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Physical Modeling of Multi-Domain System

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Agenda

- What is Physical Modeling? Why use Simscape?

- Landing Gear Modeling
  - Landing Gear Mechanism Modeling
  - Refine requirement and optimize mechanical design
  - Analyze hydraulic actuator designs

- Test system in various situations
physical modeling = Simulation models based on physical connections
system is too big
conditions are too difficult
only get

one chance
too big

ABB Optimizes Ship Energy Flows

too difficult

DCNS Simulates Handling System

one chance

Lockheed Martin Develops MRO

Courtesy NASA/JPL
Simscape

Power Systems  Electronics  Fluids  Multibody  Driveline
Why use Simscape?

Makes modeling easy
Simscape handles equations automatically

\[ F_{\text{Spring}} = k_{\text{Spring}} \cdot (z_{\text{Car}}) \]
\[ F_{\text{Shock}} = b_{\text{Shock}} \cdot \frac{dz_{\text{Car}}}{dt} \]
\[ \frac{d^2 z_{\text{Car}}}{dt^2} = -\frac{F_{\text{Spring}} - F_{\text{Shock}}}{m_{\text{Car}}} \]
\[ F_{\text{Spring}} = k_{\text{Spring}} (z_{\text{Car}} - z_{\text{Whl}}) \]
\[ F_{\text{Shock}} = b_{\text{Shock}} \left( \frac{dz_{\text{Car}}}{dt} - \frac{dz_{\text{Whl}}}{dt} \right) \]
\[ \frac{d^2 z_{\text{Car}}}{dt^2} = \frac{-F_{\text{Spring}} - F_{\text{Shock}}}{m_{\text{Car}}} \]
\[ F_{\text{Tire}} = k_{\text{Tire}} (z_{\text{Whl}}) + b_{\text{Tire}} \left( \frac{dz_{\text{Car}}}{dt} \right) \]
\[ \frac{d^2 z_{\text{Whl}}}{dt^2} = \frac{F_{\text{Spring}} + F_{\text{Shock}} - F_{\text{Tire}}}{m_{\text{Car}}} \]

Simscape handles equations automatically.
Simscape Summary

- Enables physical modeling (acausal) of multi-domain physical systems
- Simscape platform
  - Foundation libraries in 8 domains
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  - Language for defining custom blocks
    - Extension of MATLAB
  - Simulation engine and custom diagnostics
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Create Reusable System-Level Models

Models are easier to understand, reuse, and share with others.
Optimize Your Entire Engineering System

Simulate the entire system in a single environment
- Does not require learning multiple tools or co-simulation
Simscape Summary

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- Simscape platform
  - Foundation libraries in 8 domains
  - Language for defining custom blocks
    - Extension of MATLAB
  - Simulation engine and custom diagnostics
- Simscape libraries
  - Extend foundation domains with components, effects, parameterizations
  - Models can be converted to C code
To develop controller...

Less clicking, More Simulating
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Landing Gear System

Physical Model

Controller

Main Actuator

Lock Actuator
Landing Gear Mechanism Modeling

So, where do we really start?

If possible, break down a big problem into “smaller” (i.e. more manageable) problems

*** Use a “divide and conquer” approach ***
Landing Gear Mechanism Modeling

So, where do we really start?

Understand the underlying mathematics/physics of the problem
Landing Gear Mechanism Modeling

We need to “extend” the approach
Simscape Products

- Power Systems
- Driveline
- Electronics
- Fluids
- Multibody
Landing Gear Mechanism Modeling
Simscape Multibody to model the dynamics of 3D mechanisms

Can manually create and combine any number of bodies and joints…
Landing Gear Mechanism Modeling
Landing Gear CAD Import using Simscape Multibody Link

- Automatically create SimMechanics models from a CAD assembly
  - Converts mass and inertia to rigid bodies
  - Converts mate definitions to joints
  - Creates STL files for use with SimMechanics visualization

- Directly connects SolidWorks, ProEngineer and Inventor
Landing Gear Mechanism Modeling
Applying Actuation Force/Torque
Optimizing System in Mechanics
Optimizing Lock Linkage Design

Model:

Problem: Evaluate lock linkage connection points to find optimal location that meets requirements

Solution: Parameterize Simscape Multibody™ model and automate tests using MATLAB®
Optimizing System in Mechanics
Refine Lock Actuator Requirements

Model:

Problem: Determine size requirements for hydraulic actuator

Solution: Use Simscape Multibody to determine hydraulic force and power required for prescribed motion
Reviewing Simulation Results
Logging Simscape Variables

- All variables automatically logged to MATLAB Workspace
  - Structure based on model hierarchy
  - Values, time, units

- Only use sensors when signals are necessary
  - Scopes
  - Feedback signals

- Spend more time analyzing, less time simulating

```
>> simlog.Pipe_1.Chamber.A.p.plot;
```
Reviewing Simulation Results
Simscape Data Logging

- Log Simscape results to MATLAB workspace
  - Log all or only selected blocks
  - Variables, zero-crossing statistics

- Review results in Simscape Results Explorer
  - Explore results in tree view
  - Navigate between model and results

- Fewer blocks in model, efficient analysis

```matlab
>> sscexplore(simlog)
```
Simscape Logging

- Use local settings option added to selectively log simulation results
- Select results to log per block via right-click
Simscape Logging in Simulink Data Inspector

- Simscape results can be imported directly into Simulink Data Inspector
  - Import simlog
  - Can navigate from SDI to model
Zero-Crossing Statistics

- Log zero-crossing statistics for Simscape networks
  - Shows when ZCs occur
  - Can help indicate location of simulation bottlenecks

```matlab
if (abs(w) <= vel_thr)
    % Linear region
    t == brkwy_trq_th * w / vel_thr;
elseif w > 0
    t == visc_coef * w + Col_trq + ...
        (brkwy_trq - Col_trq) * exp(-
    else
        t == visc_coef * w - Col_trq - ...
        (brkwy_trq - Col_trq) * exp(-
end
end
```
Sparkline Plots for Logged Data

- Quickly scan simulation results directly on model canvas
  1. Click to show plots
  2. Cursor shows values
  3. Select variables
  4. Direct link to plot variable in Simscape Results Explorer
Landing Gear System
Hydraulic Actuator Model
Modeling Hydraulic Actuation System

**Problem:** Model a hydraulic actuation system within the Simulink environment

**Solution:** Use Simscape Fluids to model the hydraulic system
Modeling Hydraulic Actuation System
Custom Four-Way Valve

Model:

Problem:
Model a custom four-way directional valve within the Simulink environment

Solution:
Use Simscape Fluids to model the four-way directional valve
Hydraulic Actuator Modeling
Spool Axial Hydraulic Forces

Model:

Problem: Include the hydraulic axial forces on the spool to add more fidelity
Solution: Use SimHydraulics to include the hydraulic forces on the spool
Refine Main Actuator Requirements

Problem: Determine main actuator and pump size requirements

Solution: Use Simscape Fluids to model lock actuator and Simscape Multibody to determine main hydraulic force and power required for prescribed motion
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Before system-level test with physical model,
You need to integrate controller with physical model

1) Merging controller with physical model

or
Before system-level test with physical model, You need to integrate controller with physical model

1) Merge controller with physical model or

2) Add Rate Transition to a point where sample time changes

3) Use PS-Simulink Converter to convert Simulink signal to Simscape signal

4) Don’t forget to set unit of a converted signal
Problem: Design hydraulic main/lock actuator and test it against requirements

Solution: Use Simscape Fluids to model the hydraulic actuators and integrate with Simscape Multibody model of landing gear
Managing Design Variants

**Situation:**

**Physical Systems**

**Controller Alternatives**

**Problem:** Test different alternatives for physical systems and controllers in a single model.

**Solution:** Use Variants to model different configuration and manage it using Variants Manager.
Managing Design Variants

1. Define variant configuration data
2. Create configurations
3. Set control variables
4. Visualize, explore and set variant properties
5. Select the configuration
6. View diagnostics for selected configuration
Fast Restart

Model:

Bank Angle

**Problem:** Minimize the simulation time on iterative tests to determine controller robustness to changes to airplane bank angle.

**Solution:** Fast Restart & Run-Time Parameters
Fast Restart

- Run consecutive simulations more quickly
  - Efficiently run multiple interactive simulations
  - Saves simulation time eliminating recompilation between simulation runs
  - Improves calibration workflows where the user is tuning block parameters between runs

- Programmatically run consecutive simulations more quickly
  - Enable fast restart from command line using `set_param`
  - Simulate a model in fast restart using `sim` and `cvsim` commands
Simscape Run-Time Parameters

- Change parameter values without recompiling the model

- Uses:
  - Fast Restart in Simulink
  - Model Reference
  - HIL (SLRT or ERT target)

- Scope
  - Nearly all Foundation Library parameters
  - All Variable initial conditions
  - Very few Simscape Add-on Product blocks
  - No Simscape Multibody blocks
Why model the physical system?
Too big, too difficult, one chance, …

Why Simscape?
Makes modeling easy
Develop controller
Find best design