Component certification for HDV CO_2 determination

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20th February 2018

G20 Transport Task Group:

Deep Dive to Support Heavy-Duty Vehicle Efficiency Labeling and Standards Meeting #3

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

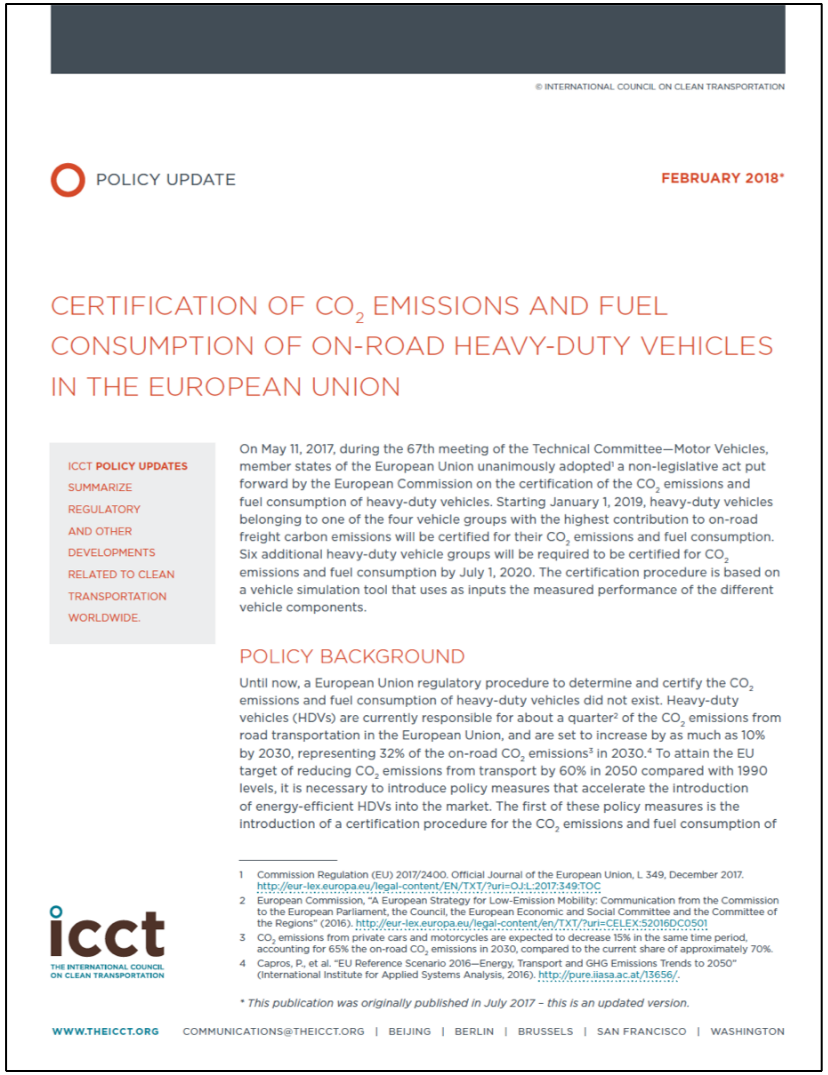
Takeaway messages from last Deep Dive Call

- **VECTO and GEM show very good agreement** when simulated over a large set of identical inputs (vehicle configurations)

- **Both GEM and VECTO can be adapted to account for the differences across regions.**

- The accurate simulation of CO_2 emissions of HDVs is more dependent on the component input data than on the selected model (VECTO vs GEM). **Harmonization of component certification benefits the implementation of future regulatory measures.**

"Certification of CO_2 emissions and fuel consumption of on-road heavy-duty vehicles in the European Union" (2018)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POLICY UPDATE

FEBRUARY 2018*

CERTIFICATION OF CO_2 EMISSIONS AND FUEL CONSUMPTION OF ON-ROAD HEAVY-DUTY VEHICLES IN THE EUROPEAN UNION

ICCT POLICY UPDATES SUMMARIZE REGULATORY AND OTHER DEVELOPMENTS RELATED TO CLEAN TRANSPORTATION WORLDWIDE.

On May 11, 2017, during the 67th meeting of the Technical Committee—Motor Vehicles, member states of the European Union unanimously adopted[1] a non-legislative act put forward by the European Commission on the certification of the CO_2 emissions and fuel consumption of heavy-duty vehicles. Starting January 1, 2019, heavy-duty vehicles belonging to one of the four vehicle groups with the highest contribution to on-road freight carbon emissions will be certified for their CO_2 emissions and fuel consumption. Six additional heavy-duty vehicle groups will be required to be certified for CO_2 emissions and fuel consumption by July 1, 2020. The certification procedure is based on a vehicle simulation tool that uses as inputs the measured performance of the different vehicle components.

POLICY BACKGROUND

Until now, a European Union regulatory procedure to determine and certify the CO_2 emissions and fuel consumption of heavy-duty vehicles did not exist. Heavy-duty vehicles (HDVs) are currently responsible for about a quarter[2] of the CO_2 emissions from road transportation in the European Union, and are set to increase by as much as 10% by 2030, representing 32% of the on-road CO_2 emissions[3] in 2030.[4] To attain the EU target of reducing CO_2 emissions from transport by 60% in 2050 compared with 1990 levels, it is necessary to introduce policy measures that accelerate the introduction of energy-efficient HDVs into the market. The first of these policy measures is the introduction of a certification procedure for the CO_2 emissions and fuel consumption of

1 Commission Regulation (EU) 2017/2400. Official Journal of the European Union, L 349, December 2017. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2017:349:TOC

2 European Commission, "A European Strategy for Low-Emission Mobility: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions" (2016). http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52016DC0501

3 CO_2 emissions from private cars and motorcycles are expected to decrease 15% in the same time period, accounting for 65% the on-road CO_2 emissions in 2030, compared to the current share of approximately 70%.

4 Capros, P., et al. "EU Reference Scenario 2016—Energy, Transport and GHG Emissions Trends to 2050" (International Institute for Applied Systems Analysis, 2016). http://pure.iiasa.ac.at/13656/.

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* This publication was originally published in July 2017 – this is an updated version.

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- ICCT policy update describing the key aspects of the CO_2 certification methodology for HDVs in the EU, and the related component certification.

- Rodríguez, F. (2018). *Certification of CO_2 emissions and fuel consumption of on-road heavy-duty vehicles in the European Union* (Policy update). International Council on Clean Transportation. https://www.theicct.org/publications/certification-co2-emissions-and-fuel-consumption-road-heavy-duty-vehicles-european

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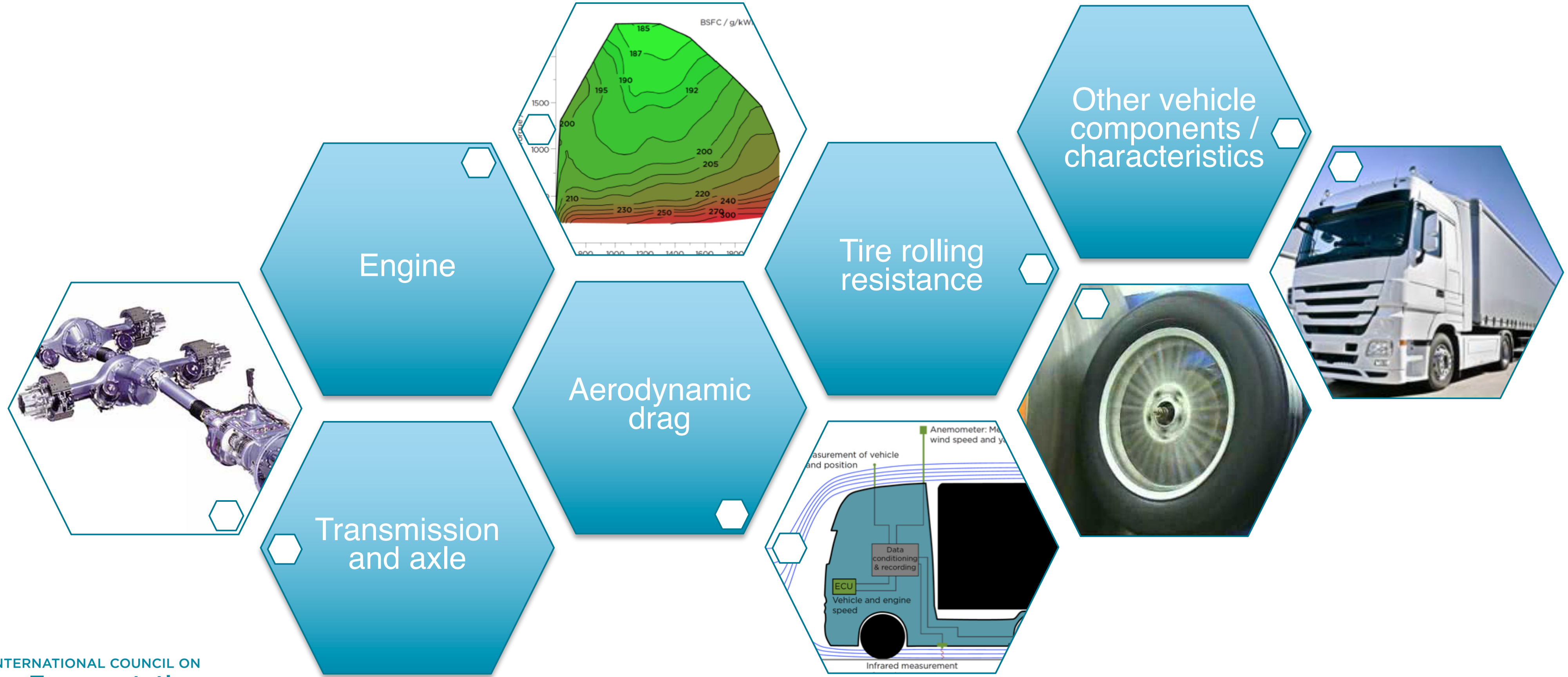
Certified component performance data

There are five key components that are measured to provide the necessary input for the simulation tools



Regulations for component certification in the EU and the US

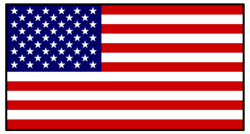
- **Regulation (EU) 2017/2400** of 12 December 2017 implementing Regulation (EC) No 595/2009 of the European Parliament and of the Council as regards the determination of the CO_2 emissions and fuel consumption of heavy-duty vehicles and amending Directive 2007/46/EC of the European Parliament and of the Council and Commission Regulation (EU) No 582/2011.

  Official Journal of the European Union, L *349*.

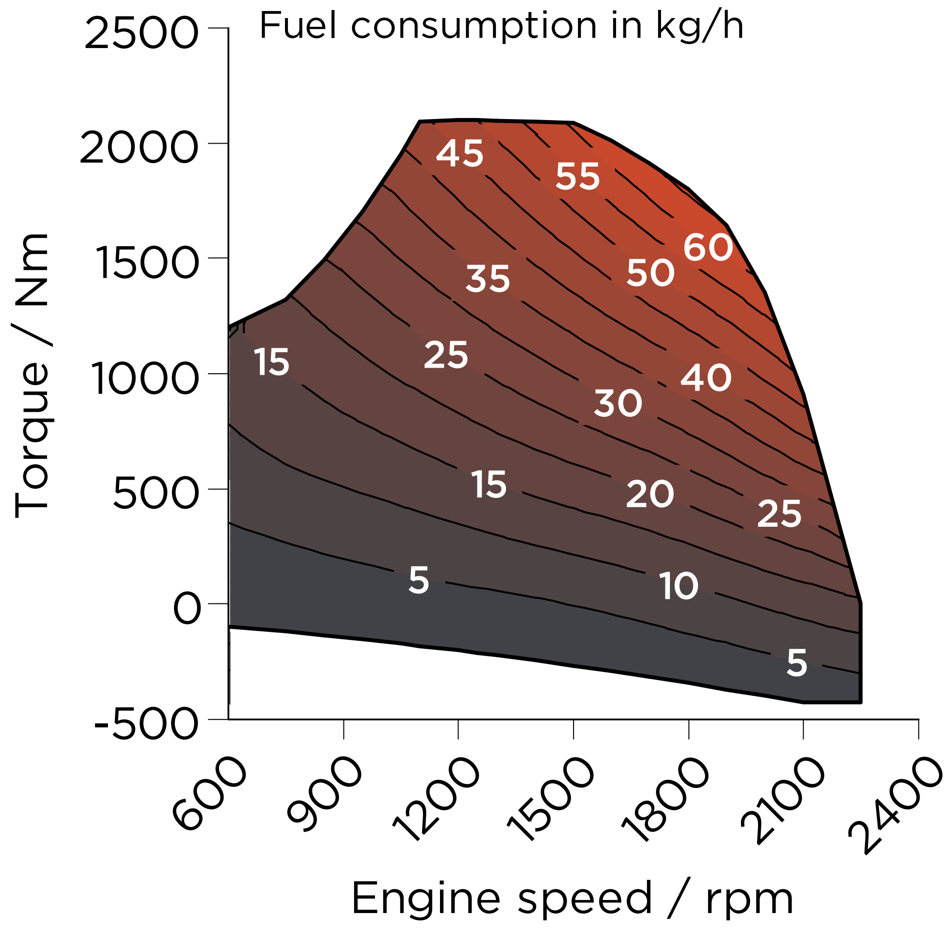
  http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2017:349:TOC

- Final Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2 **(Federal Register / Vol. 81, No. 206)**.

  https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf

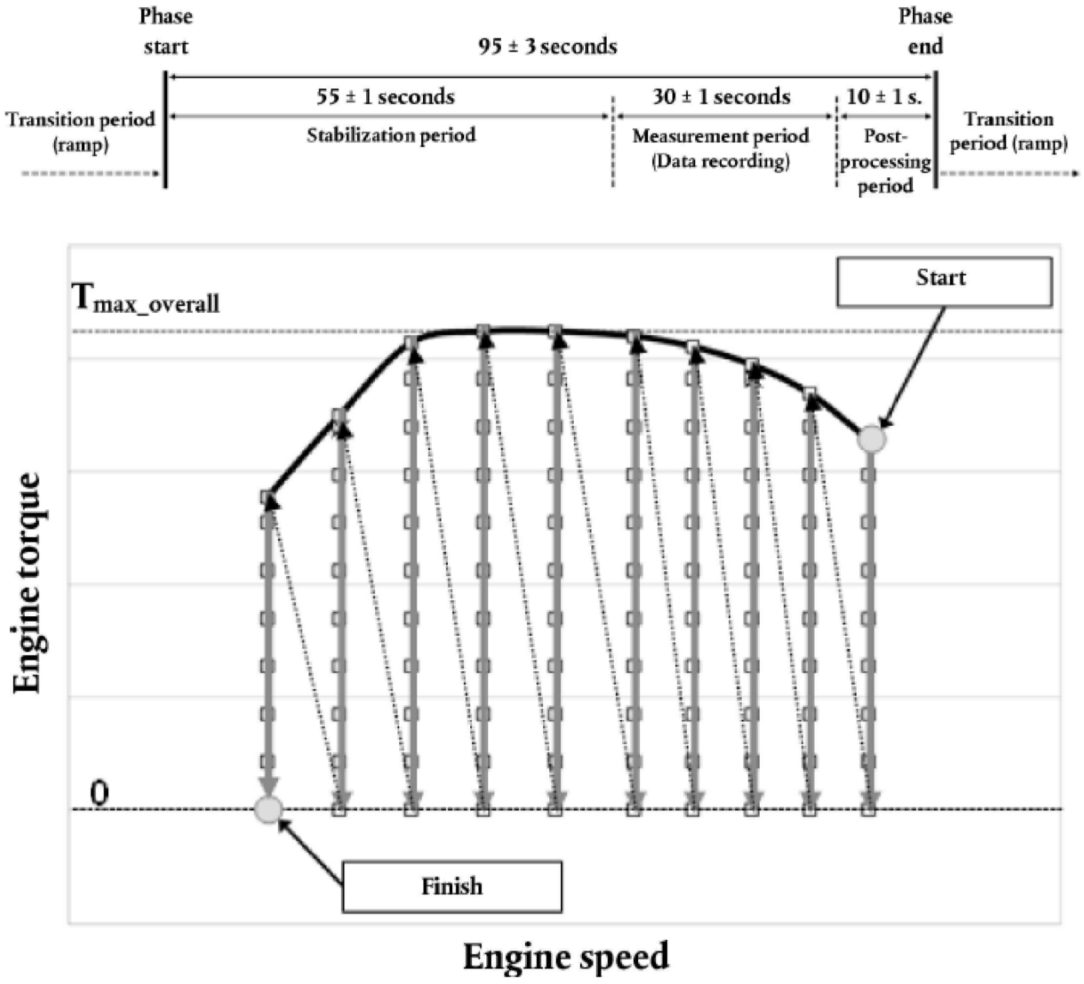


Engine fuel consumption certification

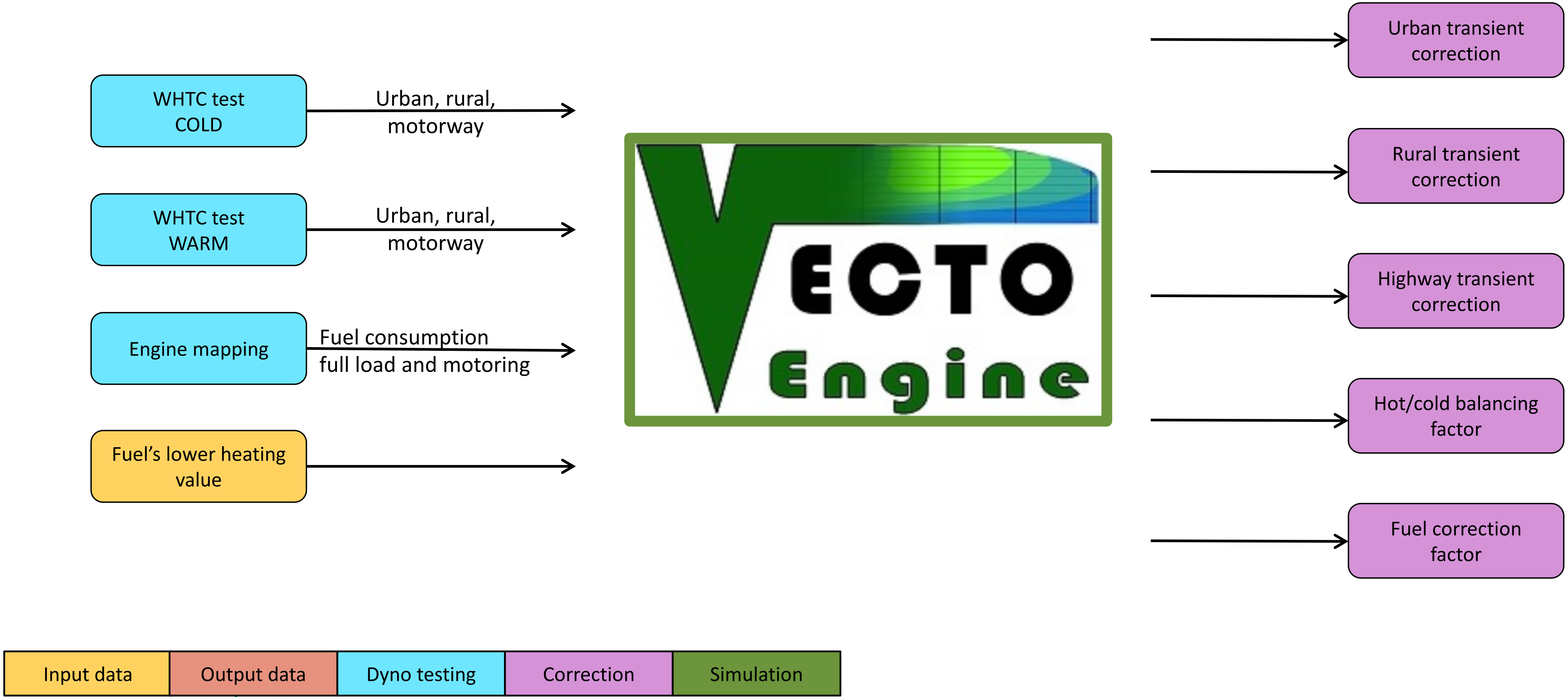


Overview of the engine mapping procedure in the EU

- **UN/ECE Regulation 49 Rev.06** (https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2013/R049r6e.pdf) summarizes laboratory test conditions, measurement equipment specifications, and testing procedures for type approval.
- The engine mapping cycle (See EU 2017/2400 Annex IV: http://eur-lex.europa.eu/eli/reg/2017/2400/oj) measures the steady-state **fuel flow** over a fixed speed-torque grid defined by the regulation.



Engine transient correction procedure in the EU



Overview of the engine mapping procedure in the US

- Emissions are sampled using the equipment and procedures outlined in **40 CFR part 1065**
- The fuel mapping procedure is described in **§1036.535**
- Steady-state map
  - Used for highway cruise cycles (55 mph and 65 mph)
  - Very similar procedure to the EU
- Cycle-averaged map
  - Used for transient cycle (ARB transient)
  - Optional for highway cycles (55mph and 65 mph)

Engine transient correction procedure in the US

Phase 2 GEM cycle generator

GREENHOUSE GAS EMISSIONS MODEL
GEM P2v3.0

Minimum 8 standard vehicle configurations

Engine mapping

Fuel consumption
full load and motoring

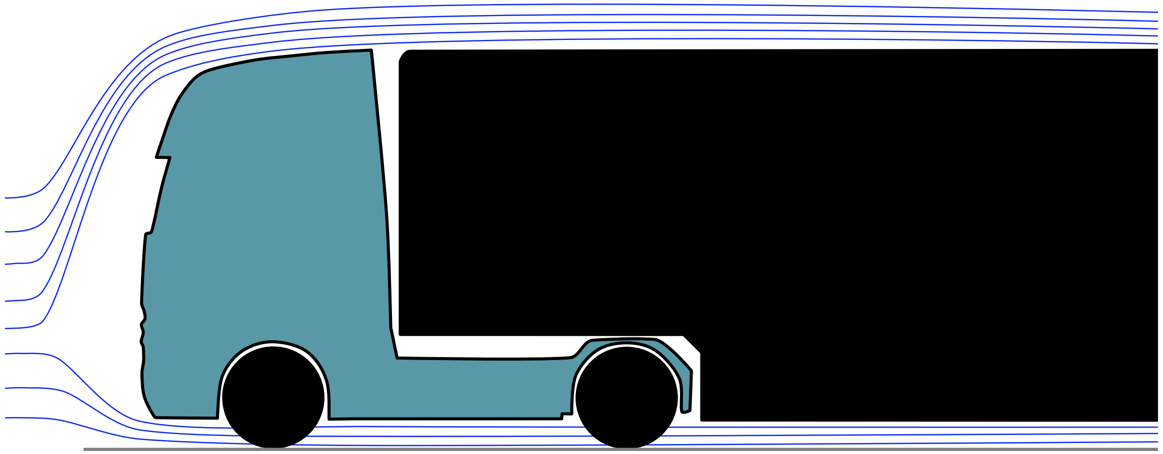
Minimum 24 engine cycles (3 vehicle cycles for 8 configurations)

Engine testing:
Cycle averaged map

Transient correction

Input data	Output data	Dyno testing	Correction	Simulation

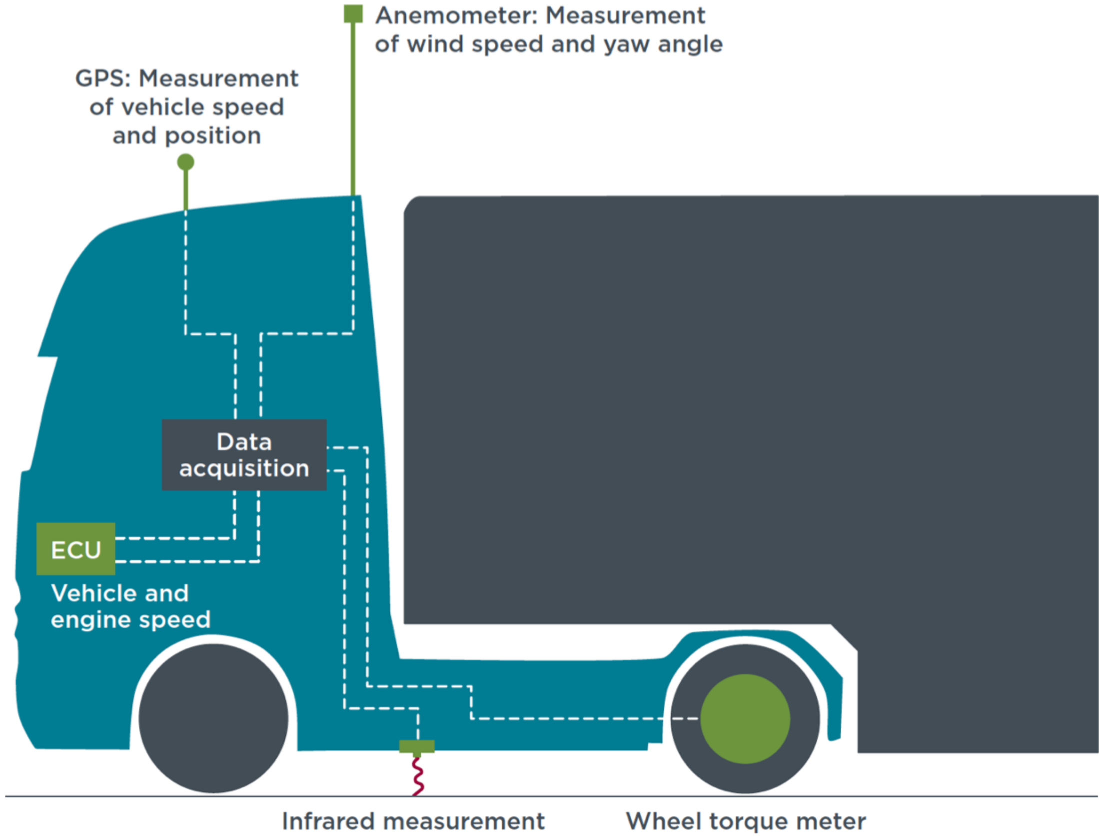
Air drag certification



EU’s constant speed test for air drag measurement

Preparation	Warm up - 90 minutes -	Torque meters zeroing	Warm up - 10 minutes -	
Measurements	Low speed	Warm up - 5 minutes -	High speed	Low speed

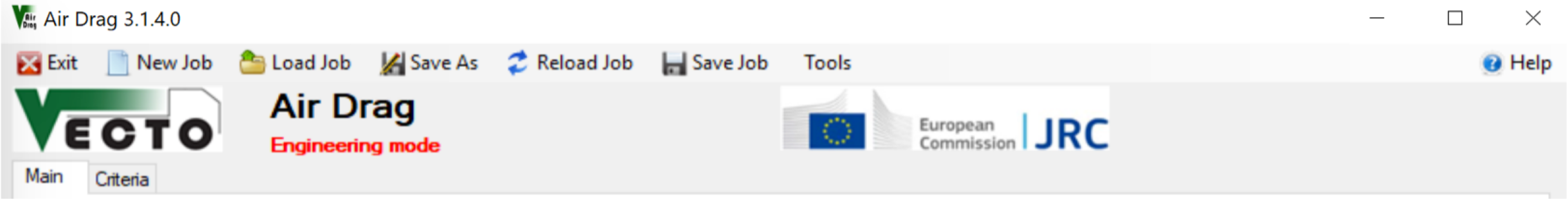
- EU’s air drag test procedure (see EU 2017/2400 Annex VIII) measures the torque at the wheel at a high and a low speed to determine the air drag area (CdA in m^2).
- The methodology requires the measurement of the torque at the wheel, the vehicle position, and the wind speed and angle as observed by the vehicle.



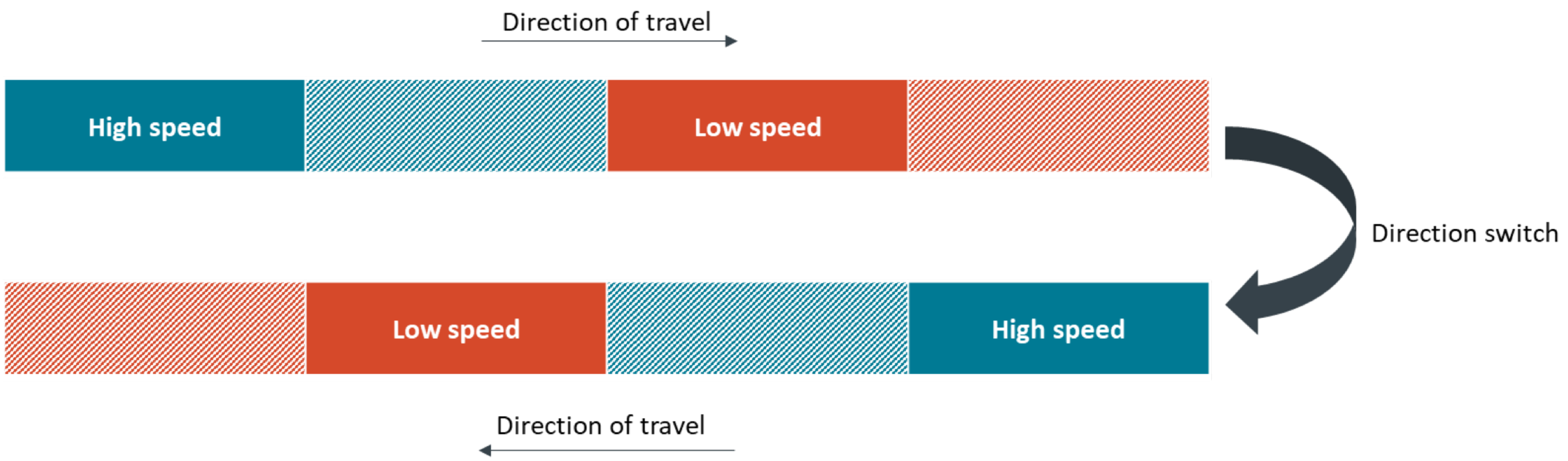
CdA calculation from measured data in EU’s air drag test

Data validation → Calibration of air speed and yaw angle → Estimate traction force and mechanical forces → Calculate final CdA at zero yaw angle

- The calculation of the air drag from the measured data takes place through the VECTO Air Drag tool.
- The post-processing tool outputs the air drag area at zero yaw angle (i.e., no cross-wind). The vehicle simulation tool VECTO corrects internally to account for real world cross-wind conditions



US’s coast-down test for air drag measurement



- The coast-down procedure that is followed in the United States it is described in §1037.528
- The data measured in the coast-down test are the vehicle speed, the air speed and direction as observed by the vehicle. Furthermore, the road grade, wind speed and direction, ambient temperature, and atmospheric pressure as measured from a stationary weather station are also recorded.

CdA calculation from measured data in US's air drag test

Data filtering → Calibration of air speed and yaw angle → Calculate road load force → Calculate drive-axle spin losses → Calculate tire rolling resistance force → Calculate final CdA value at measured yaw angle → Correct CdA to wind averaged conditions (yaw=4.5°)

- The post-processing of the data for the calculation of the air drag at the measured yaw angle is detailed in regulation §1037.528.
- An alternative method (e.g., CFD, wind-tunnel) is used to calculate a correction factor that adjusts the coastdown results to a yaw angle of 4.5°, representing the real-world wind-averaged conditions

Comparison of key points between US and EU air drag tests (1/2)

Parameter	EU constant speed	US coastdown
Torque meter	Hub, rim or half shaft torque meter	None
Vehicle warm up	90 minutes at high-speed target speed before zeroing torque meters	At least 30 minutes at 80 km/h
Low-speed test	Between 10 and 15 km/h	From 35 km/h to 12 km/h
High-speed test	Between 85 and 95 km/h	From 116 km/h to 93 km/h
Torque drift	Must not exceed 25 Nm	N/A
Anemometer calibration	Run test for anemometer calibration misalignment	No anemometer calibration for misalignment. Use of stationary weather station

Comparison of key points between US and EU air drag tests (2/2)

Parameter	EU constant speed	US coastdown
Tire rolling resistance (RRC) influence	The RRC is assumed to be constant and the same at high and low speed	The post-processing takes into account the speed dependence of the RRC
Spin axle losses	Torque measured at wheel, powertrain losses are irrelevant	The spin axle losses are estimated using a quadratic regression on the tire rotational speed.
CdA yaw angle correction	Correction to zero yaw based on generic formula	Correction to a yaw angle of 4.5° using CFD or wind tunnel testing
Cross wind correction	VECTO applies correction internally	GEM does not perform any further crosswind correction

"Air drag determination procedures in the European Union and the United States for heavy-duty vehicles" (2018)

Air drag determination procedures in the European Union and the United States for heavy-duty vehicles

1 Introduction

Heavy-duty vehicles present a wide range of vehicle configurations and usage characteristics, which makes difficult the estimation of their fuel consumption and CO_2 emissions through conventional laboratory measurements. With this in mind, both the U.S. Environmental Protection Agency (EPA) and the European Commission have decided to follow a component testing and vehicle simulation approach to estimate vehicle CO_2 emissions. The respective vehicle simulation tools developed by the EPA and the European Commission are the Greenhouse Gas Emission Model (GEM) (EPA, 2016c) and the Vehicle Energy Calculation Tool (VECTO) (European Commission, 2016). Both tools rely on vehicle related inputs, some of which are simply determined based on the vehicle's characteristics (e.g. mass and engine displacement), while others must be measured through standardized test methodologies (e.g. engine fuel maps, transmission torque losses, tire rolling resistance, and vehicle aerodynamic drag).

This study focuses on vehicle aerodynamic drag determination procedures for trucks in the United States and the European Union. The related certification procedures for calculating CO_2 emissions with both GEM and VECTO require the determination of the air drag value through vehicle testing. A better understanding of the air drag determination procedures is important as improving vehicle's aerodynamic characteristics is a key tactic to tackle CO_2 emissions in the heavy-duty sector. This study summarizes and compares the test procedures in both regions by closely examining them and applying them on available measurement data. The objectives of the study are:

- To understand the air drag determination measurement procedure in the United States and the European Union (EU).
- To understand the post-processing of measured data and how it affects the declared air drag value.

With the above objectives in mind, we applied the procedures to available data sets, compared the results, and identified procedural points that are open to interpretation in the respective regulations and could weaken the expected reductions in aerodynamic drag.

This paper is organized as follows:

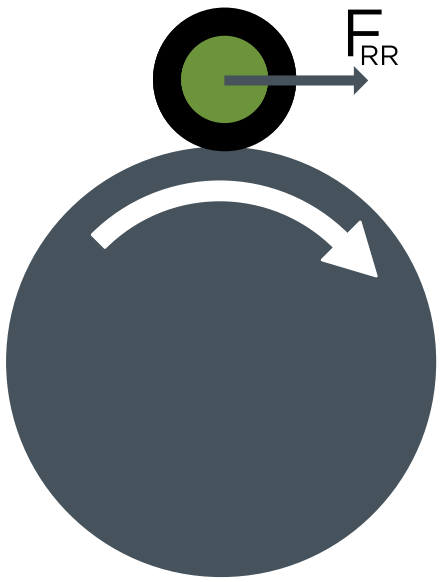
- Chapter 2 describes the available air drag determination procedures, with emphasis on the coastdown and constant speed testing, as they are the primary procedures in the United States and the European Union respectively.
- Chapter 3 describes this study's methodology.

- ICCT is carrying out air drag testing of EU and US vehicles over both testing procedures, constant speed and coast-down.
- Results will indicate the correlation of the CdA values of the testing methodologies
- The upcoming ICCT paper, comparing the US and EU air drag testing methodologies, is expected to be published around summer 2018.

Rolling resistance testing

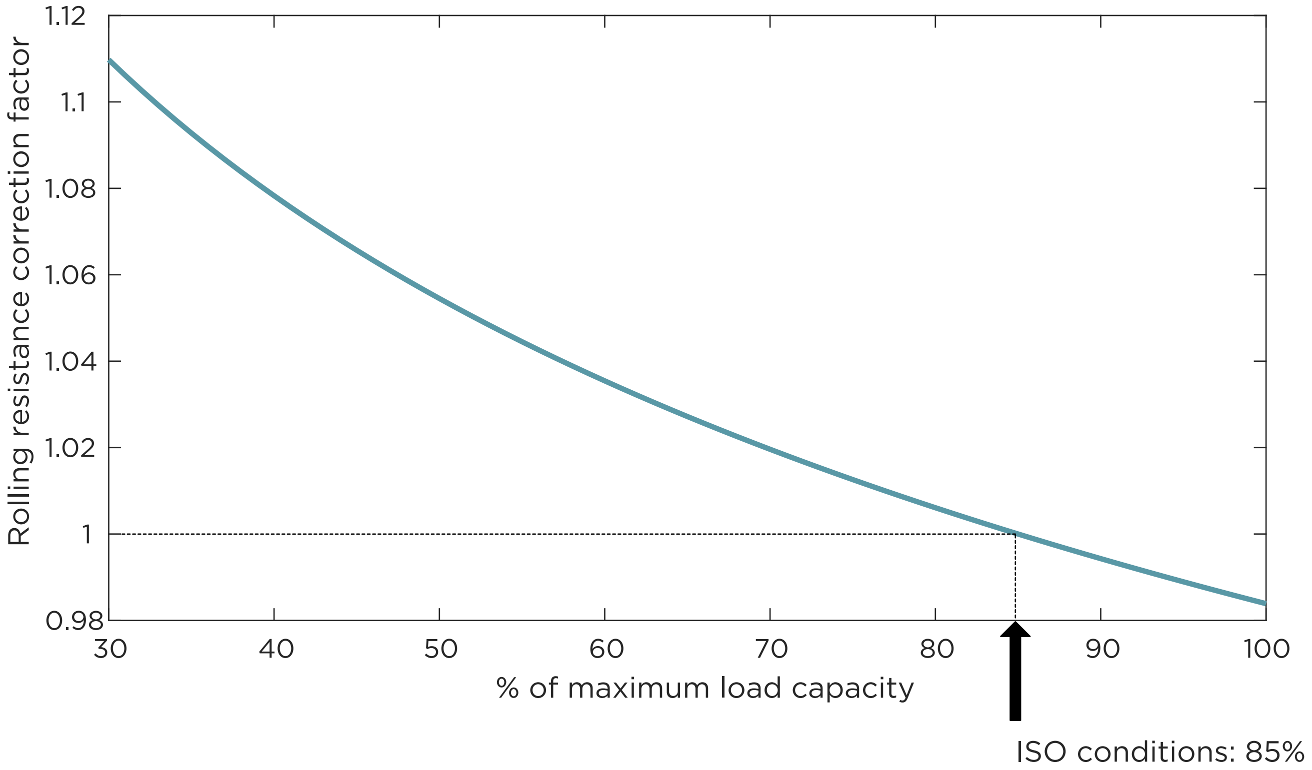
Tire rolling resistance measurement

- In the US, the tire rolling resistance is measured using the test procedure defined by the standard ISO 28580.
- In the EU, the rolling resistance is measured according to UN/ECE R117. The provisions established in UN/ECE R117 are equivalent to those in ISO 28580.
- The determination of the rolling resistance can be done by measuring the horizontal reaction force, the torque input at the drum, the tire-drum system deceleration, or the power input at the drum.
- ISO 28580 / UN/ECE R117 include provisions for an inter-laboratory alignment procedure using a control tire, to allow direct comparison between different test rigs and methods.



Tire rolling resistance post-processing in the EU

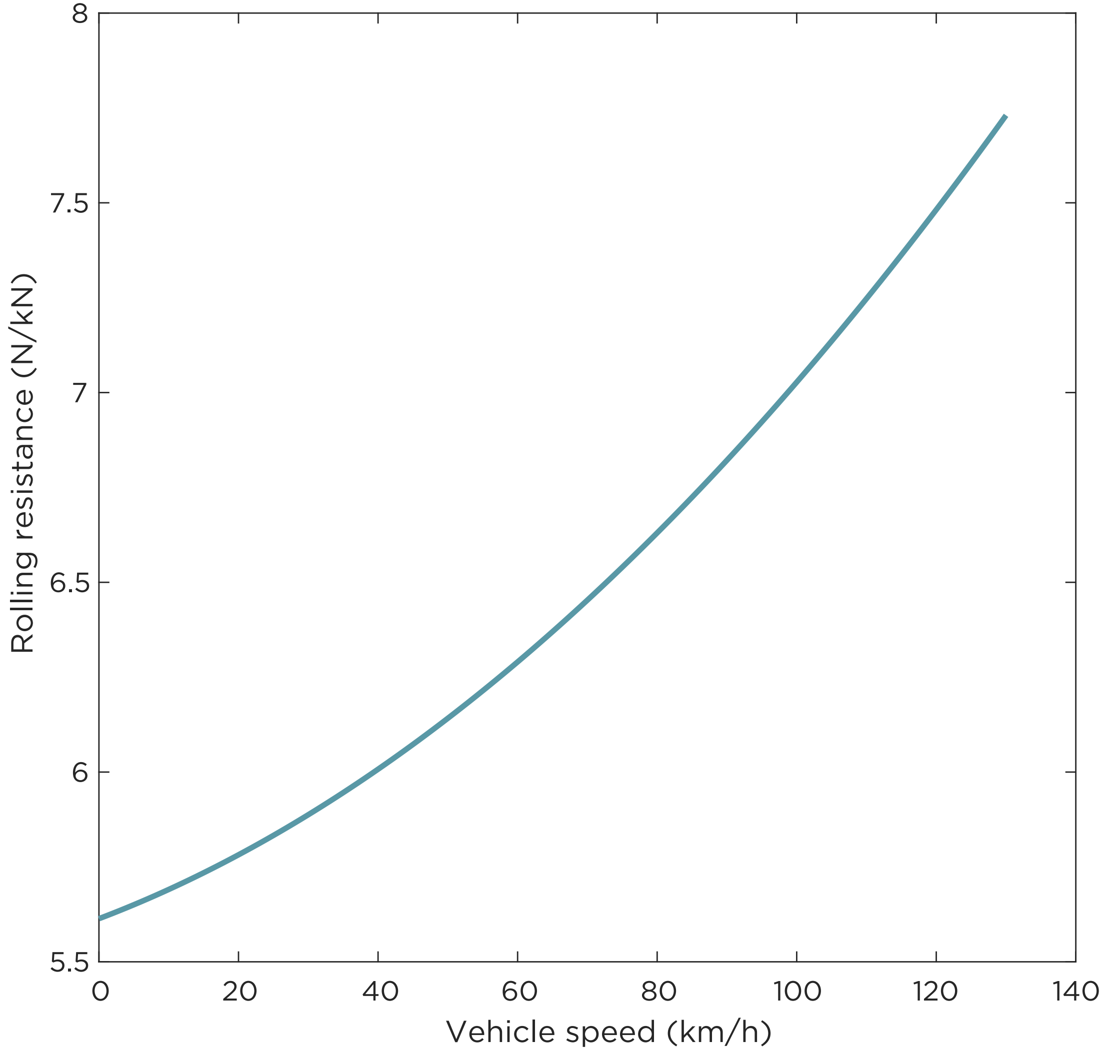
- VECTO assumes that the rolling resistance coefficient (RRC) is a function of the vertical load. VECTO corrects the measured RRC according to ISO 28850 values to capture this slight decrease in rolling resistance with increasing load.



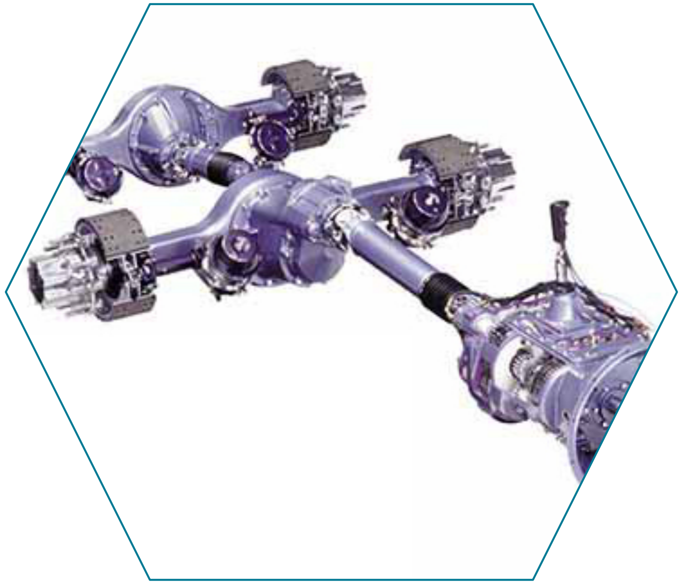
Tire rolling resistance post-processing in the US

- GEM assumes that tire rolling resistance remains constant with load, and uses the rolling resistance coefficients measured during testing directly without applying any correction factor.
- However, in the coast-down air drag testing procedure, it is assumed that the tire rolling resistance is a function of vehicle speed.

Example of RRC as a function of V for the steering tires of a Class 8 tractor-trailer



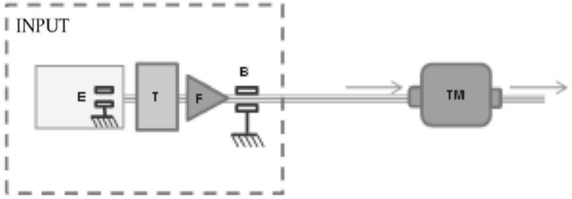
Transmission and axle testing



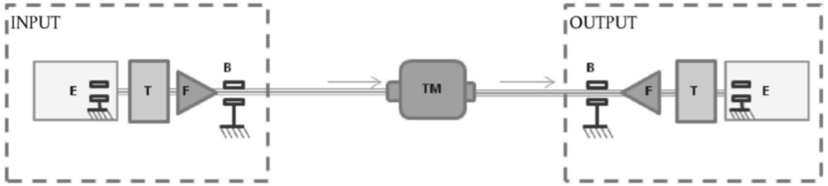
Measurement of torque losses in the EU

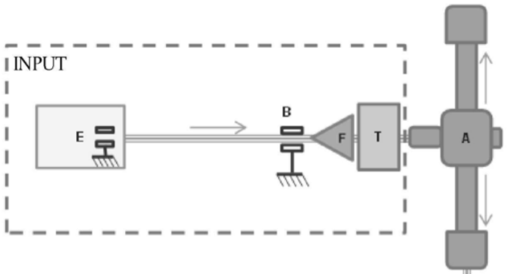
- The measurement procedure of the torque losses of transmissions and axles is described in regulation EU 2017/2400, Annexes VI and VII.
- For transmissions and other torque transferring components, three measurement options are possible, with increasing degrees of complexity:
  1. Option 1: Measurement of only the torque independent losses (i.e., those associated with spin and lubricant drag). The torque dependent losses are calculated based on worst case gear mechanical efficiencies.
  2. Option 2: Measurement of the torque independent losses and of the torque losses at the maximum allowable torque. The torque dependent losses are interpolated linearly.
  3. Option 3: Full measurement of the torque independent and dependent losses
- For axles, only option 3 is allowed.

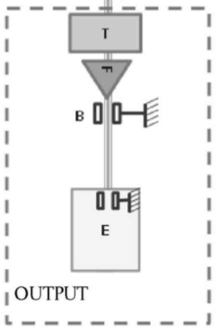
Setup for option 1:



Setup for option 3:





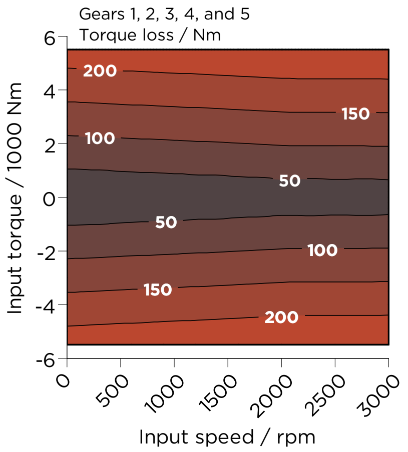


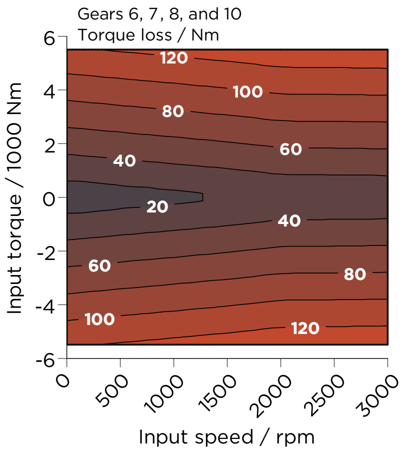
E: Electric machine (with opt. transmission)
T: Torque sensor
F: Flexible coupling/lightweight cardan shaft
B: Bearing
A: Axle

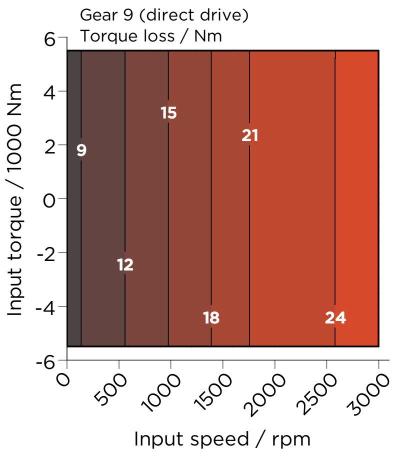
Setup for axles:

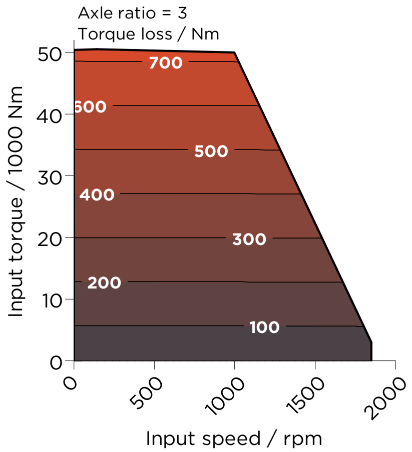
Measurement of power losses in the US

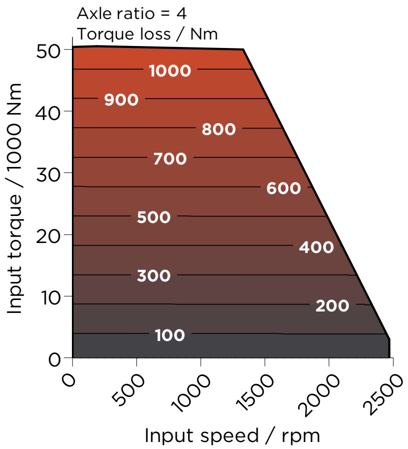
- In the US, the measurement of transmission and axles is an optional procedure. The default transmission and axle power maps are shown below.
- The measurement procedure of the power losses of transmissions and axles is described in §1037.565 and §1037.560 respectively.
  - Transmissions: a minimum of 5 speeds and 1 torque (close to the maximum) are required.
  - Axles: a minimum of 6 torque levels, and several speeds (depending on the axles ratio) are required.











Other vehicle components / characteristics

Treatment of auxiliary components in the EU

- The EU CO_2 certification has established fixed power consumption values for a set of technologies used in the vehicle's auxiliary systems. These are described in regulation EU 2017/2400, Annex IX

System	Technologies considered
Cooling fan	• Crankshaft mounted (with electronic visco-clutch, bimetallic visco-clutch, discrete step clutch or on/off clutch) • Belt or transmission driven (with electronic visco-clutch, bimetallic visco-clutch, discrete step clutch or on/off clutch) • Hydraulically driven (variable or fixed displacement) • Electrically driven
Steering system	• Fixed displacement (with or without electronical control) • Dual displacement • Variable displacement (with mechanical or electronical control) • Electric
Electric system	• LED main front headlights
Pneumatic system	• Air compressors with different displacements • Air compressor with energy saving system • Air management system with optimal regeneration • Visco-clutches • Mechanical clutches
Transmission Power Take-Off (PTO)	• Sliding gearwheel or tooth clutch • Multi-disc clutch • Oil pump

Treatment of off-cycle technologies in the US

- The US regulation (§1037.520) gives credit to certain technologies that cannot be captured by the simulation-based CO_2 certification, such as tire pressure systems, extended idle reduction, predictive cruise control, neutral coasting, and advanced accessories.

Technology area	Technology	Off-cycle credit
Advanced driver assistance systems	Predictive cruise control	2%
	Neutral coasting	1.5%
Accessories	Electric steering and coolant pumps	1%
	High-efficiency A/C compressor	0.5%
Tire pressure	Automatic tire inflation system (ATIS)	1.2%
	Tire pressure monitoring system (TPMS)	1%
Extended-idle reduction	Automatic engine shutdown (AES)	1% (4% if anti-tamper)
	Diesel auxiliary power unit (APU)	3% (4% if anti-tamper)
	Battery auxiliary power unit	5% (6% if anti-tamper)
	Automatic stop-start	3%
	Fuel-operated heater	2% (3% if anti-tamper)

Conformity of production

Conformity of production limits in the EU

- The EU CO_2 certification regulation EU 2017/2400, establishes provisions to verify the conformity of production. The conformity of production testing is the same as the one used during component certification, and is subject to the tolerances below, with respect to the declared value.

Component	Conformity-of-production metric	Tolerance for pass
Engine	Fuel consumption over the WHSC: $\left(\frac{FC_{CoP}}{FC_{TA}} - 1\right) \times 100\%$	< 3% (diesel engines) < 4% (gas engines)
Transmission	Average mechanical efficiency over 18 different torque-speed points: $\eta_{TA} - \eta_{CoP} \times 100\%$	< 3% (Automatic) < 1.5% (all others)
Axle	Average mechanical efficiency over 4 different torque-speed points: $\left(1 - \frac{\eta_{CoP}}{\eta_{TA}}\right) \times 100\%$	< 1.5% (Single reduction) < 2% (all others)
Aerodynamic drag	Air drag area as determined by the constant-speed test $\left(\frac{C_dA_{CoP}}{C_dA_{TA}} - 1\right) \times 100\%$	< 7.5%
Tires	Coefficient of rolling resistance $C_{rr,CoP} - C_{rr,TA}$	< 0.4 N/kN

Notes on abbreviations and symbols: Type approval (TA), conformity of production (CoP), fuel consumption (FC), mechanical efficiency (η), air drag area (C_dA), coefficient of rolling resistance (C_{rr}).

Conformity of production provisions in the US

- In the US, the conformity of production is verified through confirmatory testing (§1037.235) and selective enforcement audit (40 CFR Part 1068 Subpart E, and §1037.301 through §1037.320).
- A component passes a selective enforcement audit if the modeled CO_2 emissions using the results of the confirmatory testing are at or below the modeled emission result using the declared GEM input.
- The provisions in the US regulation provide greater flexibility to the agencies to carry out the testing of the vehicle and components.

Takeaway messages

- The US and EU component certification methodologies have several common points.
  - Axles, tires, and engine mapping procedures are similar.
  - Key differences include the aerodynamic drag determination methodology and the engine transient correction.
- Harmonization of component certification has many advantages:
  - Facilitates transparent comparison of performance between different markets.
  - Facilitates the implementation of future regulatory measures.
  - Facilitates adapting GEM/VECTO to country-specific needs.
  - Streamlined processes and reduced cost of compliance for international manufacturers.