Turbo MultiAir Gasoline Physical Engine models: from 1D to 0D real time for Hardware in The Loop ECU test

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Agenda

Introduction and motivations

Fully-Physical 0D Fast Running Engine Model

Deployment of the FRM on HiL

Results

Conclusions
The increasing number and complexity of electronic control systems in the vehicles requires accurate and repeatable validations, by means of Hardware-In-the-Loop (HIL) methodology.

Vehicle Input Signals
(pedal positions …)

Actuator Signals
(Injection, VGT, …)

Sensor Feedback (temperatures, airflow, engine speed…)

HIL REAL-TIME SIMULATION

ECU
HiL facility is a fundamental enabler for time to market reduction

HiL set up requires Engine/Vehicle plant models

To pull ahead the HiL availability, HiL set up should be decoupled as much as possible from experimental measurements obtained from real engine proto testing

In this perspective, predictive fully-physical engine models are needed
GT-Power Engine Models for HiL SYSTEM

Standard GT-POWER models, available from design department, already fulfill most of the requirements for HiL simulation.

Computational time is the only limitation, therefore the GT-POWER model must be reduced to a so-called Fast Running Model (FRM).
Main advantages - Technical

- **Availability of a high number of variables** (temperatures, pressures, turbine RPM, etc).

- **Once a baseline model is built, different variants of the engine can be generated very easily** in less than 1 day (e.g. add EGR circuit, change turbo maps, valve lift profiles).

- **Physical torque oscillations** for mechanical components investigation (e.g. transmission)

- **Fully integrated into a Matlab/Simulink environment** as an S-Function, exchanging information with different plant models, such as: **Transmission, Thermal Management, Emissions, Aftertreatment.**
Main input data requirements

Information required for building the FRM

- **Most data is already available in the detailed engine model**, as supplied by Design department, which usually is already calibrated to replicate **full-load curve**

- **Experimental measurements** are mainly required for tuning the model in **part-load**, thus **extending model accuracy** among all engine operating points

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<td>Turbocharger Maps</td>
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<td>Heat Exchanger Effectiveness (Intercooler, EGR cooler, etc.)</td>
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<td>Pressure drops across Air Filter, CAC, DPF, etc.</td>
<td>Detailed Full-Load Model (optional: Measurements)</td>
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GT-Power Engine Model 1.4 Multiair 2

1. Low Pressure Air Ducts
2. High Pressure Air Ducts
3. CAB Plenum
4. Runner + Intake Head Ducts
5. High Pressure Exhaust System
6. Low Pressure Exhaust System

268 flow-volumes
The standard GT-POWER model is reduced to a Fast Running Model (FRM), Real Time capable. This simplification is obtained through a well-established procedure.
Multiair II allows several valve lift strategies for different engine operating conditions:

- FULL LIFT
- LIVO strategy
- EIVC strategy
- LIVO & EIVC combined strategy

Main technical challenge of the project is to estimate correctly the engine breathing process with the MultiAir system.
ECU

IVOe = Electrical valve opening angle;
IVCe = Electrical valve closure angle;
IVOm = Mechanical valve opening angle;
IVCm = Mechanical valve closure angle.

Physical System

Current signal

IVOe

IVCe

IVOm

IVCm

EIVC

LIVO

Valve Lift

Crank Angle [deg]
Look-up **maps of valve lift** profiles are available as a function of RPM and Electrical Valve Closure Angle.

**Electrical Valve Closure** (IVCe) and **Electrical Valve Opening** (IVOe) are commanded by ECU.

**EIVC**: At a given RPM and IVCe a valve lift profile is selected.

**LIVO**: simulated acting on the valve lash.
**Combustion**: Wiebe combustion model

**Wiebe parameters**:

1. **Anchor angle MBF50** as a function of spark advance, corrected on the basis of the inlet temperature;
2. **Burn duration MBF1090** as a function of spark advance;
3. **Wiebe exponent**: constant value.
Integration with Simulink

- The **FRM is then integrated into a M/S platform** which still includes all the vehicle sub-systems (transmissions, brake, thermal management, etc.) and all the ECU signal routing.

“Air” and “Torque” mean value models replaced by GT-POWER engine model
Deployment of the FRM on HiL

- Specifically for HiL application → dedicated GT-SUITE-RT solver/libraries

- Coupled Simulink/GT-SUITE-RT model compiled and deployed

- Time-steps, a good trade-off between:
  → ECU sampling rate requirement
  → accuracy and robustness
  → computational time demand

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Results – Steady State (1/2)

Air flow

BSFC

Maximum Pressure

Int. Manifold Pressure

Exh. Manifold Pressure

Turbine Outlet Pressure
Results – Steady State (2/2)

**Turbine Speed**

- Turbine Speed
- Absolute Error (kRPM)

**Compressor Outlet Temperature**

- Compressor Outlet Temperature
- Absolute Error (°C)

**Int. Manifold Temperature**

- Intake Manifold Temperature
- Absolute Error (°C)

**Exh. Manifold Temperature**

- Exhaust Manifold Temperature
- Absolute Error (°C)

**Turbine Outlet Temperature**

- Turbine Outlet Temperature
- Absolute Error (°C)
A detailed GT-POWER model of a 4-cylinder turbocharged MultiAir2 gasoline engine was reduced to a 0D FRM, running in real time.

The FRM was integrated into a Simulink platform and connected with the ECU I/O signal.

The overall plant was successfully deployed in a dSPACE simulator, enabling HiL activities for ECU testing.

→ No ECU diagnostic faults were encountered during a NEDC execution
→ No overruns were observed under realistic operating conditions
→ Robustness of model and controls
Thank you for your attention and we look forward to your comments and questions.