Physical Modeling for Automotive Applications

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The MathWorks

Better Information Earlier

Solve Your Problems Early

Better Information Earlier

Stages of Development Process

% Problems Solved

1st prototypes

Early '90s

= Improved Communication

Mid '90s

= Use of CAD

= Improved Communication

Toyota’s Front-Loaded Development Initiatives
Better Information Earlier

1st prototypes

% Problems Solved

Now 80%

Stages of Development Process

Toyota’s Front-Loaded Development Initiatives

- Green = Use of CAE
- Blue = Use of CAD
- Light Blue = Improved Communication

Math is the Path

General Engineering Simulation

MATLAB & Simulink

Domain Knowledge

Programming Skill

Engineering Simulation

“The Math is the Path”
SimMechanics brings you further by lowering your requirements for mechanical domain knowledge and programming skills.

SimDriveline brings you even further!
SimPowerSystems brings you further by lowering your requirements for *electric power domain knowledge* and *programming skills*.

MathWorks provides best combination of tools for *Multi-Domain Simulations*.
Our View on Mechanical Systems

- They are not just mechanical, you know!
- We are The MathWorks, providers of the leading development and implementation tools for deploying **Controllers**
Mechanical Device

Actuators

Sensors

Plant

SimDriveline

Electric Motors & Actuators

SimPowerSystems
Simulink assures complete system model
- Hydraulic Actuators
- Sensors & Transducers
- Thermodynamic Models of Engines

Also, Simulate the Power System Management with SimPowerSystems
Automotive Electrical System

- **Sources**
  - Generator 1.2 kW
  - 65 Ah Battery

- **Loads**
  - Rear Window Defog 150 W
  - Audio System 70 W
  - Power Window 100 W
    - Behavior Model as Ohm load
    - Physical Model with electrical and mechanical 3D Model
  - Xenon Light 80 W
  - Fog Light 110 W
  - Fan 200 W
    - Behavior Model as Ohm load
    - Physical Model (dc motor, relay, and fan)
Simulation Result – Bus Voltage and Power

Fan switches on

Generator Current
Generator Performance

\[ a = \int -L_i \sin(\alpha) + m_w (-\sin(\alpha - \gamma)) \cos(\alpha - \gamma) dt - \frac{n \cos(\alpha - \gamma) \gamma}{1 - n \sin^2(\alpha - \gamma)} \]

Modeling Mechanics in Simulink without SimMechanics
Modeling Mechanics in Simulink without SimMechanics

Simulink Model

With SimMechanics

Bodies
- Piston Head
- Connecting Rod
- Crank Shaft

Joints
- Revolute Joint1
- Revolute Joint2

Simulink Model
Controller Development and Plant Modeling

MathWorks Control Products
- Control System Toolbox
- Robust Control Toolbox
- \( \mu \)-Analysis and Synthesis Toolbox
- LMI Control Toolbox
- Model Predictive Control Toolbox
- Fuzzy Logic Toolbox
- Nonlinear Control Design Blockset
- System Identification Toolbox
Throwing it over the Wall

Time

Mechanical Hardware

Controller

Simulation

Test Controller and Mechanical Hardware together

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**Shorten Development Time**

- Evaluate controller prior to commitment to mechanical hardware
- Test impact of mechanical resonances on control system
- Generate linear plant models for control development

**Performance and Quality Benefits**

**Collaboration**
Costs Prediction & Savings
- Provides for pre-proposal design trade-offs to investigate performance vs cost
  - Choose mechanical features that enable less expensive sensors and controllers
  - Understand limits of control system early

Collaboration

Double the work if a rework phase is introduced
Additional Benefits

- Determine nominal trajectory paths for motion driving actuators
- Identify force and power requirements of motion driving actuators
- Validate hardware performance through Hardware-in-the-Loop (HIL) testing

Rapid Control Prototyping and HIL Simulation
Code Generation

- Code Generation with Real-Time Workshop (RTW)
  - Generate ANSI C code
  - Use Real-Time Workshop and xPC Target for hardware-in-the-loop (HIL) simulations
  - Accelerator mode
  - Generate C code for S-Functions and In-House codes

SimMechanics and CAD Translation

- The SimMechanics model is automatically created from the mass, inertia, and mates defined in the SolidWorks assembly
Summary

- Build Mechanical Component Models with SimMechanics and SimDriveline
- Build Power System and Actuator Component Models with SimPowerSystems
- Define System Models through integration with Simulink
- Test controller hardware through HIL
- Develop controls without commitment to Mechanical Hardware
- Build better systems, save time and money, and reduce risks