MATLAB EXPO 2017

Modeling Mechanical and Hydraulic Systems in Simscape

Dhirendra Singh

too big

USER STORY

ABB Optimizes Ship Energy Flows

too difficult

USER STORY

DCNS Simulates Handling System

one chance

USER STORY

Lockheed Martin Develops MRO

Courtesy NASA/JPL-Caltech

Why use Simscape?

Makes modeling easy

Simscape **handles equations automatically**

$$F_{Spring} = k_{Spring}{}^{*}(z_{Car})$$

$$F_{Shock} = b_{Shock}{}^{*}(\frac{dz_{Car}}{dt})$$

$$\frac{d^2 z_{Car}}{dt^2} = \frac{-F_{Spring} - F_{Shock}}{m_{Car}}$$

Simulink

Simscape

Simscape **handles equations automatically**

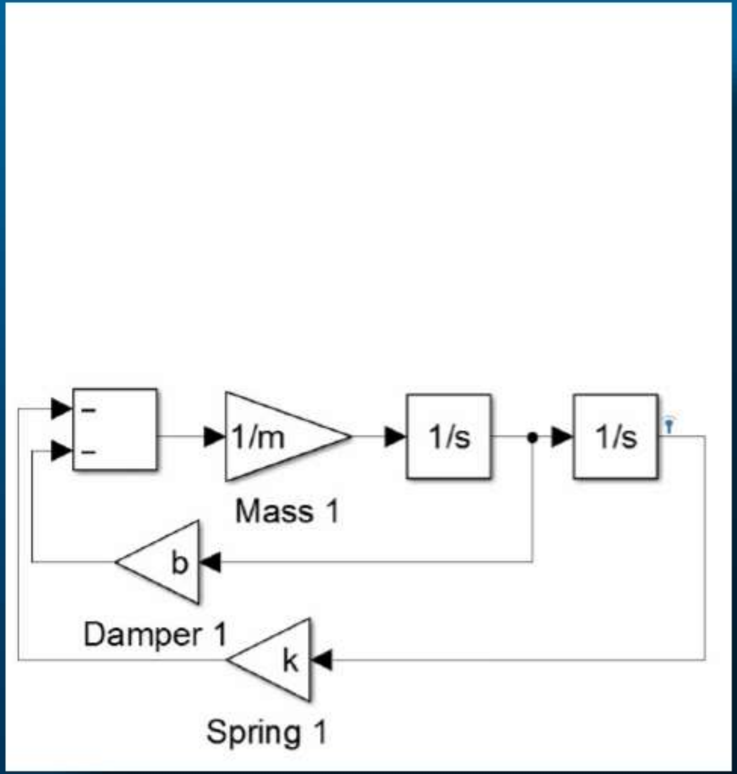
$$F_{Spring} = k_{Spring}*(z_{Car} - z_{Whl})$$

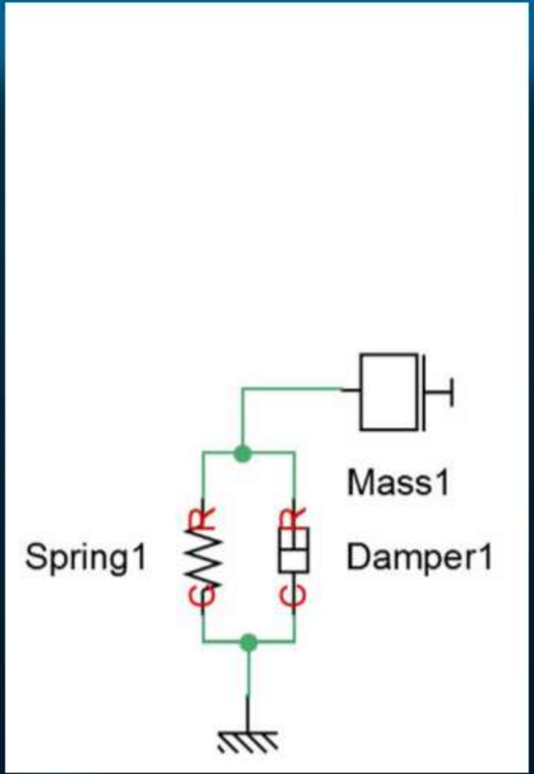
$$F_{Shock} = b_{Shock}*(\frac{dz_{Car}}{dt} - \frac{dz_{Whl}}{dt})$$

$$\frac{d^2 z_{Car}}{dt^2} = \frac{-F_{Spring} - F_{Shock}}{m_{Car}}$$

$$F_{Tire} = k_{Tire}*(z_{Whl}) + b_{Tire}*(\frac{dz_{Car}}{dt})$$

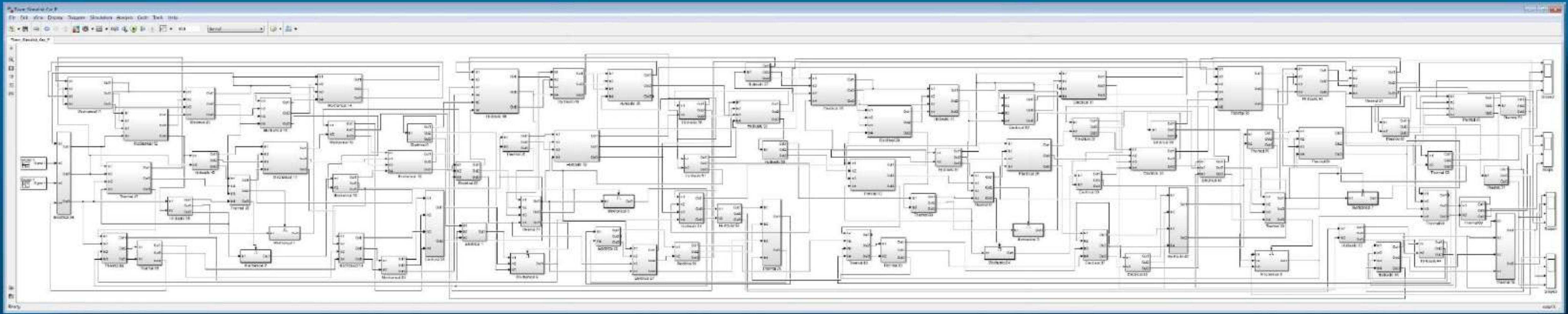
$$\frac{d^2 z_{Whl}}{dt^2} = \frac{F_{Spring} + F_{Shock} - F_{Tire}}{m_{Car}}$$

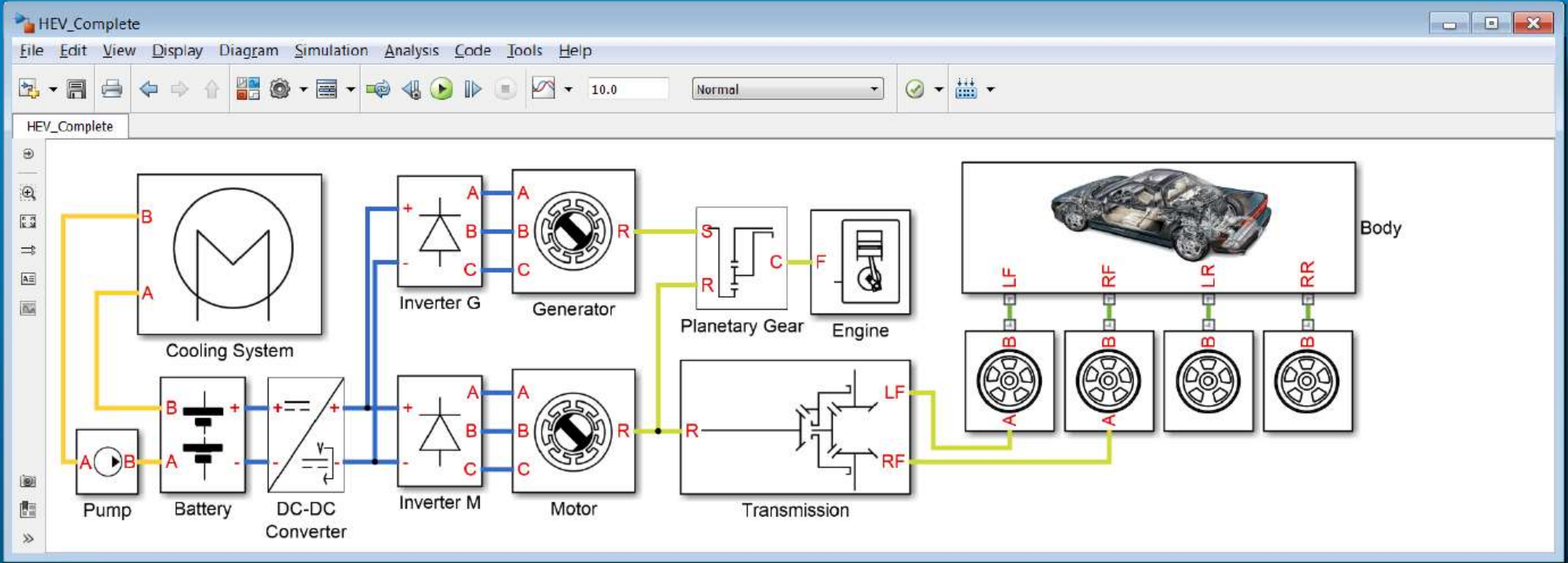




3D mechanics
hybrid powertrain

power steering
air conditioning





electrical

mechanical

hydraulic

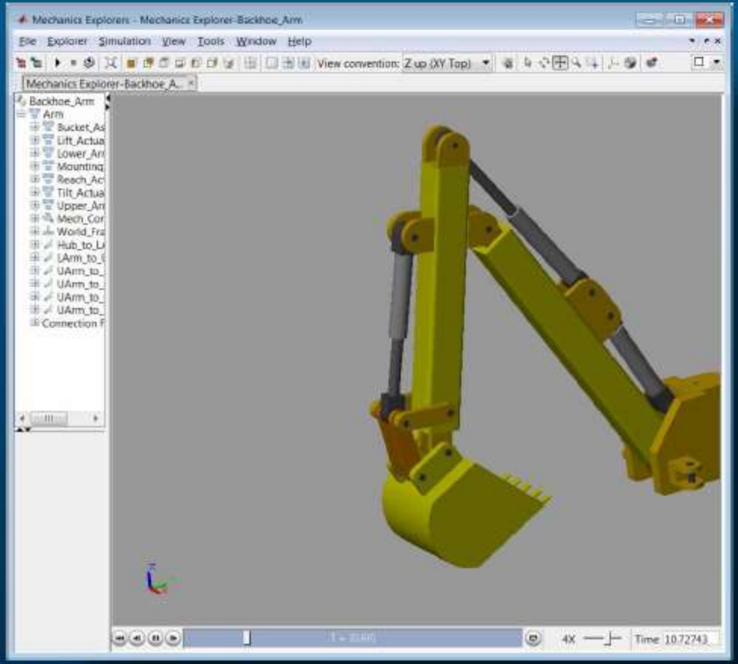
less clicking
more simulating

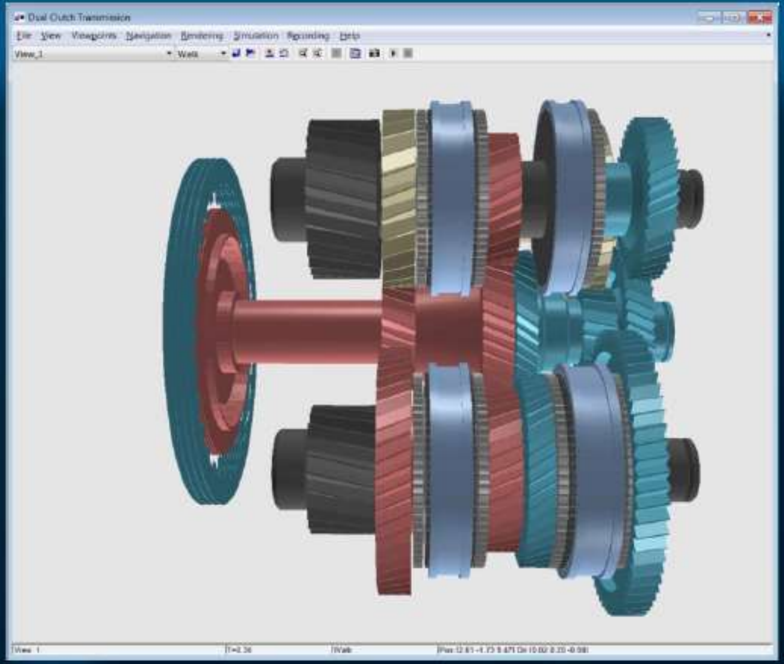
Market Demand:

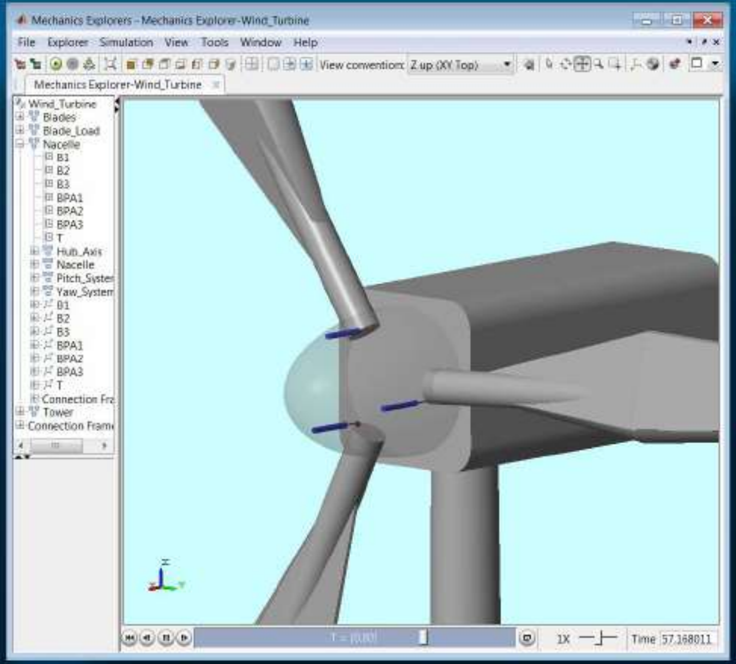
Reduce energy consumption in integrated systems

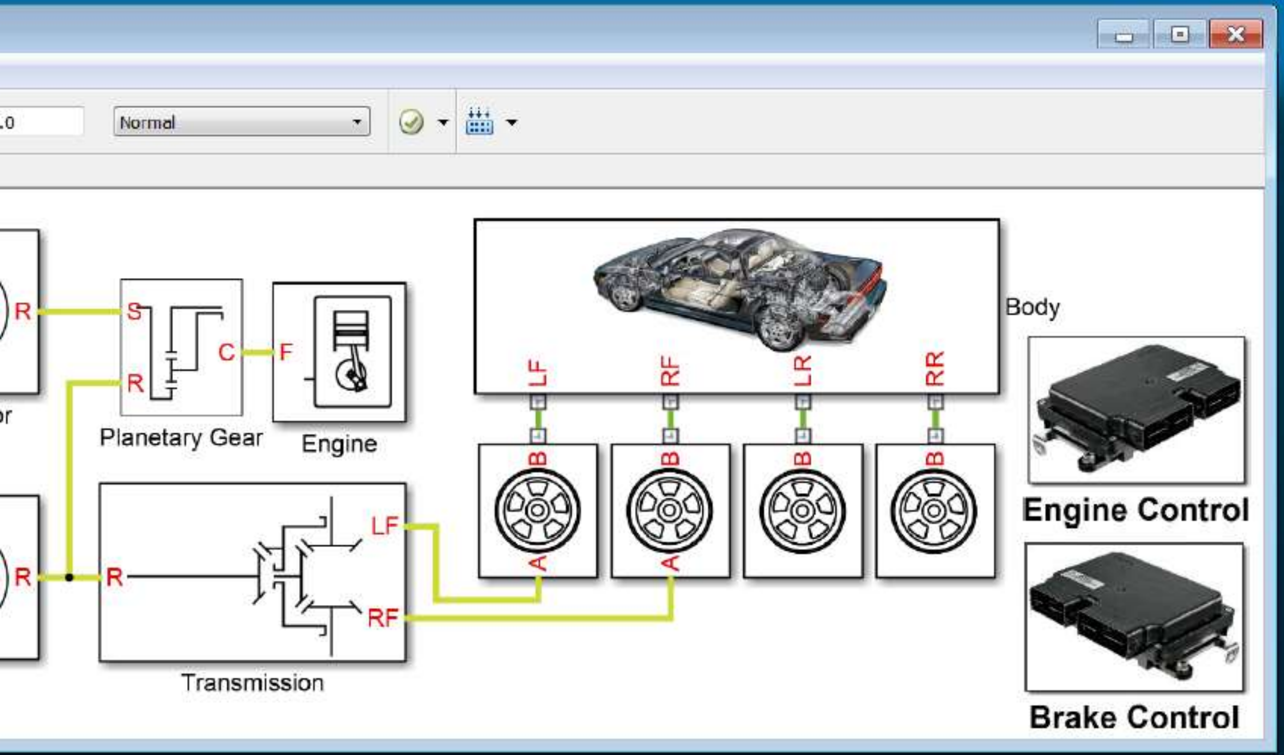
Simscape Focus:

Domain integration
Algorithm design
Optimization









Why model the physical system?

Too big, too difficult, one chance, …

Why Simscape?

Makes modeling easy
Develop controller
Find best design

Agenda

- **Motivation**
- Simscape physical network approach
- Example: BackHoe
- System Level Integration
  - Mechanical system
  - Hydraulics system
- Parameter Tuning
- Simcape in Model-Based Design

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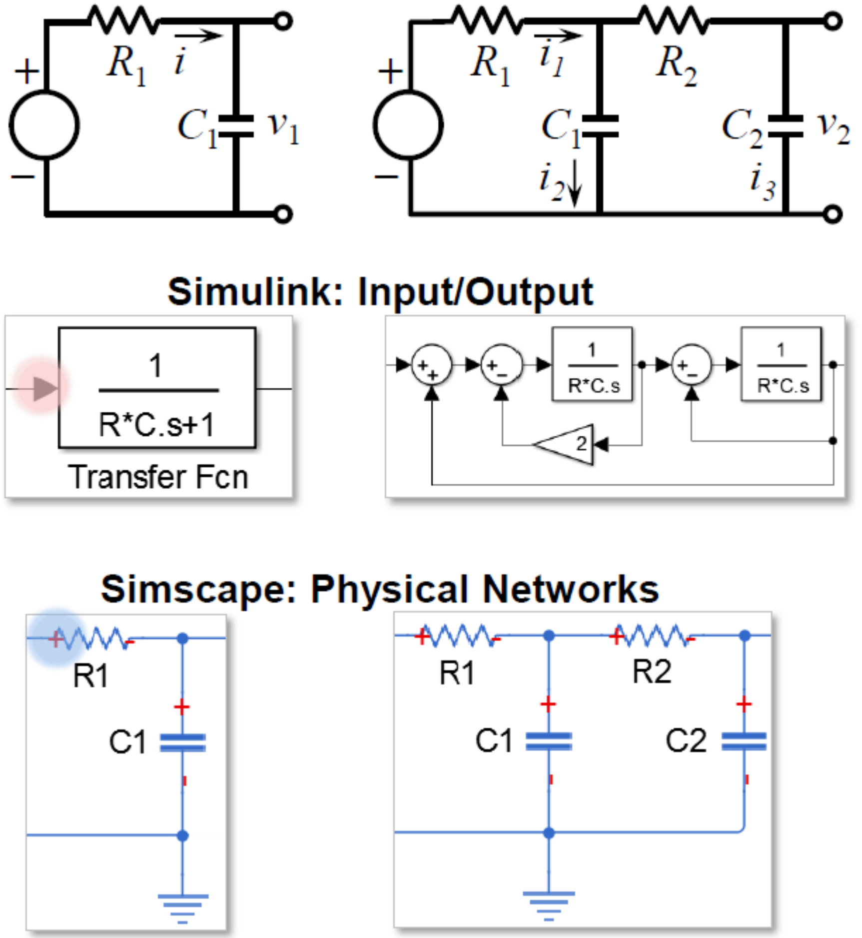
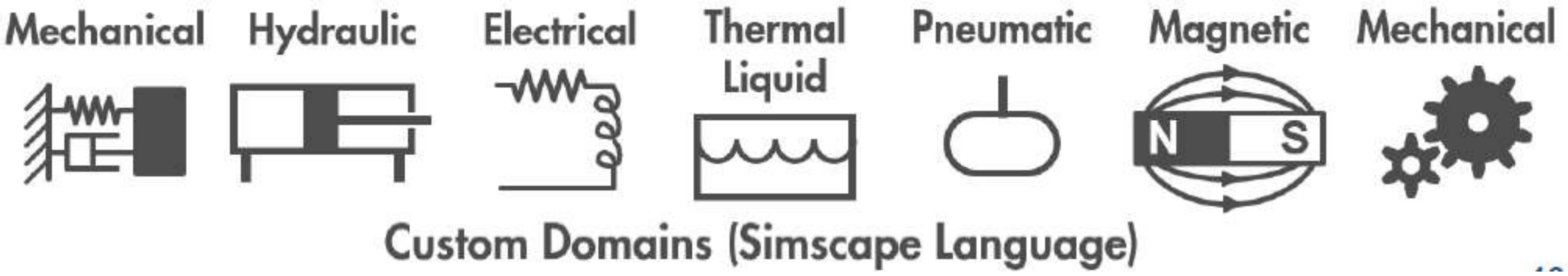
Physical Modeling with Simulink

- Simulink is best known for signal based modeling
  - Causal, or input/output
- Simscape enables bidirectional flow of energy between components
- System level equations:
  - Formulated automatically
  - Solved simultaneously
  - Cover multiple domains





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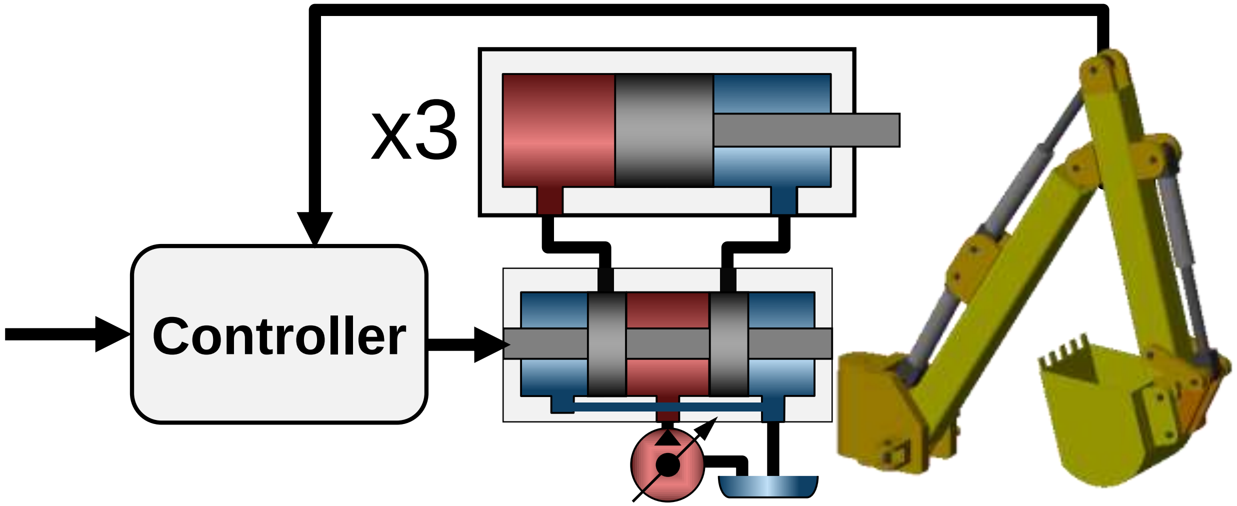
Backhoe Actuation System

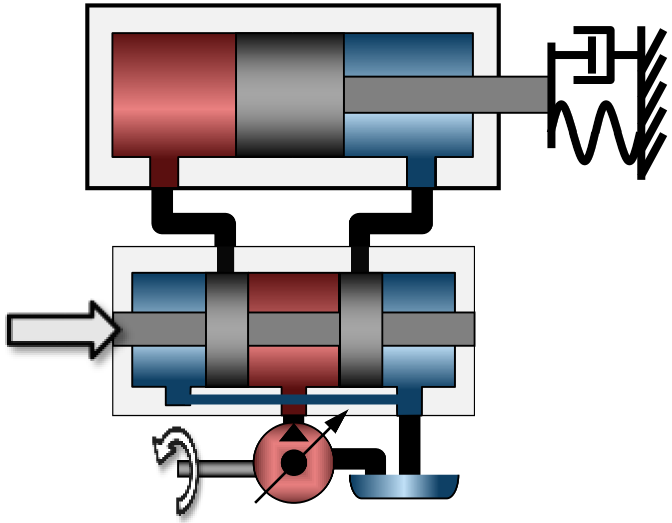
- System

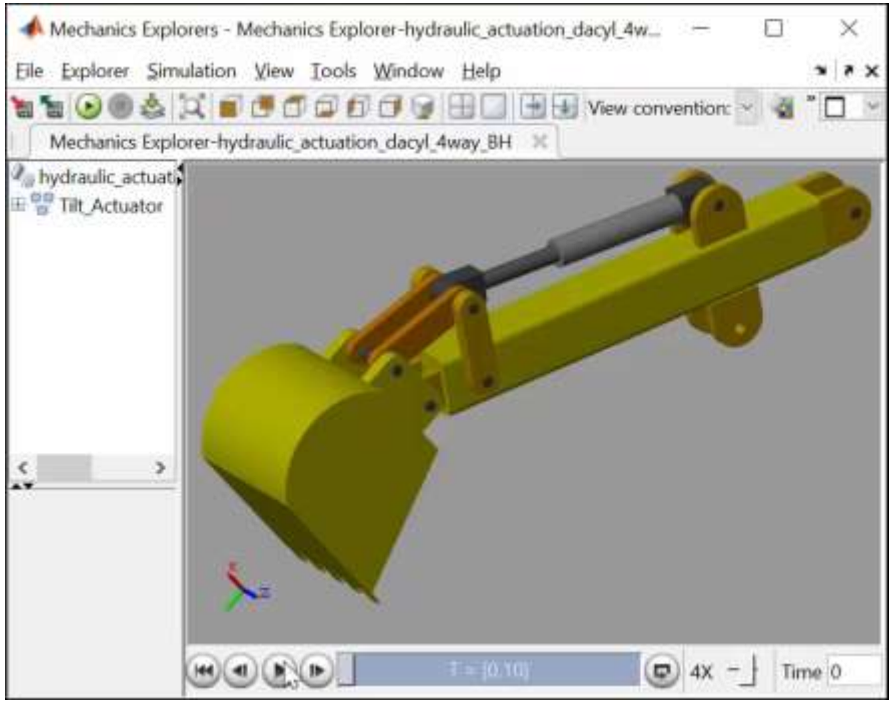


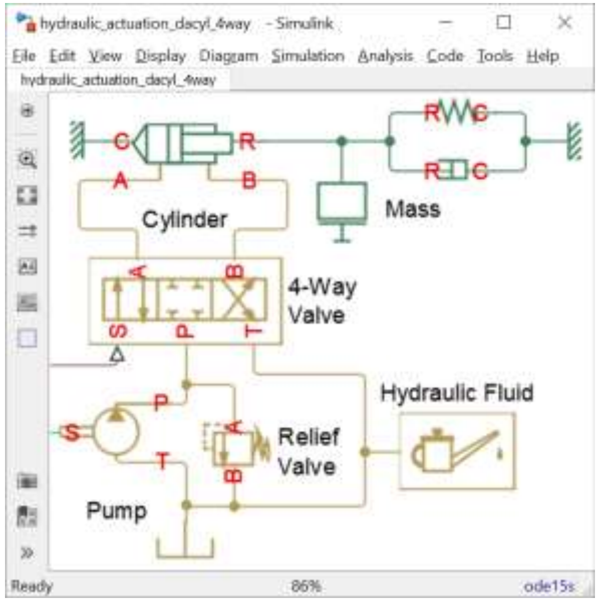
- Simulation Tasks
  1. Determine required size for actuator components
  2. Optimize design parameters in actuator and controller
  3. Measure robustness of design with relevant physical effects
  4. Test embedded hardware and software using HIL testing

Modeling a Hydraulic Actuation System

Model:







Problem: Model a hydraulic actuation system within the Simulink environment

Solution: Use Simscape Fluids to model the hydraulic system & Simscape Multibody to model mechanical system

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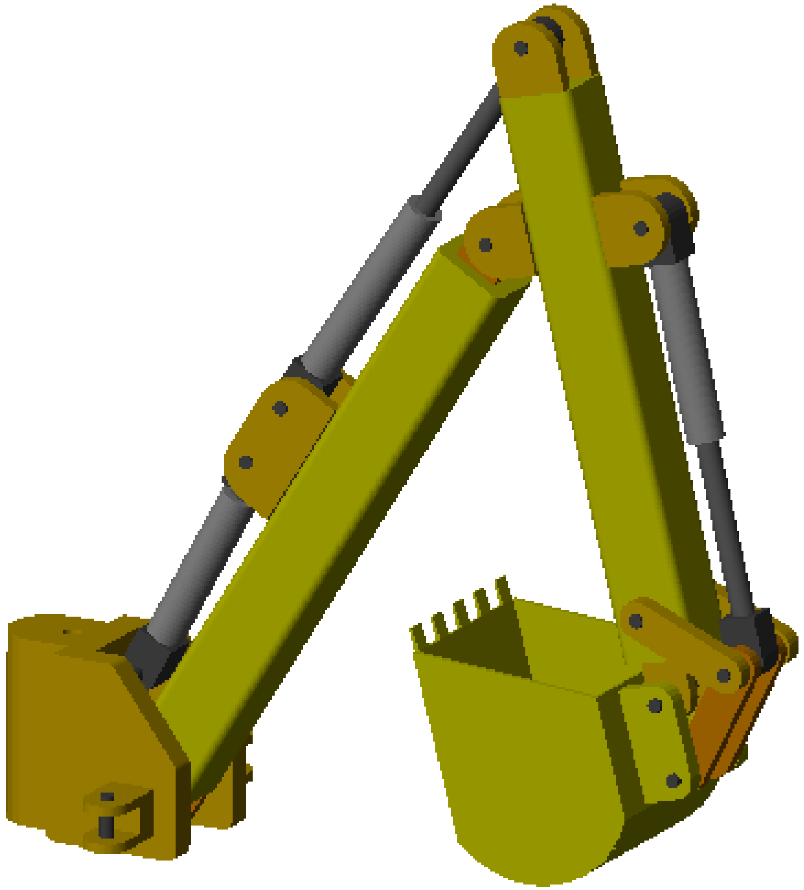
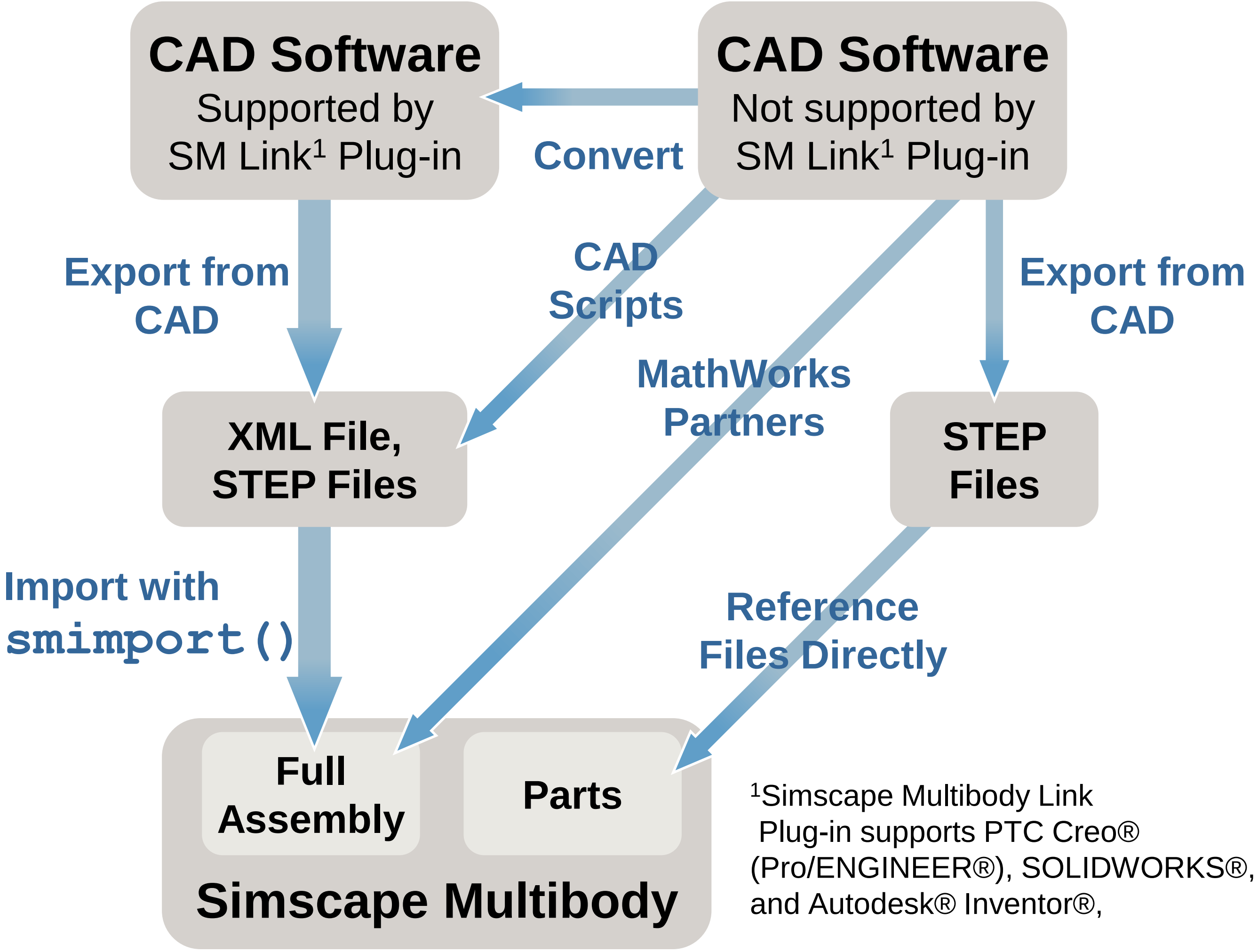
Mechanical System



CAD to Simscape Multibody Solutions

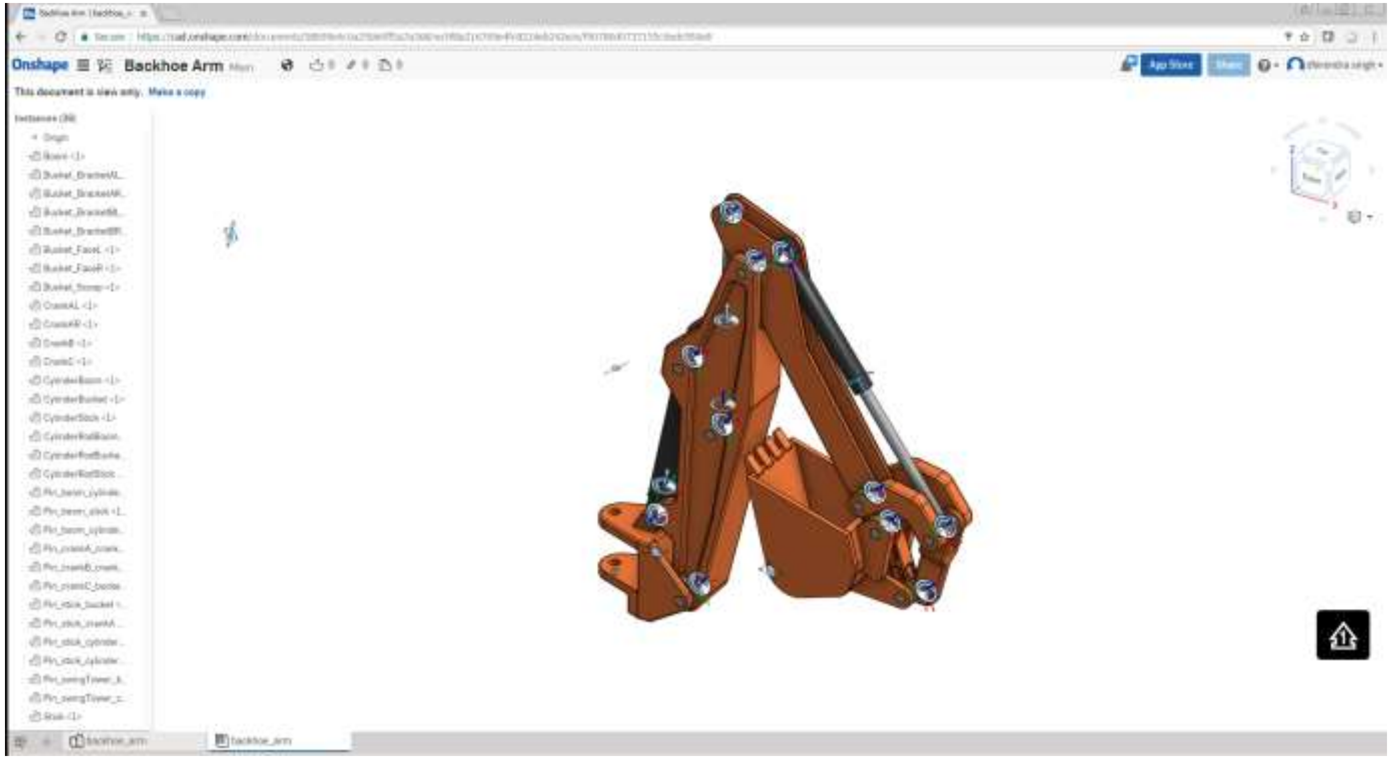
- Options for all CAD systems
- Convert full assembly via Simscape Multibody Link
  - Converts mates to joints
  - Mass, inertia, geometry, colors all converted
  - Block diagram built automatically
    - Same hierarchy as CAD model
- Reference files directly
  - STEP or STL files



[1]Simscape Multibody Link Plug-in supports PTC Creo® (Pro/ENGINEER®), SOLIDWORKS®, and Autodesk® Inventor®,

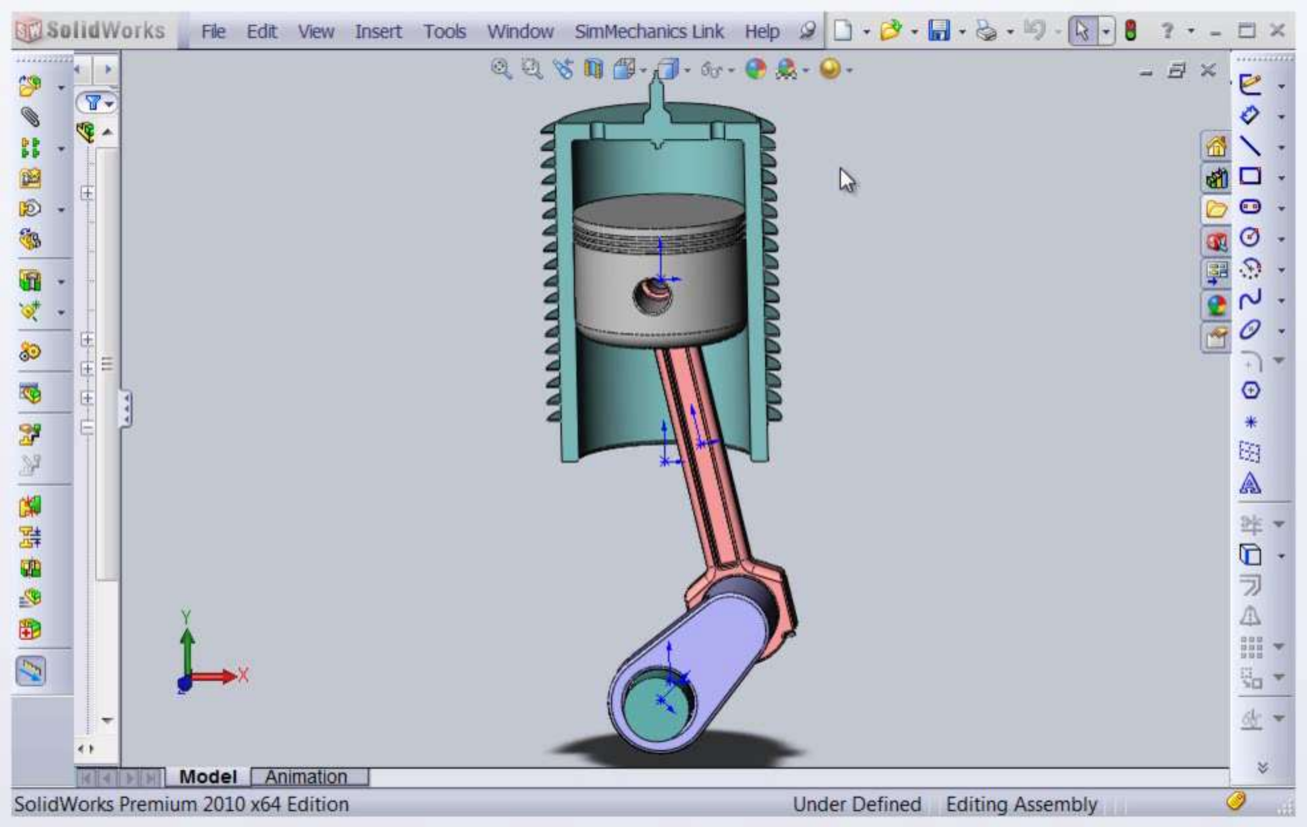
CAD model

- https://cad.onshape.com/documents/58b99e4c0a25bb0ff5a7a368/w/0f8a216769e4fc8224eb242e/e/f90780d0737155c0edc950e8



Simscape Multibody Link: Convert CAD Assembly to Simscape Mutibody

- Use Simscape Multibody Link plugin to export from CAD to XML
- Import XML file into Simscape Multibody (`>> smimport`)

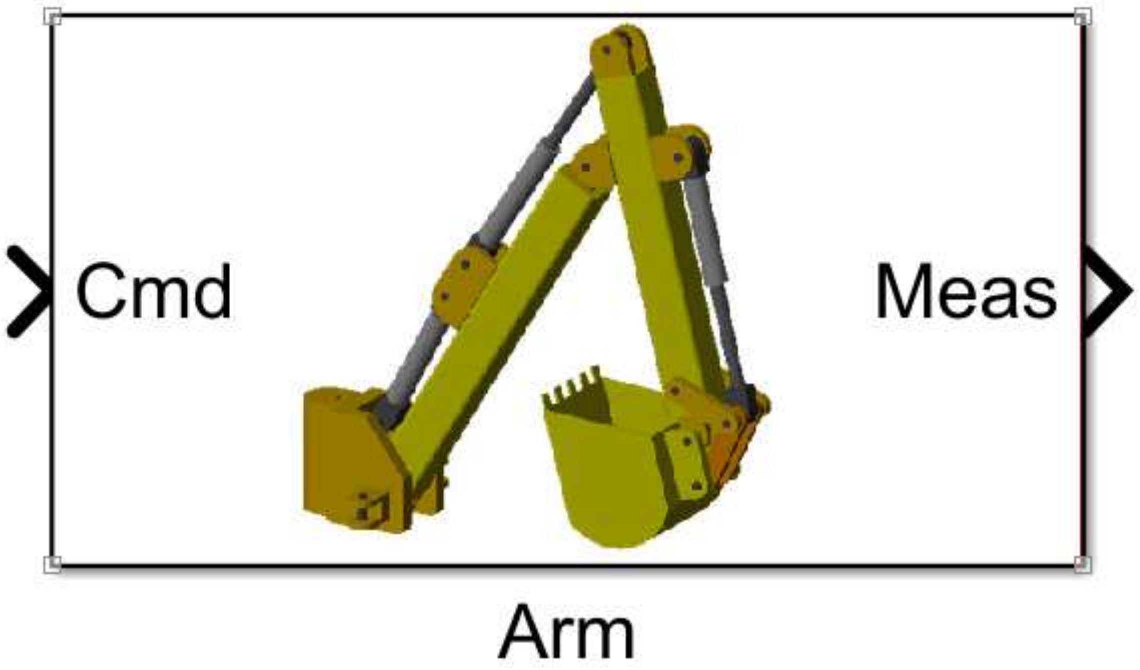


Demo

- Lets bring the CAD model into Simscacpe Multibody

Mechanical System

- **Fewer iterations on mechanical design** because requirements are refined
- **Fewer mechanical prototypes** because mistakes are caught earlier
- **Reduced system cost** because components are not oversized
- **Less system downtime** because system is debugged using virtual commissioning



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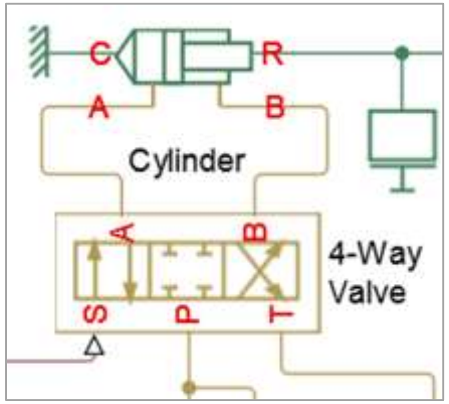
Demo

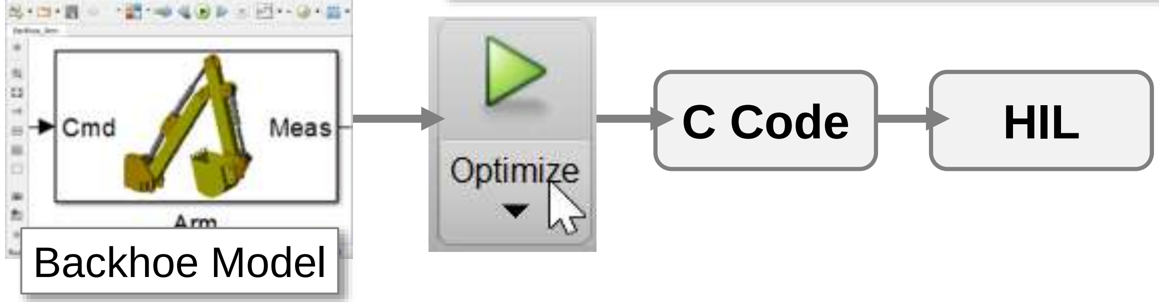
- Lets Build hydraulic actuation for our mechanical model

Hydraulic Actuation System – using Simscape Fluids

- Provides libraries of component models for fluid power systems
- Models can be customized for your needs
  - Create reusable assemblies
  - Adjust parameterization
  - Define custom components
- Leverage MATLAB and Simulink
  - System-level analysis
  - Control design and HIL testing



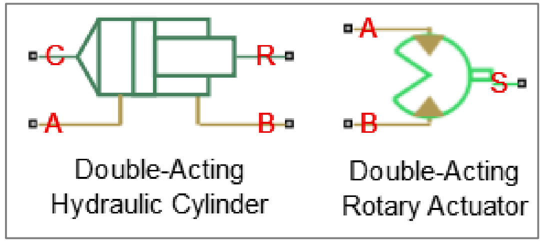
```
equations
  Re == q/(area*viscosity_kin)*I
  if(abs(Re)>=Recr) % Turbulent
    q == Cd*area*sqrt(2/density
```



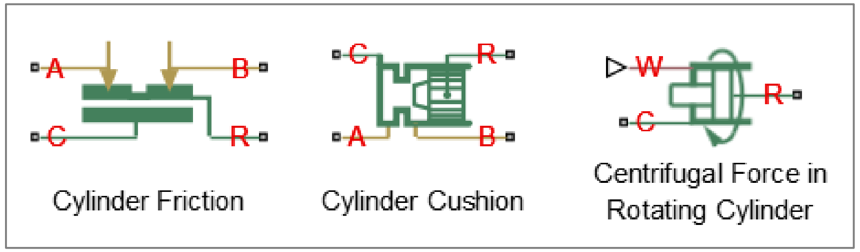
Adjusting Fidelity Using Simscape Fluids Components

Actuators, Valves, Pumps and Motors, Pipes and Tanks, Heat Exchangers

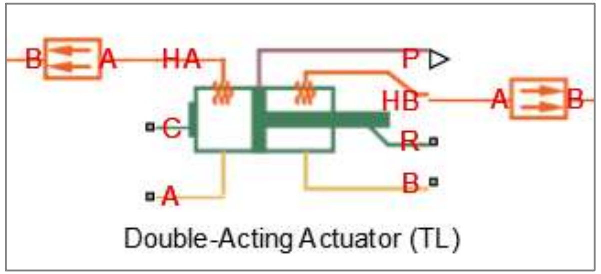
- Translational and rotational
  - Add or neglect compressibility



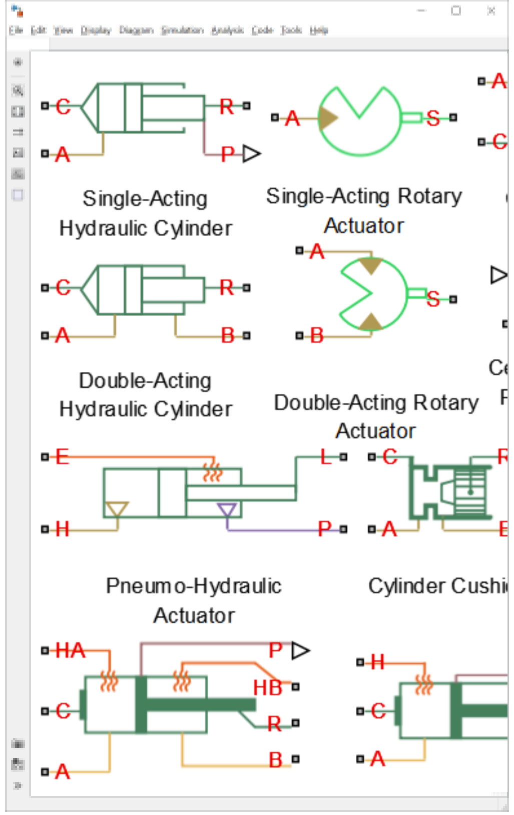
- Mechanical effects
  - Hard stops, Friction
  - Forces



- Thermal effects
  - Effect of temperature on fluid properties
  - Heat transfer to environment



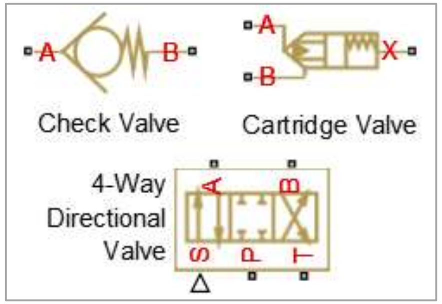
Subset of libraries

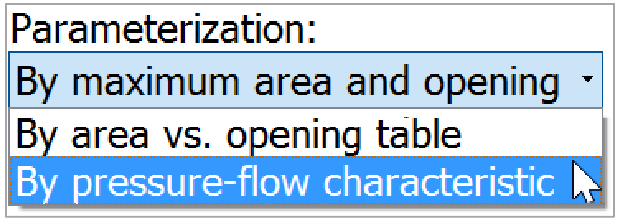


Adjusting Fidelity Using Simscape Fluids Components

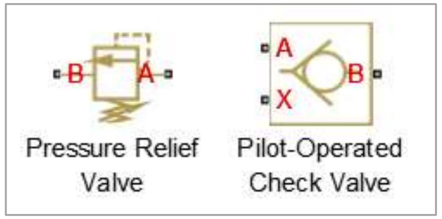
Actuators, **Valves**, Pumps and Motors, Pipes and Tanks, Heat Exchangers

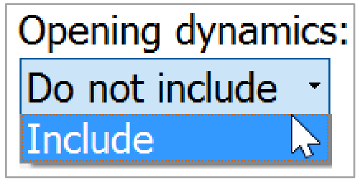
- Directional
  - Spool, check, cartridge
  - Parameterization options



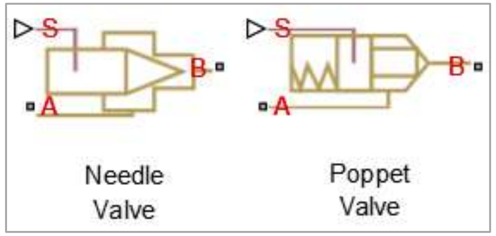


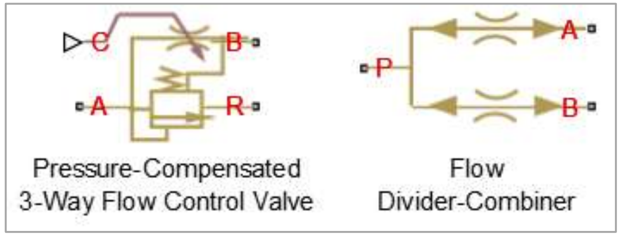
- Pressure control
  - Control tasks (variable)
  - Switching tasks (fixed)





- Flow control
  - Pressure dependent
  - Pressure independent





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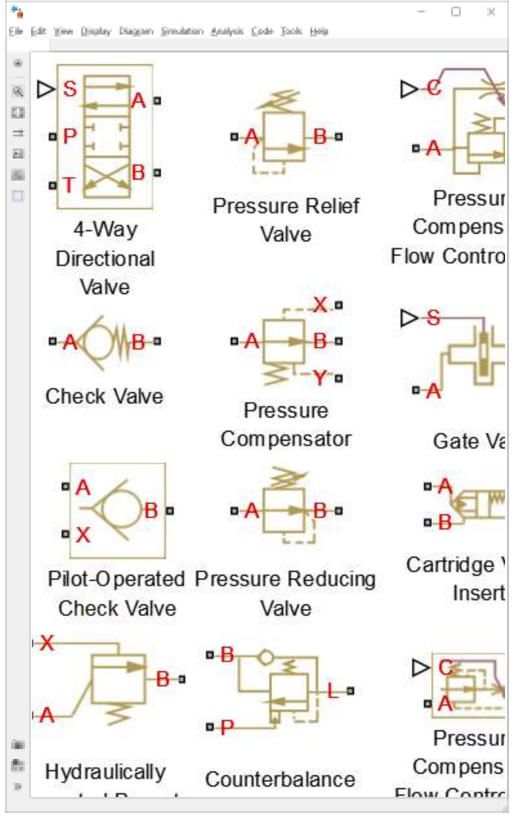
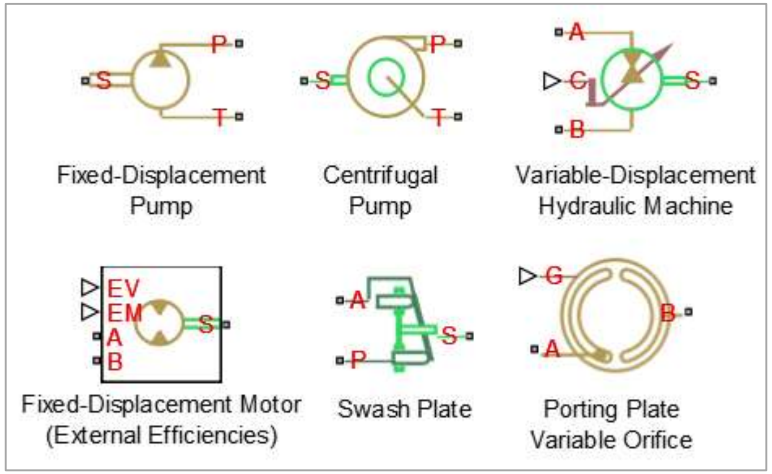


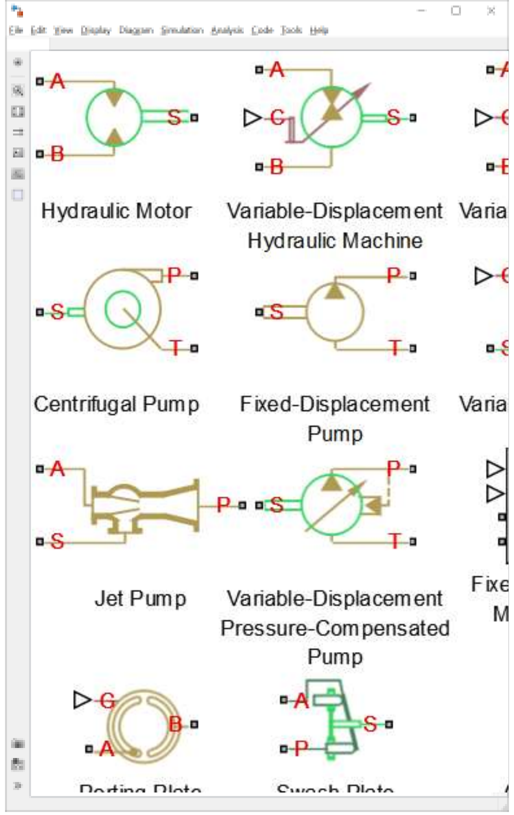
Adjusting Fidelity Using Simscape Fluids Components

Actuators, Valves, **Pumps and Motors**, Pipes and Tanks, Heat Exchangers

- Fixed and variable displacement
  - Gear pumps, vane and piston pumps
  - Custom pump designs



Subset of libraries



- Parameterization options
  - Pump delivery
  - Efficiency and losses
  - Leakage and friction

Displacement specification:
By maximum displacement and control member stroke
By displacement vs. control member position table

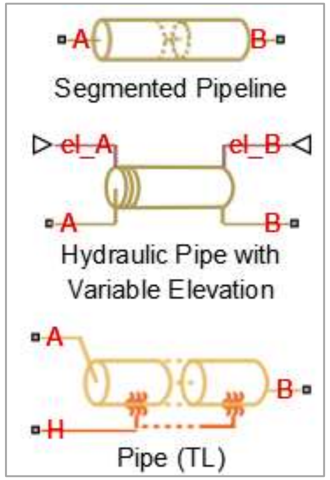
Parameterization:
By approximating polynomial
By two 1D characteristics: P-Q and N-Q
By two 2D characteristics: P-Q-W and N-Q-W

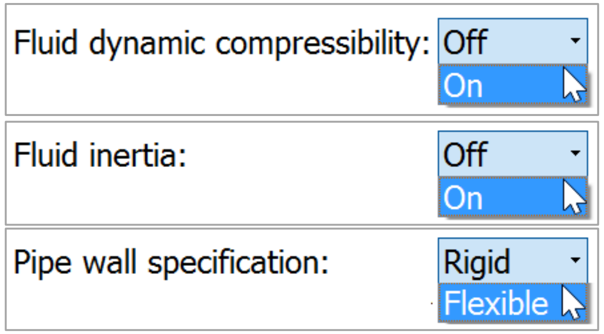
Leakage and friction: Analytical
Tabulated data

Adjusting Fidelity Using Simscape Fluids Components

Actuators, Valves, Pumps and Motors, **Pipes and Tanks**, Heat Exchangers

- Configurable pipeline models
  - Fluid compressibility
  - Fluid inertia
  - Wall compliance
  - Elevation changes
  - Heat transfer





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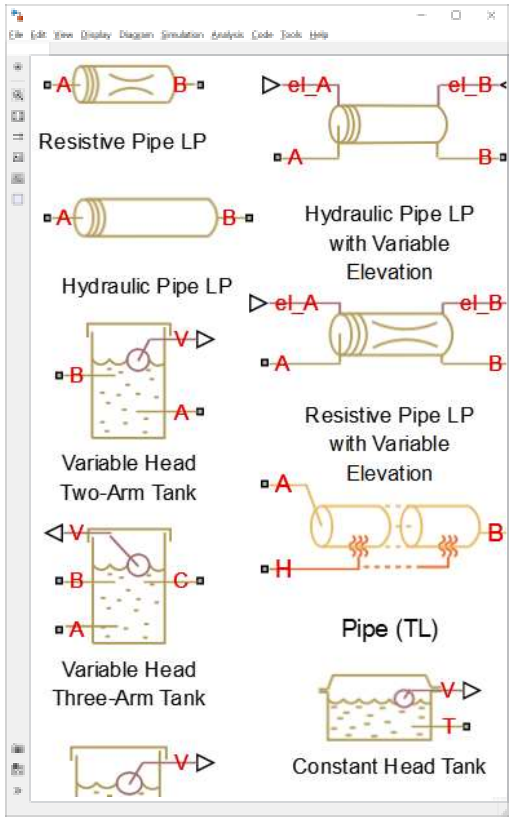
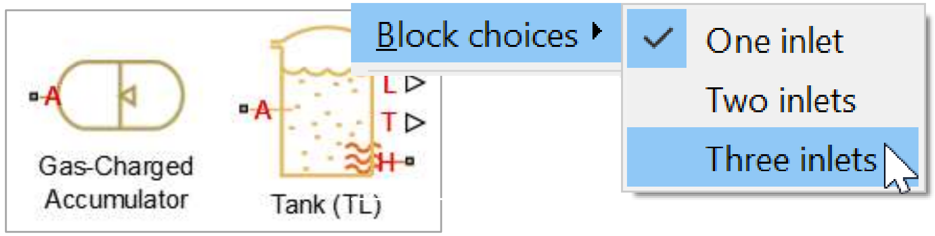
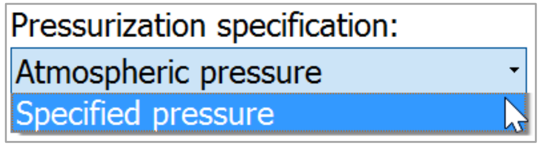
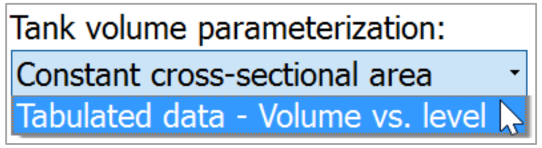


- Tanks and accumulators
  - Volume parameteriztion
  - Number of inlets
  - Pressurization



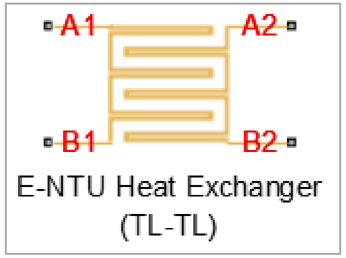


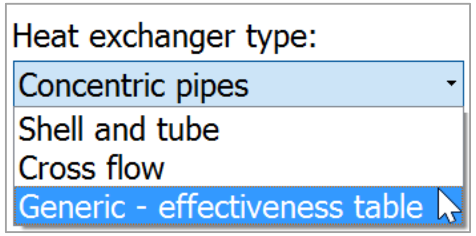


Adjusting Fidelity Using Simscape Fluids Components

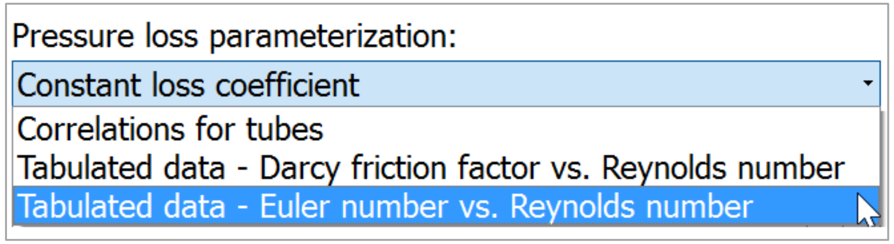
Actuators, Valves, Pumps and Motors, Pipes and Tanks, **Heat Exchangers**

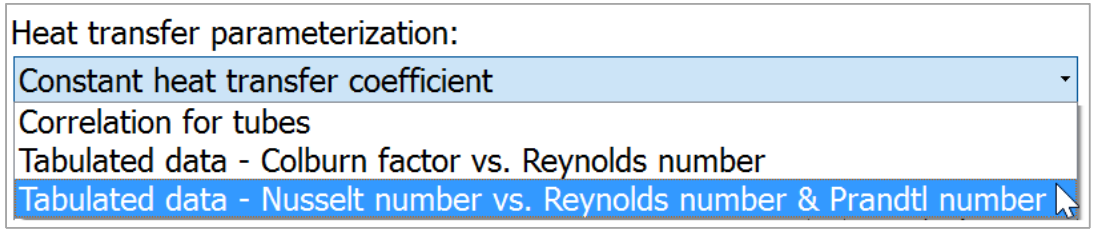
- Standard and custom types
  - Parallel or counter flow
  - Single or multiple shell passes
  - Mixed or unmixed flow



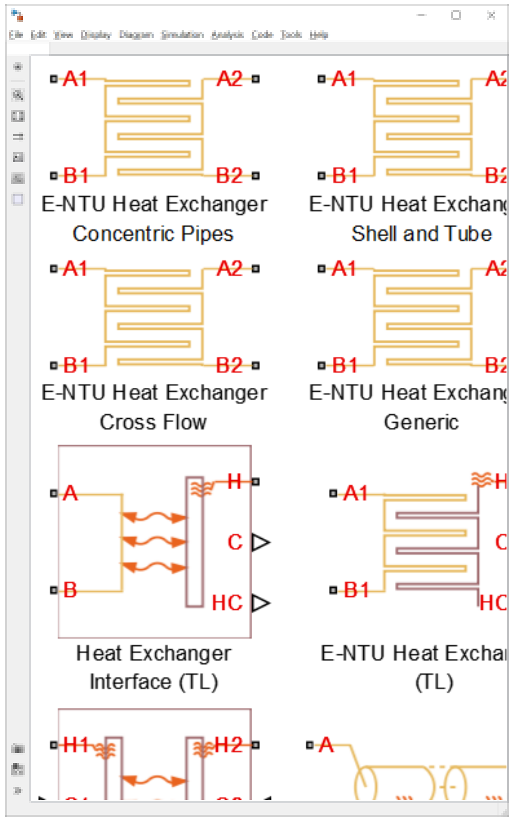


- Parameterization options
  - Pressure losses
  - Heat transfer
  - Compressibility

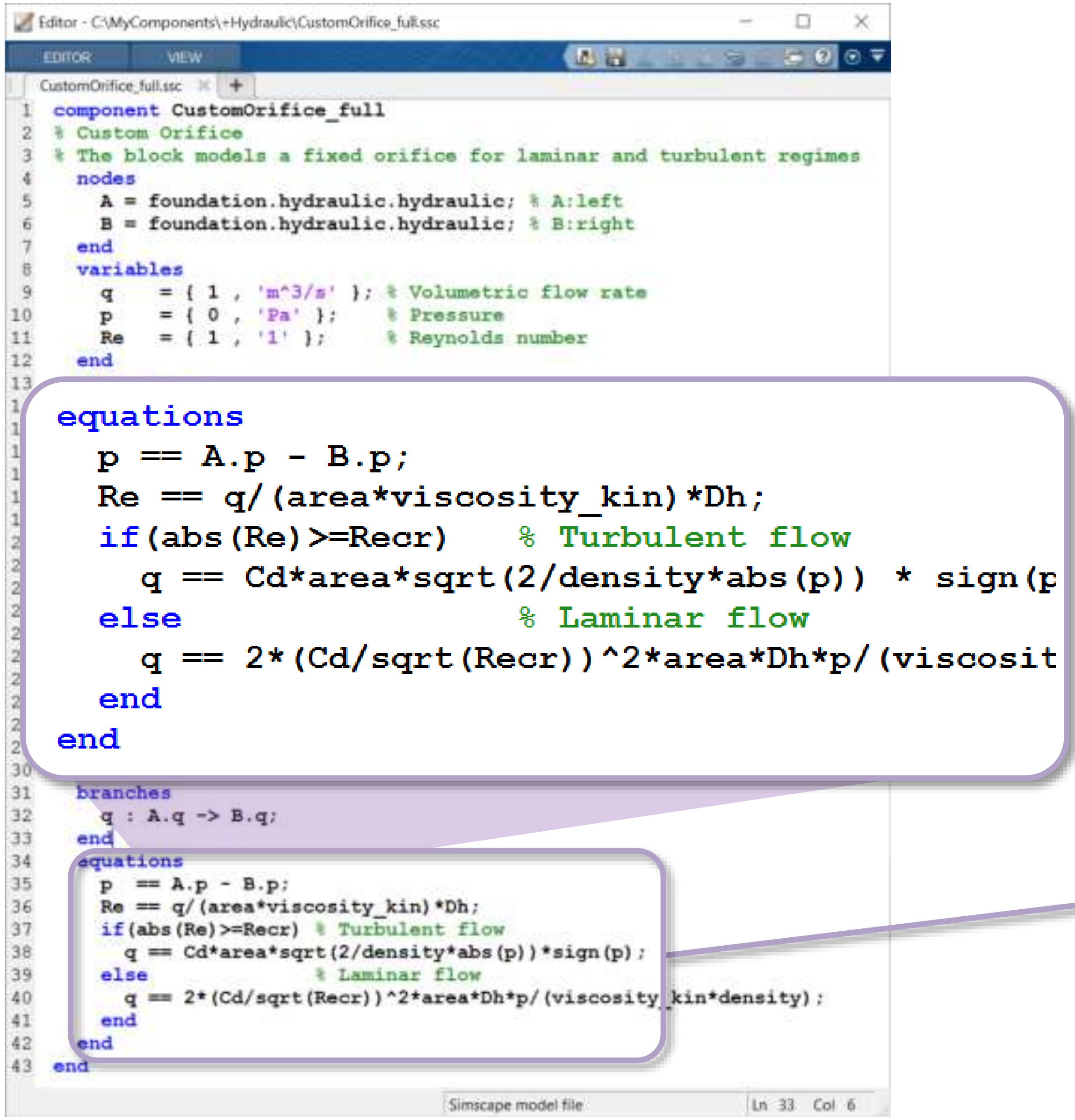




<u>Subset of libraries</u>



Create or Modify Reusable Components



Equations defined in a text-based language

- Based on variables, their time derivatives, parameters, etc.
- Define simultaneous equations
  - Can be DAEs, ODEs, etc.
  - Assignment not required
  - Specifying inputs and outputs not required

$$q = \begin{cases} C_D * \sqrt{A \frac{2}{\rho} |p|} * sign(p) & Re \geq Re_{cr} \\ 2 * C_{DL} * A \frac{D_H}{\nu\rho} p & Re < Re_{cr} \end{cases}$$

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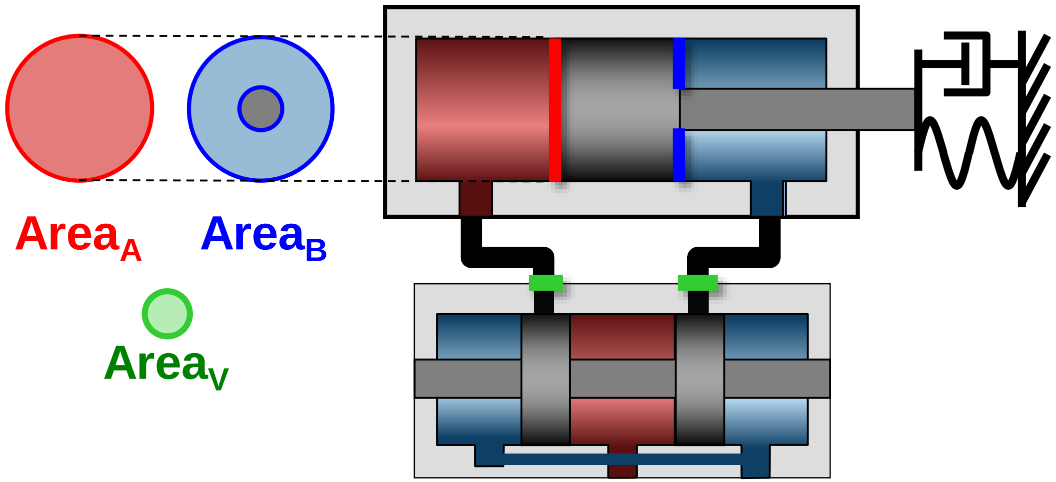
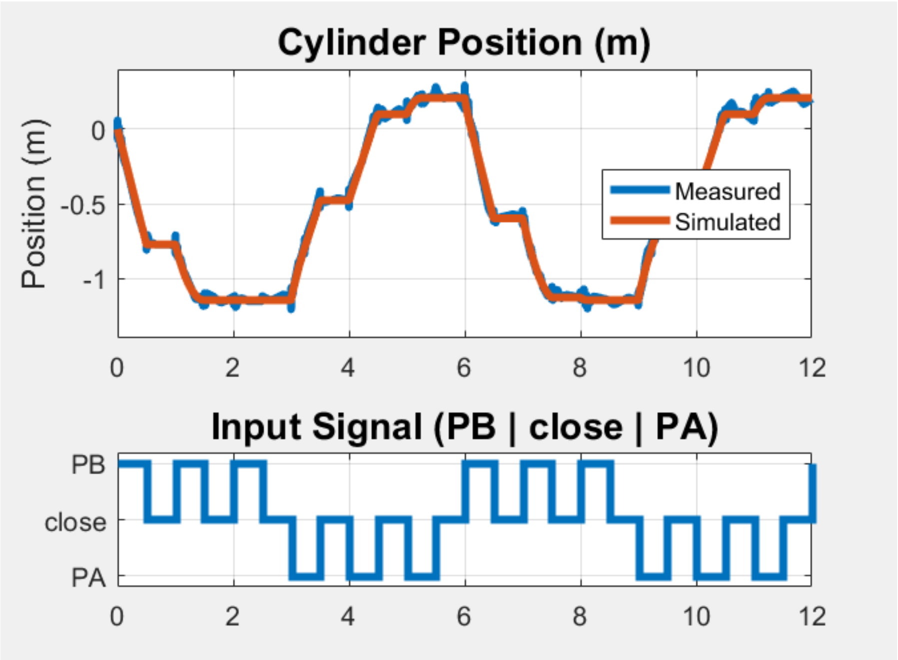
Estimating Model Parameters Using Measured Data

Model:



Problem: Simulation results do not match measured data because model parameters are incorrect

Solution: Use Simulink Design Optimization to automatically tune model parameters



$Area_A$	$Area_B$	$Area_V$
0.0176	0.0106	200

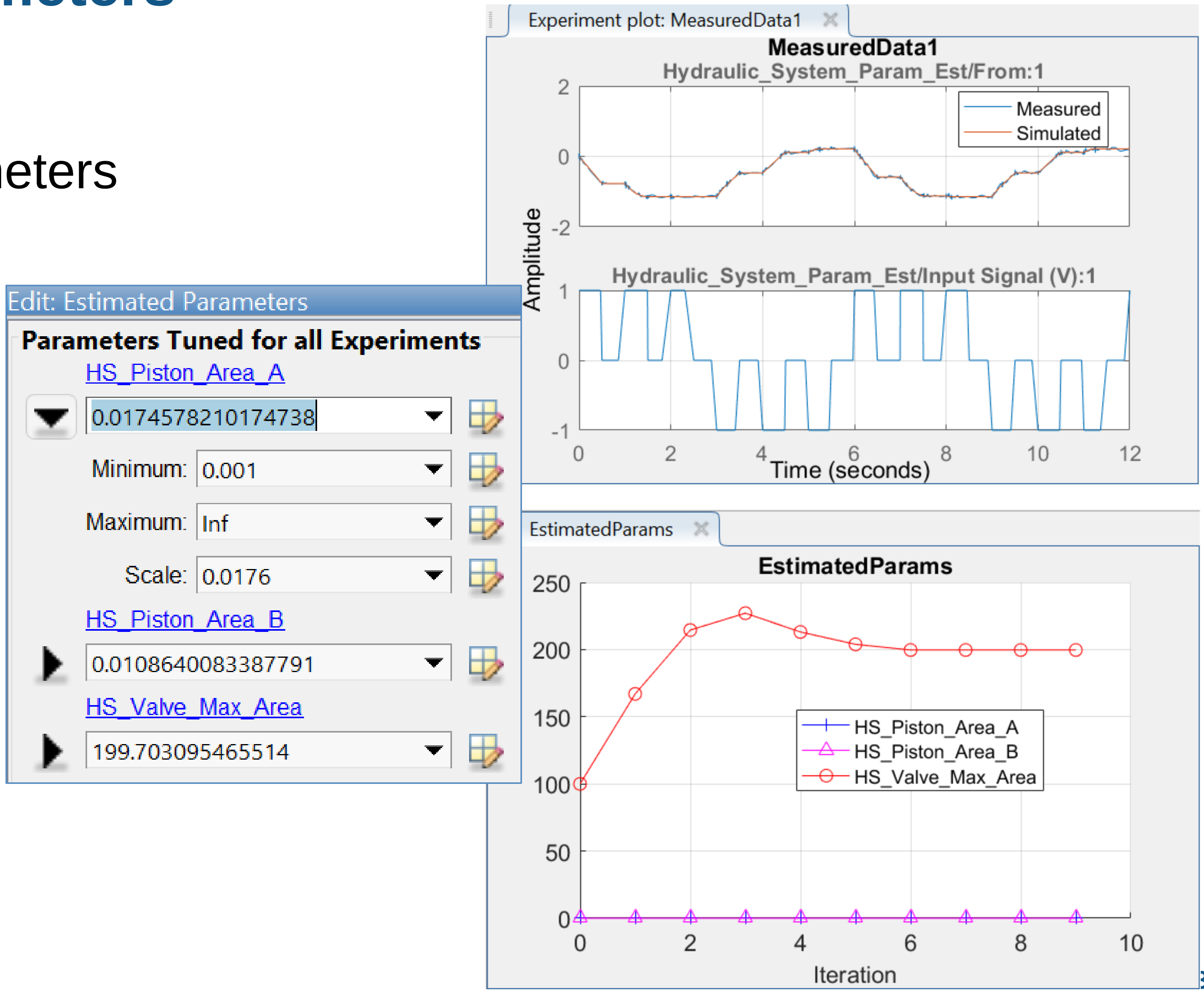
Estimating Model Parameters Using Measured Data

- Steps to Estimating Parameters

1. Import measurement data

2. Identify parameters and their ranges

3. Estimate parameters



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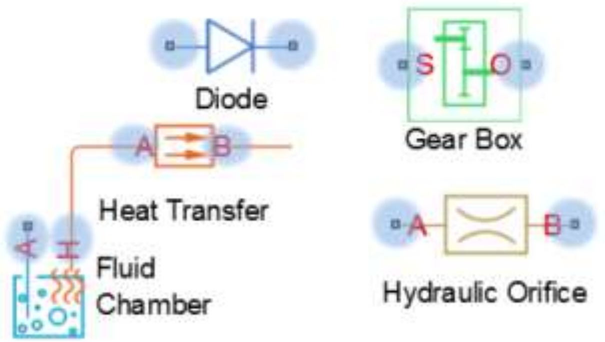
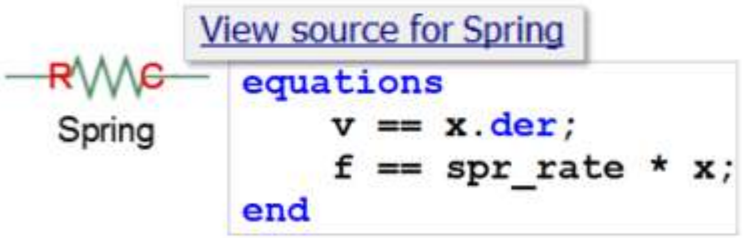
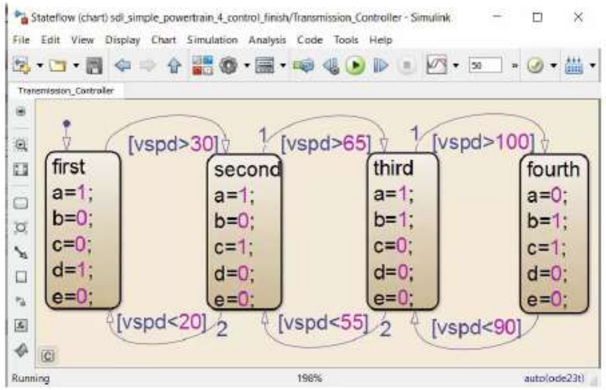
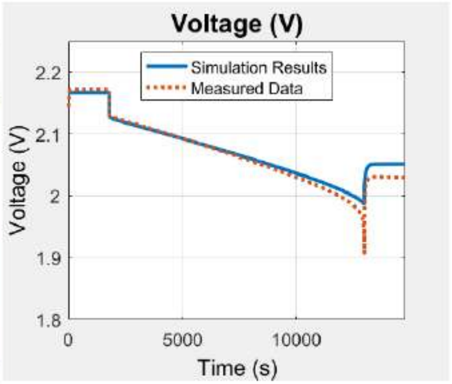
Simscape Key Points

- Enables you to use physical networks to model systems spanning multiple physical domains
- Provides a MATLAB-based language for creating custom component models
- Fully integrated with MATLAB and Simulink
  – Integration with control algorithm
  – Optimization
  – C code generation for HIL









Agenda

- Motivation
- Simscape physical network approach
- Example: Backhoe
- System Level Integration
  - Mechanical system
  - Hydraulics system
- Parameter Tuning
- Simcape in Model-Based Design

Why model the physical system?

Too big, too difficult, one chance, …

Why Simscape?

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Develop controller
Find best design

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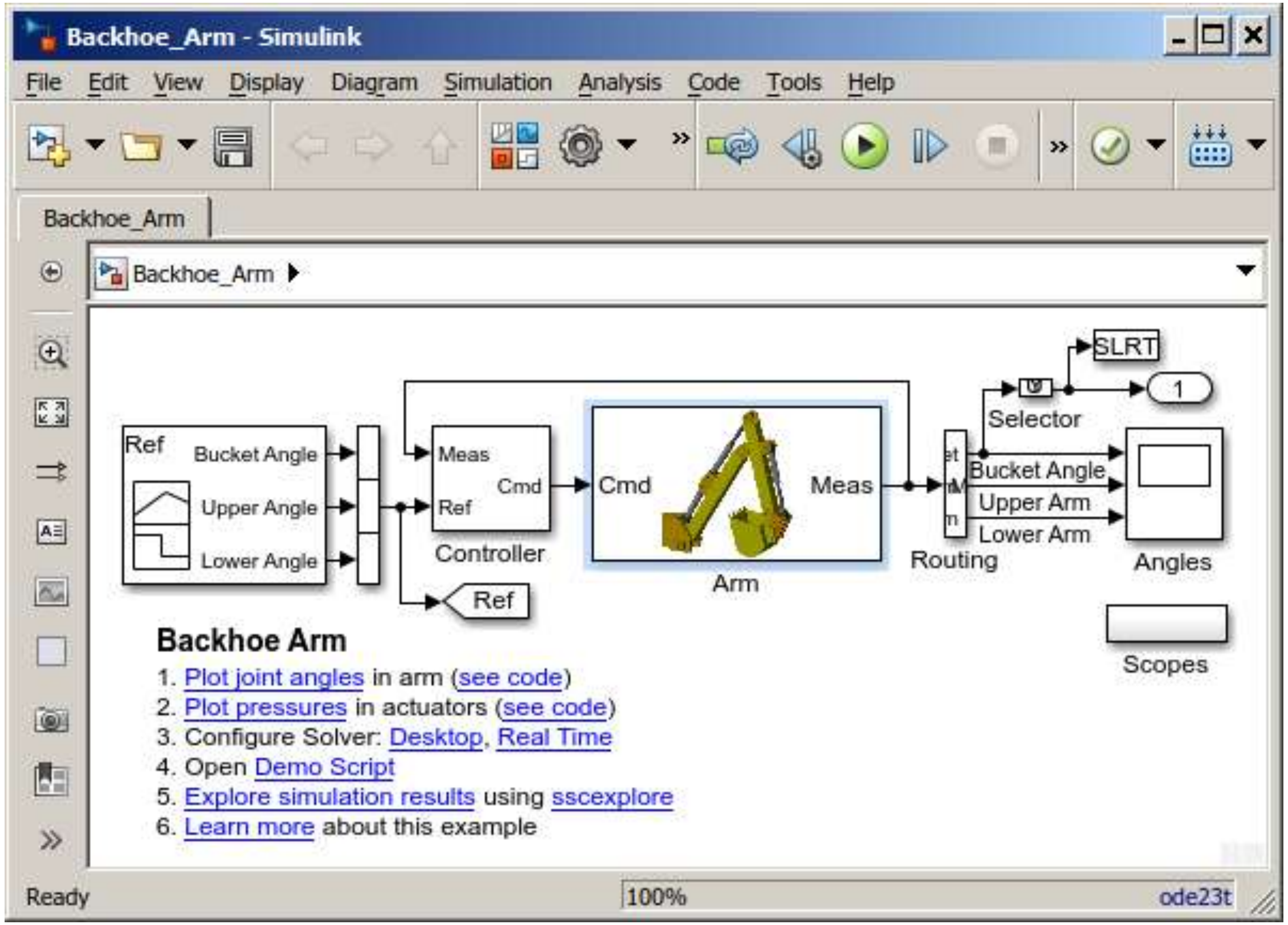
  - This one-day course discusses how to model electrical power systems in the Simulink environment using Simscape Power Systems

Questions & Discussion



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