MathWorks Technology Session at GE
Physical System Modeling with Simulink / Simscape

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Release R2012b Now Available

- Redesigned User Interfaces
  - **MATLAB**: Context-sensitive toolstrip
  - **Simulink**: Integrated model editor and debugger
Simulink Extensions

Stateflow
Logic and State Machine modeling

SimEvents
Discrete Event modeling

Simscape
Physical System modeling
Simulink Blocksets

Aerospace Blockset

Gauges Blockset

Other
- DSP System Tbx
- Data Acquisition Tbx
- Simulink Ctrl Design

SimEvents

Simscape

SimMechanics SimDriveline SimHydraulics SimPowerSystems

SimRF SimElectronics
How Does Simscape Work?

Simulink: Iterative Solution

Simscape: Simultaneous Solution

\[
\frac{V_P}{V_S} = \frac{N_P}{N_S}
\]
Tools for Further Investigation

– Training
  - Physical Modeling of Multidomain Systems with Simscape (1 day)
  - Physical Modeling of Multidomain Systems with SimMechanics (1 day)
  - Q4 public classes in France, Germany, Spain, Japan, US.
  - www.mathworks.com/services/training/index.html

– Tutorials
  - Physical modeling examples:
  - More at www.matlabcentral.com

– Books
  - www.mathworks.com/support/books/index.html

ISBN: 978-1-934404-25-6
Key Takeaways

- **Optimize system performance**
  - Develop in a single environment

- **Multi-domain Physical System**

- Eases process of modeling physical systems
Agenda

- Motivation
- Physical Modeling Platform for Multi-domain System
  - Simscape Introduction
  - Simscape Language Introduction
- Multi-domain Application Example
- Physical Modeling Tools
  - SimMechanics, SimDriveline, SimElectronics, SimHydraulics, SimPowerSystems
- Q&A
Optimize System-Level Performance

- Simulating plant and controller in one environment
- Optimize system-level performance.
Modeling Physical Systems in the Simulink Environment

Modeling Approaches

First Principles Modeling
- Code (MATLAB)
- Block Diagram (Simulink)
- Modeling Language (Simscape language)
- Symbolic Methods (Symbolic Math Toolbox)

Data-Driven Modeling
- Physical Networks (Simscape and other Physical Modeling products)
- Neural Networks (Neural Network Toolbox)
- System Identification (System Identification Toolbox)
- Statistical Methods (Model Based Calibration Toolbox)
- Parameter Optimization (Simulink Design Optimization)
Electrical Systems in Equations

DC Motor

\[ v = K_e \omega + i_m R_{\text{wind}} + L_{\text{wind}} \frac{di_m}{dt} \]

\[ T = K_t i_m - D \omega - J \frac{d\omega}{dt} \]

Simulink Model
Electrical Systems in Simscape

- Simscape model advantages
  - Easier to read than equations
  - Quicker to create
  - More intuitive – easier to explain to other engineers

\[ v = K_e \omega + i_m R_{\text{wind}} + L_{\text{wind}} \frac{di_m}{dt} \]

\[ T = K_t i_m - D \omega - J \frac{d\omega}{dt} \]
How Does Simscape Work?

- Network Approach

通过变量 $i$ 与跨变量 $v$

功率 = 通过 x 跨

基尔霍夫定律:

$$i_1 = i_2 + i_3$$

<table>
<thead>
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<th>物理域</th>
<th>跨变量</th>
<th>通过变量</th>
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<tr>
<td>电气</td>
<td>电压</td>
<td>电流</td>
</tr>
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<td>液压</td>
<td>压力</td>
<td>流量率</td>
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<tr>
<td>磁性</td>
<td>磁动势 (mmf)</td>
<td>磁通</td>
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<td>角速度</td>
<td>扭矩</td>
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<tr>
<td>热学</td>
<td>温度</td>
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</table>
Introduction to Simscape

- Enables physical modeling (acausal) of multidomain physical systems
- Eases process of modeling physical systems
  - Build models that reflect structure of physical system
  - Leverage MATLAB to create reusable models
Simscape Key Features

- Foundation physical modeling blocks
  - Mechanical, electrical, hydraulic,…
- Simscape language for text-based authoring of components
- Units for signals and parameters (automatic conversion)
- Physical network solver designed for physical systems
- Simscape Editing Mode allow use of add-on products without purchasing add-on product license
- Convert to C code for deployment
Simscape Example
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
Simscape Language: Leverage MATLAB

- Syntax closely follows MATLAB language
- Use MATLAB functions and expressions for typical physical modeling tasks like:
  - Analyze parameters
  - Perform preliminary computations
  - Initialize system variables
Simscape Language: Extend or Create Libraries

- Define the physical network ports for your Simscape block
  - Reuse existing physical domains to extend libraries
  - Define new physical domains
Simscape Language: Define User Interface

- Parameters, default values, units, and dialog box text all defined in the Simscape file (extension .ssc)
Simscape Language: Define Reusable Components

- Equations defined in a text-based language
  - Symmetrical mathematical relationship (not inputs and outputs)

\[ i = \left( C_0 + C_v v \right) \frac{dv}{dt} + \frac{v}{r_d} \]

```plaintext
equations
  i == (C0 + Cv*vc)*vc.der + vc/Rd;
  v == vc + i*R;
end
```

Simscape Summary

- Physical modeling (acausal) of Multi-domain physical systems
  - Model system not equations
- Custom components/Domain using Simscape language
- Simulate plant and controller in one environment
  - Optimize entire system
Physical Systems in Simulink

**Simscape**

- Mechanical
- Hydraulic
- Electrical
- Thermal
- Pneumatic
- Magnetic

*Custom Domains via Simscape Language*

- Multidomain physical systems
- Electrical power systems
- Fluid power and control
- Multibody mechanics (3-D)
- Mechanical systems (1-D)
- Electromechanical and electronic systems
Wind Turbine Basics

Primary Goal
Spin at or near operating speed
Wind Turbine Model


- Simulation requires licenses for these tools:
  - MATLAB
  - Simulink
  - Simscape
  - Stateflow
  - Please request a trial license if needed to experiment with the model.
Introduction to SimMechanics

- Enables multibody simulation of 3D mechanical systems

- Construct model using bodies, joints, and forces
  - Model matches structure of system
  - No need to derive and program equations

- Primary uses
  - System-level analysis
  - Control development in Simulink
SimMechanics Key Features

- Rigid body definition using standard geometry and custom extrusions defined in MATLAB
  - Mass and inertia tensor calculation
  - Easily reuse models in other designs
- 3D animation of simulation results
- Connect to control algorithms and other physical domains
Modeling 3D Mechanical Systems

- Build a model whose structure represents the system:
  - Parts (mass, inertia)
  - Coordinate systems
  - Joints and constraints
- Parameterize model using MATLAB variables
- Save subsystems for reuse in other models
- Connect directly to Simscape and Simulink
Import CAD Data Using SimMechanics 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

- Public API for other CAD tools

- Free download from www.mathworks.com
  - Requires MATLAB
Introduction to SimDriveline

- Enables physical modeling (acausal) of mechanical powertrain systems

- Provides rotational and translational component models
  - Gears, clutches, vehicle components
  - Create custom components via Simscape language

- Primary uses
  - System-level analysis of mechanical transmission systems
  - Control development in Simulink
SimDriveline Key Features

- Common gear models with meshing and viscous losses
- Clutch models
  - Cone, disk friction, and dog clutch
- Vehicle component models,
  - Engine, tire, torque converter, and vehicle dynamics
- Extend component libraries using the Simscape language
- Support for C-code generation from SimDriveline models (with Simulink Coder™)
Model 1-Dimensional Mechanical Systems

- More than 35 component models of varying fidelity
  - Gears
  - Clutches
  - Couplings/drives
  - Vehicle components
- Configure models to meet your needs
- Connect to Simscape and other libraries to include other effects
Quickly Build Drivetrain Systems

- Model topology reflects physical structure of system
  - Save subsystems for reuse in other models
- Connect directly to Simulink and Stateflow
- Parameterize models using MATLAB
Introduction to SimElectronics

- Enables physical modeling (acausal) for electronic and mechatronic systems
- Provides sensor, actuator, and semiconductor models
- Supports algorithm and control system development in Simulink
SimElectronics
Key Features

- Provides sensor, actuator, and semiconductor models
- Enter parameters values directly from data sheets
- Model temperature dependence heat production, and device temperature
- Linearize for control design or small signal analysis
- Convert to C code
  - Accelerate simulation
  - Create standalone executables
Extensive Component Libraries

- More than 90 component models
  - Actuators, drivers
  - Sensors
  - Semiconductors
  - Integrated circuits

- Models look like schematics
  - Easy to read and interpret
Demo SimElectronics: Controlled DC Motor

Model:

![DC Motor and Servoamplifier diagram]

**Problem:** Model a DC motor with a configurable PWM controller in the Simulink environment

**Solution:** Use SimElectronics to model the mechatronic system
Introduction to SimHydraulics

- Enables physical modeling (acausal) of hydraulic systems

- Enables engineers to build simulation models that look like hydraulic circuit diagrams

- Used by system engineers and control engineers to design and test hydraulic systems
SimHydraulics Key Features

- Extensive component library enables modeling of custom components
- Parameterization methods allow multiple options for setting parameters
- Customizable library of common hydraulic fluids
- Steady-state capabilities of Simscape enable efficient simulation
Extensive Component Libraries

- More than 80 models of hydraulic and mechanical components
  - Pumps and motors
  - Actuators
  - Valves (directional, check, pressure compensation, etc.)
  - Accumulators

- Hydraulic blocks use images in compliance with ISO 1219 Fluid Power Standard
  - Easily understood by hydraulics engineers
Hydraulic Actuation System

Problem: Model a hydraulic actuation system within the Simulink environment

Solution: Use SimHydraulics to model the hydraulic system
Introduction to SimPowerSystems

- Enables physical modeling (acausal) of electrical power systems and electric drives

- Electrical system topology represented by schematic circuit

- Used by electrical, system and control engineers to develop plant models and test control systems
SimPowerSystems

Key Features

- Comprehensive block libraries for building power system models
- Detailed models of common AC and DC electric drives
- Different simulation modes to speed model execution
- Ideal switching algorithm, enabling fast simulation of power electronics
- PowerGUI provides convenient tools for common analysis tasks
- Extensive set of demonstration circuits and systems
Quickly Build Electrical Systems

- Build models that look like an electrical schematic:
  - Three-phase components
  - Detailed electric drive models
  - Flexible AC Transmission Systems (FACTS)
- Parameterize model using MATLAB® variables
- Connect to Simulink with sources and sensors
- Save subsystems for reuse in other models or libraries
Model Electric Drives

- Combine power electronics, machine, and control algorithm
  - GUI to assign key parameters
  - Common strategies for speed and torque control
  - Adjustable level of fidelity (detailed, averaged)

- Common machine types can be used as motors or generators:
  - Permanent magnet
  - Synchronous, asynchronous
  - Induction
  - Single phase or 3-phase
Connecting to Simscape

- Electrical connection via interface blocks
  - Add custom components using Simscape language
  - Include other domains
- Mechanical ports
  - Synchronous, asynchronous, DC, and PMS machines
SimPowerSystems Demonstration
PM Synchronous Motor Drive (ac6_example.mdl)

Discrete solver provides fast, accurate results.
Key Takeaways

- **Optimize system performance**
  - Develop in a single environment

- **Multi-domain Physical System**

- **Eases process of modeling physical systems**
Support and Community

The MathWorks Connections Program

MATLAB CENTRAL

The MathWorks Consulting Services

The MathWorks Training Services

The MathWorks Book Program
MathWorks Investment in Physical Modeling

- Responding to customer demand, MathWorks will continue to invest heavily in tools and capabilities for physical modeling.