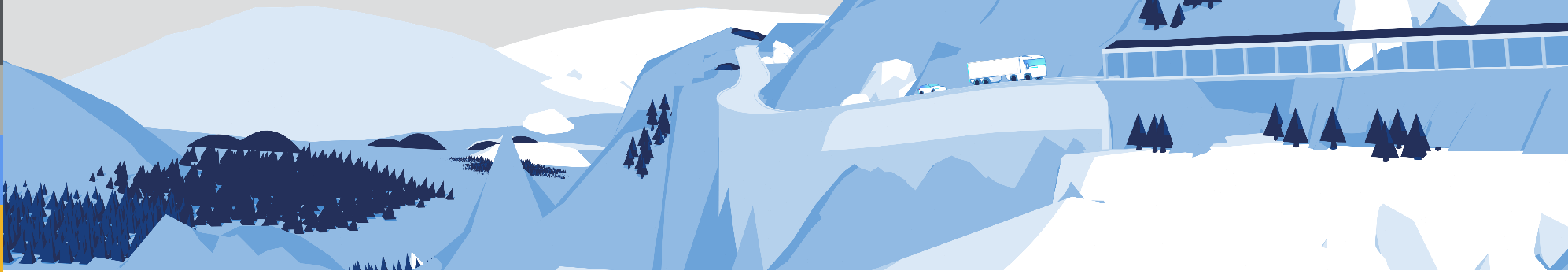
Cleaner IC Engines for Sustainable Environment with Innovative Emission Control Technologies (ECT 2019)



HORIBA RDE+ Application: Whole Vehicle RDE Compliance Solution

Pune, India - 15th November 2019

steve.whelan@horiba-mira.com

A HORIBA COMPANY MIRA

Presentation Outline

- Introduction
- Methodology
  - Road Testing
  - Chassis Dynamometer
    - Vehicle load replication (complex method)
    - "Torque Matching" (new unique HORIBA simplified method)
  - Engine-in the-Loop
  - Virtual Tools
- Conclusions

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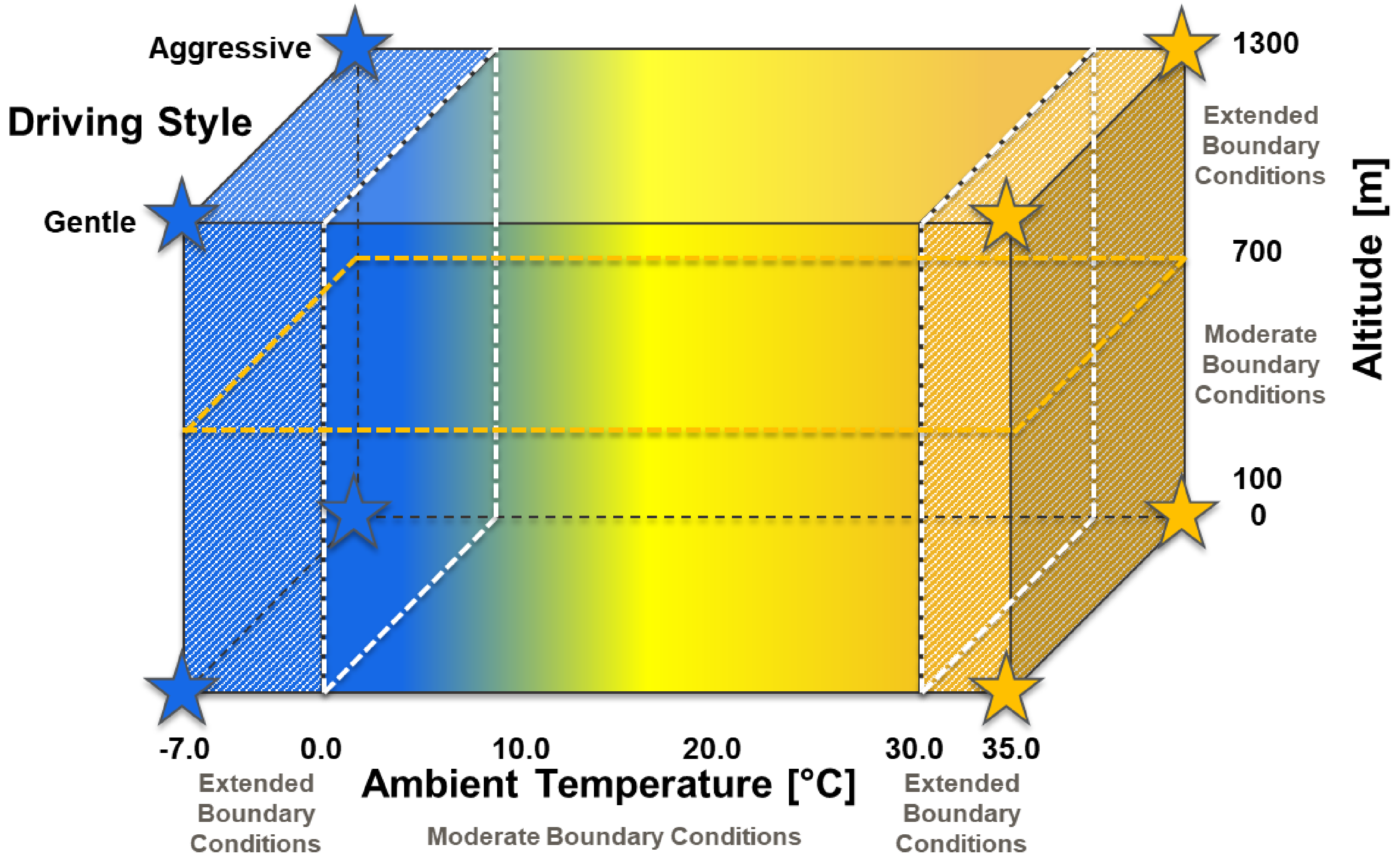
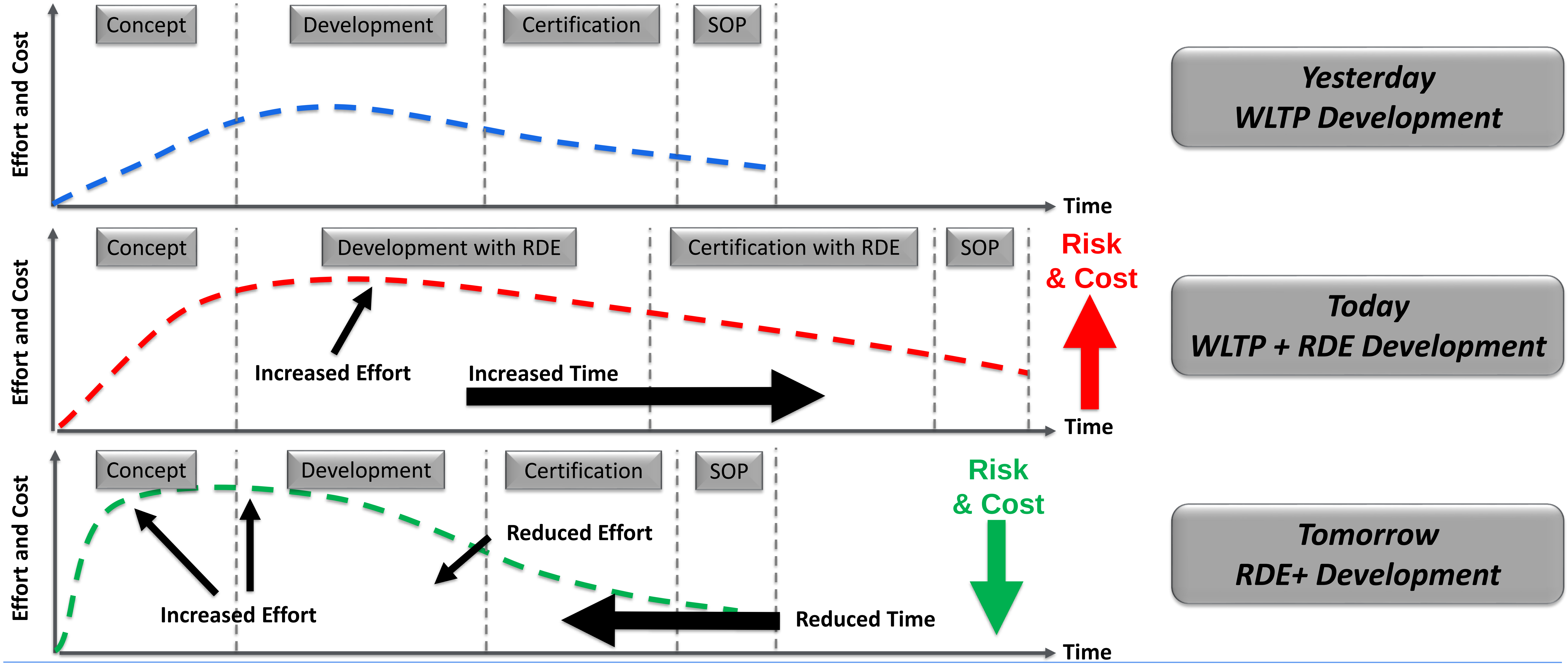
Introduction
Regulatory Standards

- To regulate light-duty vehicle emissions, the WLTP and WLTC was implemented throughout Europe in late 2017, replacing the NEDC.
- This was joined by the supplementary on-road procedure called RDE utilising PEMS.
- RDE regulations cover altitude, temperature and driving style as well as numerous other parameters.



Introduction

What can be done to reduce Time, Cost and Risk?



Introduction
RDE+ Application Portfolio

RDE + Product Portfolio Architecture

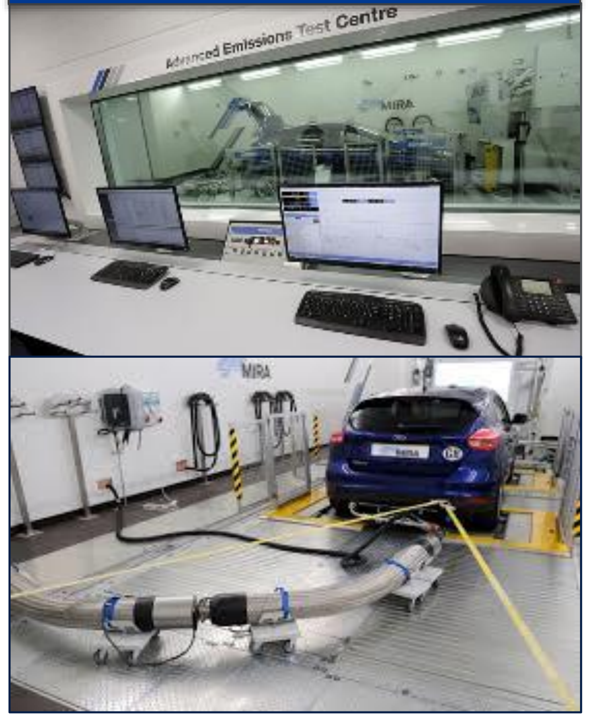
STARS Enterprise

Level 1 Road

RDE Road Test

Level 2 Chassis

RDE Chassis Test



Hardware

Software

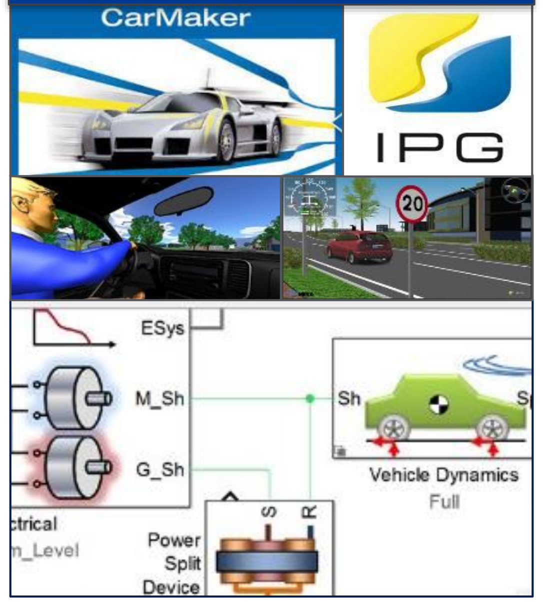
Service

Level 3 Engine

RDE Engine/PT Test

Level 4 VTs

RDE Virtual Tools & HiL



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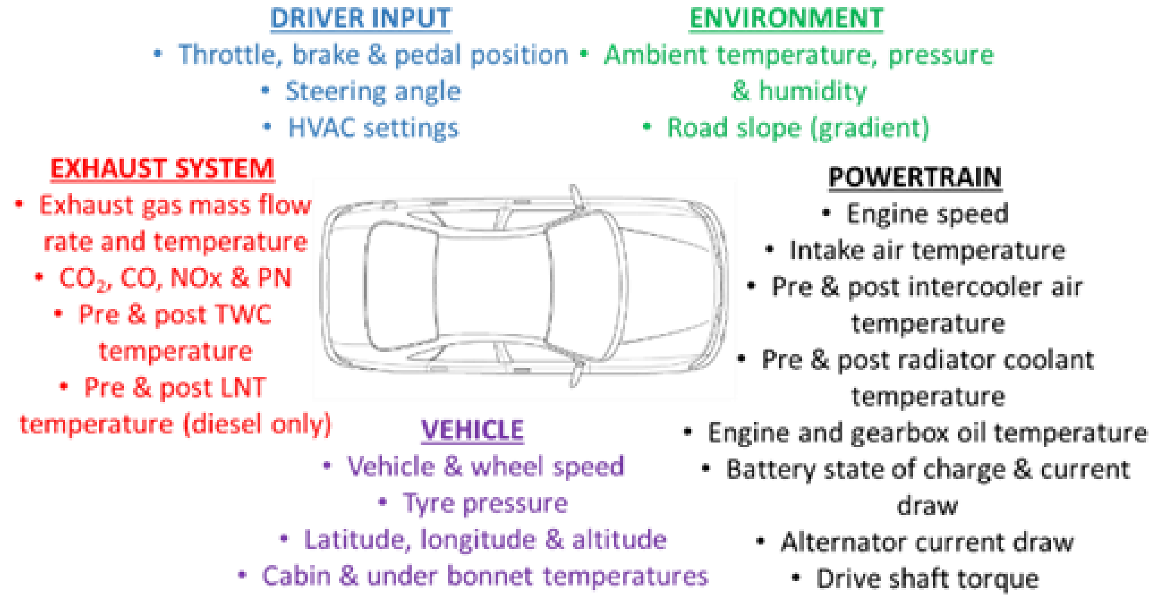
Methodology – Road Testing

Vehicles and Instrumentation

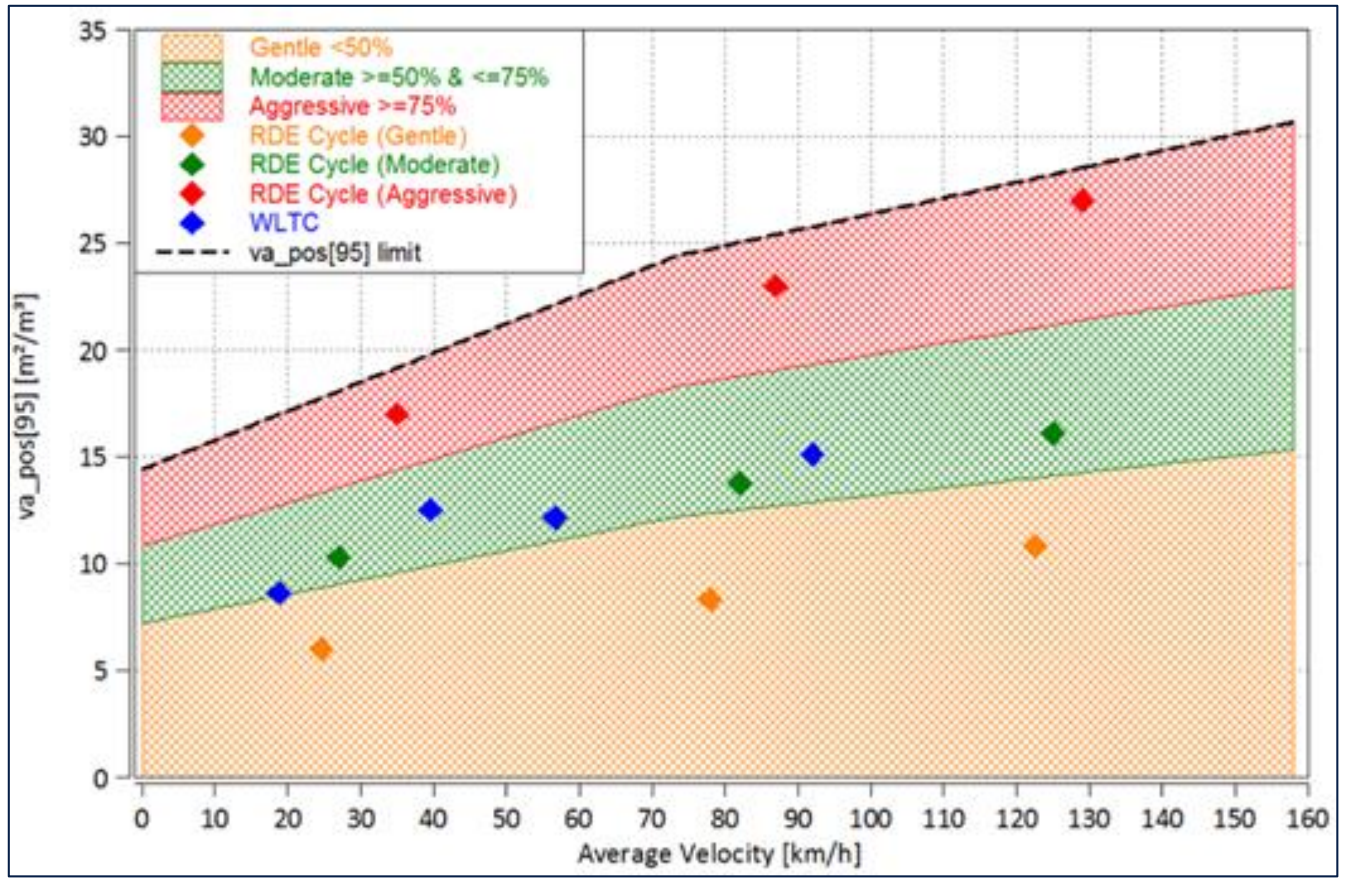
Euro Vehicle Segment	B (2016)	C (2015)	M (2017)
Body Type	5 Door Hatchback		5 Door MPV
Engine (Power)	Gasoline, 3 Cyl, 998cc, Turbocharged (74kW)	Diesel, 4 Cyl, 1499cc, Turbocharged (88kW)	Diesel, 4 Cyl, 1461cc, Turbocharged, 48v Hybrid (81kW)
Transmission	Manual 5 Spd	Manual 6 Spd	
EU Emission Standard	EURO 6b		
Aftertreatment	TWC	EGR + DOC/DPF/LNT	EGR + DOC/DPF/LNT
Mass in Service [kg]	1130	1399	1583
PEMS	HORIBA OBS ONE GS12 Gas Analyser & Particle Number Unit		
Amb. Temp. Rel. Humidity	HORIBA OBS ONE Weather Station		
Altitude [m]	HORIBA OBS ONE GPS		
Base Instrumentation	National Instruments CompactDAQ System: NI 9185/9862/9214/9205		
Driveshaft Strain Gauges	Astech Electonics Rotary Telemetry System (RE3D)		



Methodology – Road Testing

Routes and Parameters

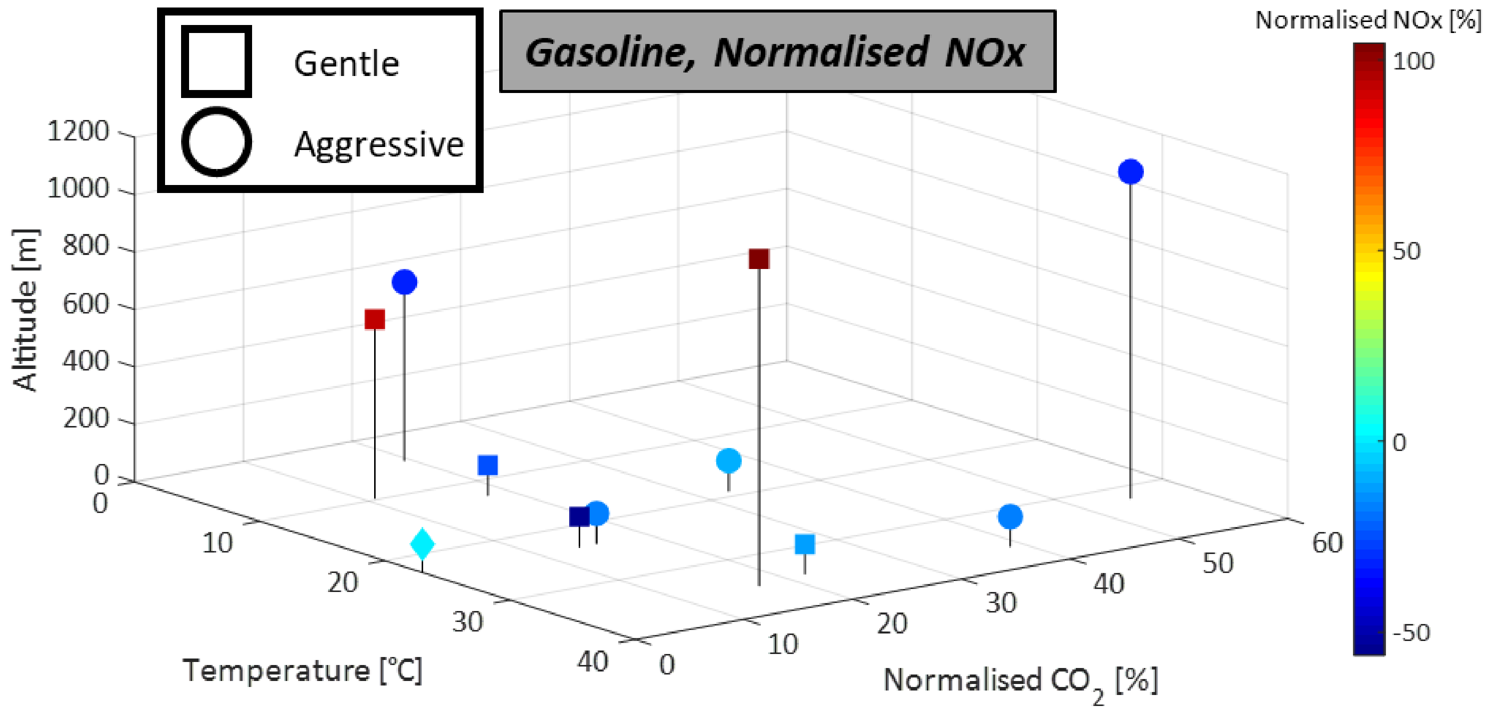
RDE Testing Phase	Location	Target Temperature [°C]	Average Altitude [m]	Total/Urban Cumulative Positive Elevation (CPE) [m/100km]	Distance Split [%] (Urban/Rural/MWay)
1	Innsbruck, Austria	-7-0	623.2	498.1/579	32.5/31.2/36.3
2 3	Nuneaton, UK	0-10 10-20	105.1	491.0/611.6	37.0/33.8/29.2
4	Vera, Spain	30-35	103.9	837.1/950.4	39.0/30.4/30.6
5	Avila, Spain	30-35	1137.9	953.1/1022.4	33.3/30.3/36.4

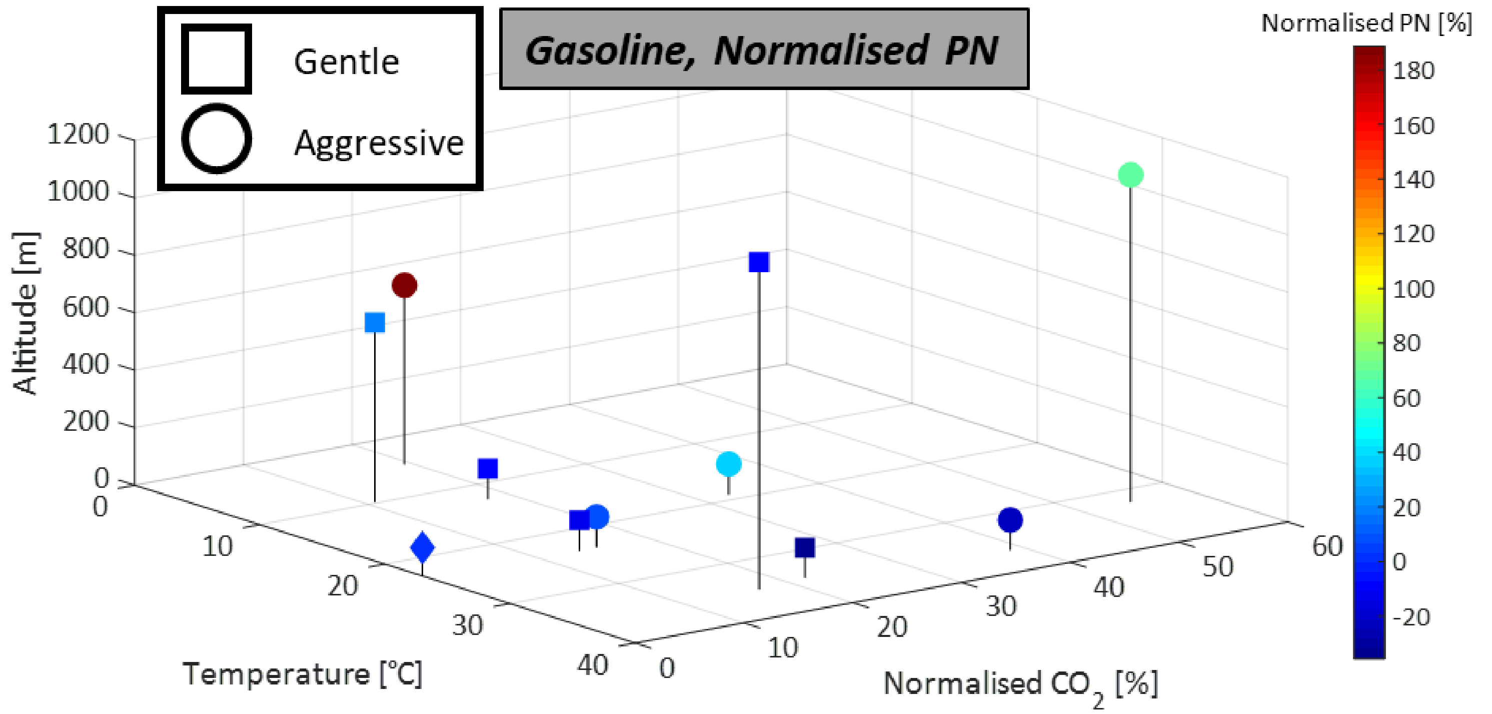


- Driver "aggressivity" characterised by RDE regulation parameter va_pos[95] as a percentage of its limit:
  - Gentle < 50%
  - Moderate ≥ 50% ≤ 70%
  - Aggressive > 70%

Methodology – Road Testing
Emissions Results Overview

- All RDE emissions data is normalised to corresponding WLTC emissions data (diamond icon); expressed as the ratio of RDE to WLTC emissions minus one.
- Significant variations in NOx and PN over full range of RDE conditions.
- CO_2 trend as expected – more aggressive driving, more work done.
- Typical results for the gasoline vehicle are shown.
- More details of the road testing and associated results is reported in SAE Technical Paper 2019-01-0756.





NOx is typically higher for gentle drives compared to aggressive drives on the same route (opposite trend for PN)

Possibly caused by “light-out” of the TWC during gentle drives?

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Methodology – Chassis Dynamometer Testing
Chassis Dynamometer Specification and Equipment

	Equipment
Analyser Room	HORIBA Supplied: DLT and DLS dilution tunnel and sampler CVS-ONE constant volume sampler MEXA ONE D2 EGR raw exhaust gas sampler MEXA ONE C1 SL OV dilute exhaust gas (bag) analyser MEXA 2000 SPCS solid particle counter MEXA ONE QL NX Quantum cascade laser system GMC ONE particulate measurement PFS ONE robotised particulate filter weighing system OBS ONE PEMS kit (gaseous and particle)
Test Cell	FWD, RWD, AWD -20°C to 35°C (plus 3 climatic soak chambers) 30-60% relative humidity Vehicle cooling fan
Dynamometer Data	230kW per axle 300km/h maximum speed

Methodology – Chassis Dynamometer Testing
Chassis Dynamometer Specification and Equipment

1.) Engine feed
2.) Reference pressure for breather system feed
3.) Reference pressure for breather system return
4.) MEDAS return from exhaust system

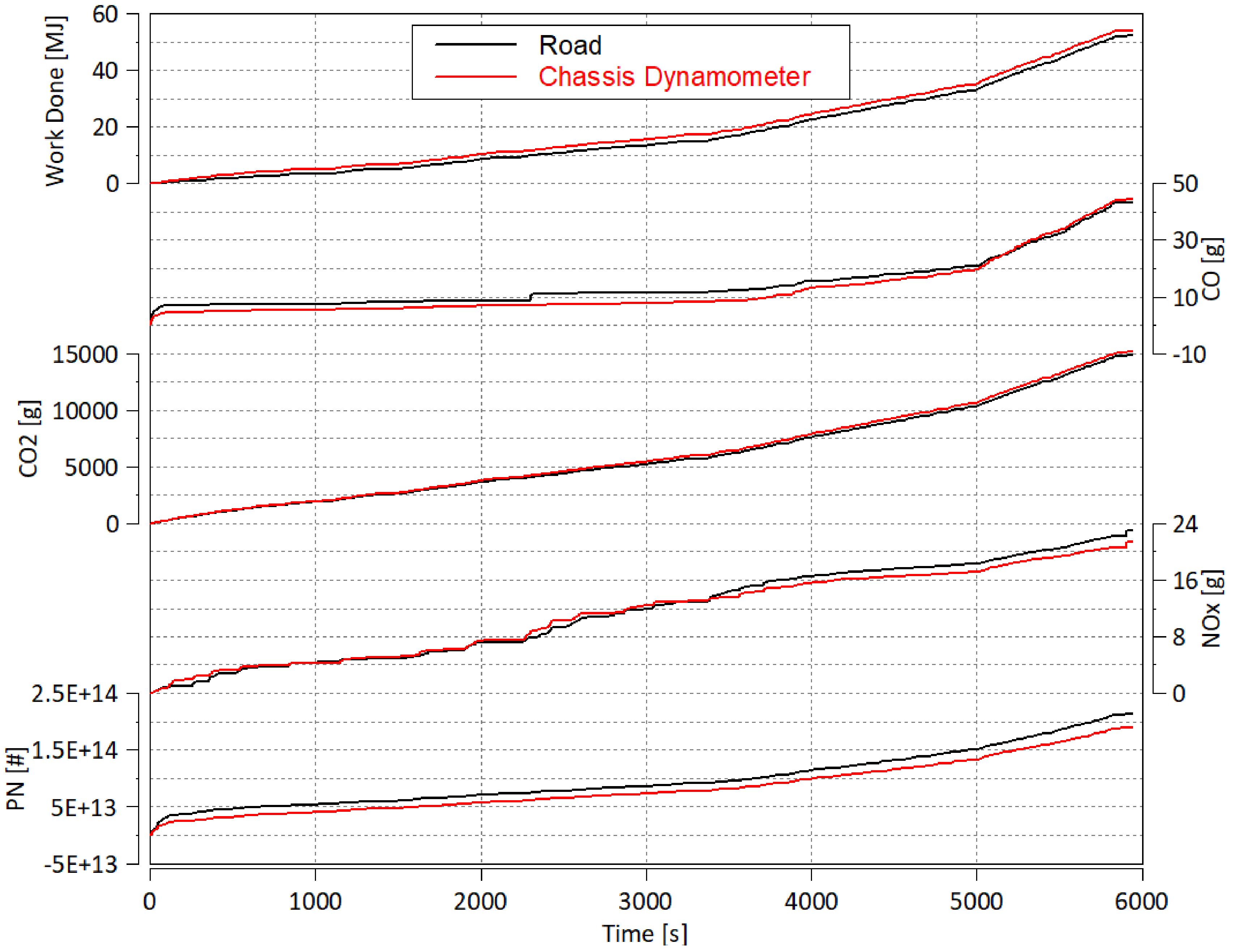
HORIBA Multi-Function Efficient Dynamic Altitude Simulation (MEDAS) unit will be used for altitude and ambient temperature requirements for RDE+

Methodology – Vehicle Load Replication

Highly instrumented vehicle to measure loads

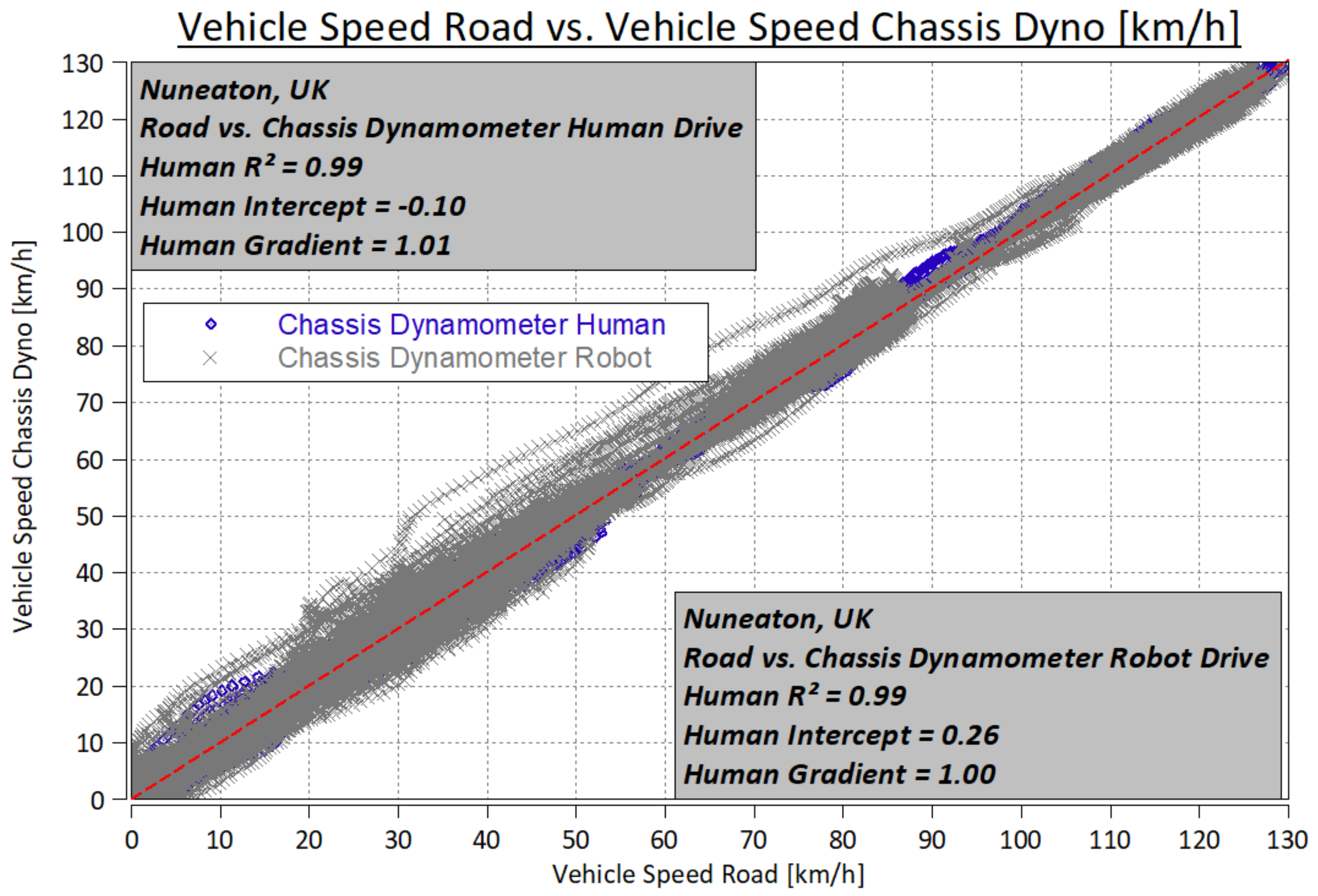
- To accelerate the R2R RDE+ methodology, the chassis dynamometer testing focused on the gasoline vehicle: simple aftertreatment, sea-level driving route (Nuneaton, UK).
- **Vehicle load measured directly via strain gauges on drive shafts**
- **"Effective road gradient" derived by subtracting coastdown terms and inertia from the measured road data – programmed into chassis dynamometer with vehicle speed and gear selection**.
- Human driver used throughout initial RDE chassis dynamometer drive.

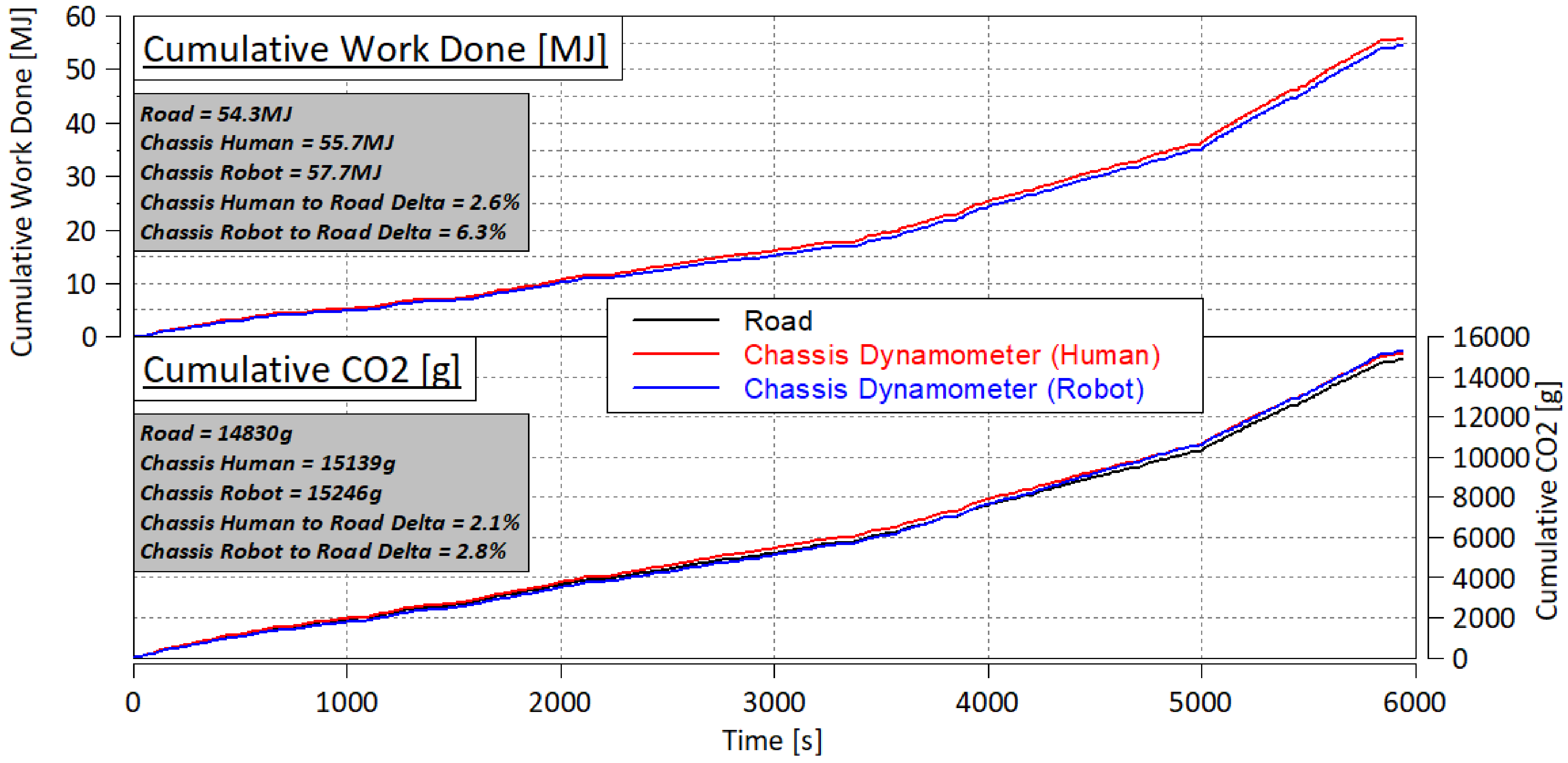
	Work [MJ]	CO [g]	CO_2 [g]	NOx [g]	PN [#]
Road	52.1	43.1	14830	22.97	2.13E+14
Chassis	54.1	44.3	15139	21.30	1.90E+14
Delta [%]	3.8	2.8	2.1	-7.3	-10.8



Methodology – Vehicle Load Replication
Human Driver vs. Robot Driver (1)

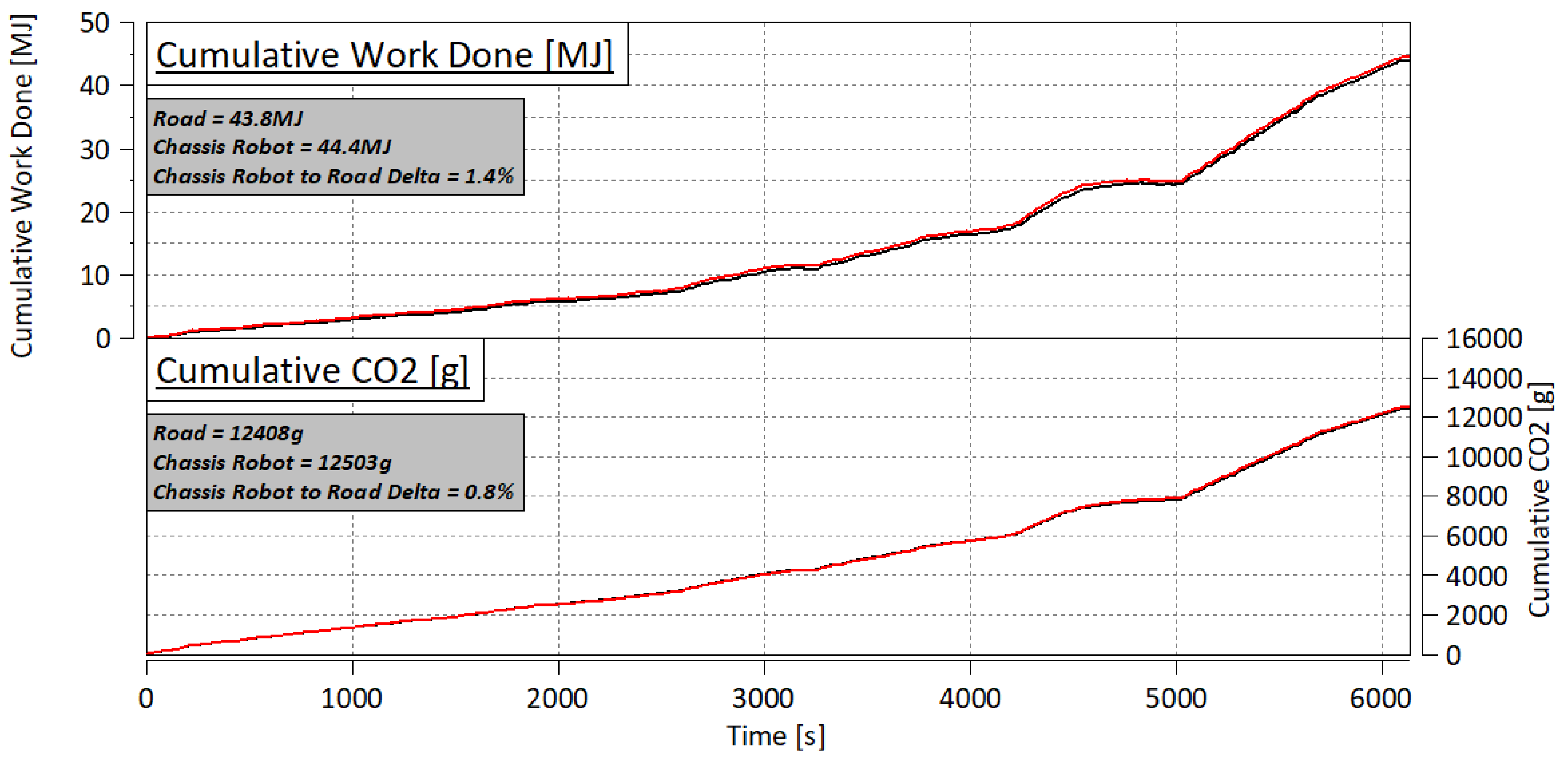
- To improve repeatability and durability of the ~90 minute RDE cycle replication, a robot driver has been used for further testing. The robot has been trained to follow the cycle, change gear and brake.
- The robot was more accurate, repeatable and durable.
- Overall, a very good correlation was made with the human driver.



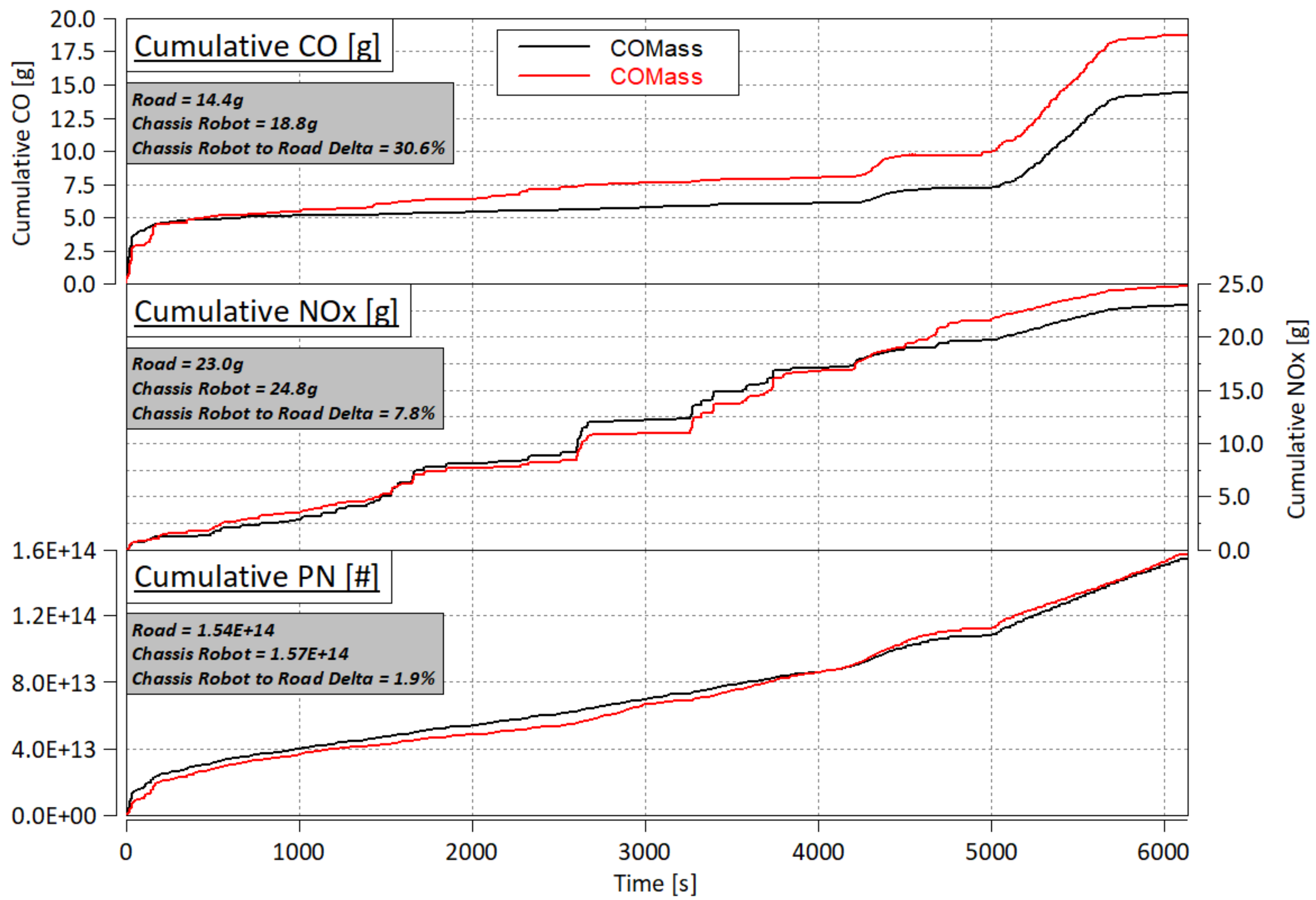


Methodology – Vehicle Load Replication

High Altitude Route, Robot Driver, Initial Results (1)



- Replication of high altitude (Innsbruck, Austria) route using HORIBA MEDAS system & robot driver.
- Excellent correlation achieved with measured RDE route data.
- Similar level of correlation with sea-level route.



	Work [MJ]	CO [g]	CO_2 [g]	NOx [g]	PN [#]
Road	43.8	14.4	12408	23.0	1.54E+14
Chassis	44.4	18.8	12503	24.8	1.57E+14
Delta [%]	1.4	30.6*	0.8	7.8	1.9

* Issue with PEMS CO analyser

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Replicating Real World Load Can Be Complicated

Traditional Track to Lab Model (Assumption):

$$F(t) = (A + B * v(t) + C * v(t)^2) + M * \frac{dv(t)}{dt}$$

But the real world has variable road grade:

$$F(t) = (A + B * v(t) + C * v(t)^2) + M * \frac{dv(t)}{dt} + M * g * sin\alpha(t)$$

But the real world has variable winds:

$$F(t) = \left(A + B * v_g(t) + C * v_a(t)^2\right) + M * \frac{dv_g(t)}{dt} + M * g * sin\alpha(t)$$

But the real world has variable air densities:

$$F(t) = \left(A + B * v_g(t) + \rho(t)/\rho_0 * C * v_a(t)^2\right) + M * \frac{dv_g(t)}{dt} + M * g * sin\alpha(t)$$

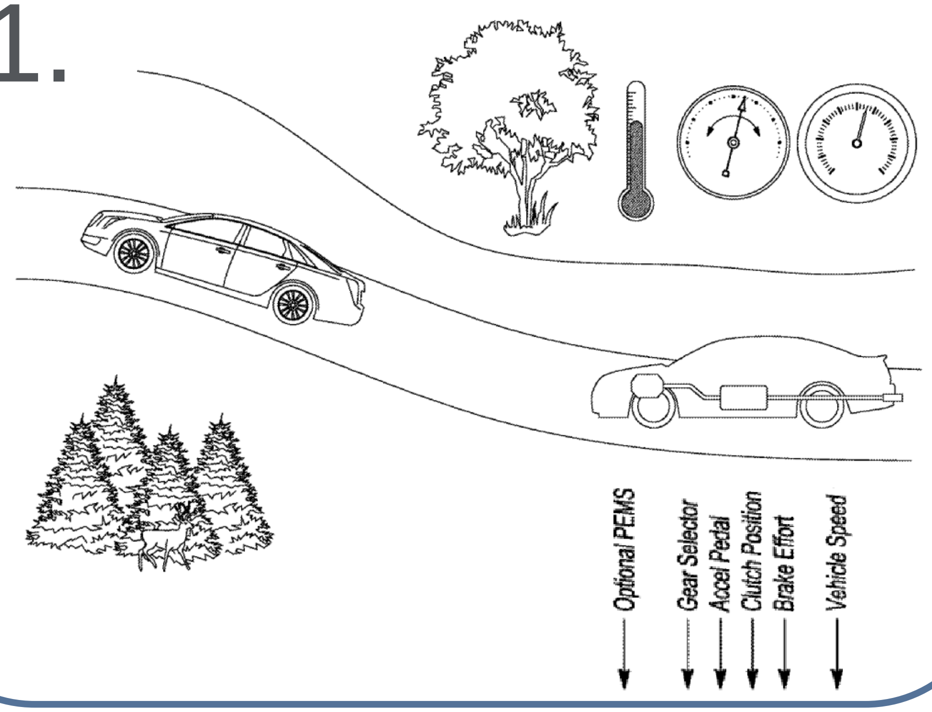
But this road load equation is still an idealization, road surfaces change from block to block, cornering affects load, and road grade is difficult to measure precisely with high resolution:

There must be a better way…

… a better way, HORIBA “Torque Matching”

Forget all the load modeling and abstractions

1.



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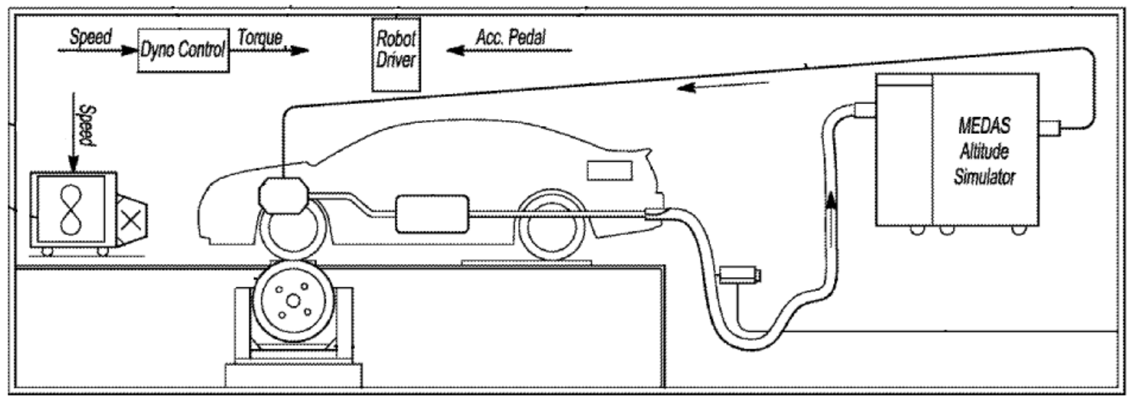
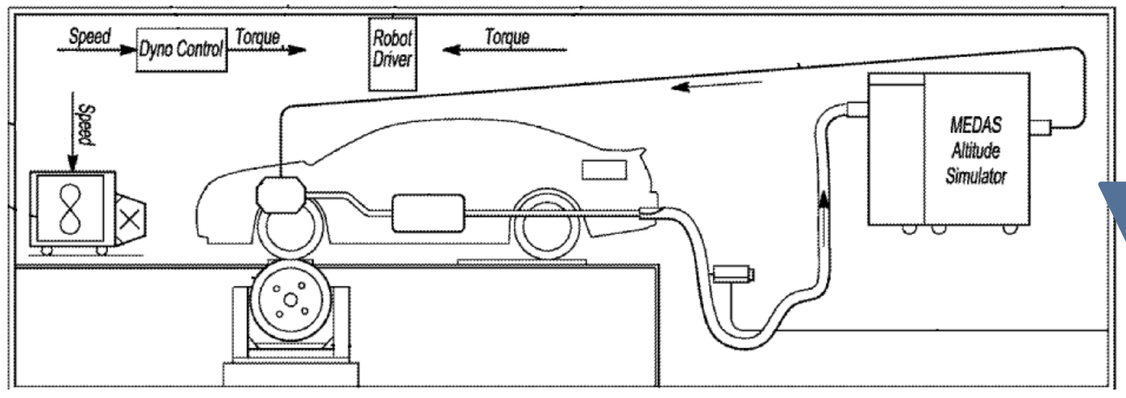


3+…



Road Test

- Record speed, pedal, weather conditions
- Any grade, surface, weather, altitude, and cornering

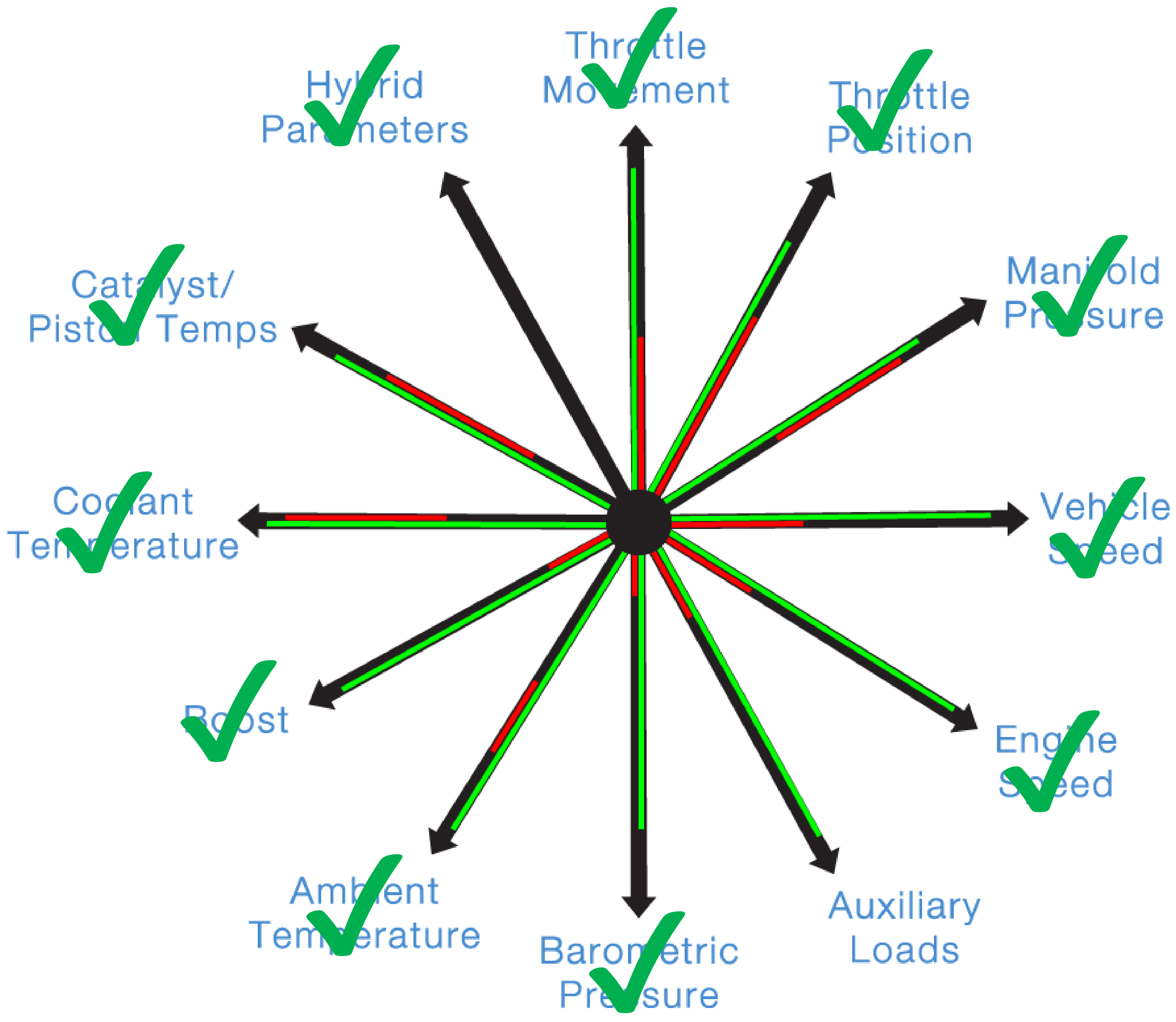
Lab Validation Test (Road Test Replication)

- MEDAS matches ambient
- Dyno matches speed
- Robot driver matches pedal
- Dyno torque recorded

Lab Tests (Road Test Simulations)

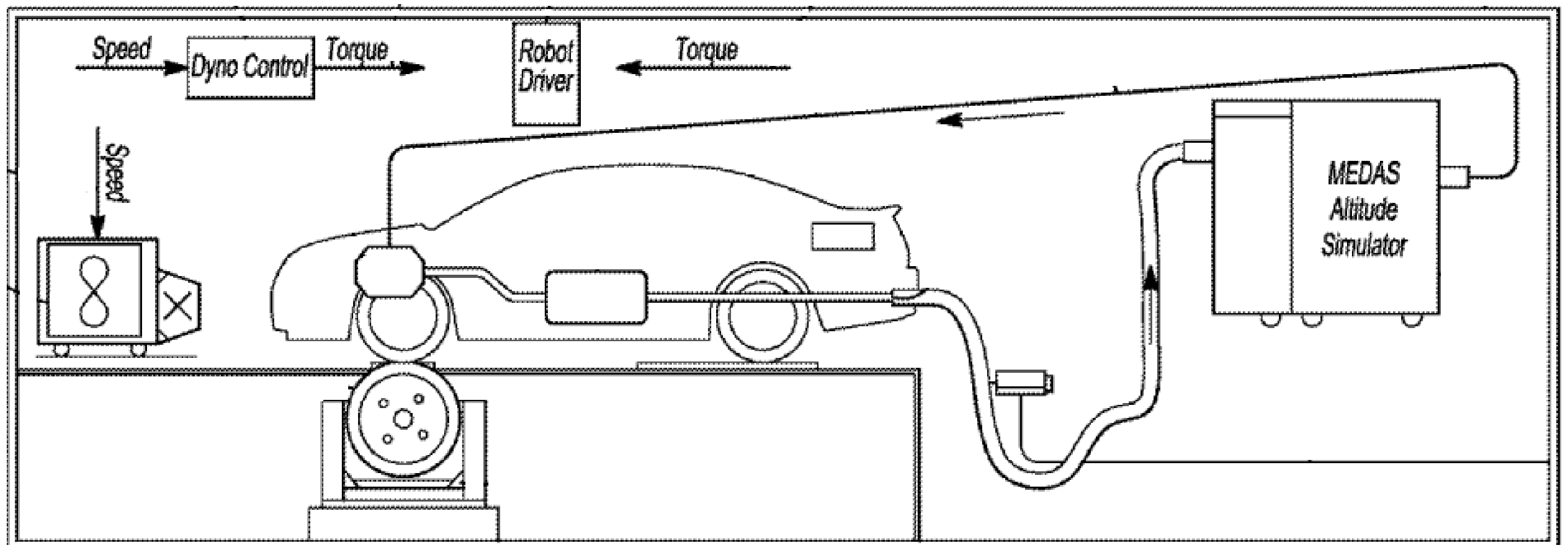
- MEDAS matches ambient
- Dyno matches speed
- Robot driver matches torque
- Change vehicle calibration or emission controls as desired and repeat test

Torque Matching Simulates Real World Load



Powertrain Calibration Space

Torque Matching on a Chassis Dynamometer



- No torque wheels or instrumented drive shafts
- No coastdowns
- No road grade measurement or estimation
- Blind testing is enabled
- Lab testing precision is enabled
- Impact of changes to vehicle or calibration can be assessed with back to back, repeatable testing

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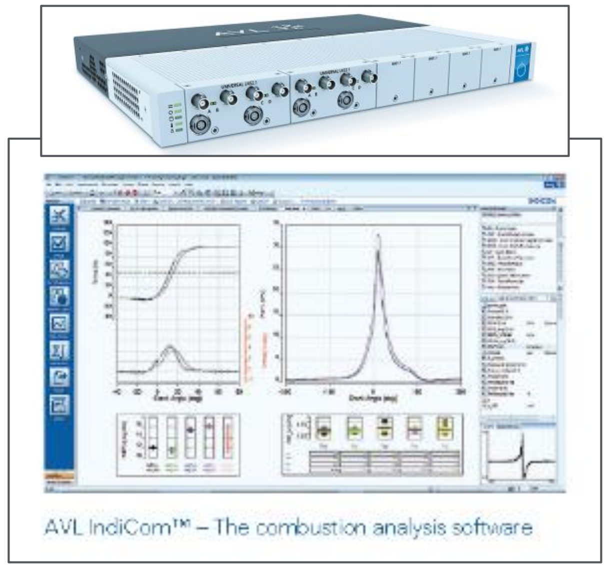
Methodology – Engine-in-the-Loop Equipment

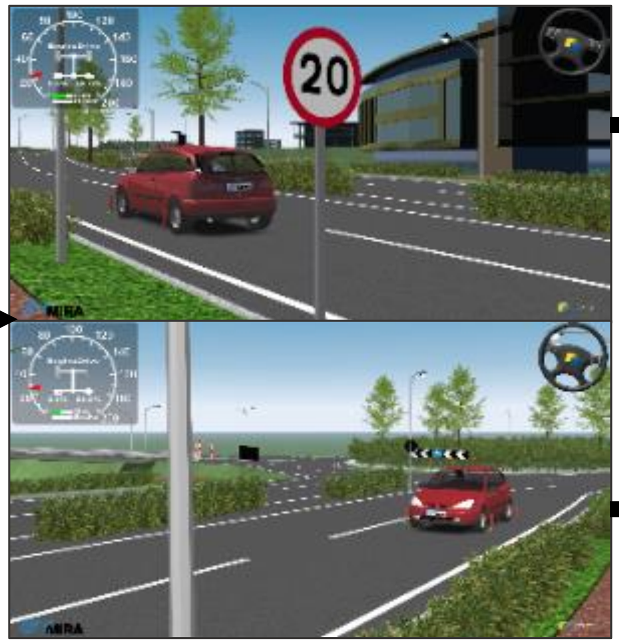
	Equipment
Analysers	MEXA ONE D2 EGR exhaust gas analysis system OBS ONE PEMS GS12 kit (gaseous and particle) MEXA-2100SPCS Real Time Particle Counter MEXA ONE QL NX Quantum cascade laser system
Test Cell	HORIBA DYNASPM LI 470 AC Dyno Hot and cold box (engine containment) -30°C to 50°C HORIBA MEDAS – temperature, pressure and humidity
Misc	AVL Indicom X-Ion high-speed data acquisition ETAS INCA HORIBA STARS SPARC HORIBA STARS Calibrate (pseudo-automapping functionality) IPG CarMaker virtual simulation tool (vehicle and driving style)



Methodology – Engine-in-the-Loop
EiL Setup (1)

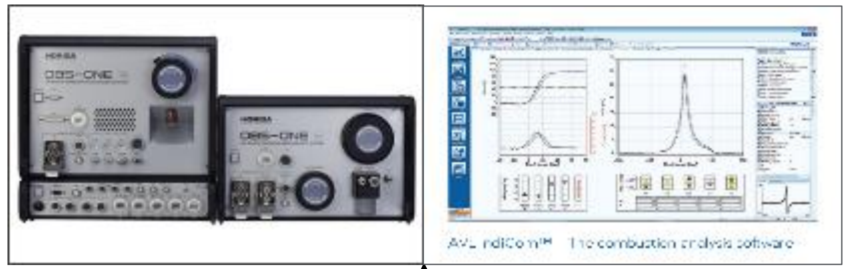
COMPLETE ROAD, ENVIRONMENTAL AND VEHICLE REPLICATION

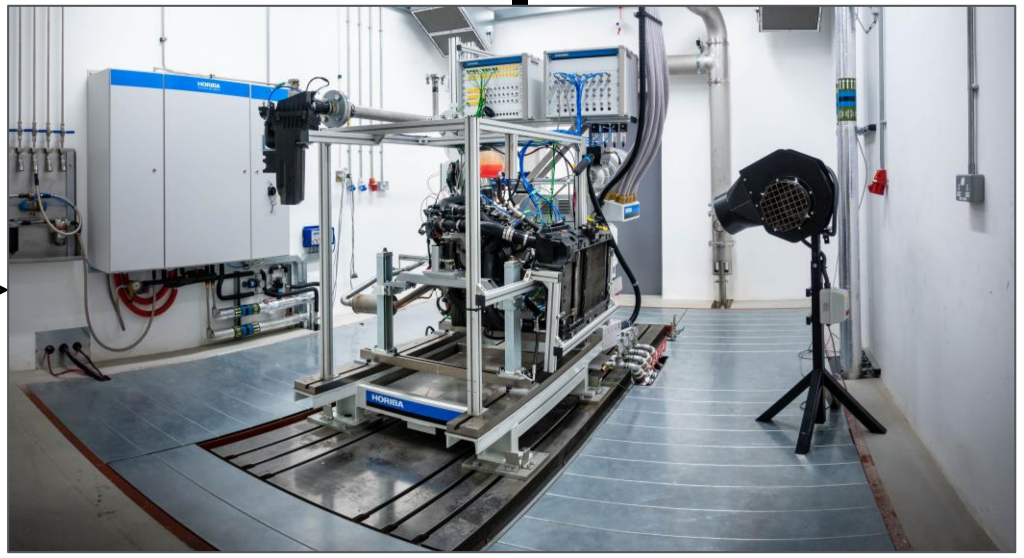
VEHICLE, ROAD, DRIVER & ENVIRONMENTAL DATA

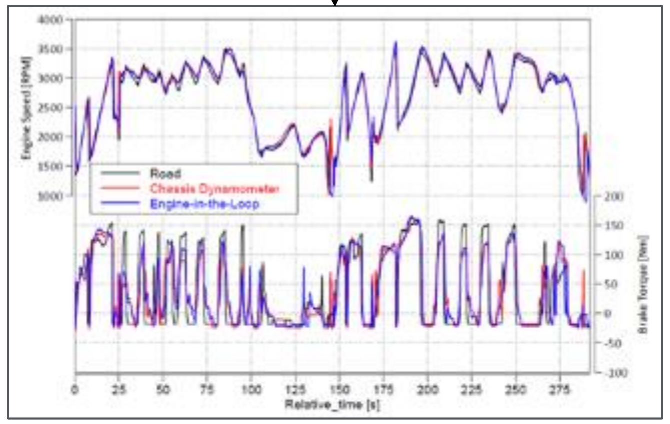


CREATION OF VIRTUAL ENVIRONMENT

ENGINE SPEED AND LOAD/PEDAL CLOSED LOOP CONTROL







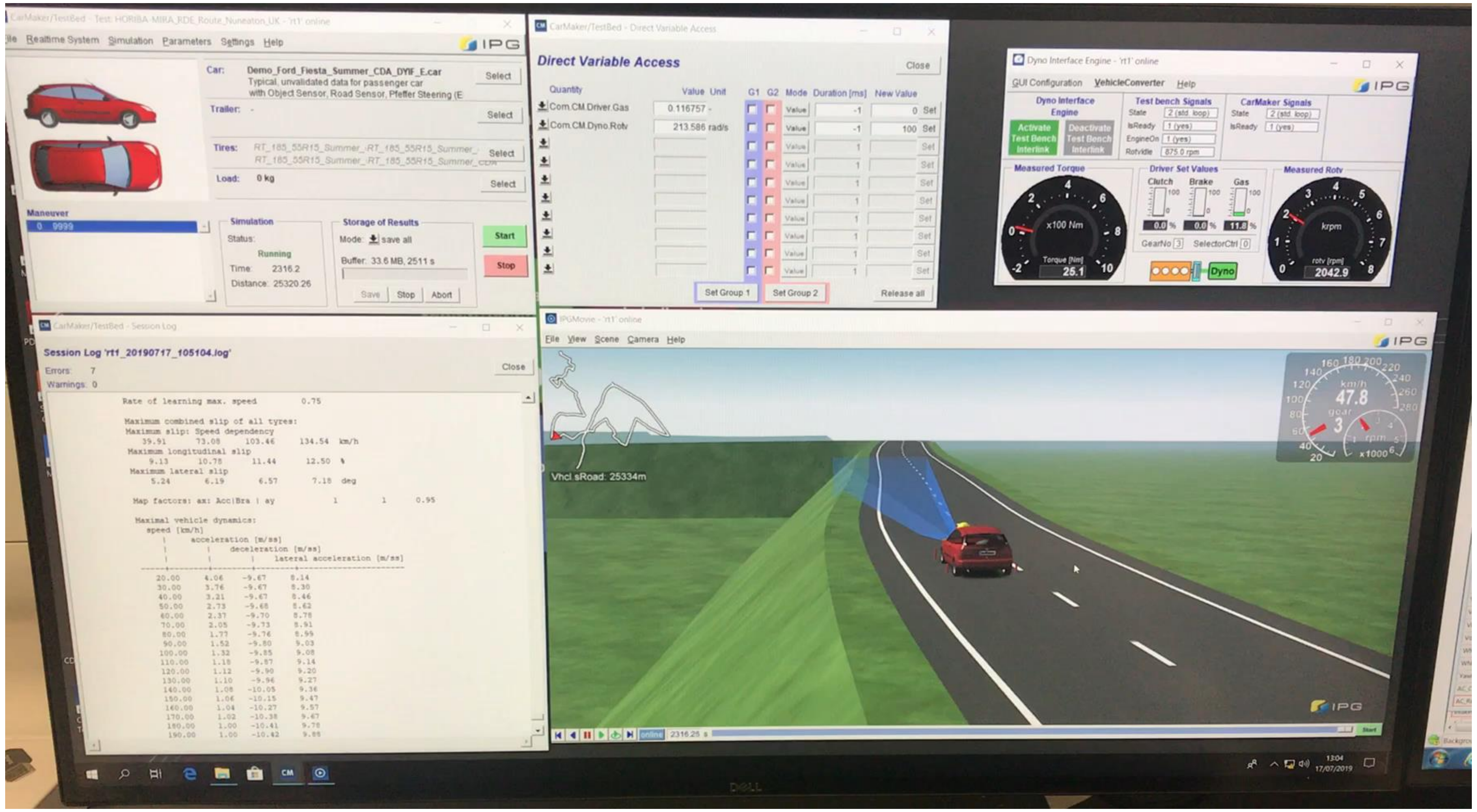
Methodology – Engine-in-the-Loop
EiL Setup (2)

- IPG CarMaker to STARS interface successfully installed – purchased vehicle, no OEM support.
- Currently running through Nuneaton RDE cycle with different driving modes.

Closed-loop load control through IPG CarMaker

Torque Demand

Speed Demand



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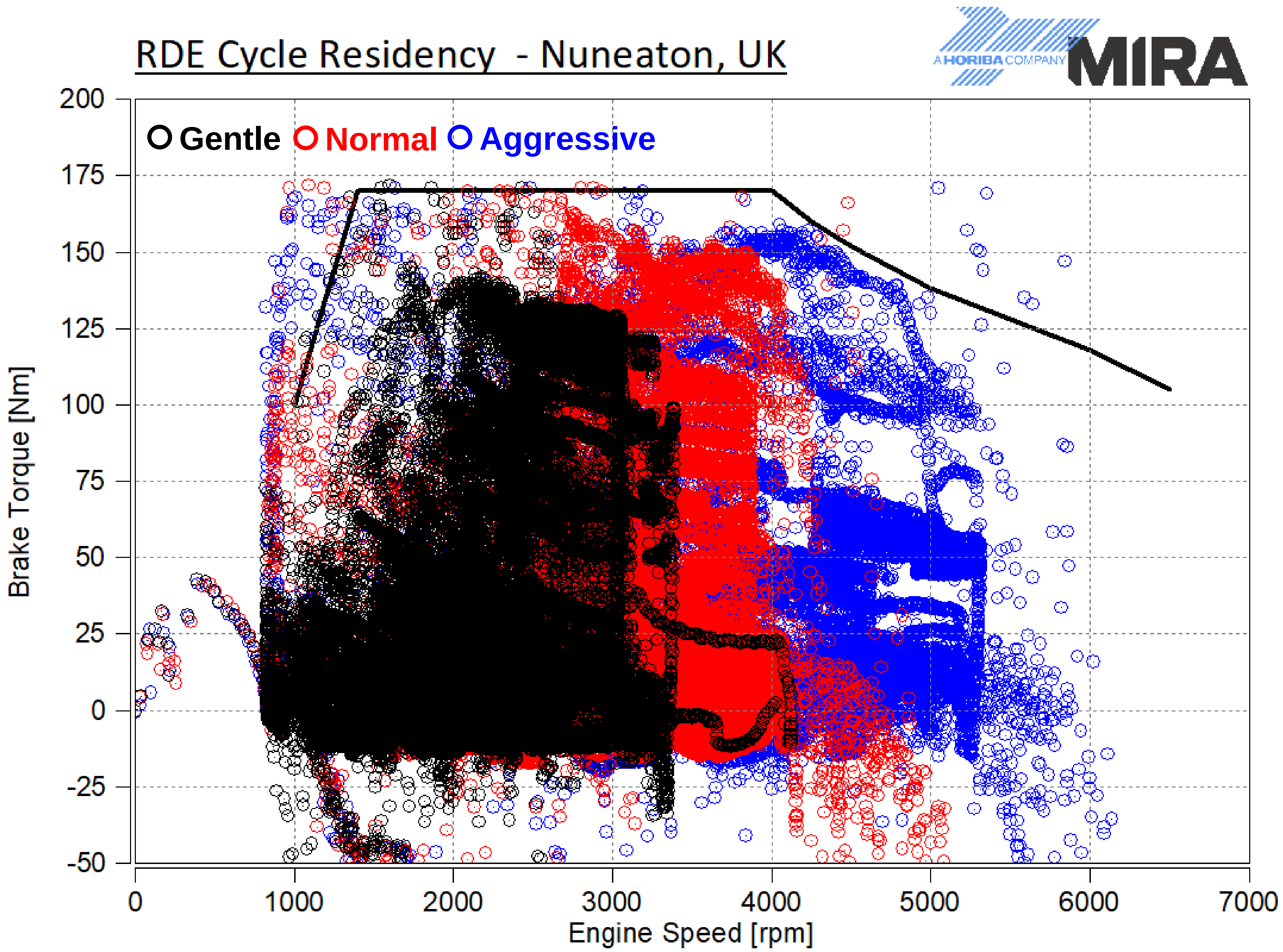
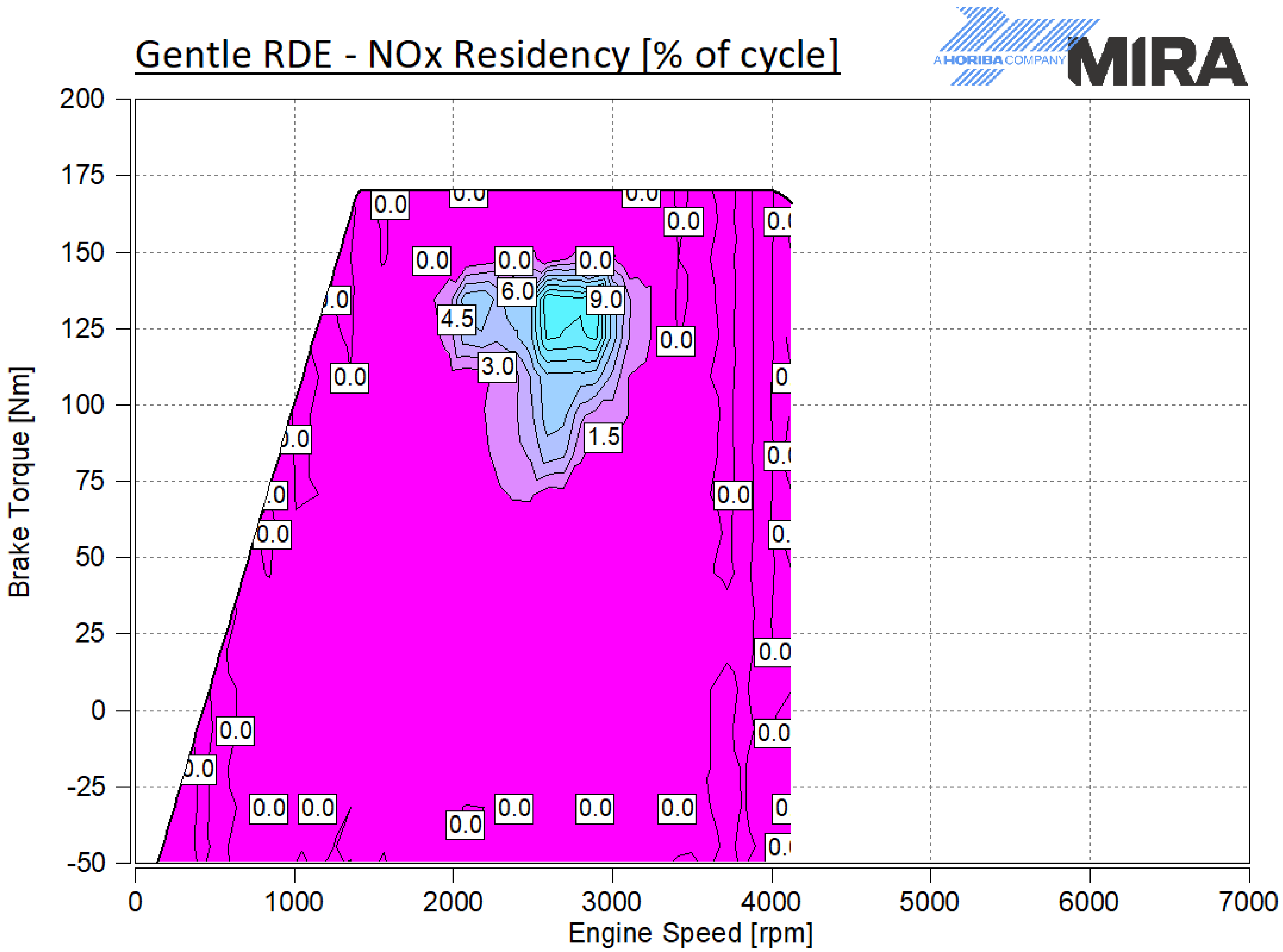
Methodology – Engine-in-the-Loop
Sea Level Route, EiL Initial Results (1)

- Effects of driving style on vehicle and engine performance across Nuneaton, UK RDE route assessed using IPG CarMaker.
- 5 parameter DOE – optimising for va_pos[95] % of limit – HORIBA MIRA definition of driving style.
  - Longitudinal and lateral acceleration
  - Longitudinal deceleration
  - Pedal dynamics
- 3 cycles run across fixed route
  - Gentle drive – va_pos[95] % of limit = 40%
  - Normal drive – va_pos[95] % of limit = 70%
  - Aggressive drive – va_pos[95] % of limit = 90

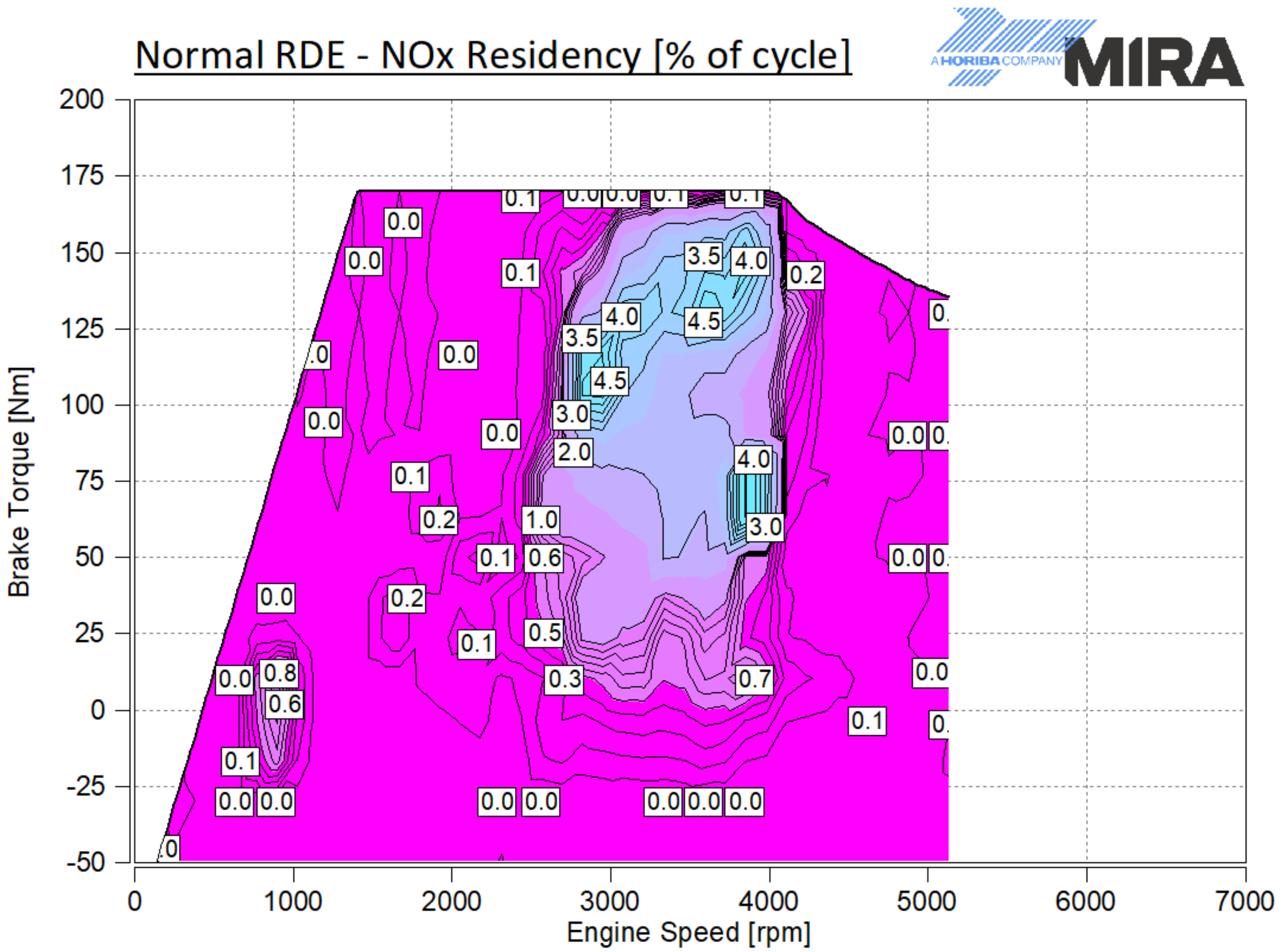


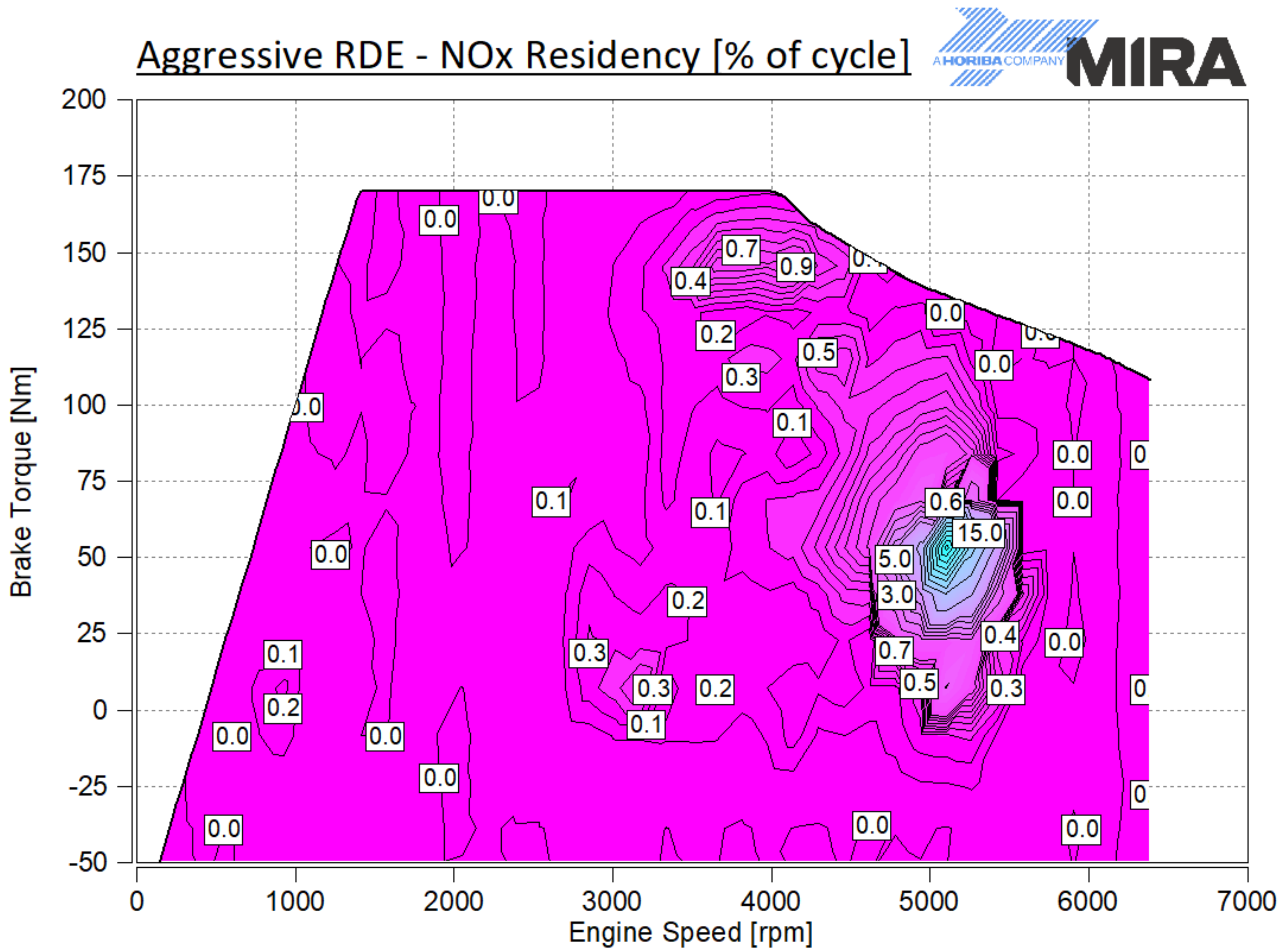
Methodology – Engine-in-the-Loop
Sea Level Route, EiL Initial Results (2)

- Rapid screening of calibration and hardware changes without needing to schedule on-road RDE testing.
- Run repeat RDEs without influences such as traffic, weather and other anomalies.
- Identify problematic areas of the engine operating map that are often not related to time residency.
- Resolve cycle emissions before prototype testing.



Methodology – Engine-in-the-Loop
Sea Level Route, EiL Initial Results (2)





	Tailpipe CO_2 [g/km]	Tailpipe NOx [mg/km]	Tailpipe PN [#/km]	Fuel Consump [l/100km]	Fuel Consump [mpg]
Gentle	136.7	32.1	4.8E+11	6.1	46.2
Normal	153.0	53.0	5.3E+11	6.8	41.4
Aggressive	170.1	100.3	1.1E+12	7.5	37.7

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Conclusions

- HORIBA MIRA's R2R RDE+ test methodology has been described.
- The road part of the programme is complete with work underway on the chassis dynamometer and EiL segments.
- Sea-level and high altitude, cold temperature RDE routes have been successfully correlated with the vehicle driven on the chassis dynamometer utilising a robot driver and HORIBA MEDAS altitude emulation device.
- The effects of driving style on engine performance and emissions for a fixed RDE route have been presented using an EiL toolchain.
- The EiL methodology will allow OEMs to front-load powertrain design, development and calibration activities thus resulting in fewer prototype vehicles and physical climatic testing to achieve RDE compliance.
- By adopting road, chassis, EiL and virtual testing (RDE+), many of the unknown scenarios that arise through real testing can be mitigated much further upstream; thus reducing time, effort, money and pollution.

Thank you

감사합니다

Cảm ơn

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Obrigado

Σας ευχαριστούμε

شُكْرًا

Tack ska ni ha

Большое спасибо

Danke

Gracias