

MATLAB EXPO 2017

Modeling Mechanical and Hydraulic Systems in Simscape

Dhirendra Singh

too
big

too
difficult

one
chance



USER STORY

ABB Optimizes Ship
Energy Flows



USER STORY

DCNS Simulates
Handling System



USER STORY

Lockheed Martin
Develops MRO

Why use Simscape?

Makes modeling easy



Simscape handles equations automatically

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

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

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

Simulink



Simscape





Simscape handles equations automatically

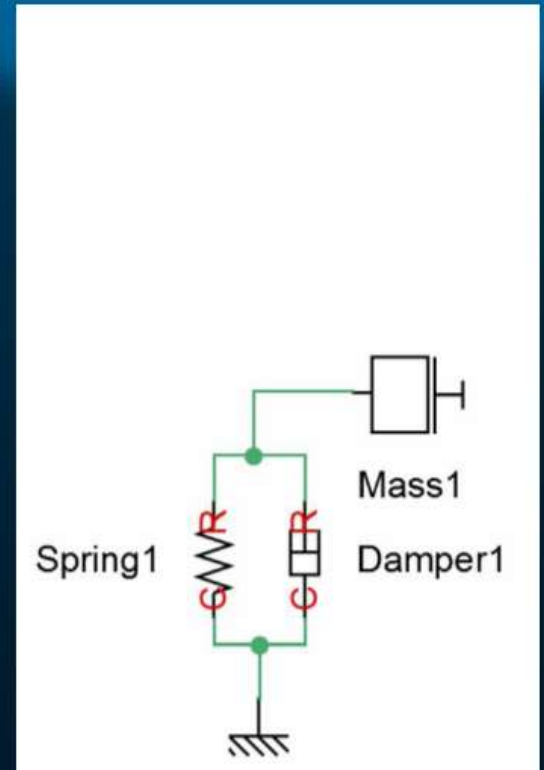
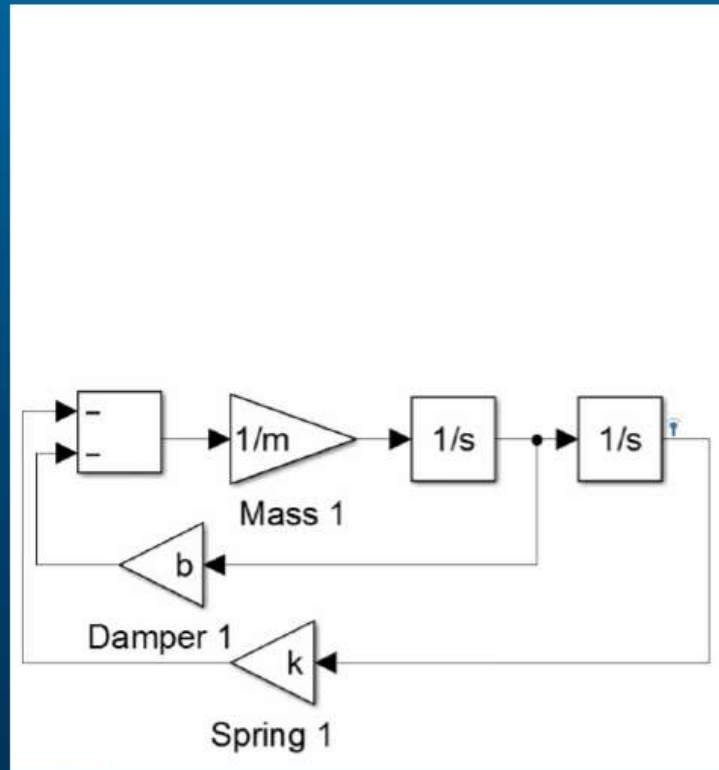
$$F_{Spring} = k_{Spring} * (z_{Car} - z_{Whl})$$

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

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

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

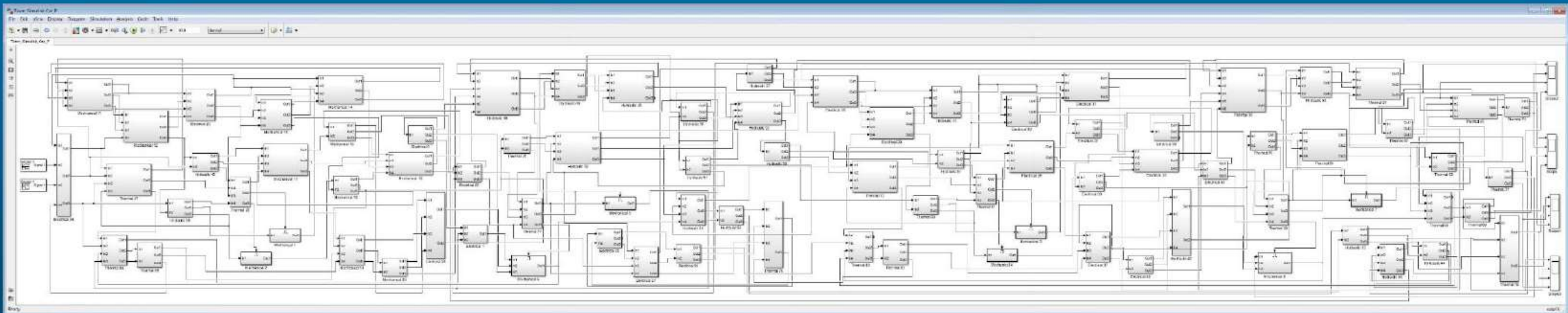
$$\frac{d^2 z_{Whl}}{dt^2} = \frac{F_{Spring} + F_{Shock} - F_{Tire}}{m_{Car}}$$

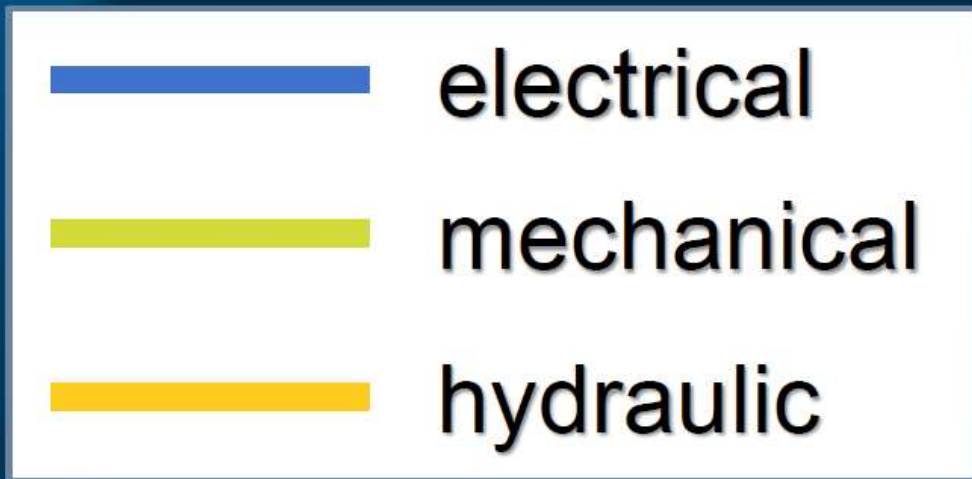
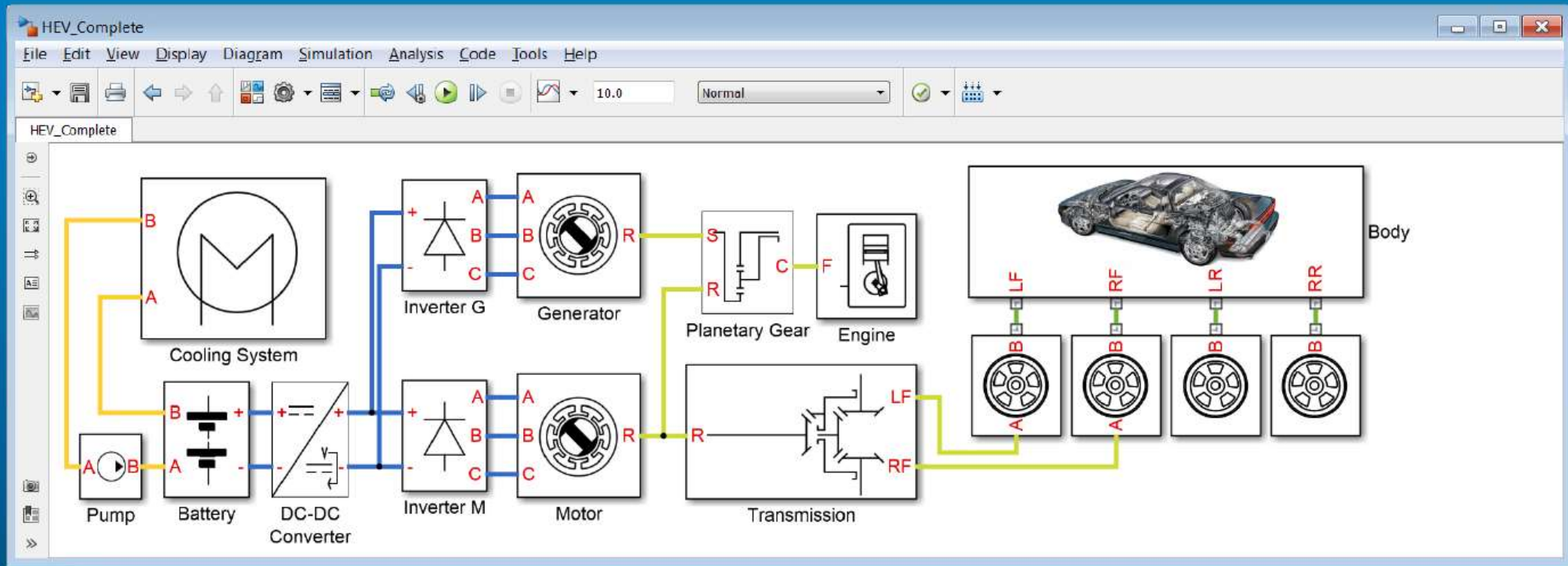


3D mechanics hybrid powertrain



power steering
air conditioning





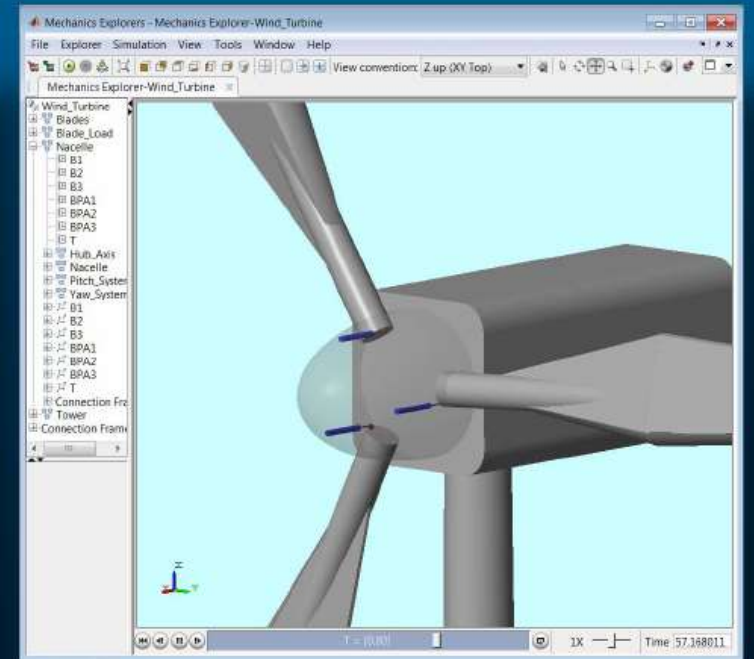
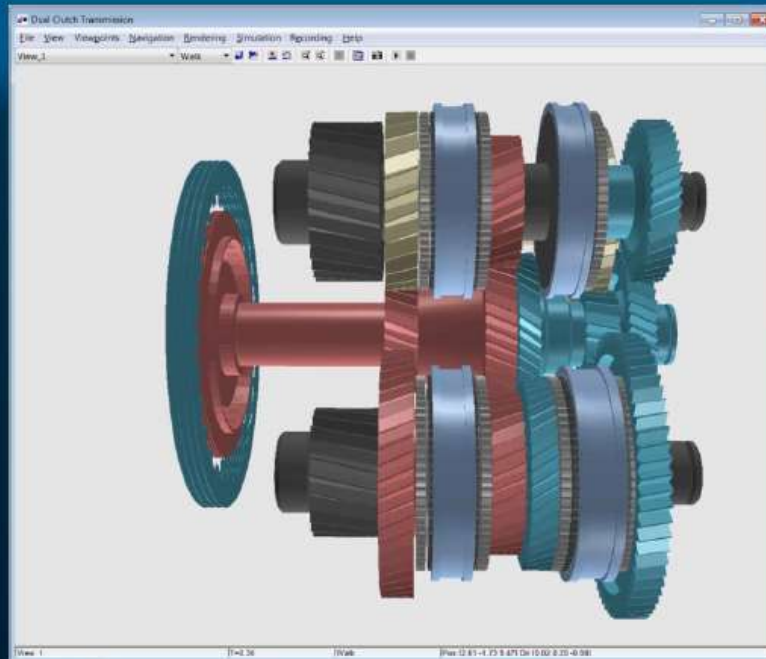
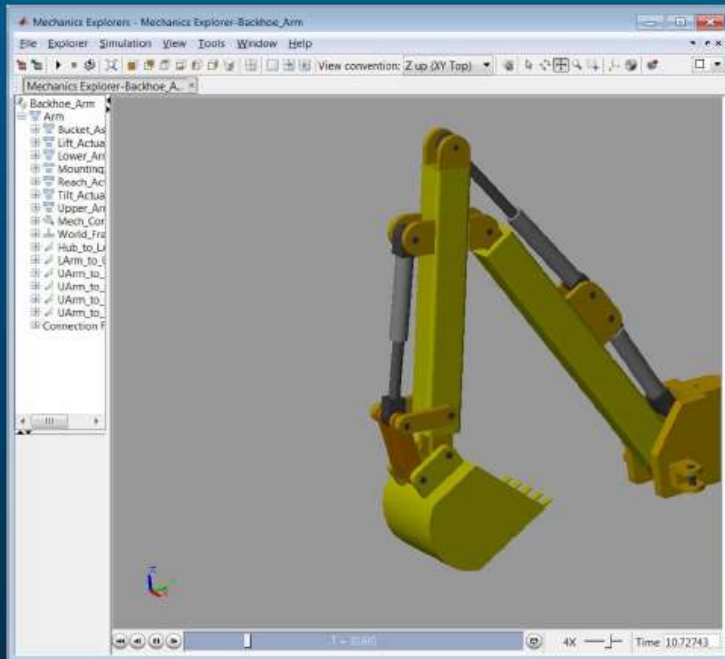
less clicking
more simulating

Market Demand:

Reduce energy consumption in integrated systems

Simscape Focus:

Domain integration
Algorithm design
Optimization

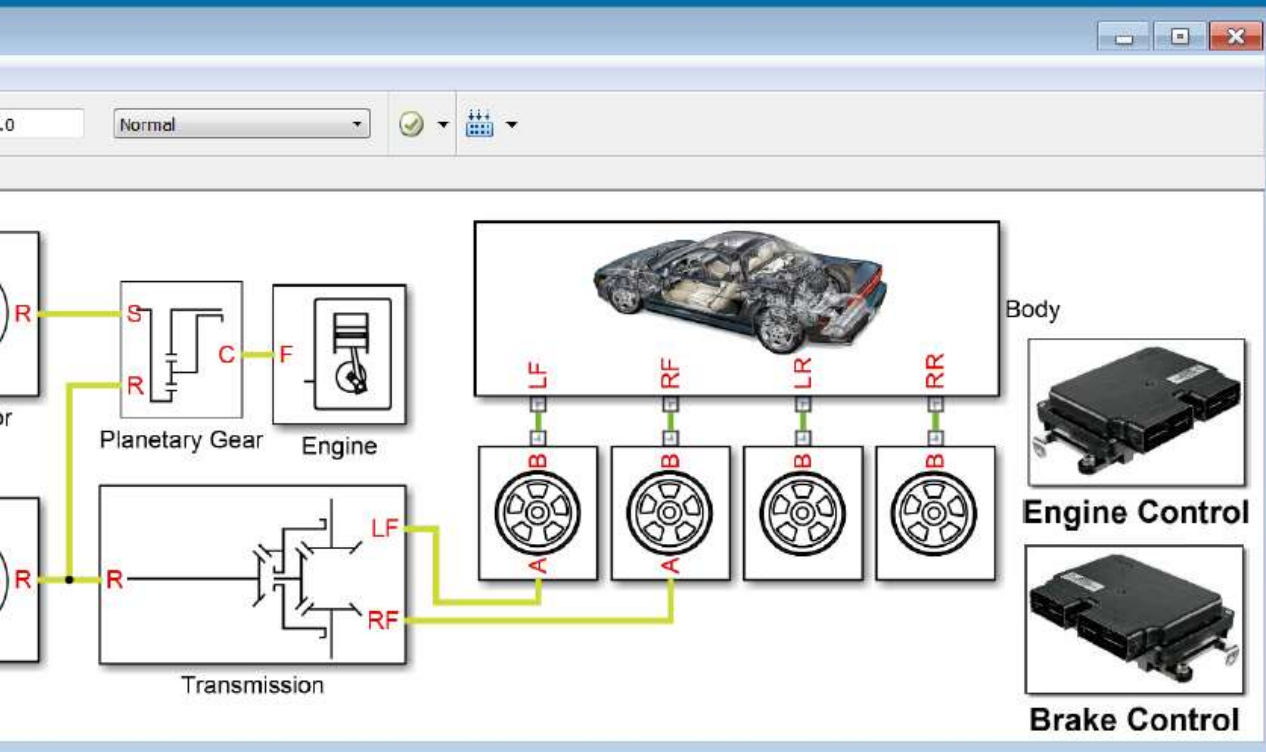


Why model the physical system?

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
- Simscape in Model-Based Design

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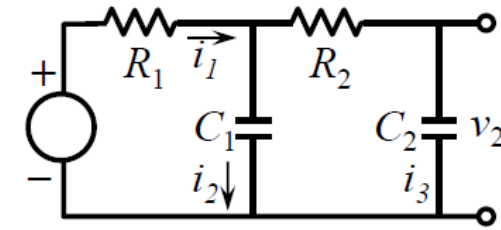
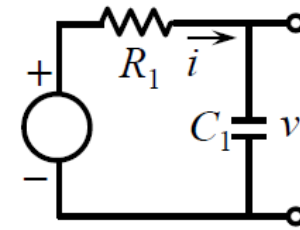
Makes modeling easy

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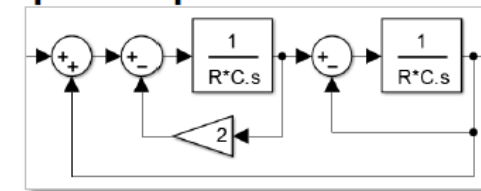
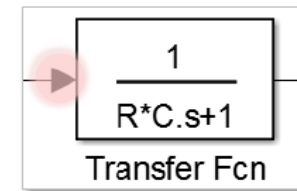
Find best design

Physical Modeling with Simulink

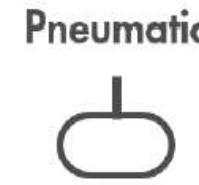
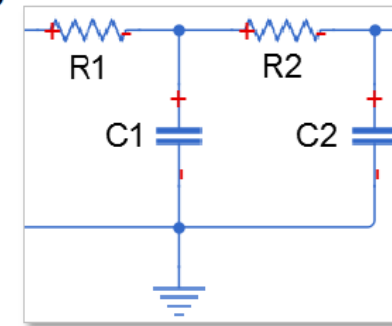
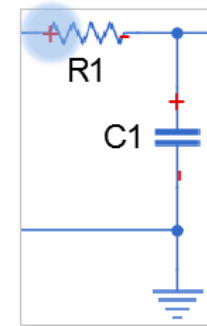
- Simulink is best known for signal based modeling
 - Causal, or input/output
- Simscape enables bidirectional flow of energy between components
- System level equations:
 - Formulated automatically
 - Solved simultaneously
 - Cover multiple domains



Simulink: Input/Output



Simscape: Physical Networks



Custom Domains (Simscape Language)

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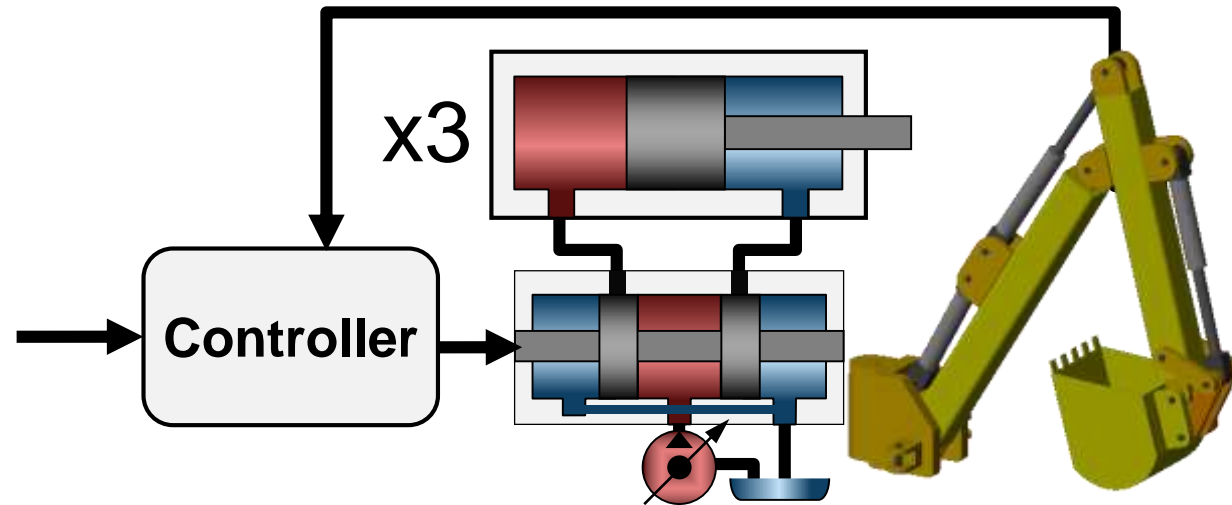
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Backhoe Actuation System

- System

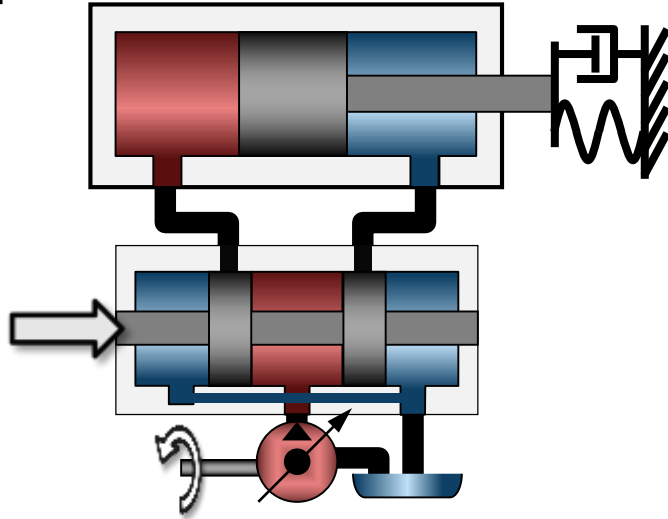


- Simulation Tasks

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

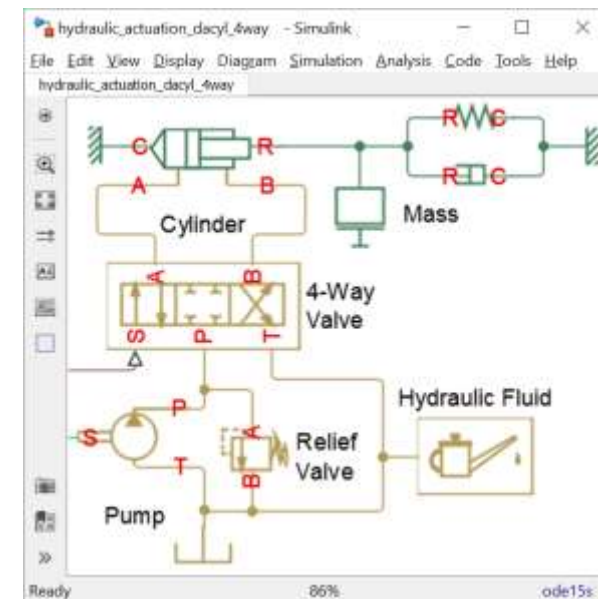
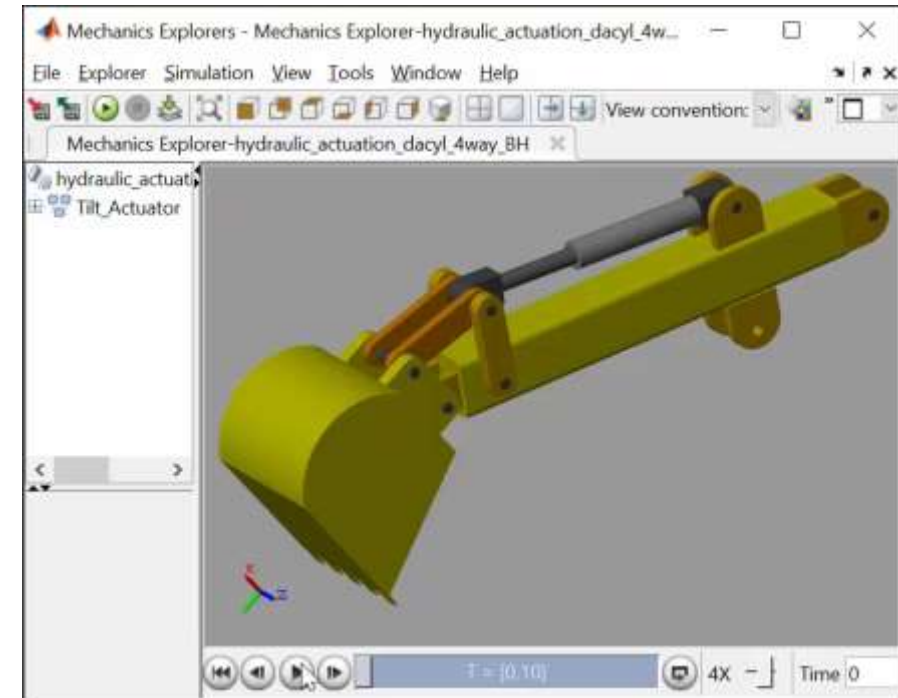
Model:



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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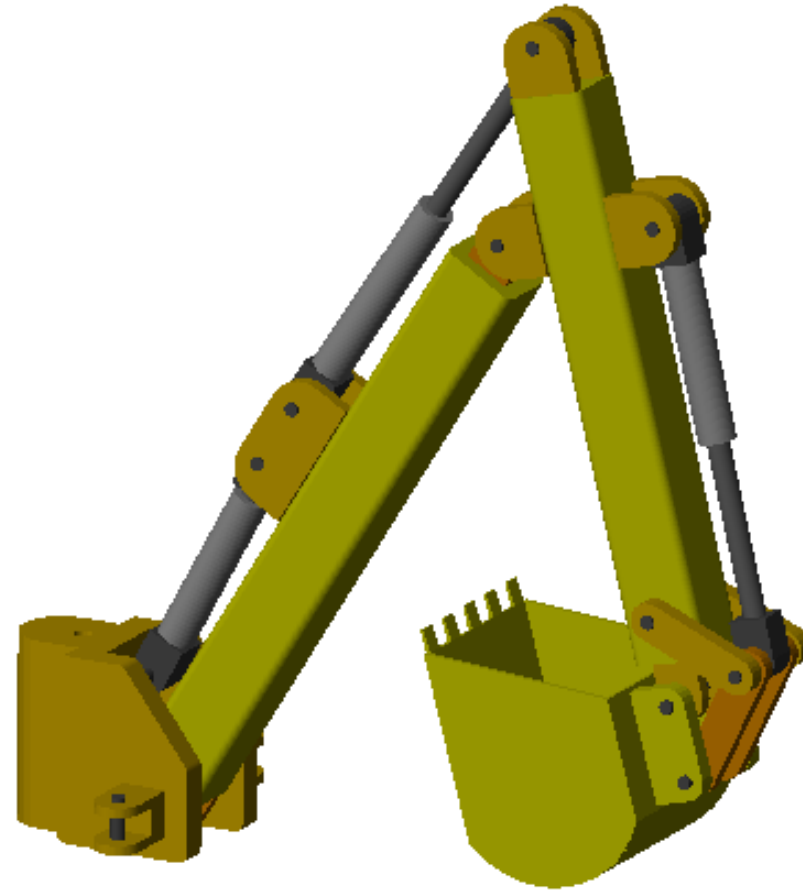
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Develop controller

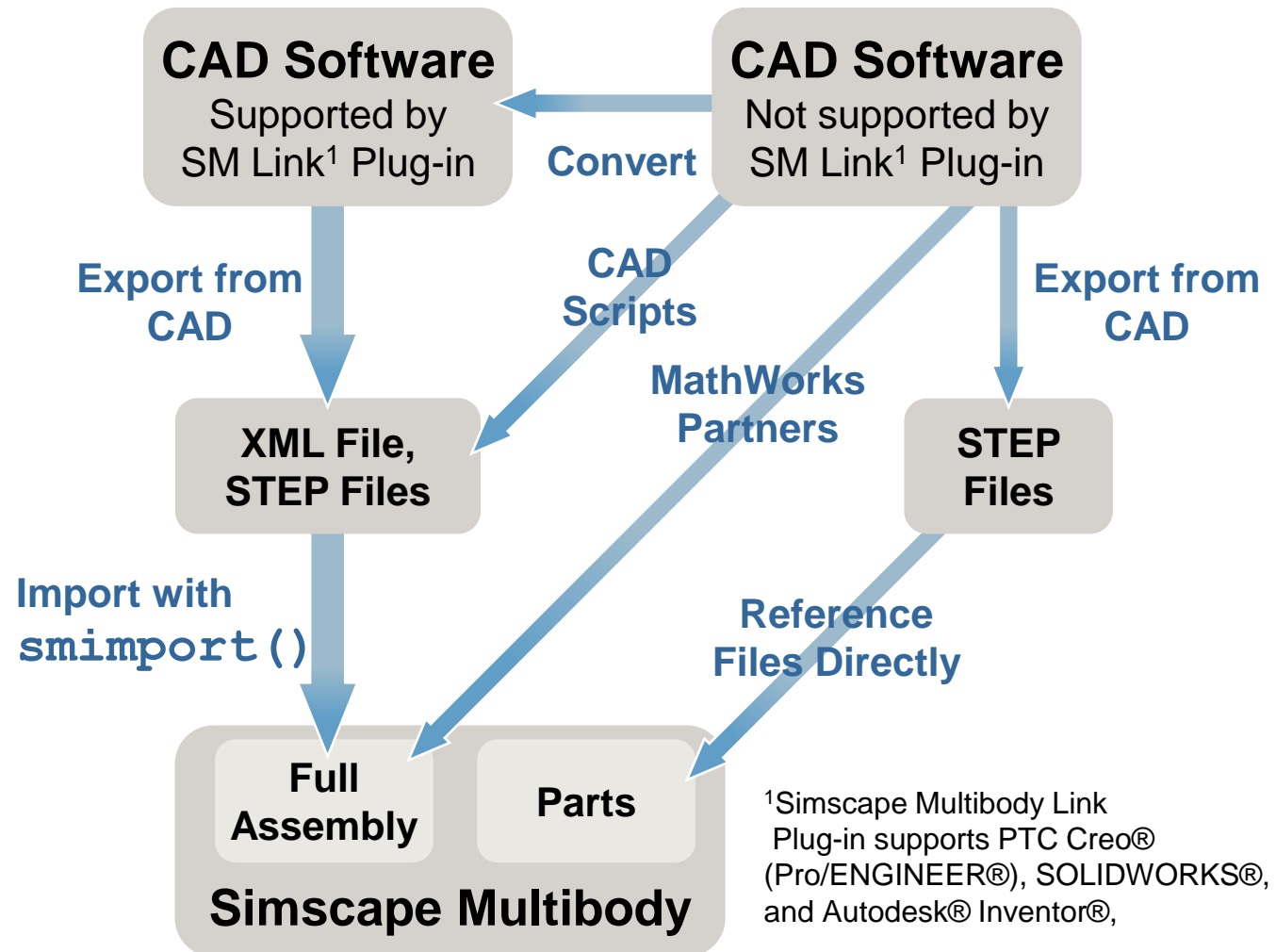
Find best design

Mechanical System



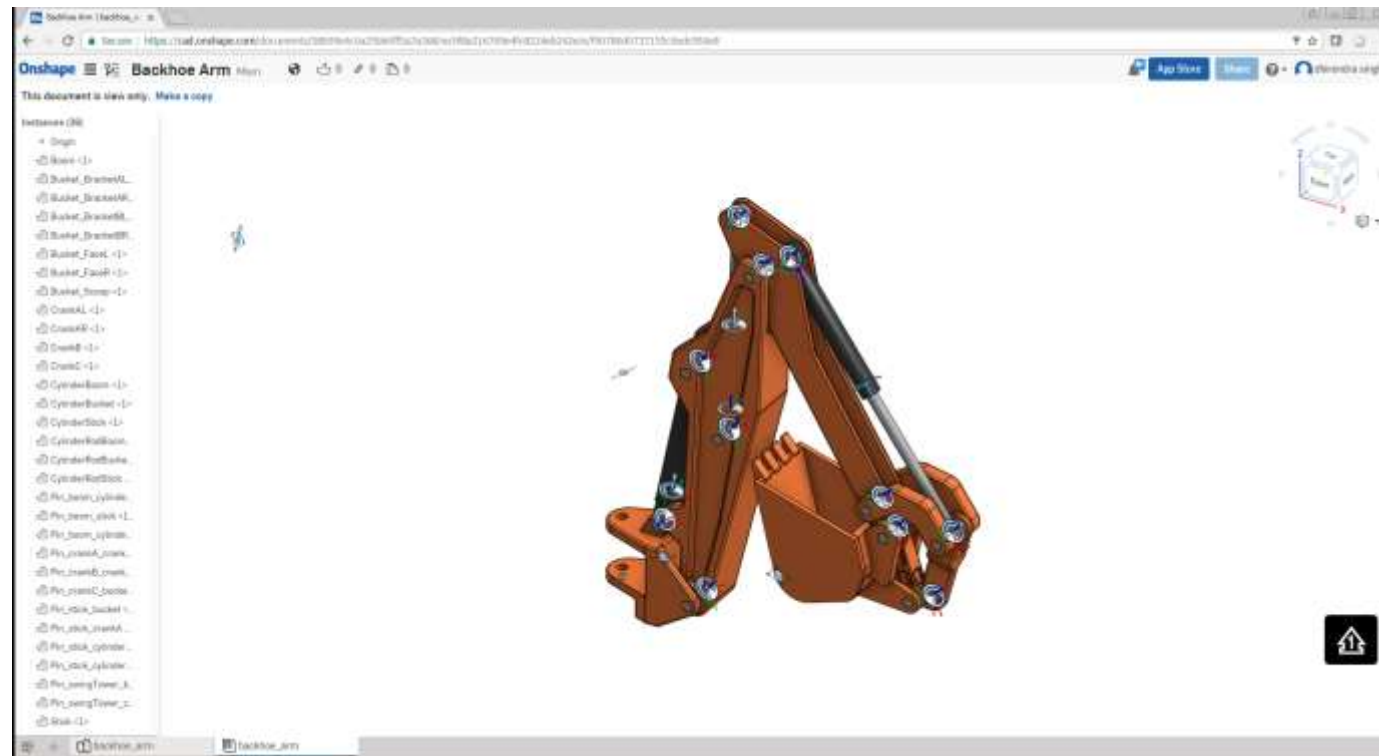
CAD to Simscape Multibody Solutions

- 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



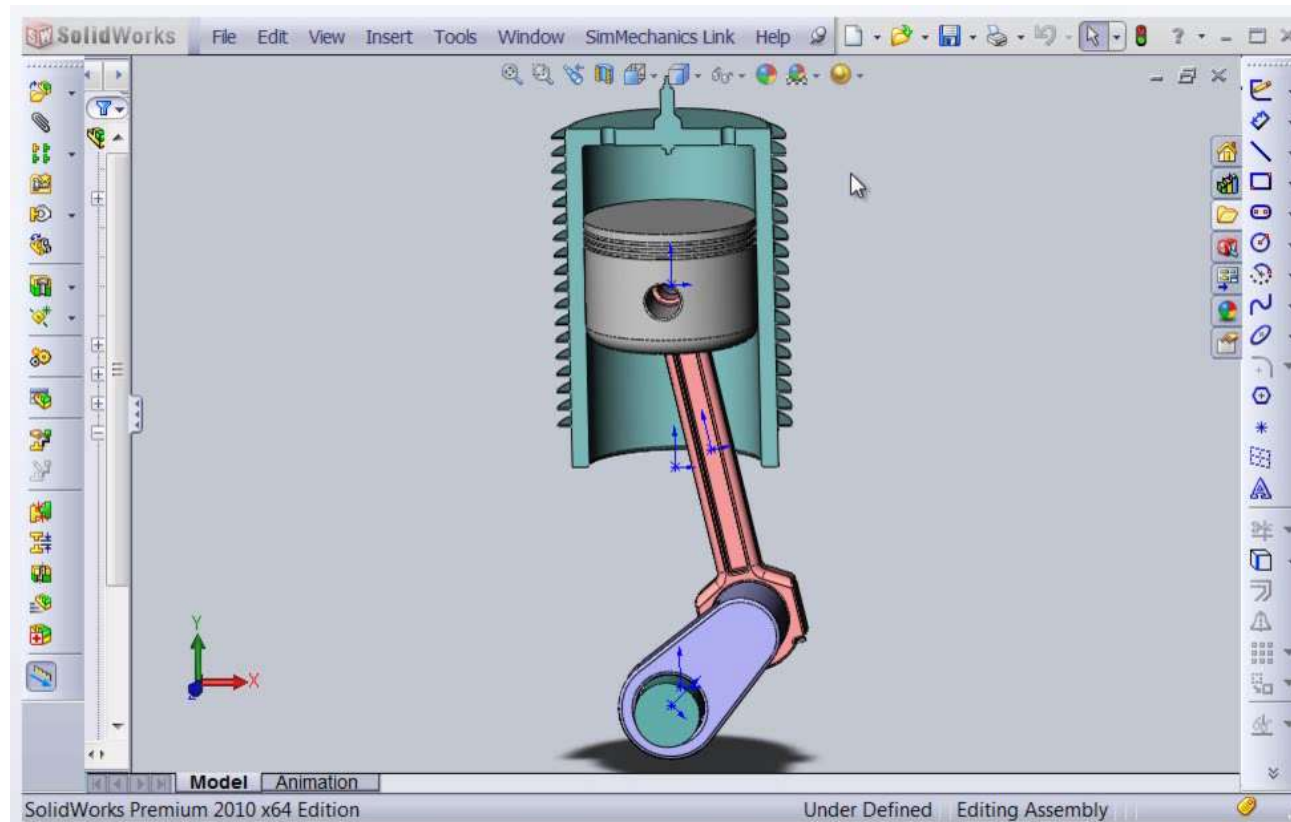
CAD model

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



Simscape Multibody Link: Convert CAD Assembly to Simscape Multibody

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

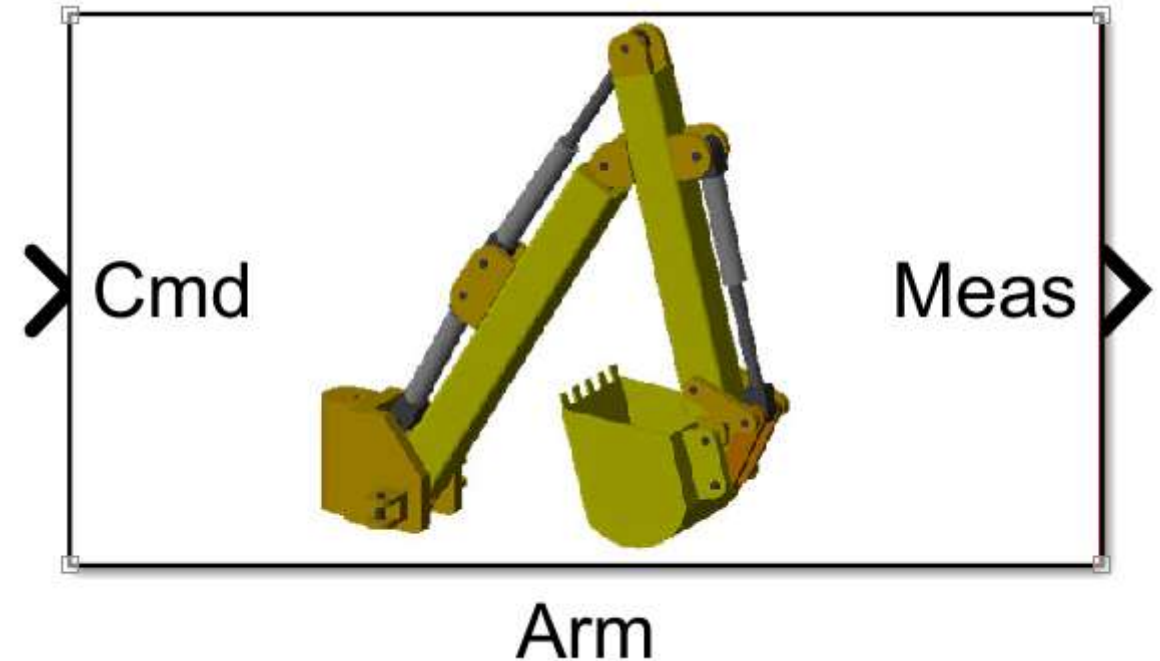


Demo

- 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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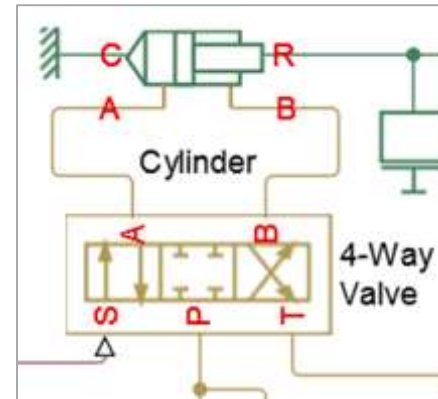
Find best design

Demo

- Lets Build hydraulic actuation for our mechanical model

Hydraulic Actuation System – using Simscape Fluids

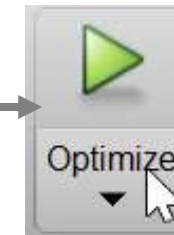
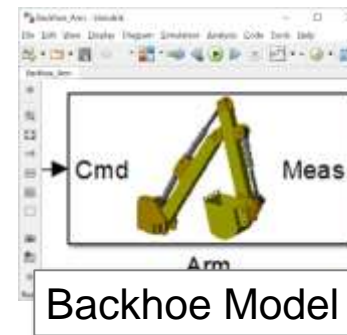
- Provides libraries of component models for fluid power systems
- Models can be customized for your needs
 - Create reusable assemblies
 - Adjust parameterization
 - Define custom components
- Leverage MATLAB and Simulink
 - System-level analysis
 - Control design and HIL testing



```

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

```



C Code

HIL

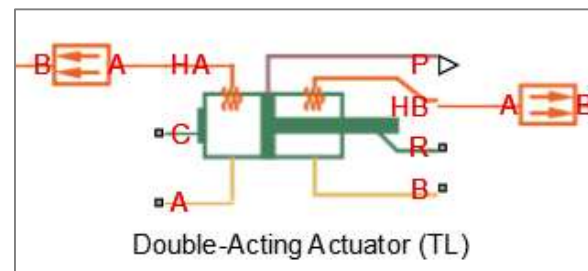
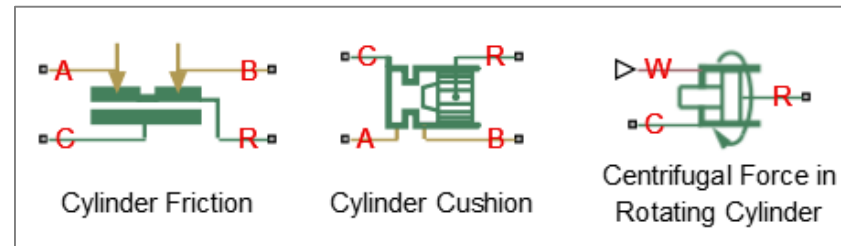
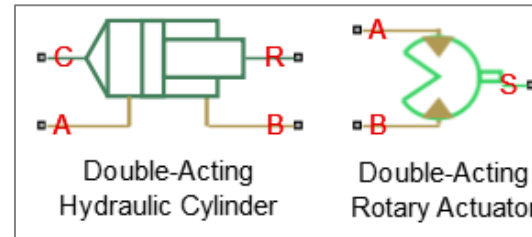
Adjusting Fidelity Using Simscape Fluids Components

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

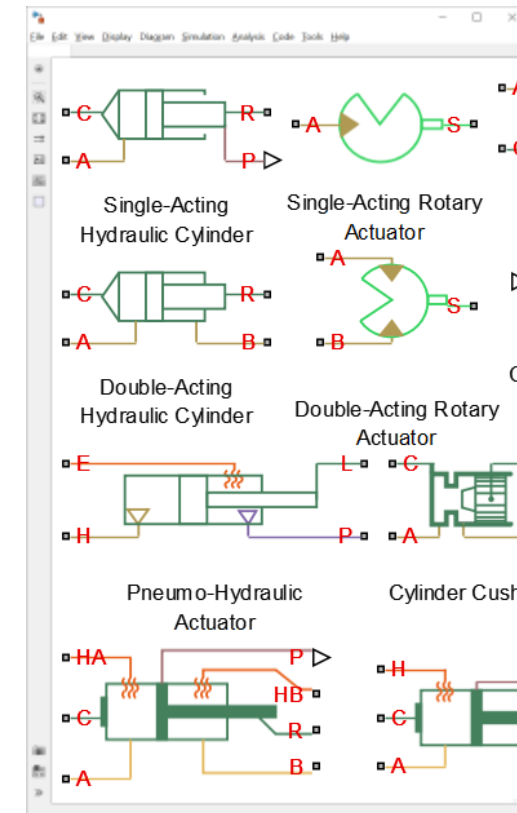
- Translational and rotational
 - Add or neglect compressibility

- Mechanical effects
 - Hard stops, Friction
 - Forces

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



Subset of libraries



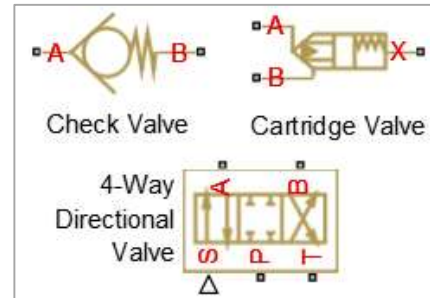
Adjusting Fidelity Using Simscape Fluids Components

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

- Directional
 - Spool, check, cartridge
 - Parameterization options

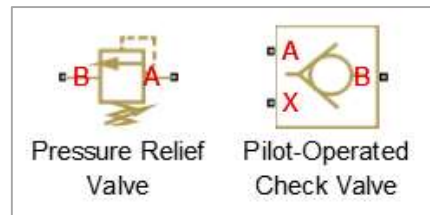
- Pressure control
 - Control tasks (variable)
 - Switching tasks (fixed)

- Flow control
 - Pressure dependent
 - Pressure independent



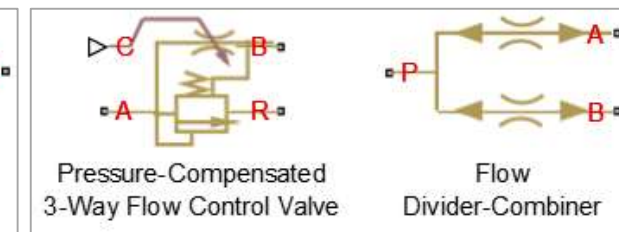
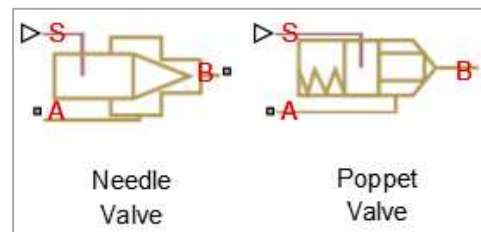
Parameterization:

- By maximum area and opening ▾
- By area vs. opening table
- By pressure-flow characteristic

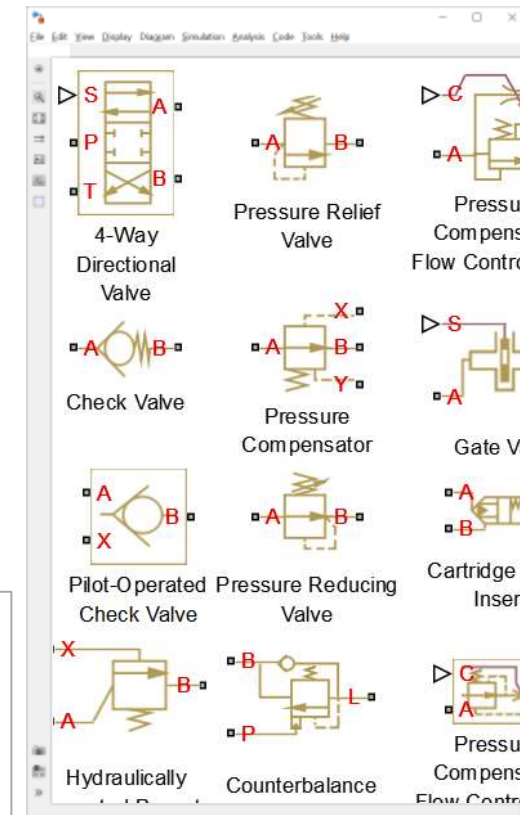


Opening dynamics:

- Do not include ▾
- Include



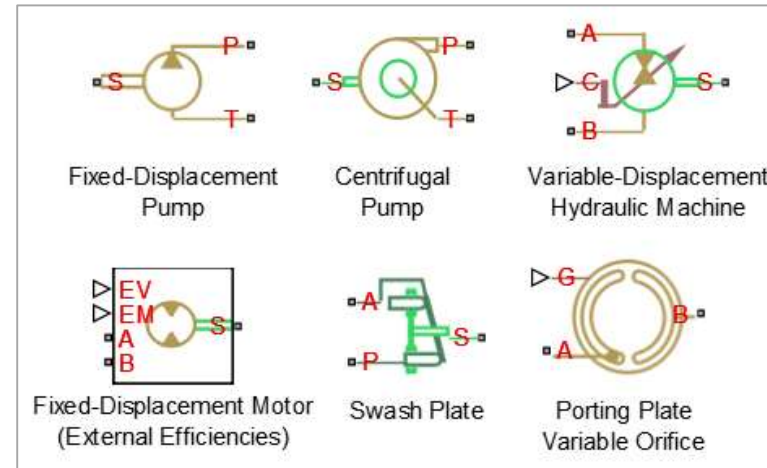
Subset of libraries



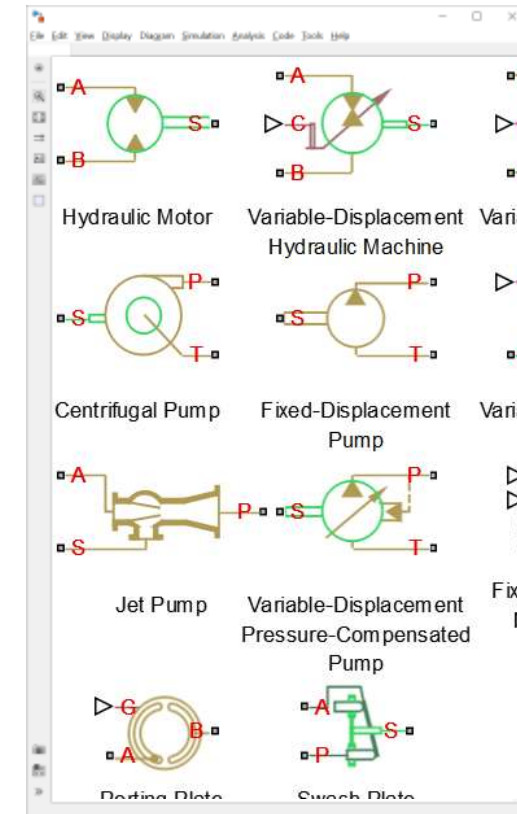
Adjusting Fidelity Using Simscape Fluids Components

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

Diagram showing three pipeline models: Segmented Pipeline, Hydraulic Pipe with Variable Elevation, and Pipe (TL). To the right are three dropdown menus for configuration:

- Fluid dynamic compressibility: Off (selected), On
- Fluid inertia: Off (selected), On
- Pipe wall specification: Rigid (selected), Flexible

- Tanks and accumulators

- Volume parameterization
- Number of inlets
- Pressurization

Diagram showing Gas-Charged Accumulator and Tank (TL) components. A 'Block choices' dropdown menu is open, showing options for the number of inlets: One inlet (checked), Two inlets, and Three inlets. Below are two dropdown menus for configuration:

- Pressurization specification: Atmospheric pressure (selected), Specified pressure
- Tank volume parameterization: Constant cross-sectional area (selected), Tabulated data - Volume vs. level

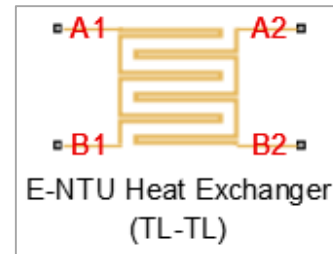
Subset of libraries

A screenshot of the Simscape Fluids library browser showing a grid of component icons. The components include: Resistive Pipe LP, Hydraulic Pipe LP with Variable Elevation, Hydraulic Pipe LP, Variable Head Two-Arm Tank, Variable Head Three-Arm Tank, Constant Head Tank, and Pipe (TL).

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



Heat exchanger type:

- Concentric pipes
- Shell and tube
- Cross flow
- Generic - effectiveness table

- Parameterization options
 - Pressure losses
 - Heat transfer
 - Compressibility

Pressure loss parameterization:

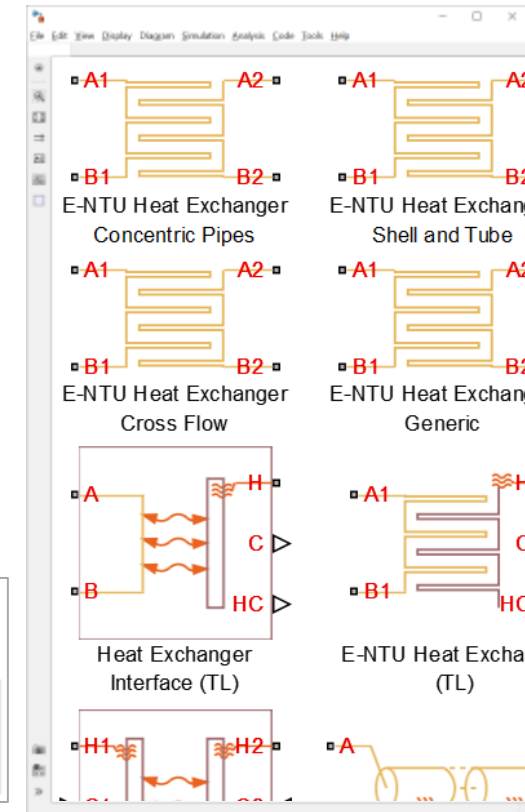
- Constant loss coefficient
- Correlations for tubes
- Tabulated data - Darcy friction factor vs. Reynolds number
- Tabulated data - Euler number vs. Reynolds number

Heat transfer parameterization:

- Constant heat transfer coefficient
- Correlation for tubes
- Tabulated data - Colburn factor vs. Reynolds number
- Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Fluid dynamic compressibility: Off / On

Subset of libraries



Create or Modify Reusable Components

```

Editor - C:\MyComponents\Hydraulic\CustomOrifice_full.ssc
CustomOrifice_full.ssc
1 component CustomOrifice_full
2 % Custom Orifice
3 % The block models a fixed orifice for laminar and turbulent regimes
4 nodes
5   A = foundation.hydraulic.hydraulic; % A:left
6   B = foundation.hydraulic.hydraulic; % B:right
7 end
8 variables
9   q = { 1, 'm^3/s' }; % Volumetric flow rate
10  p = { 0, 'Pa' }; % Pressure
11  Re = { 1, '1' }; % Reynolds number
12 end
13
14 equations
15   p == A.p - B.p;
16   Re == q/(area*viscosity_kin)*Dh;
17   if(abs(Re)>=Recr) % Turbulent flow
18     q == Cd*area*sqrt(2/density*abs(p)) * sign(p)
19   else % Laminar flow
20     q == 2*(Cd/sqrt(Recr))^2*area*Dh*p/(viscosity_kin*density)
21   end
22 end
23
24 branches
25   q : A.q -> B.q;
26 end
27
28 equations
29   p == A.p - B.p;
30   Re == q/(area*viscosity_kin)*Dh;
31   if(abs(Re)>=Recr) % Turbulent flow
32     q == Cd*area*sqrt(2/density*abs(p)) * sign(p);
33   else % Laminar flow
34     q == 2*(Cd/sqrt(Recr))^2*area*Dh*p/(viscosity_kin*density);
35   end
36 end
37 end
38
39 Simscape model file. Ln 33 Col 6

```

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

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

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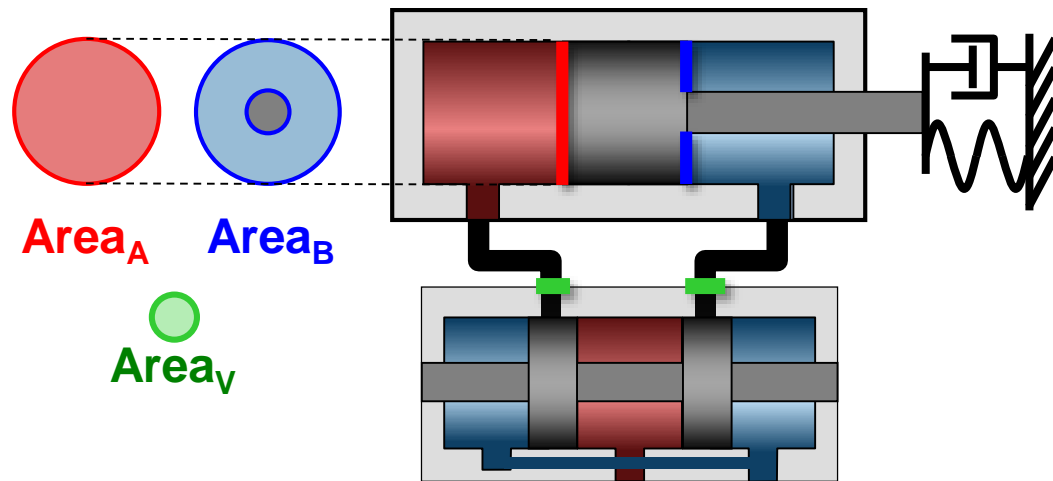
Makes modeling easy

Develop controller

Find best design

Estimating Model Parameters Using Measured Data

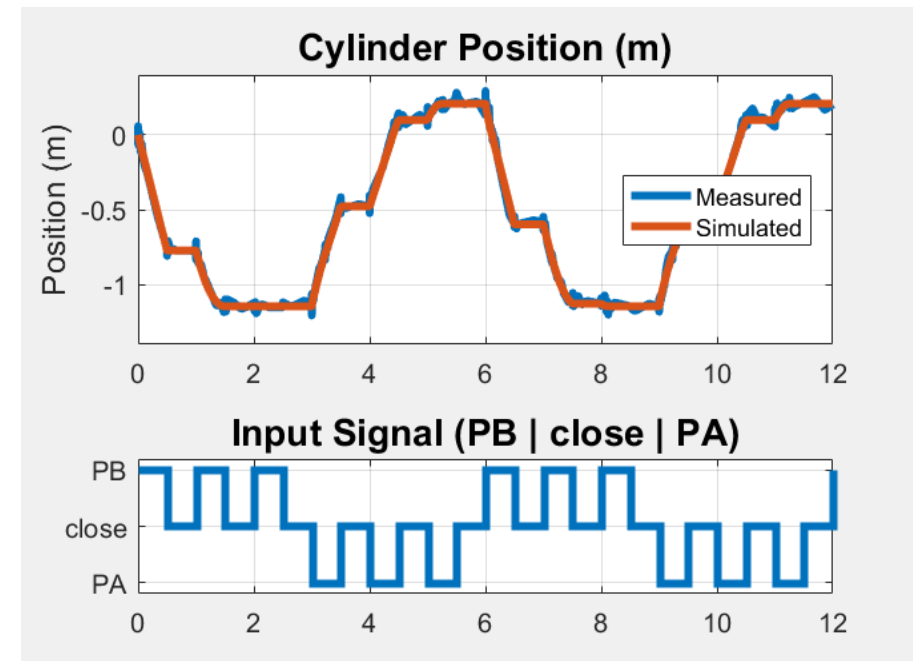
Model:



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

Solution: Use [Simulink Design Optimization](#) to automatically tune model parameters

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$Area_A$	$Area_B$	$Area_v$
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

Edit: Estimated Parameters

Parameters Tuned for all Experiments

HS_Piston_Area_A

▼ 0.0174578210174738 ▼

Minimum: 0.001 ▼

Maximum: Inf ▼

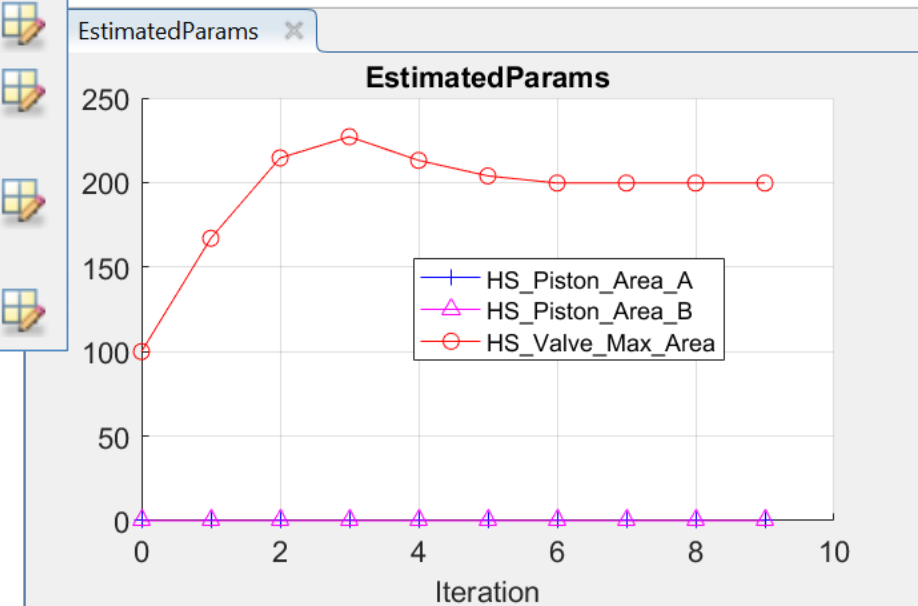
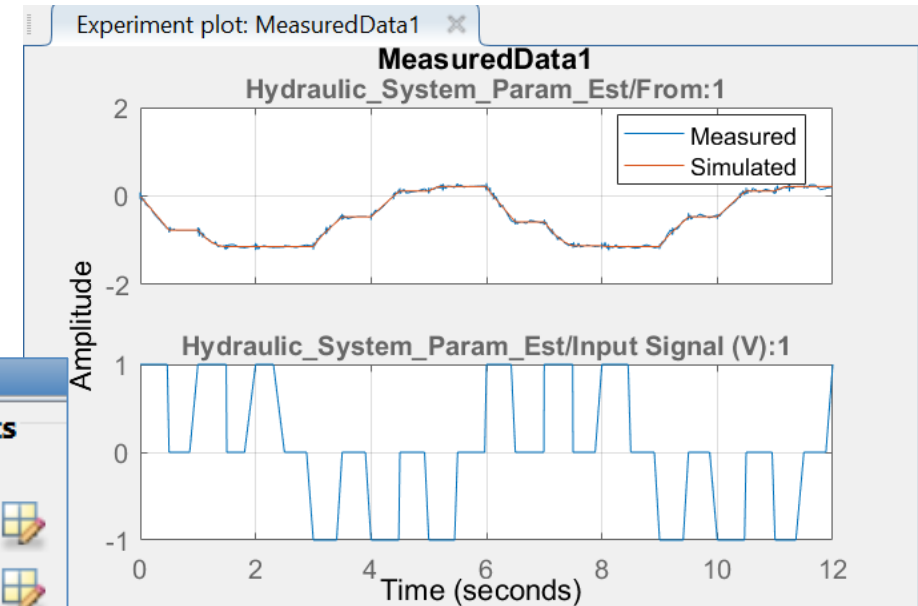
Scale: 0.0176 ▼

HS_Piston_Area_B

▶ 0.0108640083387791 ▼

HS_Valve_Max_Area

▶ 199.703095465514 ▼



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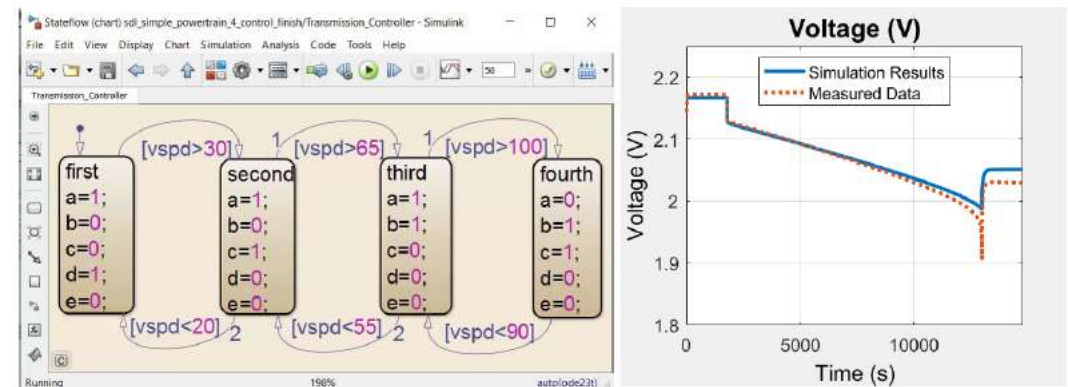
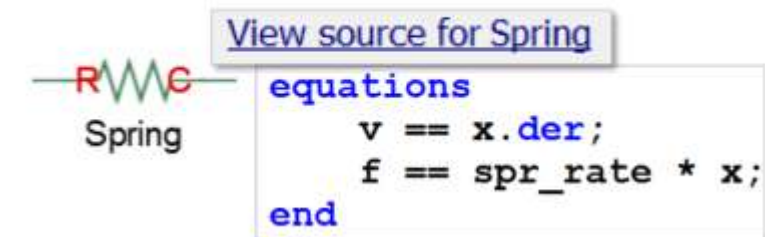
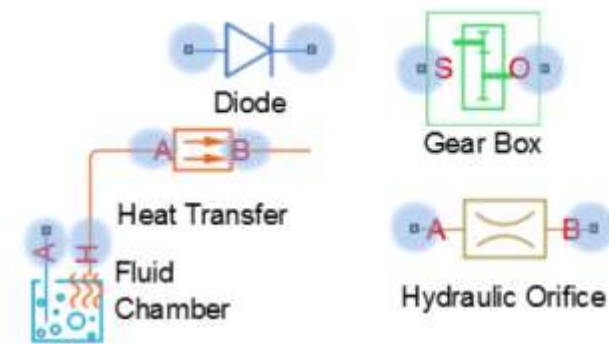
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Simscape Key Points

- 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



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Modeling Mechanical and Hydraulic Systems in Simscape

- **Modeling Physical Systems with Simscape**
 - This one-day course discusses how to model systems in several physical domains and combine them into a multidomain system in the Simulink environment using Simscape

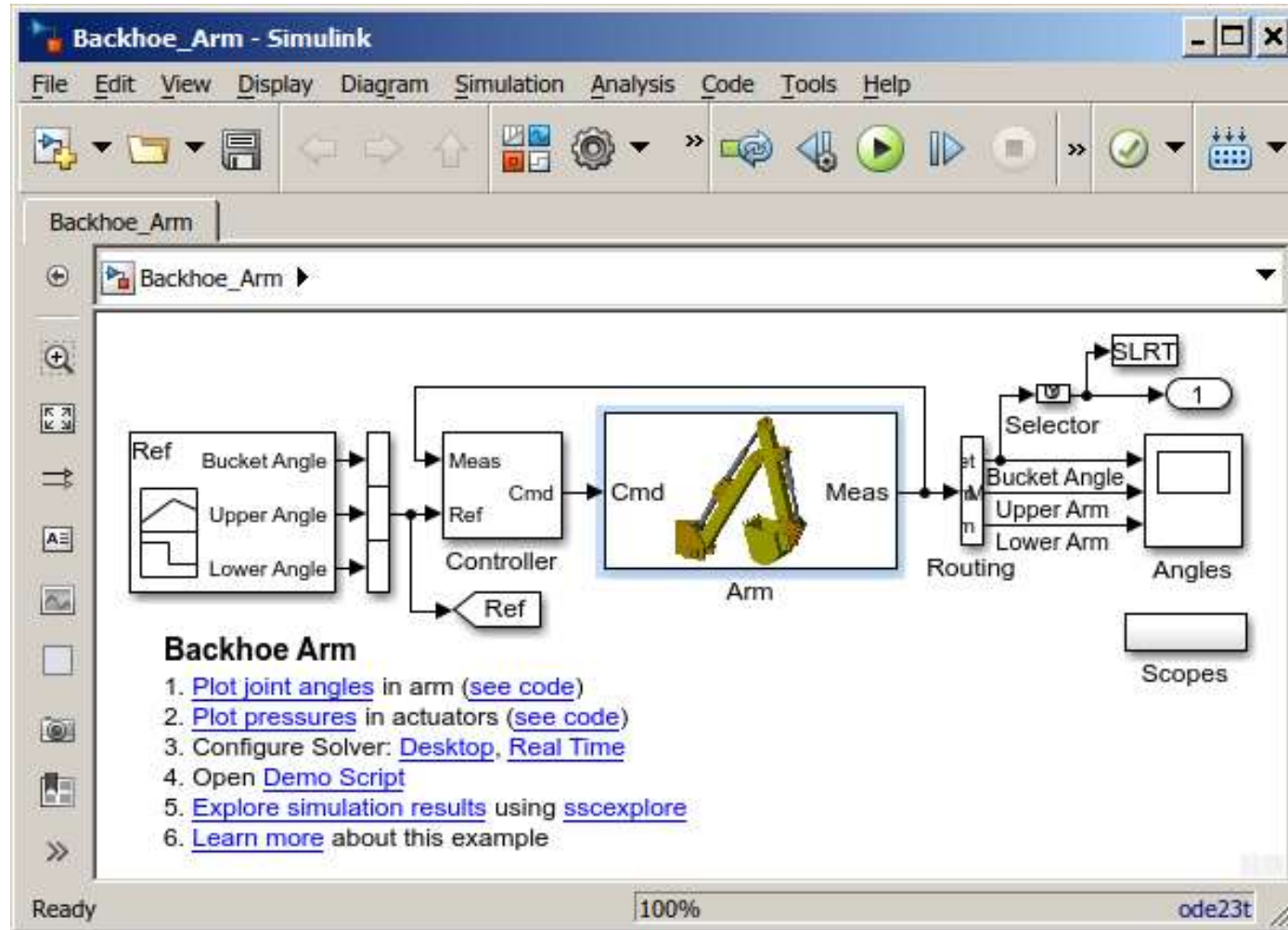
- **Modeling Fluid Systems with Simscape**
 - This one-day course focuses on modeling hydraulic systems in Simulink using Simscape Fluids

- **Modeling Driveline Systems with Simscape**
 - This one-day course focuses on modeling mechanical systems for automotive applications in the Simulink environment using Simscape Driveline

Modeling Mechanical and Hydraulic Systems in Simscape

- Modeling Multibody Mechanical Systems with Simscape
 - This one-day course discusses how to model rigid-body mechanical systems in the Simulink environment using Simscape Multibody
- Modeling Electrical Power Systems with Simscape
 - 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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