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

Courtesy NASA/JPL-Caltech
Why use Simscape?

Makes modeling easy
Simscape handles equations automatically

\[ F_{Spring} = k_{Spring} \cdot (z_{Car}) \]
\[ F_{Shock} = b_{Shock} \cdot \left( \frac{dz_{Car}}{dt} \right) \]
\[ \frac{d^2 z_{Car}}{dt^2} = -\frac{F_{Spring} - F_{Shock}}{m_{Car}} \]
Simscape handles equations automatically

\[ F_{Spring} = k_{Spring} \times (z_{Car} - z_{Whl}) \]
\[ F_{Shock} = b_{Shock} \times \left( \frac{dz_{Car}}{dt} - \frac{dz_{Whl}}{dt} \right) \]
\[ \frac{d^2 z_{Car}}{dt^2} = -F_{Spring} - F_{Shock} \]
\[ F_{Tire} = k_{Tire} \times (z_{Whl}) + b_{Tire} \times \left( \frac{dz_{Car}}{dt} \right) \]
\[ \frac{d^2 z_{Whl}}{dt^2} = \frac{F_{Spring} + F_{Shock} - F_{Tire}}{m_{Car}} \]
3D mechanics
hybrid powertrain

power steering
air conditioning
less clicking
more simulating

- electrical
- mechanical
- hydraulic
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

1Simscape 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 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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- 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
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

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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

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

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

Subset of libraries
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

- Tanks and accumulators
  - Volume parameterization
  - 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
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

\[
q = \begin{cases} 
C_D \cdot \sqrt{\frac{2}{\rho}} |p| \cdot \text{sign}(p) & \text{Re} \geq \text{Re}_{cr} \\
2 \cdot C_{DL} \cdot \frac{A}{\nu p} & \text{Re} < \text{Re}_{cr}
\end{cases}
\]
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Estimating Model Parameters Using Measured Data

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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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
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- Specialized courses in control design, signal processing, parallel computing, code generation, communications, financial analysis, and other areas
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

Backhoe Arm
1. Plot joint angles in arm (see code)
2. Plot pressures in actuators (see code)
3. Configure Solver: Desktop, Real Time
4. Open Demo Script
5. Explore simulation results using sscexplore
6. Learn more about this example
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Email: info@mathworks.in

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