Model Based Systems Engineering
Engine Control: from concept to validation

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Table of Content

- Model Driven Development
  - MiL – SiL – HiL
  - Model adaptation to Real-Time
Towards “Model Driven” Product Development
Model Based System Engineering – Enabled by Mechatronic Simulation

“Multi-physics” models
Thermal, Mechanical, Electrical...

Mechatronic Simulation

“Controls” models
Electrical, Electronics, Software...

Scalable Multi-physics Simulation
1D - 3D - Test

Model Based Controls Engineering

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LMS
ENGINEERING INNOVATION
Model Based System Engineering enhances and accelerates every Phase of the Development Process

Concept Phase
Business Case Analysis
System Architecture Trade-Offs
Target setting

Validation Phase
Frontload System Validation and Calibration
Virtual/Physical Testing

Detailed Engineering Phase
Increase Realism and Productivity of Simulation Component, Subsystem, System Virtual Verification
Full Vehicle Performance Simulation

“Multi-physics” system models
Thermal, Mechanical, Electrical…

“Controls” models
Electrical, Electronics, Software…

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Example: Engine Control

- Accuracy Predictivity
- Real Time Robustness
Main challenges for control development are time and cost reduction:

- Identify the best possible matching between test constraints and model capacity ➔ model scalability
- Ensure the continuity between modeling levels for a better efficiency ➔ models continuity

✓ Not reinvent the wheel ➔ Reuse as much as possible design models in validation stages
✓ Use physical models for earlier tests in the process
Model – Software – Hardware in the Loop

MIL: Model in the Loop
SIL: Software in the Loop
HIL: Hardware in the Loop

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Physical & Control modeling

Simulink
The de-facto standard for control system design

AMESim
Complete systems engineering simulation platform

AMESim - Simulink Interface
Coupling the plant model within a control model in Simulink

➢ Obtain the best features of both platforms
➢ Analyze coupling between engine and the control systems
➢ Eliminate the need to re-write complex models on various platforms
➢ No limitation in model size or complexity

3 types of interface:
- Co-simulation
- Export from AMESim to Simulink
- Export from Simulink to AMESim

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- Model Driven Design
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Objectives

- Understanding
- Investigation of concepts
- Function Specification
- Strategy Design

Model-in-the-Loop (Co-Simulation):
- Design the engine control strategies with help of a representative model of the engine to pilot
- Virtual models for the control (Simulink) and the engine (AMESim)
- Cosimulation feature

- Plant models can be used by both engine design and control teams
- Accurate physical representation of the engine and its actuators
- Several level of model for a good compromise accuracy/cpu

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Function Design stage (MiL)

**Target:** set-up the control of a VVA system for Burned Gas Ratio management

**Key Differentiators:**
- Detailed actuator model
- Access to in-cylinder composition
- Transient operation
- Efficient link with Simulink
Implementation stage (SiL)

- **Software-in-the-Loop:**
  - Test the C-code used in the controller using a plant model
  - Possible tests in a “virtual” real-time environment

- **Objectives:**
  - Test of algorithms & logic
  - First software validation

- Import the C code for the control directly in AMESim (SIL within AMESim)
- Import the C code in Simulink and use co-simulation with AMESim
- Enable to adapt the engine model to real-time computing

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Implementation stage (SiL)

Target: SIL and Off-line Calibration

To connect the software with the plant model and simulate the operating environment of the controller.

Compilation and link of “c” and “h” files

Synchronization of events

Direct embedded C code testing
**Objectives:**
- ECU Testing and validation
- Ensure a high robustness/quality level
- Efficient link with Simulink and RTW
- Easy-to-modify/robust physical models
- Compatibility with major hardware manufacturers
Function Test stage (HiL)

Target: validation of Diesel injection strategies using a physical plant model

Powertrain model for HIL
- Possibility to use models and/or real components for the actuators
  - Real injectors are used
  - Real throttle and EGR valve are used
- All the powertrain sensors are available

Key Differentiators:
- Physical modeling
- Several engine model levels
- Transient/robust operation
- Efficient process using RTW
Pre-Calibration stage

- **Offline pre-calibration:**
  - First step of control calibration (offline) using detailed engine/vehicle plant models
  - Put the control in usage context for a simulation of a given virtual vehicle
  - Optimize the engine testing program

- **Objectives:**
  - ECU/Engine calibration in a vehicle configuration using a virtual environment
  - Optimize the test program / reduce the number of tests
  - Physical and predictive system models (engine, transmission…) that are representative of actual ones
  - Models able to deliver accurate results in steady-state and transient operation
**Pre-Calibration stage – Virtual test cell**

**Target:** Test of a new injector and investigation of complex rate profiles for CO₂ and NOx reductions.

**Key Differentiators:**
- Detailed actuator model
- Predictive combustion models
- Real Time simulation
Controller Design Process
From MiL to HiL Simulation

FTS: Fixed Time Step Solver
VTS: Variable Time Step Solver

Control Model

Close loop system

Sensors
Actuators

Plant Model

MIL
Co-Simulation

SIL
Import C-code
or Co-Simulation

HIL
Export S-Function

Scalability

Real Time

Accuracy

Simplification Process

High Fidelity Plant Model

VTS or FTS

Low Fidelity Plant Model

Block Diagram Model of
the Control Algorithms

Generated “c” Code: Software

Embedded Software
on Hardware

Test & Mechatronic Simulation

Import C-code

or Co-Simulation

Export S-Function

FTS

Embedding Software
on Hardware

Test & Mechatronic Simulation

Import C-code

or Co-Simulation

Export S-Function

FTS
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Engine model scalability

**3D CFD model - Time scale: turbulence**

*Detailed physical models*

*Simulation time >> Real Time*

**High Frequency model - Time scale: crank angle deg.**

*Physical model for the air path & in-cylinder process*

*Simulation time >= Real Time*

**Mean Value Engine Model - Time scale: engine cycle**

*Maps for the in-cylinder process and physical model for the air path system*

*Simulation time <= Real Time*

**Map Engine - Time scale: 0.1 s**

*Maps for fuel consumption, performance & emissions*

*Simulation time << Real Time*
Model simplification - example

Keep HF Model in real time:
Simplification
- Gas properties definition
- Air path system
- Accuracy for flow calculation

Reduction
- Single cylinder equivalent approach

BENEFITS:
- Access to geometrical parameters
- Include air path dynamics & valve pulsated flows
- Analyze in-cylinder details
Linear Analysis provides fundamental information in order to:

- Optimize the time step
- Modify the model in order to match a given time step

State Count records the variables that had the **greatest difficulty in satisfying the error test** after each step.
Real Time simulation

Once plant & control models exported on platform, it works as a stand alone.

One can design any human / machine interface needed with Control Desk (scroll bars, buttons etc…).

Example of layout
Thank you!