AVL Solutions
(A comprehensive approach to RDE)
Road Testing
RDE TEST EQUIPMENT

- AVL M.O.V.E iS System
  - GAS PEMS iS
  - PN PEMS iS
  - EFM iS
  - System Control
  - Concerto M.O.V.E Postprocessing
Independence of the measured values from ambient conditions, shocks and vibrations, EMV, … is a pre-requisite for a successful RDE test!
AVL M.O.V.E PN PEMS

New!
Conclusion:

The counting efficiency of the AVL Advanced DC is equivalent to PMP systems at typical engine exhaust conditions.
AVL M.O.V.E EXHAUST FLOW METER

New!
AVL M.O.V.E IS SYSTEM VERIFICATION

 WLTC result for 4 cylinder Diesel engine vehicle
(*) real vehicle/brand is not shown

<table>
<thead>
<tr>
<th>Pollutant [g/km]</th>
<th>AVL M.O.V.E iS</th>
<th>CVS</th>
<th>Diff absolute</th>
<th>Diff [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>202,23</td>
<td>204,7</td>
<td>-2,47</td>
<td>-1,2</td>
</tr>
<tr>
<td>CO</td>
<td>0,08</td>
<td>0,073</td>
<td>0,007</td>
<td>10,2</td>
</tr>
<tr>
<td>NOx</td>
<td>0,066</td>
<td>0,062</td>
<td>0,004</td>
<td>6,6</td>
</tr>
</tbody>
</table>

Note: These results are below the legislative requirements by a factor 2-5.
HOW TO GET A VALID TEST?
TRIP REQUIREMENTS...
RDE TEST PROCEDURE

**Temperature**
Moderate 0°C to 30°C / Extended (-7°C to 35°C)

**Altitude**
Moderate < 700 m / Extended < 1350 m

**Trip / Driver**
City (34%) / Rural (33%) / Motorway (33%), up to 160 km/h, 90-120 min

**Load**
no „empty“ vehicle, heating or air condition on
AVL CONCERTO M.O.V.E POST PROCESSING
### AVL CONCERTO M.O.V.E POST PROCESSING

#### Trip Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Urban</th>
<th>Rural</th>
<th>Motorway</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity Thresholds (km/h)</td>
<td>[2-50]</td>
<td>[60-80]</td>
<td>[80-150]</td>
<td>[150-]</td>
</tr>
<tr>
<td>Ave Velocity ECU (km/h)</td>
<td>26.7</td>
<td>73.6</td>
<td>115.3</td>
<td></td>
</tr>
<tr>
<td>Share &lt;= 1 km/h, minutes &gt;= 100 km/h</td>
<td>26.4%</td>
<td></td>
<td>21.9 min</td>
<td></td>
</tr>
<tr>
<td>Trip Share ECU Distance (%)</td>
<td>26.9</td>
<td>24.7</td>
<td>49.4</td>
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<tr>
<td>Distance ECU (km)</td>
<td>29.05</td>
<td>36.46</td>
<td>52.16</td>
<td>107.84</td>
</tr>
<tr>
<td>Duration (min)</td>
<td>65</td>
<td>22</td>
<td>27</td>
<td>114</td>
</tr>
<tr>
<td>Fuel Consumption (l)</td>
<td>1.463</td>
<td>1.065</td>
<td>2.720</td>
<td>5.241</td>
</tr>
<tr>
<td>Fuel Consumption Carbon Balance</td>
<td>1.698</td>
<td>1.211</td>
<td>3.032</td>
<td>5.941</td>
</tr>
<tr>
<td>Fuel Economy (l/km100)</td>
<td>5.04</td>
<td>3.97</td>
<td>6.21</td>
<td>4.88</td>
</tr>
<tr>
<td>Fuel Economy Carbon Balance (l/km100)</td>
<td>5.86</td>
<td>4.56</td>
<td>5.81</td>
<td>4.61</td>
</tr>
</tbody>
</table>

#### Total Trip Requirements

- **Trip Shares**
  - Urban: 34% +5%
  - Rural: 33% +5%
  - Motorway: 33% +5%
  - Minimum Distance: Fail

- **Urban Requirements**
  - Average Velocity 15-30 km/h: pass
  - < 1 km/h for at least 10% urban time: pass

- **Motorway Requirements**
  - 5 Minutes >= 100 km/h: pass
  - Maximum Velocity >= 110 km/h: pass

- **Test Completeness**
  - Urban 15% Windows: pass
  - Rural 15% Windows: pass
  - Motorway 15% Windows: pass

- **Test Normality**
  - Urban 50% in Primary Tolerance: pass
  - Rural 50% in Primary Tolerance: pass
  - Motorway 50% in Primary Tolerance: pass
AVL CONCERTO M.O.V.E POST PROCESSING

### Unweighted Results

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>Trip</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\text{\textsubscript{x}}</td>
<td>g/km</td>
<td>0.3063</td>
<td>0.890</td>
</tr>
<tr>
<td>CO</td>
<td>g/km</td>
<td>0.5667</td>
<td>0.500</td>
</tr>
<tr>
<td>CO\text{\textsubscript{2}}</td>
<td>g/km</td>
<td>127.9111</td>
<td></td>
</tr>
<tr>
<td>PN</td>
<td>1/km</td>
<td>6.000e+011</td>
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</tr>
</tbody>
</table>

### JRC

<table>
<thead>
<tr>
<th></th>
<th>Trip</th>
<th>Conformity Factor</th>
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<tbody>
<tr>
<td></td>
<td>City</td>
<td>Rural</td>
</tr>
<tr>
<td>NO\text{\textsubscript{x}}</td>
<td>g/km</td>
<td>0.3063</td>
</tr>
<tr>
<td>CO</td>
<td>g/km</td>
<td>0.3998</td>
</tr>
<tr>
<td>PN</td>
<td>1/km</td>
<td>6.000e+000</td>
</tr>
</tbody>
</table>

### CLEAR

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>Trip</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\text{\textsubscript{x}}</td>
<td>g/km</td>
<td>0.3079</td>
<td>0.01</td>
</tr>
<tr>
<td>CO</td>
<td>g/km</td>
<td>0.4758</td>
<td>0.27</td>
</tr>
<tr>
<td>PN</td>
<td>1/km</td>
<td>6.000e+000</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Chassis Dynamometer
REAL DRIVING EMISSION - DEVELOPMENT

Use case 2:
Emission development, calibration, verification of development targets, based on “reference” cycles

Type Approval
In Service Compliance (Verification, Benchmark)

Use case 3:
Simulation, virtual development and frontloading

Use case 1:
Reproduction and analysis of on-road test data
RDE - TEST BED CONSIDERATIONS

Are current chassis dyno test bed able to handle vehicle driving with higher loads?
RDE engine operation will be far higher than current “standard” drive cycle requirements. The energy contained in the fuel, which is burned in a combustion engine is converted to:

- 33% to turn the wheels - Dyno must handle that
- 33% in heat - Test bed infrastructure (TGA) must handle that
- 33% heat in the exhaust - CVS and Emission Systems must handle that

Test bed infrastructure, like air-conditioning, ventilation, … must be able to handle the additional heat produced by the vehicle.

Lower dilution ratios + higher temperatures, may require double dilution for PM

Higher load requirements due to RDE, especially for high power and/or heavy vehicles, will require higher performance of the chassis dyno and cooling fan.

Larger exhaust gas flow and heat may require larger CVS or alternatives (modal diluted or raw, heated CVS, …). i.e. app. 30 m³/min CVS per 100 kW engine operation

Which additional environmental conditions do the powertrain development engineers require? That will most likely be different between an OEM (who knows how the vehicle is calibrated) and all others.
REAL DRIVING EMISSION - DEVELOPMENT

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Reproduction and analysis of on-road test data

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Use case 1:
Reproduction and analysis of on-road test data
Reproduction and analysis of a RDE road test on a test bed:

- Target is to reproduce one specific road test of one specific vehicle as close as possible on a test bed. Valid for specific maneuvers or complete road test, engine speed and torque must be directly comparable.
- With the reproduction of the test it can be repeated as often as needed, which is for analyzing a problem and later to verify a solution, a key element for any development work.
- Allows to use the full testing and analytical power of an emission laboratory.

Implementations:

- During the PEMS road test all relevant data will be recorded.
- Data import into the test bed control and automation system, without the need for long set-up or simulation model generation (“drive on the morning and reproduce on the afternoon”)
- Specific dyno control mode and test execution
- The road data will be transferred to the test bed and special functionalities (like data import, specific dyno control-modes, …) will allow the reproduction.
Results of AVL RDE reproduction development work:

- Euro-5 Diesel passenger car with DOC, SCR and DPF.
- These data were measured during preliminary tests of a new test methodology under development. It can not be expected that the here shown good correlation can always be achieved.

**CO2 mass**

Road: 178.1 g/km
Lab.: 177.9 g/km
Deviation: -0.1 %

**NOx mass**

Road: 0.633 g/km
Lab.: 0.692 g/km
Deviation: +9.3 %
REAL DRIVING EMISSION - DEVELOPMENT

Use case 1: Reproduction and analysis of on-road test data

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Type Approval

In Service Compliance (Verification, Benchmark)

Use case 1: Reproduction and analysis of on-road test data
RDE – CONVENTIONAL REFERENCE DRIVE CYCLES

Conventional drive cycle testing but with RDE “Reference” cycles:

- The current development methodology, which is mostly based on standard reference cycles, is extended by already known or newly developed “RDE Reference Cycles”.
- These include variations of velocity, road gradient, curve radius, ambient conditions, …
- Reproducible and comparable results, also between different vehicles

Drive Cycle based development:

- Beside the well known emission cycles, like WLTC, NEDC or FTP75 also other known cycles will be used. Like
  - Artimis (also known as CADC), which was used in the past mainly for emission modeling and emission inventory estimations
  - Standardized Random Test Sequence, like RTS95 (“aggressive”)
  - Drive cycles generated by a “Random Cycle Generator”, like the one developed by TNO on base of the WLTC data base.
  - Specific “RDE Reference cycles” which are generated by an OEM specifically for its vehicle types.
  - or specific drive cycle maneuver elements combined to a test sequence like a “finite element approach”.
RDE – CONVENTIONAL REFERENCE DRIVE CYCLES

Implementation:
• AVL Graz RDE Reference road and cycle

<table>
<thead>
<tr>
<th>Distance/Time</th>
<th>52.6km</th>
<th>4300s</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>20%</td>
<td>47%</td>
</tr>
<tr>
<td>Highway</td>
<td>43%</td>
<td>23%</td>
</tr>
<tr>
<td>Interstate</td>
<td>37%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Altitude, m

Vehicle Speed

Distance/Time

Altitude

0 300 600 900 1200 1500 1800 2100 2400 2700 3000 3300 3600 3900 4200

0 300 600 900 1200 1500 1800 2100 2400 2700 3000 3300 3600 3900 4200
time (s)
v vehicle (km/h)
RDE – CONVENTIONAL REFERENCE DRIVE CYCLES

Implementation:

- Road load simulation requires additional elements for RDE, like:
  - Slope of street (needs also support for the driver via the driver aid)
  - Curve resistance load simulation based on curve radius and vehicle speed
  - Ambient conditions (temperature, humidity)
  - Altitude (absolute pressure)

\[ F_{WK} = \frac{m_d^3 \cdot v^4}{R_k^2 \cdot 2 \cdot C_{s_p}} + \frac{m_h^3 \cdot v^4}{R_k^2 \cdot 2 \cdot C_{s_h}} \]
REAL DRIVING EMISSION - DEVELOPMENT

Use case 1:
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Use case 1:
Reproduction and analysis of on-road test data
REAL DRIVING EMISSION

Simulation technologies to:
- address the “infinite variables involved in real world driving”
- master today’s “large number of vehicle models and variants”.

Virtual Integration and Front-Loading Calibration:
- Virtual simulation of random driving maneuvers with full variability of ambient conditions, driver types, vehicle variants, connected powertrain, …
- from pure simulation, Hardware in the Loop (HIL) to conventional test beds
- Evaluation of powertrain and vehicle concepts, definition of solutions and engineering targets, calibration in non standard ambient conditions

Implementation:
- Based on InMotion
- Engine- or Powertrain test beds
- 4x4 Chassis dyno test beds with individual wheel dynos.
- up to GPS Emulation on chassis dyno testbed for car to infrastructure integration

Innovation Adoption:
- Simulation approach, especially for “classic” emission development and testing groups, require still a high willingness and ramp up time to adopted to such innovations.
REAL DRIVING EMISSION

TÜV Hessen Advanced Chassis DynoTestbed:

• Focus on alternative powertrain, alternative fuel and Real Driving Emissions Testing
• Chassis Dyno Emission Test Cell for Certification and R&D with additional “Real Driving Emission” Simulation capabilities.
• also Portable Emission Measurement Systems
CLOSING THE GAP
REAL DRIVING EMISSION

Virtual Front-Loading Calibration:

- xIL Station with Hardware in the loop (HIL) and full variability to simulate ambient conditions, driver types, vehicle variants, connected powertrain, …
- Same AVL user interface and functionalities as AVL conventional test beds (“only the engine sound is missing”)

Hardware in the loop: ECU, injection nozzles and intake throttle.
Base Calibration in the LAB
THE CONVENTIONAL APPROACH

Determination of Speed/Load Area out of driving cycle

CAMEO Cluster Points Calculation

Local DoE tests to reduce the testing effort
MULTI-VARIANT PROFILES

Weight: 1590kg
Weight: 1810kg
Weight: 1700kg

MORE POINTS
SPECIFIC ADJUSTMENTS ON CHASSIS DYNO

Different speed/load profile
Different cluster points amongst variants
DRIVING STYLE/CONDITIONS

Differences due to driving style (exemplary):
- Fuel Economy: *Factor 1.4*
- NOx Emissions: *Factor 4.7*

<table>
<thead>
<tr>
<th>RDE</th>
<th>NEDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual profile which must meet certain legal requirements</td>
<td>Compulsory velocity profile</td>
</tr>
<tr>
<td>Changing real road conditions</td>
<td>Chassis Dyno</td>
</tr>
<tr>
<td>Changing driver/behavior</td>
<td>Tight tolerances</td>
</tr>
<tr>
<td>Changing ambient conditions</td>
<td>Defined ambient conditions</td>
</tr>
<tr>
<td>RDE in worst case can require entire operational range of an engine</td>
<td>NEDC cycle can easily be represented by cluster points with local models</td>
</tr>
</tbody>
</table>
GLOBAL ENGINE MODELING

LESS POINTS

LESS IN-VEHICLE ADAPTIONS

Comprehensive and Efficient Engine Identification

Simple and Fast Variant Calibration
CAMEO
RDE OPTIMIZATION IN 4 STEPS

Easy Test Generation
- Automatic clustering of cycle data
- Easy generation of test points

Online Test Adaption
- Smooth constraints during optimization
- Maps ready to be used

One-Click Modeling
- Auto-adaption of test points for best model quality
- No additional iterations needed

Cycle Optimization
- Automatic generation of models direct from raw data.
- No expert knowledge needed
- Expert interaction still possible

Smooth Optimization
- Smoothing constraints during optimization
- Maps ready to be used
Simulation (Virtual Calibration)
EVOLUTION OF MODEL-BASED CALIBRATION TOWARDS VIRTUAL CALIBRATION

AREA OF OPTIMIZATION

NUMBER OF VARIATION PARAMETERS

Models
Neural Network
Polynomial Model
Semi-Physical
Experimental Designs

Real Driving
Global
Local

EU2 / EU3
EU3 / EU4
EU4 / EU5
EU6 / RDE

Best Point
FF
AVL connects multiple methods and tools to a beneficial one-stop solution.
FLEXIBILITY ENABLES EFFICIENCY

Virtual Testbed (closed loop)

- Calibration
- Environment
- Testbed
- Vehicle Validation
- Production Tolerances
- Aging effects
- Transient Profiles
- ECU
- Actuators
- Sensors

FLEXIBILITY ENABLES EFFICIENCY

production tolerances aging effects
AVL VIRTUAL TEST FIELD
WORKFLOW
THE MODEL PARAMETRIZATION

Model Parametrization

INPUT DATA
Engine Maps & Cold/Hot NEDC

Validation
WORKFLOW
THE MODEL PARAMETRIZATION

Validation

Model Parametrization

AVAILABLE AND FEW MORE MEASUREMENTS

HIGH ACCURACY WITH DYNAMIC CAPABILITY

Torque [Nm]

0
50
100
150
200

Speed [rpm]

500
1000
1500
2000
2500
3000

Measurement
Simulation

EUDC

UDC 1

EUDC

NOx [mg/km]

CO2 [g/km]

model 173.91 165.6
measurement 163.08 161.3
deviation 6.23 % 2.6 %

Torque [Nm]0
50
100
150
200

Speed [rpm]

500
1100
1700
2300
2900
3500

Measurement
Simulation

EUDC

UDC 1

EUDC

NOx [g/h]

CO2 [kg/h]

model 308.54 183.23
measurement 294.66 178.65
deviation 4.5 % 2.5 %

AVAILABLE AND FEW MORE MEASUREMENTS

HIGH ACCURACY WITH DYNAMIC CAPABILITY
RESULTS - NEDC

Vehicle Measurement and Virtual Test Bed comparison on NEDC:

![Graph showing measurements and simulations for NEDC with torque, speed, NOx, CO2, and temperature data.](image)

- **Torque [Nm]**: 0, 50, 100, 150, 200
- **Speed [rpm]**: 500, 1100, 1700, 2300, 2900
- **Measurement** vs **Simulation**
- **EUDC** and **UDC 1**

<table>
<thead>
<tr>
<th></th>
<th>NOx [mg/km]</th>
<th>CO2 [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>model</strong></td>
<td>173.91</td>
<td>165.6</td>
</tr>
<tr>
<td><strong>measurement</strong></td>
<td>163.08</td>
<td>161.3</td>
</tr>
<tr>
<td><strong>deviation</strong></td>
<td>6.23 %</td>
<td>2.6 %</td>
</tr>
</tbody>
</table>
RESULTS - ARTEMIS

Vehicle Measurement and Virtual Test Bed comparison on ARTEMIS:

<table>
<thead>
<tr>
<th>Speed [rpm]</th>
<th>Torque [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>50</td>
</tr>
<tr>
<td>1500</td>
<td>100</td>
</tr>
<tr>
<td>2000</td>
<td>150</td>
</tr>
<tr>
<td>2500</td>
<td>200</td>
</tr>
<tr>
<td>3000</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>NOx [mg/km]</th>
<th>CO2 [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>308.54</td>
</tr>
<tr>
<td>Measurement</td>
<td>294.66</td>
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<tr>
<td>Deviation</td>
<td>4.5%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Temp. Us TC [°C]</th>
<th>CO2 [kg/h]</th>
<th>NOx [g/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>300</td>
<td>20</td>
<td>20</td>
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<tr>
<td>400</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>500</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>600</td>
<td>50</td>
<td>50</td>
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</table>

<table>
<thead>
<tr>
<th>CO2 [g/km]</th>
<th>NOx [mg/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>183.23</td>
</tr>
<tr>
<td>Measurement</td>
<td>178.65</td>
</tr>
<tr>
<td>Deviation</td>
<td>2.5%</td>
</tr>
</tbody>
</table>
RESULTS - NEDC

Vehicle Measurement and Virtual Test Bed comparison on NEDC:

- Base Calibration Cold Test
- Base Calibration Hot Test
- NOx Optimized Calibration Hot Test

**NEDC NOx EO**

- Cold: Vehicle 10%, Virtual TB 90%
- Hot: Vehicle 9%, Virtual TB 114%
- Hot - NOx Optimized: Vehicle 65%, Virtual TB 62%

**NEDC CO2 EO**

- Cold: Vehicle 100%, Virtual TB 91%
- Hot: Vehicle 104%, Virtual TB 97%
- Hot - NOx Optimized: Vehicle 91%, Virtual TB 91%
RESULTS - NEDC

Vehicle Measurement and Virtual Test Bed comparison on NEDC:

Base Calibration
Cold Test

Base Calibration
Hot Test

NOx Optimized
Calibration Hot Test

NEDC NOx EO

Vehicle Virtual TB

MAX 10% DEVIATION

NEDC CO2 EO

Vehicle Virtual TB

COLD HOT HOT - NOX OPTIMIZED

0% 20% 40% 60% 80% 100% 120% 140%

0% 20% 40% 60% 80% 100% 120% 140%

0% 20% 40% 60% 80% 100%
Vehicle Measurement and Virtual Test Bed comparison on **WLTC**:  

<table>
<thead>
<tr>
<th>NOx Optimized Calibration Cold Test</th>
<th>Base Calibration Hot Test</th>
<th>NOx Optimized Calibration Hot Test</th>
<th>NOx Optimized Calibration Step 2 Hot Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WLTC NOx EO</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COLD - NOX OPTIMIZED</td>
<td>HOT</td>
<td>HOT - NOX OPTIMIZED</td>
<td>HOT - NOX OPTIMIZED STEP 2</td>
</tr>
<tr>
<td>NOx EO (%)</td>
<td>Deviation (%)</td>
<td>NOx EO (%)</td>
<td>Deviation (%)</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Virtual TB</td>
<td>Vehicle</td>
<td>Virtual TB</td>
</tr>
<tr>
<td>100%</td>
<td>144%</td>
<td>111%</td>
<td>90%</td>
</tr>
<tr>
<td>100%</td>
<td>134%</td>
<td>106%</td>
<td>89%</td>
</tr>
<tr>
<td>7%</td>
<td>5%</td>
<td>1%</td>
<td>0%</td>
</tr>
</tbody>
</table>

| **WLTC CO2 EO**                     |                           |                                   |                                          |
| COLD - NOX OPTIMIZED               | HOT                       | HOT - NOX OPTIMIZED               | HOT - NOX OPTIMIZED STEP 2 |
| CO2 EO (%)                         | Deviation (%)             | CO2 EO (%)                        | Deviation (%)                 |
| Vehicle                            | Virtual TB                | Vehicle                           | Virtual TB                        |
| 100%                               | 103%                      | 101%                              | 97%                         |
| 100%                               | 102%                      | 96%                               | 97%                         |
| 3%                                 | 1%                        | 2%                                | 0%                          |
Vehicle Measurement and Virtual Test Bed comparison on **WLTC**:

<table>
<thead>
<tr>
<th>Comparison</th>
<th>NOx Optimized Calibration Cold Test</th>
<th>Base Calibration Hot Test</th>
<th>NOx Optimized Calibration Hot Test</th>
<th>NOx Optimized Calibration Step 2 Hot Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation (%), WLTC NOx EO</td>
<td>0%</td>
<td>1%</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>CO2 EO (%)</td>
<td>0%</td>
<td>1%</td>
<td>3%</td>
<td>2%</td>
</tr>
</tbody>
</table>

**DEVIATION < 10% DYNAMIC!!!**
ENGINE PROTECTION AND AMBIENT CORRECTIONS ON A VIRTUAL TESTBED

**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: 220 hours

80% Test Bed Time saved!

**Cal. Quality**

- **G5** – Validated
- **G4** – Robust
- **G3** – Test Bed Target Achievement
- **G2** – Emission Targets Achieved
- **G1** – Engine Runnable
- **G0** – Engine Startable

**Model Based Calibration Approach:**

- 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

Additional effort for model set-up and parameterization has to be considered.
THE AVL VIRTUAL TESTBED
BASED ON MOBEO-CRUISE M MODELING

- Fully Transient Capable
- Test Repeatability
- Open to any kind of test at any environment condition
- Flexible to be adapted for variant calibration
CONCLUSIONS AND SUMMARY

- Being „RDE Ready“ is truly a Challenge!
- We take care …