European Commission

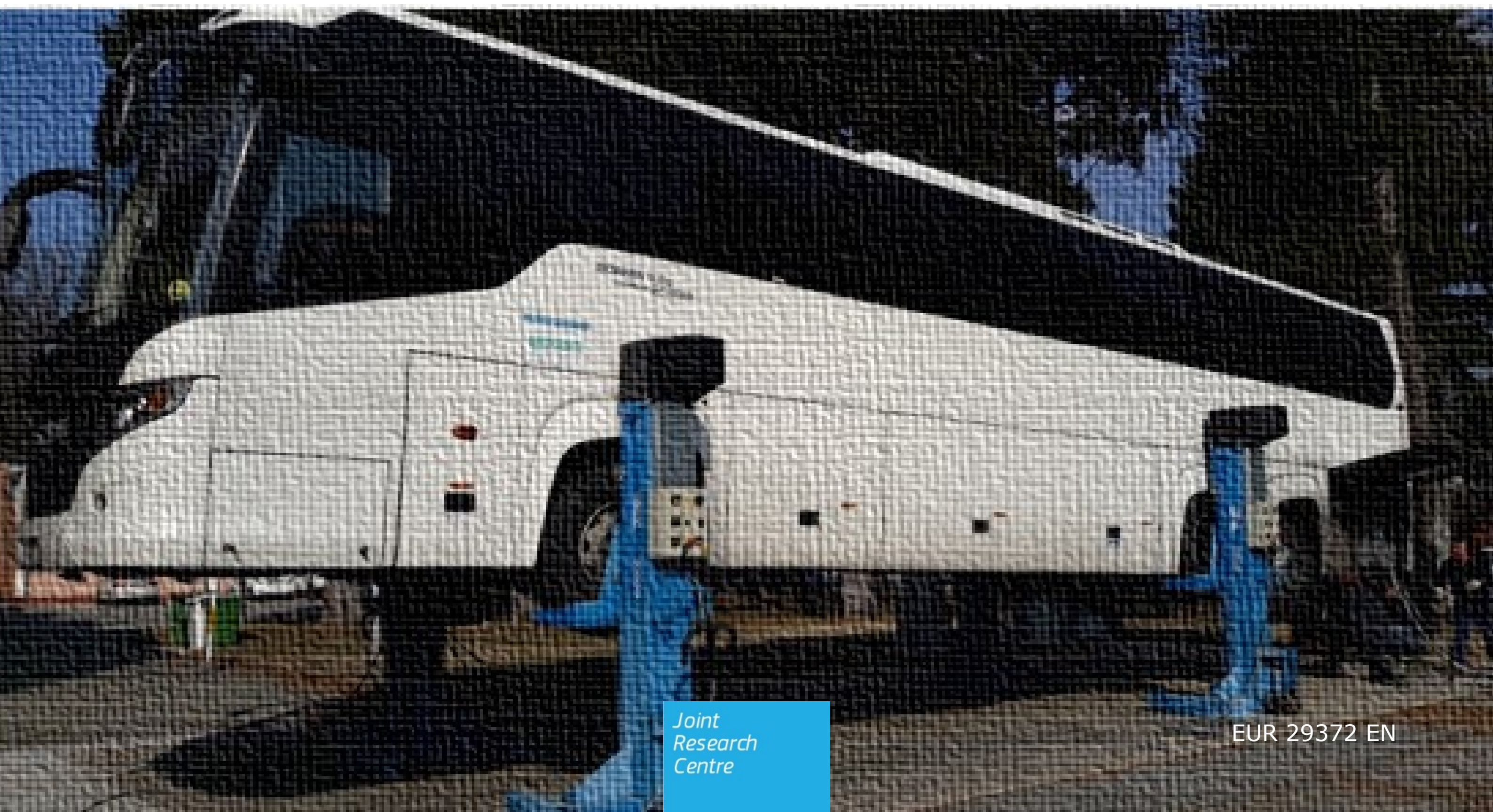
JRC TECHNICAL REPORTS

Assessment of the measurement methodology for CO_2 emissions from heavy-duty buses and coaches

Pre-pilot phase (PPP) – Test-campaign report

Grigoratos T., Fontaras G., Tansini A., Giechaskiel B., Savvidis D., Ciuffo B.

2018



Joint Research Centre

EUR 29372 EN

Contact information
Name: Theodoros Grigoratos
Address: European Commission, Joint Research Centre, Via E. Fermi 2749, 21027, Ispra (VA), Italy
Email: theodoros.grigoratos@ec.europa.eu
Tel.: +39 0332 78 6597

Name: Georgios Fontaras
Address: European Commission, Joint Research Centre, Via E. Fermi 2749, 21027, Ispra (VA), Italy
Email: georgios.fontaras@ec.europa.eu
Tel.: +39 0332 78 6425

JRC Science Hub
https://ec.europa.eu/jrc

JRC113307

EUR 29372 EN

PDF ISBN 978-92-79-94184-9 ISSN 1831-9424 doi:10.2760/74053

Luxembourg: Publications Office of the European Union, 2018

How to cite this report: Grigoratos T., Fontaras G., Tansini A., Giechaskiel B., Savvidis D., Ciuffo B., *Assessment of the measurement methodology for CO2 emissions from heavy-duty buses and coaches: Pre-pilot phase (PPP) – Test-campaign report*, EUR 29372 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-94184-9, doi:10.2760/74053, JRC113307

Contents

Foreword 1
Acknowledgements 4
Abstract 5
1 Introduction 6
2 Experimental methods 7
2.1 VELA 7 facilities and setup 7
2.2 Test vehicles 8
2.3 Daily test protocol and test cycles 9
2.4 Air Drag measurement with the constant speed test 13
2.4.1 Definitions 13
2.4.2 Instrumentation 14
2.4.3 Requirements 14
2.4.4 Execution of the constant speed test 16
2.4.5 Post-Processing of the experimental data 17
2.5 Vehicle simulator 17
3 Air-drag measurements 20
3.1 Constant speed tests 20
3.1.1 Vehicles and experimental setup 20
3.1.2 Issues encountered 20
3.1.3 Results 23
4 CO_2 measurements 24
4.1 Chassis Dyno 24
4.1.1 Vehicle #1 24
4.1.2 Vehicle #2 27
4.2 On-road measurements 29
4.2.1 Vehicle #1 30
4.2.2 Vehicle #2 32
5 Conclusions 35
References 37
List of abbreviations and definitions 38
List of tables 39

Foreword

Policy context

The European Commission has decided to proceed with the preparation of a new regulatory initiative for the certification of CO_2 emissions and Fuel Consumption from buses and coaches. This initiative follows the adoption of the HDV CO_2 Certification Regulation on the determination of the CO_2 emissions and fuel consumption (FC) of heavy-duty (HD) trucks (EU/2017/2400) – as well as the subsequent development of an appropriate verification procedure to be applied randomly on complete vehicles after the certification processes (currently under development). The new methodology is intended to be a continuation of the HDV CO_2 Certification Regulation and it will be based on a combination of component testing and computer simulation of the vehicles' FC.

A dedicated software simulator has been developed for certification purposes (Vehicle Energy Consumption calculation Tool – VECTO). In parallel, a series of new component testing protocols and methods have also been introduced in order to measure vehicle components and provide the necessary input data for running VECTO. As a result, the final vehicle CO_2 emissions are calculated based on data received from components testing and computer simulations. This method allows vehicle-specific CO_2 emission values to be attributed to each vehicle, provides the necessary flexibility to the vehicle manufacturers as the HDV market is highly differentiated with limited common features between different vehicle models and reduces the costs of vehicle certification.

However, some form of verification of the final CO_2 result and the quality of input data used in the simulations was deemed necessary by various stakeholders and the European Member States. In this framework, the European Commission's Diretorate-General for Climate (DG CLIMA) and Directorate-General for Growth (DG GROW) requested from the the European Commission's Joint Research Centre (JRC) to launch a preliminary test-campaign in order to investigate the validity, accuracy, and plausibility of the proposed methodology in the case of buses and coaches. This particular test campaign was decided to be a part of a pre-pilot phase (PPP) organised by DG CLIMA, the JRC, the Graz University of Technology (TUG), and vehicle manufacturers (ACEA). Experiments were conducted on two Euro VI vehicles, one interurban bus and one coach, both on the chassis dyno and on the road, in order to:

- Evaluate the repeatability of CO_2 verification tests over transient laboratory test-conditions as well as over real-world on-road tests and help in the extension of the ex-post verification method to cover buses and coaches;
- Provide the additional evidence that VECTO results are coupled and analogous to real-world CO_2 emissions of vehicles, within the same boundary conditions considered in the certification procedure, an issue brought up by several non-industrial stakeholders

Two vehicle OEMs participated to the exercise (in alphabetical order Daimler and Scania) by providing a bus along with the necessary technical support. Additionally, IVECO participated to the exercise by providing the Balocco proving ground for the execution of the air-drag tests.

Quick guide / Experimental

Tests were conducted at the facilities of JRC (VELA 7). Two vehicles were tested equipped with state of the art exhaust after treatment systems like Diesel Particulate Filters (DPF) and Selective Catalyst Reduction of NO_x (SCR). Both vehicles were Euro VI certified. The vehicles were tested in the laboratory over the respective bus and coach cycles developed by ACEA, namely the interurban and coach driving cycles. Additionally, real-world on-road tests were performed over a 200 km route which included distinct urban, rural, and motorway parts and over a 70 km route which included distinct urban and rural parts for the coach and the interurban bus, respectively.

An AVL i60 AMA 4000 system was used for the analysis of pollutants emissions. A Heated NDIR (Non-Dispersive Infra-Red sensor) was used for CO_2 emissions measurement and the subsequent calculation of the fuel consumption. Additionally, a PEMS system was used for the analysis of CO_2 emissions in order to have a common measurement instrument both in the laboratory and on-road (Semtech-DS PEMS - Sensors Inc.). However, comparison between measured and simulated values in the laboratory was conducted based on AMA values. For the chassis dyno tests, the climatic room was adjusted at 3 different temperatures (2°C, 20°C and 35°C). CO_2 was measured downstream of the exhaust after-treatment system of the vehicle. The calculation of the wheel work output over each sub-cycle was based on the instantaneous wheel torque values measured by a dedicated wheel-rim torque measurement system. Further to the standard instantaneous CO_2 measurement, instantaneous fuel consumption was measured also with mobile fuel flow meter for cross-checking purposes.

A minimum of three repetitions of each cycle were conducted. Tests were performed during the same day but also over different days. Tests were performed always under warm start conditions with the vehicles being stabilised. A minimum of six on-road tests were performed for all vehicles. The same PEMS system as in the laboratory was used for the analysis of CO_2 emissions on-road. The comparison between measured and simulated values on-road was conducted using PEMS CO_2 values corrected by a correlation factor which was calculated during the laboratory tests.

➔ ***All FC values provided in the report are normalised to the average FC of each vehicle separately. Thus, normalised FC values of different vehicles cannot be compared to each other by any means.***

Results Analysis - Main findings

This part of the Pre-Pilot Phase was conducted in two phases:

- The experimental phase which took place between February and April 2017 in JRC and involved testing of two Euro VI buses in the laboratory and on-road.
- The simulations phase, which took place between May 2017 and March 2018, where simulations were performed by each individual OEM following the guidelines of the JRC.

The manufacturers performed the simulations after tests had been finalised by the JRC without knowing the fuel consumption/CO_2 emissions results. Simulation results were then communicated to the JRC who performed an independent comparison between the results of the simulations and those of the measurements. At a final step, conclusions were communicated to the respective OEM. The findings of the primary evaluation phase can be summarised to the following:

Air-drag Tests

Air-drag tests proved to be very accurate. The test is relatively simple and very well defined in the Annex VIII of the respective regulation. However, the vehicles should be equipped appropriately and there is a need to perform the tests in a dedicated proving ground. Difficulties encountered during testing related to the malfunctioning or not accurate functioning of specific equipment as well as with non-compatible weather conditions.

Laboratory Transient Tests

Laboratory tests showed high measurement repeatability for both VECTO interurban and coach cycles. Despite the long duration and high transient character of both cycles, the repeatability of the measurements was lower than 5% regardless of the testing conditions. The same applies also to the time based real world cycle tested in the case of the interurban bus.

A satisfactory agreement was observed between measured and simulated FC for the coach. The deviation between tests and simulations was generally lower than 4% and only in few cases reached 6%. VECTO Engineering mode provided more accurate results compared to the VECTO P_{Wheel} mode probably due to not very accurate input data recorded by the torquemeter. Deviations between measured and simulated values were higher when the fuel flowmeter values are considered. On the other hand, the interurban bus demonstrated much lower deviations between measured and simulated values with only, however, the Engineering mode being available. FC values from the AMA and the fuel flowmeter were comparable unlike in the case of the coach.

Despite the overall positive results, there are various drawbacks related to a transient testing method in the laboratory. First of all, there are difficulties for the driver to reproduce some braking events and accelerate the vehicle under high gradient conditions. Another problem has to do with the definition of the road loads during the set-up of the dyno. If these values are not known in advance there is the risk to run the tests under non-normal resistance conditions. In addition, some vehicles currently, and more vehicles in the future, are equipped with sensors or GPS systems that define the operation of certain components (e.g. gearbox) according to specific external parameters. The effect of such systems is excluded entirely when testing on a dyno. In addition, the vehicle control system understands that vehicle operates under static conditions, with this having potentially compromising the integrity and scope of a validation test. Finally, there is a need for expensive and difficult to maintain equipment (chassis dyno, special braking trailers, etc.).

On-road Tests

On-road tests proved to be highly repeatable regardless of the route tested. The coefficient of variation of VSFC measurements over three repetitions was 0.5% for the coach and 4.5% for the interurban bus. The difference can be attributed to the higher transient nature of the interurban route compared to the coach route. This result is in-line with the conclusions drawn during the truck campaign published in 2017 [Grigoratos et al. 2017].

Overall, a good agreement between measured and simulated FC values was observed over on-road tests with the deviation not exceeding 5%. When the fuel flowmeter measurements are considered the deviation is very high for the coach (~10%) and relatively low for the interurban bus (4.5%). VECTO Engineering mode proved to be more precise in simulating measured FC values compared to P_{Wheel} mode (coach). Overall, it seems that VECTO is capable of providing reliable results over on-road tests despite the difficulty in attributing accurate auxiliary values.

On-road tests seem to be a good solution for the ex-post verification procedure as they overcome most of the drawbacks related to the laboratory-based testing methodologies (list above).

Related and future JRC work

Based on the results of the validation phase, the Graz University of Technology (TUG) will conduct an error propagation analysis in order to confirm the findings and conclusions of JRC. The JRC will support/participate the respective Directorates-General in all future steps concerning HD CO_2 certification of buses and coaches.

Acknowledgements

The authors would like to acknowledge ACEA for providing the vehicles and in particular the following companies that supported the tests and the people who supported the simulations:

- Daimler & EVO Bus (Tobias Reuter, Knut Winde, Rainer Bickel)
- Scania (Johan Forss)
- IVECO for making available the Balocco test track

We are thankful to the technical staff of VELA laboratories for the execution of the tests in such a short period of time and in particular to: Mauro Cadario, Rinaldo Colombo, Alessandro Zappia and Andrea Bonamin. Special thanks to Georgia Karamountzou and the PUBSY team for their editorial support.

Authors

- Theodoros GRIGORATOS
- Georgios FONTARAS
- Alessandro TANSINI
- Barouch GIECHASKIEL
- Dimitrios SAVVIDIS
- Biagio CIUFFO

Abstract

After the adoption of the CO_2 Certification Regulation on the determination of the CO_2 emissions and fuel consumption of heavy-duty trucks, the European Commission has decided to proceed with the preparation of a new regulatory initiative for the certification of CO_2 emissions and fuel consumption from buses and coaches. The new methodology is intended to be a continuation of the heavy-duty vehicles CO_2 certification regulation and it will be based on a combination of component testing and computer simulation of the vehicles' fuel consumption. Following a request from the European Commission's Directorate-General for Climate Action (DG CLIMA), the European Commission's Joint Research Centre (JRC) launched a test-campaign in order to investigate the possibility to extend the methodology proposed for the verification of the certified CO_2 emissions from heavy-duty trucks to buses and coaches. In addition, the scope of the test campaign was to demonstrate the representativeness of the CO_2 emissions calculations made by the official simulator (VECTO) by comparing against the actual performance of vehicles. Experiments were conducted on two Euro VI buses, one interurban bus and one coach, both on the chassis dyno and on the road, with the aim of understanding the advantages and disadvantages of different approaches proposed. The official simulation software (VECTO) was used for simulating the operation of vehicles under the different test conditions. The principal conclusion of the test campaign is that an ex-post verification method which is based on transient, on-road tests is possible also for buses and coaches. However, there is a clear need to work on the details of the test protocol to be finally implemented, define boundary conditions for transient tests on the road, and establish the necessary acceptance and rejection margins for any such validation. Additional care should be paid to the auxiliary components as they are a special part of buses and coaches and contribute highly to the overall fuel consumption of these vehicles. Finally, additional testing is necessary in order to calculate accurately any systematic deviation between the officially reported, simulated, CO_2 values and those actually occurring in reality.

1 Introduction

The introduction of the HDV CO_2 certification legislation in 2017 (EU/2017/2400), initially covering Heavy Duty Trucks, as well as the establishment of the respective simulation-based CO_2 quantification methodology has been an essential first step for quantifying CO_2 emissions and – among others – it is expected to contribute towards lowering CO_2 emissions in the EU. However, HDV emissions monitoring in a standardised and consistent way still remains a significant challenge. The EC has initiated a series of projects with the aim of establishing a comprehensive, standardised and accurate method to quantify and report CO_2 emissions from HDVs. Moreover, the EC has taken a series of initiatives in order to extend certification legislation and monitoring activities to another important HD category namely buses and coaches.

The approach that best fits the characteristics and particularities of the HDV sector is founded on a combination of component testing and computer simulation (AEA-Ricardo, 2013). Measurement of vehicles or their components is fundamental for building accurate and reliable models and it is foreseen in all certification approaches already established. Vehicle Energy consumption Calculation TOol (VECTO) has been developed to be used for the purpose (Fontaras et al. 2013), while it has been tested both by the EC and individual OEMs regarding its capacity to calculate representative CO_2 emissions. In this model fuel consumption (FC) is simulated based on vehicle longitudinal dynamics. Input data regarding the vehicle, its driveline and engine characteristics are supplied in order to simulate their performance over given operating conditions adequately. Equally important are the established test protocols for measuring the energy efficiency or power losses of individual vehicle components and producing the required input data for running the simulations (EC, 2017). The plausibility of such a simulation-based approach was assessed for HD Trucks through two extensive experimental campaigns conducted by the EC's Joint Research Centre (JRC). The studies provided detailed experimental results for supporting the plausibility of the simulation-based approach and were used for supporting the establishment of the HDV CO_2 certification legislation (Fontaras et al. 2013; Grigoratos et al. 2017).

Following a request from the European Commission's Directorate General for Climate (DG CLIMA) and Directorate-General for Growth (DG GROW), the JRC launched a preliminary test-campaign in order to investigate the validity, accuracy, and plausibility of the proposed testing and simulation methodology in the case of buses and coaches. This particular test campaign was decided to be a part of a Pre-Pilot Phase (PPP) organised by DG CLIMA, the JRC, the University of Technology Graz (TUG), and ACEA. In addition, JRC was asked to produce data that demonstrated the representativeness of VECTO's FC calculations by comparing simulation results against the measured fuel consumption of the vehicles. Experiments were conducted on two Euro VI vehicles, one interurban bus and one coach, both on the chassis dyno and on the road. This report summarises the outcome of the above mentioned experimental test campaign. In addition, the data retrieved from the measurements come to supplement those of the previous test campaigns regarding the capacity of VECTO and the proposed approach to capture the CO_2 emissions of buses and coaches.

2 Experimental methods

Measurements took place between February and April 2017. Both tested vehicles were Euro VI certified. Fuel consumption measurements included tests on the chassis dyno and on the road following real-world driving patterns. Air-drag tests were also performed for both vehicles following the official testing procedure [COMMISSION REGULATION (EU) 2017/2400 – Annex VIII]. Detailed descriptions of the vehicles, protocols and test conditions are provided in this chapter.

2.1 VELA 7 facilities and setup

Chassis dyno measurements were performed at the Heavy Duty Chassis dynamometer of the Vehicle Emissions Laboratory (VELA 7) of the European Commission's Joint Research Centre (JRC).

The two-roller chassis dynamometer (Zoellner GmbH, Germany) has been designed to host even 4-wheel drive HDVs of up to 30 t in weight, 12 m in length, and 5 m in height. HDVs of 2 axles can also be accommodated. Maximal test speed is set at 150 km/h. The test cell can be conditioned in temperatures between -30°C and +50°C and relative humidity between 15% and 95%, providing thus the ability to test vehicles under extreme conditions. The constant-volume sampler (CVS) for full exhaust dilution (AVL, Graz, Austria) is equipped with 4 Venturi of 10, 20, 40, and 80 m^3/min in order to achieve a maximum airflow of 150 m^3/min. Tests were usually performed with an air flow of **100 m^3/min**. Dilution air is taken from the test cell, conditioned to 22°C, and filtered through high-efficiency particulate air (HEPA) and activated charcoal filters. The climatic test cell of VELA 7 has an air circulation system that provides enough number of cell air changes (≥15) in order to allow the testing of vehicles regardless of the fuel used. Figure 1 provides an overview of the VELA 7 facilities.

Both vehicles were equipped with fuel flowmeters installed by the OEMs and fuel consumption was recorded through a respective Controller Area Network (CAN) signal. FC from the fuel flowmeters was used as a secondary source of comparison between the measured and the simulated values. The reason is that the fuel flowmeters employed by the two manufacturers were different and there was a decision to perform the primary comparison with a standard instrument for both vehicles. Further to the fuel flowmeters, CO_2 was measured downstream of the exhaust aftertreatment system of each vehicle. Fuel consumption calculations in the laboratory were performed based on the CO_2 measurements from the AMA analyser. ***FC calculated from the AMA analyser was used for the first comparison with simulated results in both vehicles***. Finally, a GAS-PEMS system was used both in the lab and on-road. The reason for using gas-PEMS in all tests was to maintain a standard reference instrument for all vehicles and all test conditions. However, PEMS CO_2 values measured on-road were corrected by a correlation factor calculated over laboratory tests through the concurrent measurement by AMA and PEMS (hereafter mentioned as AMA/PEMS). The reason for applying the correction factor is that AMA is more stable and reliable than PEMS and therefore it was selected as the reference measurement system. A Semtech-DS PEMS system was used, manufactured by Sensors Inc., and it consisted of tailpipe attachment, heated exhaust lines, an exhaust flow meter (EFM) (4''), exhaust gas analysers, data logger to vehicle network, a global positioning system (GPS), and a weather station for ambient temperature and humidity. All data were recorded at a frequency of 1 Hz and the whole system added further ~100 kg of instrumentation to the vehicle. An independent power generator was used to produce current for the needs of the PEMS. The measurement principles and accuracy from the Semtech DS were in-line to those described by current legislation for this type of testing. As a standard procedure, test runs preparation included routine calibration of pollutant analysers (zero and span of gases). On-road fuel consumption calculations for confirmation purposes were performed based on the CO_2 measurements from the PEMS system.

In all cases, the on-board fuel flow indication provided by the vehicles was also used for recording instantaneous fuel consumption. However, as explained previously fuel consumption results were reported based on the AMA analyser and the Fuel Flowmeter.

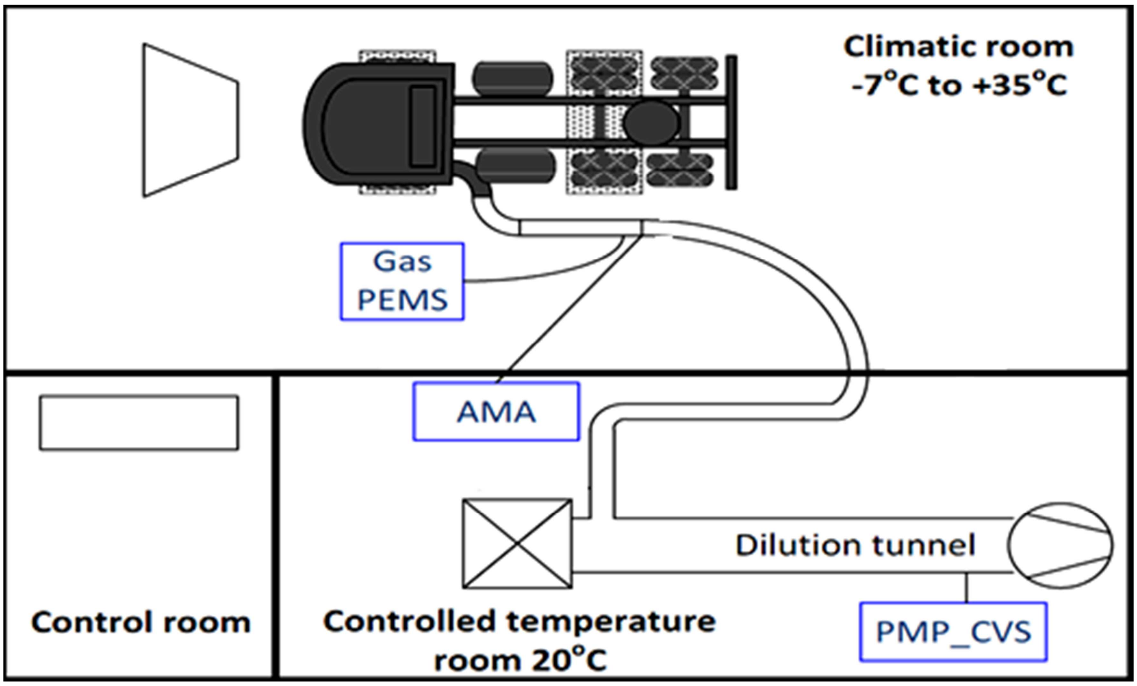


Figure 1. VELA 7 facilities Source: Grigoratos et al. 2017

2.2 Test vehicles

Two vehicles were employed for the purposes of the present study. One interurban bus and one coach were selected. Some general specifications of the vehicles are provided in Table 1. Both vehicles were provided by the respective OEMs in their standard operating conditions. Figure 2 demonstrates vehicles tested in VELA 7 and on-road.

Table 1. Main vehicle characteristics.

Characteristic	Vehicle #1 (coach)	Vehicle #2 (interurban bus)
Engine Displacement [cm^3]	12740	7700
Rated Power [kW]	331	261
Gearbox	AMT	AT-P
Max load [kg]	25,000	18,000
Test Mass [kg]	19,600	16,700
Emissions Category	EURO VI	EURO VI
Torque measurement	In-house rim sensors	Kistler Wheel Rim
Exhaust emissions control	EGR, DPF, SCR	EGR, DPF, SCR

During all tests, signals from the vehicles' On-Board Diagnostic (OBD) port were recorded. The calculation of the engine work output over each cycle was based on the instantaneous engine torque and rpm values which were recorded via the vehicle's ECU (Engine Control Unit). However, this value was not used for the calculation of the specific fuel consumption but only for cross-validation purposes.

Vehicle specific fuel consumption was calculated using the loads imposed on the vehicles during the tests. For these calculations, the total work output of the driveline system (positive or absolute) was calculated from torque measurement devices installed at the wheels. This allowed on a second step a better validation of the resistances simulated by VECTO and an assessment of the origin of the inaccuracies in the calculations.

Figure 2. Buses being prepared and tested in the climatic room and on-road

2.3 Daily test protocol and test cycles

The Vehicle Energy Consumption TOol (VECTO) contains a series of mission profiles that are used by the tool in order to simulate a realistic driving scenario. The driving cycles that are used in each case depend on the vehicle type and application. The driving cycles are distance based, which means that the vehicle travels over a route and attempts to reach a target speed that depends on the route's segment. The daily test protocol in the laboratory consisted of two different types of test cycles, one for each type of vehicle. A complete driving profile contains the following data:

- Distance
- Target speed
- Road grade
- The time that the vehicle remains still

ACEA in their White Book have provided feedback on the bus and coaches driving cycles. Gearbox manufacturers in Europe performed a thorough analysis based on long-time gearbox statistics and they have suggested a series of cycles. The cycles should comply with the following criteria set by ACEA:

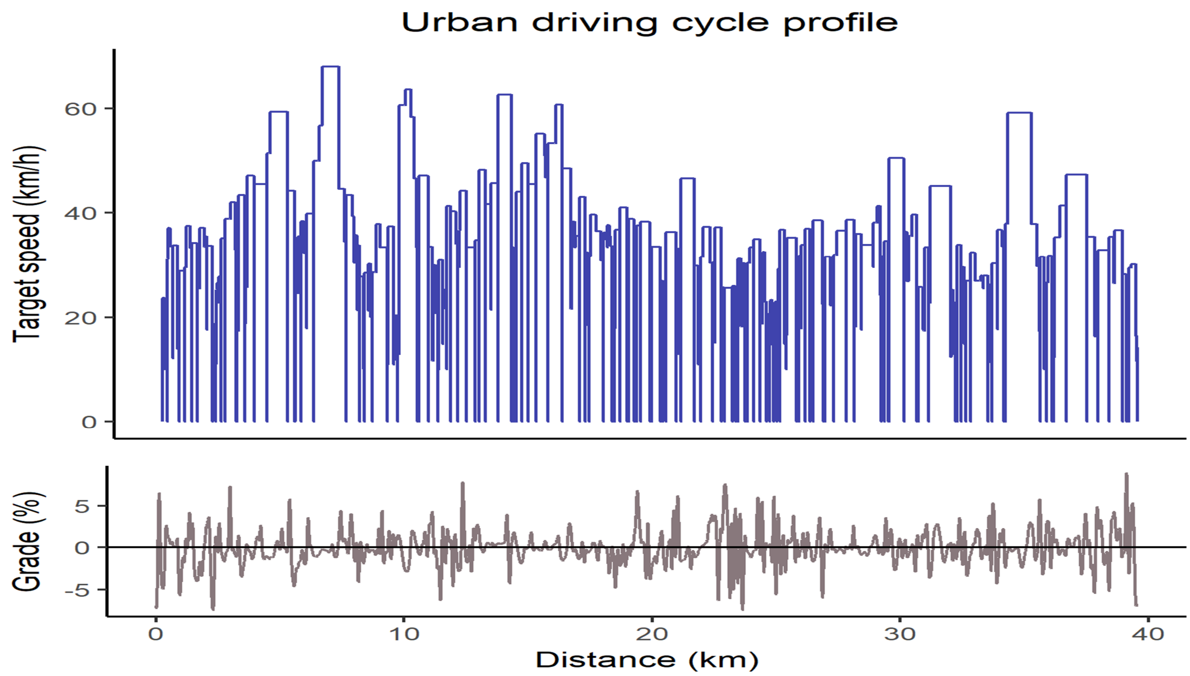
- The present good separation between different cycles in terms of average speed, stops per km and idle time
- Good separation between velocity profile
- Match long time statistics
- Represent moderate topography

Currently, three of the VECTO driving cycles are dedicated to bus and coaches: urban, interurban and coach. Table 2 briefly presents the main characteristics of each one of the three VECTO bus related cycles:

Table 2. Main characteristics of the VECTO bus related cycles.

Cycle	Distance (km)	Average speed (km/h)	Maximum speed (km/h)	Average grade (%)	Minimum grade (%)	Maximum grade (%)
Urban	39.6	33.6	68.1	0.15	-7.5	8.9
Interurban	123.6	55.3	85.0	0.19	-6.7	13.7
Coach	275.2	76.2	100.0	0.13	-7.2	13.7

Figure 3 shows the driving profile of the three VECTO bus related cycles. The upper part of the Figure depicts the speed versus distance profile of each cycle, while the lower part shows the gradient of the road versus distance profile. All three VECTO bus related cycles are given in Figure 4, but only the interurban and the coach cycles were tested for the purposes of the current exercise.



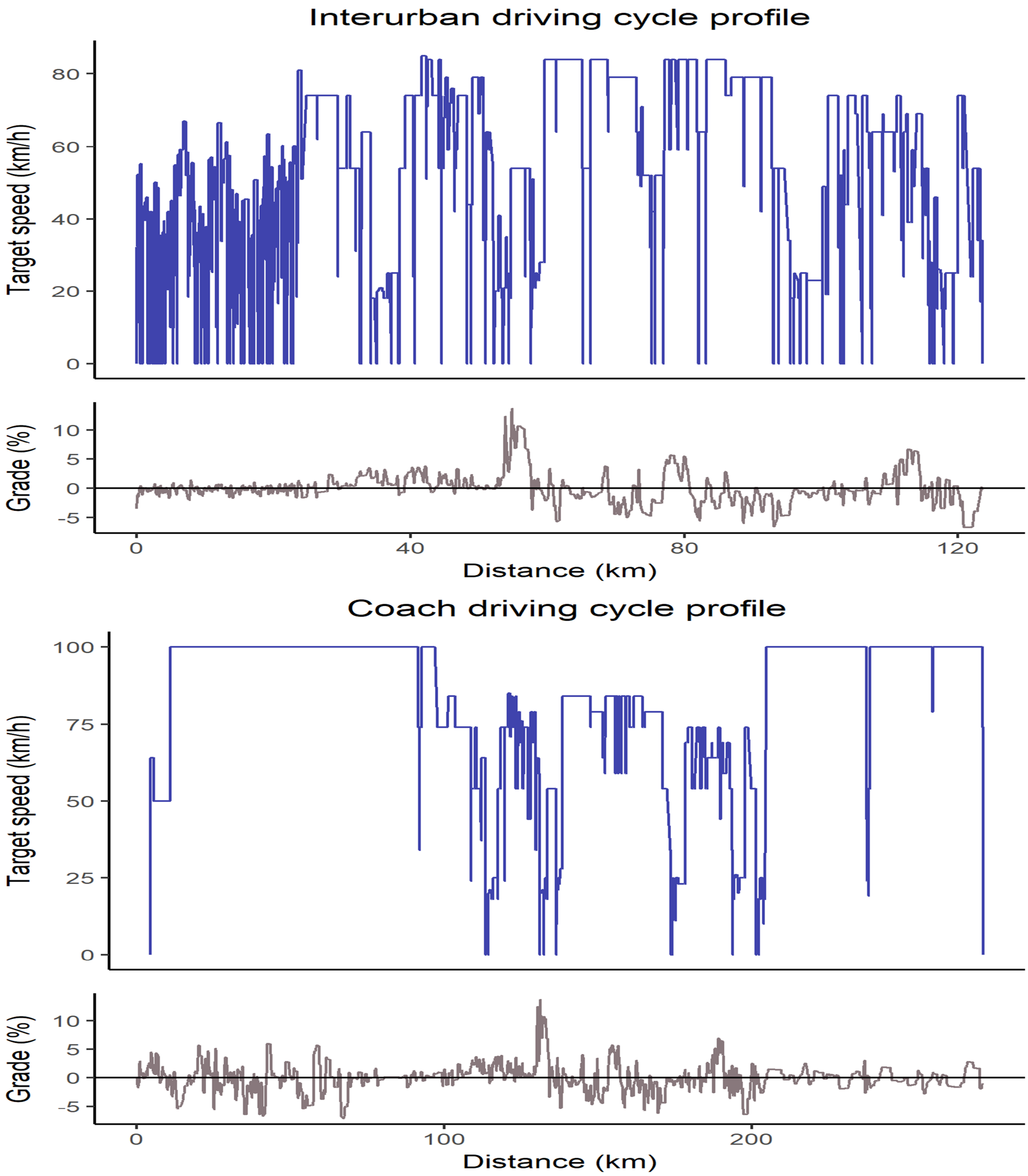


Figure 3. Speed (upper) and slope (lower) vs distance profile of VECTO bus cycles

On-road tests around the JRC site were performed to simulate real-world emissions. A mixed route of the total distance of approximately 60 km which consists of urban and rural parts as well as a route of 200 km which consists of urban, rural and highway parts were driven with the interurban bus and the coach, respectively (Figure 4). In Figure 4 the highway part (coach cycle) has been marked with a red line, whereas urban and rural parts are depicted with the blue line. Figure 5 shows the speed profile of the interurban bus and the coach over the described routes.

The scope of on-road tests was to obtain a mix of operating conditions similar to those of the chassis dynamometer tests. Also, there was a need for investigating parameters such as the repeatability of the tests and the agreement between measured and simulated values since on-road tests were considered to be less repeatable compared to laboratory tests.

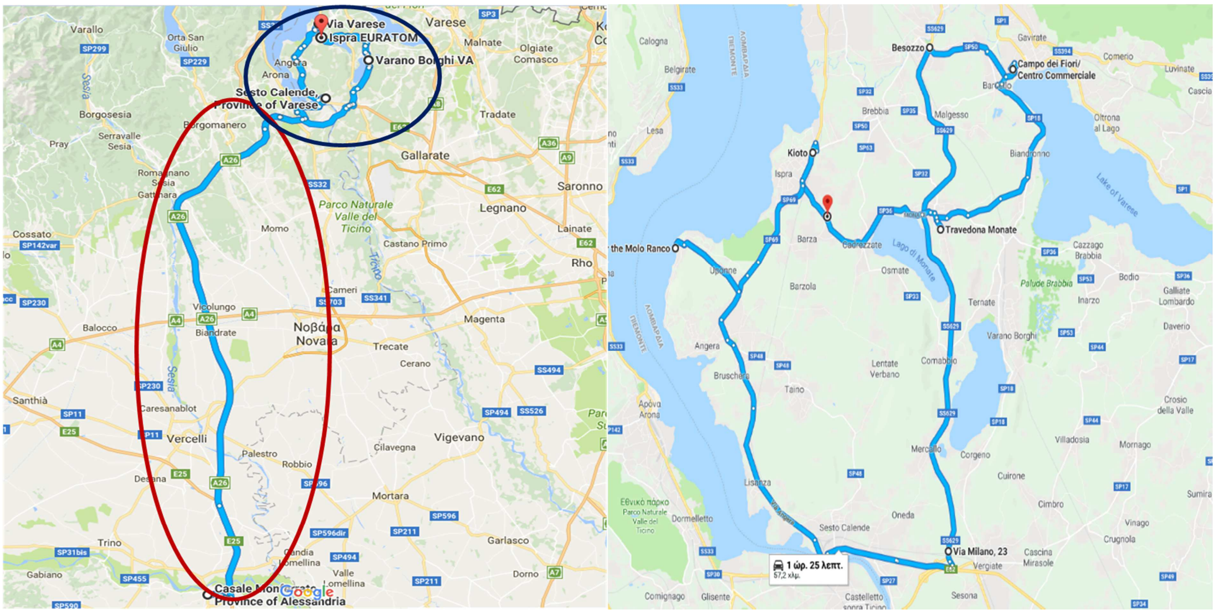


Figure 4. On-road tests route. Left: Coach – Right: Interurban bus

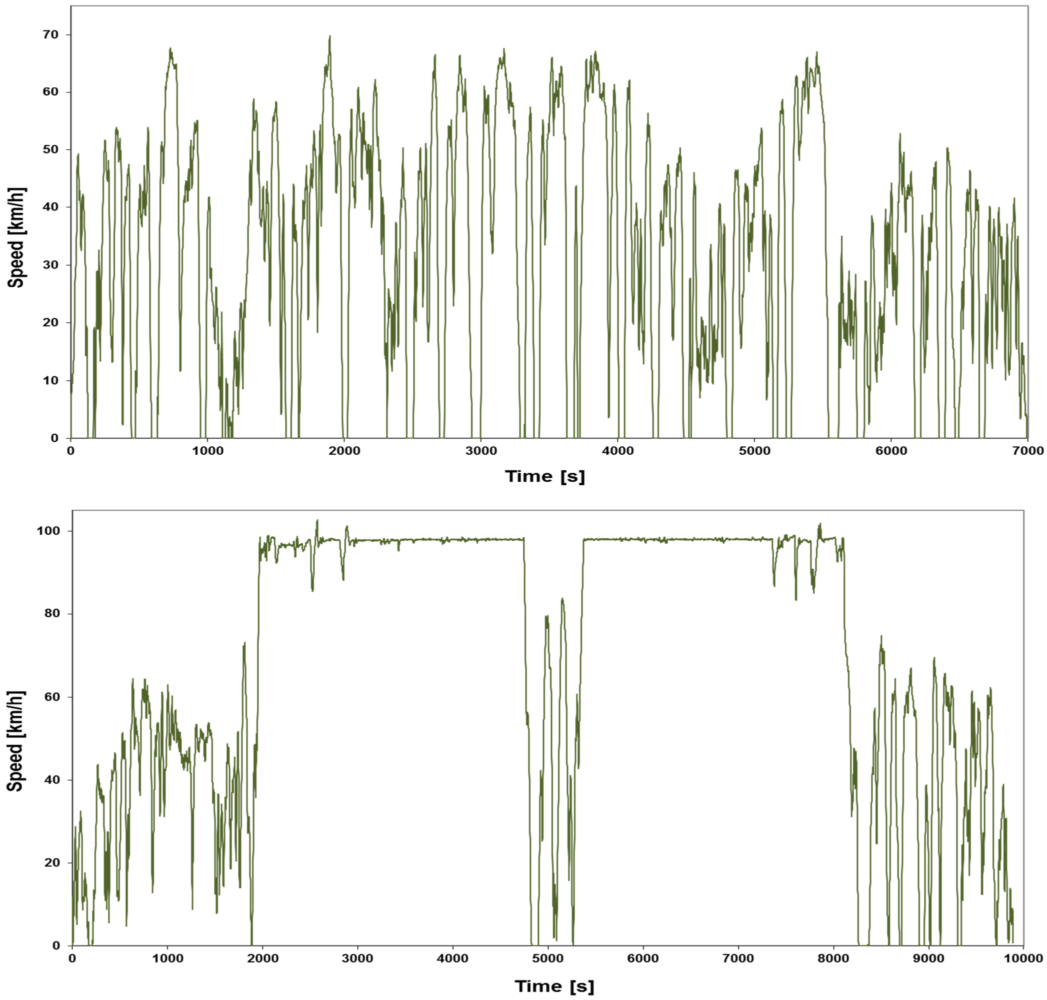


Figure 5. Interurban bus (upper) and coach (lower) speed profiles on the road

The routes' statistics with the two vehicles are summarised in Table 3. A PEMS compliant trip would stop at around time 6000s. However, it was decided to extend the measurement period throughout the whole trip for the purposes of this project. Both vehicles were tested six times each over temperatures that ranged from 10-18°C.

Table 3. Driving phase distributions and average speeds of on-road trips.

Speed Classification	Time share [%] (interurban)	Average Speed [km/h]	Time share [%] (coach)	Average Speed [km/h]
Low Speed <50 km/h	**60.9**	**25**	**4.9**	**17.2**
Medium Speed 50-70 km/h	**39.1**	**42.5**	**31.7**	**38.6**
High Speed >70 km/h	**n/a**	**n/a**	**63.4**	**93.5**

2.4 Air Drag measurement with the constant speed test

Air resistance is one of the parameters affecting fuel consumption in HDVs. In principle, air resistance becomes more critical with the increase of vehicle's speed (extra-urban and highway driving). The necessary energy to overcome air resistance depends mainly on vehicle speed, but it is also affected by the vehicle's aero-dynamicity. The latest is defined by the drag coefficient (C_d) and the frontal area of the vehicle (A) and is generally referred to as C_dxA.

For the purpose of simulating HDVs fuel consumption with VECTO, it was necessary to develop a methodology to calculate the C_dxA value of the vehicle. The developed methodology had to ensure accuracy and repeatability of the measurement. For that purpose, the EC conducted a thorough study in order to compare multiple methodologies based on different principles:

- Simulation approach by means of Computational Fluid Dynamics (CFD);
- Physical testing by means of the coast down test;
- Physical testing by means of constant speed driving

The EC decided to adopt the latter solution as the official methodology to be applied to the definition of vehicles' C_dxA. The adoption of this solution to define a vehicle air drag also enables to define another critical parameter that affects fuel consumption, the rolling resistance of tyres. The following section describes the way air drag can be measured for HDVs and the experimental activities performed by JRC in the framework of the PPP.

The methodology defines the vehicle to drive in a proving ground with specific characteristics and atmospheric conditions, while specific predefined signals like vehicle speed, torque at the wheel, engine rpm and airspeed are measured. The data obtained during the constant speed test are then processed by a dedicated tool that calculates C_dxA (VECTO Air Drag). The following paragraphs present the main points of this methodology as described in the regulation [COMMISSION REGULATION (EU) 2017/2400 – Annex VIII].

2.4.1 Definitions

This section provides some of the terminology used in the respective regulation for the measurement of the C_dxA.

- Measurement section: A designated part of the test track which is relevant for data recording and data evaluation;
- Measurement area(s): Designated part(s) of the test track consisting of at least one measurement section and a preceded stabilisation section;

- Dataset: The set of data recorded during a single passing of a measurement section;
- Yaw angle: The angle between vehicle longitudinal axis and direction of air flow;
- Heading: The instantaneous direction to which the vehicle is pointing during the constant speed test

2.4.2 Instrumentation

The instruments needed in order to perform the constant speed test on the test track are summarised in Table 4.

2.4.3 Requirements

In order to ensure repeatability and accuracy of the methodology there are some requirements related to the proving ground itself as well as the prevailing ambient conditions that need to be met. Also in a technical point of view tested vehicles and measurement equipment shall meet specific requirements which are described below.

Proving ground requirements

The track can be either a circuit or a straight line (Figure 6). In the case of a circuit track, the possibility to drive the vehicle in both track directions should be granted in order to perform the anemometer misalignment correction. For the other phases of the constant speed test the circuit should be driven in just one direction. In the case of a straight line, the track should be drivable in both directions for the entire constant speed test and turn around areas where the vehicle can reverse the direction of travel should be present.

Table 4. Instruments required for constant speed test on the test track.

Measured Parameter	Instrument Required
Torque at wheels	Hub torquemeter or Rim torquemeter or Half shaft torquemeter
Vehicle position	GPS system or Differential GPS system
Start and stop of measurement parts	Differential GPS system
Pressure and humidity of ambient air	Stationary weather station
Ambient temperature	Temperature transducer
Airflow velocity and yaw angle (β)	Mobile anemometer
Proving ground temperature	Contactless IR sensor
Vehicle and engine speed	CAN-bus interface – data logger

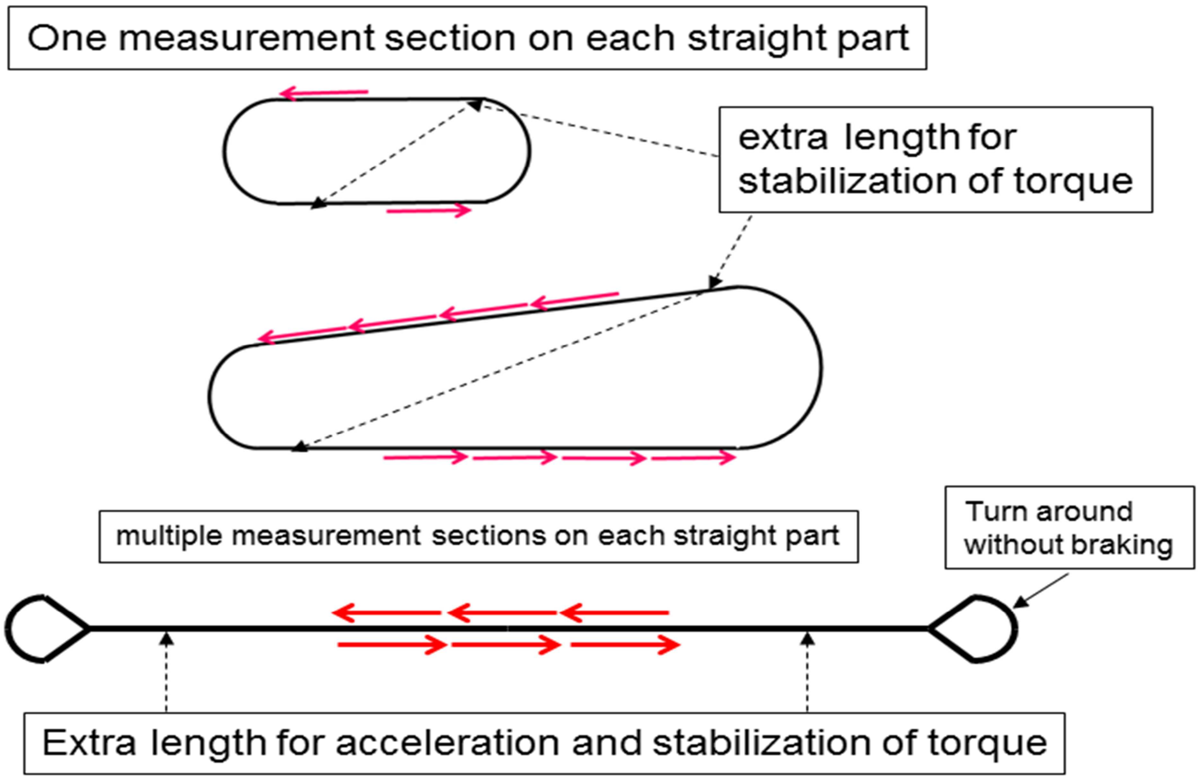


Figure 6. Proving ground geometry layouts

The track should consist of parts where it is possible to fit measurement areas. The vehicle should be able of entering the stabilisation part of a measurement area with the maximum speed. The surface has to be regular with a maximum longitudinal slope that shall not exceed ±1%. Each measurement section shall be made exclusively of asphalt or concrete. Different measurement section can be made of different materials. A standstill area should be present to stop the vehicle and perform drift check and zeroing of the torque meter.

Ambient and surface conditions

Conditions impacting on vehicle resistance to motion are summarised in Table 5.

Table 5. Ambient and surface conditions for the constant speed test.

Parameter	Condition
Ambient temperature	From 0°C to 25°C
Ground temperature	<40°C
Road surface	Dry
Wind specifications	• Average speed: ≤ 5 m/s • Gusts: ≤ 8 m/s • Yaw: ≤ 3° (≤ 5° misalignment test)

Table 6. Minimum sample rates of signals measured during the constant speed test.

Signal	Sample rate [Hz]	Remarks
Time	100	
Heading	≥4	
GPS position	≥4	There are requirements regarding the minimum number of digits
DGPS position	100	In case no optoelectronic barriers are used
DGPS velocity	≥20	
Airspeed and Yaw angle	≥4	
Torque	≥20	
Engine speed	≥20	Cardan speed for vehicles with torque converter not locked in a low-speed test
Ambient temperature	≥1	On vehicle measure
Ground temperature	≥1	
Trigger signal	100	In case opto-electronic barriers are used

Vehicle requirements

The vehicle should be tested without payload. Tyres have to be of the best class or second-best class for rolling resistance and be inflated at the maximum allowable pressure. No active tyre pressure control system should be used.

Measurement requirements

The instruments that are necessary for the test can be subject to fulfil requirements of accuracy, linearity, repeatability, crosstalk, measurement rate and range. All the requirements are specified and described in Annex VIII of the certification regulation.

The anemometer shall be mounted on a dedicated pole on the roof of the vehicle, on the longitudinal plane of symmetry in the 1st to the 3rd fourth of vehicle's length. The anemometer pole height has to be one-third of vehicle's height, with a tolerance ranging in between +0.0m and +0.2m.

The signals measured during the constant speed test also have to fulfil requirements about minimum sample rate. A summary of these requirements is presented in Table 6.

2.4.4 Execution of the constant speed test

The constant speed test comprises different phases including the preparation, warm-up and the actual test. The different phases are listed below:

- Preparation of vehicle and measurement systems
- Warm-up phase (min 90 minutes)
- Zeroing of torquemeters
- Warm-up phase (min 10 minutes)

- Low-speed test 1 (max 20 minutes)
- Warm-up phase (min 5 minutes)
- High-speed test (min 10 valid passes per heading)
- Low-speed test 2 (max 20 minutes)
- Drift check of torquemeters

To identify and correct the possible misalignment of the anemometer VECTO Air Drag processes some data measured during a test with the vehicle running at high speed in both directions of the test track. Five valid passes of a 250m ± 3m straight section should be performed in each driving direction. The data could be collected either during one of the warm-up phases, the high-speed test (fulfilling some specific requirements) or independently from the constant speed test (valid as long as the anemometer is not moved or dismounted between the misalignment test and the constant speed test).

The data collected during the misalignment calibration test will serve to estimate the misalignment error that affects the measurement of airflow yaw angle. The misalignment dataset is the first one to be processed with VECTO Air. At the end of the process, the misalignment error in degrees is shown and automatically kept into consideration for processing the data of the low speed and high-speed tests.

2.4.5 Post-Processing of the experimental data

Different files have to be prepared for running the air drag calculation. The files are summarised below:

- Vehicle data (csveh)
- Ambient condition data (csamb)
- Misalignment and calibration run data (csdat)
- Low speed 1 data (csdat)
- High-speed data (csdat)
- Low speed 2 data (csdat)
- Misalignment run measurement sections coordinates (csms)
- Low speed and high-speed tests measurement sections coordinates (csms)

The data measured during the constant speed test have to be put in the files with csdat extension, but their validity should be checked beforehand.

Data might be rejected because of:

- Invalidating events (technical errors, other vehicles disturbance, improper drive)
- Saturation events of instruments
- Torque meters' drifting over the limits of acceptance

Additional checks on the data are performed by VECTO Air Drag tool. All the measured data have to be aligned and re-sampled at 100Hz.

2.5 Vehicle simulator

The VECTO-simulator is the core component of the proposed methodology. The software simulates CO_2 emissions and fuel consumption based on longitudinal vehicle dynamics using a driver model for simulation of target speed cycles. The load required by the internal combustion engine is calculated internally in 1Hz steps based on the driving resistances, the power losses in the drive train system, and the power consumption of the vehicle auxiliary units. Engine speed is determined based on a gear-shifting model, the gear ratios, and the wheel diameter. Fuel consumption and CO_2 emissions are then interpolated from an engine fuel/CO_2 map.

Currently, in each timestamp, VECTO interpolates the engine fuel consumption based on the simulated engine speed and torque from an engine fuel map measured in steady state conditions at the engine test bed. A correction factor for transient operation is applied to the simulation results to overcome the shortcomings introduced by the use of steady state fuel map in for the simulation. This correction factor shall be determined based on the quotient of measured fuel consumption in a transient real-world cycle (most probably the WHTC) and the simulated fuel consumption for this cycle based on the steady state engine fuel map. More details on the procedure for obtaining the map and the correction function are provided by Luz et al. [2014].

The main characteristics of the current VECTO version can be summarised in the following list:

- Backwards-calculating, quasi-stationary longitudinal dynamics model with pre- and post-processing loops (e.g. for time to distance conversions, driving aids and WHVC corrections);
- Time-based or Distance-based cycles (time-steps may have varying duration, distance-steps must be at most 1min length);
- 1 s (1 Hz) Internal and Output time-steps;
- The driving model considers real-life driving behaviour (e.g. acceleration and breaking curves, gear shifting, coasting);
- Input and output via text-files;
- Implemented as Visual Basic. NET application (Windows);
- The graphical user interface for calculation control and editing of the primary input files;
- Declaration mode with locked-values and cryptographic signing of results for certification purposes

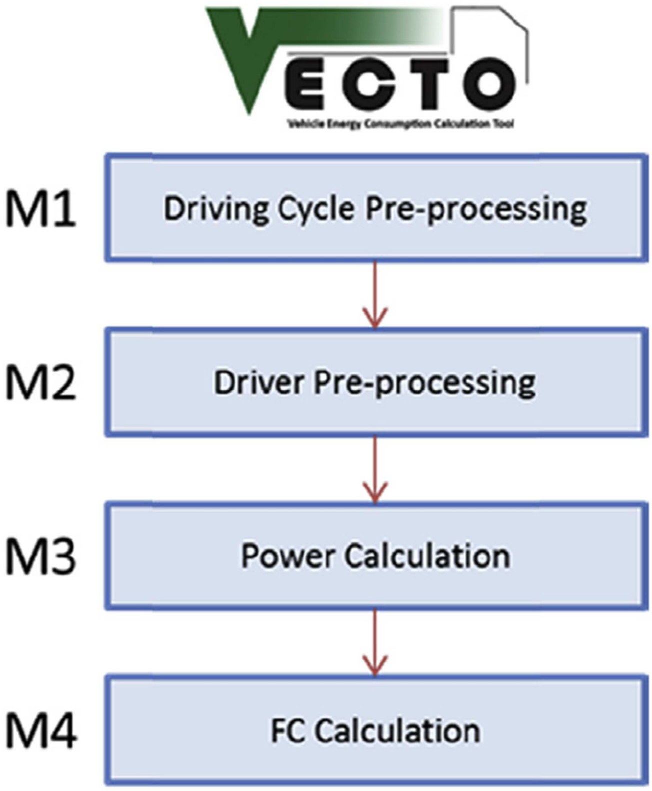


Figure 7. VECTO's simulation core

The simulation-core is summarised schematically in Figure 7. Additional information about the software and its functionality can be found in Fontaras et al. (2013) and Luz et al. (2014). A series of studies have shown that VECTO performs adequately and in a similar way as other established commercial or regulation oriented simulators Franco et al. (2015), ACEA (2013).

Table 7 briefly describes the available VECTO modes. The official (declaration) mode uses official values and input (as in certification) for all parameters (i.e. mass, road loads, gearbox, axle, engine) as well as predefined constant values for the auxiliaries. Declaration mode was not examined in the current study as it does not exist yet for buses and coaches. The engineering model uses as input values for mass, road loads and drive cycle those measured by the JRC. Additionally, VECTO considers power losses for gearbox, axle, engine and some of the auxiliaries. Engineering mode was applied in several tests and in particular to those conducted on-road. Finally, the P_{Wheel} mode requires the measured values of the torque at the wheel or at the half-shaft along with the measured engine RPM. All other input comes from the stock gearbox, axle and engine maps. The SiCo mode was applied in all executed tests. VECTO simulations were all run by the respective OEM with data provided by the JRC. Different versions of the tool were used depending on each OEM. The versions used by each OEM are given at the respective results section of this report.

Table 7. VECTO modes description.

Test	Mass & Road loads	Gearbox & Axle	Engine	Auxiliaries	Drive cycle
Declaration mode	Official values and input (certification)	Official values and input (certification)	Official values and input (certification)	Official values and input (certification)	Official values and input (certification)
Engineering mode	JRC tests (F0, F1, F2)	Official Values	Official Values	Official & JRC test values	Speed profile & slope JRC tests
P_{Wheel} Mode	Not relevant	Official Values	Official Values	Official & JRC test values	Wheel Torque, Engine RPM JRC tests

3 Air-drag measurements

3.1 Constant speed tests

JRC performed constant speed tests on two different vehicles provided by two different OEMs. The activities were performed on the proving ground of Balocco (Piedmont, Italy, Figure 8) on two different days (the first one in February and the second one in March 2017). The atmospheric and track conditions fulfilled the test procedure requirements as described in a previous paragraph.

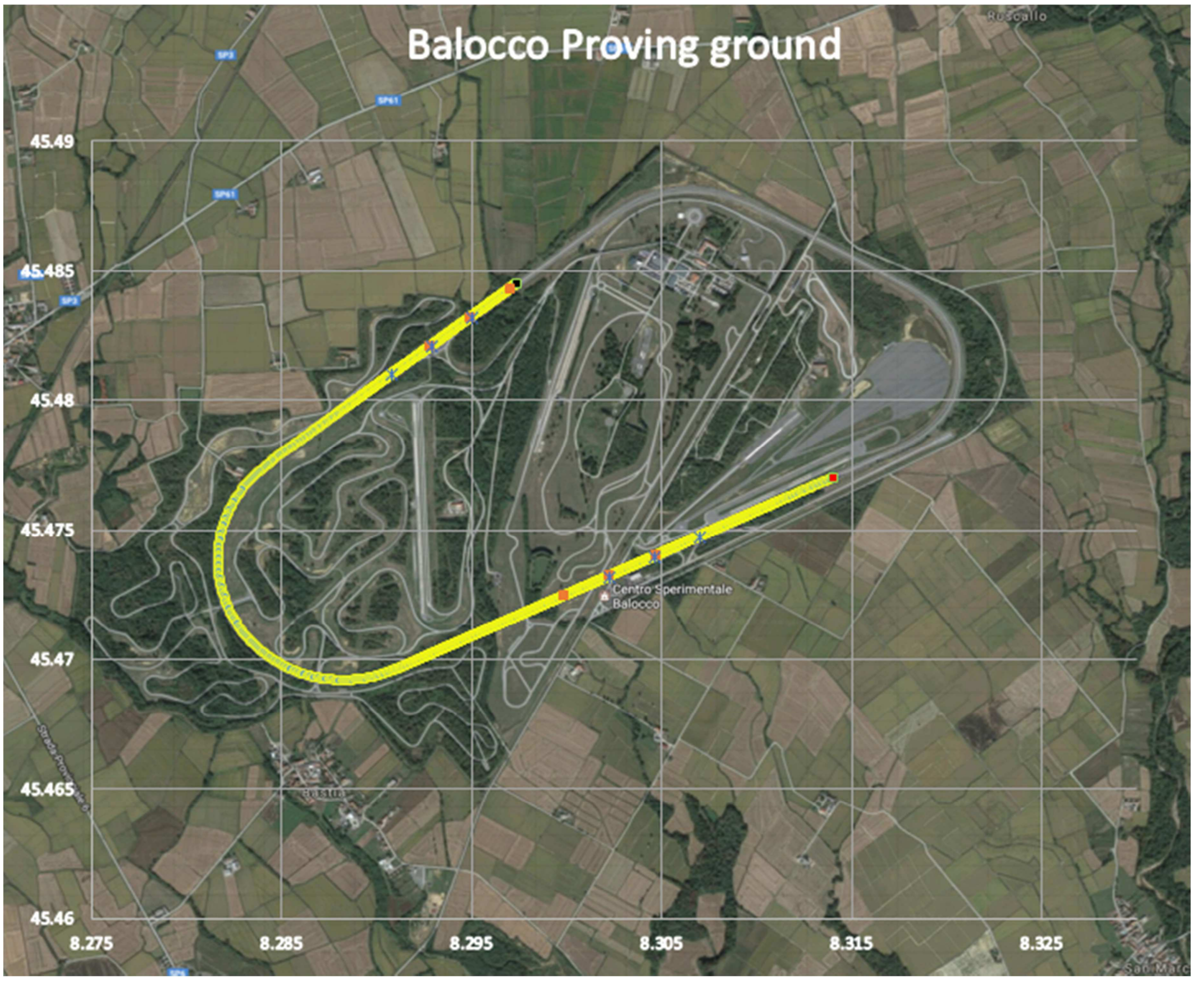


Figure 8. Visualisation of GPS data from the constant speed test

3.1.1 Vehicles and experimental setup

Vehicle data for the air-drag measurement tests are presented in Table 1, in which, for confidentiality reasons, many of the details are omitted and generic names are used. Additional to the parameters provided in Table 1 the frontal areas of the two vehicles (coach – 9.7 m^2 and interurban bus – 8.8 m^2) were considered for the calculations of the results of the air-drag test. For both Vehicle #1 and 2 the torquemeters were provided by the respective OEM, together with other on-board measurement instruments (OBD, temperatures, fuel flowmeters, etc.), while JRC followed the anemometer mounting, calibration and use. The testing procedure applied was the same for both vehicles.

3.1.2 Issues encountered

While performing the experimental activities and the post-processing of the data, some technical issues have been encountered. These issues led to the rejection of some of the experimental results or the need to apply some corrections to be able to use the data. For some specific calculations of the VECTO Air Drag tool, additional not valid measurements were found and rejected. The latter led to lack of data for some of the phases. In this case, it was necessary to slightly modify some of the constraints related to data validity and processing to run the VECTO Air Drag tool. The assumptions taken have a minor influence on the accuracy of the results.

Vehicle #1 - Issues

The main problems/possible source of errors encountered with Vehicle #1 are described below:

- It was not possible for JRC to perform the zeroing and the drift check of the torquemeters on the test track due to lack of dedicated tools and know-how. Controls on torquemeters were performed before the departure and after the return of the vehicle to and from the test track. However, according to the torquemeters supplier – and the respective OEM that supplied the vehicle – the specific model used in this case does not require zeroing and drift check since an auto-adjust feature is installed. JRC was not in the position to evaluate the function of the feature and accepted the equipment as it was.
- During the post-processing of the data, JRC realised that the values recorded during the constant speed test were not accurate. Original input data resulted in VECTO unrealistic values for C_dxA (low values) and rolling resistance (high values). After the examination of all possible sources of error, this behaviour was attributed to incorrect calibration of the torquemeters. However, the experimental activity had been already completed when the post-processing of the data started, and therefore it was not possible to repeat the test. An approach for correcting the values of the constant speed test which included the correction of the torquemeter signal was followed. For that reason, data obtained during chassis dyno testing were used in order to compare the real resisting torque applied by the dyno on the roller with the one measured with the torquemeters on the wheels of the vehicle. This comparison highlighted the calibration problem of the instruments (Figure 9) and returned a formula that was used to correct the experimental data from the constant speed test

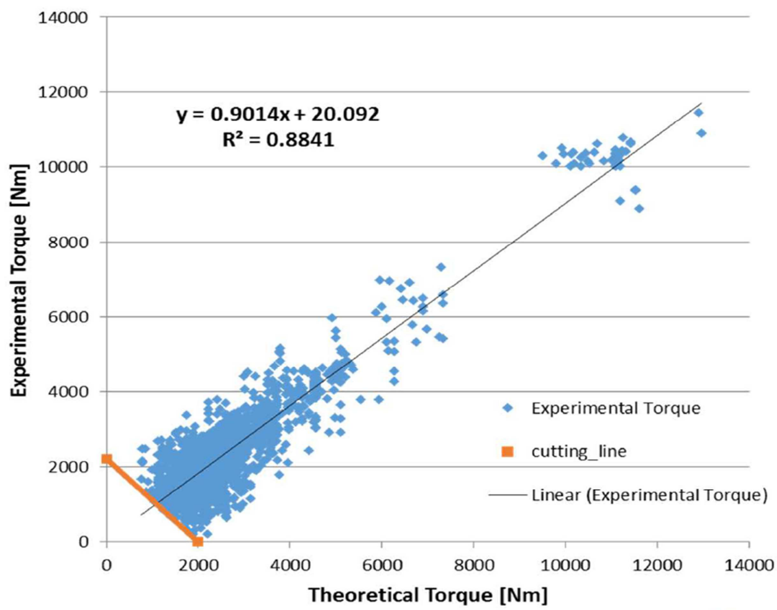


Figure 9. Torquemeters calibration on Vehicle #1

Vehicle #2 - Issues

In case of Vehicle #2 the most important issue had to do with the checks performed on the torquemeters during the constant speed test which highlighted a drifting behaviour outside of the tolerances reported in the test procedure document. The drift was found to be time-related (Figure 10 – Upper part). The discrepancy between the values indicated by the right and left instruments increased lap after lap with the time. To overcome this effect a linear correction (based on the time passed from the zeroing procedure) to the values recorded from the left torquemeter was applied. This fix returned a more credible torque at the wheel (Figure 10 – Lower Part), in which the left-right torquemeters discrepancy is constant among the laps driven in the same condition. Additionally, weather conditions during the constant speed test were not ideal due to intermittent rain. Since this phenomenon was of light intensity, it was still possible to perform the test in proper conditions for the definition of vehicle resistance to motion and the calculation of the C_dxA value. Anyhow, those laps in which the rain changed the surface properties had to be discarded.

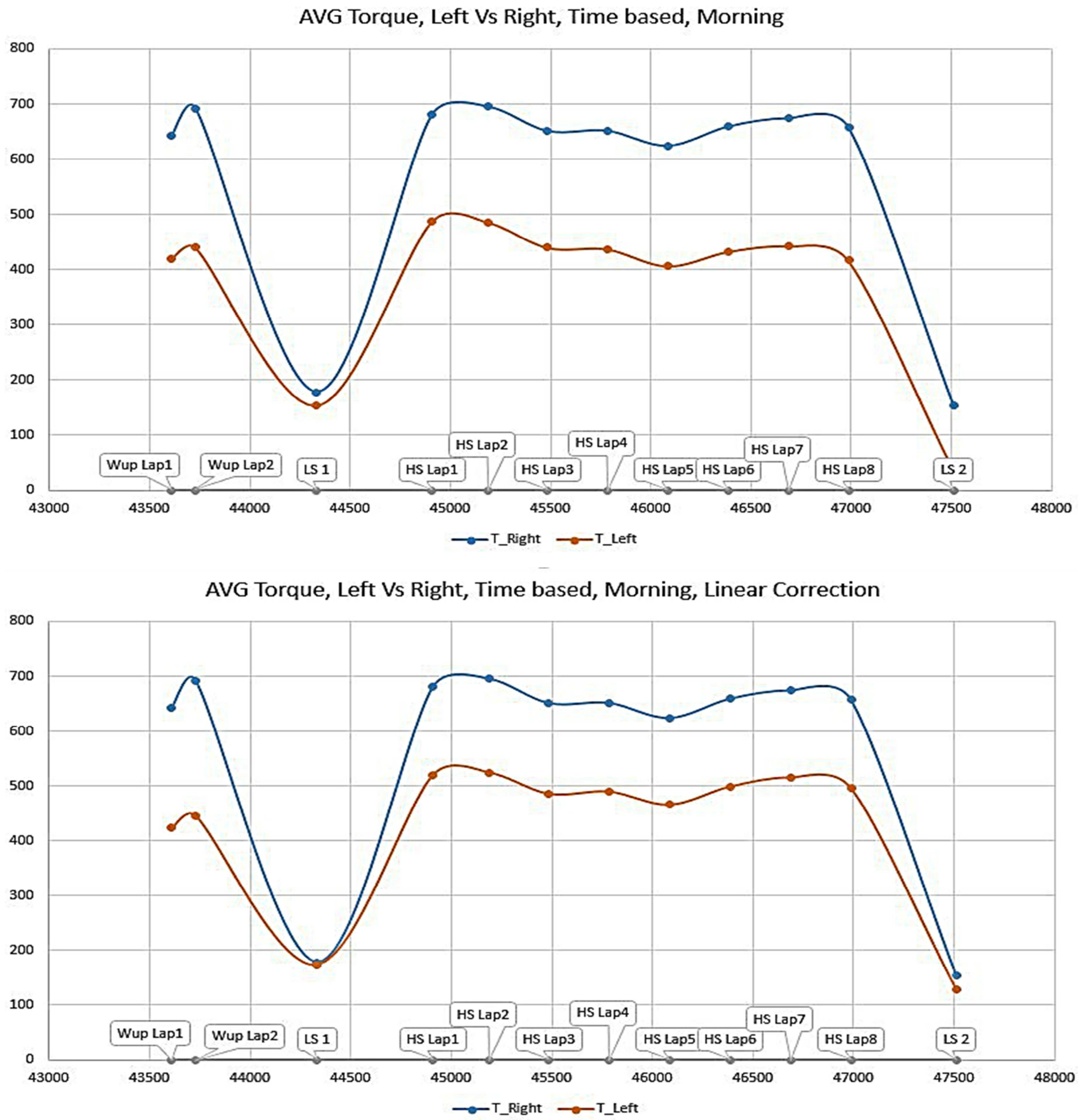


Figure 10. Torquemeters drifting with time and linear correction applied

3.1.3 Results

According to the regulation the data obtained during the track measurements have been aligned, re-sampled to 100 Hz, and post-processed with VECTO Air Drag tool. The deviations in the C_dxA and the Rolling Resistance Coefficient (RRC) values as they were measured and reported from the OEMs for each of the two vehicles are shown in Table 8. Despite the issues discussed in the previous section, high level of agreement was found between JRC results obtained from the constant speed test and OEM declared values, especially for Vehicle #2. The higher deviation with Vehicle #1 could be explained by the problems encountered with the torquemeters.

Table 8. Calculated deviations of C_dxA and Rolling Resistance (RRC).

	Vehicle #1	Vehicle #2
C_dxA deviation [%] (JRC vs OEM suggested value)	+5.95	+0.87
RRC deviation [%] (JRC vs OEM suggested value)	+8.82	+1.07

Real driving tests performed on the vehicles have been simulated with VECTO using the C_dxA obtained with the constant speed tests. The good level of the agreement obtained with regards to fuel consumption is an additional confirmation of the validity of the constant speed tests results.

4 CO_2 measurements

4.1 Chassis Dyno

The scope of the laboratory tests was twofold, to check the repeatability of the methodologies in the lab, under highly controlled conditions, and to investigate the quality of the simulations under different operating conditions. According to feedback received from involved stakeholders and indications from previous experimental campaigns, HDV's transient tests were expected to be reasonably repeatable in the laboratory even if there was no feedback for bus and coach measurements. Further to the test's robustness, the data would be used to compare the uncertainty of the simulation runs under transient conditions, and obtain a broader picture of VECTO's accuracy. These aspects have been covered for HD trucks in previous JRC studies (Fontaras et al. 2016; Grigoratos et al. 2017). Table 9 summarises the tests conducted with the two vehicles in the laboratory as well as the type of simulations run with VECTO.

Table 9. Combinations of tests and simulations for both tested vehicles in the lab.

Vehicle	Tested cycles	Ambient Test Conditions	VECTO Simulations	Auxiliaries Considered
Coach	VECTO coach	• Cold (1-3°C) • Standard (20-22°C) • Hot (32-35°C)	• Engineering Mode • P_{Wheel} Mode	• HVAC (Calculated) • Electric (Calculated) • Pneumatic (Std) • Steering Pump (Std) • Cooling fan (Std)
Interurban bus	• VECTO interurban • Real-World cycle	• Standard (20-22°C) • Hot (32-35°C)	• Engineering Mode	• HVAC (Estimated) • Electric (Calculated) • Pneumatic (Std) • Steering Pump (Std) • Cooling fan (Std)

4.1.1 Vehicle #1

Table 10 briefly summarises the main statistic parameters derived from transient testing of Vehicle #1 in the laboratory under different temperature conditions. Cold conditions refer to room temperature set at 1-3°C, normal conditions to a temperature of 20°C and hot conditions to temperatures close to 33-35°C (Table 9). Measurements over cold and normal ambient temperature conditions were conducted with minimised HVAC function (switched off in case of 20°C tests), while for hot tests HVAC was selected to be switched on with the respective signal being recorded for the estimation of the consumed energy (added to the VECTO simulations as P_{add}). All transient tests were performed with at least 1h warming up of the vehicle at high load conditions (90 km/h with 5% inclination).

All values presented in Table 10 are averaged over three measurements, while ± values correspond to the standard deviation of the three measurements. Vehicle Specific Fuel Consumption (VSFC) has been Normalised to the average value of all valid laboratory and on-road tests (g Fuel/kWh). The last column represents the relative standard deviation – % (coefficient of variation) of the three measurements for the VSFC (g Fuel/kWh), practically giving an indication for the repeatability of the cycle in the laboratory.

Table 10 shows that the VECTO coach cycle is highly repeatable in the laboratory under all tested conditions despite its long duration (~14906 s) and its relatively transient nature. Ambient temperature does not affect the repeatability of the cycle as coefficients of variation for vehicle speed and energy at the wheel do not exceed 1% in any of the testing conditions. When the VSFC values, as measured with AMA are examined, it is observed that there is a higher deviation under hot conditions most probably due to the non-identical functioning of the HVAC over the three repetitions (this is confirmed by the

HVAC data recorded). In some cases, there were some difficulties for the driver to reproduce some braking events as well as to follow some parts with high positive inclination. However, this was mainly due to the set-up of the dyno with a slightly higher C_dxA value compared to the realistic one (~5-6%). Finally, Normalised VSFC is significantly higher over the hot tests due to the higher auxiliaries' consumption, and in particular due to the usage of HVAC and the engine cooling fan.

Table 10. Averaged values derived from transient testing of vehicle #1 in the lab.

Test Conditions	Average Speed [km/h]	Energy at Wheel [kWh]	Normalised VSFC (AMA) [g/kWh]	Relative SD [%]
Cold	66.6±0.3	285.2±3.9	**0.987**	**2.4**
Normal	67.1±0.6	289.2±2.7	**0.952**	**0.2**
Hot	66.2±0.4	284.7±1.1	**1.080**	**4.5**

Table 11 briefly presents the comparison between measured and simulated FC values over the tested cycle for Vehicle #1. The comparison is performed with the results Normalised to the average of all valid measurements as the AMA analyser recorded them. Table 11 shows that the VECTO simulated FC (Engineering Mode) did match the experimentally measured values (AMA) closely. The difference between simulated and measured FC did not exceed 4.5% which is considered satisfactory based on the duration and the transient nature of the cycle. The deviations were somewhat higher when the VECTO P_{Wheel} mode was considered. The difference in the performance of the two VECTO modes can be attributed to the not very accurate input data in case of the P_{Wheel} mode, and more particularly to the not very accurate values of power at wheel (kW). This is due to the torquemeter device which in case of Vehicle #1 was not possible to re-calibrate or zero before and after each testing. In all cases, cold tests showed slightly higher deviations compared to standard temperature tests pointing to some underestimation of the auxiliaries function (P_{add}), while standard temperature tests were accurately simulated by both VECTO modes. Figure 11 depicts the Normalised simulated vs measured (=1.0) VSFC of vehicle #1 for laboratory tests (AMA) over different ambient conditions.

Table 11. Measured (AMA) vs simulated FC over VECTO coach cycle for Vehicle #1.

Test Conditions	Normalised VSFC – AMA [g/kWh]	Normalised VSFC – P_{Wheel} [g/h]	Normalised VSFC – Eng [g/h]	Deviation AMA vs. P_{Wheel} [%]	Deviation AMA vs. Eng [%]
Cold #1	0.969	0.909	0.937	**-6.2**	**-3.3**
Cold #2	1.004	0.956	0.968	**-4.7**	**-3.5**
Normal #1	0.953	0.940	0.931	**-1.4**	**-2.3**
Normal #2	0.950	0.940	0.937	**-1.1**	**-1.4**
Hot #1	1.134	1.080	1.085	**-4.8**	**-4.4**
Hot #2	1.043	0.998	1.000	**-4.2**	**-4.1**

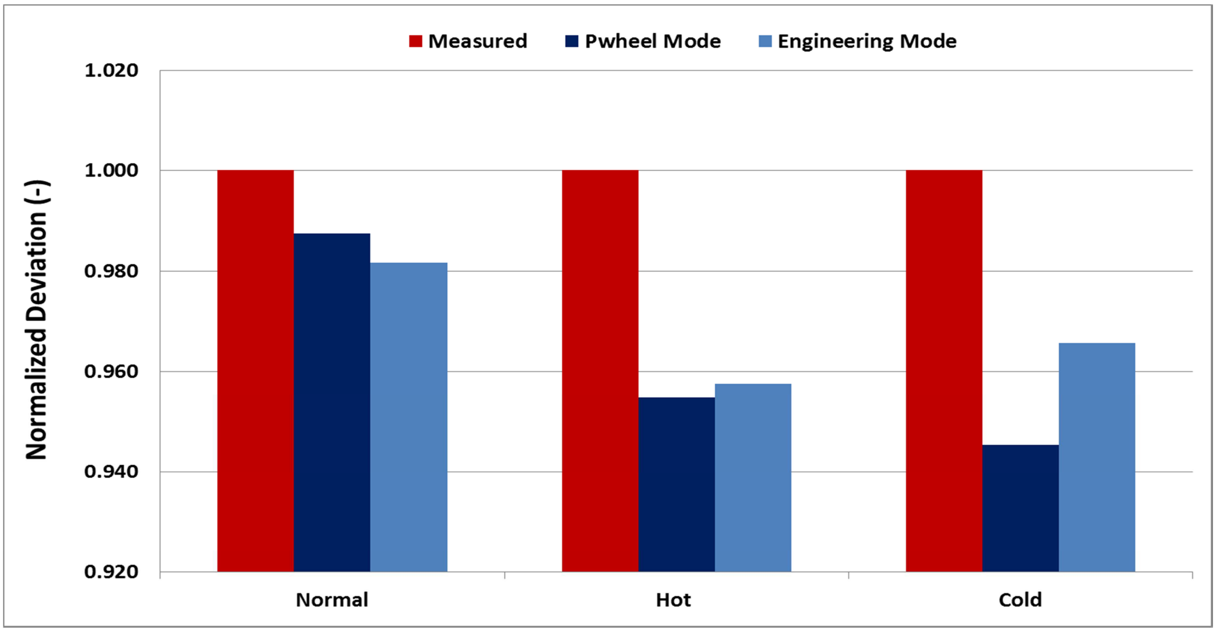


Figure 11. Normalised lab simulated vs measured (=1) FC deviation of Vehicle #1

Table 12 presents a similar comparison but with measurements from the fuel flowmeter (FFM) installed by the OEM. In this case, comparisons are performed with the results Normalised to the average of all valid measurements as the FFM recorded them. In both cases, simulated values were extracted from both VECTO Engineering and P_{Wheel} mode considering the limitation for auxiliaries described in Table 9. VECTO simulations were performed for two out of three available tests for each testing condition.

The picture changes significantly when FFM measured values are examined. In all cases measured values are lower than the VECTO simulated, regardless the VECTO mode. It appears that VECTO overestimates the FC in both Engineering and P_{Wheel} mode. Deviations goes up to almost 10% and only hot tests are simulated accurately (<3%). The FFM was installed by the OEM and there was no possibility to calibrate or crosscheck its good function. Therefore it was decided not to consider it as the primary instrument for the comparisons. P_{Wheel} mode again exhibited higher deviations compared to the Engineering mode, but this has been attributed to the not very accurate values of power at wheel (kW) used as VECTO input. Again cold tests showed higher deviations compared to normal tests pointing to some underestimation of the auxiliaries function (P_{add}).

Table 12. Measured (FFM) vs simulated FC over VECTO coach cycle for Vehicle #1.

Test Conditions	Normalised VSFC – FFM [g/kWh]	Normalised VSFC – P_{Wheel} [g/h]	Normalised VSFC – Eng [g/h]	Deviation FFM vs. P_{Wheel} [%]	Deviation FFM vs. Eng [%]
Cold #1	1.003	1.065	1.097	**6.1**	**9.4**
Cold #2	1.017	1.099	1.112	**8.1**	**9.4**
Normal #1	1.023	1.094	1.084	**6.9**	**5.9**
Normal #2	1.023	1.114	1.111	**8.9**	**8.6**
Hot #1	1.220	1.246	1.252	**2.2**	**2.6**
Hot #2	1.125	1.155	1.157	**2.7**	**2.8**

Overall, it is concluded that laboratory tests with the coach are highly repeatable regardless the testing conditions. VECTO Engineering mode simulates measured values well while VECTO P_{Wheel} mode shows somewhat higher deviations, particularly over cold ambient temperature tests. The difference in the performance of the two VECTO modes is attributed to the uncertainty and inaccuracy in some cases of the input data (mainly in the P_{Wheel} mode). Finally, FFM recorded significantly lower FC values compared to AMA, thus resulting in significantly higher deviations with the simulated values of both VECTO modes.

4.1.2 Vehicle #2

Table 13 briefly summarises the main statistic parameters derived from transient testing of Vehicle #2 in the laboratory under different temperature conditions. Normal conditions refer to temperature of 20°C and hot conditions to temperatures close to 33-35°C (Table 9). Measurements over normal conditions were conducted with minimised HVAC function, while for hot tests HVAC was selected to be switched on and set at its standard configuration. The VECTO interurban cycle was translated from distance based to time-based due to some difficulties encountered during its execution. Apart from the VECTO interurban cycle, a few repetitions of the real-world cycle were run under normal environmental conditions. This cycle was derived from the on-road tests and was translated to a dyno time-based script. All transient tests were performed with at least 1h warming up of the vehicle at high load conditions (90 km/h with 5% inclination).

All values presented in Table 13 are averaged over two measurements, while ± values correspond to the standard deviation of the measurements. VSFC has been Normalised to the average value of all valid laboratory and on-road tests (g Fuel/kWh). The last column represents the relative standard deviation – % (coefficient of variation) of the two measurements for the VSFC (g Fuel/kWh), practically giving an indication for the repeatability of the cycle in the laboratory.

Table 13. Averaged values derived from transient testing of vehicle #2 in the lab.

Test Conditions	Average Speed [km/h]	Energy at Wheel [kWh]	Normalised VSFC (AMA) [g/kWh]	Relative SD [%]
Interurban cycle - Normal	33.7±0.0	129.1±0.5	**1.084**	**3.4**
Interurban cycle - Hot	33.6±0.0	131.3±0.9	**1.141**	**0.1**
Real World cycle - Normal	32.1±0.1	64.5±1.5	**0.968**	**1.2**

Table 13 shows that the VECTO interurban cycle is highly repeatable in the laboratory under all tested conditions and despite its high transience. Ambient temperature does not affect the repeatability of the cycle as coefficients of variation for vehicle speed and energy at the wheel do not exceed 1% in any of the testing conditions. Higher Normalised VSFC is observed over the hot execution of the test due to the higher usage of the auxiliaries and in particular of the HVAC and the engine fan. In some cases, there were some difficulties for the driver to follow some parts with high positive road grade. However, this was mainly due to the set-up of the dyno with a slightly higher C_dxA value compared to the realistic one (~5%). Lower Normalised VSFC is observed over the real-world test cycle compared to the VECTO interurban cycle probably due to the less pronounced urban share of the cycle.

Table 14. Measured (AMA) vs simulated FC over transient testing for Vehicle #2.

Test Conditions	Normalised VSFC Measured [g/kWh]	Normalised VSFC VECTO Eng. Mode [g/h]	Deviation Measured vs Eng. [%]
Interurban cycle – Normal – Test 1	1.107	1.095	**-1.1**
Interurban cycle – Normal – Test 2	1.060	1.073	**1.2**
Interurban cycle – Hot – Test 1	1.140	1.144	**0.3**
Interurban cycle – Hot – Test 2	1.142	1.142	**0.0**
Real World cycle – Normal – Test 1	0.977	0.985	**0.9**
Real World cycle – Normal – Test 2	0.959	0.993	**3.6**

Table 14 briefly presents the comparison between measured and simulated VSFC values over the tested cycles for Vehicle #2. The comparison is performed over Normalised to the average of all valid measurements (laboratory and on-road) as the AMA analyser recorded them. Table 15 presents a similar comparison but with measurements from the FFM installed by the OEM. The comparison is performed over normalised to the average of all valid measurements (laboratory and on-road) as the FFM recorded them. In both cases, simulated values were extracted only from VECTO Engineering mode. VECTO P_{Wheel} mode is not currently available for the type of gearbox tested (AT-P). VECTO simulations were performed for both available tests for each testing condition/cycle.

Table 15. Measured (FFM) vs simulated FC over transient testing for Vehicle #2.

Test Conditions	Normalised VSFC Measured [g/kWh]	Normalised VSFC VECTO Eng. Mode [g/h]	Deviation Measured vs Eng. [%]
Interurban cycle – Normal – Test 1	1.049	1.065	**1.6**
Interurban cycle – Normal – Test 2	1.024	1.043	**1.9**
Interurban cycle – Hot – Test 1	1.200	1.112	**-7.3**
Interurban cycle – Hot – Test 2	1.212	1.110	**-8.4**
Real World cycle – Normal – Test 1	0.978	0.958	**-2.1**
Real World cycle – Normal – Test 2	0.959	0.966	**0.8**

Table 14 shows that the VECTO Engineering mode simulated experimentally measured values (AMA) accurately. The difference between simulated and measured FC did not exceed 4.0% which is considered satisfactorily based on the transient nature of the cycle. Similar observations come out when the FFM values are examined. FC values under normal environmental conditions are very close to the simulated values for both tested cycles. However, much higher deviations (~8%) are observed when the hot test is considered. In that case, VECTO significantly underestimates the FC meaning that the P_{add} used for the simulations was rather low. It is, however, strange that the same effect was not observed when AMA values were compared to the simulated values. Figure 12 presents the Normalised simulated vs measured (=1.0) VSFC of vehicle #2 for laboratory tests over different ambient conditions. Figure 12 focuses on the deviation between VECTO simulations and the AMA measurements.

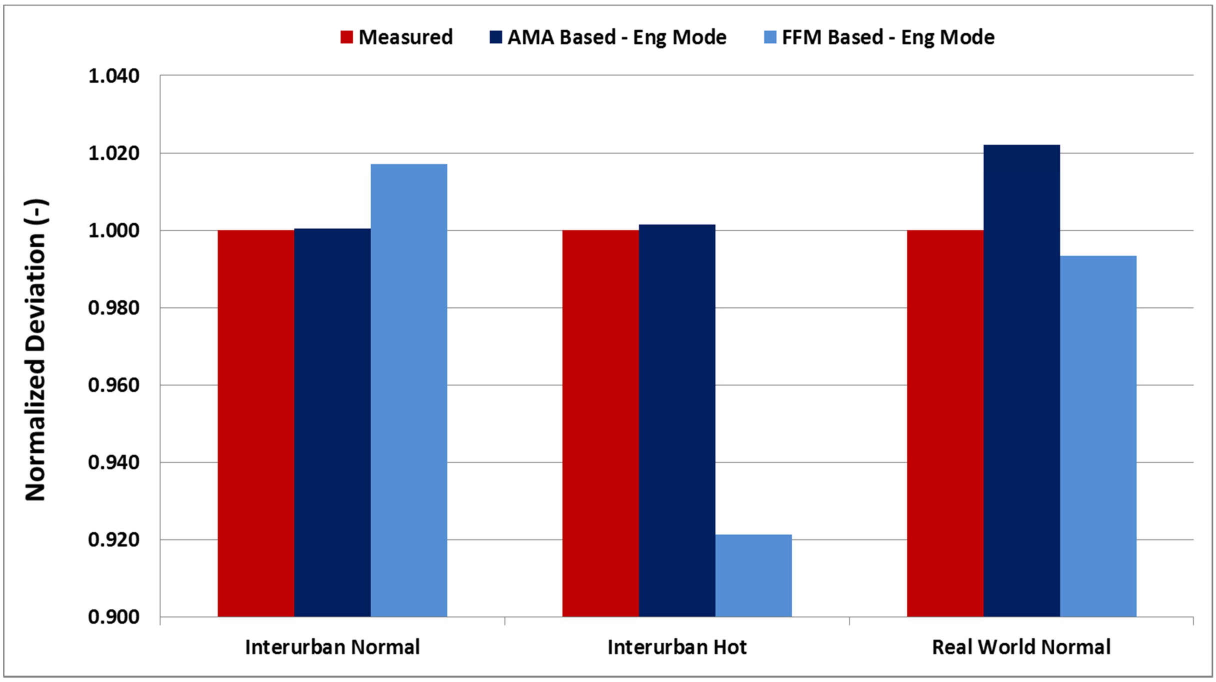


Figure 12. Normalised lab simulated vs measured (=1) FC deviation of Vehicle #2

Overall, it is concluded that laboratory tests with the interurban bus are highly repeatable regardless the cycle and testing conditions. VECTO Engineering mode simulates measured values satisfactorily. Deviation between measured and simulated values becomes high (8%) when hot tests are examined, and the FFM FC is considered.

4.2 On-road measurements

The scope of on-road tests was to check the repeatability of the applied methodology due to the high level of uncertainty compared to laboratory tests and to investigate the quality of the simulations under not controlled environment and operating conditions. Table 16 summarises the tests conducted with the two vehicles in the laboratory as well as the type of simulations run with VECTO.

The same PEMS system as in the laboratory was used for the analysis of CO_2 emissions on-road. The comparison between measured and simulated values on-road was conducted using PEMS CO_2 values corrected by a correlation factor which was calculated during the laboratory tests (AMA/PEMS). The reason for applying the correction factor is that AMA is more stable and reliable than PEMS, and therefore it was selected as the reference measurement system (Giechaskiel et al. 2018).

Table 16. Combinations of tests and simulations for both tested Vehicles on-road.

Test	Tested Route	Test Conditions	VECTO Simulations	Auxiliaries
Vehicle #1	Coach route (Chapter 2.3)	Normal (11-19°C)	• Engineering Mode • P_{Wheel} Mode	• HVAC (Calculated) • Electric (Calculated) • Pneumatic (Std) • Steering Pump (Std) • Cooling fan (Std)
Vehicle #2	Interurban route (Chapter 2.3)	Normal (11-19°C)	• Engineering Mode	• HVAC (Estimated) • Electric (Calculated) • Pneumatic (Std) • Steering Pump (Std) • Cooling fan (Std)

4.2.1 Vehicle #1

Table 17 gives an overview of on-road test results. Six on-road tests were performed, and three of them were selected for the analysis of the results. Measurements were conducted with minimised HVAC function and the respective signal being recorded for the estimation of the consumed energy (added to the VECTO simulations as P_{add}). All tests were performed with 30 min warming up of the vehicle at medium load conditions, and the first 15 min of the route were disregarded. This way a minimum of conditioning for the engine as well as for the gearbox and the axle was achieved as VECTO does not consider the cold behaviour of the components. Tests were performed over an average temperature of 14.8±3.9°C and 47±7% RH without any form of precipitation. Values given in the last row of Table 17 are averaged over the three selected measurements, and ± values correspond to the standard deviation of the three measurements. VSFC has been Normalised to the average value of all valid laboratory and on-road tests (g Fuel/kWh). The last column represents the relative standard deviation – % (coefficient of variation) of the three measurements for the VSFC (g Fuel/kWh).

Table 17 demonstrates that on-road tests of the coach proved to be highly repeatable despite the approximately 3h duration. The coefficient of variation over the three different tests was lower than 0.5%. Unlike transient tests in the laboratory, there are no specific difficulties for the driver to reproduce braking events over on-road tests because the driving behaviour is normal. All tests exhibited similar speed profile with an average speed close to 75 km/h.

Table 17. Averaged values derived from testing of vehicle #1 on-road.

Test	Average Speed [km/h]	Energy at Wheel [kWh]	Normalised VSFC (AMA/PEMS) [g/kWh]	Relative SD [%]
Test #1	73.5	173.1	0.980	-
Test #2	72.5	167.9	0.981	-
Test #3	74.4	172.9	0.986	-
Average	**73.5±1.0**	**171.3±2.9**	**0.982**	**0.3**

Table 18 presents the comparison between measured and simulated VSFC values over the three considered on-road tests. The comparison is performed over Normalised to the average of all laboratory and on-road measurements g Fuel/h values as recorded by the PEMS analyser and corrected based on AMA/PEMS correlation. Both VECTO P_{Wheel} and

Engineering mode were tested and compared to the measured FC values. Values given in the last row are averaged over the three tests, and ± values correspond to the SD of the three measurements. Table 19 presents a similar comparison to that of Table 18 but with measurements from the FFM installed by the OEM. The comparison is performed over Normalised to the average of all valid measurements as the fuel flowmeter recorded them. In both cases, simulated values were derived from VECTO Engineering and P_{Wheel} mode (Table 9).

As shown in Table 18 the average deviation between the measured and the simulated VSFC was found to be 1.6% with the VECTO SiCO mode and 3.2% with the VECTO Engineering mode. VECTO succeeded in reproducing the on-road tests of the coach similarly to what was reported previously by Fontaras et al. (2016) and Grigoratos et al. (2017) with 5 Euro VI trucks. The most accurate results were achieved with the P_{Wheel} mode meaning that the measured torque was of high accuracy. Figure 13 depicts the Normalised simulated vs measured (=1.0) VSFC of vehicle #1 for on-road tests.

Table 18. Measured (PEMS) vs simulated FC over on-road tests for Vehicle #1.

Test	Normalised VSFC – AMA [g/kWh]	Normalised VSFC – P_{Wheel} [g/h]	Normalised VSFC – Eng [g/h]	Deviation AMA vs. P_{Wheel} [%]	Deviation AMA vs. Eng [%]
Test #1	0.980	0.967	0.942	**-1.4**	**-3.9**
Test #2	0.981	0.969	0.958	**-1.2**	**-2.3**
Test #3	0.986	0.963	0.952	**-2.3**	**-3.5**
Average	**0.982**	**0.966**	**0.951**	**-1.6**	**-3.2**

Table 19. Measured (FFM) vs simulated FC over on-road tests for Vehicle #1.

Test	Normalised VSFC – FFM [g/kWh]	Normalised VSFC – P_{Wheel} [g/h]	Normalised VSFC – Eng [g/h]	Deviation FFM vs. P_{Wheel} [%]	Deviation FFM vs. Eng [%]
Test #1	0.871	0.961	0.936	**10.3**	**7.5**
Test #2	0.846	0.939	0.929	**11.0**	**9.8**
Test #3	0.872	0.957	0.946	**9.8**	**8.5**
Average	**0.863**	**0.952**	**0.937**	**10.4**	**8.6**

The picture changes completely when the FFM results are compared to VECTO simulations. It can be seen in Table 19 that the deviation between measured and simulated values are very high (~10%) regardless of the VECTO mode examined. It is either the FFM that underestimates significantly the FC or VECTO that overestimates the values leading to a high discrepancy.

Figure 13 depicts the Normalised simulated vs measured (=1.0) VSFC of vehicle #1 for the three valid on-road tests. Figure 12 focuses on the deviation between VECTO simulations and the reference instrument in this exercise (AMA).

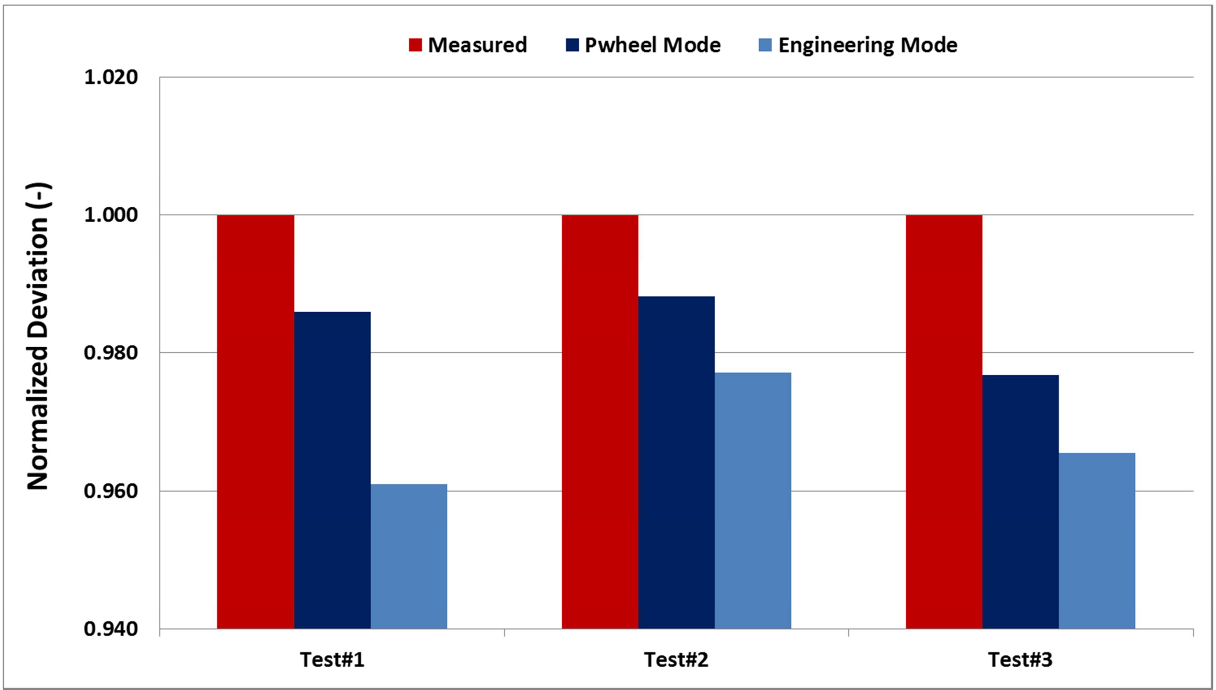


Figure 13. Normalised on-road simulated vs measured (=1) FC deviation

Overall, on-road tests proved to be highly repeatable in the case of the coach. This is not surprising if the high proportion of the motorway driven over the overall route of these vehicles is considered. There was a good agreement between measured and simulated values for both VECTO Engineering and SiCO mode when PEMS (AMA corrected) values were considered. On the other hand, there was a high deviation of both VECTO modes and the FFM measured values. In any case, it is seen that the VECTO tool seems to perform robustly as the coefficient of variation for the three measurements was found to be lower than 1.5% for both P_{Wheel} and the Engineering mode.

4.2.2 Vehicle #2

Table 20 gives an overview of on-road test results with Vehicle #2. Six on-road tests were performed, and three of them were considered for the analysis of the results. Measurements were conducted with minimised HVAC function. All tests were performed with 30 min warming up of the vehicle at medium load conditions, and the first 15 min of the route were disregarded. Tests were performed over an average temperature of 16.1±1.0°C without any form of precipitation. Values given in the last row of Table 20 are averaged over the 3 selected measurements, and ± values correspond to the standard deviation of the 3 measurements. VSFC has been Normalised to the average value of all valid laboratory and on-road tests (g Fuel/kWh). The last column represents the relative standard deviation – % (coefficient of variation) of the three measurements for the VSFC (g Fuel/kWh).

Table 20 demonstrates that on-road tests of the interurban bus proved to be highly repeatable in terms of average vehicle speed and total energy consumed. It also proved to be satisfactorily repeatable regarding VSFC. The coefficient of variation over the three different tests was lower than 5% with one test giving different results than the two others. Unlike transient tests in the laboratory, there are no specific difficulties for the driver to reproduce braking events over on-road tests because the driving behaviour is normal.

Table 20. Averaged values derived from testing of Vehicle #2 on-road.

Test	Average Speed [km/h]	Energy at Wheel [kWh]	Normalised VSFC (AMA/PEMS) [g/kWh]	Relative SD [%]
Test #1	32.2	57.8	0.897	-
Test #2	32.2	57.2	0.886	-
Test #3	32.4	54.1	0.831	-
Average	**32.2±0.1**	**56.4±2.2**	**0.872**	**4.5**

Table 21 presents the comparison between measured and simulated VSFC values over the three considered on-road tests of Vehicle #2. The comparison is performed over Normalised to the average of all laboratory and on-road measurements FC values [g Fuel/h] as recorded by the PEMS analyser and corrected based on AMA/PEMS correlation. Only VECTO Engineering mode was tested and compared to the measured FC values. Values given in the last row are averaged over the three tests, and ± values correspond to the SD of the three measurements. Figure 14 depicts the Normalised simulated vs measured (=1.0) VSFC of Vehicle #2 for the three valid on-road tests. Figure 14 focuses on the deviation between VECTO simulations and the reference instrument during this exercise (AMA).

Table 21. Measured (AMA/PEMS) vs simulated FC over on-road tests for Vehicle #2.

Test	Normalised VSFC AMA [g/kWh]	Normalised VSFC VECTO Eng Mode [g/h]	Deviation Measured vs. Eng Mode [%]
Test #1	0.897	0.933	**3.9**
Test #2	0.886	0.928	**4.7**
Test #3	0.831	0.907	**9.1**
Average	**0.872**	**0.922**	**5.8**

Table 22 presents a similar comparison to Table 21 but with measurements from the FFM installed by the OEM. The comparison is performed over Normalised to the average of all valid measurements as the instrument recorded them. In both cases, simulated values were extracted from VECTO Engineering and P_{Wheel} mode (Table 9).

Table 22. Measured (FFM) vs simulated FC over on-road tests for Vehicle #2.

Test	Normalised VSFC FFM [g/kWh]	Normalised VSFC VECTO Eng Mode [g/h]	Deviation Measured vs. Eng Mode [%]
Test #1	0.878	0.907	**3.4**
Test #2	0.871	0.902	**3.6**
Test #3	0.829	0.882	**6.3**
Average	**0.859**	**0.897**	**4.4**

As shown in Table 21 the average deviation between the measured (AMA/PEMS) and the simulated VSFC was found to be close to 6%. VECTO succeeded in reproducing two of the on-road tests relatively accurately (<5%) and failed in the third test (9.1%). VECTO significantly overestimated FC over the third test without any apparent reason. In all three tests, the P_{add} attributed to the auxiliaries was similar, and thus it could not be the source of the deviation between the different tests. A similar picture is observed when the FFM results are examined. It can be seen in Table 23 that the deviation between measured and simulated values is low for the two tests (<4%) and it increases over the third. However, FFM measurements, in this case, proved to be more accurately simulated by VECTO compared to the PEMS measurement. The overall deviation of the three tests was found to be lower than 4.5%.

Overall, on-road tests proved to be repeatable also in the case of the interurban bus despite the highly transient nature of the route. However, a more accurate calculation of the auxiliaries demand is necessary for the method to be applied successfully. FFM measured values proved to be much closer to these of PEMS and in all cases were more accurately simulated by VECTO Engineering mode.

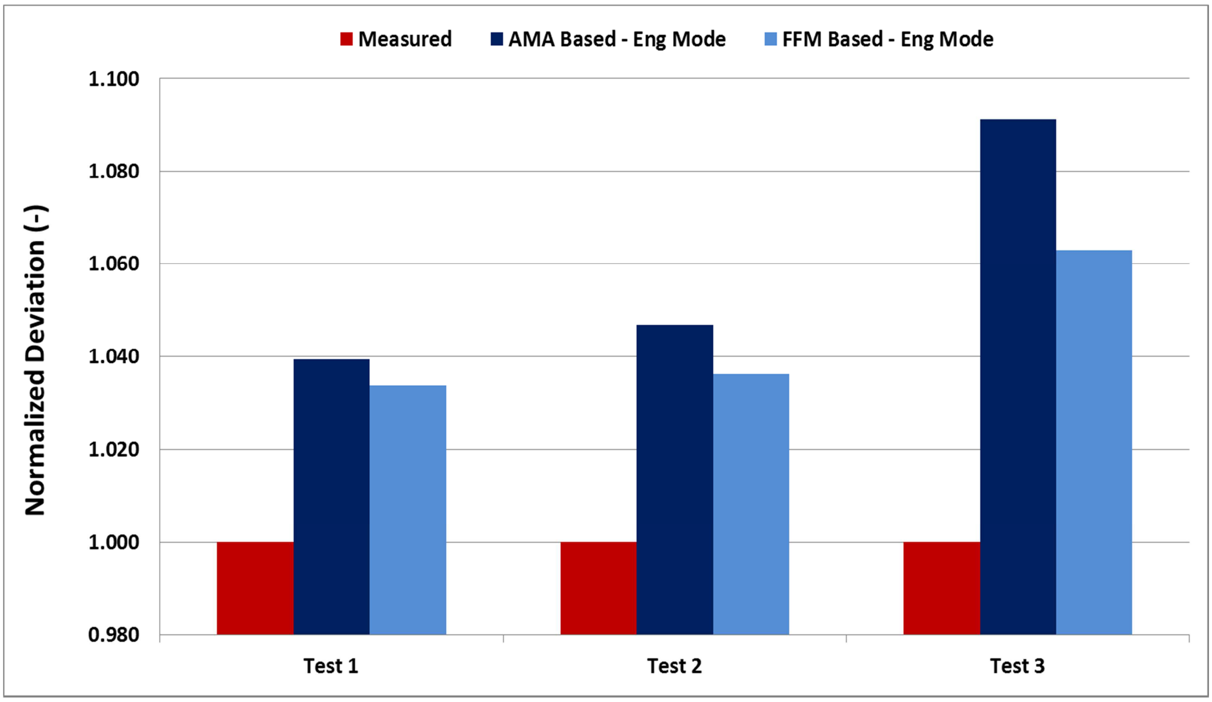


Figure 14. Normalised on-road simulated vs measured (=1) FC deviation

5 Conclusions

This Pre-Pilot Phase test campaign was conducted in two phases. The experimental phase took place between February and April 2017 in JRC and involved testing of two Euro VI buses in the laboratory and on-road. The simulations phase, took place between May 2017 and March 2018, during which each OEM performed simulations following the guidelines of the JRC. Afterwards, JRC performed an independent comparison between the results of the simulations and those of the measurements. The findings of the main evaluation phase are summarised in Table 23 and are briefly listed below:

Air-drag Tests

- Air-drag tests proved to be very accurate. The test is relatively simple and very well defined in the Annex VIII of the regulation. However, the vehicles should be equipped appropriately, and there is a need to perform the tests in a dedicated proving ground. Difficulties encountered during testing related to the malfunctioning or not accurate functioning of specific equipment as well as with non-compatible weather conditions. An advisable practice is to assess measurement data direcly on site.

Laboratory Transient Tests

- Laboratory tests showed very good measurement repeatability for both the interurban and coach cycles. Despite the long duration and high transient character of both cycles, the repeatability of the measurements was within 5% regardless of the testing conditions. The same also applies to the time based real world cycle tested in the case of the interurban bus.
- A satisfactory agreement was observed between measured and simulated FC for the coach. The deviation between tests and simulations was generally lower than 4% and only in few cases reached up to about 6%. VECTO Engineering mode provided more accurate results compared to the VECTO P_{Wheel} mode probably due to inaccuracies in the input data measured with the torquemeter. Deviations between measured and simulated values were higher when the fuel flowmeter values were considered. On the other hand, the interurban bus demonstrated much lower deviations between measured and simulated values with only, however, the Engineering mode being available. FC values from the AMA and the fuel flowmeter were comparable unlike in the case of the coach.
- Despite the overall positive results, there are various drawbacks related to a transient testing method in the laboratory. First of all, there are difficulties for the driver to reproduce some braking events and accelerate the vehicle under high gradient conditions. Another problem has to do with the definition of the road loads during the set-up of the dyno. If these values are not known in advance, there is the risk to run the tests under non-normal resistance conditions. Also, some vehicles currently, and more vehicles in the future, are equipped with sensors or GPS systems that define the operation of individual components (e.g. gearbox) according to certain external parameters. The effect of such systems is excluded when testing on a dyno. Finally, there is a need for expensive and difficult to maintain equipment (chassis dyno, special braking trailers).

On-road Tests

- On-road tests proved to be highly repeatable regardless of the route. The coefficient of variation of VSFC measurements over three repetitions was 0.5% for the coach and 4.5% for the interurban bus. The difference can be attributed to the higher transient nature of the interurban route compared to the coach route. This result is in-line with the conclusions drawn during the truck campaign published in 2017 [Grigoratos et al. 2017].
- Overall, a good agreement between measured (AMA/PEMS) and simulated FC values was observed over on-road tests with the deviation not exceeding 5%. When the OEM fuel flowmeter measurements are considered the divergence is

very high for the coach (~10%) and very low for the interurban bus (4.5%). VECTO Engineering mode proved to be more precise in simulating measured FC values compared to P_{Wheel} mode (coach). Overall, it seems that VECTO is capable of providing reliable results over on-road tests despite the difficulty in attributing actual auxiliary values.

- On-road tests seem to be a good solution for the ex-post verification procedure as they overcome most of the drawbacks related to the laboratory-based testing methodologies (list above).

On-road tests seem to be a good solution for the ex-post verification procedure as they overcome most of the drawbacks related to the laboratory-based testing methodologies (list above).

Table 23. Summarised findings of the evaluation phase.

Option	Chassis Dyno Transient Tests	On-road Tests
Repeatability	Very good	Very good
Representativeness of actual vehicle operation	High with some restrictions in brake applications & acceleration phases over high road gradient	Highest
Applicability to buses and coaches	Restrictions for some categories over a certain length	Without restrictions
Cost	High due to specific equipment required and high maintenance costs of the laboratory facilities	High due to specific equipment required
Complexity	Medium provided all equipment available. There is a need for dealing with the auxiliaries	Medium if specific test protocol is established. Still there is a need for dealing with the auxiliaries
Test Data analysis	Low	Medium due to need for specific boundary conditions
Maturity (how close to actual implementation)	Poor - New protocol is required	Fair - Elements from PEMS protocol and verification tests for trucks can be adopted

References

ACEA; Evaluation of VECTO tool. In: Clima JD, editor. ACEA report communicated to the European Commission; 2013

AEA-Ricardo; Reduction and testing of GHG emissions from HDVs - Final Report. 2011. http://ec.europa.eu/clima/policies/transport/vehicles/docs/ec_hdv_ghg_strategy_en.pdf

European Commission 2017; COMMISSION REGULATION (EU) 2017/2400; Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R2400&from=EN

Fontaras G., Grigoratos T., Savvidis D., Anagnostopoulos K., Luz R., Rexeis M., Hausberger S.; An experimental evaluation of the methodology proposed for the monitoring and certification of CO_2 emissions from heavy-duty vehicles in Europe; Energy 102 (2016) 354-364

Fontaras G., Rexeis M., Dilara P., Hausberger S., Anagnostopoulos K.; The development of a simulation Tool for monitoring heavy-duty vehicle CO_2 emissions and fuel consumption in Europe. 2013. SAE Technical Paper 2013-24-0150

Franco V., Delgado O., Muncrief R.; Heavy-duty vehicle fuel-efficiency simulation: A comparison of US and EU tools. April 2015. ICCT report – White Paper, Available at: http://www.theicct.org/sites/default/files/publications/ICCT_GEM-VECTO-comparison_20150511.pdf

Giechaskiel B., Riccobono F., Villafuerte PM., Grigoratos T.; Particle Number (PN) - Portable Emissions Measurement Systems (PEMS). Heavy Duty Vehicles Evaluation phase at the Joint Research Centre (JRC); JRC Science for Policy Report. 2016

Giechaskiel B., Suarez-Bertoa R., Lähde T., Clairotte M., Carriero M., Bonnel P., Maggiore M.; Evaluation of NOx emissions of a retrofitted Euro 5 passenger car for the Horizon prize "Engine retrofit"; Environmental Research Volume 166, October 2018, Pages 298-309

Grigoratos T. and Fontaras G.; Ex-post Verification – SiCO and VECTO validation exercise Preliminary Results; September 2016. Editing Board

Grigoratos T., Fontaras G. Giechaskiel B. Ciuffo B.; Assessment of the Monitoring Methodology for CO_2 Emissions from Heavy Duty Vehicles; EUR 28409 EN, doi:10.2760/081827

Luz R., Rexeis M., Hausberger S., Jajcevic D., Lang W., Schulte L.E.; Development and validation of a methodology for monitoring and certification of greenhouse gas emissions from heavy duty vehicles through vehicle simulation. 2014. Final Report. Available at: https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/heavy/docs/draft_certification_en.pdf

List of abbreviations and definitions

ACEA	European Automobile Manufacturers' Association
CLD	ChemiLuminescence Detector
CVS	Constant Volume Sampler
DPF	Diesel Particulate Filter
EC	European Commission
EFM	Exhaust Flow Meter
FC	Fuel Consumption
FFM	Fuel Flow Meter
FTIR	Fourier Transform Infra-Red spectrometer
GPS	Global Positioning System
HDV	Heavy Duty Vehicle
HEPA	High Efficiency Particulate Air filter
HFID	Heated Flame Ionisation Detector
JRC	Joint Research Centre
NDIR	Non-Dispersive Infra-Red sensor
NDUV	Non-Dispersive Ultra-Violet sensor
OBD	On-Board Diagnostics
PEMS	Portable Emissions Measurement System
PN	Particle Number
RD	Regional Delivery cycle
SCR	Selective Catalyst Reduction of NO_x
SiCO	Simplified Constant Speed Test
SS	Steady State
THC	Total Hydrocarbons
VECTO	Vehicle Energy consumption Calculation Tool
VSFC	Vehicle Specific Fuel Consumption
VELA	Vehicle Emissions Laboratories
WHTC	World harmonised transient cycle
WHVC	World harmonised vehicle cycle

List of tables

Table 1. Main vehicle characteristics. 8
Table 2. Main characteristics of the VECTO bus related cycles. 10
Table 3. Driving phase distributions and average speeds of on-road trips. 13
Table 4. Instruments required for constant speed test on the test track. 14
Table 5. Ambient and surface conditions for the constant speed test. 15
Table 6. Minimum sample rates of signals measured during the constant speed test. ...16
Table 7. VECTO modes description. 19
Table 8. Calculated deviations of C_dxA and Rolling Resistance (RRC). 23
Table 9. Combinations of tests and simulations for both tested vehicles in the lab. 24
Table 10. Averaged values derived from transient testing of vehicle #1 in the lab. 25
Table 11. Measured (AMA) vs simulated FC over VECTO coach cycle for Vehicle #1. 25
Table 12. Measured (FFM) vs simulated FC over VECTO coach cycle for Vehicle #1......26
Table 13. Averaged values derived from transient testing of vehicle #2 in the lab. 27
Table 14. Measured (AMA) vs simulated FC over transient testing for Vehicle #2. 28
Table 15. Measured (FFM) vs simulated FC over transient testing for Vehicle #2. 28
Table 16. Combinations of tests and simulations for both tested Vehicles on-road. 30
Table 17. Averaged values derived from testing of vehicle #1 on-road. 30
Table 18. Measured (PEMS) vs simulated FC over on-road tests for Vehicle #1. 31
Table 19. Measured (FFM) vs simulated FC over on-road tests for Vehicle #1. 31
Table 20. Averaged values derived from testing of Vehicle #2 on-road. 33
Table 21. Measured (AMA/PEMS) vs simulated FC over on-road tests for Vehicle #2. ...33
Table 22. Measured (FFM) vs simulated FC over on-road tests for Vehicle #2. 34
Table 23. Summarised findings of the evaluation phase. 36

KJ-NA-29372-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub

ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2760/74053

ISBN 978-92-79-94184-9