MATLAB EXPO 2016

Modeling Physical Systems in Simscape

Steve Miller, MathWorks
too big

ABB Optimizes Ship Energy Flows

too difficult

DCNS Simulates Handling System

one chance

Lockheed Martin Develops MRO

Courtesy NASA/JPL-Caltech
Why use Simscape?

Makes modeling easy
Simscape handles equations automatically

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

Simscape handles equations automatically
3D mechanics
hybrid powertrain

power steering
air conditioning
electrical
mechanical
hydraulic

less clicking
more simulating
Parallel Series Power Split
Simscape + MATLAB & Simulink
any design

best design
optimize to find the best design
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: Vehicle Powertrain
- System-level integration
  - Vehicle Dynamics
  - Hybrid powertrain
- Parameter tuning
- Simscape in Model-Based Design

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Physical Modeling Within 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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Vehicle Powertrain

Problem: Create a vehicle powertrain model that can be reused for controls development

Solution: Use Simscape to model the system within the Simulink environment
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 Language For Modeling Custom Components

- MATLAB-based language for text-based authoring of physical modeling domains, components, and libraries
  - Leverages MATLAB
  - Object-oriented for model reuse
  - Generate Simulink blocks
  - Save as binary to protect IP
Vehicle Transmission Controller

Model:

Problem: Add a four-speed transmission and a controller to a powertrain model.

Solution: Use Simscape Driveline and Stateflow to model the system in the Simulink environment.
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Suspension Analysis in Simscape Multibody

Problem: Analyze behavior of vehicle suspension modeled in CAD

Solution: Import CAD model into Simscape™ Multibody™, add Delft-Tyre model and automate tests using MATLAB®
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®.
Hybrid Electrical Vehicle Model Balance Fidelity and Speed

- **Electrical**
  - System Level
    - Test integration, optimize system
  - Mean Value
    - Three-phase electrical system
  - Detailed
    - Test power quality

- **Battery**
  - Generic, predefined, and custom models

- **Vehicle**
  - Inertial & Aero Effects
  - Tire models
Simscape Products

- Simscape platform
  - Foundation libraries in 8 domains
  - Language for defining custom blocks
    - Extension of MATLAB
  - Simulation engine and custom diagnostics

- Simscape add-on libraries
  - Extend foundation domains with components, effects, parameterizations
  - Multibody simulation
  - Editing Mode permits use of add-ons with Simscape license only
  - Models can be converted to C code
Simscape Add-on Libraries

- Simscape Power Systems
  - Three-phase electrical networks
- Simscape Electronics
  - Actuators, sensors, and semiconductors
- Simscape Fluids
  - Pumps, actuators, pipelines, valves, tanks
- Simscape Multibody
  - Multibody systems: joints, bodies, frames
- Simscape Driveline
  - Gears, leadscrew, clutches, tires, engines
Sharing Models Using Simscape Editing Modes

- Share models with other Simscape users
  - Simulate, analyze, generate code without purchasing extra licenses

<table>
<thead>
<tr>
<th>Function</th>
<th>Full Mode</th>
<th>Restricted Mode</th>
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<tbody>
<tr>
<td>Add or delete regular Simulink blocks</td>
<td>Yes</td>
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<tr>
<td>Change Simulink solver, simulate</td>
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<tr>
<td>Change numerical parameters</td>
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<td>Access PowerGUI functions, settings</td>
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<td>View animations in Mechanics Explorer</td>
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<td>Generate code</td>
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<td>Make or break physical connections</td>
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<tr>
<td>Change Simscape Local Solver</td>
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Model Developer
Purchases Simscape and add-on products

Model Users
Purchases Simscape
Add-on product *installed*, No add-on purchases required
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Problem: Simulation results do not match measured data because the parameters are incorrect

Solution: Use Simulink Design Optimization to automatically tune model parameters
Simscape Runtime Parameters
Iterative Workflow: Parameter Tuning
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 algorithms
  - Optimization
  - C Code generation for HIL

```matlab
equations
v == x.der;
f == spr_rate * x;
end
```
Download Models from MATLAB Central File Exchange

- Complete example and many intermediate steps shown
- Scripts for running tests, generating reports, and other tasks
- Many other examples available
  - Simscape language
  - Simulink models
  - MATLAB tools and scripts

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- Questions and Discussion

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