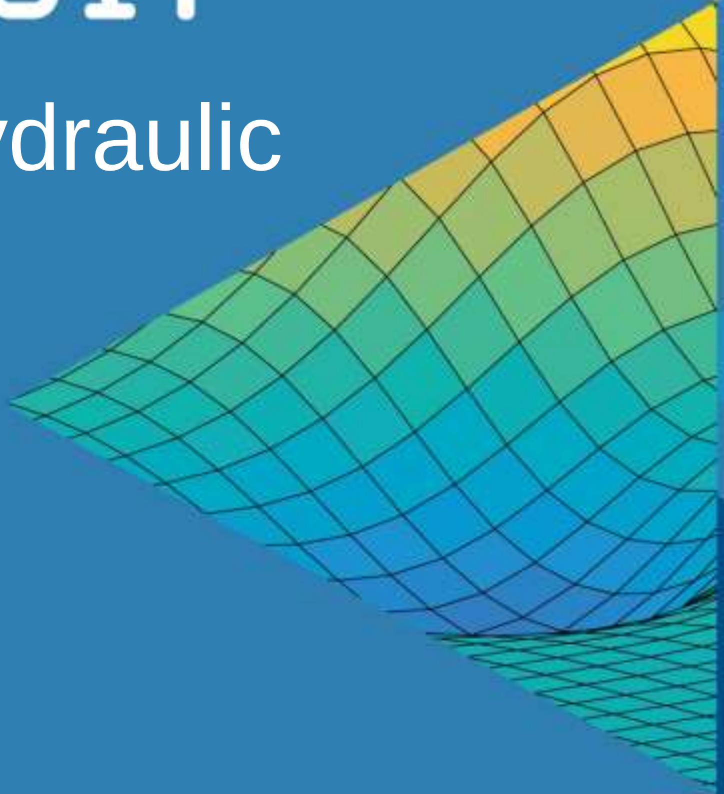
MATLAB EXPO 2017

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**

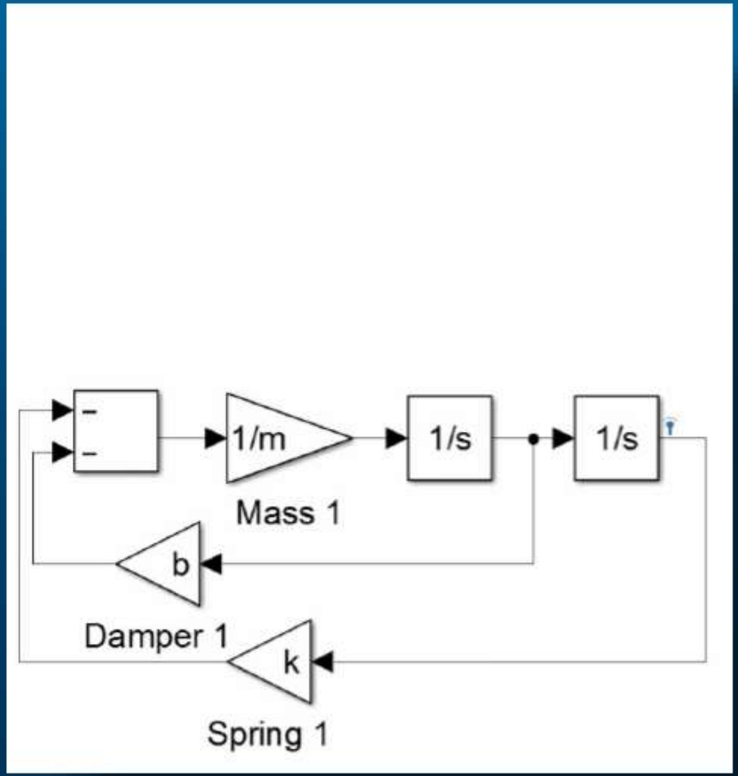
$$F_{Spring} = k_{Spring}{}^{*}(z_{Car} - z_{Whl})$$

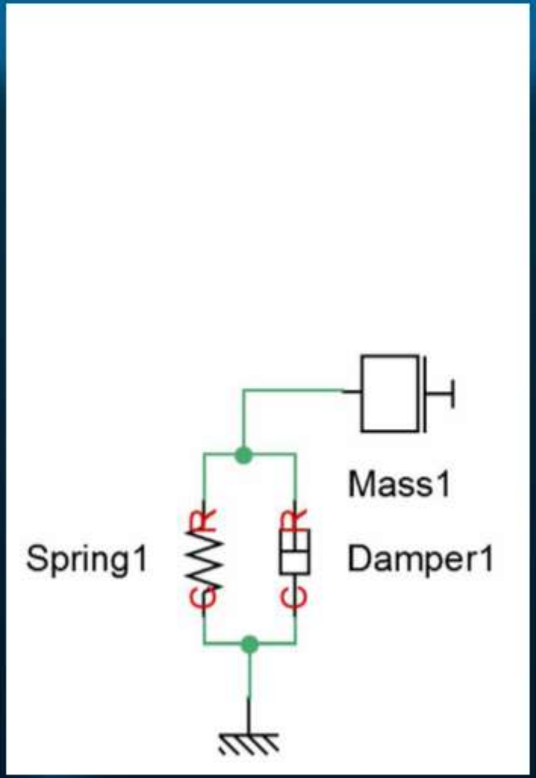
$$F_{Shock} = b_{Shock}{}^{*}\left(\frac{dz_{Car}}{dt} - \frac{dz_{Whl}}{dt}\right)$$

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

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

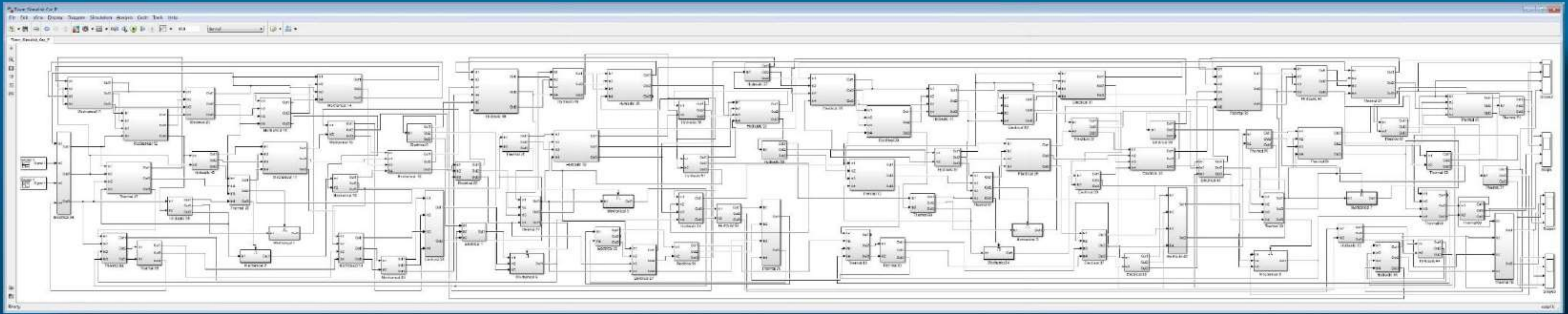
$$\frac{d^2 z_{Whl}}{dt^2} = \frac{F_{Spring} + F_{Shock} - F_{Tire}}{m_{Car}}$$

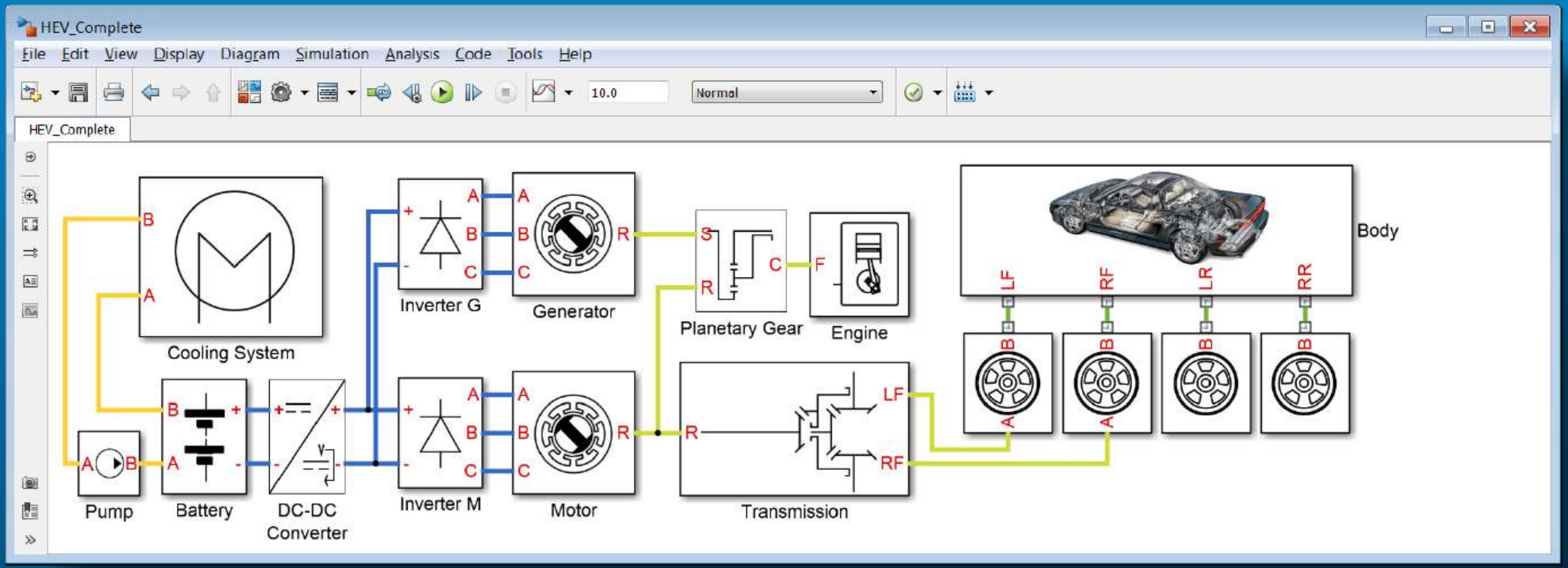


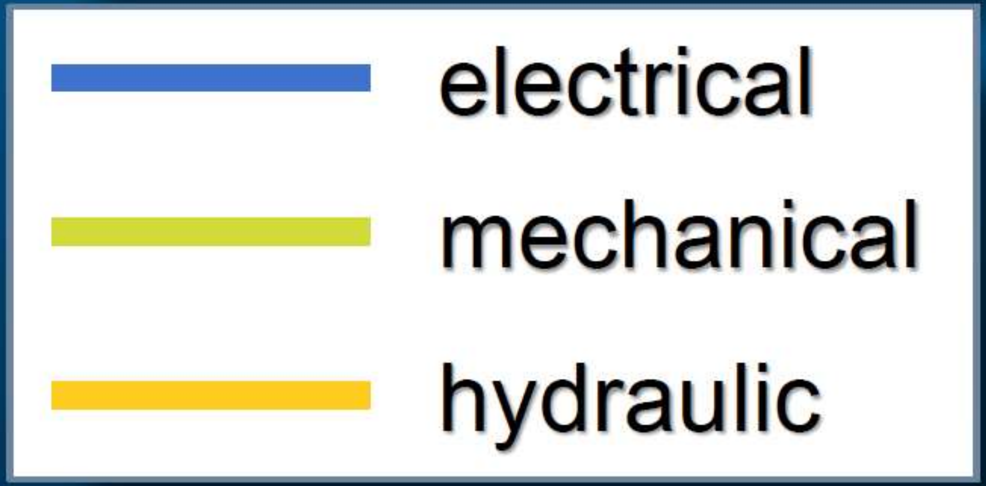


3D mechanics
hybrid powertrain

power steering
air conditioning







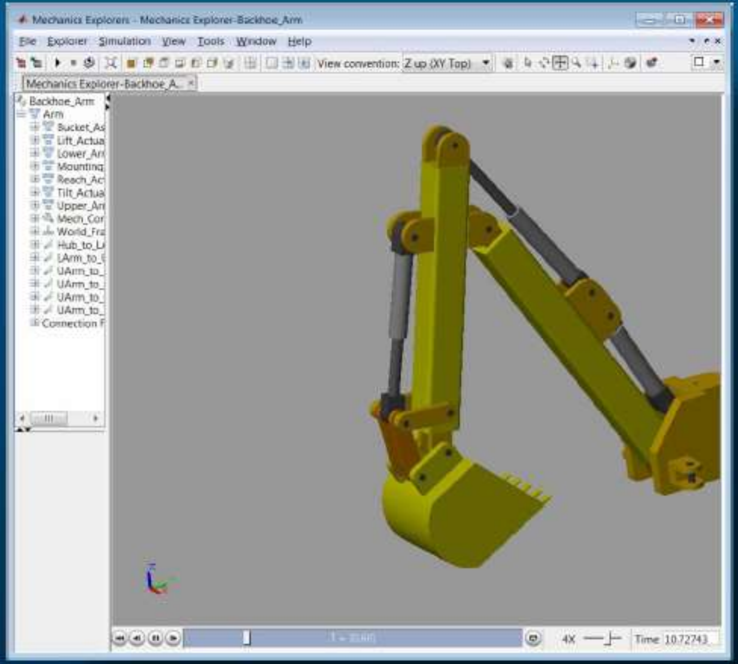
less clicking
more simulating

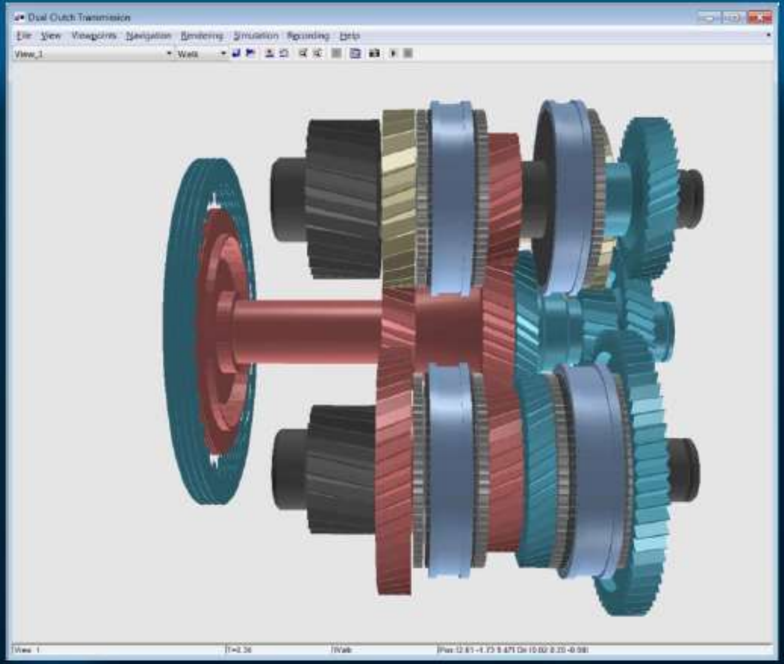
Market Demand:

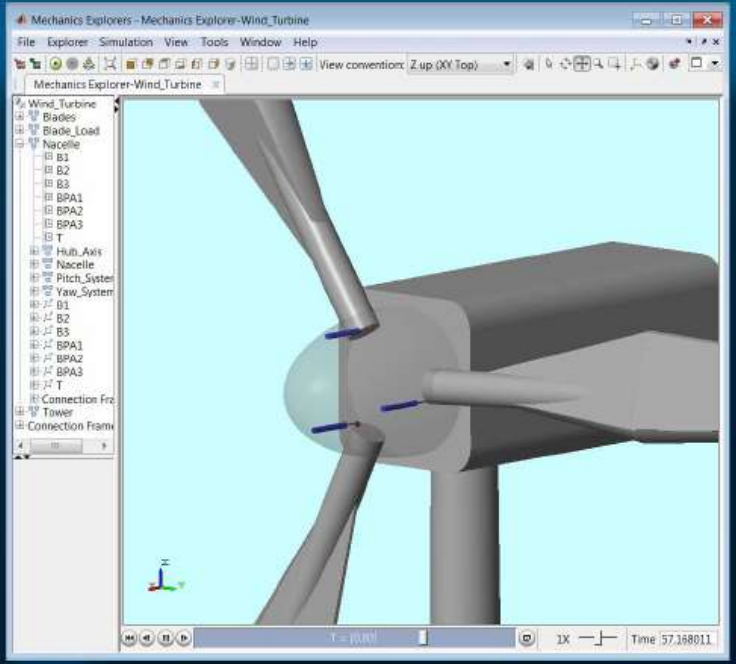
Reduce energy consumption in integrated systems

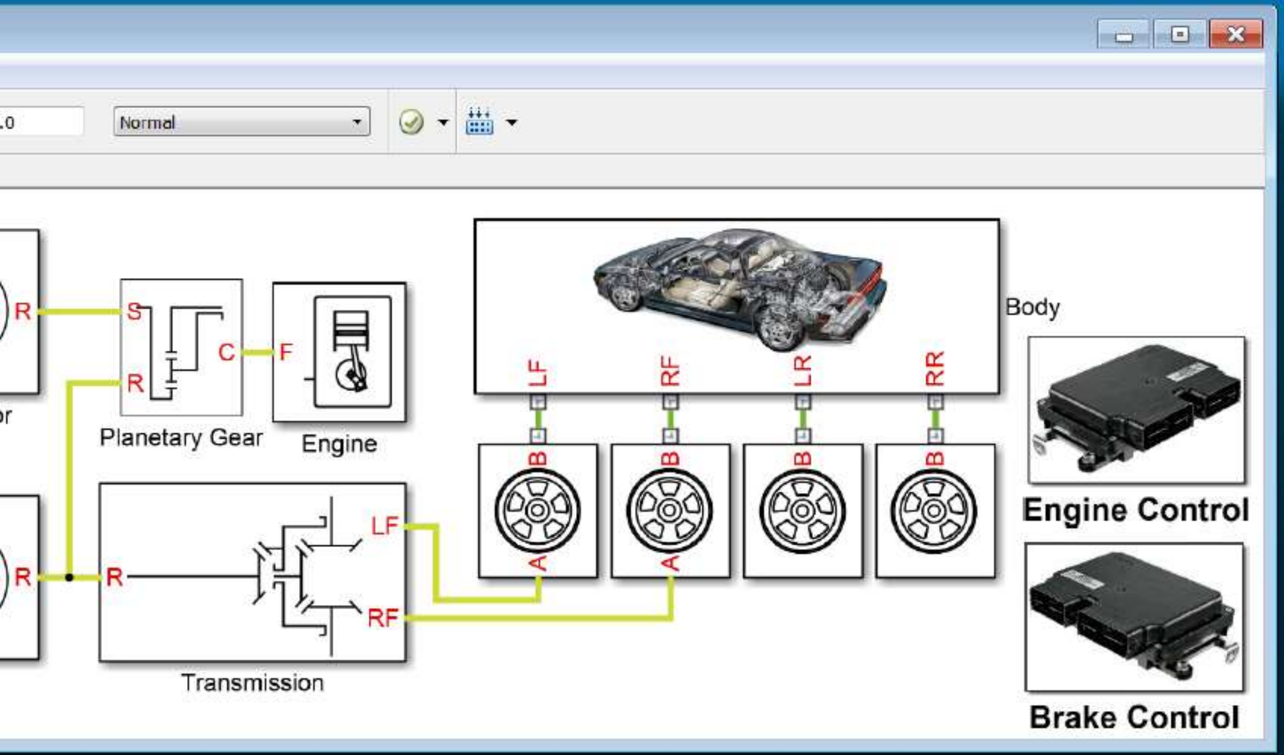
Simscape Focus:

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
- Simcape in Model-Based Design

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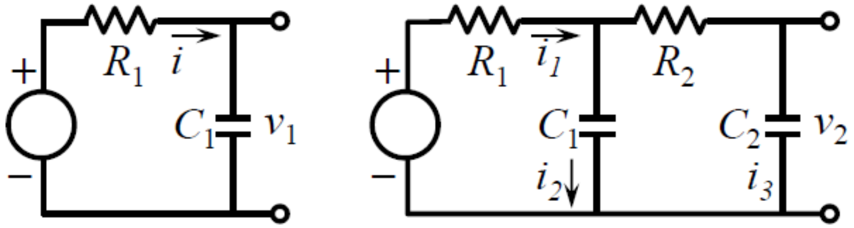
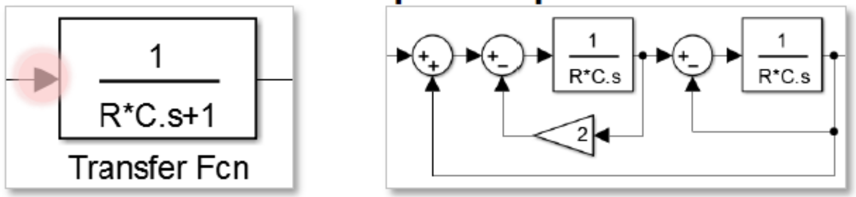
Physical Modeling with Simulink

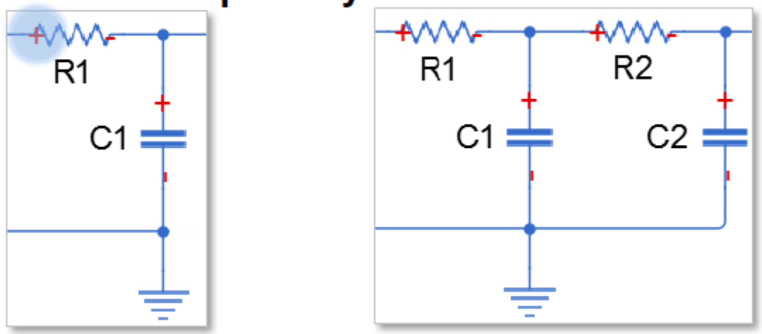
- Simulink is best known for signal based modeling
  - Causal, or input/output
- Simscape enables bidirectional flow of energy between components
- System level equations:
  - Formulated automatically
  - Solved simultaneously
  - Cover multiple domains

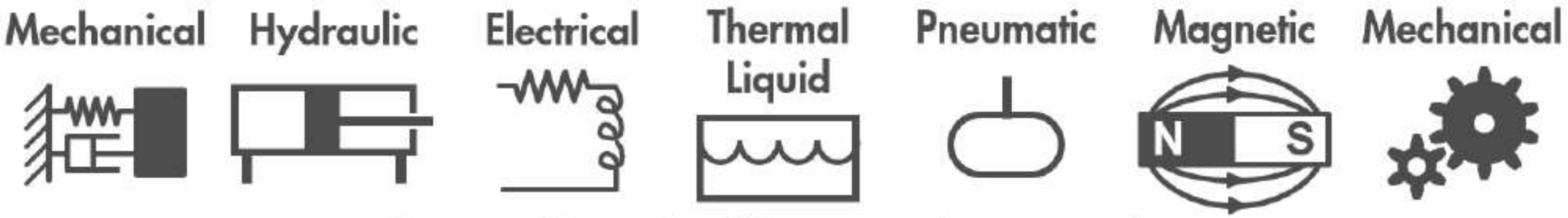


Simulink: Input/Output



Simscape: Physical Networks





Custom Domains (Simscape Language)

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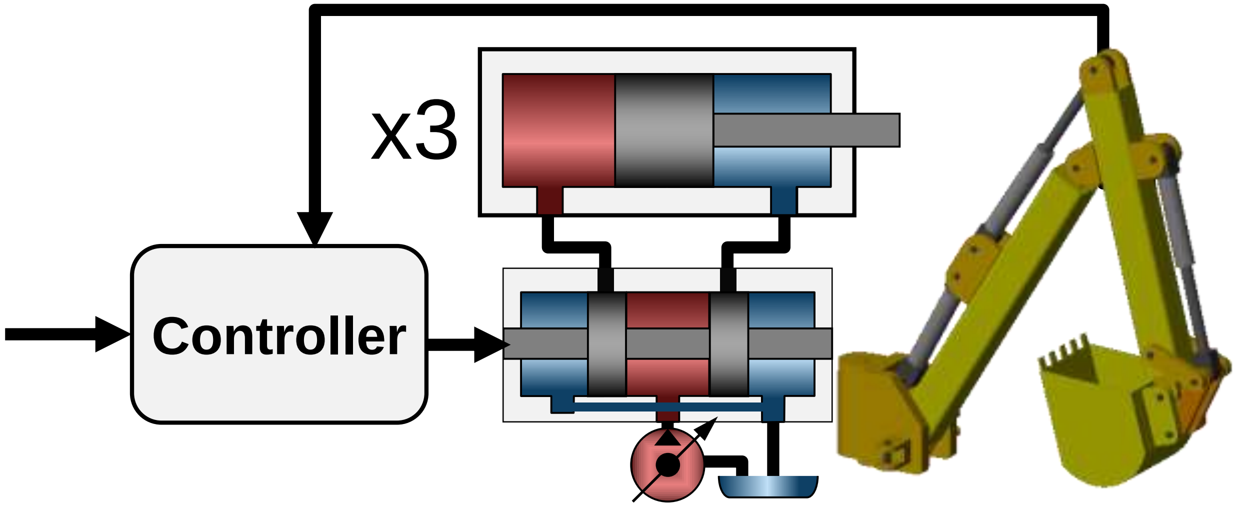
Backhoe Actuation System

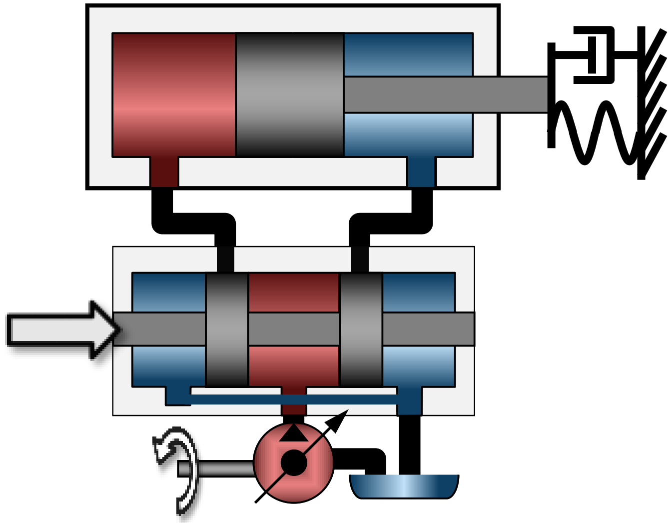
- System

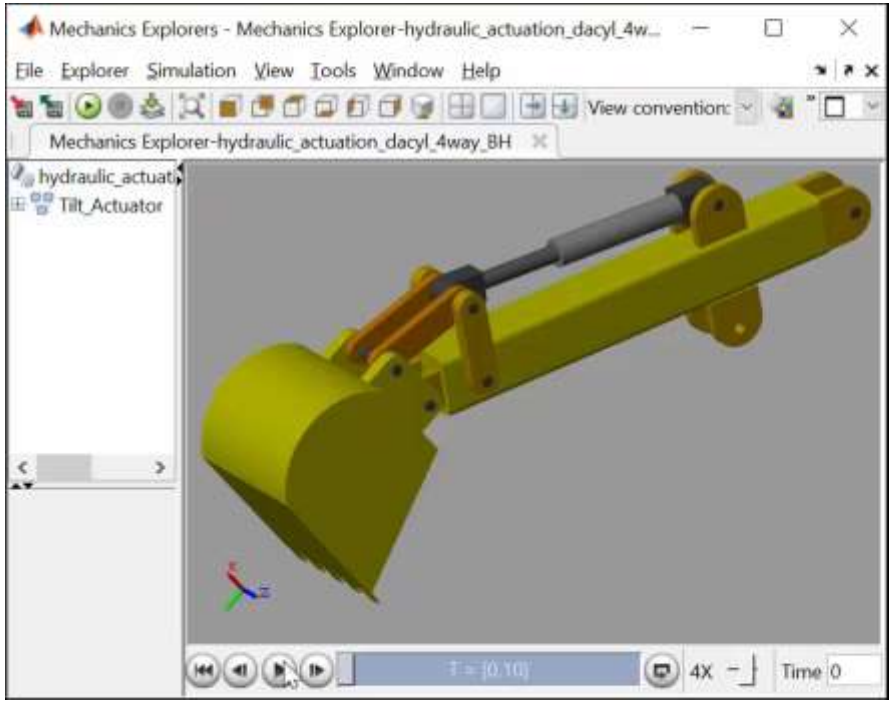


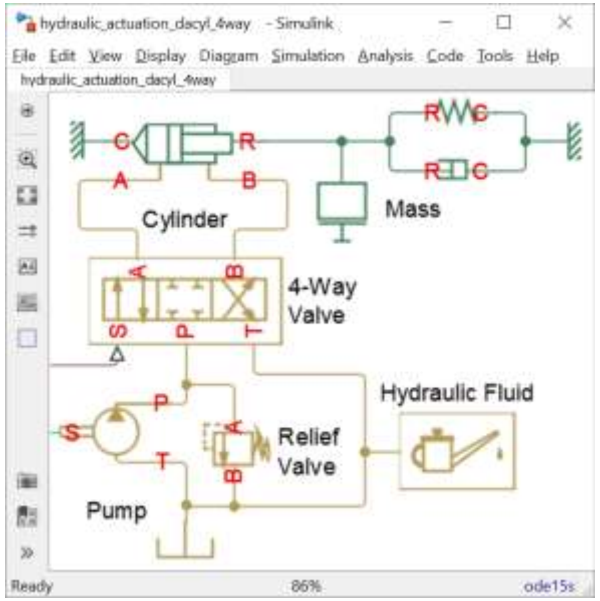
- Simulation Tasks
  1. Determine required size for actuator components
  2. Optimize design parameters in actuator and controller
  3. Measure robustness of design with relevant physical effects
  4. Test embedded hardware and software using HIL testing

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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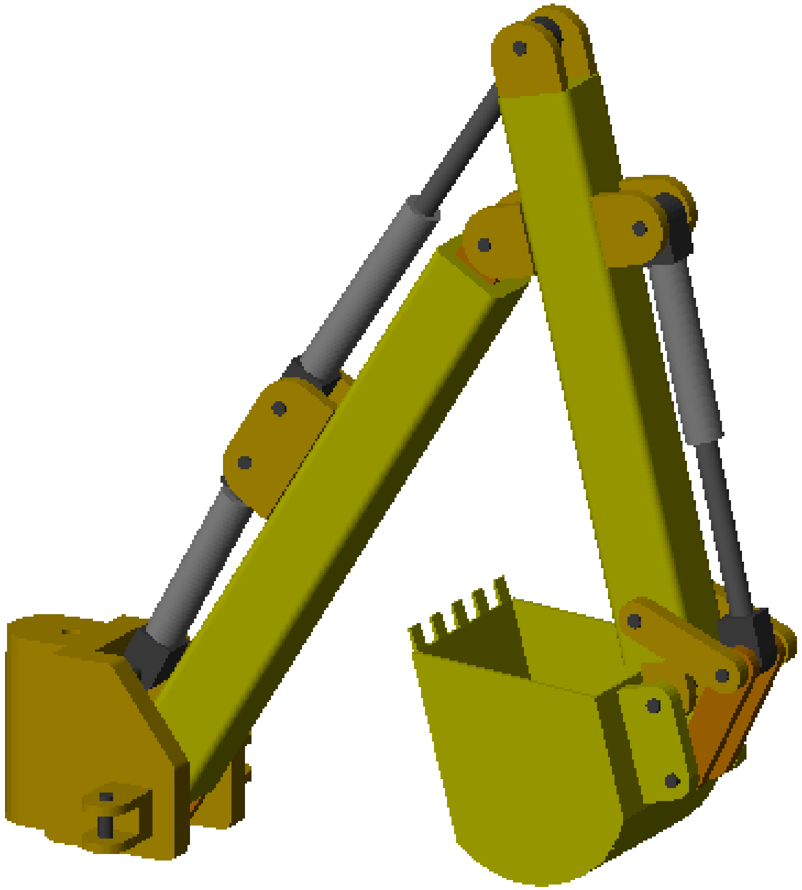
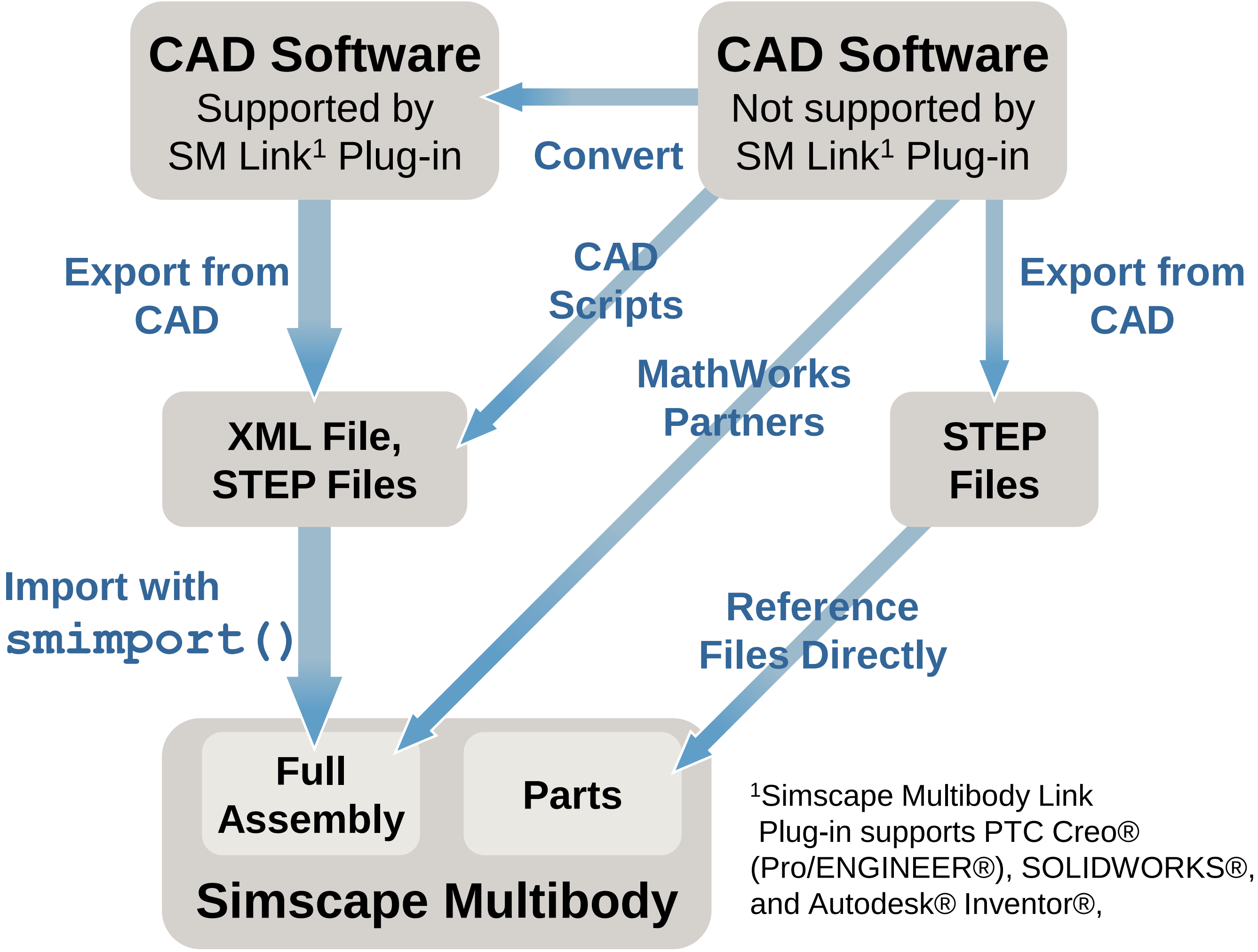
Mechanical System



CAD to Simscape Multibody Solutions

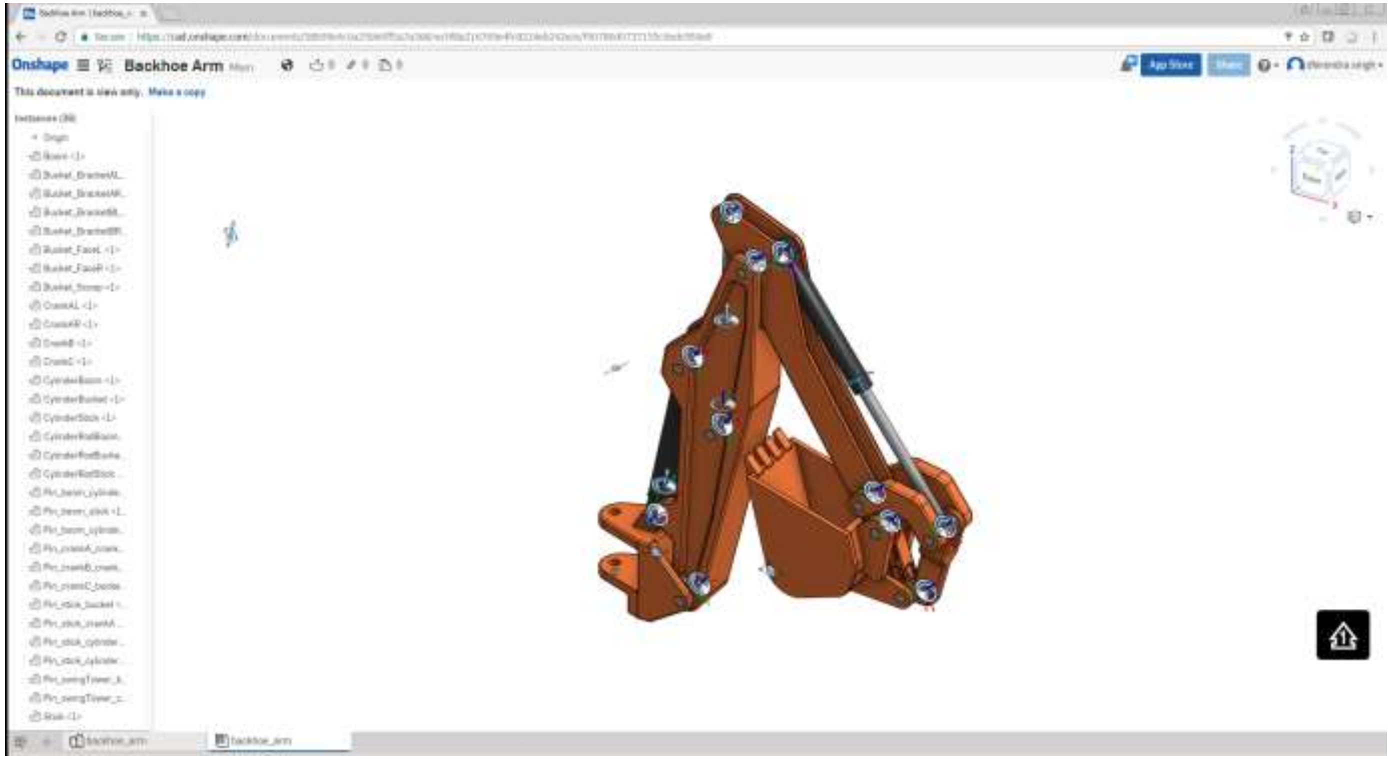
- Options for all CAD systems
- Convert full assembly via Simscape Multibody Link
  - Converts mates to joints
  - Mass, inertia, geometry, colors all converted
  - Block diagram built automatically
    - Same hierarchy as CAD model
- Reference files directly
  - STEP or STL files



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

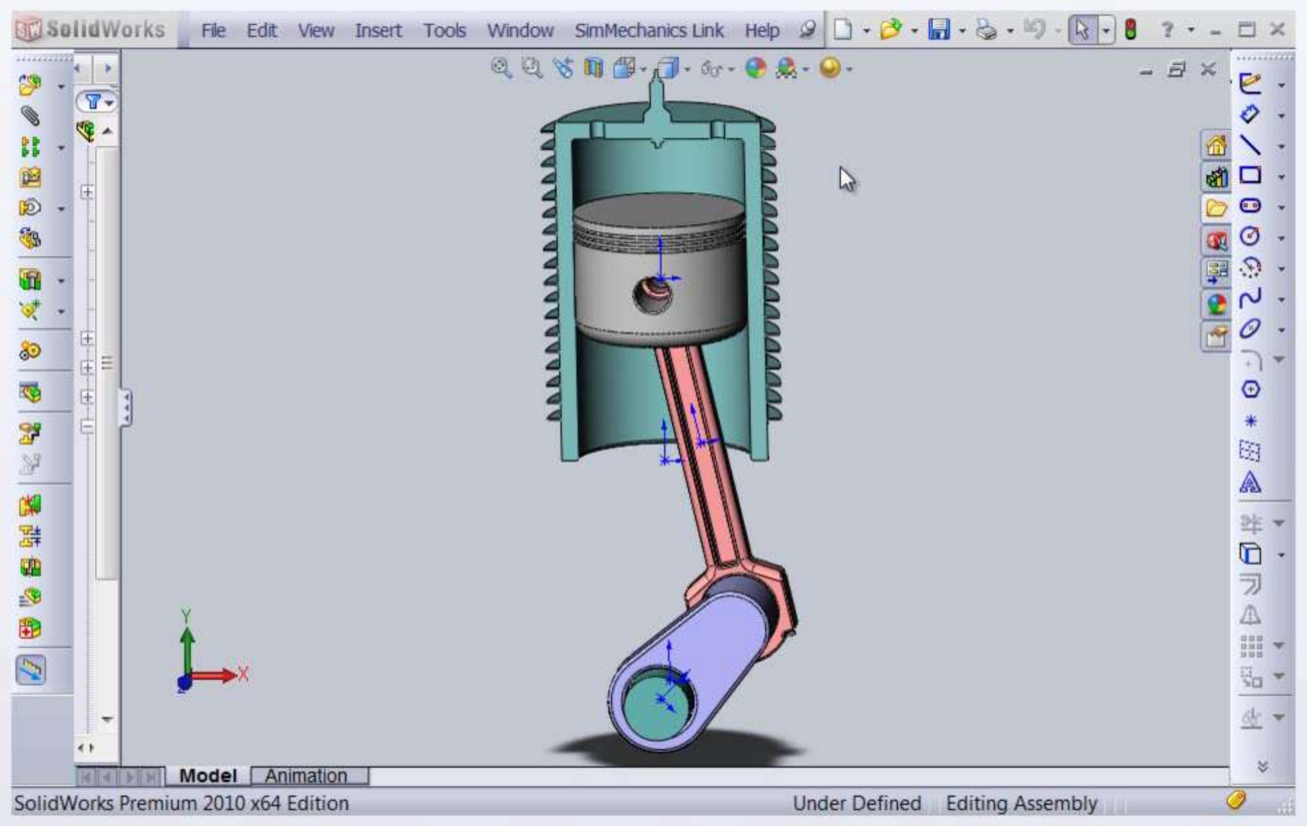
CAD model

- 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`**)

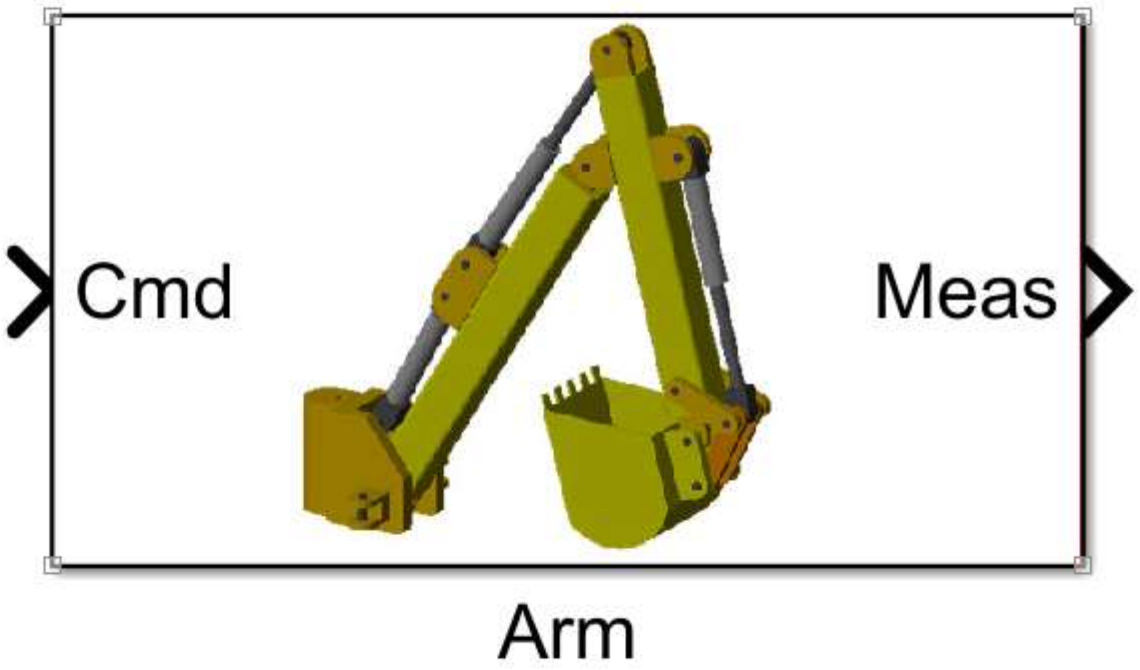


Demo

- 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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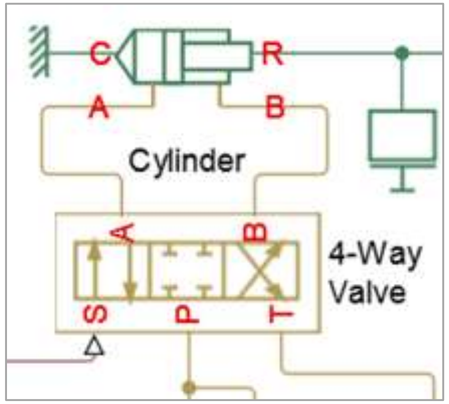
Demo

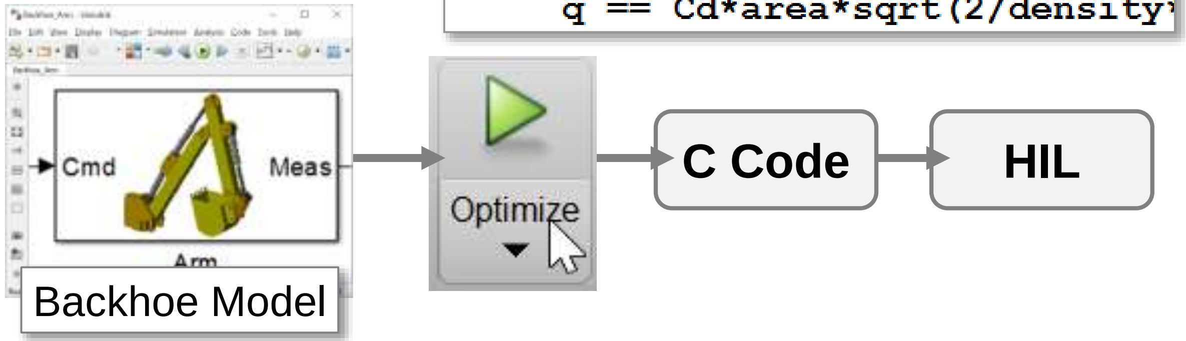
- Lets Build hydraulic actuation for our mechanical model

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



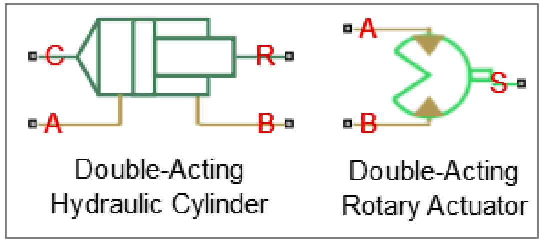
```
equations
  Re == q/(area*viscosity_kin)*I
  if(abs(Re)>=Recr) % Turbulent
    q == Cd*area*sqrt(2/density*
```



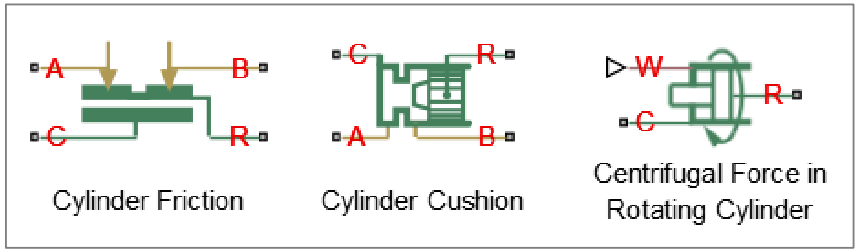
Adjusting Fidelity Using Simscape Fluids Components

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

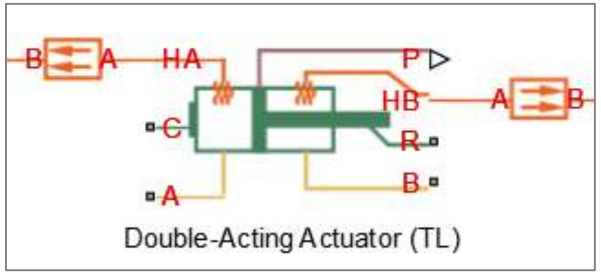
- Translational and rotational
  - Add or neglect compressibility



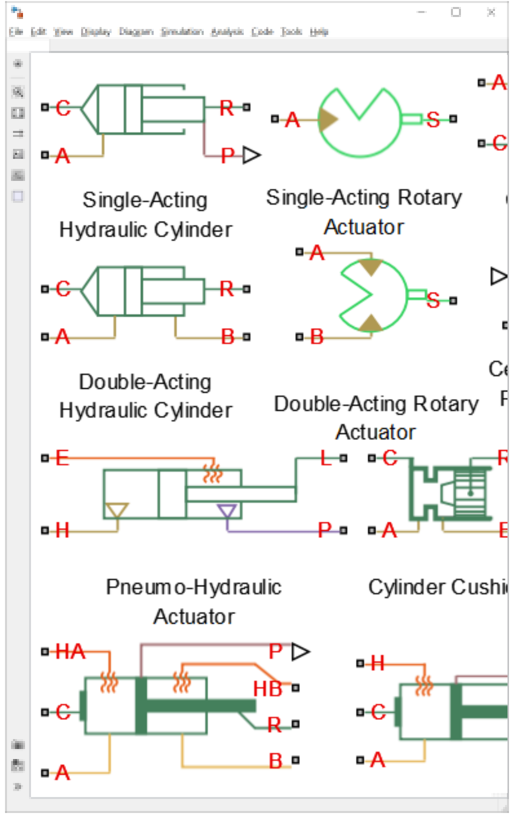
- Mechanical effects
  - Hard stops, Friction
  - Forces



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



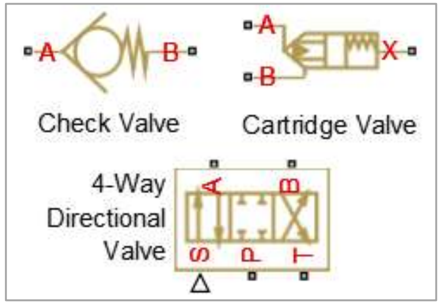
Subset of libraries

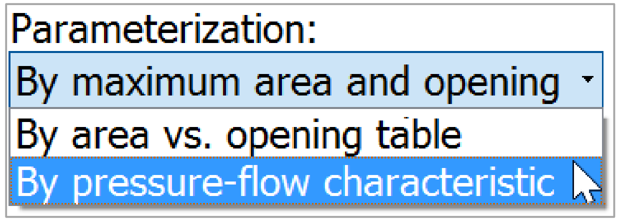


Adjusting Fidelity Using Simscape Fluids Components

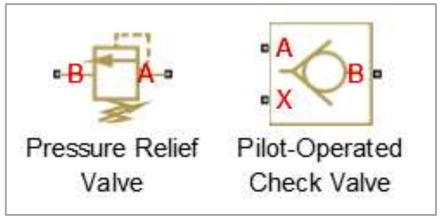
Actuators, **Valves**, Pumps and Motors, Pipes and Tanks, Heat Exchangers

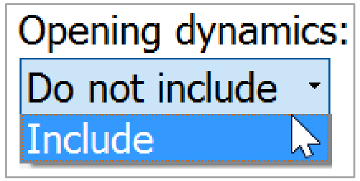
- Directional
  - Spool, check, cartridge
  - Parameterization options



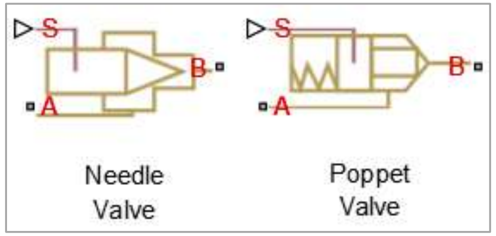


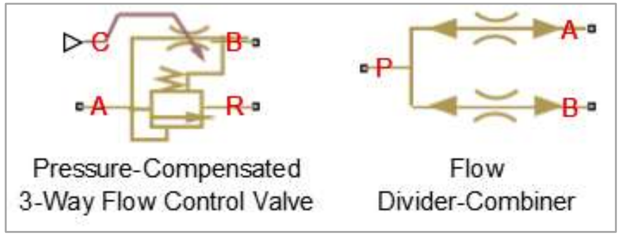
- Pressure control
  - Control tasks (variable)
  - Switching tasks (fixed)



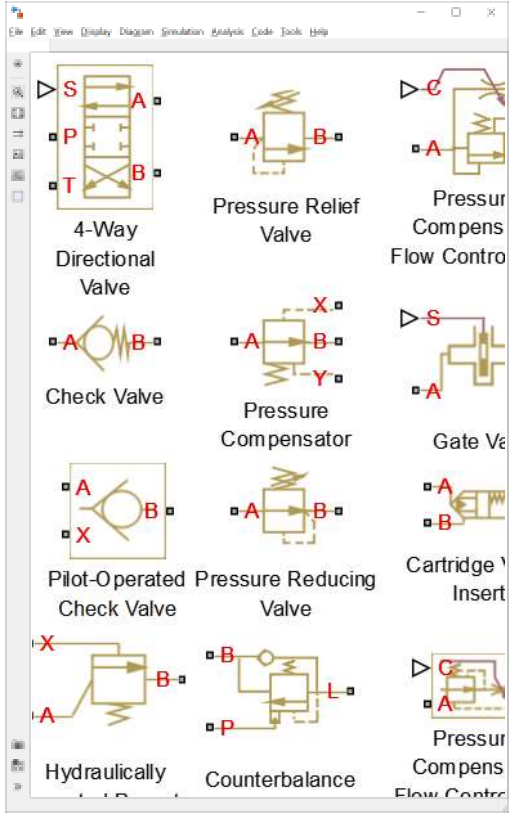


- Flow control
  - Pressure dependent
  - Pressure independent





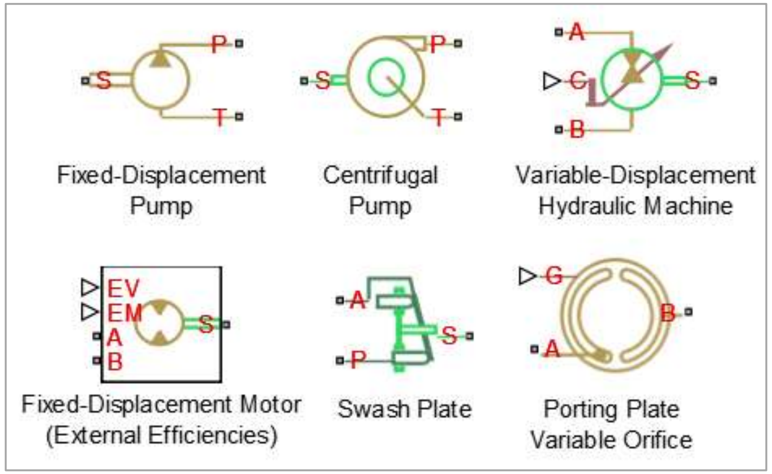
<u>Subset of libraries</u>



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



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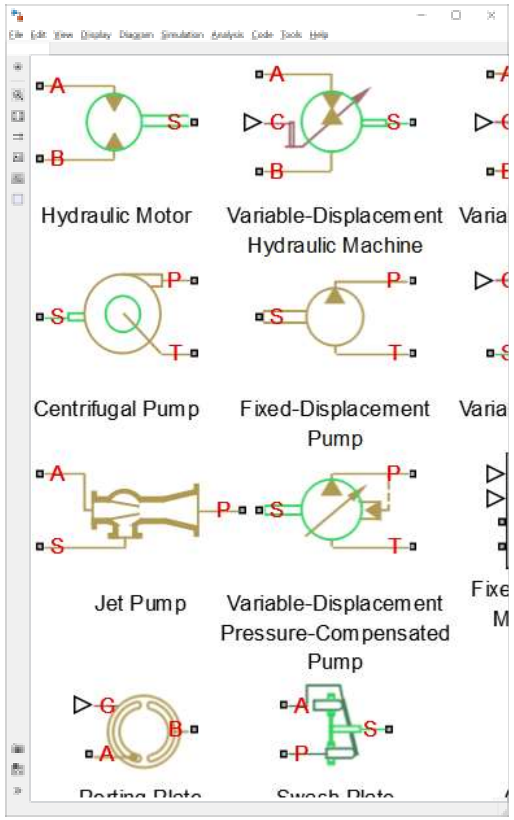
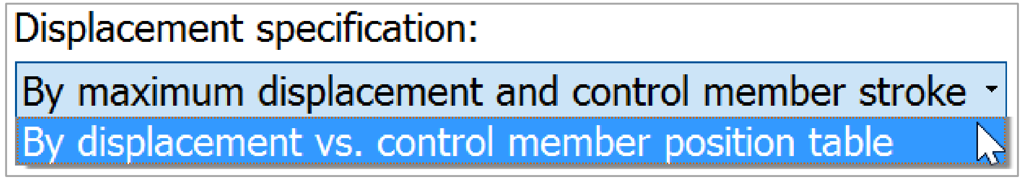
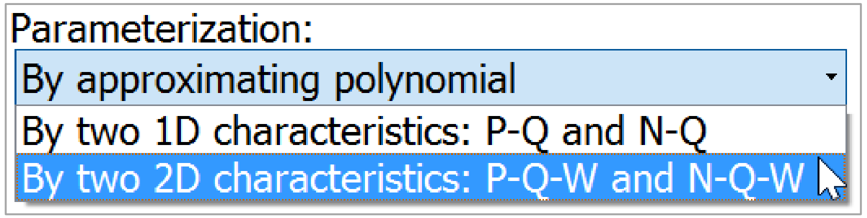
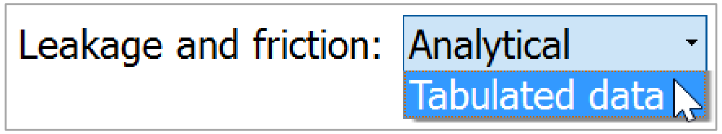


- Parameterization options
  - Pump delivery
  - Efficiency and losses
  - Leakage and friction



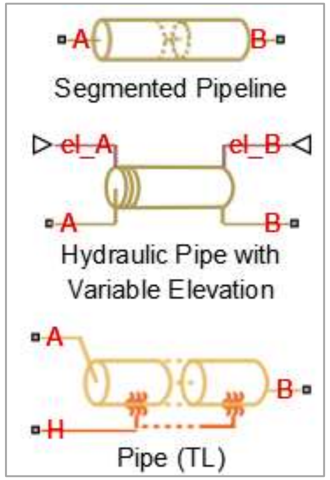


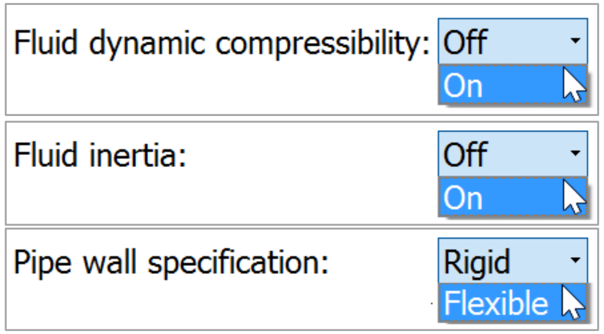


Adjusting Fidelity Using Simscape Fluids Components

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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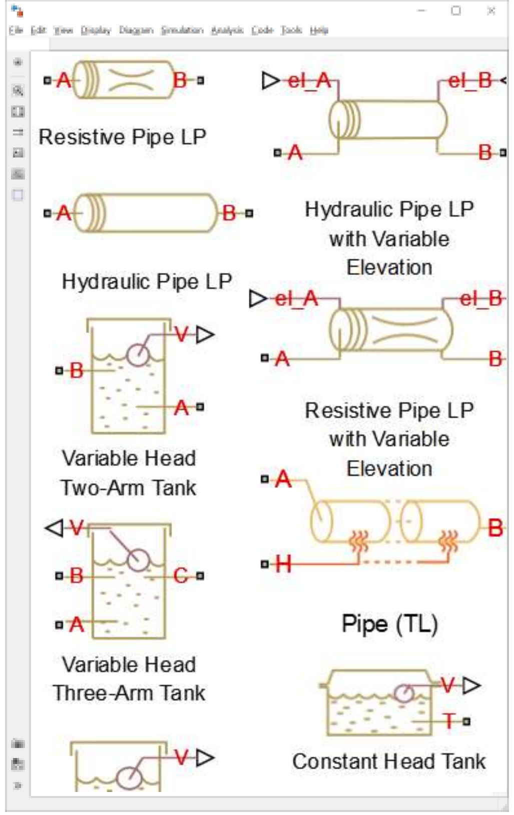
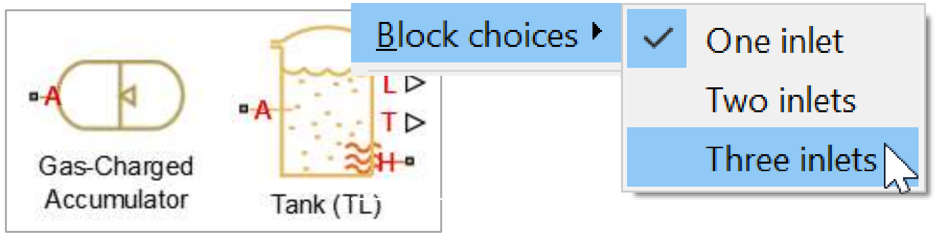
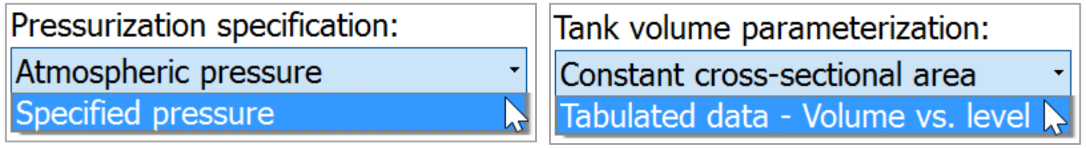


- Tanks and accumulators
  - Volume parameteriztion
  - Number of inlets
  - Pressurization

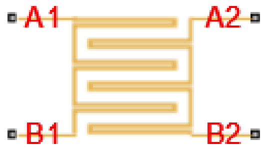




Adjusting Fidelity Using Simscape Fluids Components

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

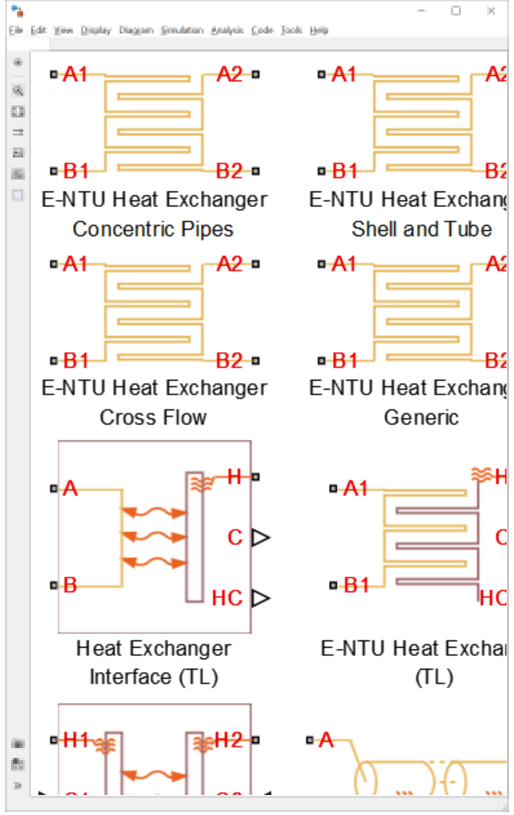
- Standard and custom types
  - Parallel or counter flow
  - Single or multiple shell passes
  - Mixed or unmixed flow



E-NTU Heat Exchanger (TL-TL)

Heat exchanger type:
Concentric pipes
Shell and tube
Cross flow
Generic - effectiveness table

Subset of libraries



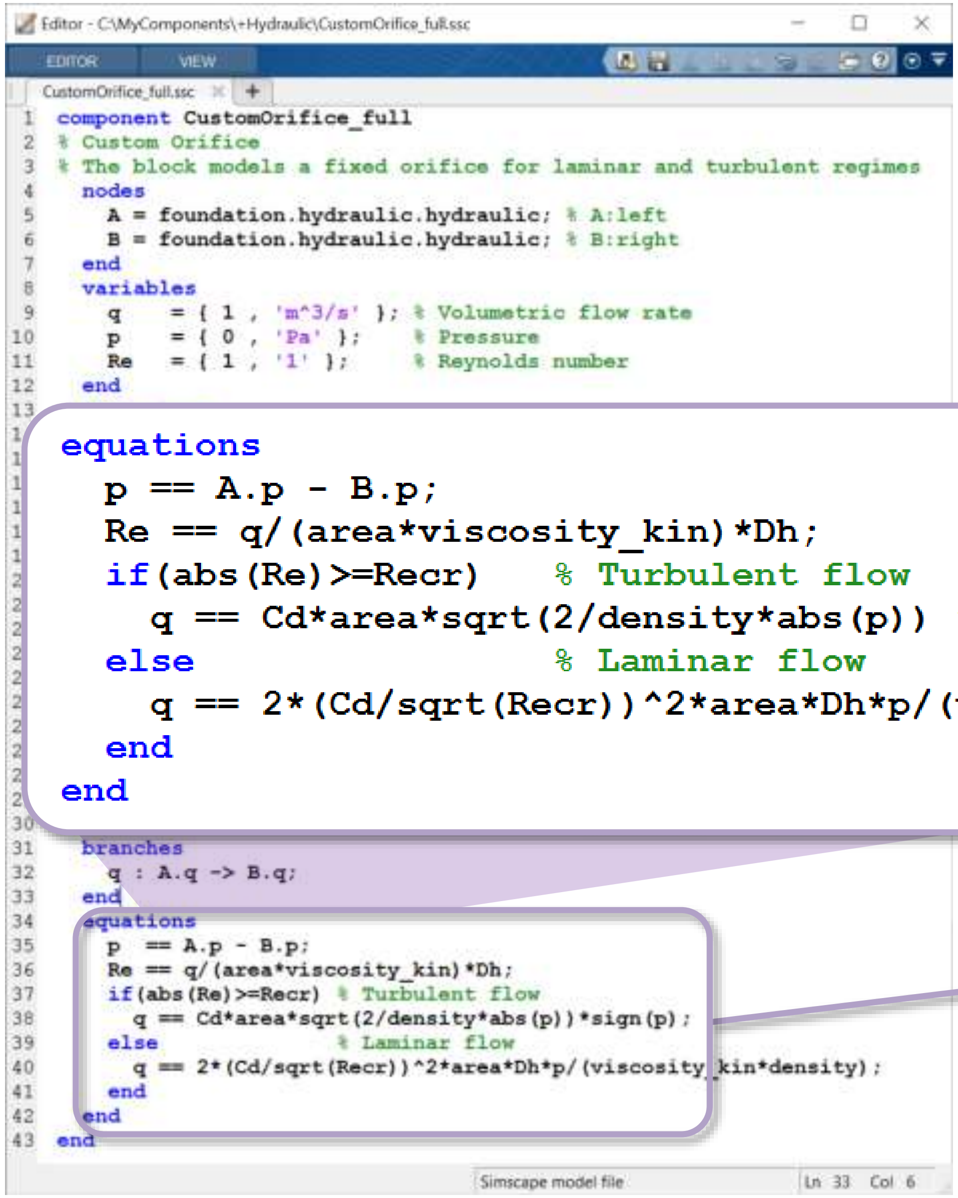
- Parameterization options
  - Pressure losses
  - Heat transfer
  - Compressibility

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

Create or Modify Reusable Components




```
equations
  p == A.p - B.p;
  Re == q/(area*viscosity_kin)*Dh;
  if(abs(Re)>=Recr)    % Turbulent flow
    q == Cd*area*sqrt(2/density*abs(p)) * sign(p
  else                 % Laminar flow
    q == 2*(Cd/sqrt(Recr))^2*area*Dh*p/(viscosit
  end
end
```

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

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

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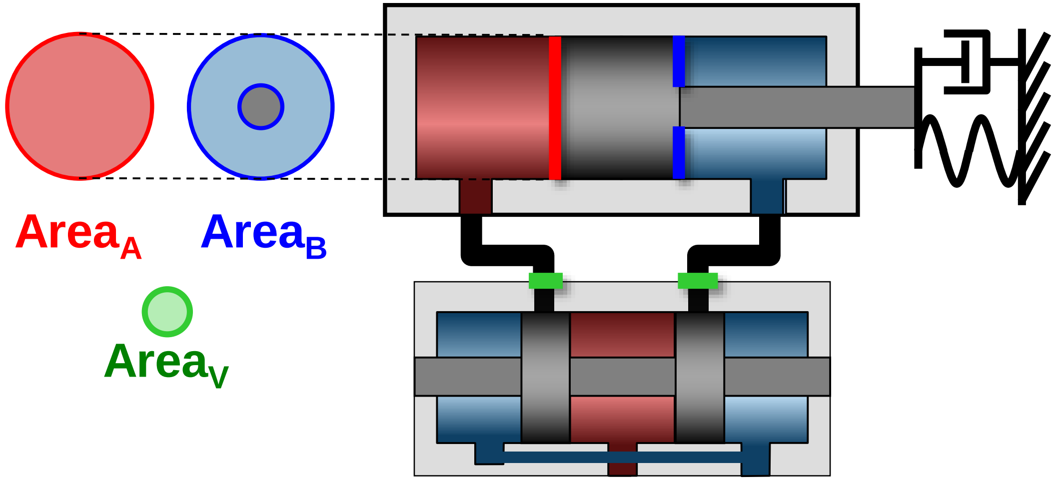
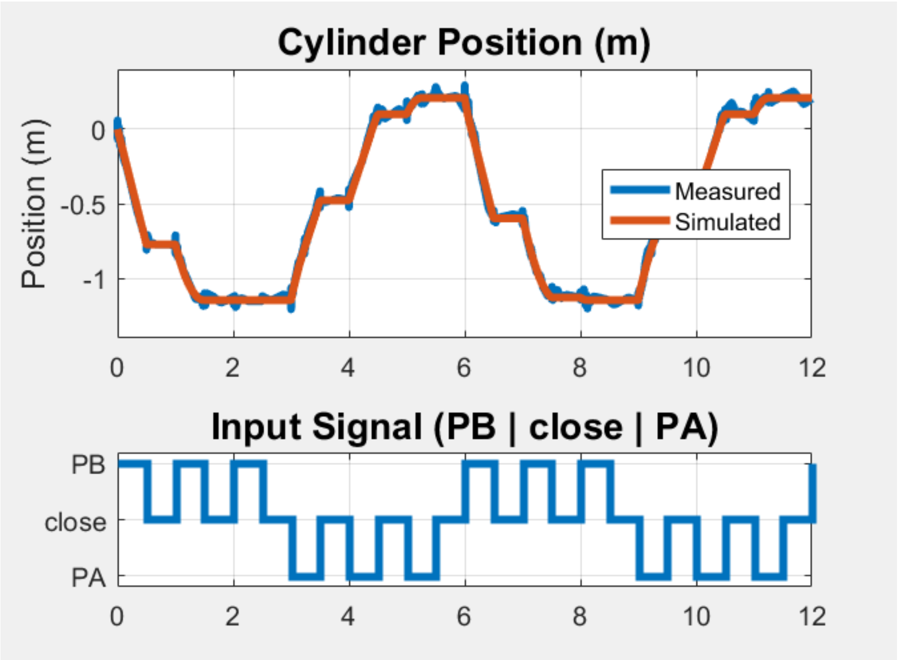
Estimating Model Parameters Using Measured Data

Model:





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

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

Solution: Use Simulink Design Optimization to automatically tune model parameters

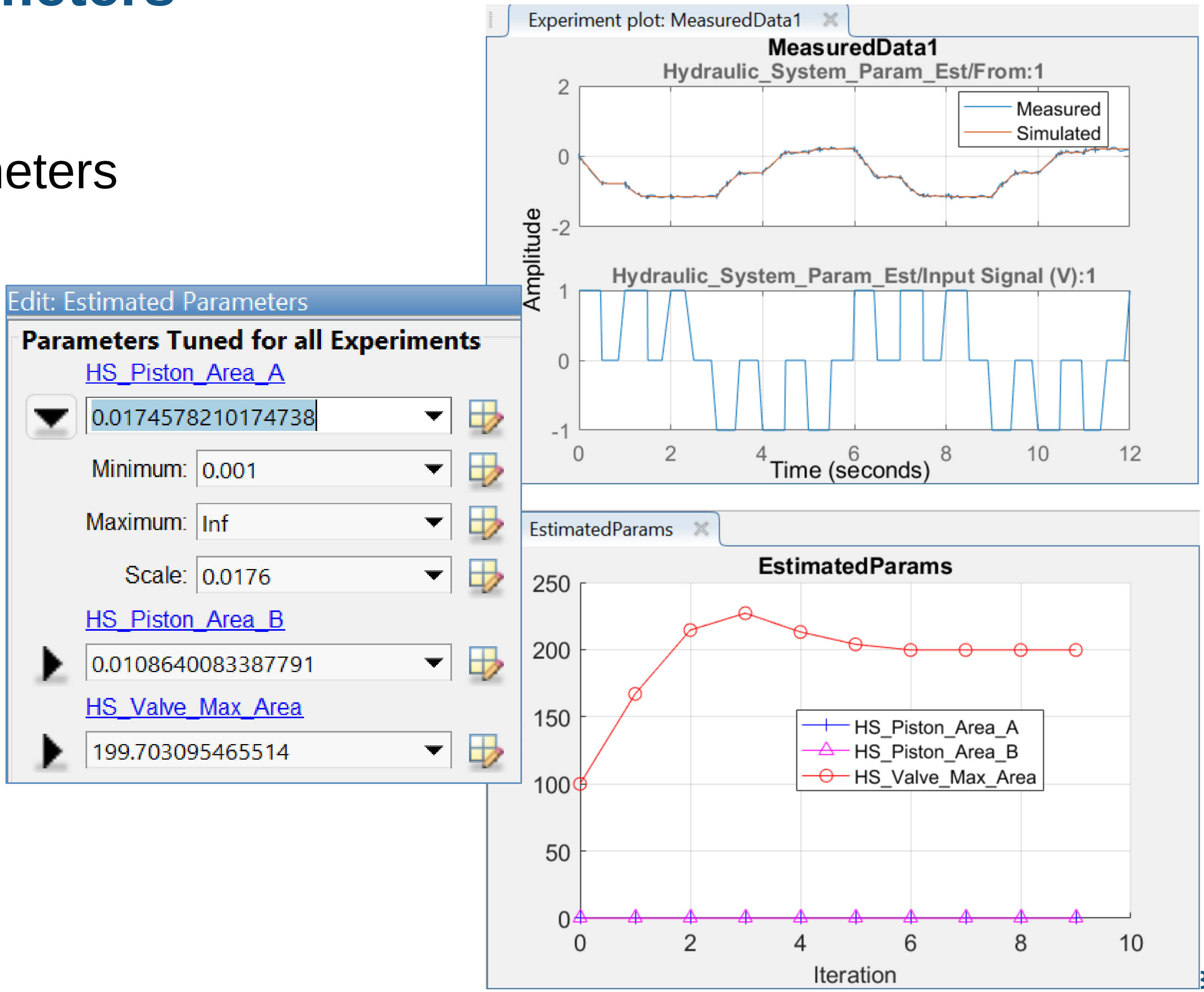
Estimating Model Parameters Using Measured Data

- Steps to Estimating Parameters

1. Import measurement data

2. Identify parameters and their ranges

3. Estimate parameters



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?

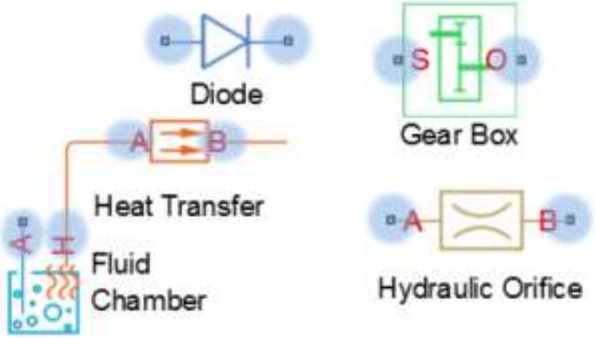
Too big, too difficult, one chance, …

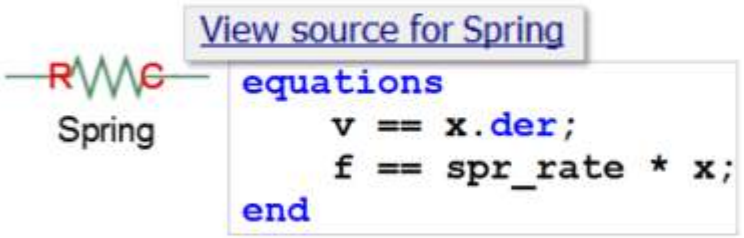
Why Simscape?

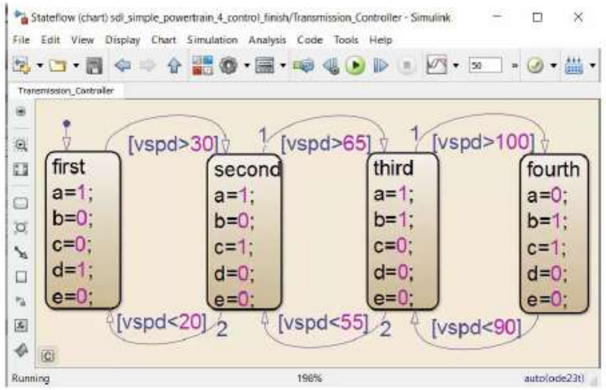
Makes modeling easy
Develop controller
Find best design

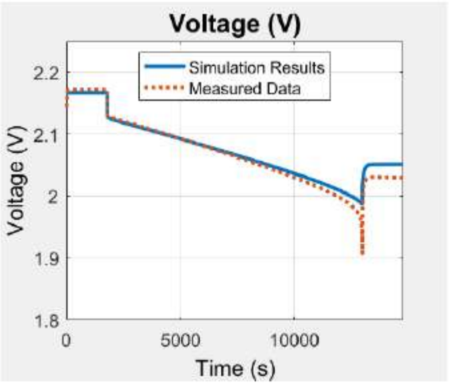
Simscape Key Points

- 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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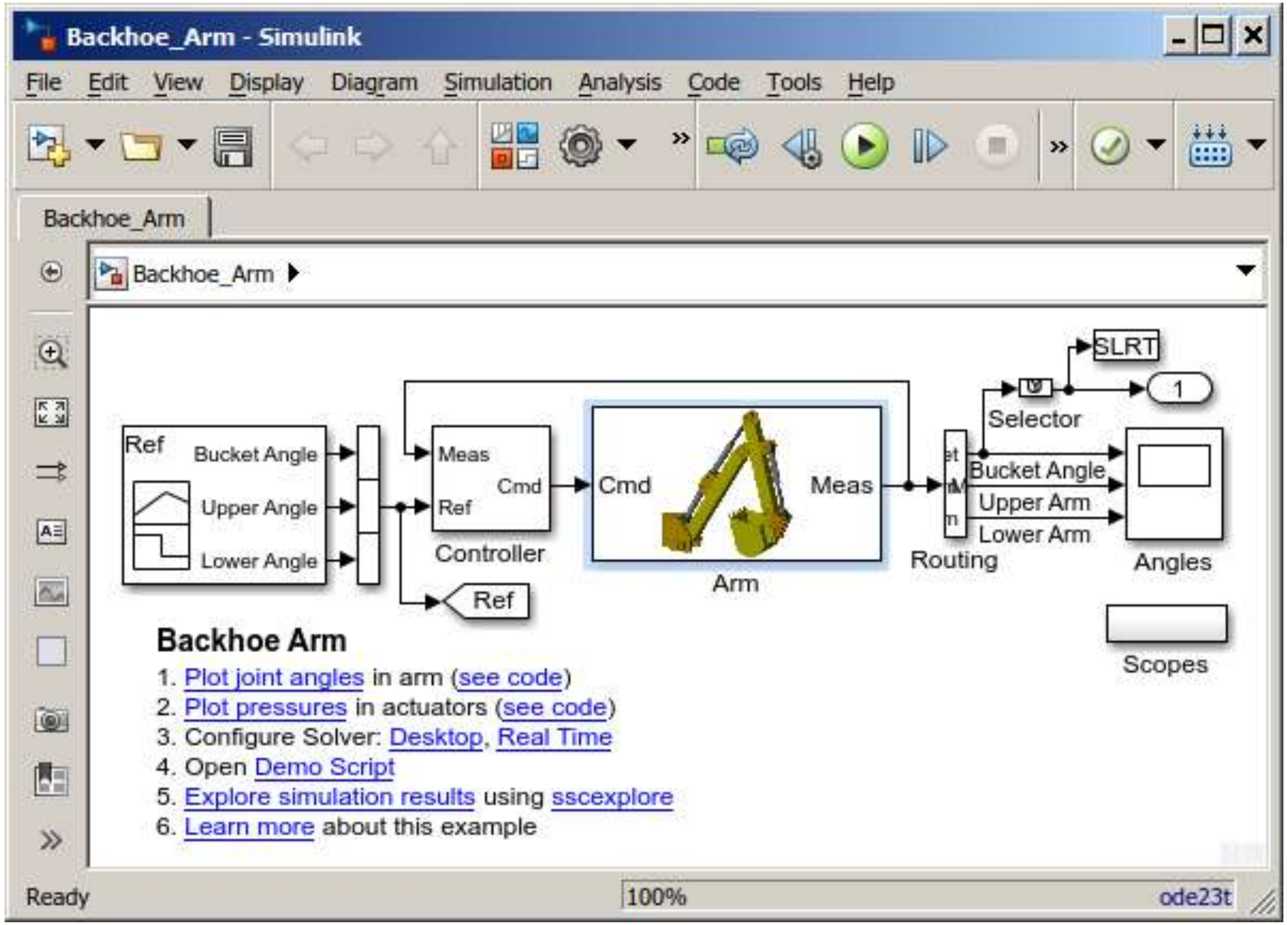
Questions & Discussion



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