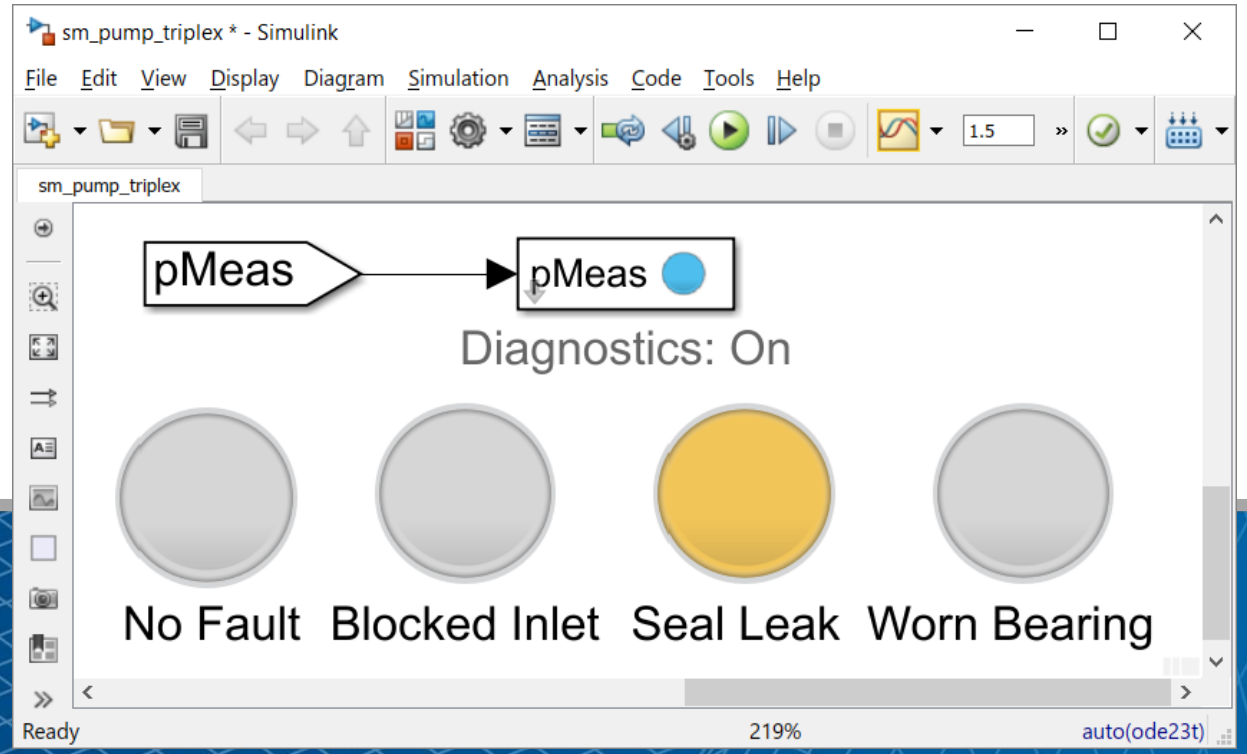
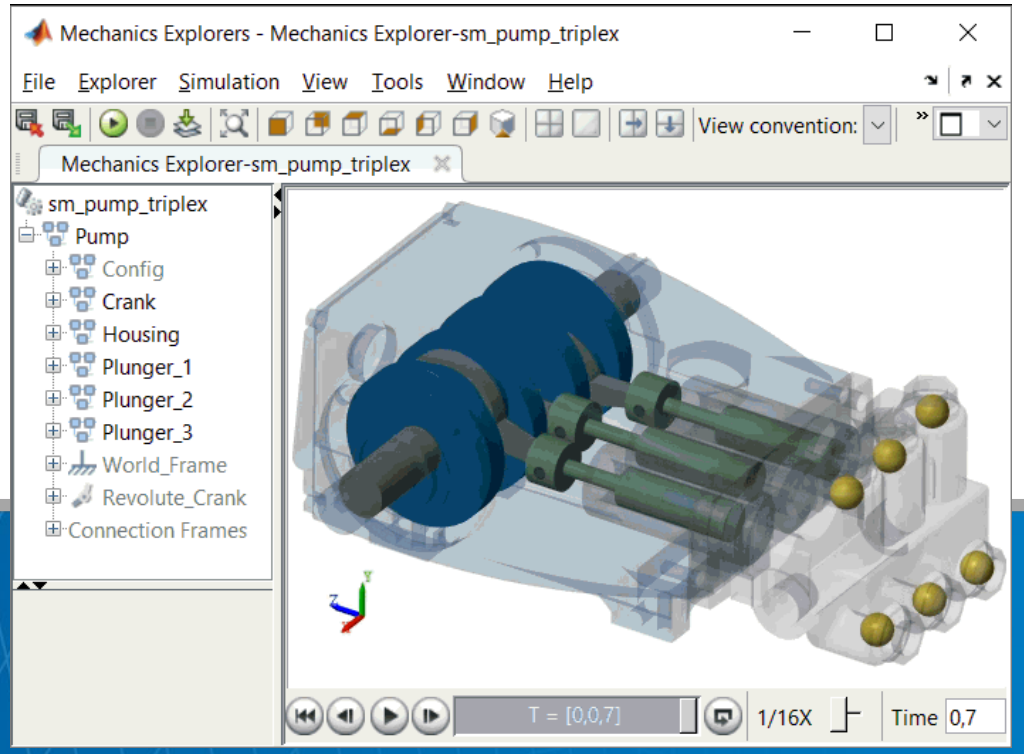
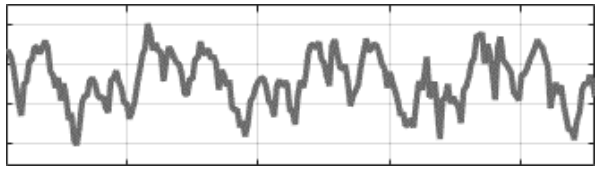
Predictive Maintenance Using Digital Twins



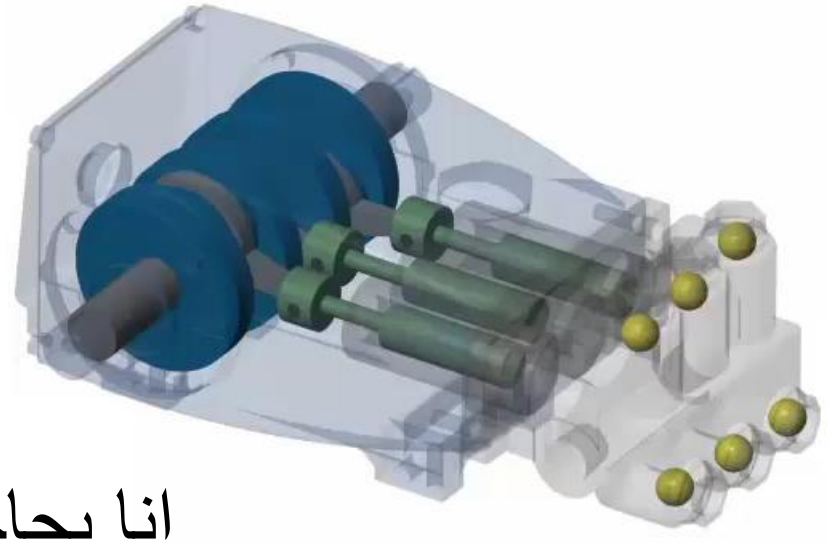


ฉันต้องการความช่วยเหลือ.

Ich brauche Hilfe.



Segítségre van szükségem.



Necesito ayuda.

Мне нужна помощь.

انا بحاجة الى مساعدة.

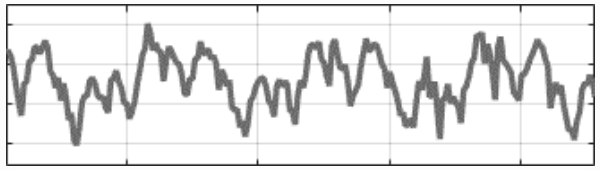
J'ai besoin d'aide.

I need help.

Χρειάζομαι βοήθεια.

ฉันต้องการความช่วยเหลือ.

Ich brauche Hilfe.



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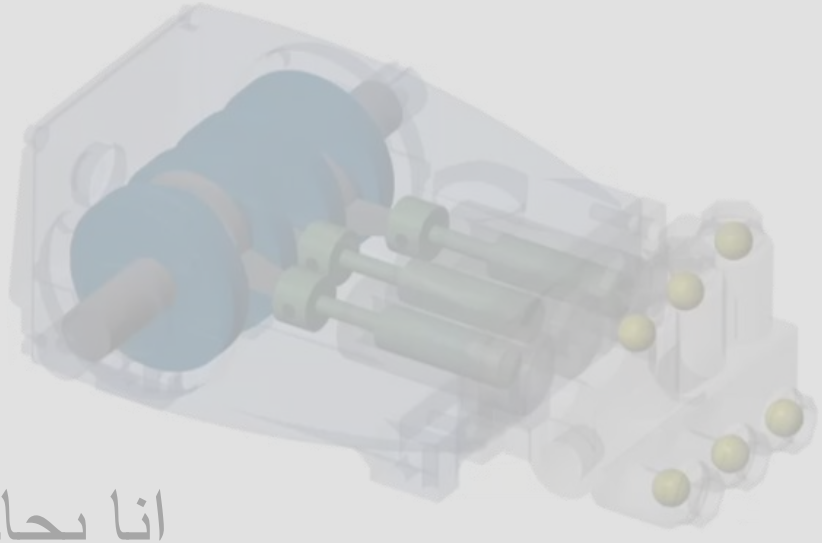


Necesito ayuda.

Мне нужна помощь.

انا بحاجة الى مساعدة.

J'ai besoin d'aide.

I need help.

Χρειάζομαι βοήθεια.

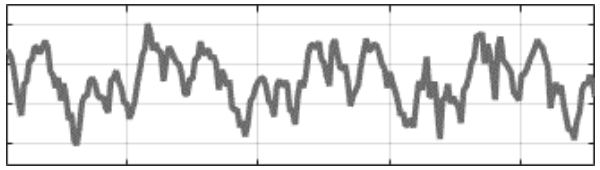
Translate

Turn off instant translation

English | Spanish | French | Pump - detected

English | Russian | Greek

Translate



1/5000

I need help.

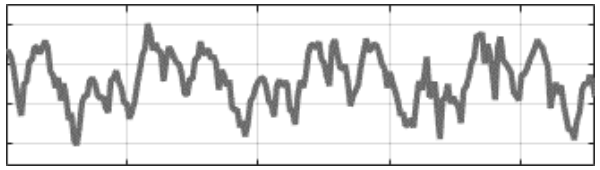
Translate

Turn off instant translation

English | Spanish | French | Pump - detected

English | Russian | Greek

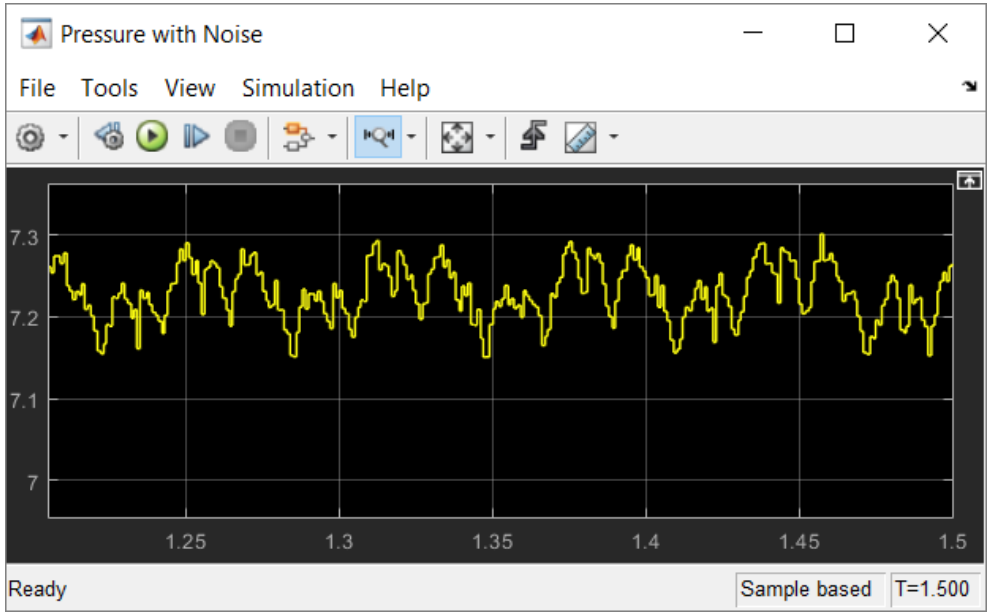
Translate



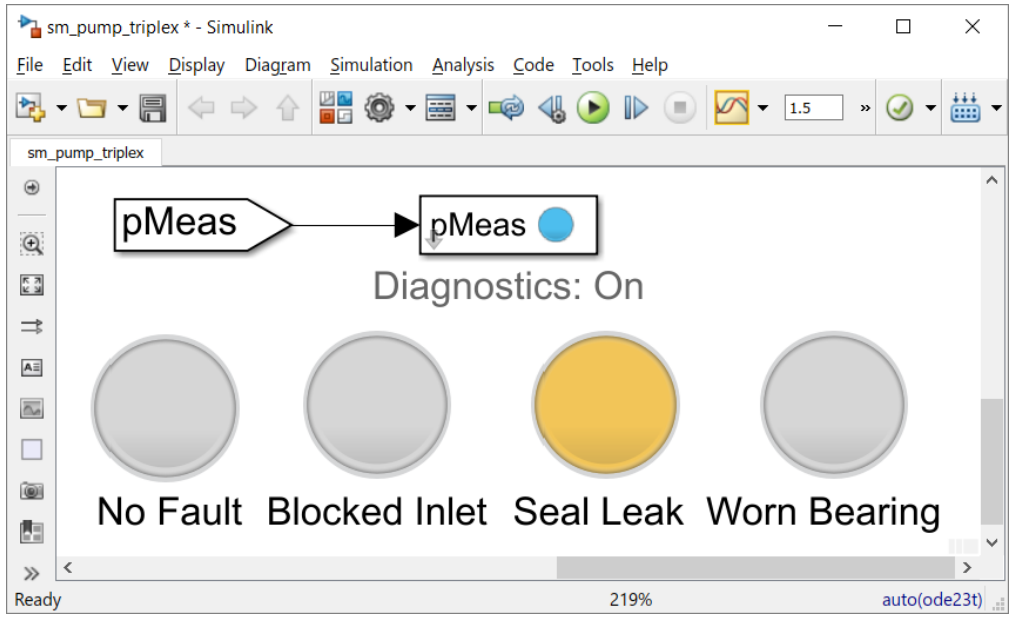
1/5000

I need help. One of my seals is leaking. I will shut down your line in 5 days

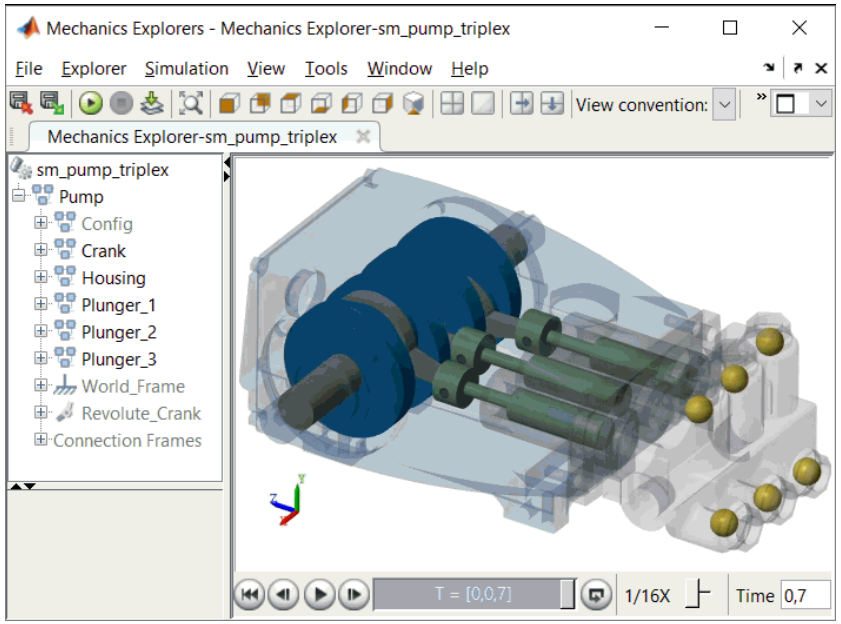
Prevent system downtime



by sending sensor data

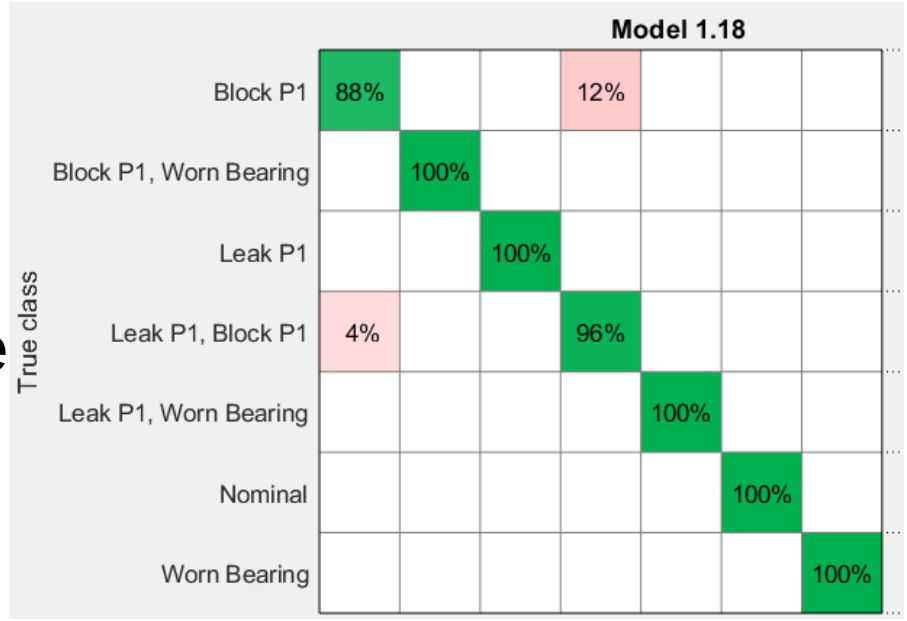


to a predictive maintenance algorithm



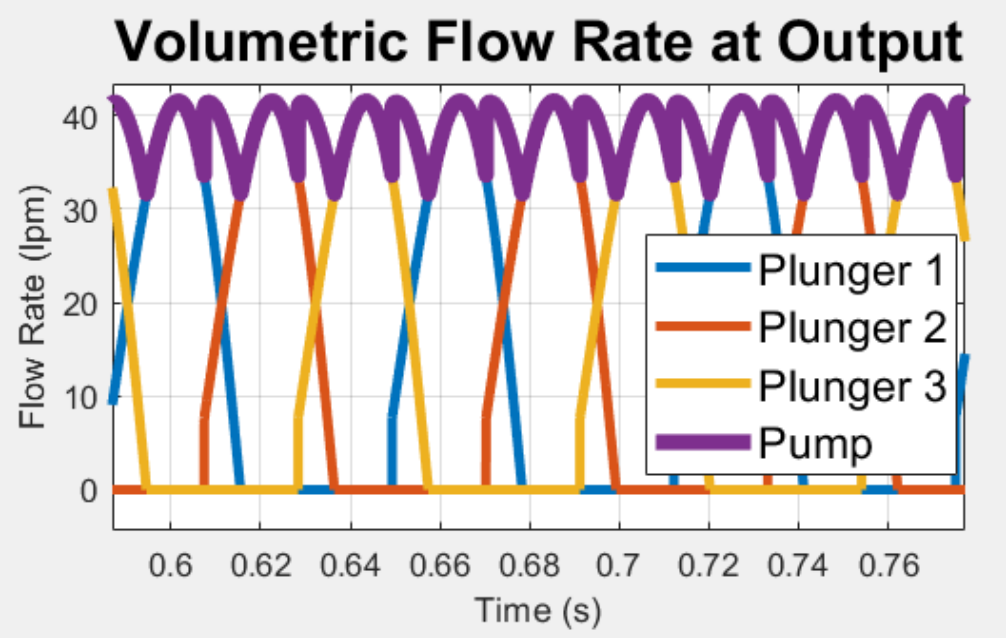
created using a Digital Twin

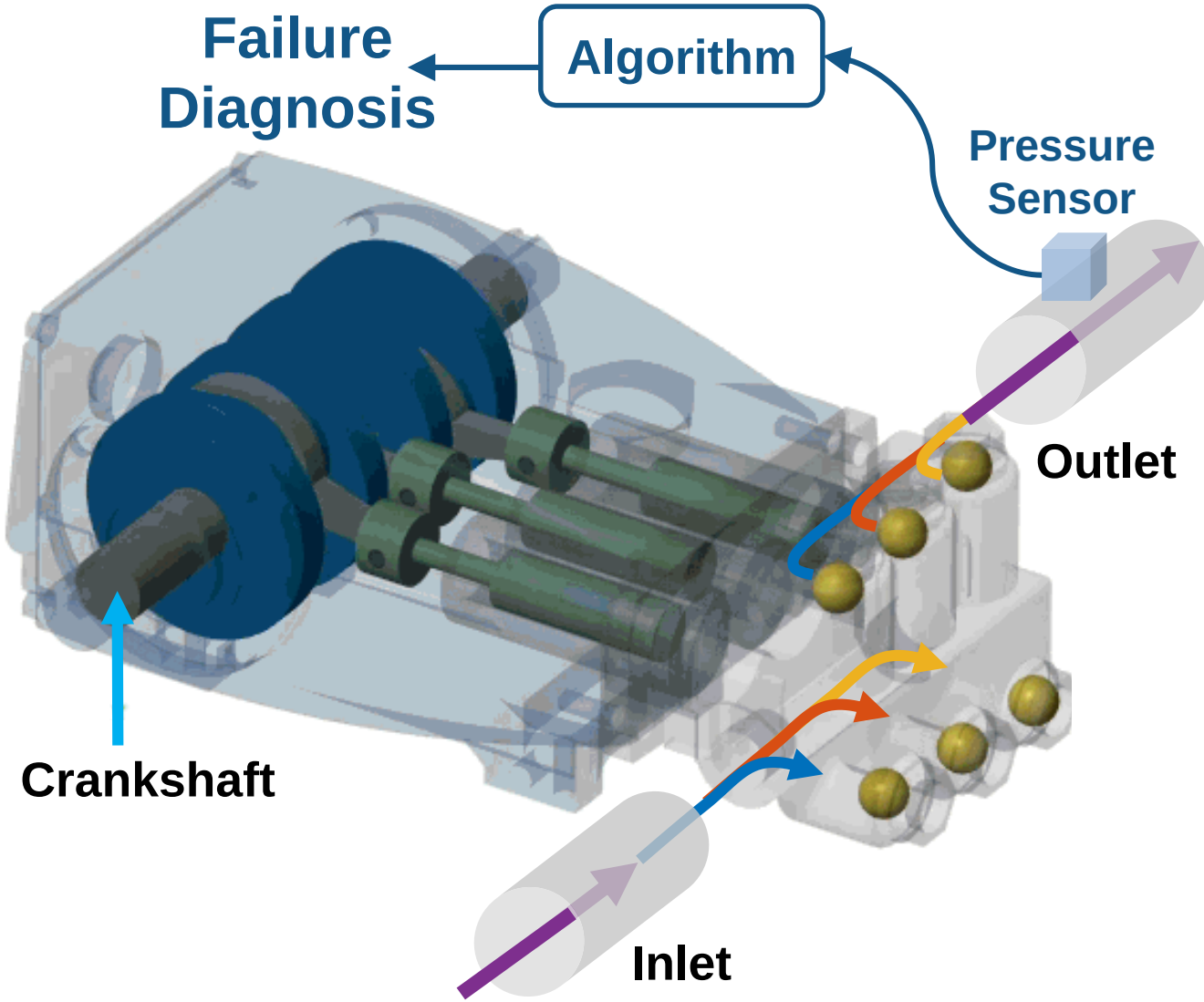
and machine learning in MATLAB.

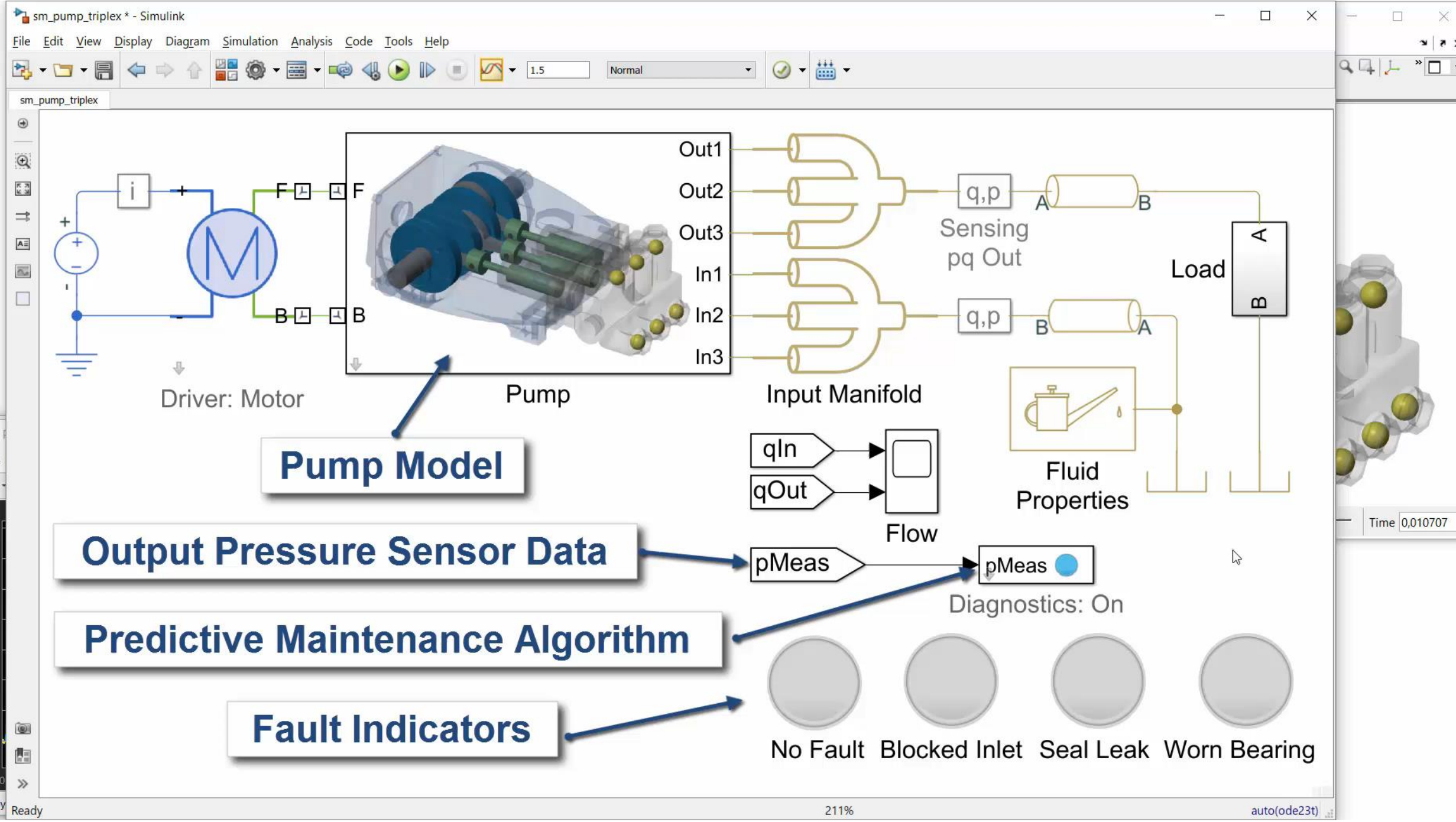


Triplex Pump

- Crankshaft drives three plungers
  - Each 120 degrees out of phase
  - One chamber always discharging
  - Smoother flow than single or duplex piston pumps






sm_pump_triplex * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
sm_pump_triplex
Driver: Motor
Pump
Input Manifold
Sensing
pq Out
Load
Fluid
Properties
Flow
Pump Model
Output Pressure Sensor Data
Predictive Maintenance Algorithm
Fault Indicators
qIn
qOut
pMeas
Diagnostics: On
No Fault
Blocked Inlet
Seal Leak
Worn Bearing
Ready
211%
auto(ode23t)

Agenda

- Predictive Maintenance Workflow
- Build a Digital Twin
  - Model physical system
  - Tune using measured data
- Create Predictive Model
  - Model component failure
  - Generate training data
  - Select and train classification model
- Deploy Fault Diagnostics Algorithm

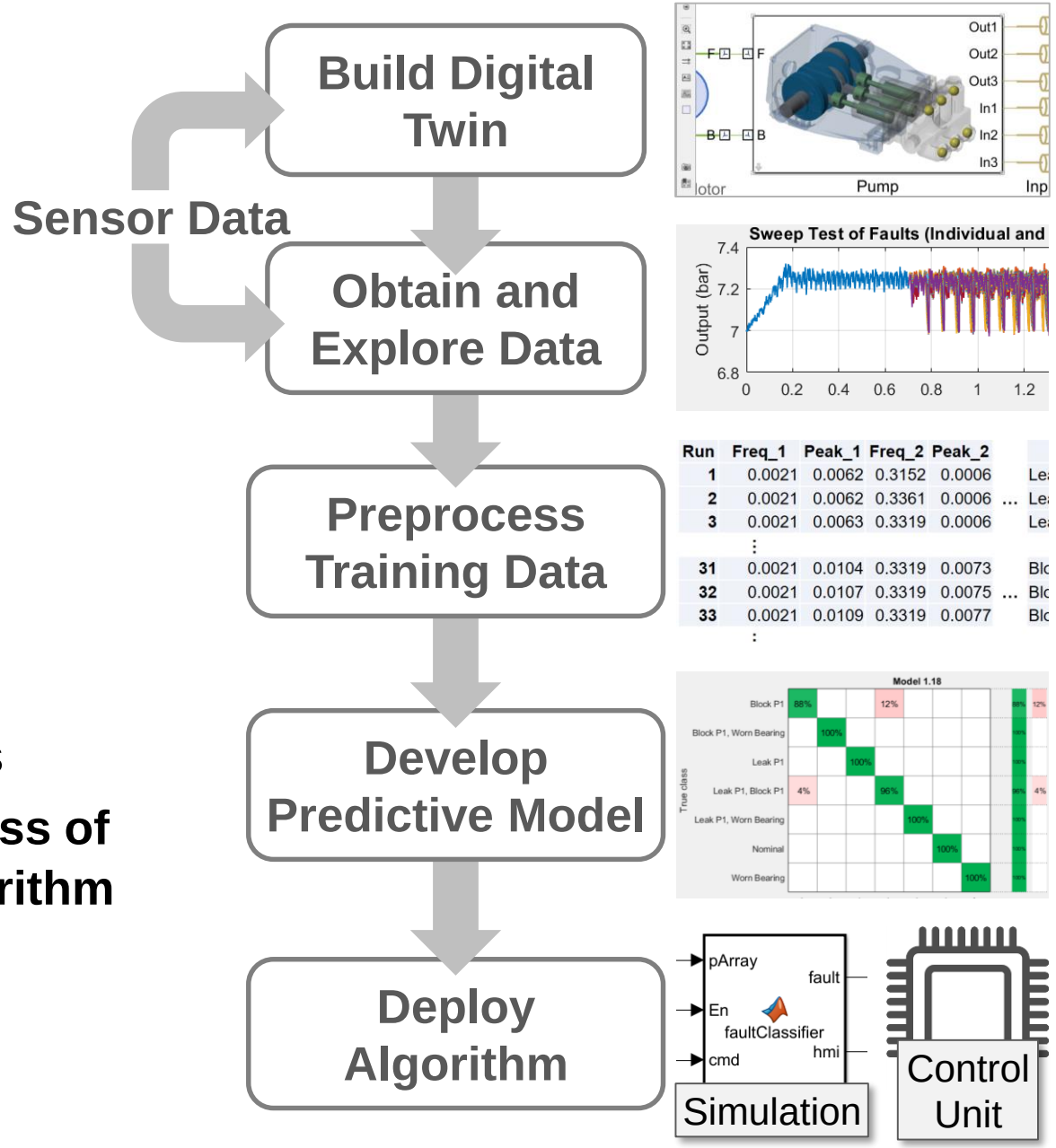
Predictive Maintenance Workflow

- Sensor data isn‘t always available
  - Failure conditions difficult to reproduce
  - Time consuming or costly to generate

  Solution: Build digital twin and generate sensor data using simulation

- Developing algorithm is complex
  - Requires complex concepts and analysis

  Solution: Use MATLAB to simplify process of developing and deploying algorithm




5" 12,000 PSI
5" 12,000 PSI
BAKER HUGHES

Baker Hughes Develops Predictive Maintenance Software for Gas and Oil Extraction Equipment Using Data Analytics and Machine Learning

Challenge

Develop a predictive maintenance system to reduce pump equipment costs and downtime

Solution

Use MATLAB to analyze nearly one terabyte of data and create a neural network that can predict machine failures before they occur

Results

- Savings of more than $10 million projected
- Development time reduced tenfold
- Multiple types of data easily accessed

Truck with positive displacement pump.

"MATLAB gave us the ability to convert previously unreadable data into a usable format; automate filtering, spectral analysis, and transform steps for multiple trucks and regions; and ultimately, apply machine learning techniques in real time to predict the ideal time to perform maintenance."

- Gulshan Singh, Baker Hughes

Link to user story

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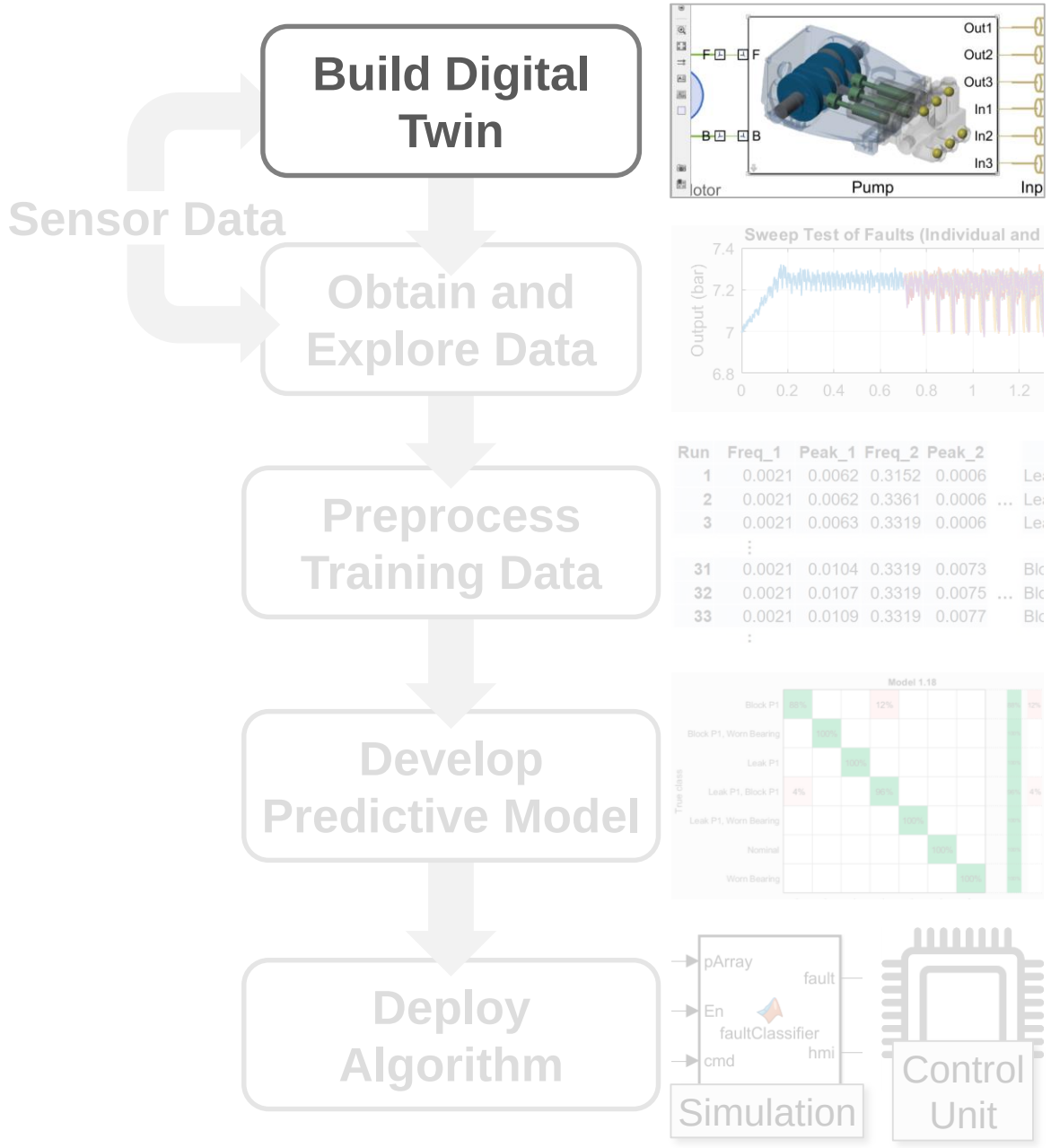
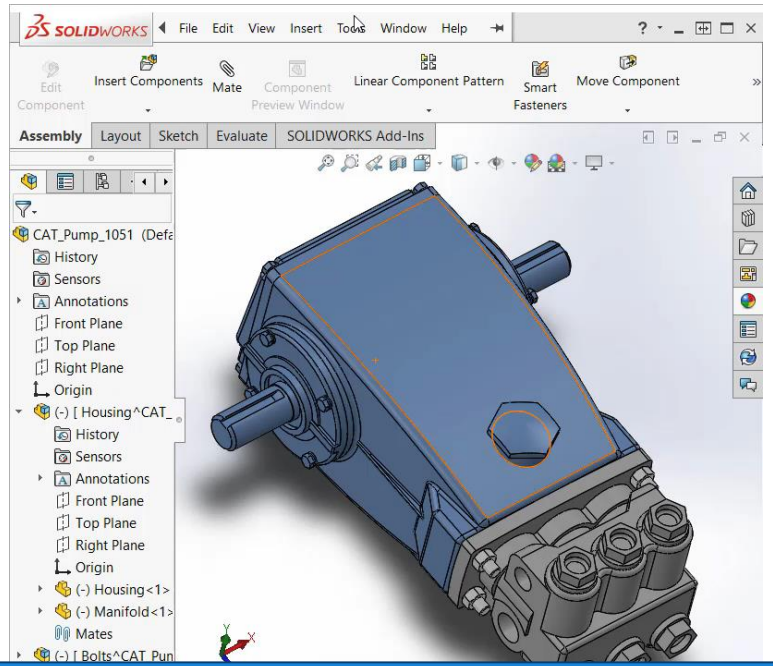
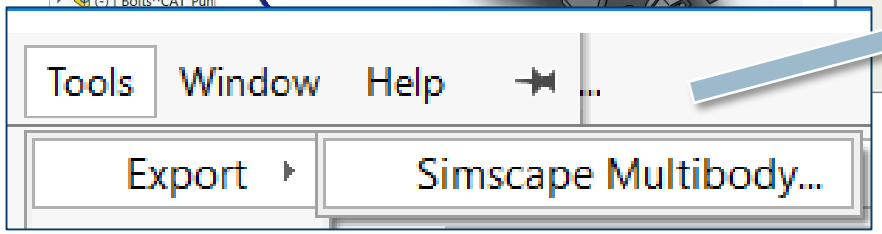


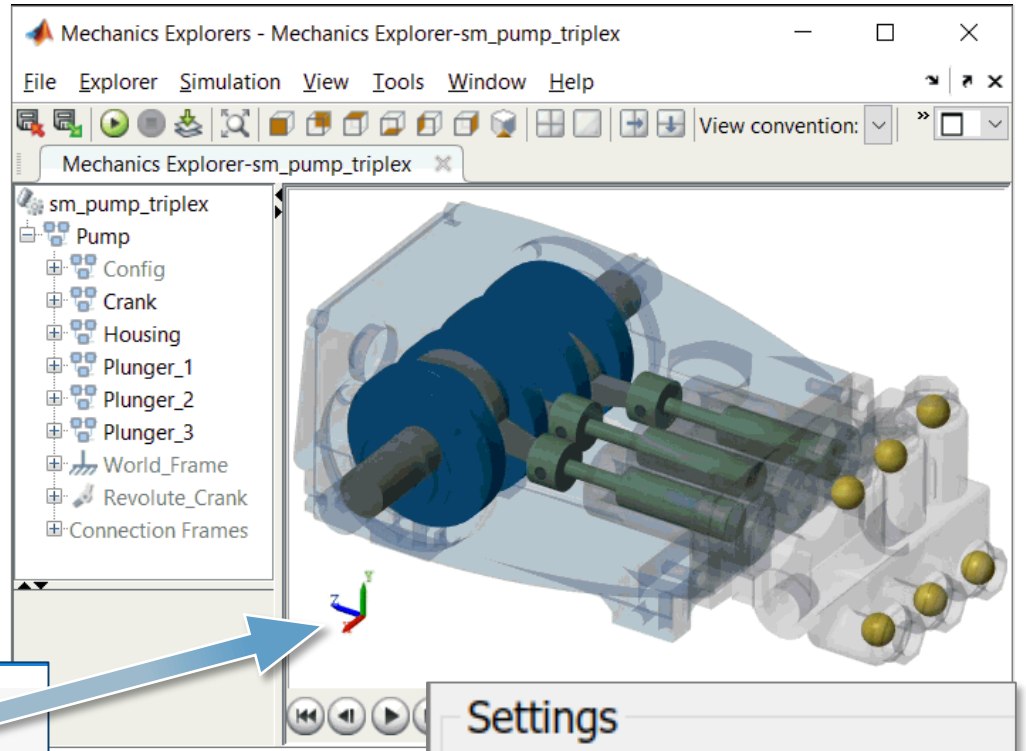
Build Digital Twin of Hydraulic Pump

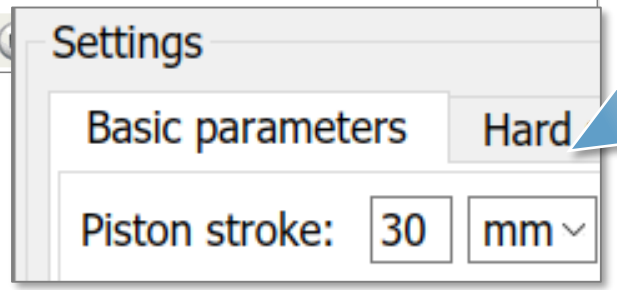
Import CAD Data



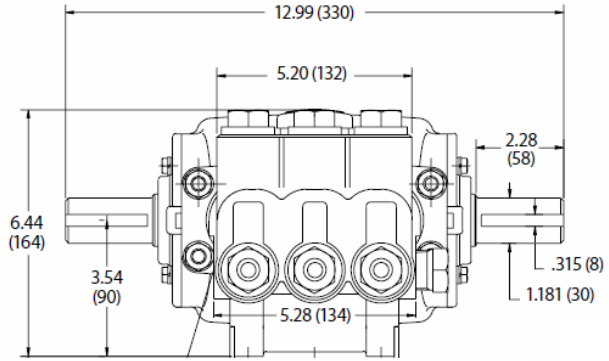


Digital Twin (Dynamic Model)





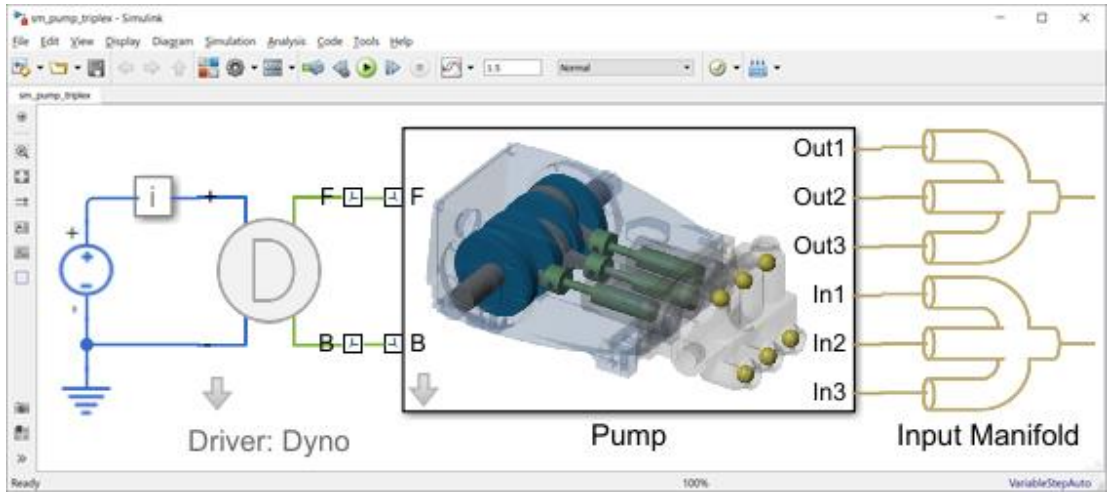
Tune to Datasheet

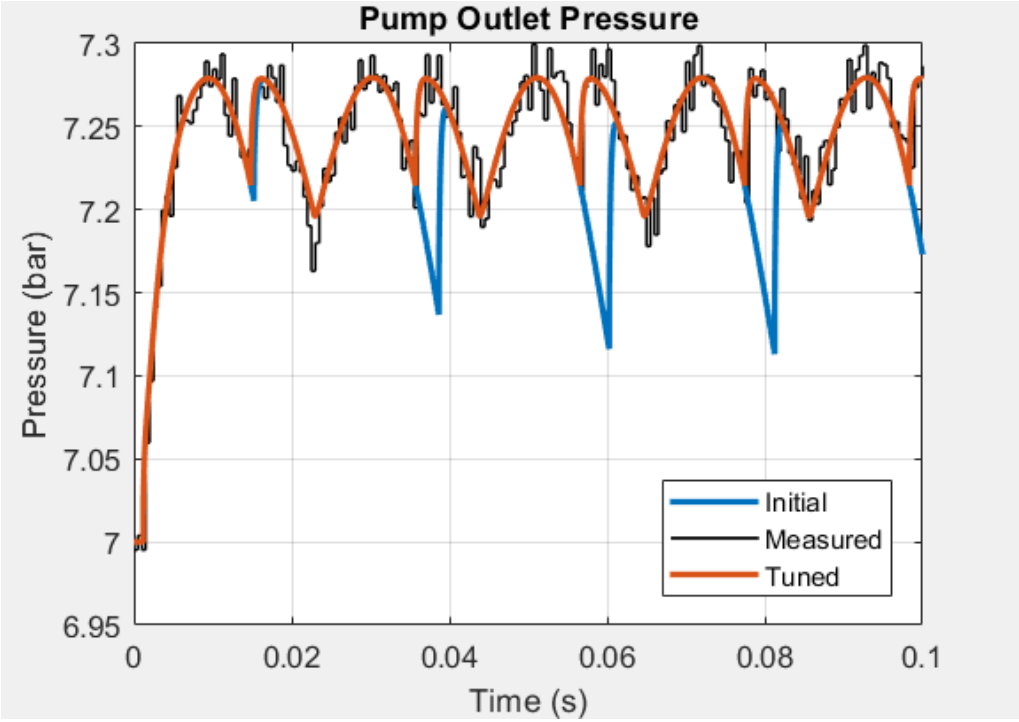


COMMON SPECIFICATIONS	U.S.	Metric
Bore	0.945"	24 mm
Stroke	1.18"	30 mm
Crankcase Capacity	42 oz.	1.26 l
Shaft Diameter	1.181"	30 mm

Estimate Parameters Using Measured Data

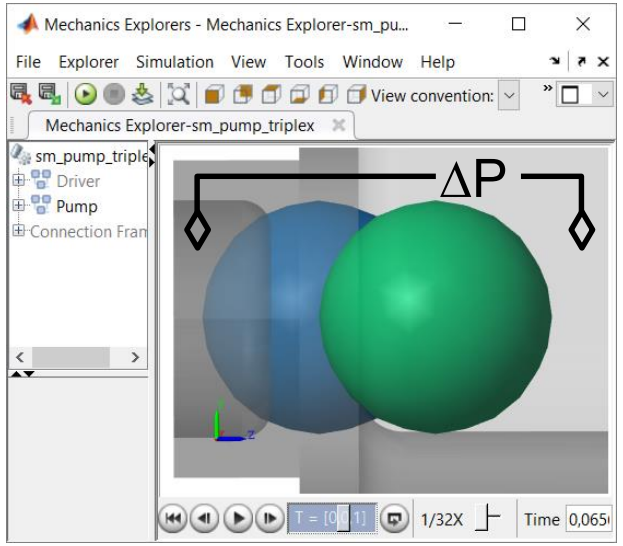
Model:



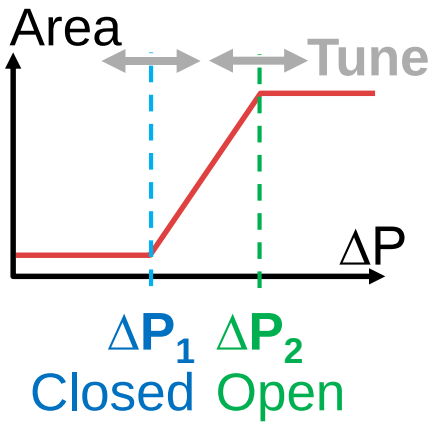


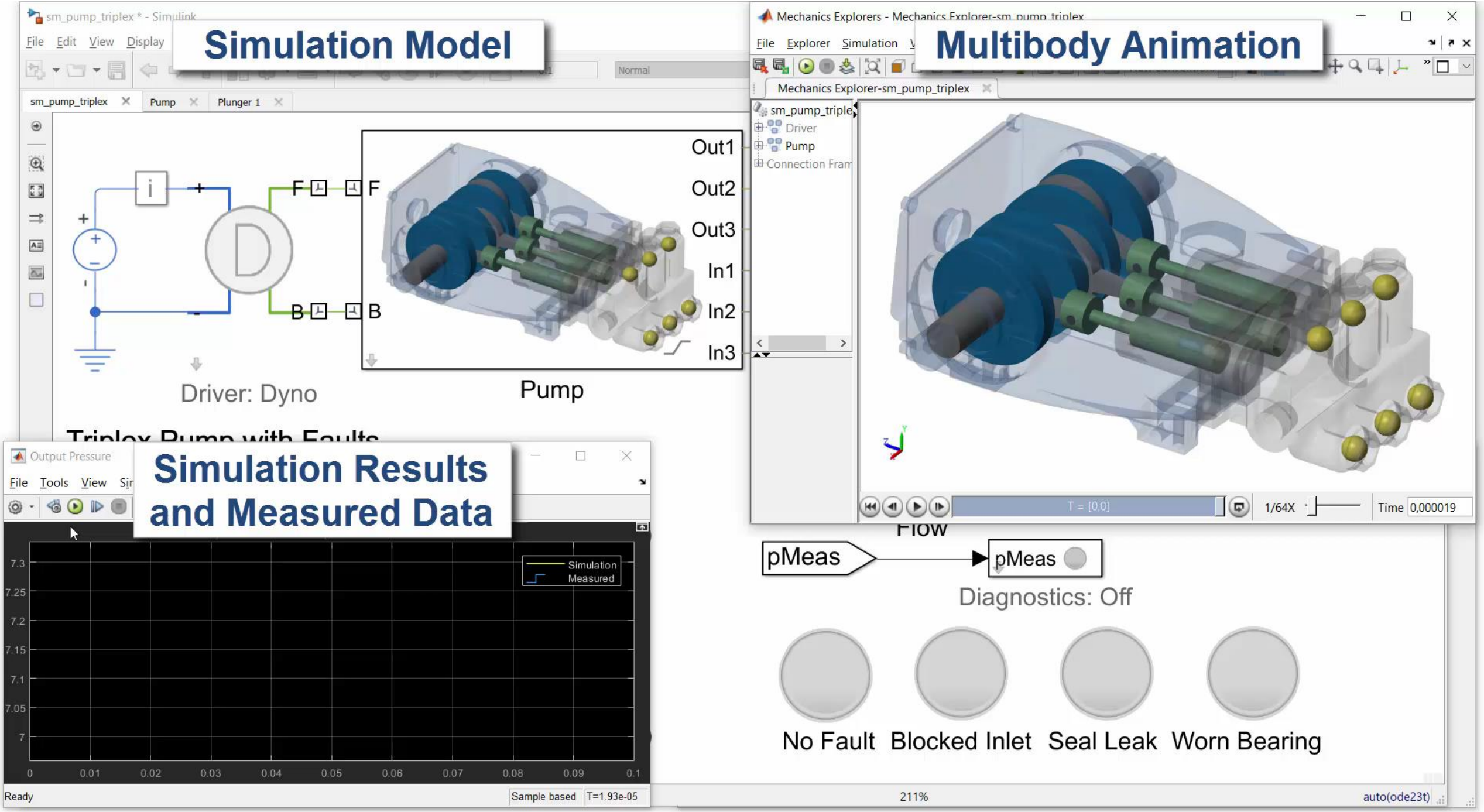
Challenge: Simulation results do not match behavior of real system

Solution: Use Simulink Design Optimization to automatically tune model parameters



Check Valve Characteristic




Simulation Model
Multibody Animation
Simulation Results and Measured Data
sm_pump_triplex * - Simulink
File Edit View Display
sm_pump_triplex
Pump
Plunger 1
Out1
Out2
Out3
In1
In2
In3
F
B
Driver: Dyno
Pump
Triplex Pump with Faults
Mechanics Explorers - Mechanics Explorer-sm_pump_triplex
File Explorer Simulation
Mechanics Explorer-sm_pump_triplex
sm_pump_triple
Driver
Pump
Connection Fram
T = [0,0]
1/64X
Time 0,000019
Output Pressure
File Tools View
Simulation
Measured
7.3
7.25
7.2
7.15
7.1
7.05
7
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Ready
Sample based
T=1.93e-05
Flow
pMeas
pMeas
Diagnostics: Off
No Fault
Blocked Inlet
Seal Leak
Worn Bearing
211%
auto(ode23t)

Agenda

- Predictive Maintenance Workflow
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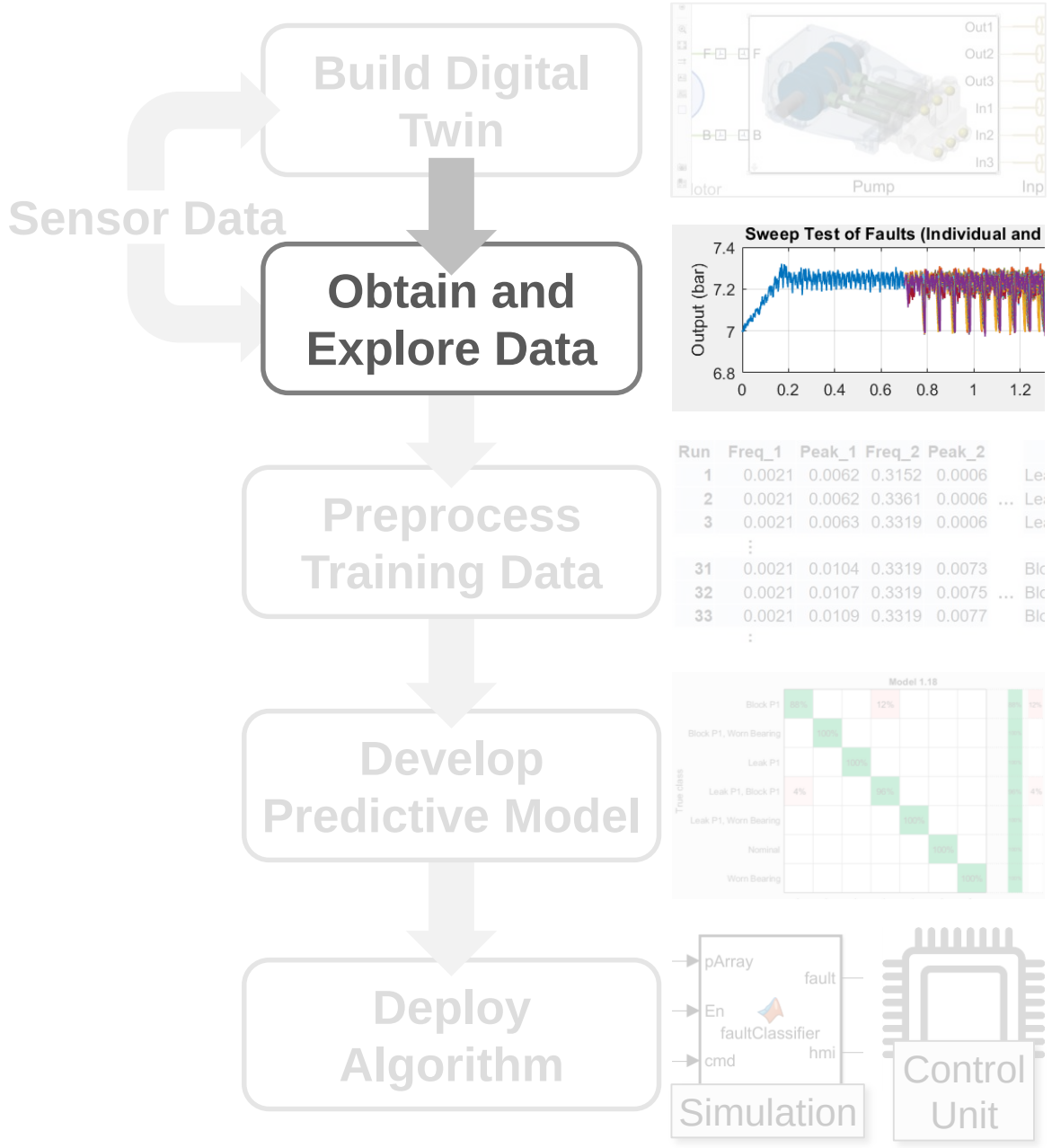
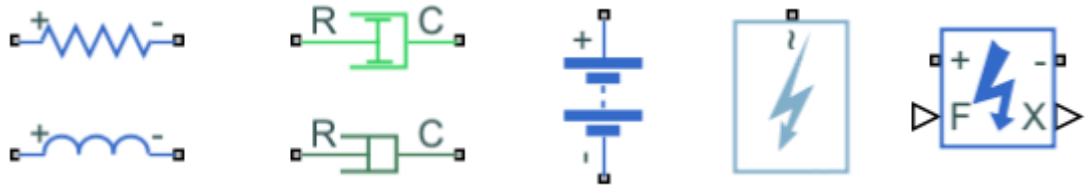
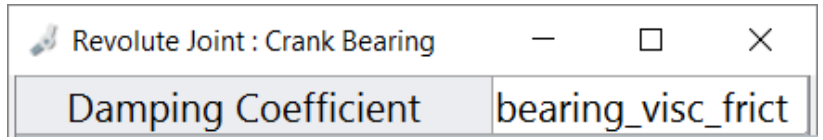
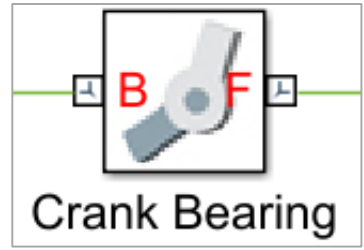


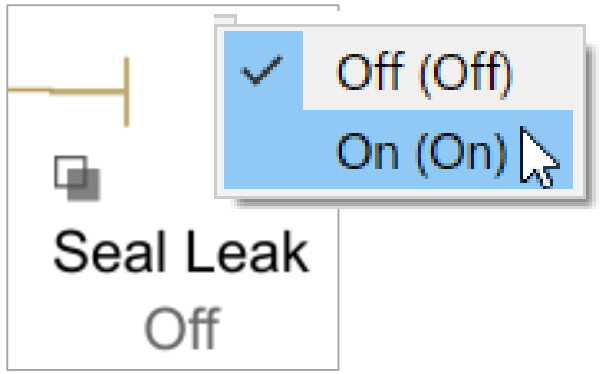
Model Component Failure

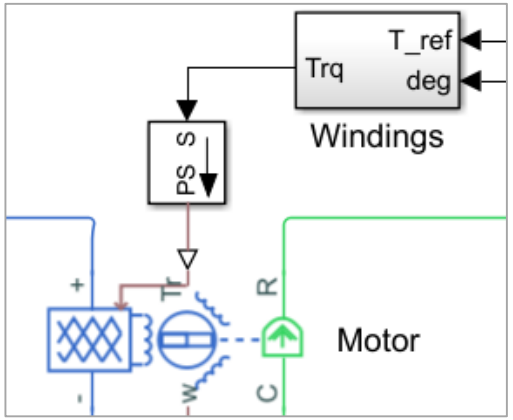
- Generic faults in many components
  - Short circuit, open circuit, friction, fade, etc.
  - Trigger based on time or conditions
- Adjust parameter values
  - Worn bearing adds friction
  - Blocked inlet has reduced passage area
- Adjust network
  - Seal leakage adds flow path
- Custom effects in Simulink
  - Broken winding applies no torque for 1/3 of every revolution





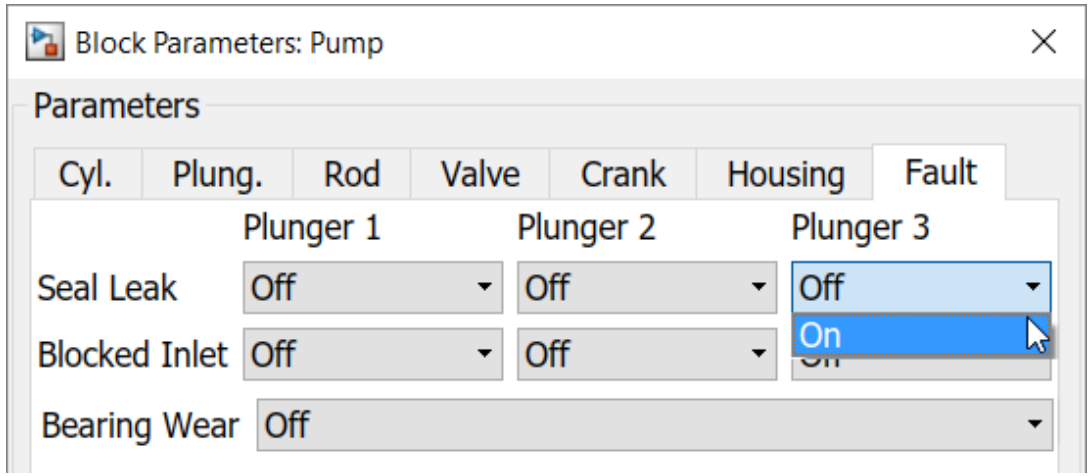


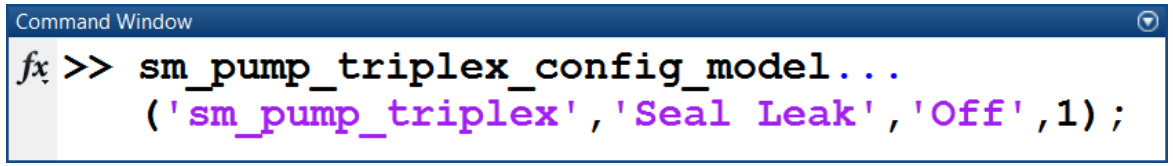




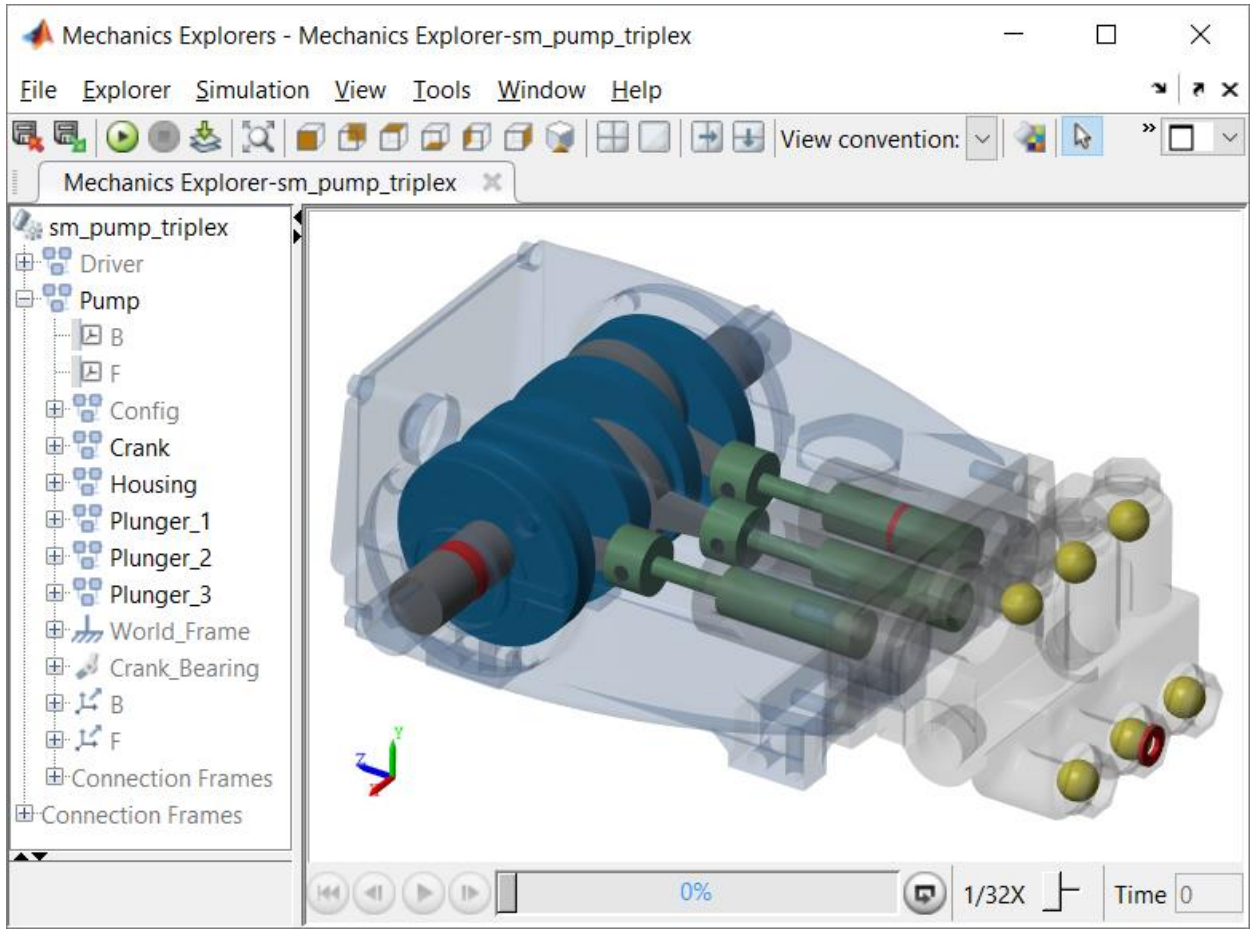
Model Component Failure in Pump

- Enable from UI or MATLAB

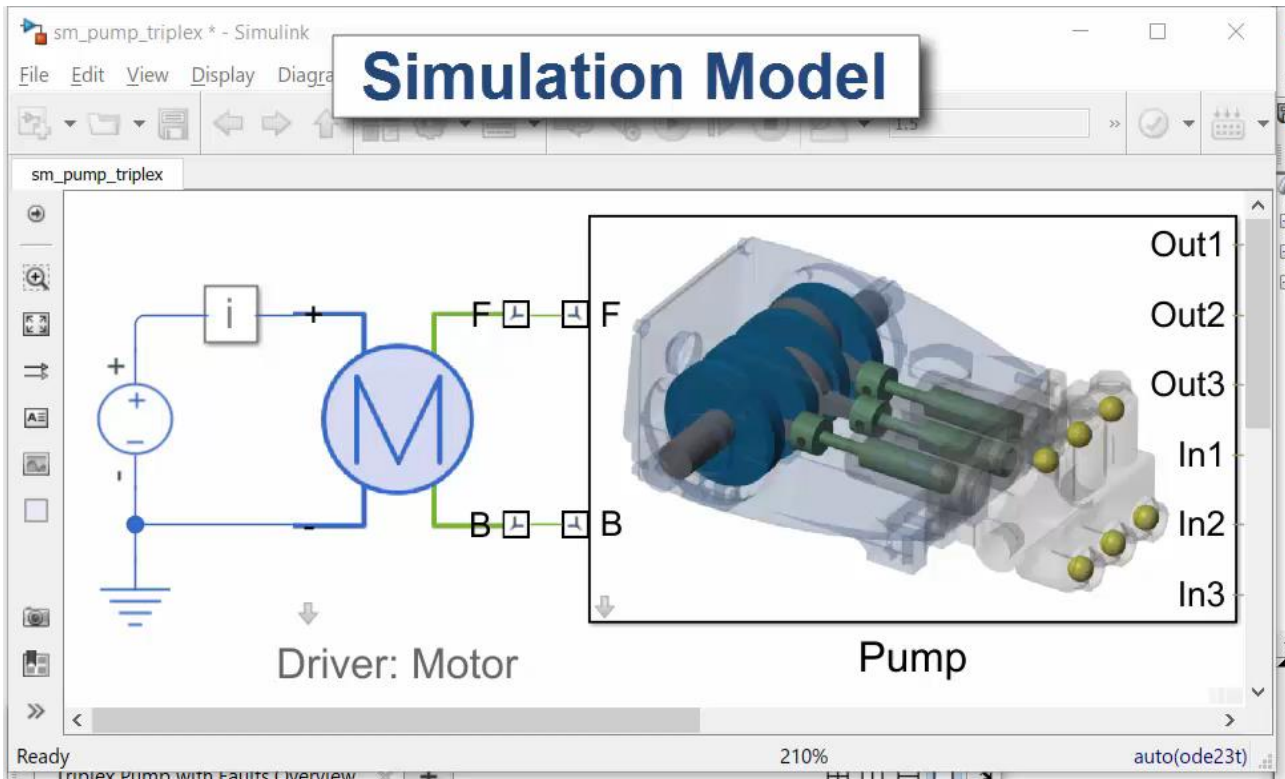




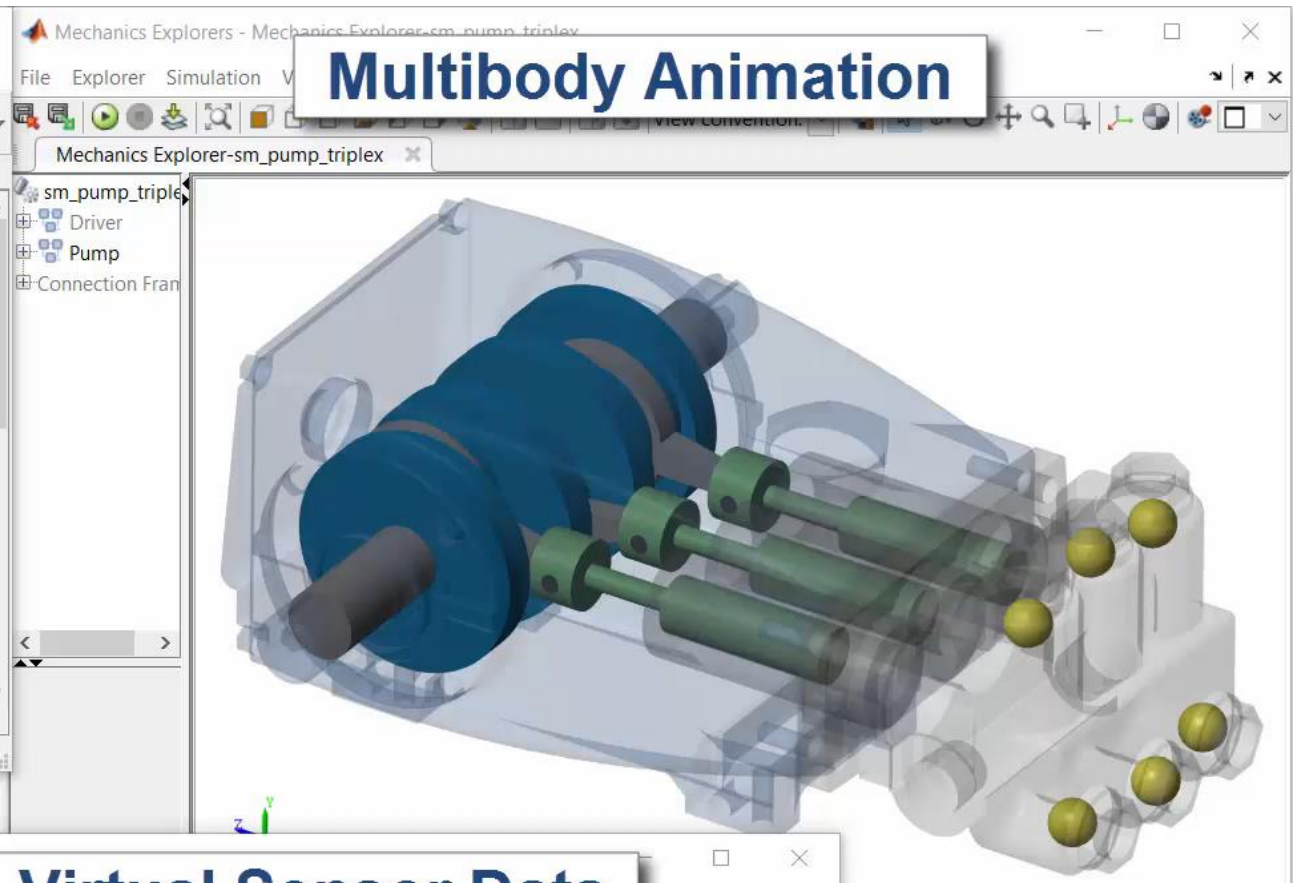
- Visual indication of fault



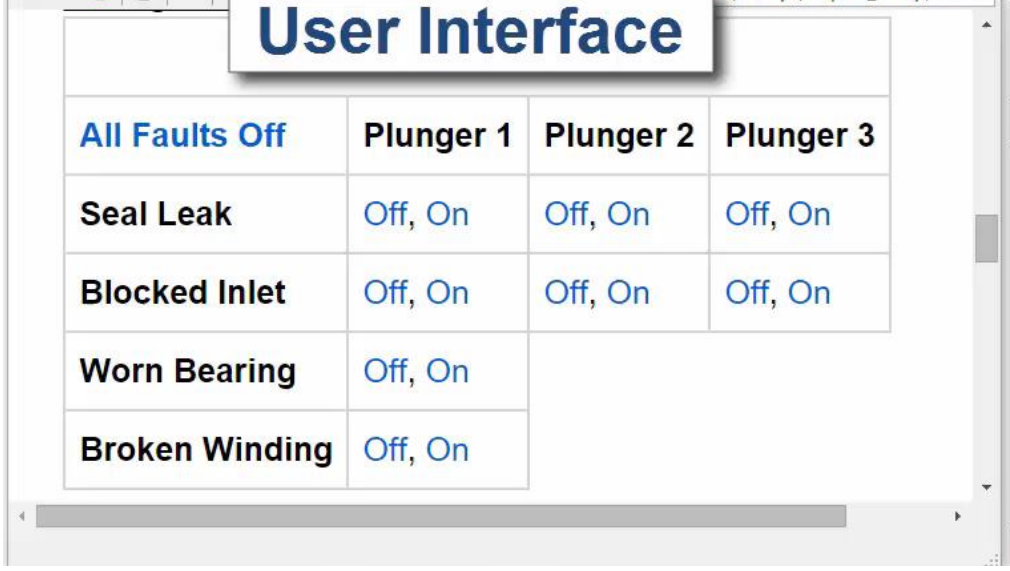
Simulation Model



Multibody Animation

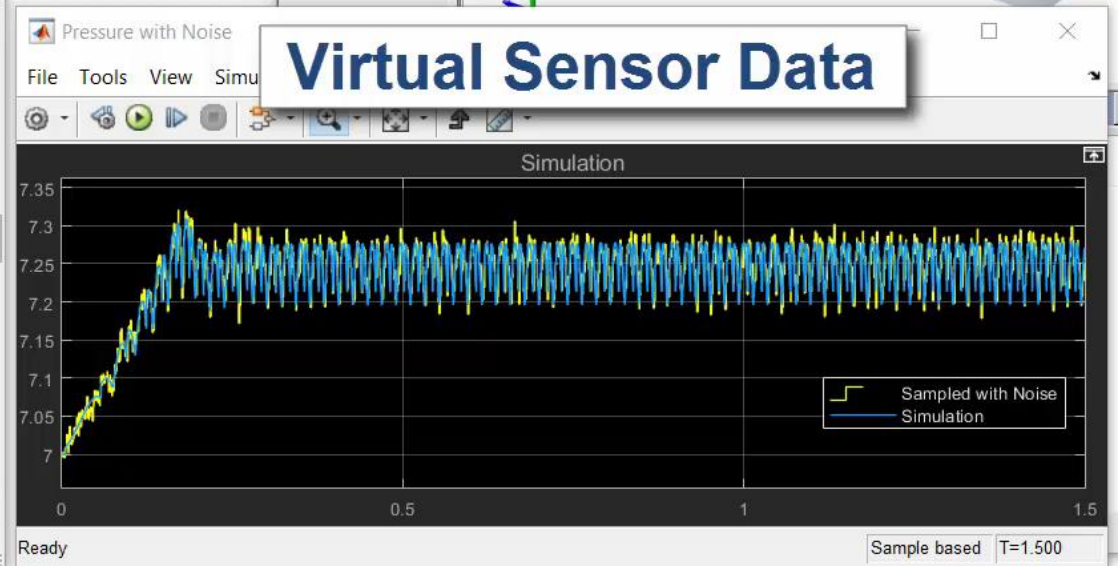


User Interface



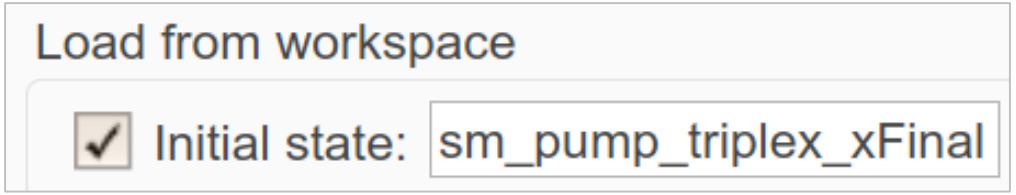
All Faults Off	Plunger 1	Plunger 2	Plunger 3
Seal Leak	Off, On	Off, On	Off, On
Blocked Inlet	Off, On	Off, On	Off, On
Worn Bearing	Off, On		
Broken Winding	Off, On		

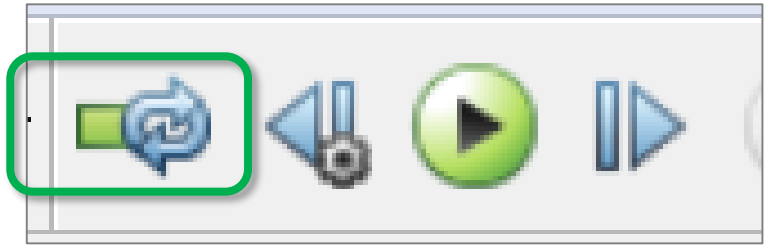
Virtual Sensor Data

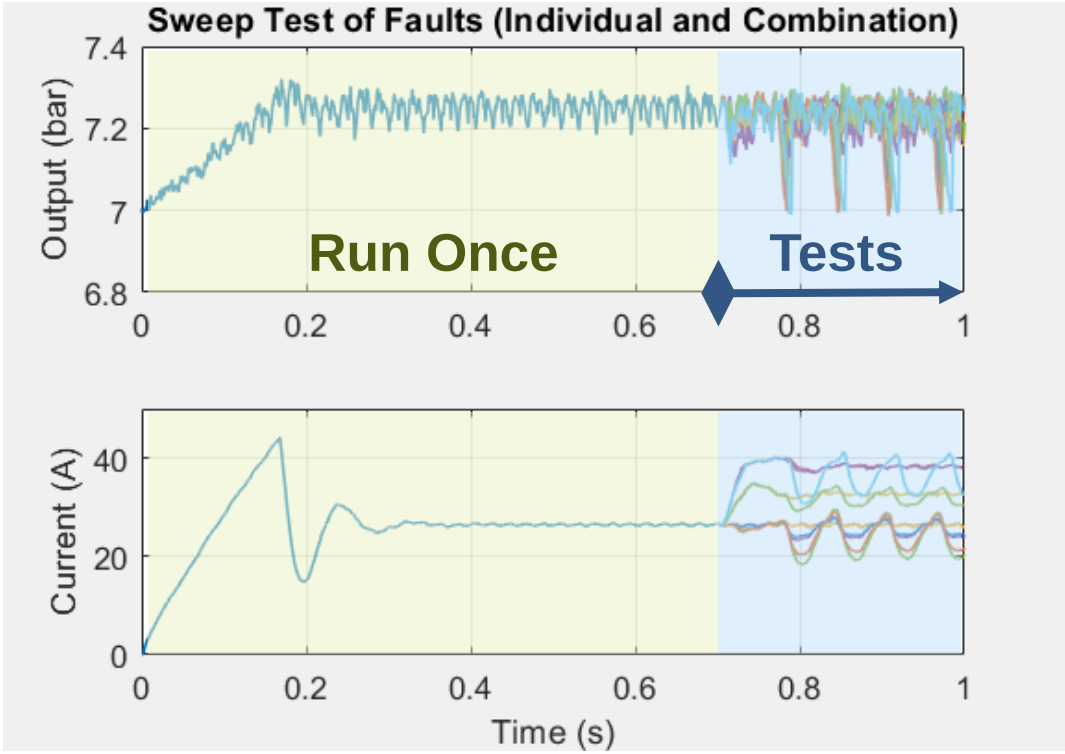


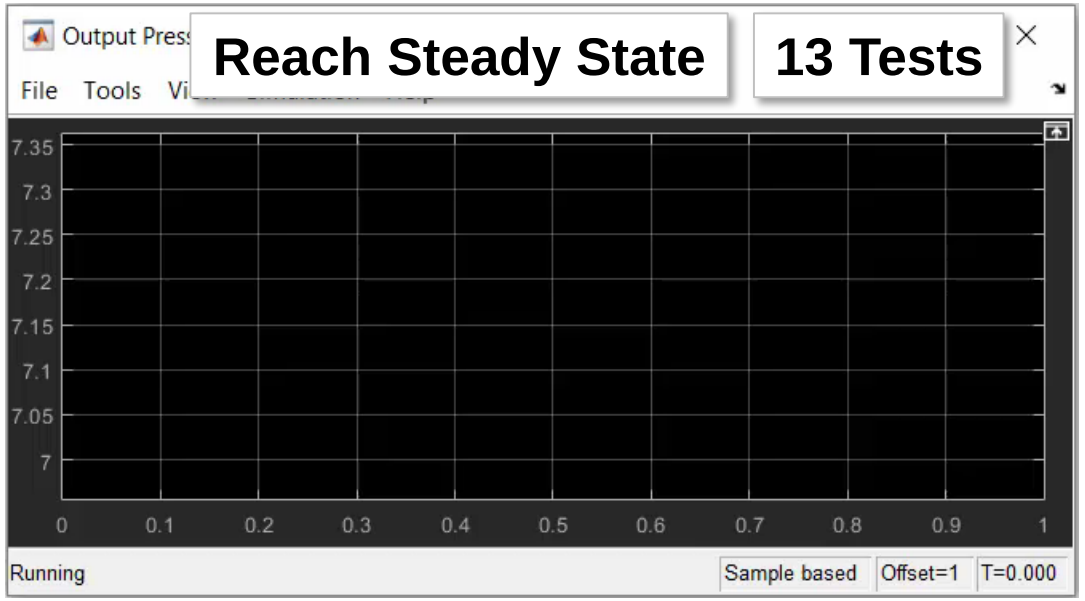
Quickly Create Sensor Data Using Parallel Computing and Initial State

- Classification model requires data at various levels of failure for all fault combinations of interest
  - Many tests required
- Speed up tests
  - Start from steady state





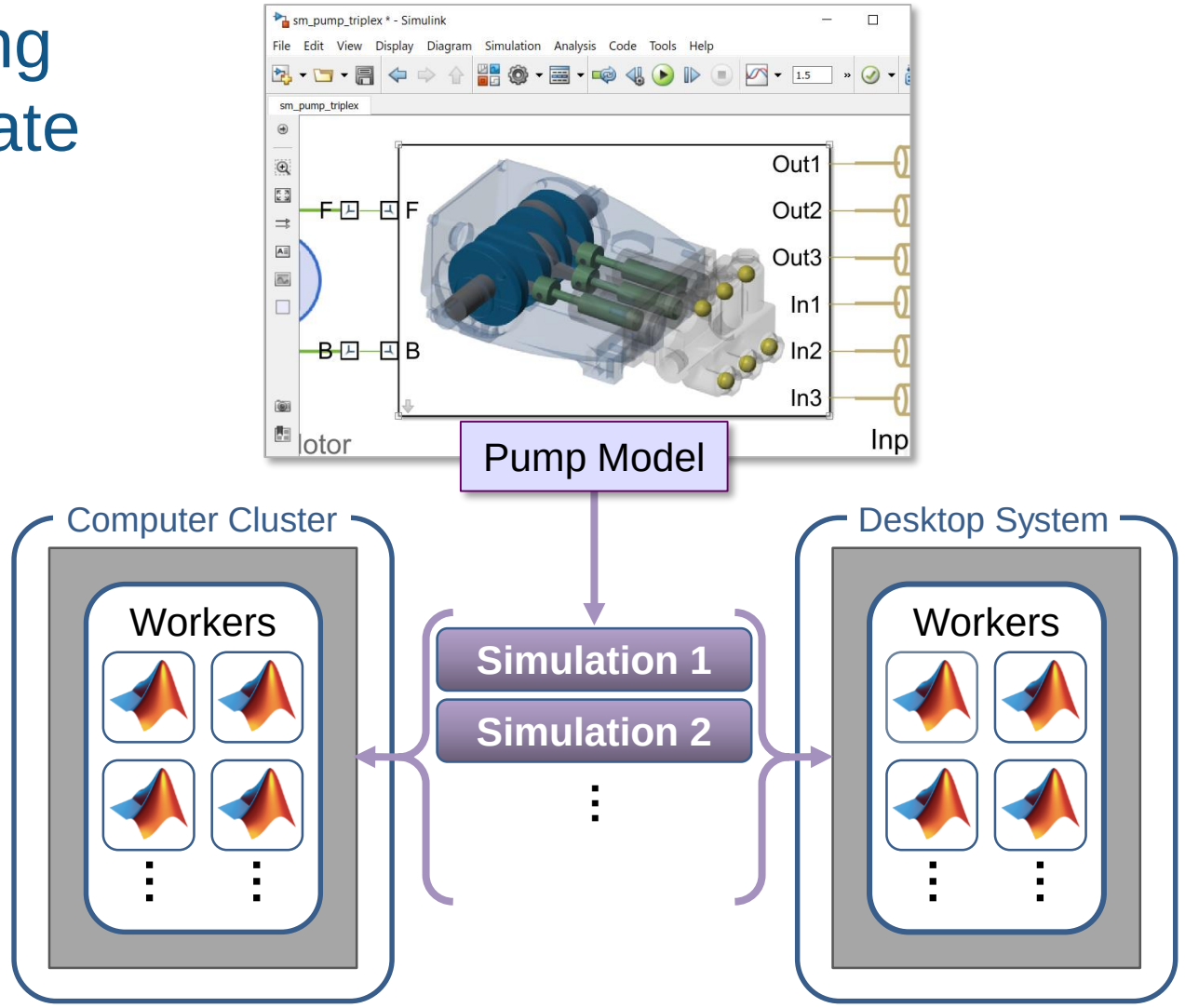




Quickly Create Sensor Data Using Parallel Computing and Initial State

- Classification model requires data at various levels of failure for all fault combinations of interest
  - Many tests required
- Speed up tests
  - Start from steady state
  - Run tests in parallel

  Distribute to multiple desktop workers or across a computing cluster



Running simulations in parallel speeds up your testing process.

Agenda

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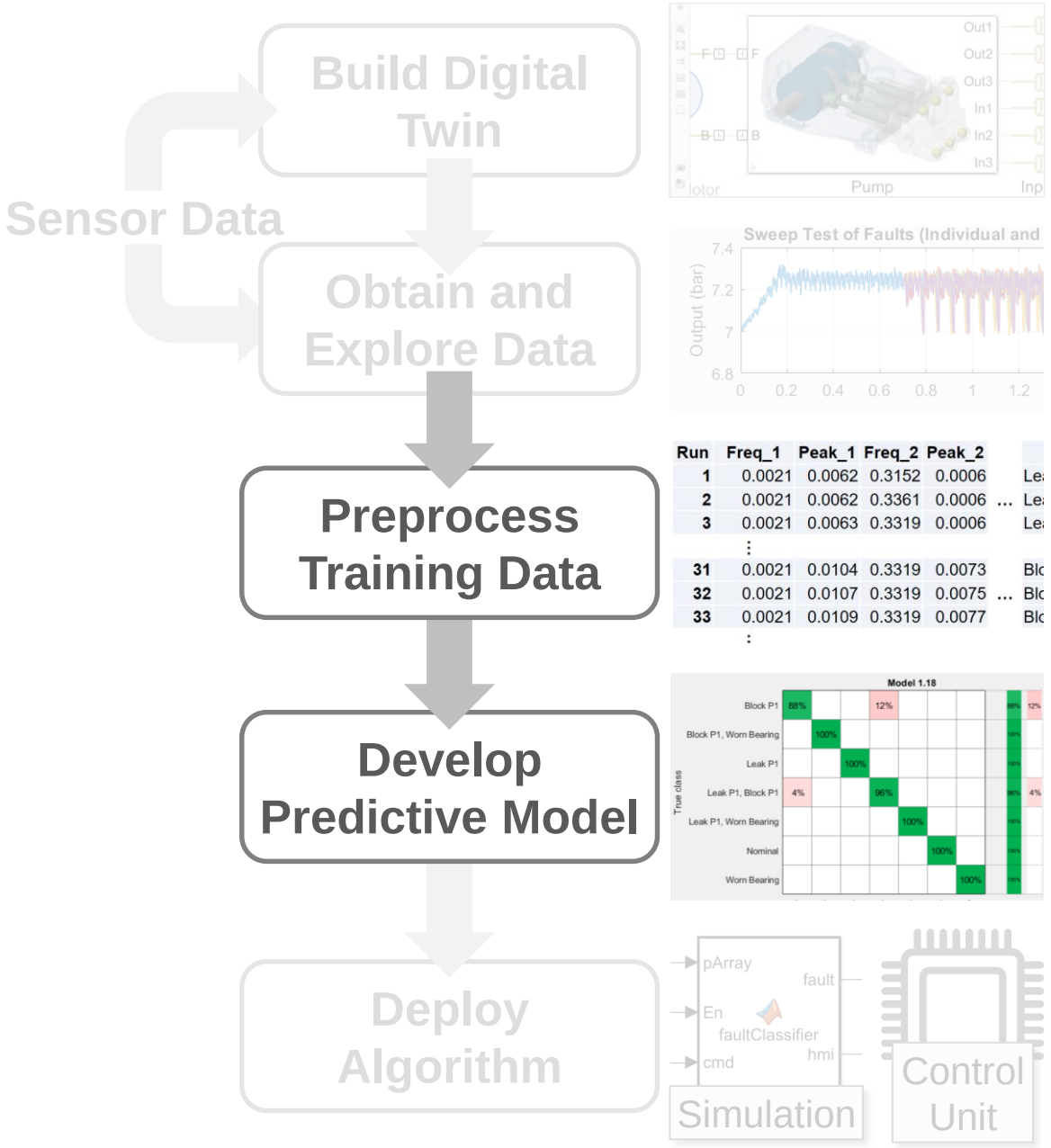
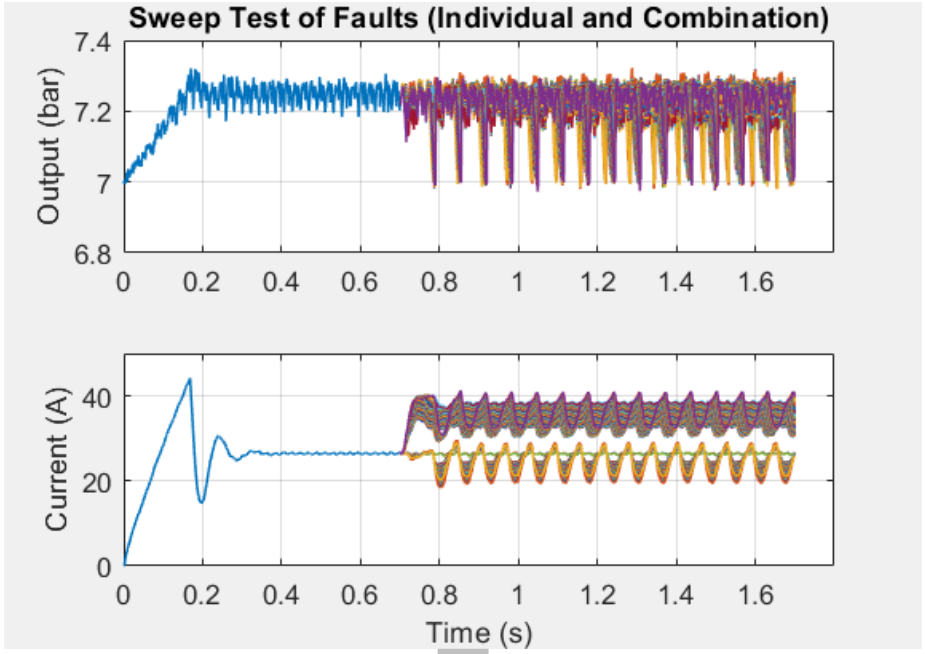


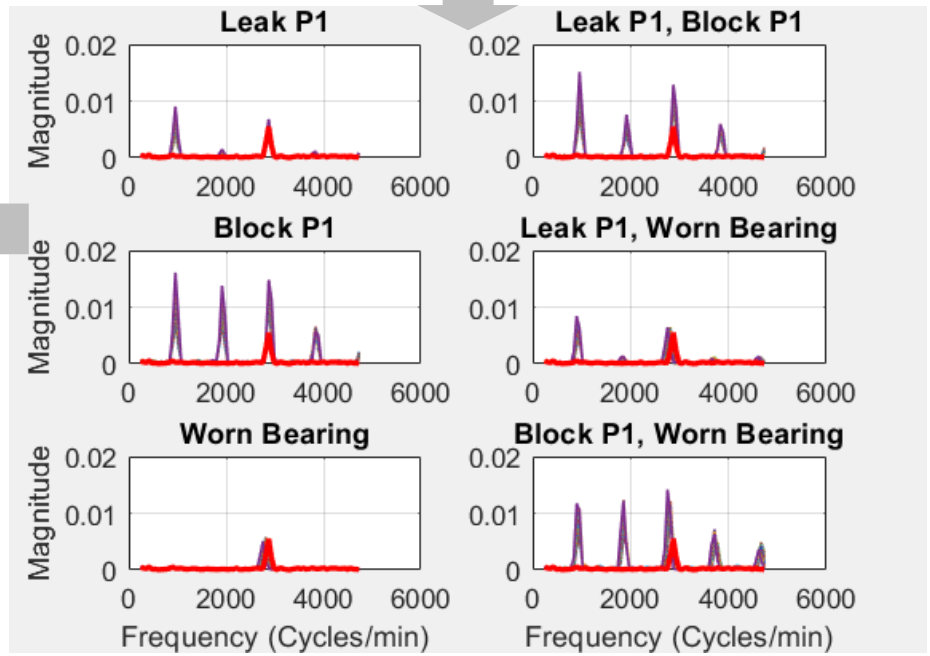
Extract Training Data from Sensor Measurements

- Perform FFT on results
  - Save frequencies, magnitudes, fault type

Classification Model Training Data

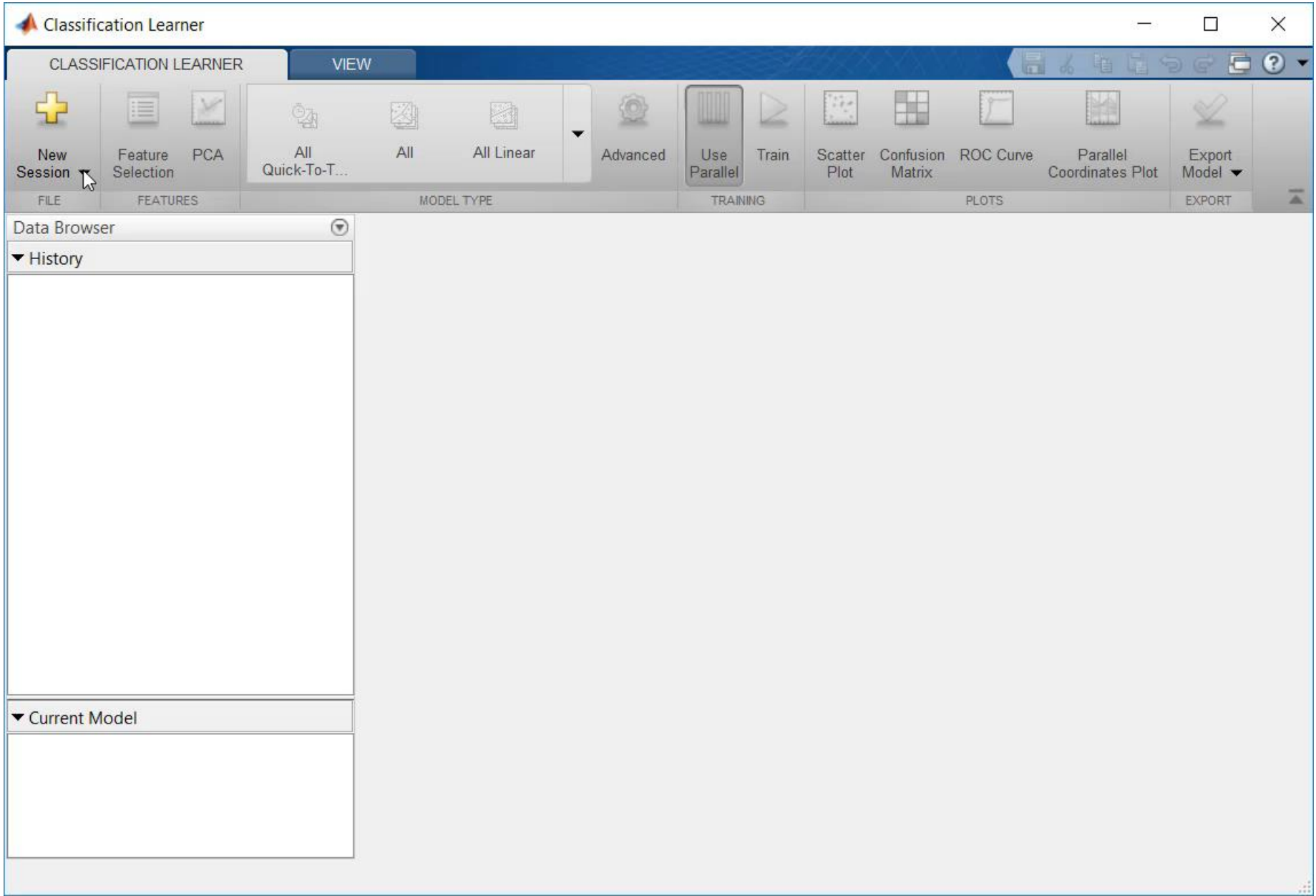
Run	Freq_1	Peak_1	Freq_2	Peak_2		Fault
1	0.0021	0.0062	0.3152	0.0006		Leak_P1
2	0.0021	0.0062	0.3361	0.0006	…	Leak_P1
3	0.0021	0.0063	0.3319	0.0006		Leak_P1
	⋮					⋮
31	0.0021	0.0104	0.3319	0.0073		Block_P1
32	0.0021	0.0107	0.3319	0.0075	…	Block_P1
33	0.0021	0.0109	0.3319	0.0077		Block_P1
	⋮					⋮
91	0.0021	0.0092	0.3319	0.0042		Leak P1, Block P1
92	0.0021	0.0095	0.3319	0.0044	…	Leak P1, Block P1
93	0.0021	0.0097	0.3319	0.0045		Leak P1, Block P1
	⋮					⋮
181	0.0021	0.0055				Nominal





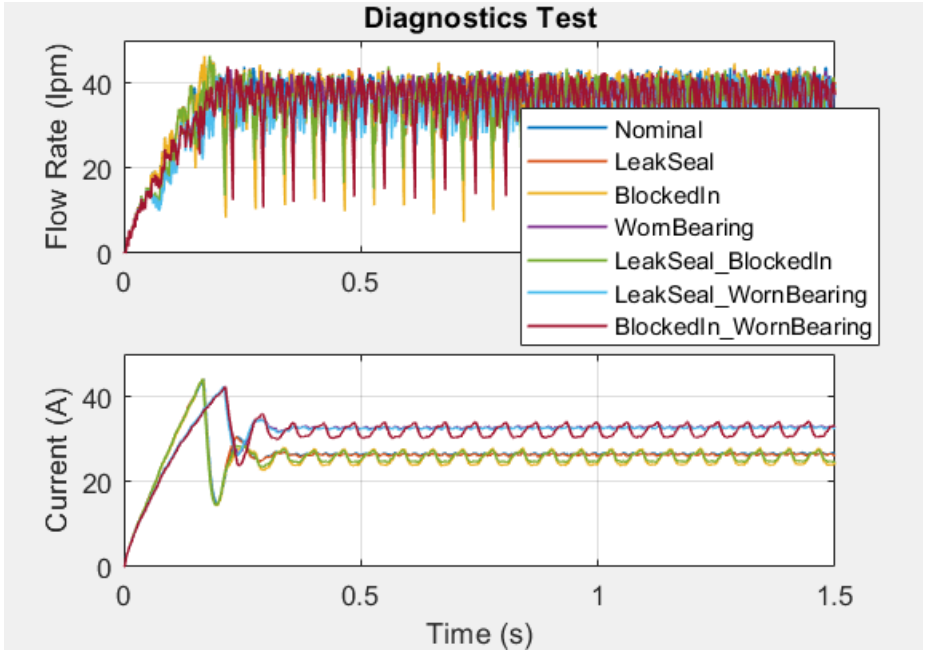
Evaluate all Classification Models

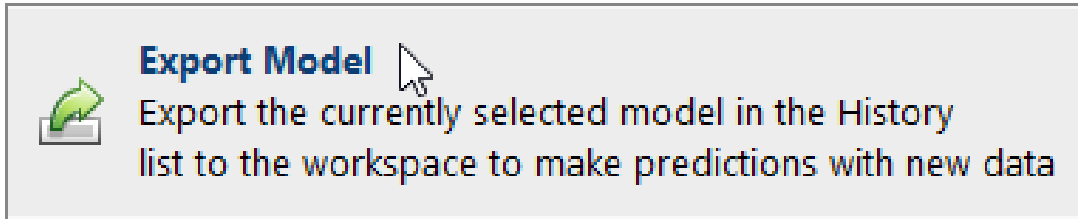
- Select data for training
- Train classifers
- Evaluate results
- Export trained classifer for testing in Digital Twin

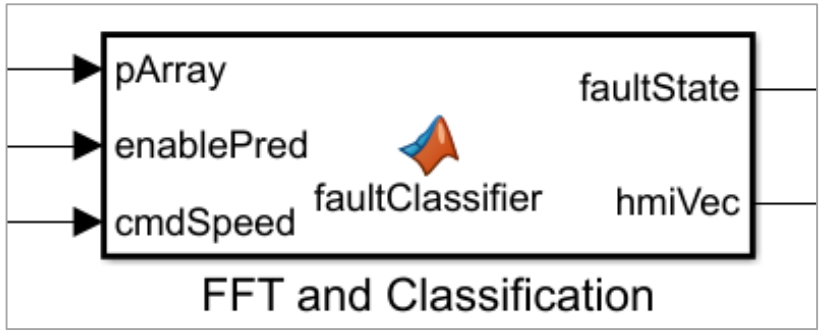


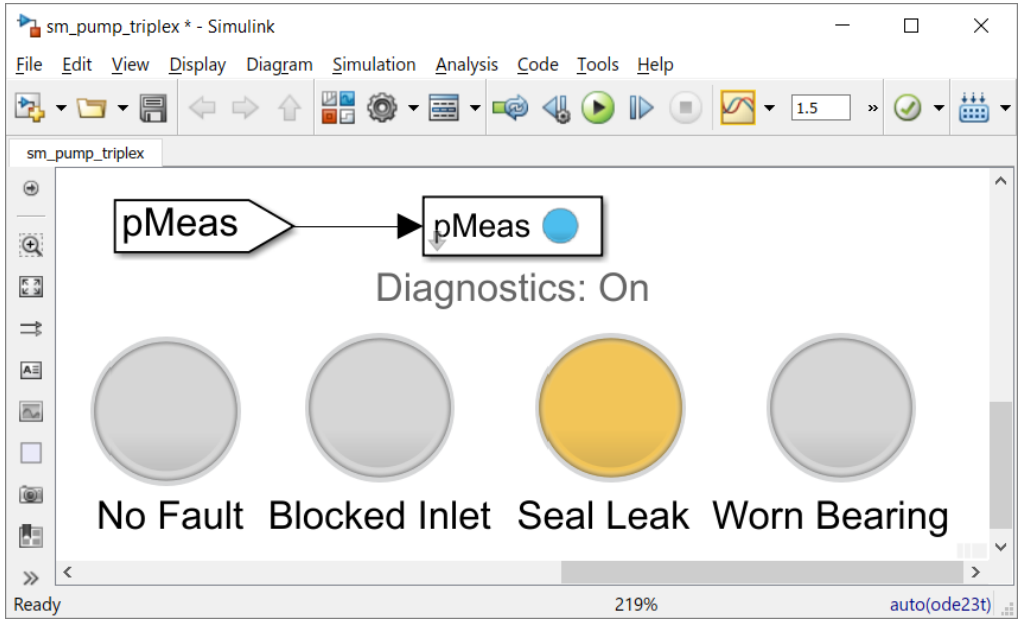
Test Algorithm in Simulation

- Connect trained algorithm to digital twin
  - Verify behavior on new scenarios before deploying in embedded code





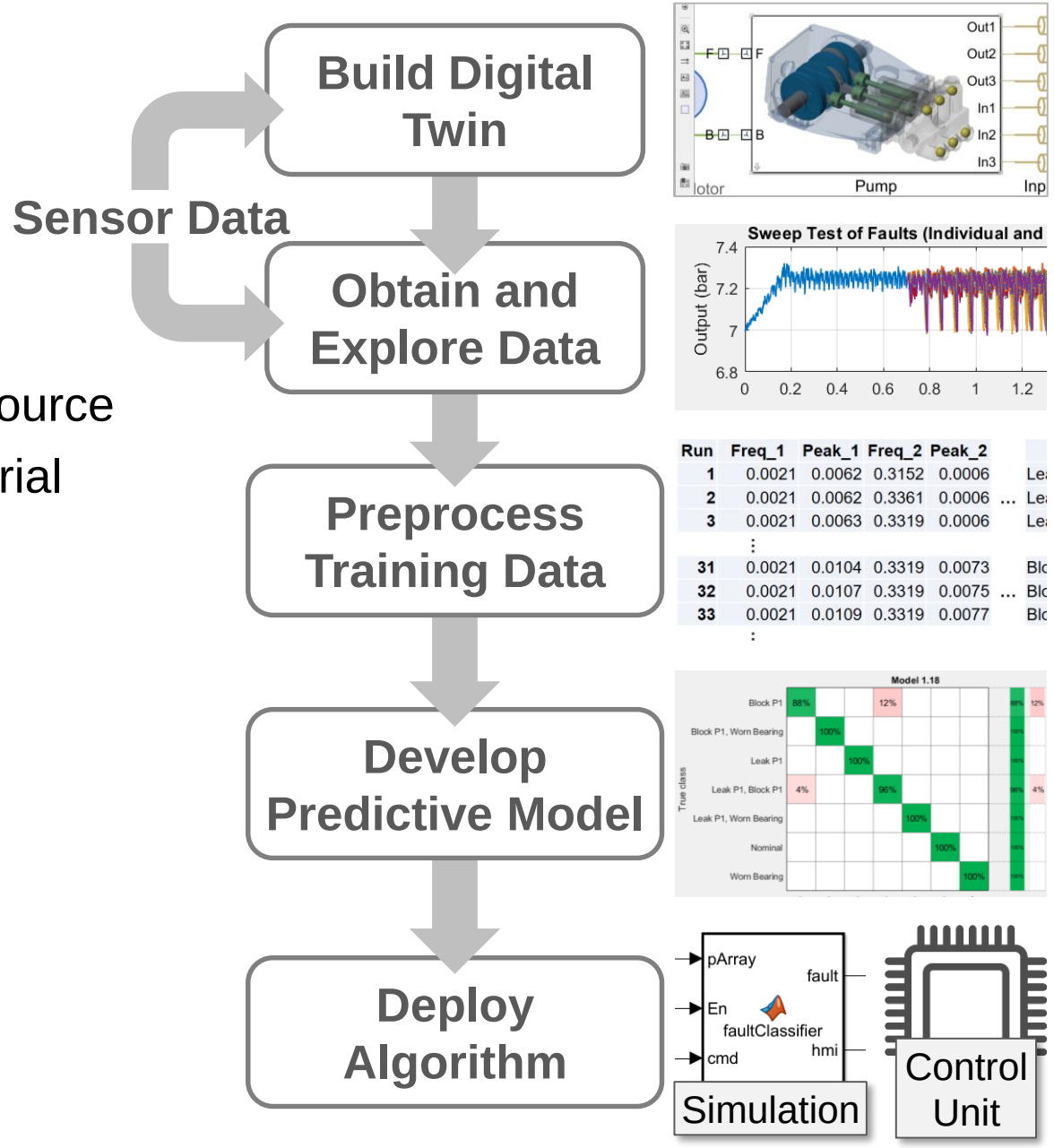




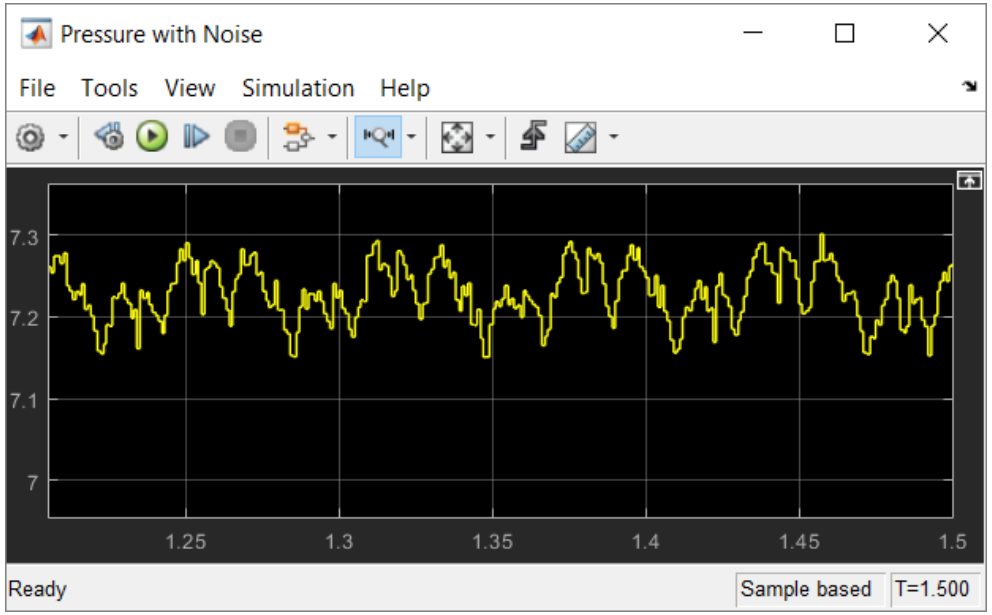
Automate Entire Algorithm Development Process

- Test and update algorithm when any aspect of system changes
  - Environment: temperature, fluid, power source
  - Supplier: Seals, valves, tolerances, material
  - Design: Larger, smaller, new markets

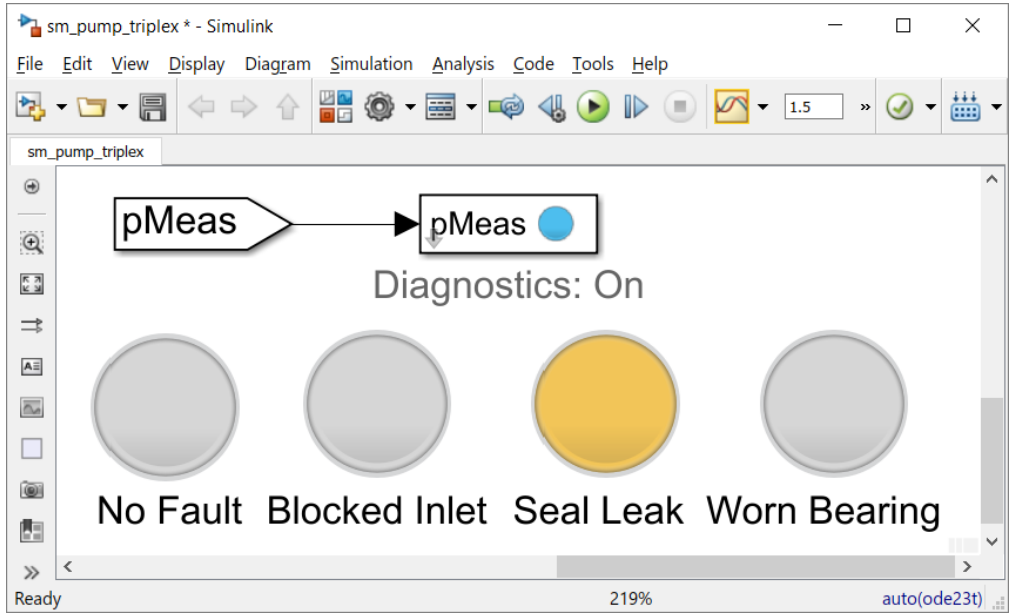
- Improve algorithm with new data
  - Tune digital twin with field data, automatically update algorithm



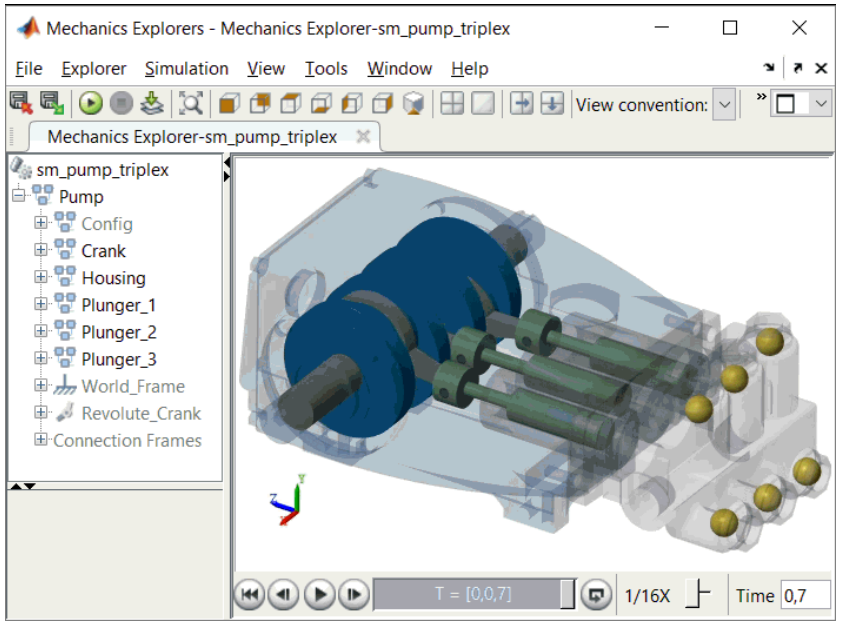
Prevent system downtime



by sending sensor data



to a predictive maintenance algorithm



created using a Digital Twin

and machine learning in MATLAB.