Model Based Development and Calibration
Challenges in the Powertrain Development and AVLs Solutions

- CO2 / Fuel Consumption
- Real Driving Emissions
- Broad Vehicle Portfolio

AVL Solutions

- Clustering of hardware and engineering activities
- Reduced test facilities/variant through front-loading
- Multi-variant simulation with the same engine family (RDE, OBD, EAS)
- Improved quality and robustness through additional virtual validation
- Independence of environmental testing from seasonal conditions and vehicles availability

Model-Based Development
Need for Model Based Development

Front Loading: from Road to Office

- Measuring
- Post Processing
- Validation

Planning / Monitoring

Dataset Management

Test Field Host

Vehicle Data

Test Bed

Vehicle

Test Environments
Need for Model Based Development

*Front Loading: from Road to Office*

- Measuring
- Post Processing
- Validation

**Planning / Monitoring**

**Dataset Management**

**Test Field Host**  **Vehicle Data**

**Test Environments**

*Extension to the Virtual Environments*

*MOBEO Methodology*
Need for Model Based Development
Front Loading: from Road to Office

Planning / Monitoring
Dataset Management
Test Field Host
Vehicle Data

Actual effort

Advanced Test Automation
CAMEO, PUMA,
(SDS, RTC, iMean)

Extension to the Virtual Environments
MOBEO Methodology

Test Environments

Office
HIL
Vehicle
Test Bed

Measuring
Post Processing
Validation

CAMEO, PUMA, SDS, RTC, iMean

MOBEO Methodology

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Need for Model Based Development
Front Loading: from Road to Office

![Diagram showing planning, monitoring, actual effort, dataset management, test field host, vehicle data, advanced post processing, MOBEO methodology, advanced test automation, test environments, and MOBEO methodology extension to virtual environments.]

AVL UK Expo 2015
Need for Model Based Development
Front Loading: from Road to Office

- Measuring
- Post Processing
- Validation

Planning / Monitoring

Dataset Management
Test Field Host  Vehicle Data

Quality Management
Calibration Process, CRETA

MOBEO Methodology
Advanced Test Automation
Advanced Post Processing
Quality Management

Test Environments

Extension to the Virtual Environments
MOBEO Methodology
Model Based Development
CRUISE M and MoBEO

MoBEO Modules

- Generic semi-physical combustion model
- Exhaust gas after treatment
- Advanced heat transfer models in the gas path
- Sensor and actuator models
- Calibration know-how included
- Parameterization wizards for cylinder and SCR

Parameterization Wizard

Engine
After Treatment
Flow
Driveline
Multi-physics system simulation

- Scalable physical modeling depth for concept, calibration and test
- Single platform for all AVL powertrain real-time models
- Open interfaces to 3rd party tools supporting standards (FMI)
MOBEO

Model overview
Model Based Engine Optimization
What is it?

- Model based development using a real time capable engine model
- Starting from concept phase until SOP calibration
- Engine model based on semi-physical modeling approach
  - empirical model components derived from AVL experience and test bed data
  - physical components increase the range of application due to better extrapolation
- Easy usability due to the use of suitable simulation environments
Model Based Development - MoBEO
Modelling Approach

Virtual

Basic model setup MoBEO
Semi-physical Basic Model without measurement data
Empirical static global HC, CO, Soot, SPL,... Cameo M&M

Pre-calibration

Testbed results

Semi-physical Thermodynamic NOx-Emission EAS System (DOC, DPF, SCR, NLT)
Combined model Increased number of engine specific outputs

Model refinement

HIL Setup

MIL Setup 10X Cal

Model-based calibration of various variants
Variant specific hardware change (e.g. intake piping,...) (No combustion HW change)

Robustness analysis

Real

First engine Run Puma / Cameo T&M
Base engine testbed development Puma / Cameo T&M
DoE Measurements Puma / Cameo T&M

Pre-calibration Field data

Extension to the Virtual Environments
Advanced Test Automation
Post-Processing

Emission validation
Environmental validation
Model Based Development - MoBEO
Step 1 – Modeling EU6 Base Engine

Engine Model combined with EAS Model – Modular combined Semi-physical models with high flexibility
Model Based Development - MoBEO
Step 2 – Modelling of Different Elements
Development Process

Consequent usage of real-time system simulation

- Concept / Layout
- Component and system development
- Endurance testing
- Calibration / Validation

Consequent usage of real-time system simulation

AVL data base, measurements of single components

Data engine test bed

Data vehicle testing

Model quality

Start of Production

AVL UK Expo 2015
MOBEO
Application environment
Changing Calibration Paradigm

The right application environment at the right time

**Model in the Loop (MiL)**

**Advantages**
- Simulation faster than real time (app. 5 to 10 times faster)
- No hardware parts needed
- Simulation on normal PC possible

**Disadvantages**
- Availability of software ECU
- Often not all ECU functionalities available

**Hardware in the Loop (HiL)**

**Advantages**
- All ECU functions available
- Pre-Calibration of all ECU functions possible
- Possibility of ECU software and dataset validation

**Disadvantages**
- Only real time simulation possible
- Need of hardware in the loop test bed

→ Both environments can be used for pre-calibration of specific tasks
WORK ENVIRONMENTS - XIL-STATION

HiL Cabinet, including AVL Load-Drawer + HIL Base System (e.g. dSPACE, ETAS) with RTPC and I/O boards

Operator Station, including 4 x 24inch Monitors

PUMA Testbed Workstation

CAMEO Workstation

HiL Host PC including, HiL Operator Software and ECU Application Software
AVL Standardized HiL Simulator Concept
Real ECU & MoBEO Models in an Closed Loop

Actuators:
e.g.: Throttle body, injectors, EGR valve,…

Sensors:
e.g.: Pressures, Temperatures, Speeds, AirFuelRatio,…

Closed Loop

Full Size HiL System
MOBEO

Model accuracy
Model Accuracy in NEDC – Passenger Car

High model accuracy as base for model based calibration

Model is only adopted on one steady state operating map and one NEDC
Model Accuracy in Artemis – Passenger Car
High model accuracy as base for model based calibration

- Minimal parameterization effort due to semi-physical modeling approach
- Simulation of different driving profiles without model refinement possible
- High model quality independent from calibration and operating conditions
Model Accuracy – Commercial Vehicle

High model accuracy as base for model based calibration

Typical deviations of the cycle emissions and fuel consumption as well as achievable temperature accuracy:

- Fuel Consumption < 3%
- NOx Emission < 10%
- Insoluble Particulate Emission < 15%
- Temperature Intake Side < 10°C
- Temperature Exhaust Side < 20°C
MODEL BASED DEVELOPMENT

Use - Cases
Model Based Development

Model based concept investigations

- Assessment of technology route
- Simulation of transient behaviour of engine in early concept phase on MiL environment
- Definition of possible concepts considering the interaction between
  - engine
  - exhaust aftertreatment system
  - software and calibration
  - Sensors and actuators
  - environmental conditions
Model Based Development
Powertrain Use cases

Powertrain Calibration tasks for MiL/HiL:

- RDE – Real Driving Emission evaluation
- EAS Simulation
- Calibration for non-standard ambient conditions
- Calibration of component protection
- In-Use Compliance - PEMS
- Sensitivity studies taking into account system interactions
- OBD – Diagnoses, IUPR
- Software and dataset validation
Model Based Development
Calibration of Ambient Corrections

Simulation of full load altitude operation for validation of ambient correction and engine protection functions

970mbar = 350m (Graz)
750mbar = 2500m
660mbar = 3500m
540mbar = 5000m

Limits for component protection
Model Based Development
Calibration of Component Protection Functions

Simulation of engine failure at full load for validation of engine protection functions

Limits for component protection

- Limit temperature upstream turbine
- Limit temperature downstream compressor
- Limit pressure upstream turbine
- Limit LP turbochargerspeed
- Limit HP turbochargerspeed

- 5% leakage downstream turbocharger
- 25% leakage downstream turbocharger
- 50% exhaust restriction
- 50% intake restriction
- Baseline
Model Based Development

OBD validation

Simulation of Low Pressure EGR valve struck
Boarders of applicability for HiL test bed

- Final Calibration Validation
- Certification
- Durability testing
- Pre-calibration of Start and Cold Start
- Idle stability
- Missfire
Model Based Calibration on XiL - test beds

**Front Loading**

Ideal Lead Variant Calibration Project (i.e. no relevant H/W changes)

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<tbody>
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<td><strong>Base</strong></td>
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Facilities:
- HiL
- Engine Testbed
- Chassy Dyno
- Road
Model Based Calibration on XiL - test beds

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Multi-variant projects can be addressed by: an extension of the test environment through HiL (MiL/SiL) Testing

- Keep calibration quality through additional HiL testing, though high number of variants
- Multi-variant simulation (calibration clustering, RDE, EAS, OBD)
- Keep test facilities usage by a feasible level
- Make environmental testing more flexible and efficient
Model based calibration approach
Example based on customer feedback:

NTE, Engine Protection and Ambient Corrections (1 Mode)

Test Bed Time in Hours

Conventional Approach
- Calibration: 100 hours
- Validation: 150 hours
- Frontloading: 200 hours

Model Based Approach
- Calibration: 10 hours
- Validation: 40 hours
- Frontloading: 200 hours

80% Test Bed Time Saved!

Calibration on XiL instead of Test Bed
80% Test Bed Time Saved per Engine Mode
Test Bed available for Frontloading Tasks
Dataset Quality & Maturity increased in earlier phase of Development

AVL Diesel-Calibration Quality Gates
- G0 – Engine Startable
- G1 – Engine Runnable
- G2 – Emission Targets Achieved
- G3 – Test Bed Target Achievement
- G4 – Robust
- G5 – Validated

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Model Based Calibration Approach:
Changing Calibration Paradigm:

Innovative ways to increase xCU calibration quality

AVL model based development methodology is the consequent usage of real-time system simulation from concept to SOP on suitable development environments with smart calibration tools.