"REAL ENGINE/VEHICLE CALIBRATION EXPERIENCE WITH VIRTUAL TEST BED"

Experience with using virtual test bed support for engine and vehicle calibration

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AVL Italia S.r. L.

VIRTUAL ENGINE CALIBRATION

1 From the Manual Calibration Age to the Automated Virtual Calibration Age

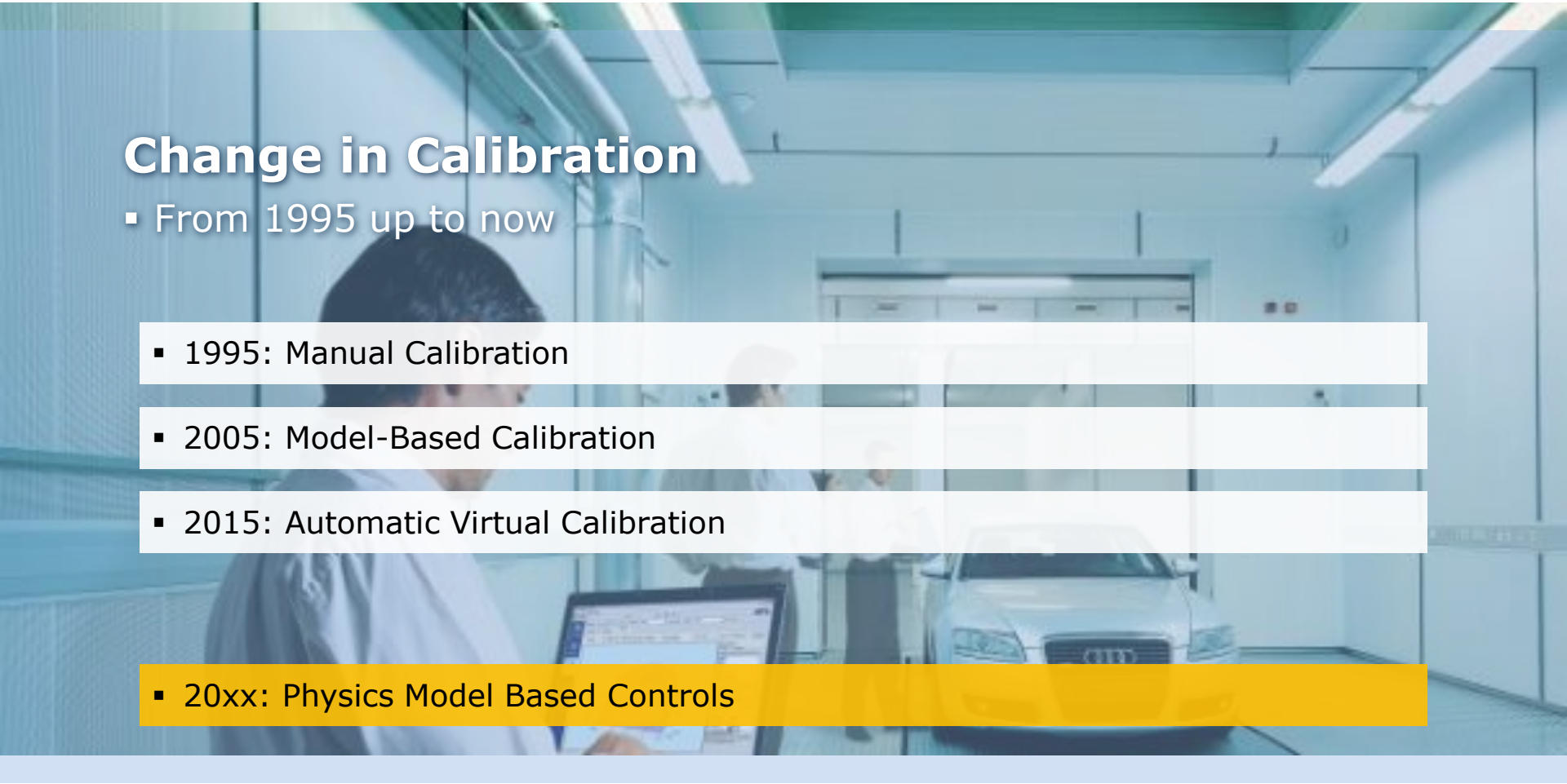
2 Complexity increase in Calibration: Provide High Quality Results in earlier phase of Development

3 Complete Turn-Key Solution

4 Ready to meet future Challenges

5 Increase Quality - Frontloading

CALIBRATION
EVOLUTION OVER THE LAST 20 YEARS

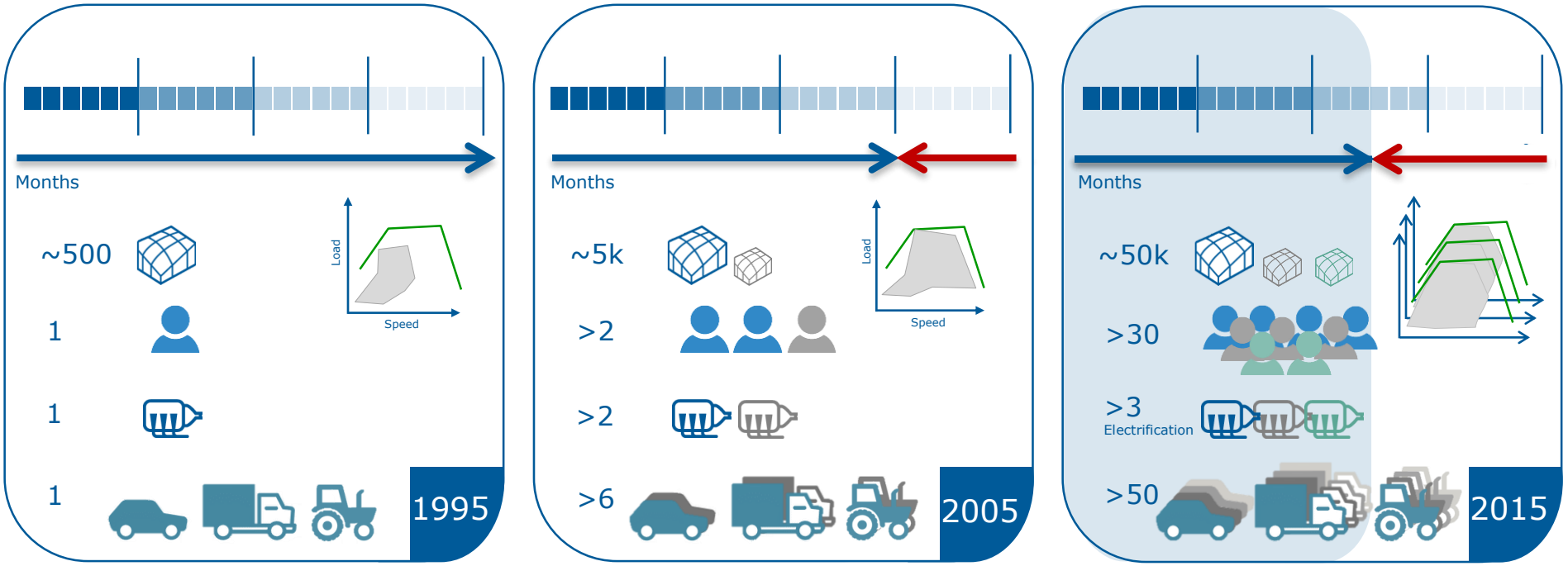


Change in Calibration

- From 1995 up to now

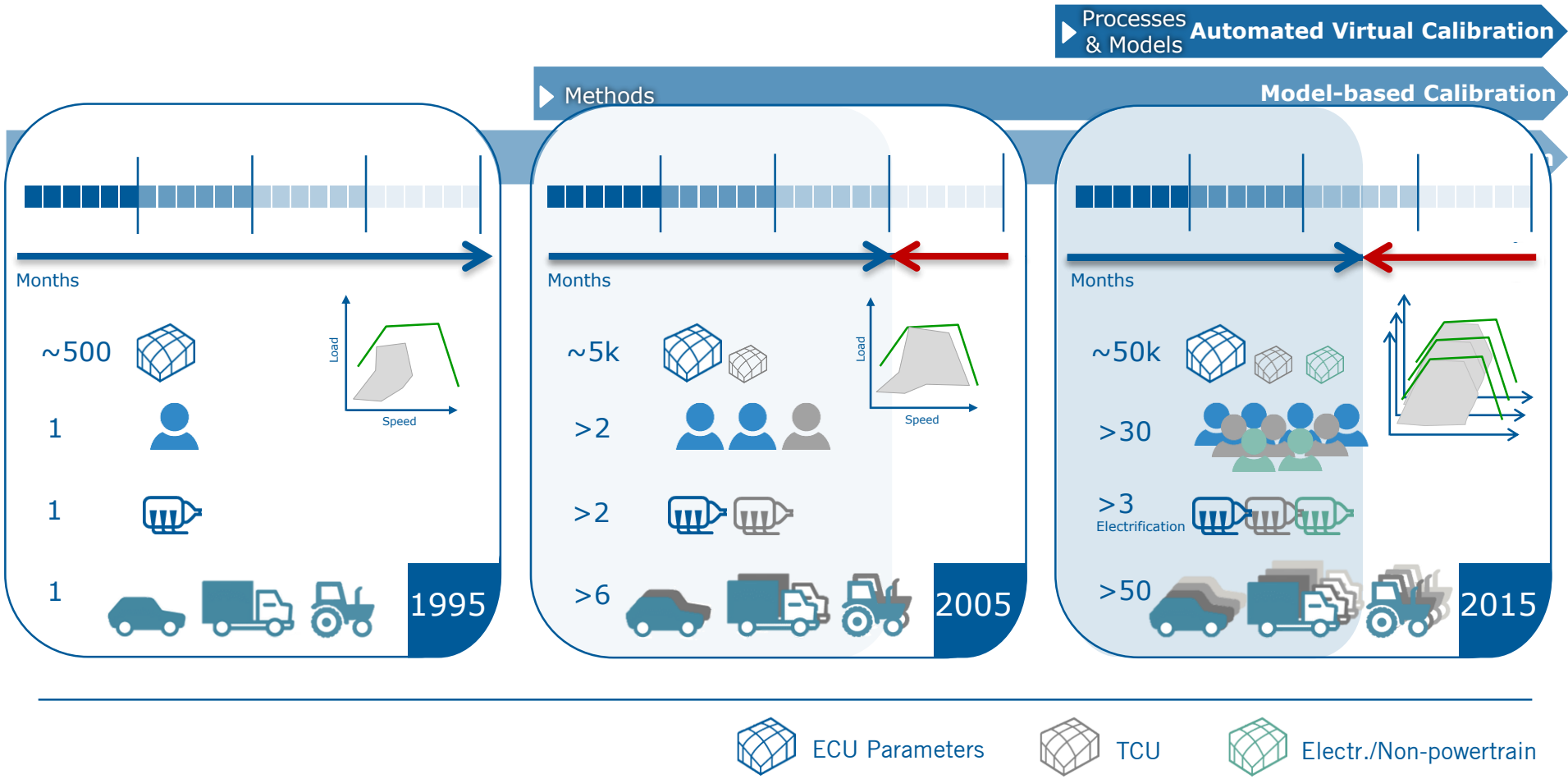
- 1995: Manual Calibration
- 2005: Model-Based Calibration
- 2015: Automatic Virtual Calibration
- 20xx: Physics Model Based Controls

CALIBRATION
EVOLUTION OVER THE LAST 20 YEARS



ECU Parameters TCU Electr./Non-powertrain

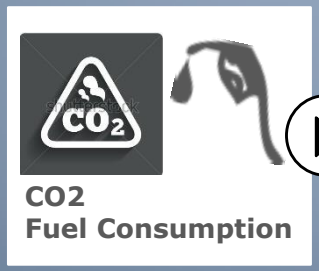
CALIBRATION
EVOLUTION OVER THE LAST 20 YEARS



WELL KNOWN CHALLENGES IN CALIBRATION

How to keep the quality standards or even increase quality?

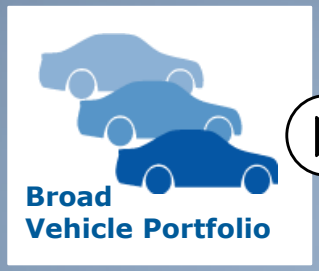
When facing challenges like …



Increasing System Complexity

(EAS, OBD, Hybridization)

Increasing Development Costs



Shorter Development Times

Increasing Facility and Vehicle Management Complexity

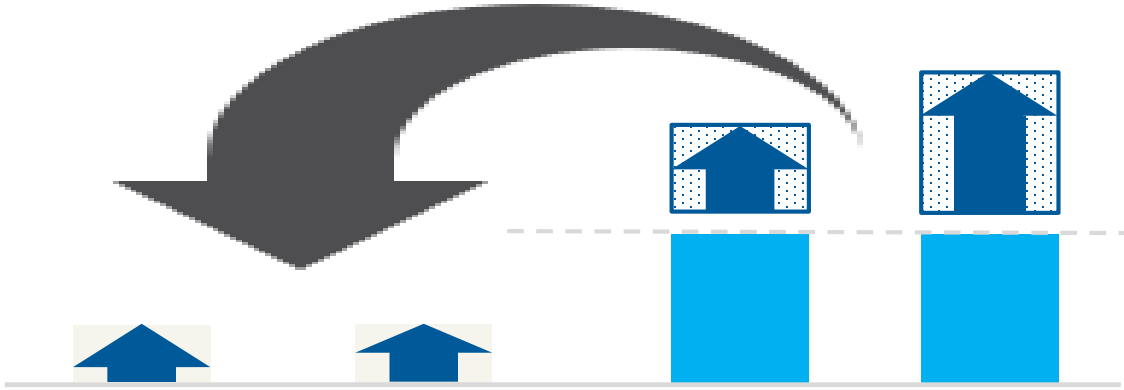
EXTEND YOUR CALIBRATION CAPABILITY

AVL VIRTUAL TEST BED

- The complete Turn Key Solution for Calibration

- Real Time Capable, Powerful and Accurate Models with CRUISE M/MoBEO
- Identical Environment as on Real Test Bed, well known by Calibration Engineer
- Training, Application and Support from Experienced AVL Engineers

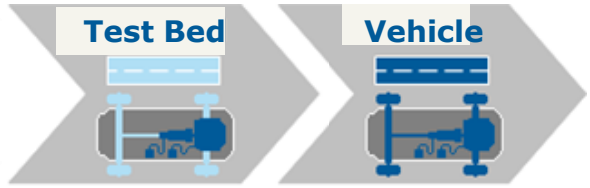
VIRTUAL TEST BED



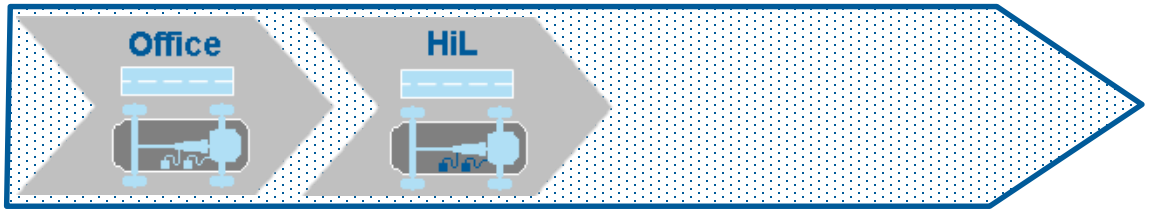
Potential additional effort as consequence of more stringent Legislation

Actual effort: 100%

Empowerment of the Virtual Environments for Calibration until SoP **CRUISEM/MOBEO Methodology**



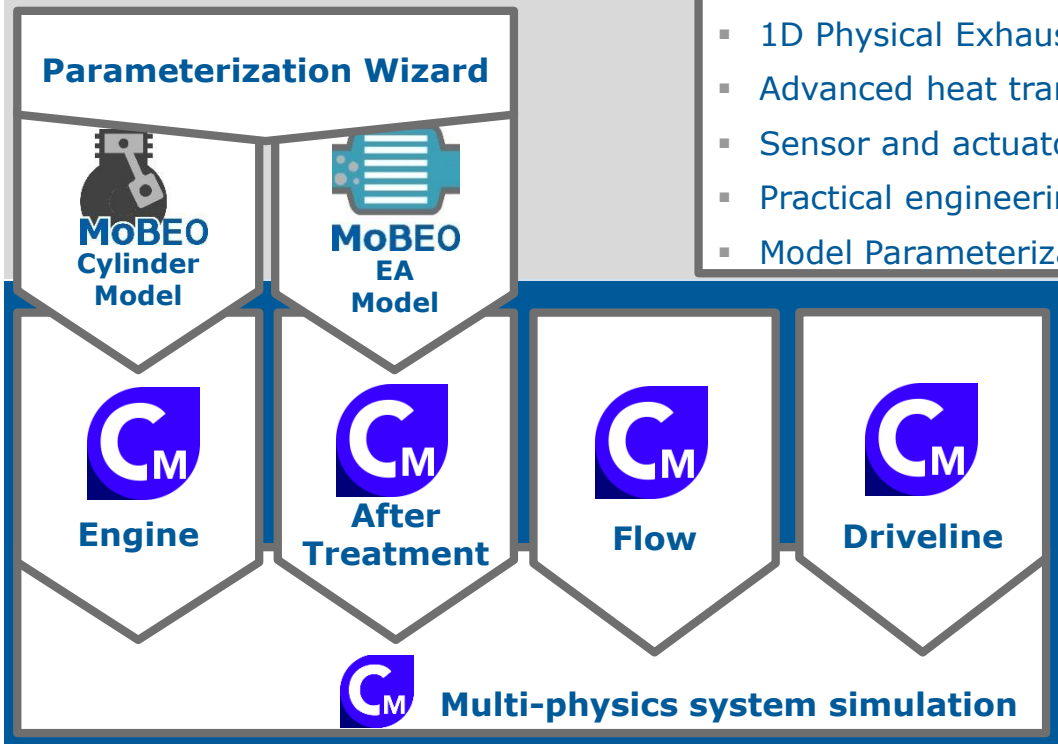
Development Environments



S tart
o f
P roduction

VIRTUAL TEST BED

MoBEO Modules



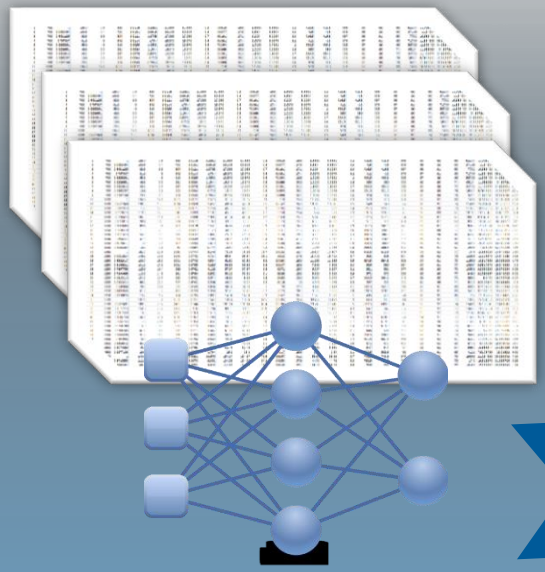
- Generic semi-physical combustion model
- 1D Physical Exhaust gas after treatment model
- Advanced heat transfer models in the gas path
- Sensor and actuator models
- Practical engineering know-how included
- Model Parameterization tools ("wizards") included

- 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)

- Multi-disciplinary system simulation

VIRTUAL TEST BED

Empirical Models

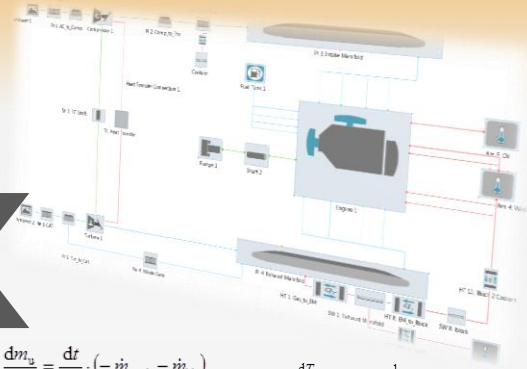


Semi-physical Models

MoBEO

MoBEO

Physics - Based Models



$$\frac{dm_u}{d\xi} = \frac{dt}{d\xi}\cdot\left(-\dot{m}_{u\to b} - \dot{m}_{bb}\right)$$

$$\frac{dm_b}{d\xi} = \frac{dt}{d\xi}\cdot\left(+\dot{m}_{u\to b} - \dot{m}_{bb} + \dot{r}_{evap}\right)$$

$$\frac{dw_{j,u}}{d\xi} = 0$$

$$\frac{dw_{j,b}}{d\xi} = \frac{dt}{d\xi}\cdot\frac{1}{m_b}\cdot\left[\begin{array}{l}+\left(w_{j,u} - w_{j,b}\right)\cdot\dot{m}_{u\to b}\\ +\left(w_{j,evap} - w_{j,b}\right)\cdot\dot{r}_{evap} + w_{j,b}\cdot\dot{r}_{comb}\end{array}\right]$$

$$\frac{dT_u}{d\xi} = \frac{1}{\left(\frac{\partial u_u}{\partial T_u} + R_u + T_u\cdot\frac{\partial R_u}{\partial T_u}\right)}\cdot\left\{\begin{array}{l}-\frac{d\xi}{dt}\cdot\frac{1}{m_u}\cdot\dot{Q}_{u,wall}\\ -\left[\frac{\partial u_u}{\partial p} - T_u\cdot\left(\frac{R_u}{p} - \frac{\partial R_u}{\partial p}\right)\right]\cdot\frac{dp}{d\xi}\end{array}\right.$$

- MoBEO model approaches contain
  - Empirical Models for Calculation Speed and Accuracy
  - Physics-based Models for extrapolation capability

MoBEO MoBEO

VIRTUAL TEST BED

VIRTUAL

MoBEO
Basic model setup

SEMI-PHYSICAL
basic Model without measurement data

MoBEO REFINED MODEL SET-UP
Engine Cylinder
Engine Air Path
EAS

SEMI-PHYSICAL
Thermodynamic
NOx-Emission
EAS System

EMPIRICAL STATIC GLOBAL
HC, CO,
Soot, SPL, ...

COMBINED MODEL
Increased number of engine specific outputs

Model refinement

HiL Setup

MiL Setup

MODEL-BASED CALIBRATION OF VARIOUS VARIANTS
Variant specific hardware change (e.g. intake piping, ...)
(No combustion HW change)

ROBUSTNESS ANALYSIS

PRE-CALIBRATION

TEST RESULTS
Component testing

TESTBED RESULTS
Base engine testbed development

Doe TEST RESULTS
DoE Measurements

PRE-CALIBRATION

FIELD DATA

FIELD DATA

EMISSION VALIDATION

ENVIRONMENTAL VALIDATION

REAL

VIRTUAL TEST BED

AVL Virtual Test Bed is an advanced hardware-in-the-loop test bed extended with:

dSpace or ETAS pre-configured HiL System with AVL specified extensions

Calibration software (INCA,…)

CRETA dataset management to store and share the DCM calibrated on VTB

CONCERTO post-processing using same layouts & scripts for data analyzing

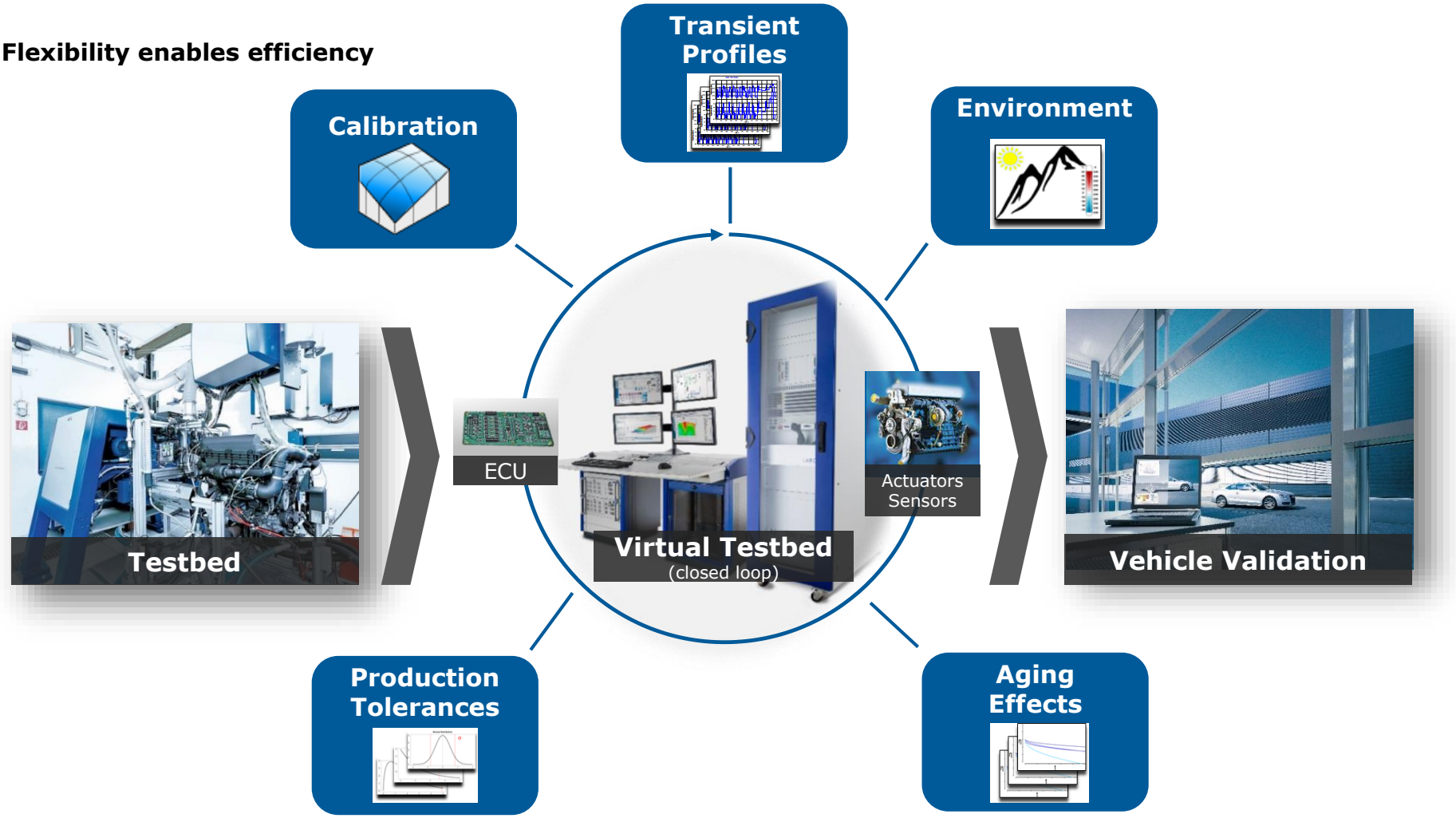
Advanced semi-physical powertrain model (**CRUISE M with MoBEO add-on**, Customer specific models)

PUMA & CAMEO test bed automation delivering identical interface for the calibration engineer as on real test bed

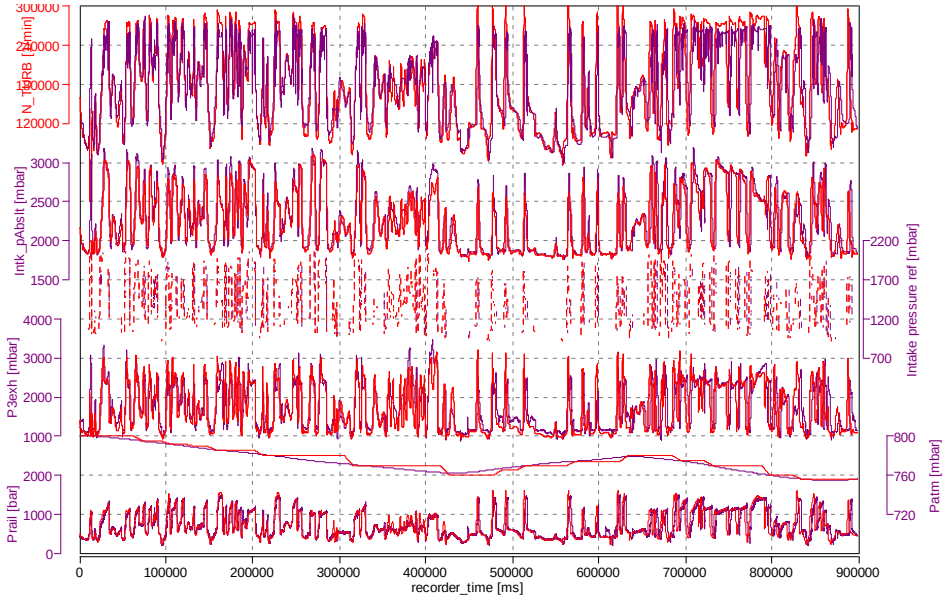
SANTORIN Host server connection storing simulation results in same format as real test data

VIRTUAL TEST BED

Flexibility enables efficiency



CUSTOMER EXPERIENCE – PASSENGER CAR ON WINTER TEST TRIP (REAL DRIVE MISSION)

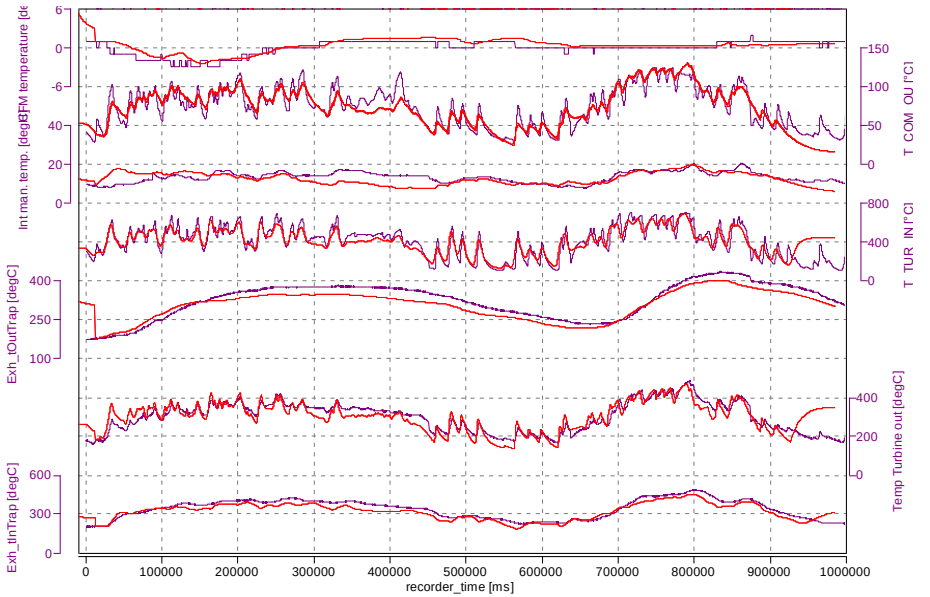


Pressures with barometric changes on the mountains

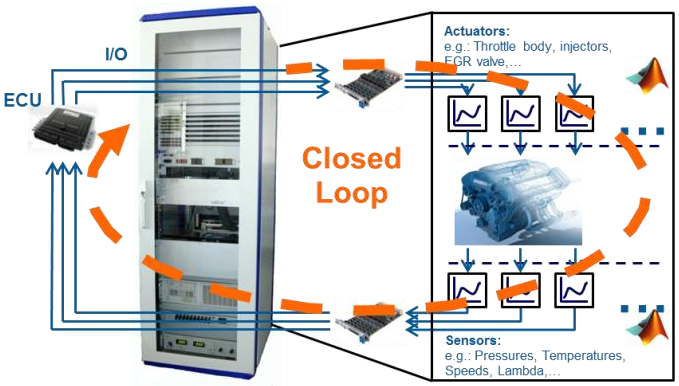
HIL

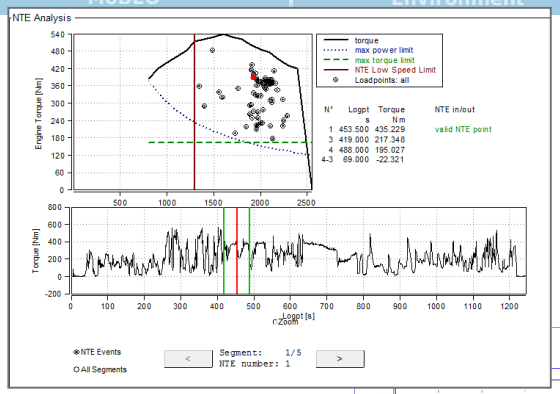
Vehicle

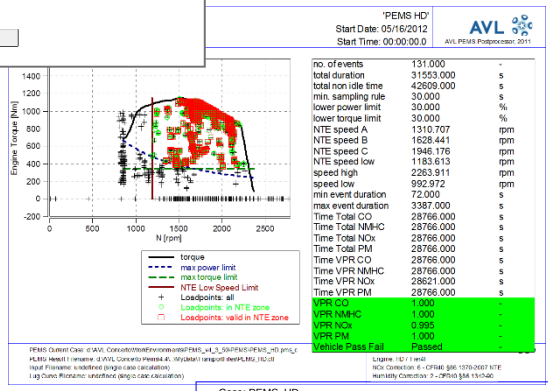
Temperatures



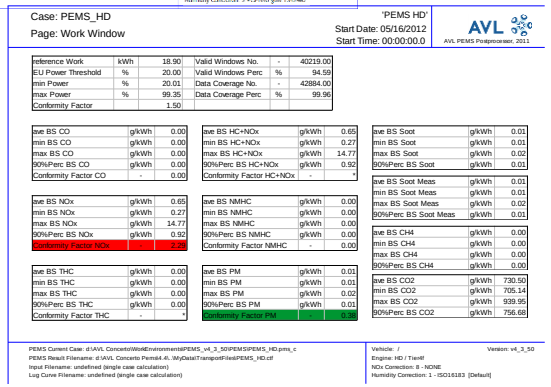
CUSTOMER EXPERIENCE – IN USE COMPLIANCE TEST







no. of events	131.000	-	
total duration	31553.000	s	
total non idle time	42609.000	s	
min. sampling rule	30.000	s	
lower power limit	30.000	%	
lower torque limit	30.000	%	
NTE speed A	1310.707	rpm	
NTE speed B	1628.441	rpm	
NTE speed C	1946.176	rpm	
NTE speed low	1183.613	rpm	
speed high	2263.911	rpm	
speed low	992.972	rpm	
min event duration	72.000	s	
max event duration	3387.000	s	
Time Total CO	28766.000	s	
Time Total NMHC	28766.000	s	
Time Total NOx	28766.000	s	
Time Total PM	28766.000	s	
Time VPR CO	28766.000	s	
Time VPR NMHC	28766.000	s	
Time VPR NOx	28621.000	s	
Time VPR PM	28766.000	s	
VPR CO	1.000	-	
VPR NMHC	1.000	-	
VPR NOx	0.995	-	
VPR PM	1.000	-	
Vehicle Pass Fail	Passed	-	



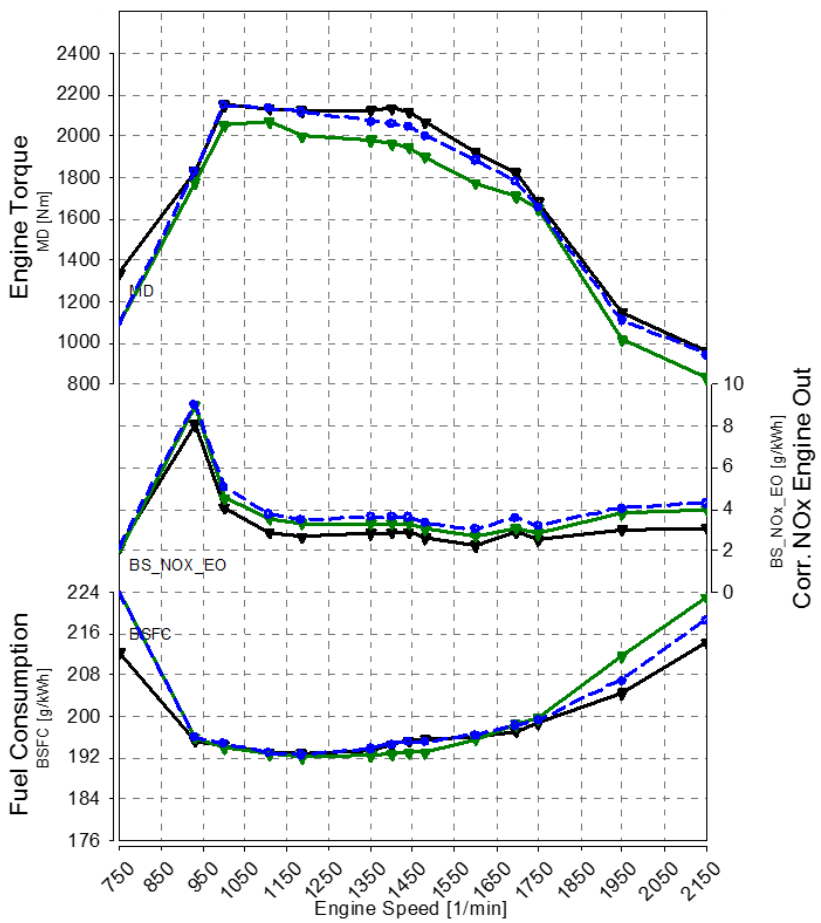
reference Work	kWh	18.90	Valid Windows No.	-	40219.00			
EU Power Threshold	%	20.00	Valid Windows Perc	%	94.59			
min Power	%	20.01	Data Coverage No.	-	42884.00			
max Power	%	99.35	Data Coverage Perc	%	99.96			
Conformity Factor		1.50						

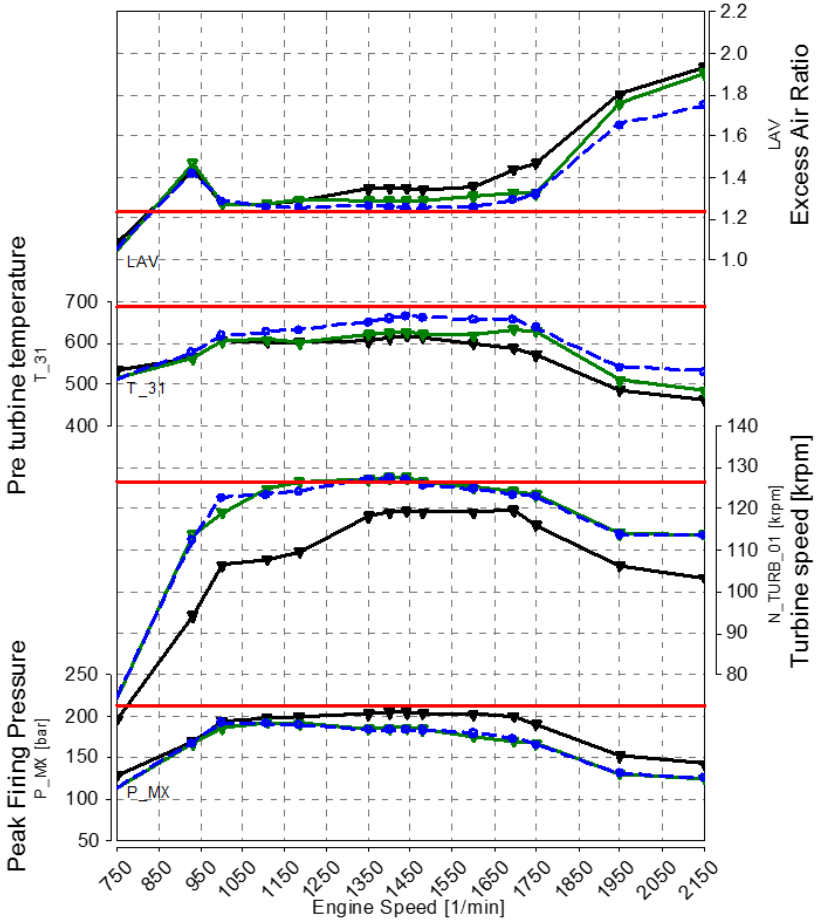
ave BS CO	g/kWh	0.00	ave BS HC+NOx	g/kWh	0.65	ave BS Soot	g/kWh	0.01
min BS CO	g/kWh	0.00	min BS HC+NOx	g/kWh	0.27	min BS Soot	g/kWh	0.01
max BS CO	g/kWh	0.00	max BS HC+NOx	g/kWh	14.77	max BS Soot	g/kWh	0.02
90%Perc BS CO	g/kWh	0.00	90%Perc BS HC+NOx	g/kWh	0.92	90%Perc BS Soot	g/kWh	0.01
Conformity Factor CO	-	0.00	Conformity Factor HC+NOx	-	*			
ave BS NOx	g/kWh	0.65	ave BS NMHC	g/kWh	0.00	ave BS Soot Meas	g/kWh	0.01
min BS NOx	g/kWh	0.27	min BS NMHC	g/kWh	0.00	min BS Soot Meas	g/kWh	0.01
max BS NOx	g/kWh	14.77	max BS NMHC	g/kWh	0.00	max BS Soot Meas	g/kWh	0.02
90%Perc BS NOx	g/kWh	0.92	90%Perc BS NMHC	g/kWh	0.00	90%Perc BS Soot Meas	g/kWh	0.01
Conformity Factor NOx		2.24	Conformity Factor NMHC	-	0.00			
ave BS THC	g/kWh	0.00	ave BS PM	g/kWh	0.01	ave BS CH4	g/kWh	0.00
min BS THC	g/kWh	0.00	min BS PM	g/kWh	0.01	min BS CH4	g/kWh	0.00
max BS THC	g/kWh	0.00	max BS PM	g/kWh	0.02	max BS CH4	g/kWh	0.00
90%Perc BS THC	g/kWh	0.00	90%Perc BS PM	g/kWh	0.01	90%Perc BS CH4	g/kWh	0.00
Conformity Factor THC	-	*	Conformity Factor PM	-	0.34	ave BS CO2	g/kWh	730.50
						min BS CO2	g/kWh	705.14
						max BS CO2	g/kWh	939.95
						90%Perc BS CO2	g/kWh	756.68

Post-processing according to legislative requirements - Independent if virtual or real testing

CUSTOMER EXPERIENCE – HD TORQUE SHAPE IN ALTITUDE (75 KPA @ 25°C)

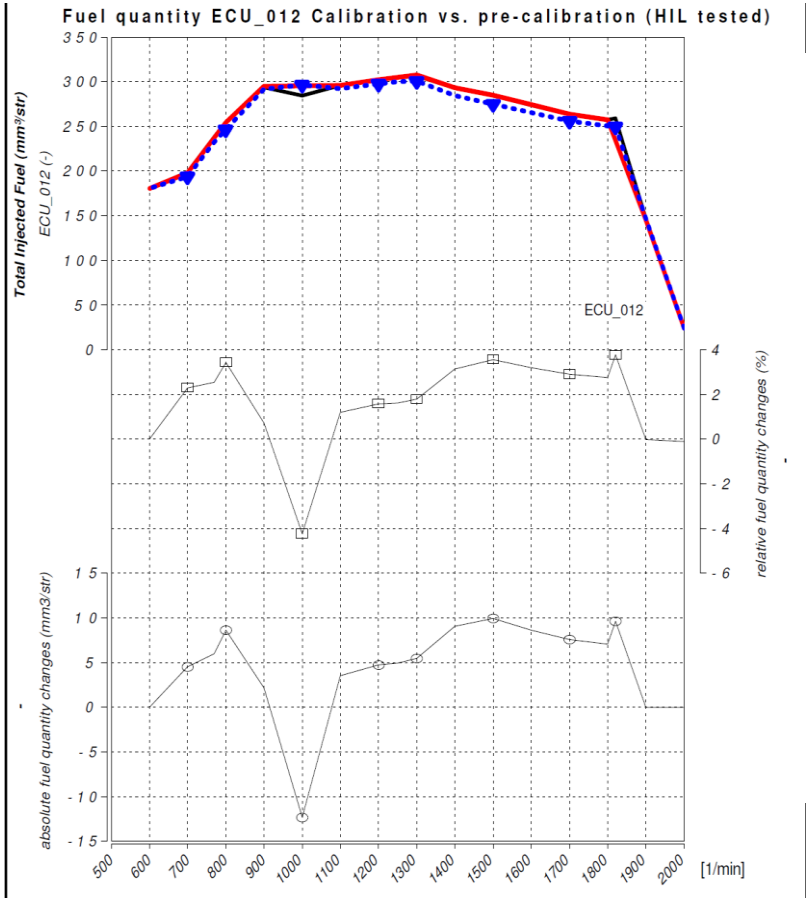
- 100 kPa/25degC Iso conditions
- 75 kPa/25degC Customer calibration
- 75 kPa/25degC AVL calibration MoBEO/HIL/CAMEO

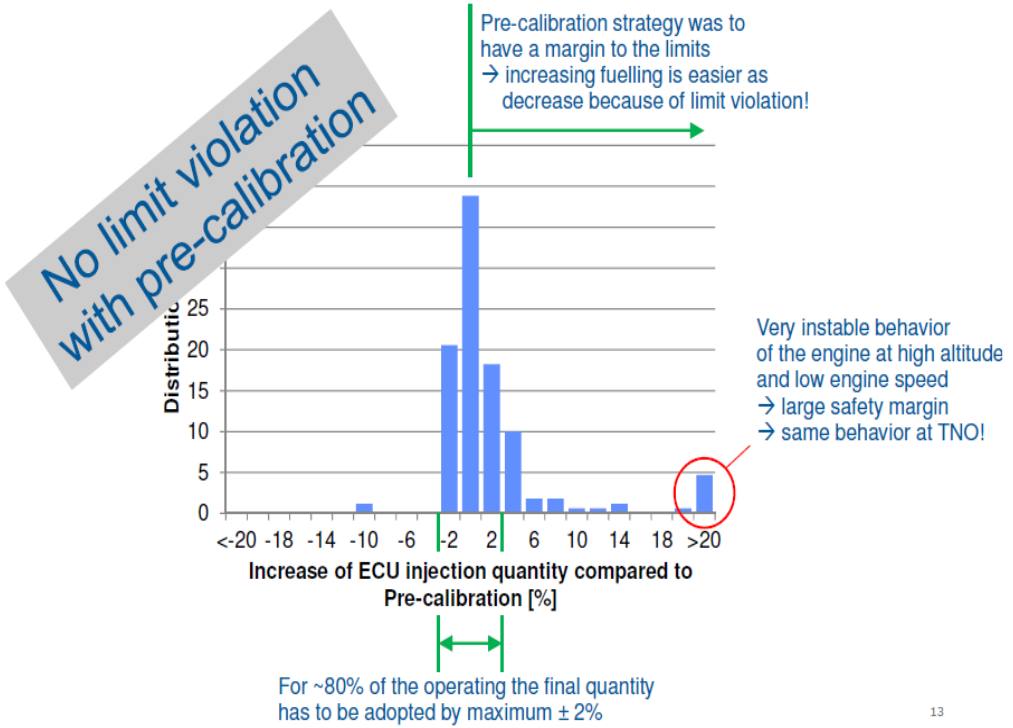




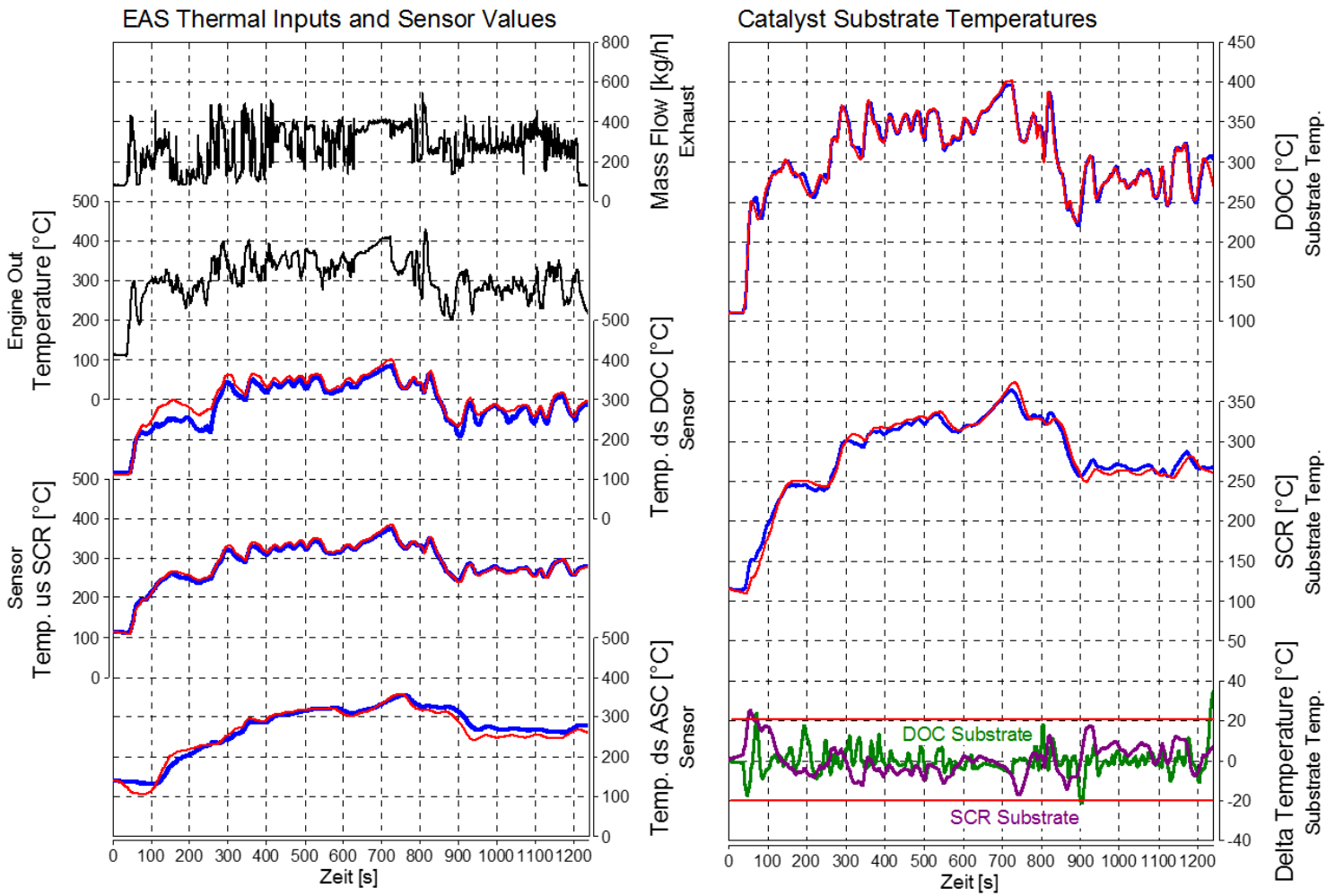
CUSTOMER EXPERIENCE – FUEL INJECTION CALIBRATION FOR ALTITUDE

HIL final calibration
TNO final calibration
HIL pre-calibrated





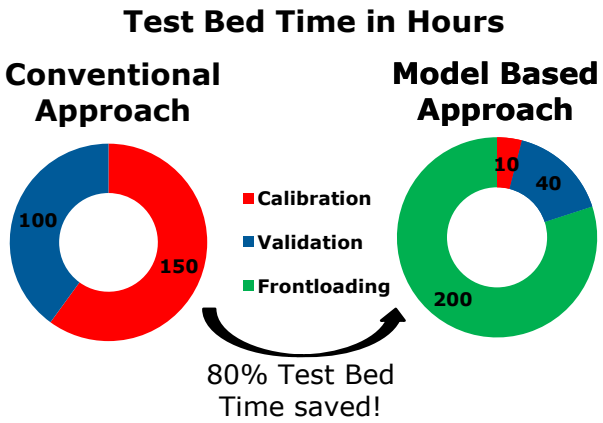
CUSTOMER EXPERIENCE – THERMAL AFTERTREATMENT SIMULATION (WARM NRTC)



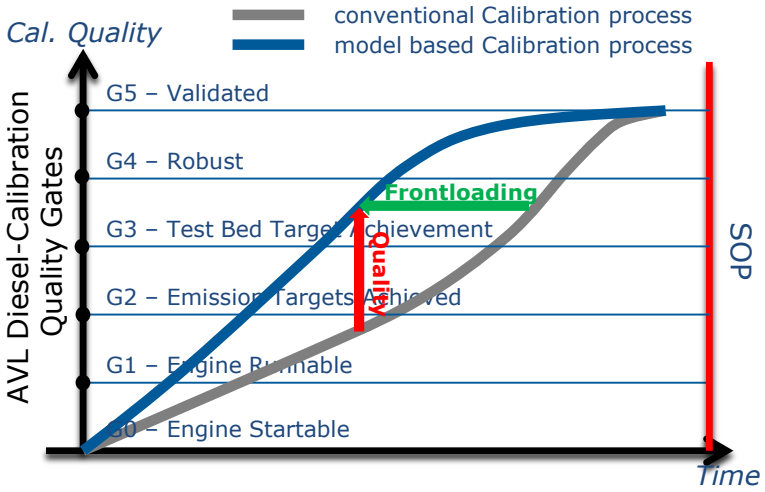
HiL
Test Bed

CUSTOMER EXPERIENCE: DEVELOPMENT EFFORT

Example based on customer feedback:
NTE, Engine Protection and Ambient Corrections (1 Mode)



Additional effort for model set-up and parameterization has to be considered



Virtual Calibration Approach:

- Calibration on VTB 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

ITS ALL ABOUT INTERPLAY…

3 PILLARS FOR MoBEO SUCCESS:

Employees

→Employees who know how to use real and virtual test facilities

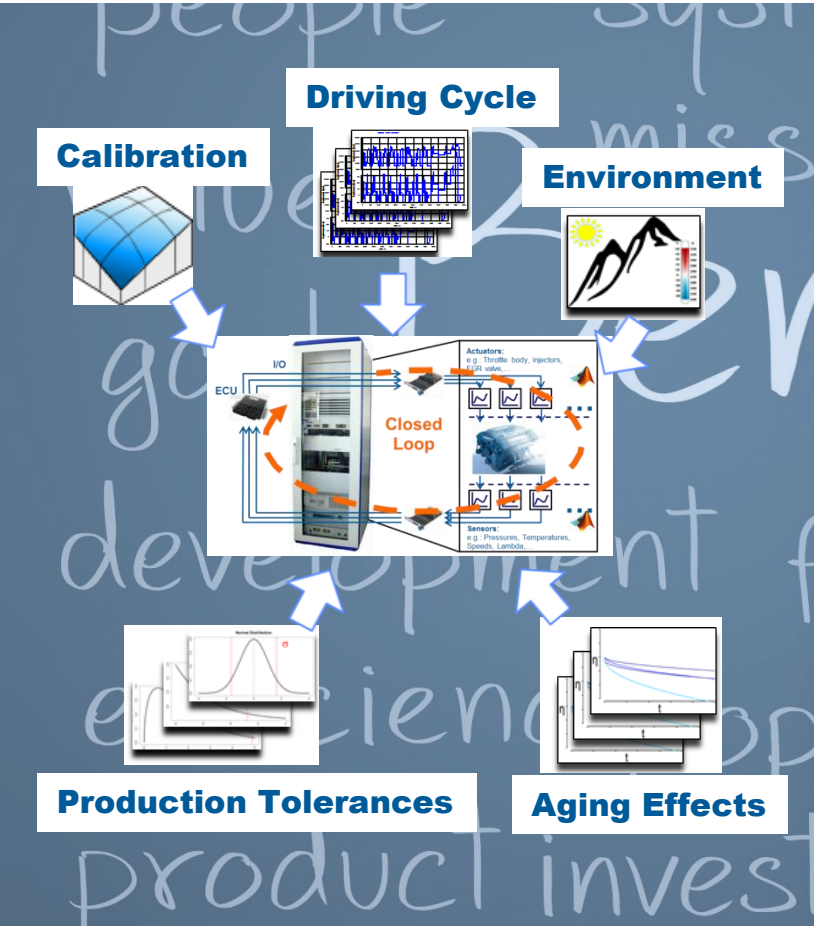
Models

→Models where complex parts can be substituted by development experience out of 100reds engine developments

Workflow

→A model based development workflow with a realistic extended calibration process taking into account all available calibration environments

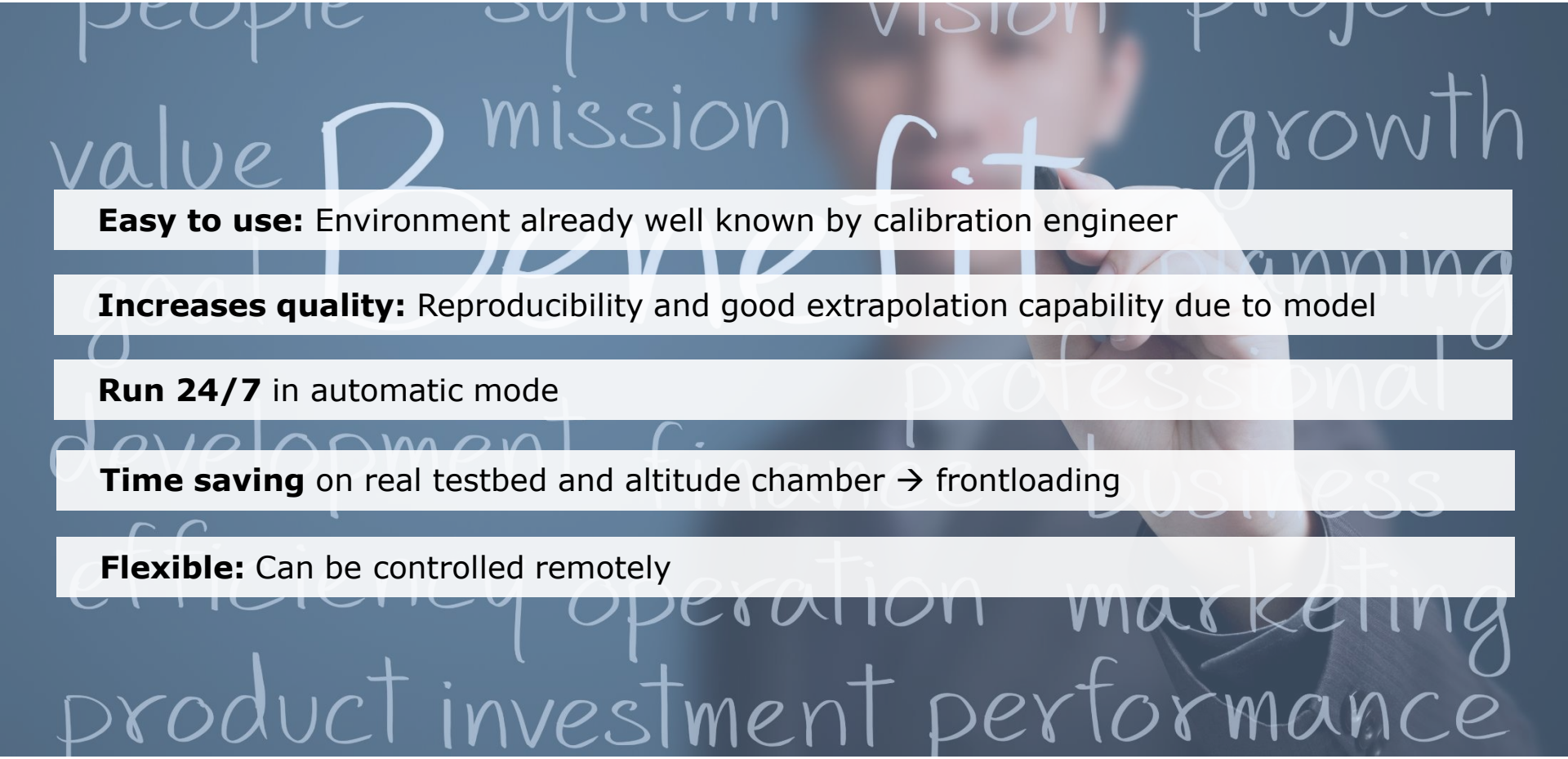
TAKE AWAY



Powertrain calibration tasks used cases for HiL

- Pre-calibration of different calibration work packages:
  - Calibration for non-standard ambient conditions
  - Calibration of component protection
- RDE - PEMS
- In-Use Compliance - PEMS
- Vehicle/Engine derivate calibration
- Real world fluid consumption optimization
- Sensitivity/Robustness studies taking into account system interactions
- OBD – Pre-calibration Diagnoses, IUPR
- Software and dataset validation
- Post SOP support

CONCLUSION: MOBEO AND VIRTUAL TEST BED



Easy to use: Environment already well known by calibration engineer

Increases quality: Reproducibility and good extrapolation capability due to model

Run 24/7 in automatic mode

Time saving on real testbed and altitude chamber → frontloading

Flexible: Can be controlled remotely

BENEFITS

Calibration cost savings Through Reduction of Vehicle Number and Test Facilities Utilization

- RDE increase effort: + 30%-40%
- MoBEO saving: 10-20%

Reduced Time for Primary & Derivative Application

Increased Quality Management for future Emission Legislation (RDE)

THANK YOU

AVL

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