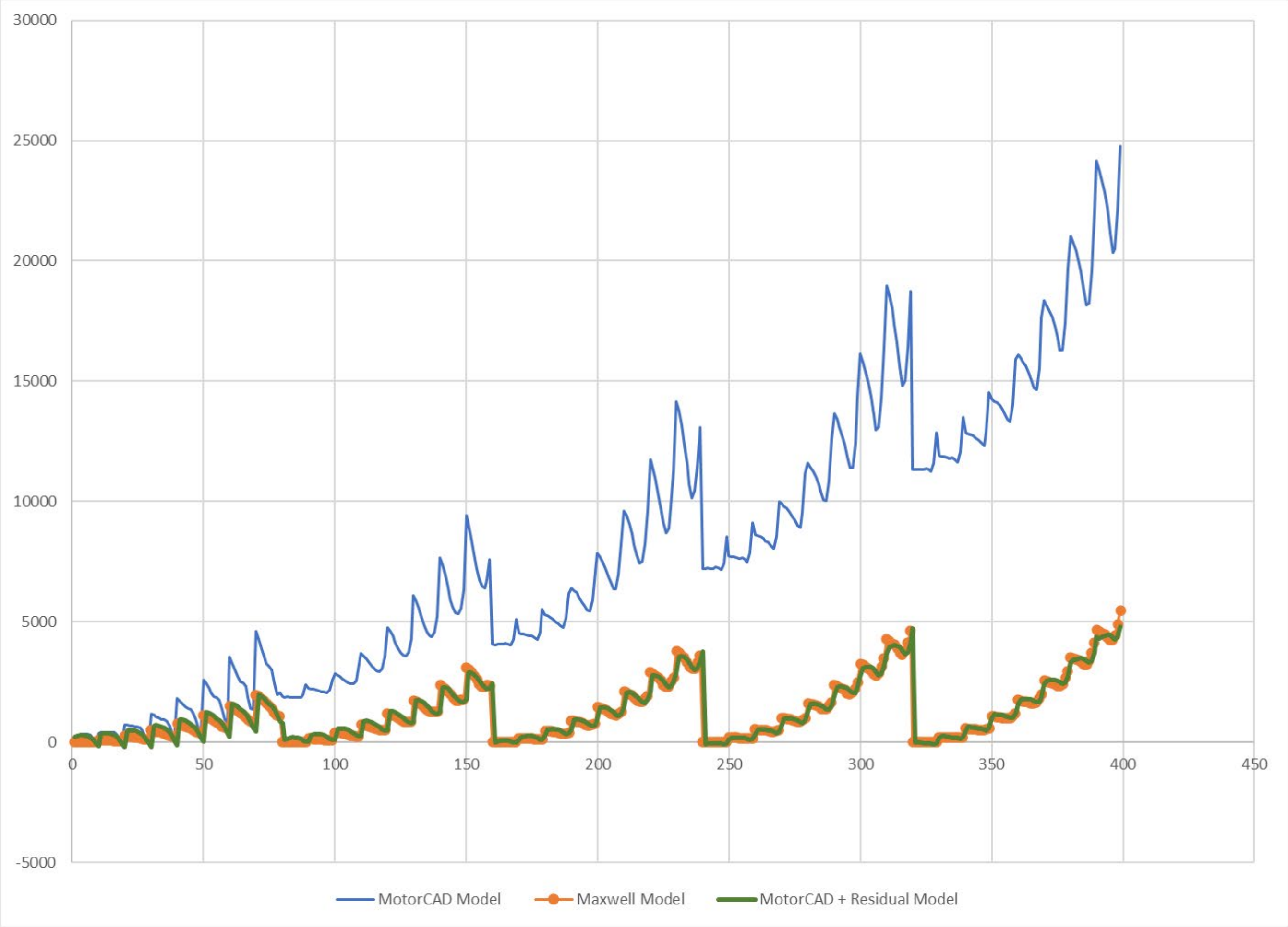




Fusion Use Case: Approximating 3D Models

- 3D simulations can be costly
- Lower fidelity 1D models are an approximation to 3D simulations
- Build a multifidelity regression model to fill in gaps in 3D model by fitting the difference between the higher fidelity and lower fidelity models

- For the case shown at the left, a Maxwell model gives much higher results than a MotorCAD model
- But, the MotorCAD model plus a trained fusion model performs about the same as the full Maxwell model



Summary

- Hybrid Digital Twins solve challenges inherent in creating Digital Twins.
- The Hybrid Analytics toolset combines data and physics modeling together to create the best possible Hybrid Digital Twins.
- Hybrid Digital Twins ingest field data to adapt to changing environmental conditions.

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