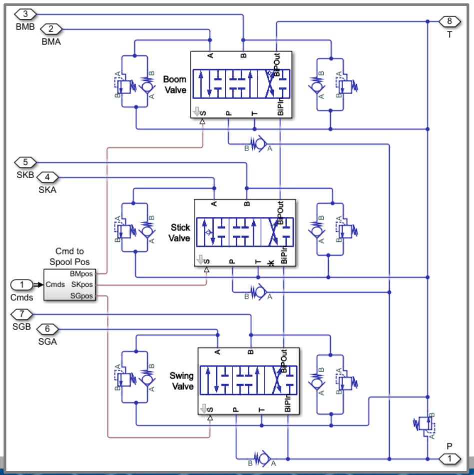
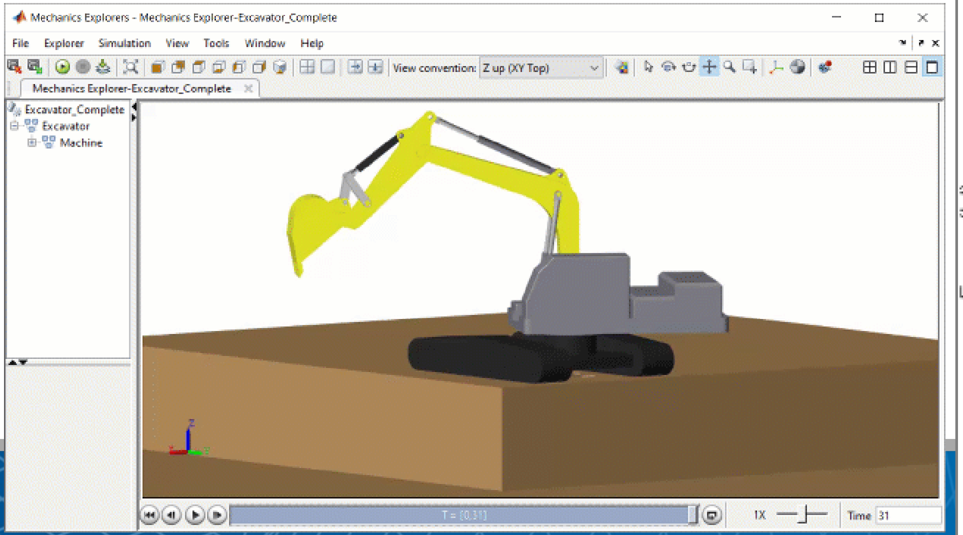
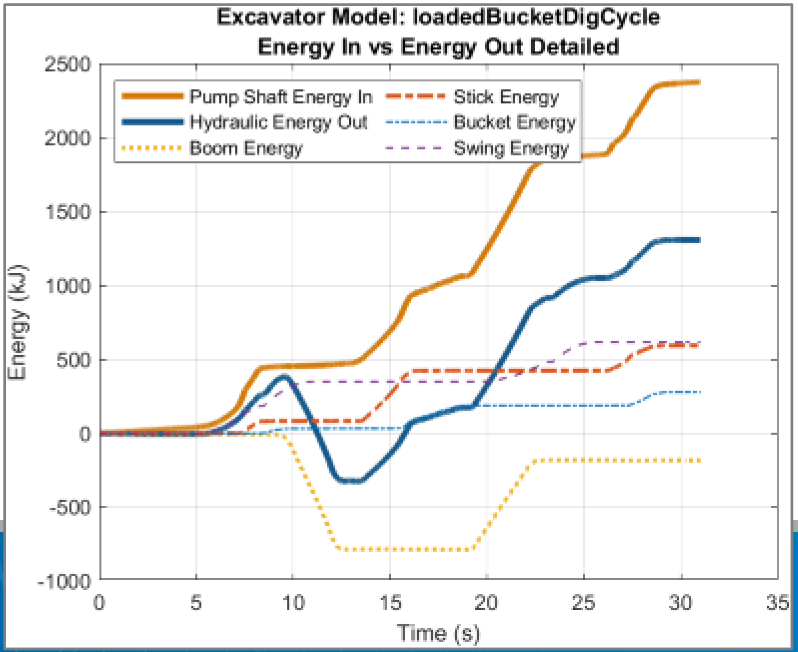
Virtuelle Maschinenentwicklung mit MATLAB und Simulink



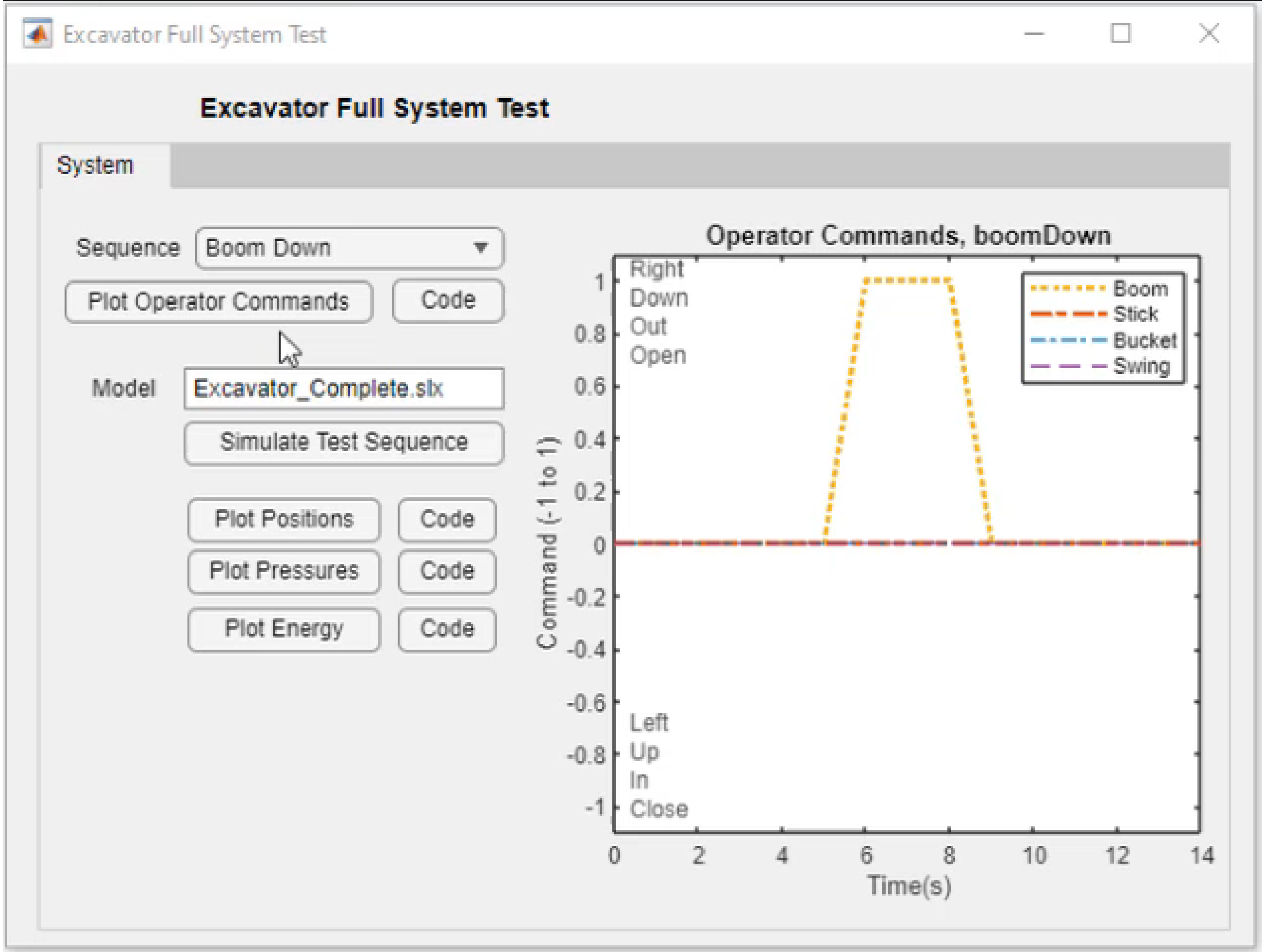


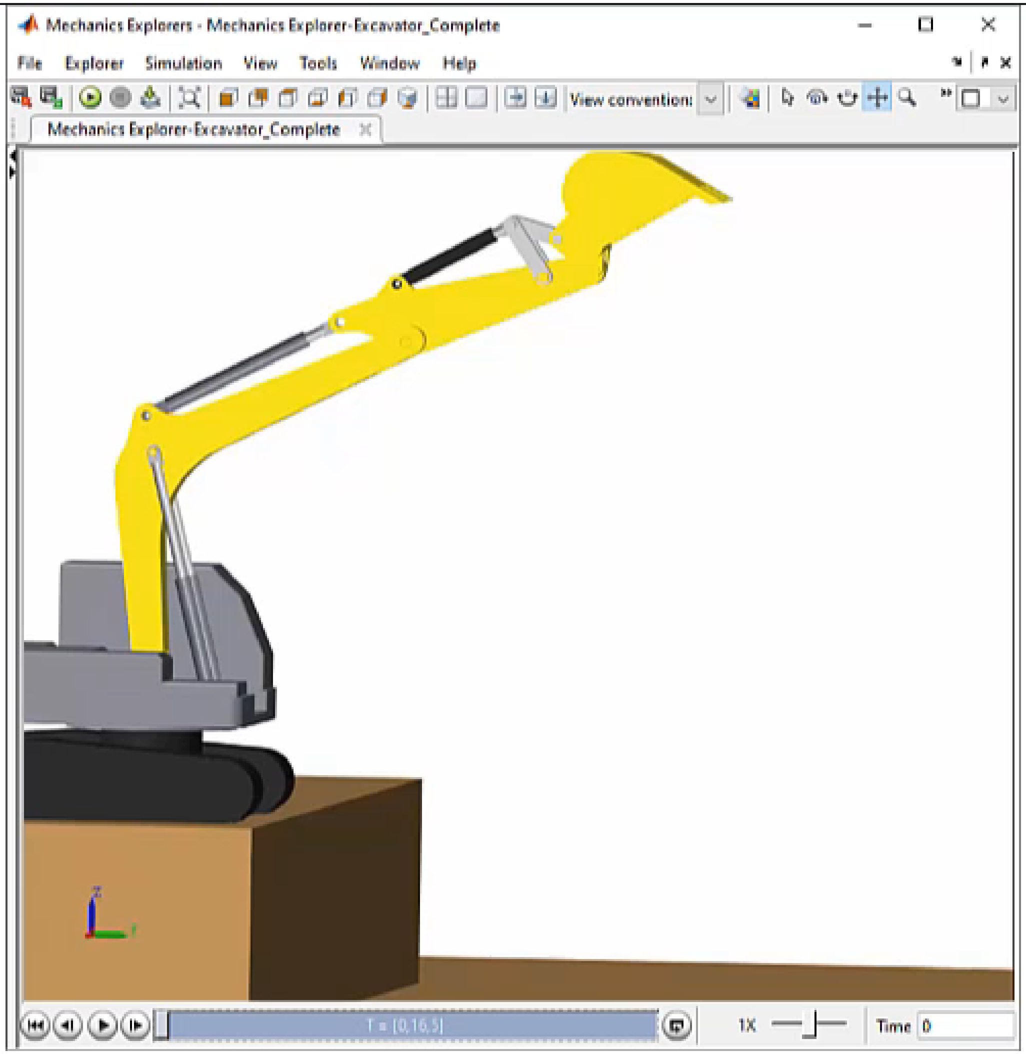


Eva Pelster, Application Engineering (epelster@mathworks.com)
04.05.2023

Excavator Model

Test by function or full cycle and review results





Aalto University Works with Industry Partners to Develop Energy-Efficient Designs for Construction Equipment

Challenge

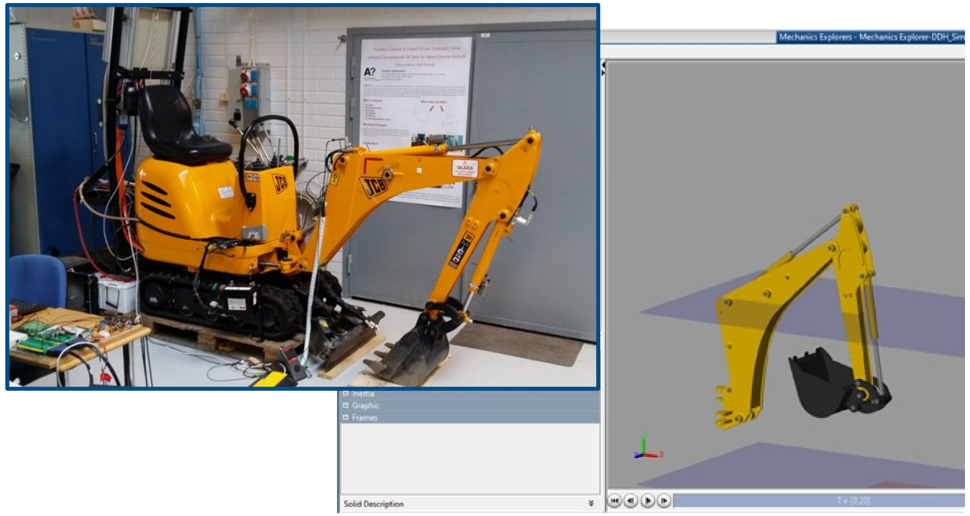
Work with manufacturers to develop more energy-efficient excavators, loaders, and other construction and off-road machinery

Solution

Use MATLAB, Simulink, and Simscape to model and simulate designs that incorporate hybrid technologies and decentralized hydraulic systems

Results

- Energy efficiency doubled
- Industry-academia collaboration established
- In-demand skills developed



The one-tonne micro excavator modeled by Aalto University and Tampere University researchers in the EL-Zon and EZE projects.

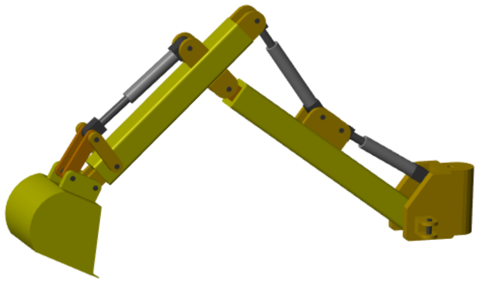
"With MATLAB, Simulink, and Simscape we were able to create and validate designs spanning multiple domains—mechanical, electrical, and hydraulic—that are now being used by our commercial partners to improve energy efficiency on their machines."

- Tatiana Minav, Aalto University and Tampere University

Link to user story

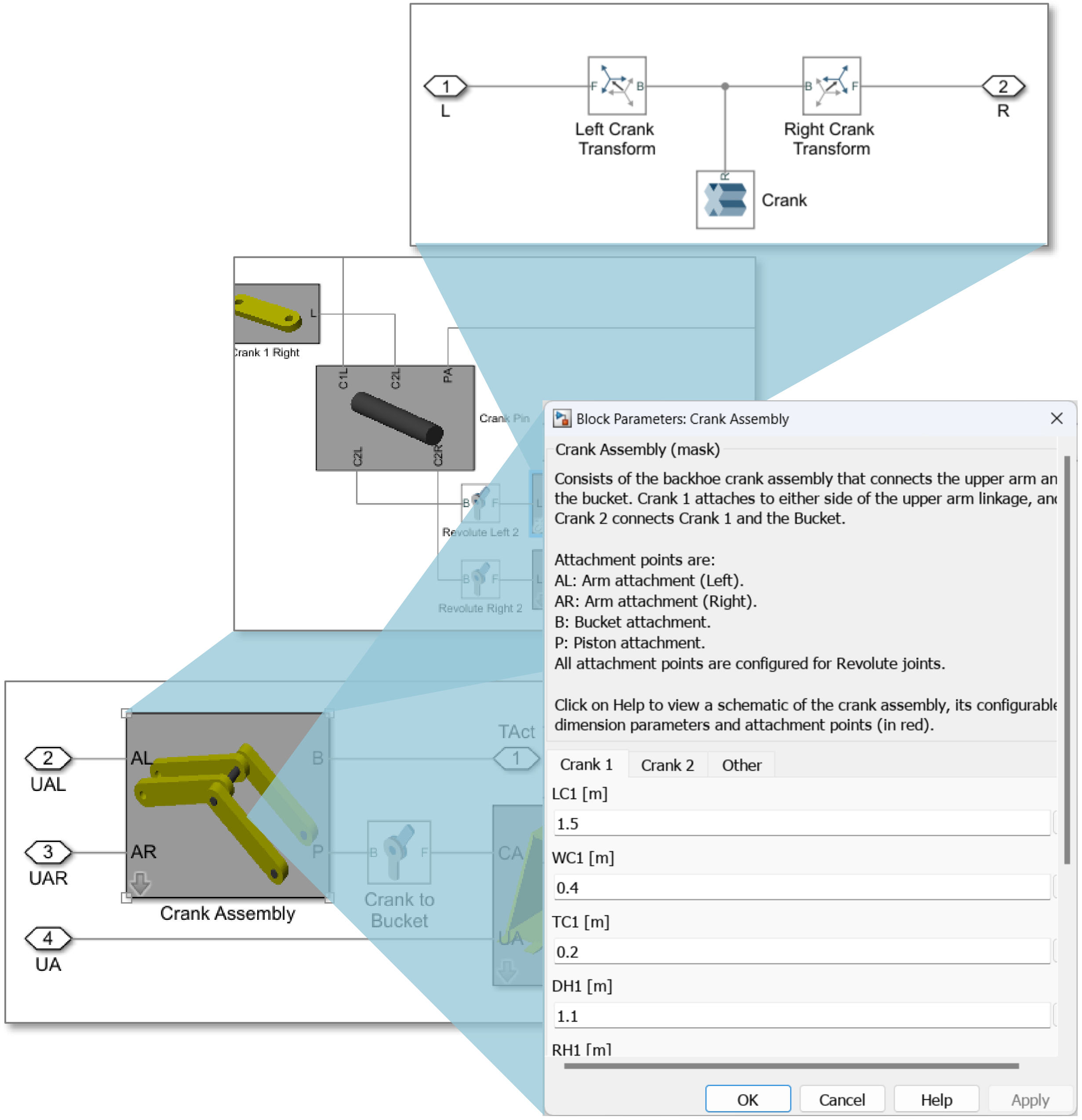
Modeling the Mechanical System

Model:



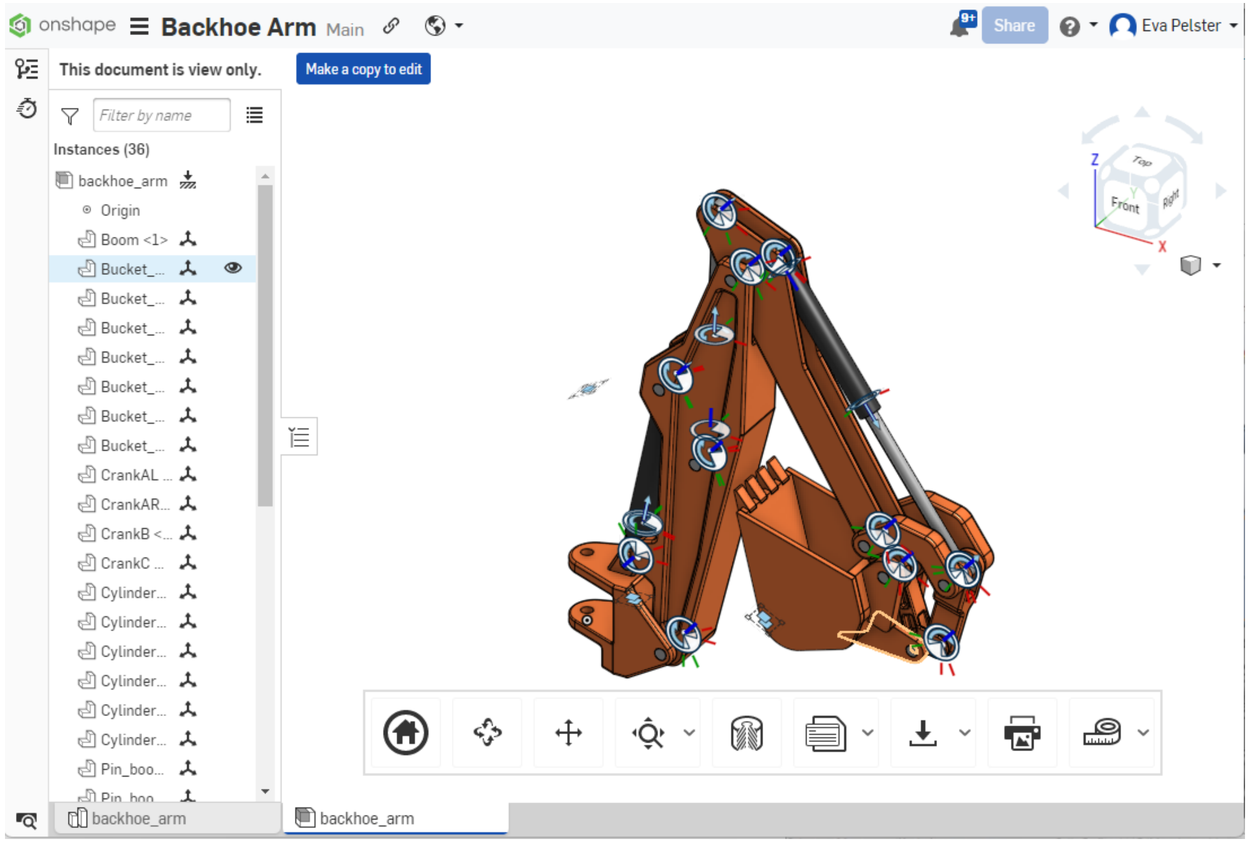
Challenge: Create a (parameterized) mechanical model of the backhoe

Solution: Use components created in Simscape Multibody to rapidly assemble the model in Simulink.



Reusing CAD Data

- Import CAD assemblies
  - Part definitions
  - Converts mate definitions to joints
  - SOLIDWORKS, Inventor, Onshape, and PTC Creo® (Pro/ENGINEER®)
- Import CAD Parts
  - CATIA, NX, SolidEdge, and others
  - STEP files

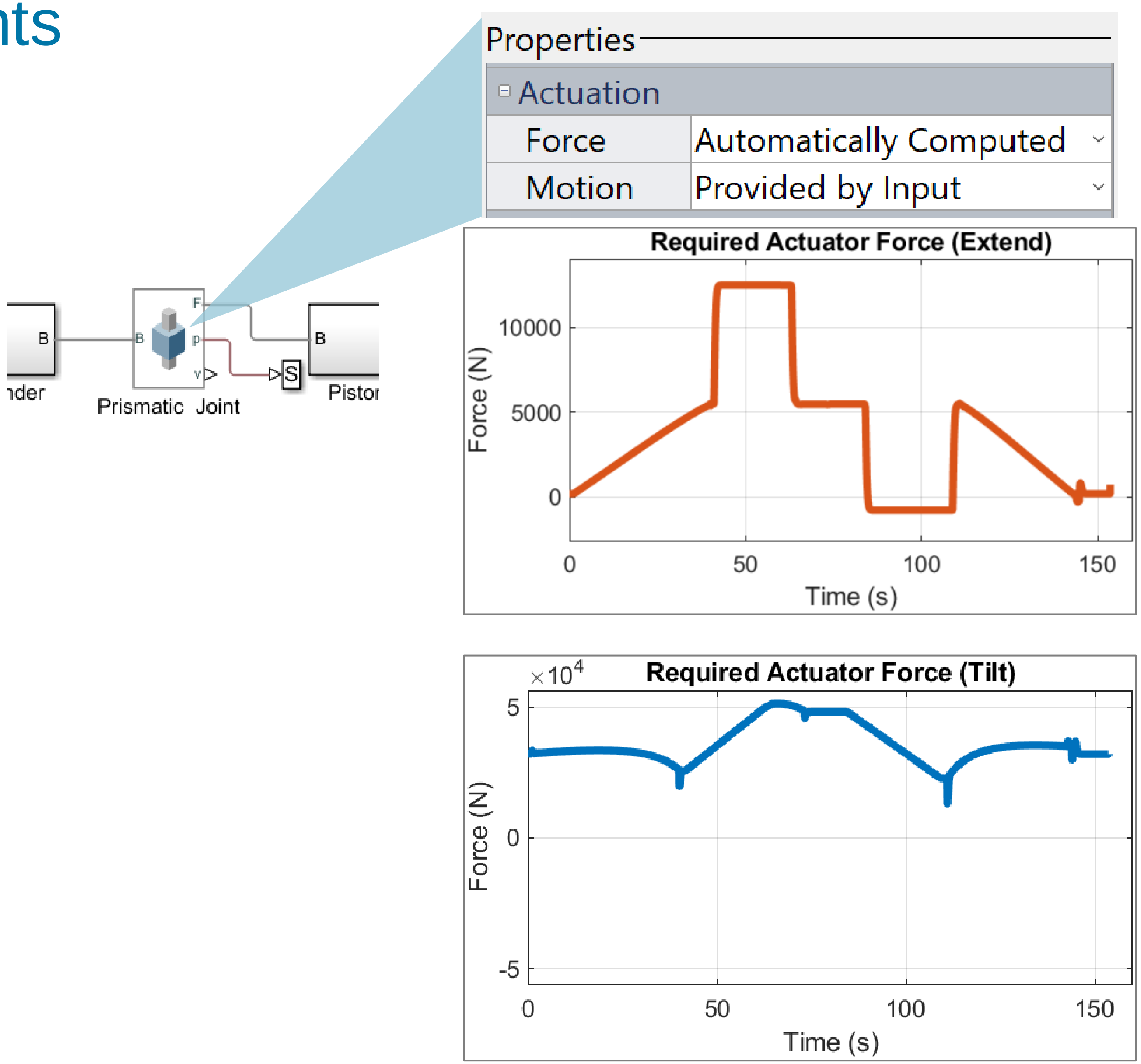


Determine Actuator Requirements

- Define and run a set of tests
  - Maximum payload, speed
  - Worst case friction levels
  - Full range of movement

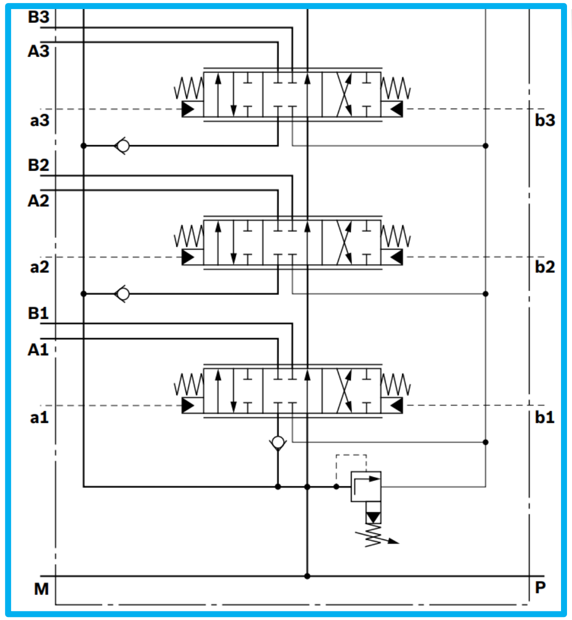
- Use dynamic simulations to calculate required torque and bearing forces

- If design changes, automatically rerun tests and re-evaluate results

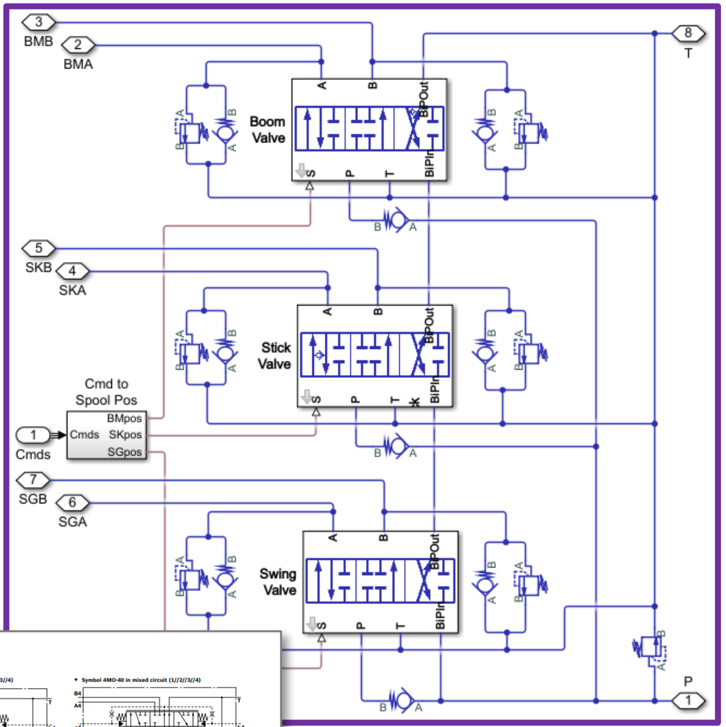


Modeling the Hydraulic Actuation System

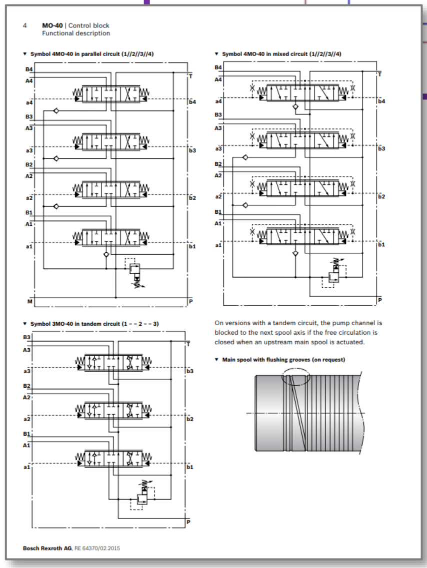
Model:



Schematic



Simscape Model



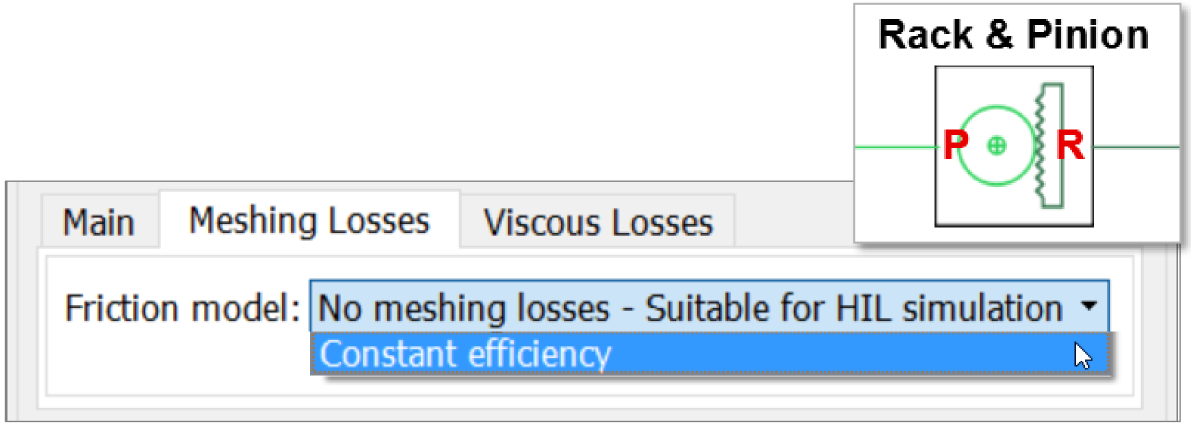
Data Sheet

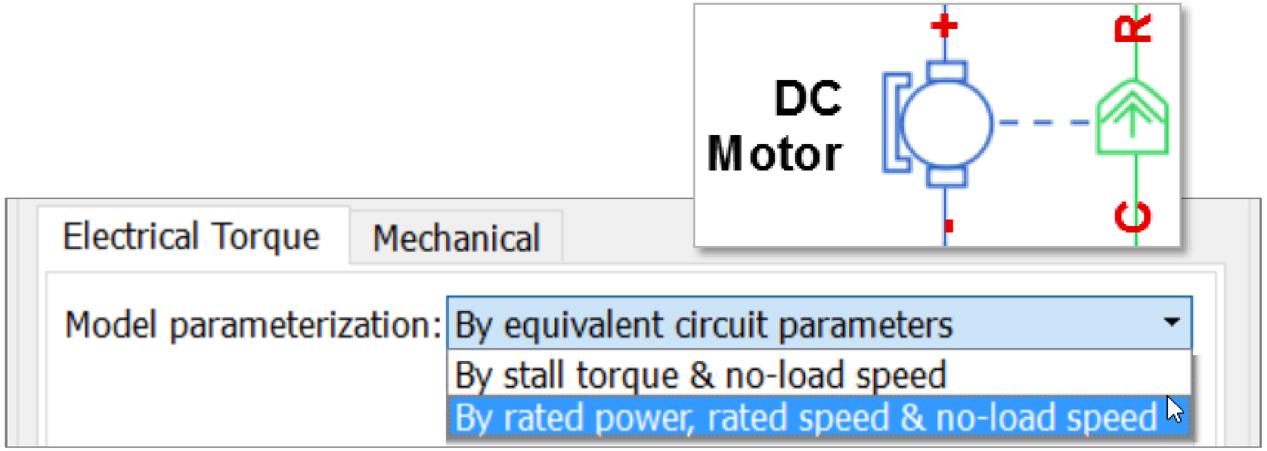
Problem: Translate the hydraulic schematic into a models

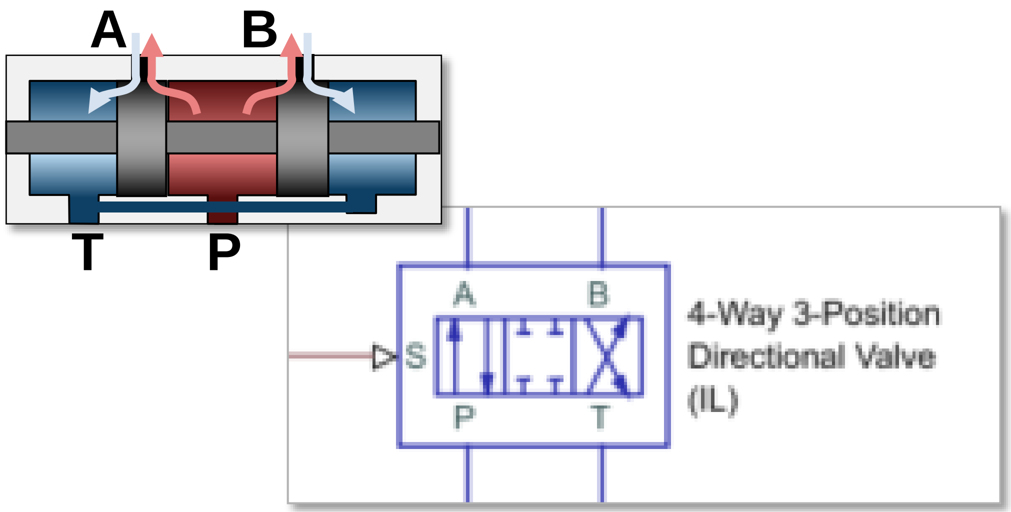
Solution: Use Simscape Fluids blocks ans parameterize using data sheets

Enhancing the Model with Simscape Add-on Libraries

- Advanced components and effects
  - Comprehensive components
  - Parameterization options
  - Physical effects (losses, thermal dependency)

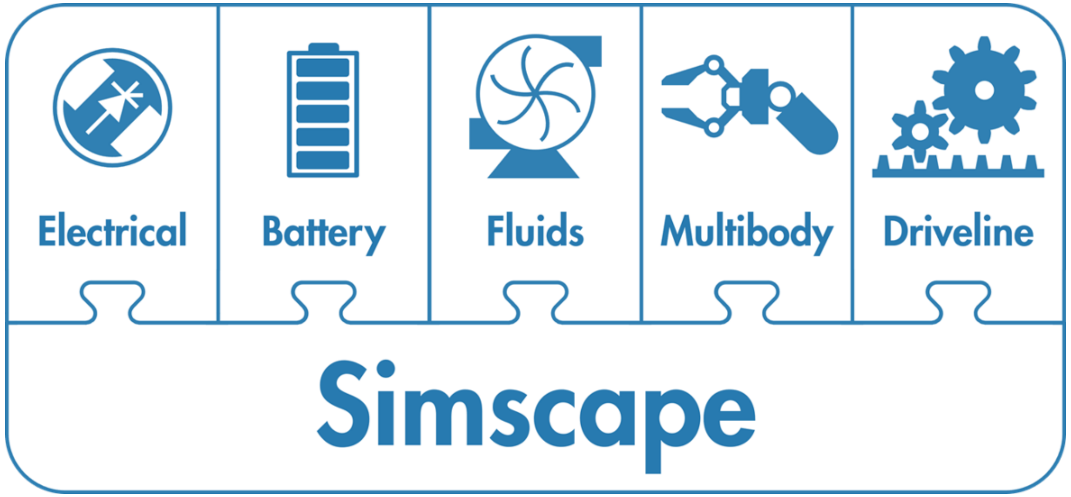


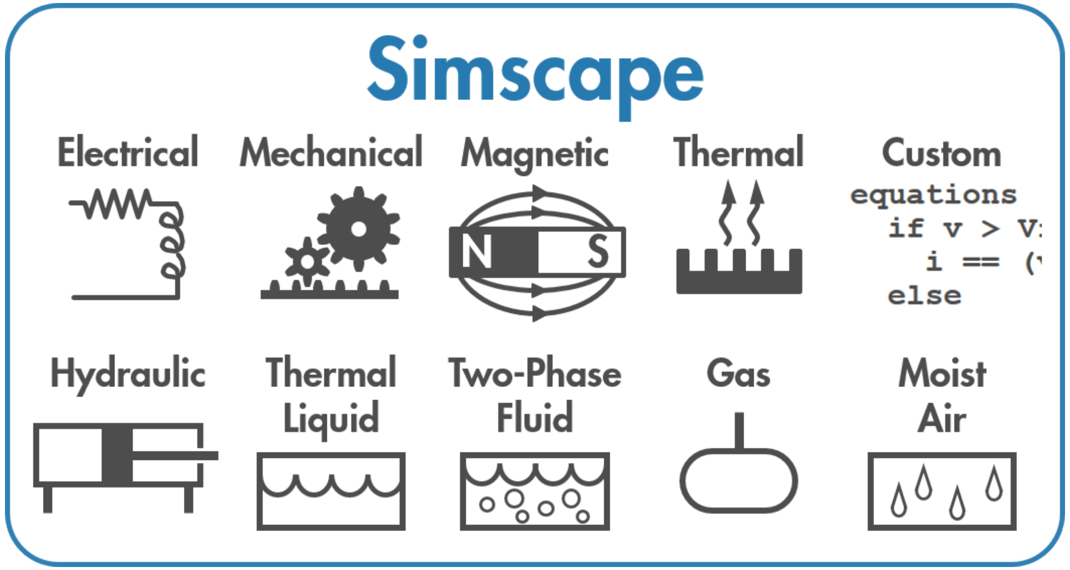




Simscape Add-on Libraries

- Simscape Battery
  - Battery packs, cooling, charge management
- Simscape Electrical
  - Electronics, mechatronics, and power systems
- Simscape Driveline
  - Gears, leadscrew, clutches, tires, engines
- Simscape Multibody
  - Multibody systems: joints, bodies, frames
- Simscape Fluids
  - Pumps, actuators, pipelines, valves, tanks

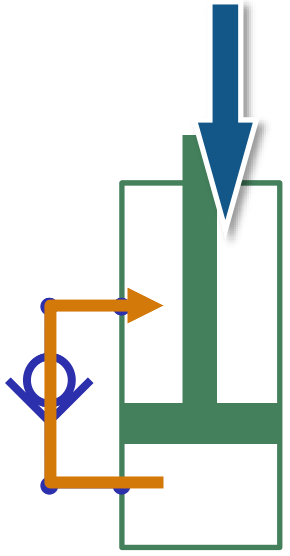


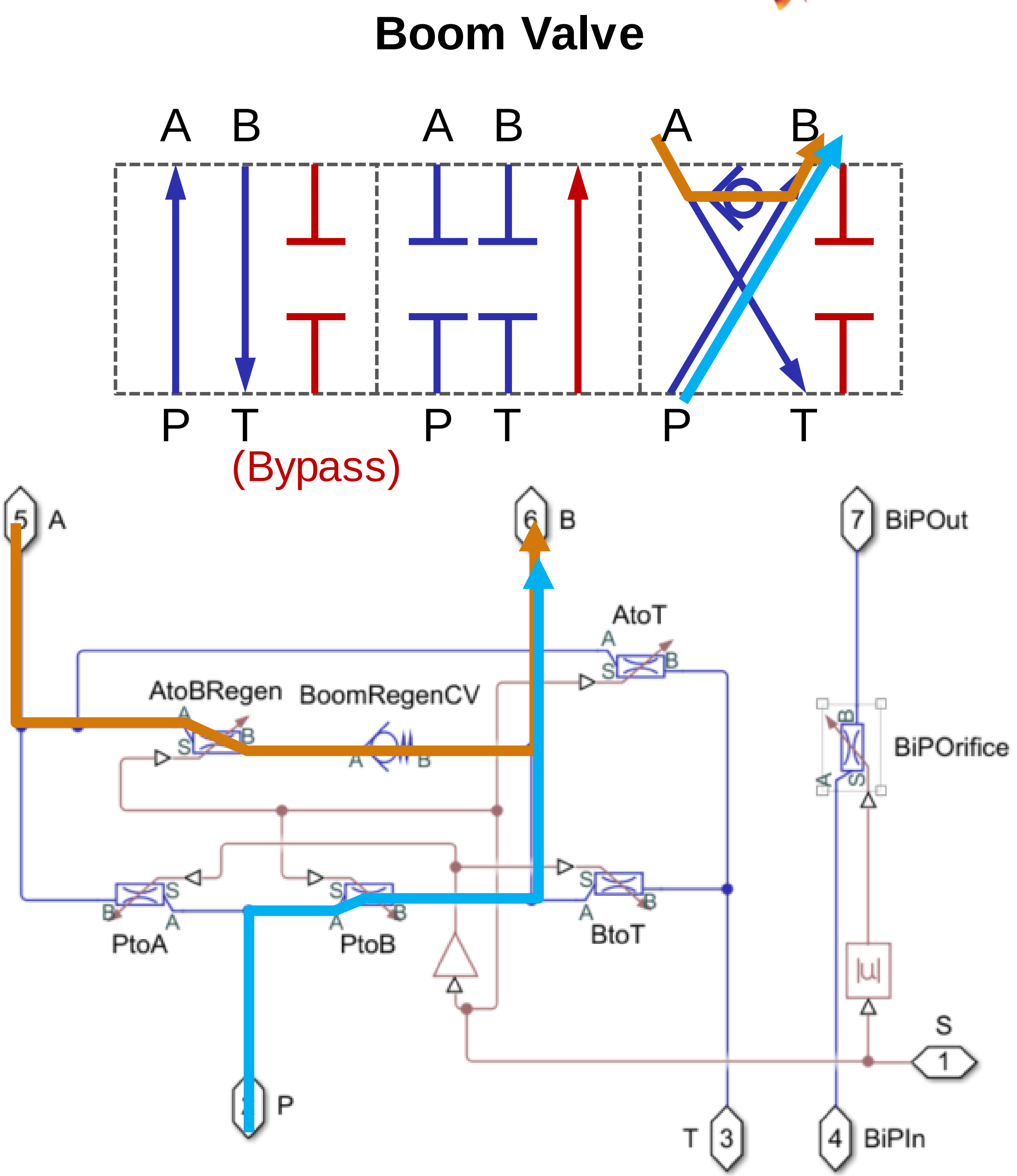


Add Regeneration Valves

- Regeneration valves
  - As cylinders move with gravity, oil from high pressure side is fed to low pressure side
  - Reduces load on pump and increases efficiency

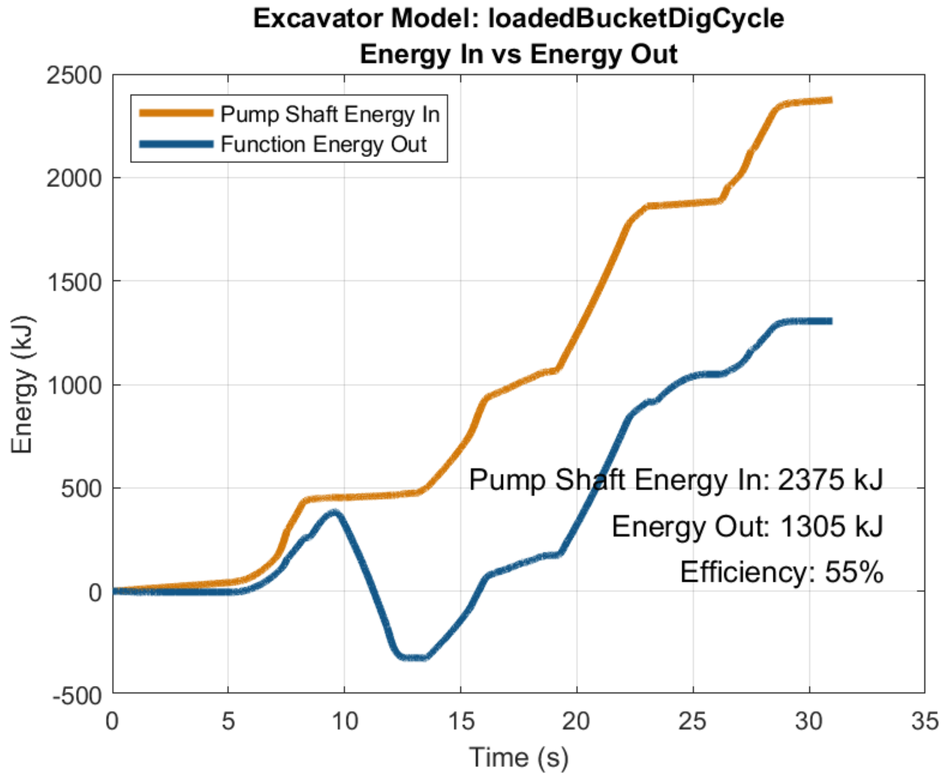
Boom cylinder: regeneration when pump supplies rod end

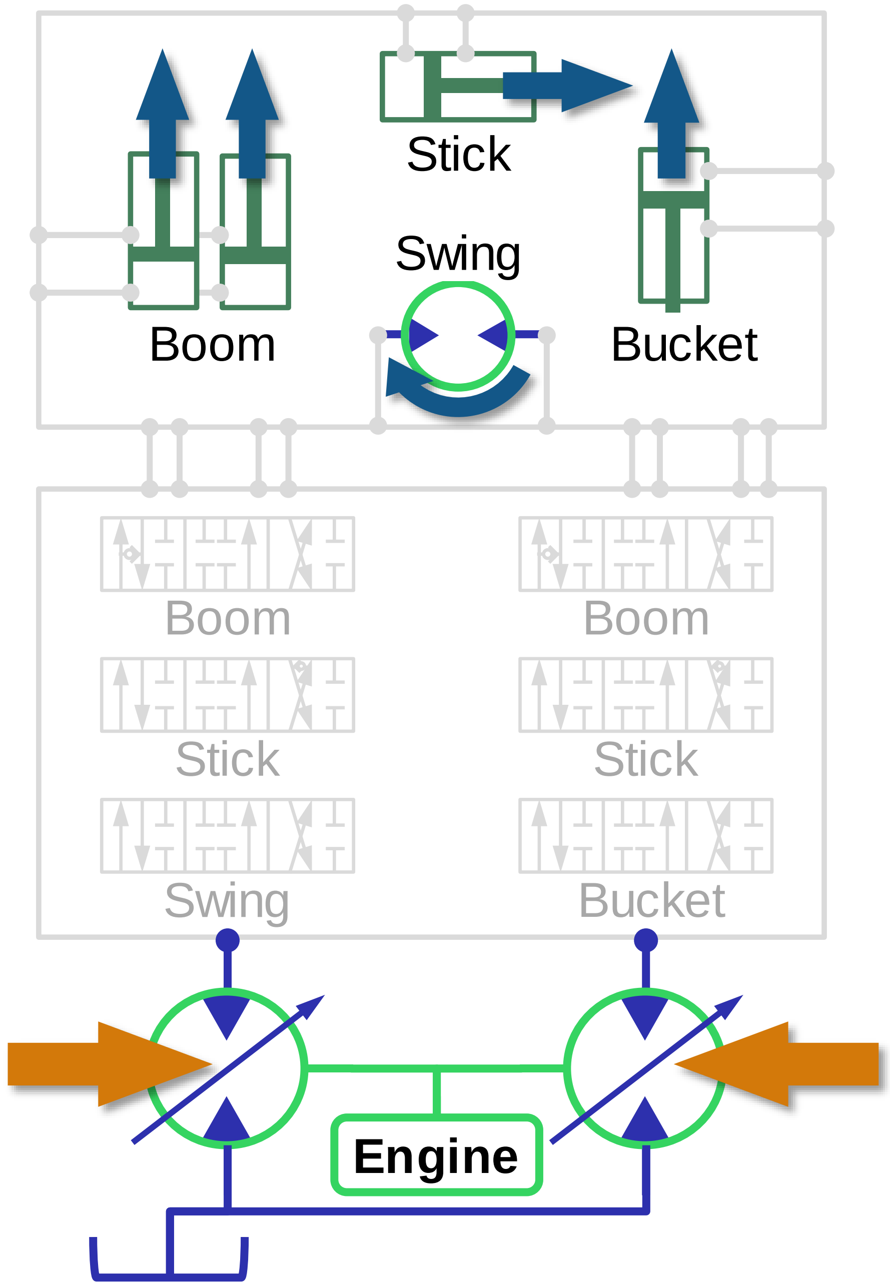




Assessing Overall Efficiency

- Simulation results used to calculate
  - Energy input to excavator
  - Energy output by excavator

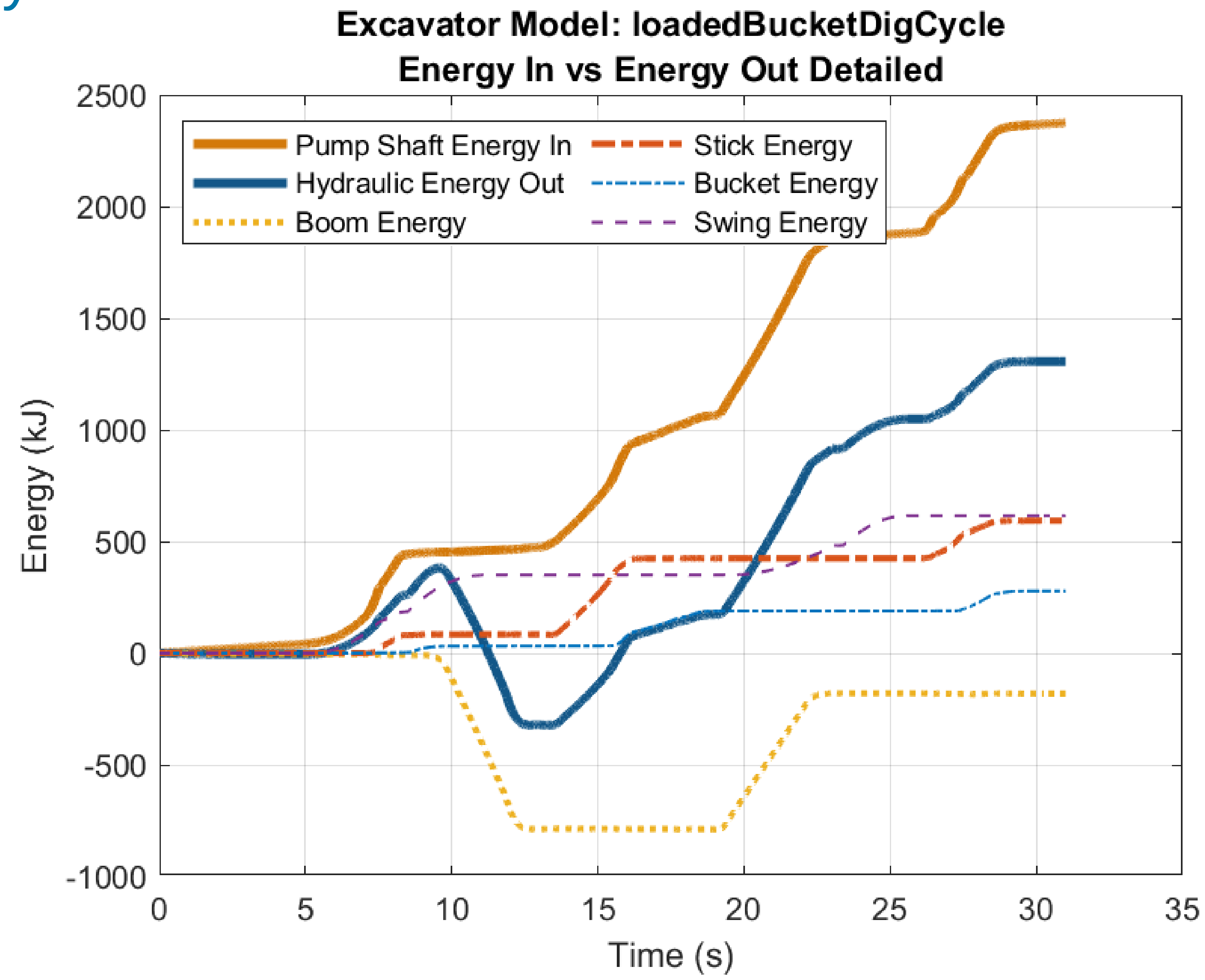




Assessing Overall Efficiency

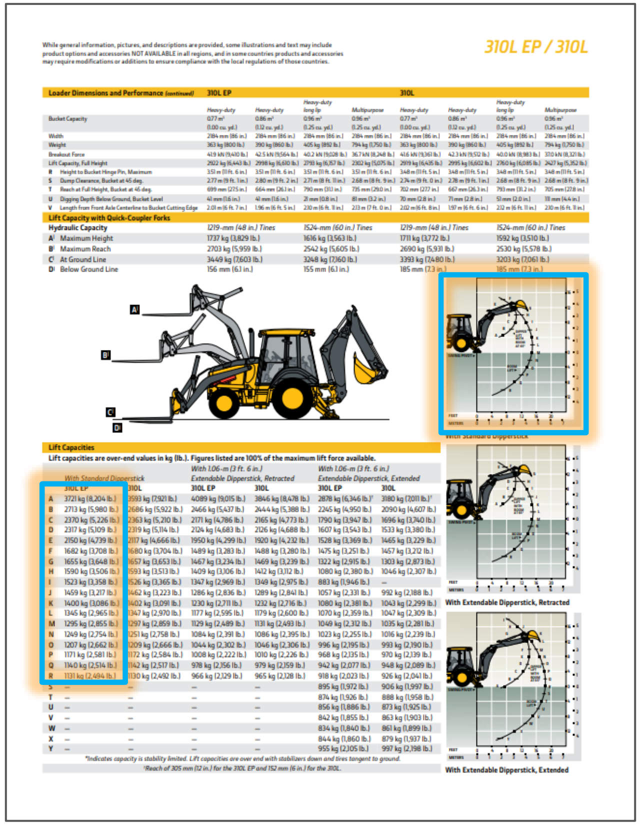
- Periods of “negative“ energy show where gravity helped lower the arm
  - Potential energy converted to energy we measured

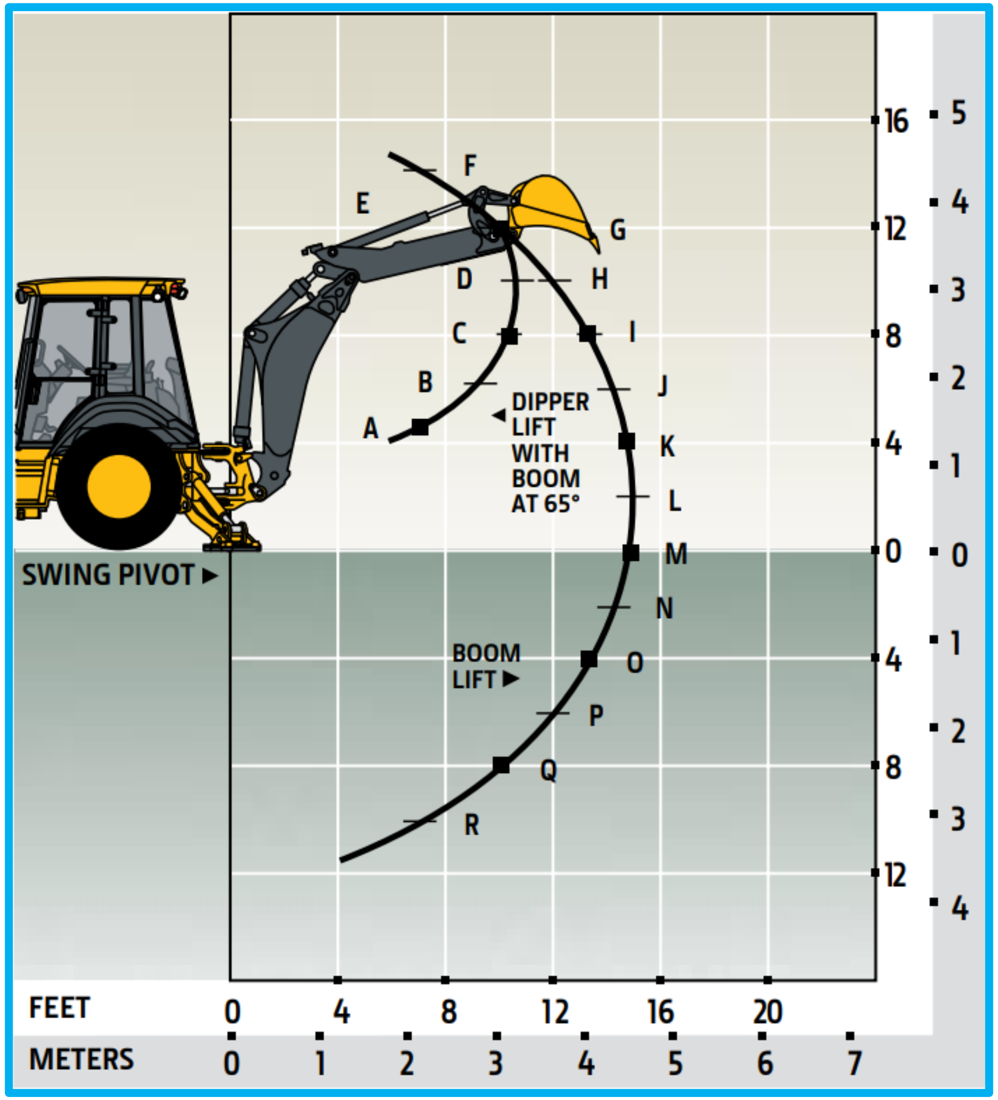
- Efficiency would be lower if we did not use regenerative flow



Explore Design Space: Load Chart

- Datasheets provide load charts to show lift capacity throughout excavator reach zone

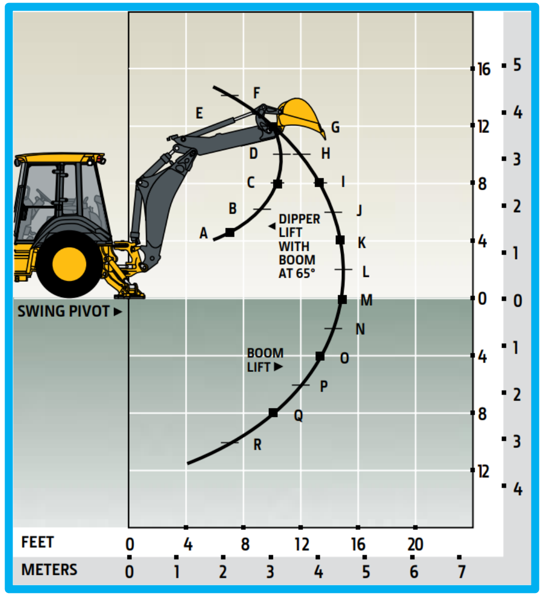


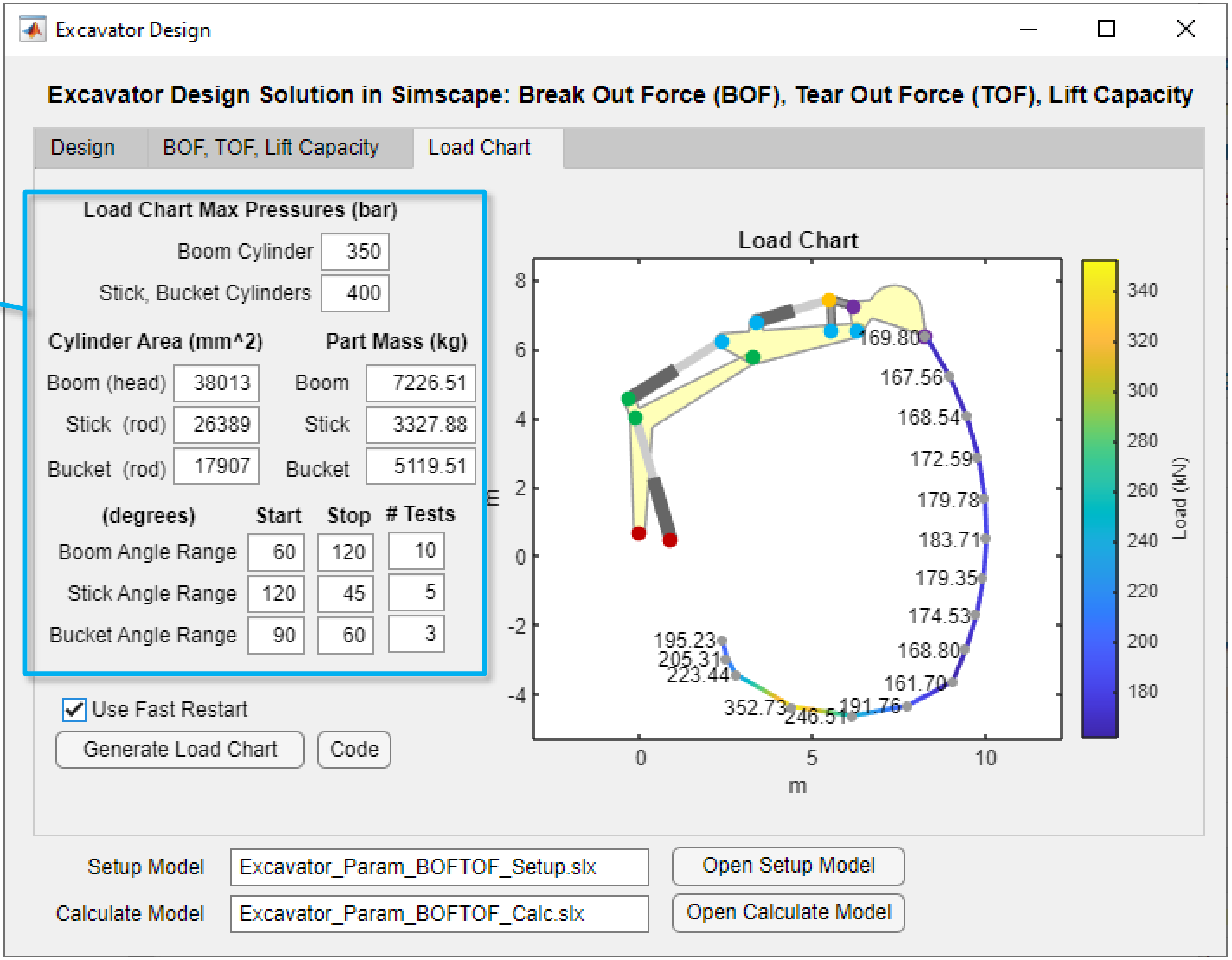


A	3721 kg (8,204 lb.)
B	2713 kg (5,980 lb.)
C	2370 kg (5,226 lb.)
D	2317 kg (5,109 lb.)
E	2150 kg (4,739 lb.)
F	1682 kg (3,708 lb.)
G	1655 kg (3,648 lb.)
H	1590 kg (3,506 lb.)
I	1523 kg (3,358 lb.)
J	1459 kg (3,217 lb.)
K	1400 kg (3,086 lb.)
L	1345 kg (2,965 lb.)
M	1295 kg (2,855 lb.)
N	1249 kg (2,754 lb.)
O	1207 kg (2,662 lb.)
P	1171 kg (2,581 lb.)
Q	1140 kg (2,514 lb.)
R	1131 kg (2,494 lb.)

Explore Design Space: Load Chart

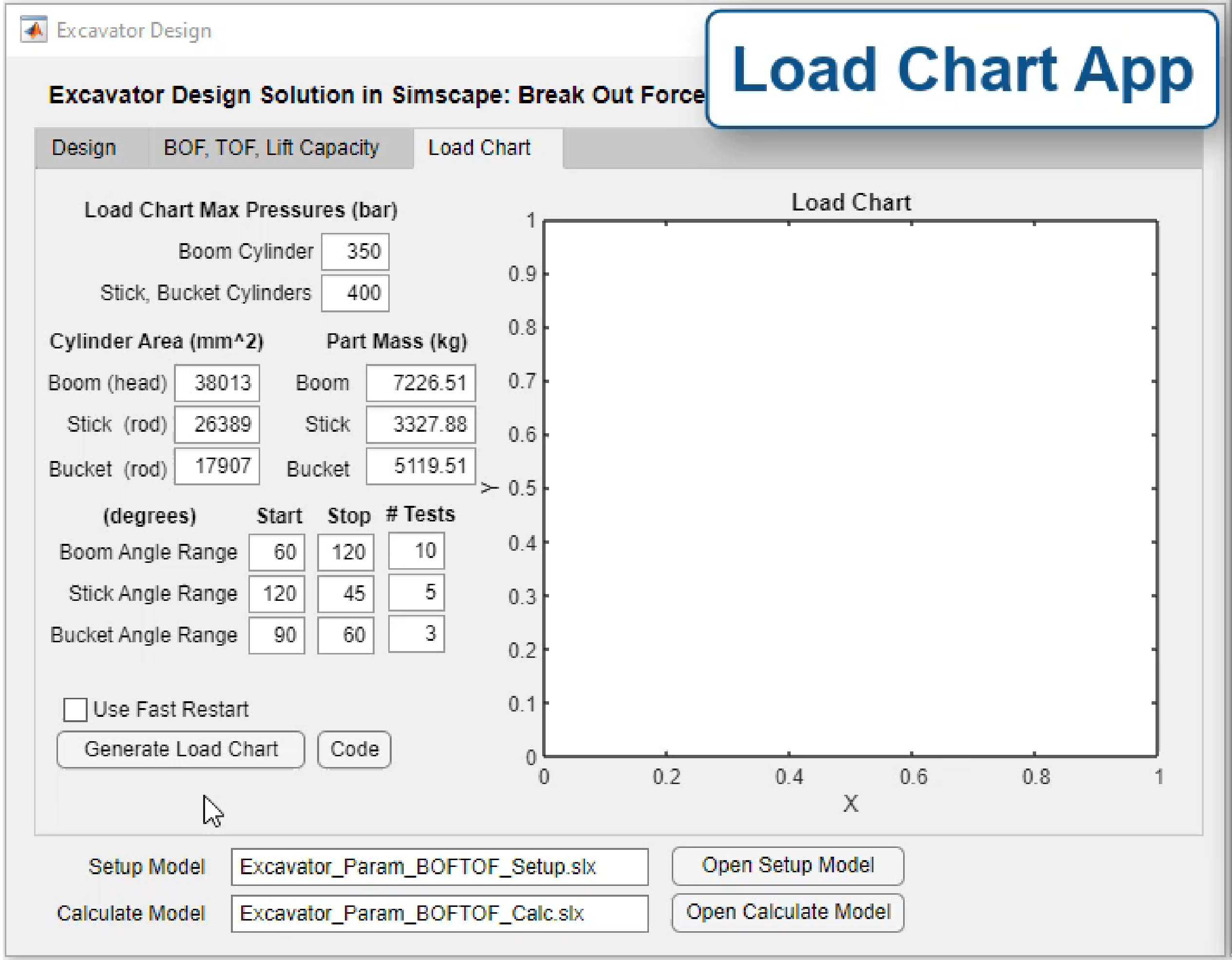
- MATLAB App lets you specify design space for load chart
  - Test positions
  - Pressure limits, actuator sizes
  - Part masses
- Results displayed in a plot

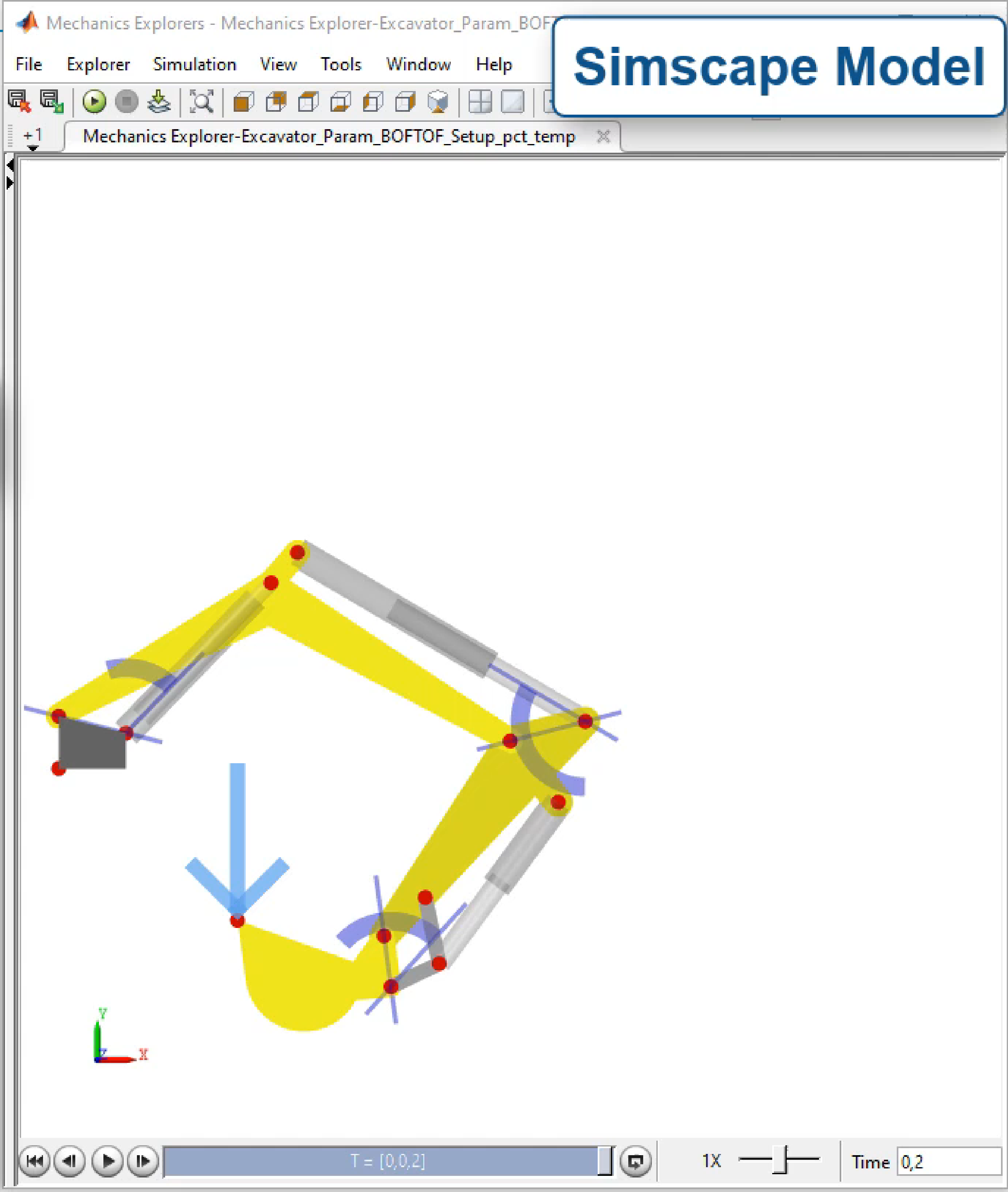




Explore Design Space: Load Chart

- Parameter sweep
  - Can run on multiple cores





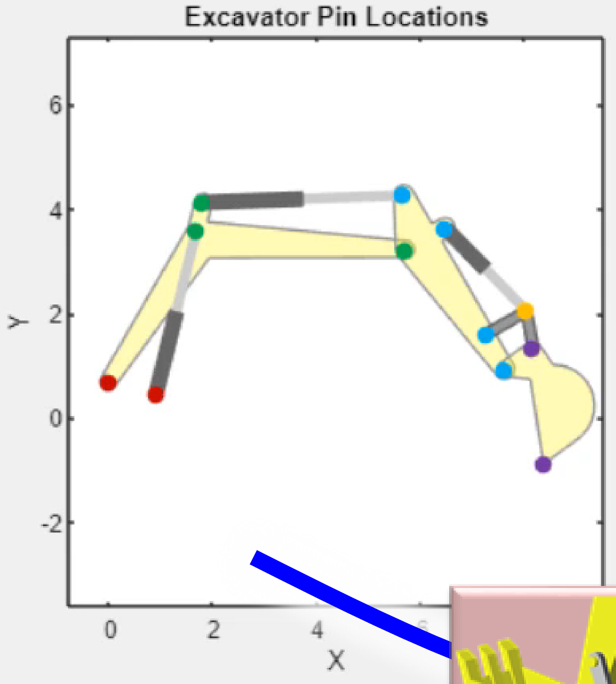
Roles of Design Solution and Full Actuation Model

Excavator Design

Excavator Design Solution in Simscape: Break Out Force (BOF), Tear Out Force (TOF), Lift Capacity

Design | BOF, TOF, Lift Capacity | Load Chart

Label	Part	Location	X(m)	Y(m)
A1	Chassis	Boom	0	0.7000
A2	Chassis	Boom Cylinder	0.9000	0.4750
B1	Boom	Boom Cylinder	1.6825	3.6050
B2	Boom	Stick Cylinder	1.8050	4.1269
B3	Boom	Stick	5.7012	3.2253
C1	Stick	Stick Cylinder	5.6642	4.2641
C2	Stick	Bucket Cylinder	6.4528	3.6418
C3	Stick	Linkage	7.2375	1.5979
C4	Stick	Bucket	7.5958	0.9339
E1	Linkage	Bucket Cylinder	8.0225	2.0441
D1	Bucket	Linkage	8.1467	1.3393
D2	Bucket	Cutting Edge	8.3501	-0.8885
D3	Bucket	CG	8.3501	-0.8885



Plot Design Position | Model Design Position

Load Design and Modify Points | Design A | Load | View in Excel

Setup Model: Excavator_Param_BOFTOF_Setup.slx | Open Setup Model

Calculate Model: Excavator_Param_BOFTOF_Calc.slx | Open Calculate Model

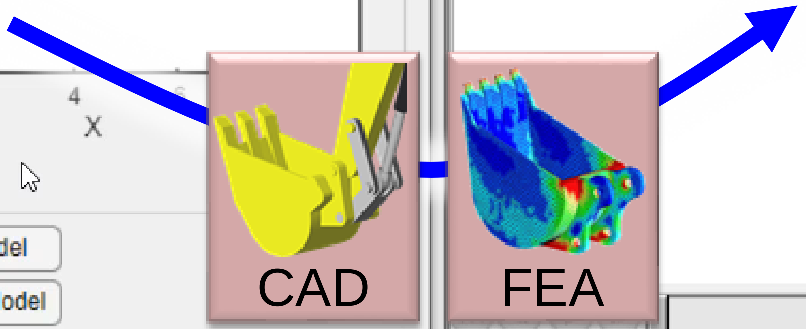
Mechanics Explorers - Mechanics Explorer-Excavator_start

File Explorer Simulation View Tools Window Help

View convention:

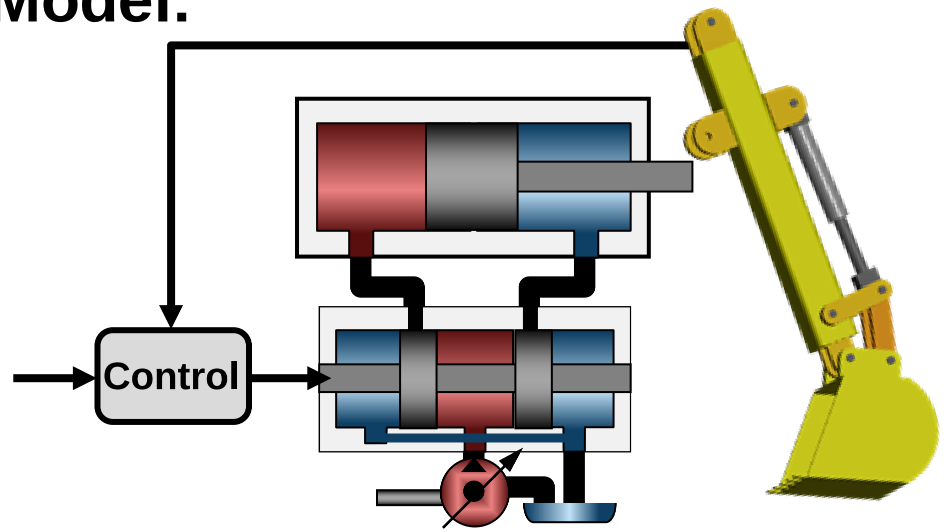
Mechanics Explorer-Excavator_start

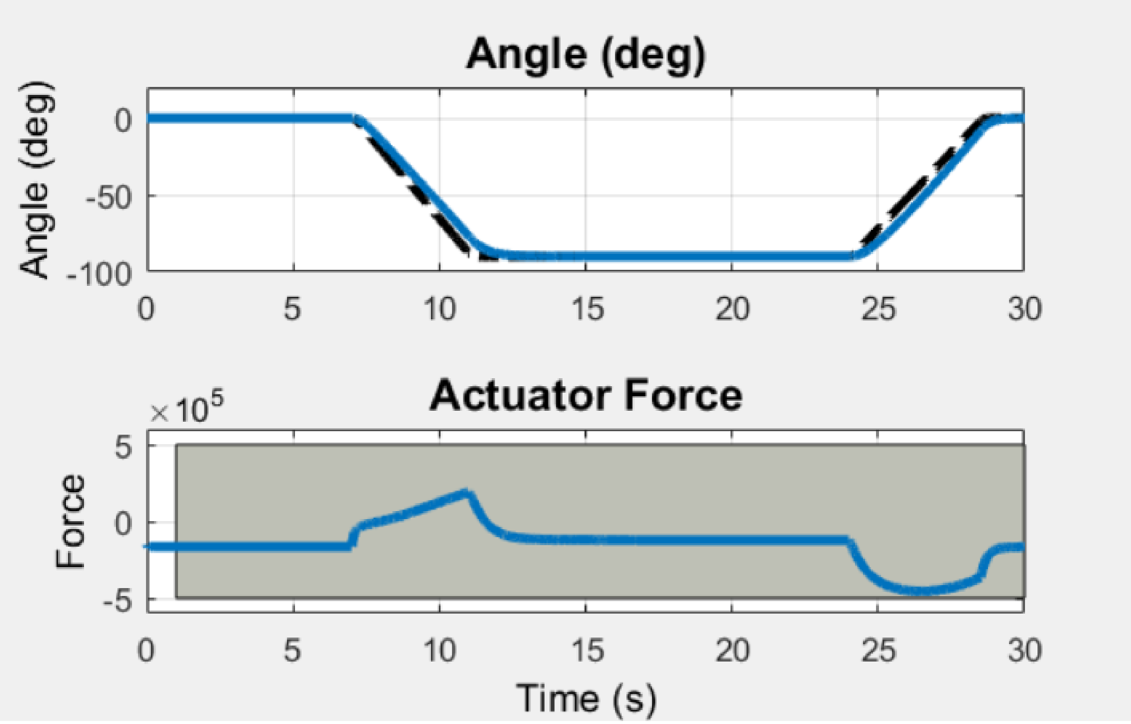
0% | 1X | Time 0



Optimizing System Performance

Model:





Problem: Optimize the position controller to meet system requirements

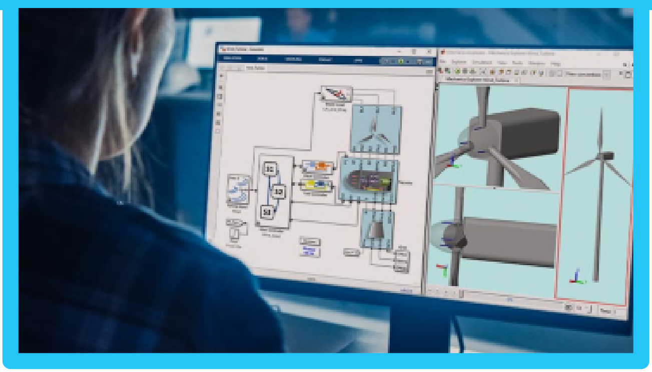
Solution: Tune controller parameters with Simulink Design Optimization

K_p	K_i
23.4	3.67

Use Physical Model in Model-Based Design Workflow

Model-Based Design

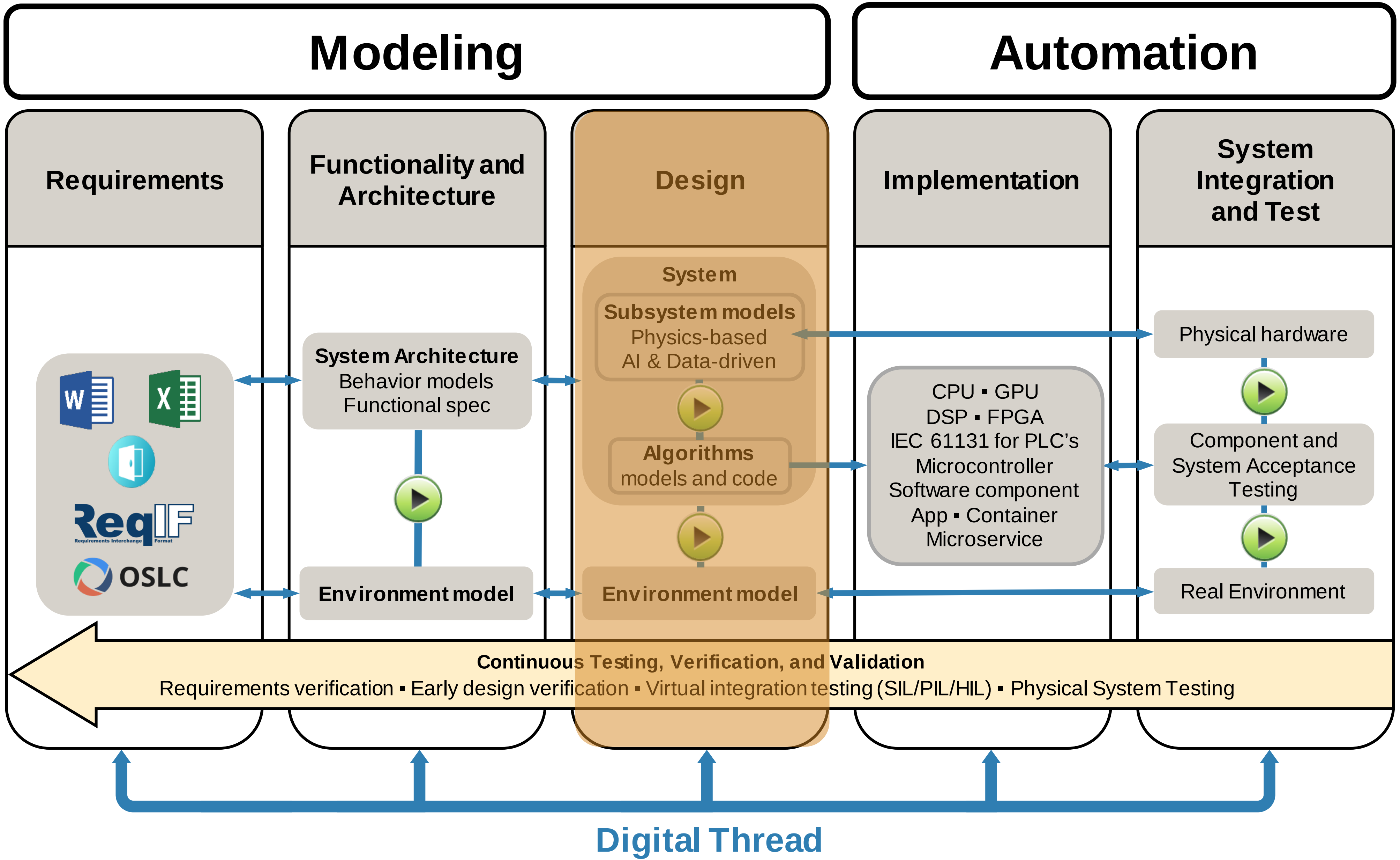
Requirements | **Functionality and Architecture** | **Design** | **Implementation** | **System Integration and Test**



Models are at the **center** of your development process

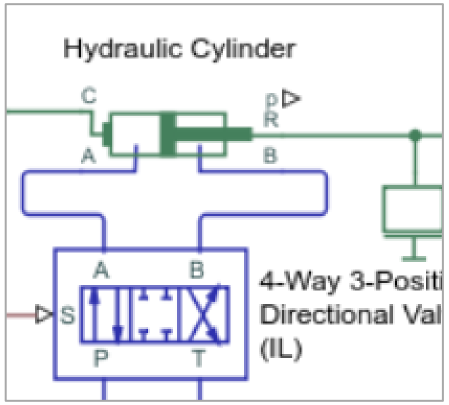
Create a **digital thread**

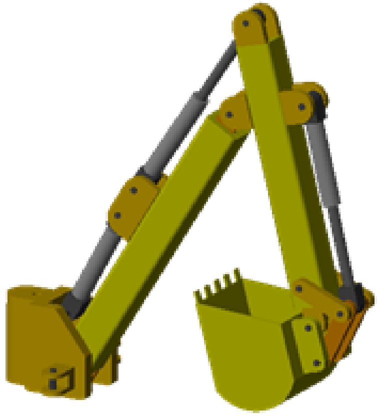
Model-Based Design = Modeling + Automation

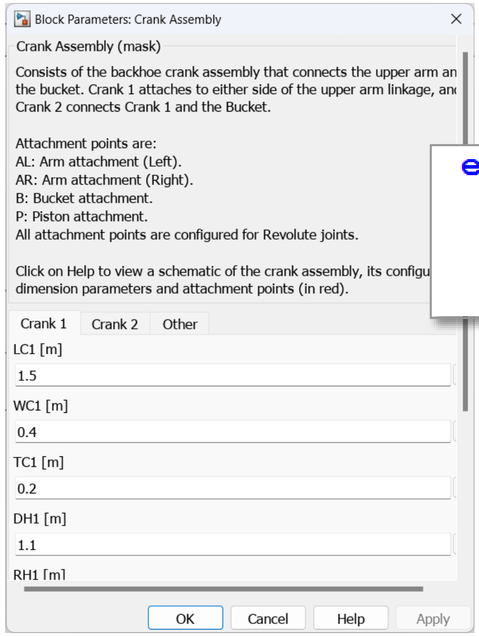


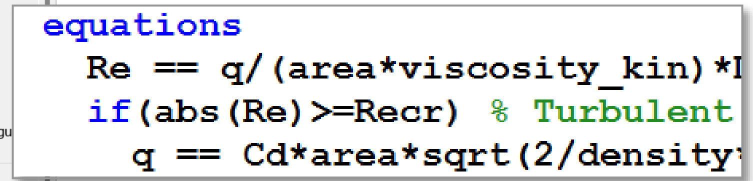
Key Points

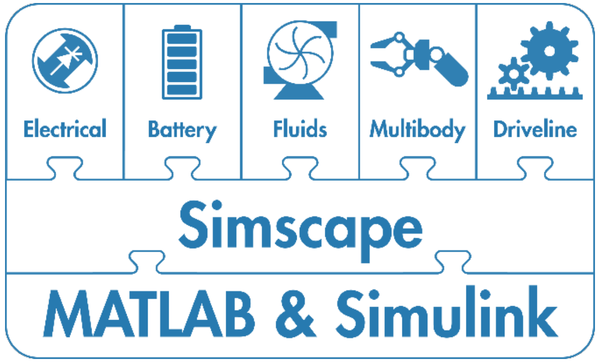
- Simscape provides powerful libraries of component models for multi-domain systems
- Models can be adapted to your needs
  - Create reusable assemblies
  - Adjust parameterization
  - Define custom components
- Leverage MATLAB and Simulink
  - Use powerful analysis tools
  - Perform parameter sweeps and optimization











Start with free Onramp Training

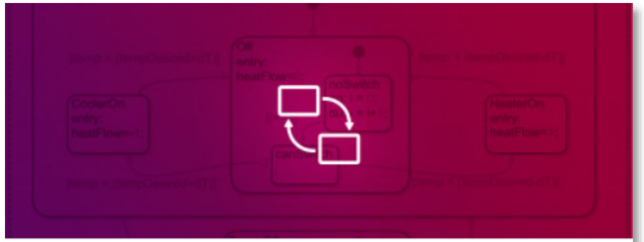
- Free hands-on tutorials
- Short videos and hands-on exercises with feedback
- Get up and running with MATLAB, Simulink and Simscape in hours

MATLAB Onramp

Get started quickly with the basics of MATLAB.

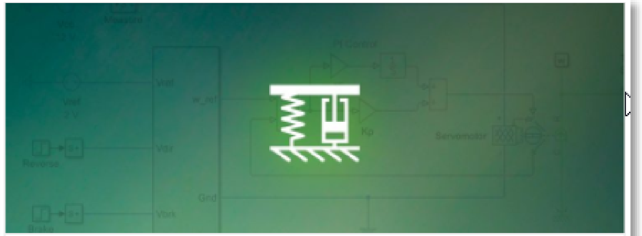
Simulink Onramp

Get started quickly with the basics of Simulink.



Stateflow Onramp

Learn the basics of creating, editing, and simulating state machines in Stateflow.



Simscape Onramp

Erlernen Sie die Grundlagen der Simulation physikalischer Systeme in Simscape.

…and more at matlabacademy.mathworks.com