Support Preparation of Legislation on Trailers Certification

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Task 2. Development of a detailed methodology and procedure for the determination of the effect of trailers and semi-trailers bodyworks with regards to the CO_2 emissions / fuel consumption of the towing vehicle

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Acronyms and abbreviations

Acronym	Meaning
ACEA	*European Automobile Manufacturers Association*
CFD	*Computational Fluid Dynamics*
CLCCR	*International Association of the Body and Trailer Building Industry*
CST	*Constant Speed Test*
EMS	*European Modular System*
HDV	Heavy Duty Vehicles
ICCT	International Council on Clean Transportation
RRC	Rolling Resistance Coefficient
TPMLM	Technically permissible maximum laden mass
VECTO	Vehicle Energy Consumption calculation TOol

Definitions

Term	Definition
Efficiency ratio	Ratio of two CO_2-values as results from VECTO Trailer Tool for specific (semi-)trailers in the nominator and the results for the corresponding reference trailer in the denominator
Reference ratio	Ratio between two CO2 emission values simulated with a generic towing vehicle, coupled to the reference trailer as defined for each trailer vehicle group and coupled to the standard trailer as defined for the towing vehicle group in Regulation (EU) 2017/2400
CO_2-value	Result from the simulation tool for vehicles in the units [g/km], [g/pass.-km],[g/t-km] or [g/m³-km]
DA	Code for semi-trailer according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DB	Code for Drawbar trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DC	Code for Centre-axle trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
HDV	Vehicles with type approval according to Regulation (EC) 595/2009 and its amending Regulations”
LDV	Vehicles with type approval according to Regulation (EC) 715/2007 and its amending Regulations”. These are officially called “Light Passenger and Commercial vehicles”
Lorry	A vehicle that is designed and constructed exclusively or principally for conveying goods which may also tow a trailer according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4). Lorries cover chassis-cab HDVs, vans and tractors.
Rigid Lorry	A lorry that is not designed or constructed for the towing of a semi-trailer and that is not a van; according to point (17) in Article 3 of the upcoming amendment of regulation (EU) 2017/2400
Tractor	A towing vehicle that is designed and constructed exclusively or principally to tow semi-trailers according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
Trailer	Any non-self-propelled vehicle on wheels designed and constructed to be towed by a motor vehicle, that can articulate at least around a horizontal axis perpendicular to the longitudinal median plane and around a vertical axis parallel to the longitudinal median plane of the towing motor vehicle
Semi-trailer	means a towed vehicle in which the axle, or axles are positioned behind the centre of gravity of the vehicle (when uniformly loaded), and which is equipped with a connecting

Term	Definition
	device permitting horizontal and vertical forces to be transmitted to the towing vehicle
Light Lorry	N1 and N2 not exceeding 5 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Medium Lorry	N2 exceeding 5 tons and not exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Heavy Lorry	N2 exceeding 7.4 tons maximum mass and N3 with engine type approval according to Regulation (EU) 595/2009
Primary Lorry	Lorry with complete chassis, engine, transmission, axles, tyres and auxiliaries but with standard body or semi-trailer for declaration of the vehicles CO_2-value
Complete(d) Lorry	Lorry with its final body and equipment for declaration of the CO_2-Factor
Final body and equipment	Body, auxiliaries and any other equipment mounted to a Primary Lorry or a Primary Bus until the final stage, which changes weight, aerodynamics or auxiliary power consumption in the input data of the simulation tool.
Standard body or trailer	Body, trailer or semi-trailer defined in Appendix 4 to Annex VIII with standardised dimensions for air drag testing of lorries and with generic mass as input for the CO_2 calculation tool

Executive Summary

Overall Context and objectives

This report is part of the work developed in the project *Support Preparation of Legislation on Trailers Certification,* for DG CLIMA under the contract CLIMA.C.4/SER/2019/0003.

The aim of this project is to develop a detailed certification methodology for determining heavy-duty vehicles (HDV) CO_2 emissions, fuel and energy consumption with regards of their bodies and trailers, on the basis of technical properties of their components, such as engine, transmission, tyres and also aerodynamic drag, together with an extension of VECTO (Vehicle Energy Consumption calculation Tool). To achieve this, the project aims to:

- **Define a classification system** for O4 category vehicles and rigid lorry bodyworks for their effect on the CO_2 emissions and fuel consumption of the towing vehicle / base vehicle.

- **Define a certification methodology** including the development of test requirements for determining the necessary inputs for the IT tool(s) used for CO_2 emissions / fuel consumption calculations and the definition of the algorithms, standard values and generic equations to be used for the CO_2 emissions / fuel consumption calculations.

- **Develop and validate the required IT tool**.

- **Provide legislative support** throughout the project concerning the content of the technical annexes of a draft regulation.

To this purposes, the goal of Task 2 has been to define a procedure to evaluate the CO_2 emissions of the bodies and trailers that can be coupled or assembled on the motorized vehicles covered by the Regulation (EU) 2017/2400, nowadays assessed with VECTO.

Due to the fundamental differences in methodology between trailers and bodies, the description of Task 2 in this report is divided into two main parts:

- Part A: Methodology for (semi-)trailers (Chapter 2 of this report)
- Part B: Methodology for bodies, i.e. complete(d) rigid lorries (Chapter 3 of this report)

As a general convention in this report, the term "trailers" includes semitrailers, drawbar and centre axle trailers.

Part A: Methodology for (semi-)trailers

The work performed in the elaboration of a methodology for trailers has been divided into the following sub-tasks:

- Task 2.0: Elaboration of general approach
- Task 2.1: Definition of inputs to the tool
- Task 2.2: Definition of the methodology including 3D vehicle model creation

- Task 2.3: Definition of algorithms, standard values and generic equations for the IT tool

Task 2.0: Elaboration of general approach

The main purpose of the VECTO trailer tool is to provide data that allows a comparison of different trailers in terms of their overall impact on CO_2 emissions (and if towed by electric vehicles: energy consumption) per km and also with respect to the payload and cargo volume. This is achieved by applying the VECTO trailer tool according to the regulation developed during this project. In the simulations, the trailer, to be specified by the trailer manufacturer (dimensions, tyres, masses etc.), is towed by a standardised generic towing vehicle and simulated with two different payloads and in different mission profiles depending on the respective combination of lorry and trailer.

In addition, the VECTO trailer tool also calculates the CO_2 emissions of the generic towing vehicle in combination with a reference trailer, so that a ratio, the “Efficiency ratio”, can be determined by dividing the CO_2 values of the specific and the reference trailer. This value represents the relative reduction or growth factor of CO_2 emissions (or in general energy consumption) that a specific trailer achieves compared to the use of a reference trailer as a benchmark. To enable the performance of a particular trailer to be compared with a trailer from another group in the classification, the VECTO trailer tool also outputs the simulated absolute values for fuel consumption and CO_2 emissions.

Following the main principles as already operational in official CO_2 determination for motor vehicles in accordance with Regulation (EU) 2017/2400, the VECTO trailer tool provides the abovementioned results per mission profile and payload combination and also as a weighted overall result. Also analogous to Regulation (EU) 2017/2400, the VECTO trailer tool generates two different output files with legal implications: The Manufacturer’s Records File (MRF) and the Customer’s Information File (CIF).

Task 2.1: Definition of inputs to the tool

A set of 27 input parameters to the VECTO trailer tool has been defined not only for calculation purposes, but also for documentation and classification purposes. Table 1 gives a general overview of the defined groups of input data including parameter examples for each group as well as a short description why these inputs are required. A detailed explanation of each defined input parameter is given in chapter 2.2.1.

Table 1. Overview of inputs to the tool

Input data group	Input parameters	Description
Documentation	- Manufacturer - Manufacturer Address - VIN - …	Parameters needed for documentation purposes e.g. allocation of results to the corresponding manufacturer

Input data group	Input parameters	Description
Classification	- Trailer type - Bodywork code - Number of axles	Parameters needed for complete classification of the trailer
Calculation	- Masses - Dimensions - Tyre information - Axle information	Parameters needed for calculating each individual trailer

It should be noted that based on this set of input data the VECTO trailer tool does not consider all technologies, which were proposed by stakeholders either in the 2020 survey or in subsequent consultations. Section 0 in this report lists the technologies not considered in this project, and thus in the first phase of trailer regulation, and provides the reasons for this.

Task 2.2: Definition of the methodology including 3D vehicle model creation

Computational Fluid Dynamics (CFD) plays an important role within this task as it is used to predict the aerodynamic resistance (C_DxA) of different vehicle configurations, as well as its evolution along the vehicle advancing direction.

A large collection of these C_DxA values are then used to build, evaluate and fine-tune the corresponding algorithms and equations that should be able to return an estimated drag resistance value for a given trailer or semitrailer, without the need to run a CFD simulation, and purely based on vehicle dimensions.

In order to validate the CFD methodology, an IVECO Stralis pulling a standard semitrailer with different aerodynamic devices has been tested at IDIADA facilities in Spain. This has been part of a 2nd CFD vs CST campaign, being the first campaign already documented in “Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005”.

One of the main outcomes of the current project is a set of 3D CAD geometries that can be openly used by body and trailer manufacturers, as well as suppliers of aerodynamic solutions. Standard designs of the most used truck configurations, including tractors, rigid trucks, semi-trailer and rigid bodies have been created in order to be used in CFD simulations and are provided as open source geometry models.

The very same CFD methodology applied to the IVECO Stralis during the correlation phase against CST testing data has been used in all simulations using the generic vehicles listed above, as well as all their combinations.

Task 2.3: Definition of algorithms, standard values and generic equations for the IT tool

<u>Generic towing vehicles</u>
Table 2 gives an overview on all elaborated generic towing vehicles models and their allocation to trailer groups. The allocation is based on proposals from CLCCR and was fine-tuned in a number of working meetings with the Consortium.

Table 2. Overview towing vehicles and allocation to trailer groups

Generic towing vehicle			Allocated to trailer groups
Code	**Vehicle group**	**Config / body**	
A1	5-RD	day cab	1- axle DA
A2	5-LH	sleeper cab	2- and 3-axle DA
A3	10-LH	sleeper cab	Only for >3 axle vehicles, thus not yet relevant according to the planned coverage of the first stage of the trailer Regulation
R1	2-RD	day cab, B2 in specific variants	1- axle DC and 2 axle DC with a TPMLM axle assembly ≤ 13.5 tons
R2	9-LH	B4, B5 in specific variants	2- axle DB, 2 axle DC with a TPMLM axle assembly > 13.5 tons
R3	4-LH	B6 in specific variants	3- axle DB, DC

In order to achieve most informative and robust results from the trailer Regulation, it is important that the generic vehicle models stored in the VECTO trailer tool are as representative as possible for typical towing vehicles in the fleet. Due to the availability of the data from the HDV CO_2 monitoring in accordance with Regulation (EU) 2018/956 for the "baseline year" 1 July 2019 to 30 June 2020, it was possible in this project to create such vehicle models in a high level of detail. The vehicle models determined in this way represent the average state of vehicle technology of new vehicles in the above-mentioned "baseline" year.

Specifications of the reference trailers

As explained for Task 2.0 above, a reference trailer needs to be defined for each trailer group to be covered by the new Regulation. The main parameters describing reference trailer influencing the simulation are curb mass, cargo volume, dimensions and C_DxA. The specifications of the reference trailers have been provided by CLCCR and have been fine-tuned in consultation with the Commission.

Generic operation conditions

For the simulations by the VECTO Trailer Tool, the following generic definitions of the typical operating conditions of trailers had to be made:

1. Mission profile allocation and weighting factors
2. Payloads
3. Axle load distributions

These generic operating conditions apply equally to the specific and the reference trailer in the simulations. In the development of these data, the generic values used by VECTO according to Regulation (EU) 2017/2400 were taken as a starting point. These were adapted based on information provided by CLCCR and in close consultation with the Commission for the different vehicle groups occurring in the trailer classification. It should be mentioned that - as already noted in the predecessor project 2019 - very little systematic data on the typical use of trailers is available.

Methodology for liftable and steered axles

The basic principle for the consideration of lift and steered axles in the VECTO trailer tool is to apply bonus factors on fuel consumption/CO_2 emissions for each of the technologies and additional special rules for combinations of both features. The elaboration of those factors was done based on an approach proposed by TUG for liftable axles and based on empirical data as provided by industry for steered axles.

Determination of C_DxA

The method to compute the C_DxA of each vehicle modification, utilises a combination CFD results, computed in this project with several correction methods obtained from bibliography and documented in this document. Five corrections of the truck dimensions are considered: length, width, height, volume & aerodynamic devices. These techniques are applied to both, the C_DxA of the vehicle in straight direction and with crosswind (polar curve). Finally, the combination of different vehicle modifications and aerodynamic devices are considered. This methodology applies for trucks and trailers and for rigid trucks with different towing elements.

Abstract of this deliverable

This report is mostly focused on defining a certification methodology for CO_2 emissions and fuel consumption of a motorized vehicle depending on the semitrailers and trailers being pulled by it.

A general approach is initially presented where the efficiency ratio to be applied to a reference vehicle, together the list of inputs, is explained.

The following pages also cover the details of the so-called generic 3D shapes in an attempt to make the (semi-)trailer aero performance independent from the pulling unit, as well as the CFD methods applied to them.

Finally, the assessment of the different algorithms and equations to be applied to the corresponding input variables of the IT tool(s) is further detailed.

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Tables

1 Introduction

The aim of this task is to define a procedure (or procedures) to evaluate the CO_2 emissions of the bodies and trailers that can be coupled or assembled on the motorized vehicles covered by the Regulation (EU) 2017/2400, nowadays assessed with VECTO.

The possible methods described in this task are based on the work developed in the previous task and is also nurtured by the information obtained in the outcomes of the “Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005”.

Due to the fundamental differences in methodology between trailers and bodies, the description of Task 2 in this report is divided into two main parts:

- Part A: Methodology for (semi-)trailers (Chapter 2 of this report)
- Part B: Methodology for bodies, i.e. complete(d) rigid lorries (Chapter 3 of this report)

As a general convention in this report, the term "trailers" includes semitrailers, drawbar trailers and centre axle trailers.

2 Part A: Methodology for (semi-)trailers

The work performed for the definition of a methodology for (semi-)trailers is divided into the following sub-tasks:

- Task 2.0: Elaboration of general approach
- Task 2.1: Definition of inputs to the tool
- Task 2.2: Definition of the methodology including 3D vehicle model creation
- Task 2.3: Definition of algorithms, standard values and generic equations for the IT tool

2.1 Task 2.0: Elaboration of general approach

The main purpose of the VECTO trailer tool is to provide data that allows a comparison of different trailers in terms of their overall impact on CO_2 emissions (and if towed by electric vehicles: energy consumption) per km and also with respect to the payload and cargo volume. This is achieved by applying the VECTO trailer tool according to the regulation developed during this project. In the simulations, the trailer, to be specified by the trailer manufacturer (dimensions, tyres, masses etc.), is towed by a standardised generic towing vehicle and simulated with different payloads and in different mission profiles depending on the respective combination of lorry and trailer.

In addition, the VECTO trailer tool also calculates the CO_2 emissions of the generic towing vehicle in combination with a reference trailer, so that a ratio, the “Efficiency ratio”, can be determined by dividing the CO_2 values of the specific and the reference trailer. This value represents the relative reduction or growth factor of CO_2 emissions (or in general energy consumption) that a specific trailer achieves compared to the use of a reference trailer as a benchmark.

The whole methodology of the approach including definition of inputs/outputs, generic data (vehicles, trailers) as well as general algorithms and equations are described in detail in the following chapters.

2.1.1 Efficiency ratio, Reference ratio

The original approach proposed by the consortium in 2020 was to calculate the efficiency ratio and in a follow-up step the CO_2 emissions of the combined vehicle according to equations (2-1) and (2-2).

$$EffRatio = \frac{CO_{2\,spec\,(S)T}}{CO_{2\,stand\,(S)T}} \tag{2-1}$$

$EffRatio$	Efficiency ratio [-]
$CO_{2\,spec\,(S)T}$	CO_2 of the generic towing vehicle + specific trailer

$CO_{2\,stand\,(S)T}$	CO_2 of the specific towing vehicle + standard trailer acc. to Reg. (EU) 2017/2400

Using this approach has the benefit that only the specifications of the specific trailers (and of course the generic towing vehicles) need to be elaborated, as the standard trailers are already defined in Regulation (EU) 2017/2400 depending on the towing vehicle and mission profile. The CO_2 emissions of the combined vehicle can be then calculated as:

$$CO2_{spec\,L+spec(S)T} = CO2_{spec\,L+stand(S)T} \cdot Efficiency\,Ratio \tag{2-2}$$

$CO2_{spec\,L+spec(S)T}$	CO_2 for a specific lorry + specific trailer
$CO2_{spec\,L+stand(S)T}$	CO_2 for a specific lorry + standard trailer acc. to Reg. (EU) 2017/2400

At this point it should be noted that the task of this work is primarily to manage a reliable and customer-friendly assessment of the energy efficiency of a specific trailer (via the Efficiency ratio). The possibility of an accurate calculation of the energy efficiency of the combination of a specific towing vehicle and a specific trailer should also be made possible but is assessed to be of secondary importance.

For the approach to calculate the efficiency ratio based on equation (2-1) several drawbacks have been identified:

- For certain groups the efficiency ratio will not be “centered” around 1, e.g.
  - Reefers, as mass and width are usually higher than defined for the standard (dry box) trailer
  - DB and DC trailers in Regional and Urban Delivery, as in those mission profiles no trailer is considered in Regulation (EU) 2017/2400

  From a purely technical point of view, this is not a problem, as the comparability/usability of the efficiency ratio is given in any case, if specific cycle allocations for lorry/trailer operations are additionally defined, which are not part of Reg. (EU) 2017/2400. However, psychologically, it is a problem because certain industry sectors can only offer trailers with an efficiency ratio of >1.

- For certain trailer groups the allocated “standard body” of the generic towing vehicle is not reasonable, as the combination of lorry + trailer would violate the maximum length provisions and thus the sum of cargo-volume reflected in the results is not reasonable.

To address these issues, CLCCR proposed an updated/enhanced approach, which was agreed to and is therefore applied in the latest version of the VECTO trailer tool. In this revised approach the efficiency ratio is calculated as follows:

$$EffRatio = \frac{CO2_{spec\,(S)T}}{CO2_{ref(S)T}} \tag{2-3}$$

$EffRatio$	Efficiency ratio [-]
$CO2_{ref(S)T}$	CO_2 of the generic towing vehicle + reference trailer

The reference trailers must be defined individually for each trailer group covered by the regulation (see chapter 2.4.2 for detailed specs of the defined reference trailers) resulting in more effort for the tool but also major advantages:

- Calculating the ratio in this way "centers" the results for each trailer group around 1, allowing for an easy-to-understand trailer comparison in public perception.
- Additionally, this approach allows for smooth integration of new elements into the regulation, as the reference trailers only need to be updated accordingly. For example, for refrigerated vehicles, if CO_2/energy consumption for the A/C system is added at a later stage of the regulation, the then defined "standard fuel CO_2/energy consumption" can be added to the respective reference trailer. Similar reefers using standard technology would then get similar efficiency ratios based on the old and the updated regulation.

However, in the end the updated approach must provide the same figures for the combined CO_2 emissions for the specific lorry + specific trailer as the original approach. To achieve this, an additional ratio must be defined as follows:

$$RefRatio = \frac{CO2_{ref\,(S)T}\left[\frac{g}{km}\right]}{CO2_{stand(S)T}\left[\frac{g}{km}\right]} \tag{2-4}$$

$RefRatio$	Reference ratio [-]

Although calculating this ratio results in additional features needed in the tool, it is actually very easy to handle due to the following properties:

- The reference ratio represents a matrix of separate values for each combination of trailer group, mission profile and payload (approximately 300 values). These values are fixed numbers for a certain version of the regulation / VECTO version, as both the standard and the reference trailers are pre-defined resulting in low calculation effort.
- The reference ratios can simply be part of the VECTO documentation and have a special mode of the trailer tool used to calculate them (launched in the compilation process).

Finally, the combined CO_2 is calculated according to equation (2-5). This calculation can only be performed for the units [l/100km] or [g/km] because calculating the reference ratio can only be done on a kilometre-basis. Hence, for the efficiency ratio also the “kilometre-based” values have to be applied.

$$CO2_{spec\,L+spec(S)T} = CO2_{specL+stand(S)T} \cdot RefRatio \cdot EffRatio \qquad (2\text{-}5)$$

By substituting the definitions for the two ratios, it is easy to see that the final CO_2 figure is consistent with the previous approach.

$$CO2_{spec\,L+spec(S)T} = CO2_{specL+stand(S)T} \cdot \frac{CO2_{ref\,(S)T}}{CO2_{stand(S)T}} \cdot \frac{CO2_{spec\,(S)T}}{CO2_{ref(S)T}} \qquad (2\text{-}6)$$

$$CO2_{spec\,L+spec(S)T} = CO2_{specL+stand(S)T} \cdot \frac{CO2_{spec\,(S)T}}{CO2_{stand(S)T}} \qquad (2\text{-}7)$$

To enable the customer to easily calculate the CO_2 emissions of his specific combination of towing vehicle and trailer, the relevant reference ratios are also outputs in the Customer Information File of the VECTO Trailer Tool. The method to be used is also explained in detail in the User Manual.

2.1.2 Efficiency-, Reference ratio method validation

The method on how to calculate the specific combination of towing vehicle and trailer via the two ratios was validated on an example calculation carried out using the latest version of the VECTO trailer tool and the official VECTO for motor vehicles. The calculations/results are summarized in Table 3.

The evaluation was carried out for a group 9 towing vehicle. For the specific towing vehicle simulated in the motor vehicle VECTO (Standard 2 axle DC in LH and no trailer in RD) the generic group 9 from the trailer tool was used as a basis and slightly modified (different RRCs and Air-resistance). The results of this simulation can be found in column 4. The simulation of the VECTO trailer tool was carried out with the generic group 9 towing vehicle and a specific 2-axle DB trailer that is of course different from the generic trailer used in the official VECTO. The results of this simulation run can be found in columns 5 and 6. Based on these results the fuel consumption of the specific combination was calculated using the reference-, efficiency ratio approach (see column 7). To validate this approach the specific combination was modelled in the official VECTO and directly simulated representing the reference results. As one can see in the last column, the deviations are very small ranging from below 0.1% to still under 1% depending on the specific mission and payload combination.

Table 3: Validation example of the reference-, efficiency ratio approach

	VECTO Trailer Tool	Result specific combination

			Motor vehicle VECTO			calculated via Reference-, Efficiency ratio	simulated via Motor vehicle VECTO	
Vehicle configuration as in VECTO for motor vehicles	**Vehicle configuration as in VECTO Trailer Tool**	**Mission profile + payload**	**FC [l/100 km]**	**Reference ratio [-]**	**Efficiency ratio [-]**	**FC [l/100 km]**	**FC [l/100 km]**	**Δ FC [%]**
Specific group 9 lorry + T2 standard trailer (type DC)	Generic group 9 lorry + **specific DB trailer**	LH low payl.	26.82	0.929	0.973	24.25	24.23	0.08%
		LH rep payl.	34.77	0.949	0.965	31.84	31.66	0.57%
Specific group 9 lorry as rigid solo	Generic group 9 lorry + **specific DB trailer**	RD low payl.	19.96	1.282	0.976	24.98	25.22	-0.96%
		RD rep payl.	23.42	1.368	0.972	31.14	31.33	-0.62%

These deviations observed here are in the range that was also determined for the factor method as applied in the motor vehicle VECTO for heavy buses.

2.1.3 Outputs of the simulation tool

In terms of output files, the VECTO trailer tool automatically generates several files with different purposes as well as legal implications. The most important ones are of course the files with official purpose, which contain a defined set of information about input/simulation parameters, vehicle/trailer parameters, and results (see Table 4). Since the VECTO trailer tool also uses the “VECTO core”, similar additional files as by the classic VECTO are provided besides the mandatory files for legal purposes. These files contain additional outputs of the simulation and can thus be used for further analysis by the manufacturer.

2.1.3.1 Output files /options

Output with official purpose / legal reference:

The idea is to follow the approach already used in Regulation (EU) 2017/2400 with two different output files with different purposes:

- MRF (Manufacturer's Records file): *means a file produced by the simulation tool, which contains manufacturer related information, a documentation of the input data and input information to the simulation tool and the results for* CO_2 *emissions and fuel consumption.*

- CIF (Customer's Information file): *means a file produced by the simulation tool, which contains a defined set of vehicle related information and the results for* CO_2 *emissions and fuel consumption.*

The MRF is not only created, but also hashed automatically by the tool to ensure that no subsequent changes are made to the file guaranteeing that the information in the file matches the actual inputs/results which are used/created by the tool. The MRF, among other information, is also the file that must be made available to the approval authority and the Commission upon request. The CIF, on the other hand, contains a reduced set of information compared to the MRF, with only the most important vehicle specifications and results relevant to the customer.

Table 4 shows a general overview of the parameters stored in the two files, including a short parameter description for clarification (differences between the two files are highlighted in colour). The main information the CIF does not contain can be summarised as:

- Information of the trailer or specific components of the trailer that is not important to the customer (e.g. dimensions which are used in the tool for certain calculations but are not considered "main" dimensions of the trailer; or registration number of the tyres) or,

- Information from the simulation that must be checked in advance in order to successfully complete the certification process and pass on the results to the customer (e.g., status, whether the simulation was successful, or hashes to check that inputs have not been changed subsequently).

Table 4. Content of preliminary MRF, CIF output files

Parameter information	Manufacturer's Records File (MRF)	Customer's Information File (CIF)	Comments
Input Parameter (Trailer)[1]			
Manufacturer	yes	yes	
Manufacturer Address	yes	yes	
Model / Commercial Name	yes	yes	
VIN	yes	yes	Vehicle Identification Number
Date	yes	yes	Date and time when input information and input data is created
Legislative Category	yes	yes	O4: trailers with a maximum mass exceeding 10 tons O3: trailers with a maximum mass below 10 tons
Number of Axles	yes	yes	
Trailer Type	yes	yes	DA - Semi-trailer DB - Drawbar trailer DC - Centre Axle trailer
Bodywork Type	yes	yes	- dry box - refrigerated - conditioned - curtain-sided - drop-side tarpaulin body
Volume orientation	yes	yes	
Trailer Coupling Point	yes	yes	Defines coupling point for DC trailers
Corrected Mass in running order [kg]	yes	yes	
TPMLM Trailer [kg]	yes	yes	
TPMLM Axle Assembly [kg]	yes	yes	
Vehicle Group Annex1	yes	yes	Vehicle ID acc. To Annex 1
Vehicle Group Tool Internal	yes	yes	Vehicle ID used in the tool
External length of the body [m]	yes	yes	
External width of the body [m]	yes	yes	
External height of the body [m]	yes	yes	

[1] See chapter 2.2.1 for detailed explanation of input parameters

Parameter information	Manufacturer's Records File (MRF)	Customer's Information File (CIF)	Comments
Total height of the trailer [m]	yes	yes	
Length from trailer front end to centre of first axle [m]	yes	no	Input used to calculate C_DxA
Length between centres of axles [m]	yes	no	Input used to calculate C_DxA
Cargo volume [m³]	yes	yes	
Standard aerodynamic devices	yes	yes	Name of applied aero feature(s) (e.g. boat tail long)
Certification number of certified aerodynamic device	yes	yes	
Aerodynamic reduction	yes	yes	Percent reduction in air drag compared to standard aerodynamic configuration for yaw angles 0°, 3°, 6° and 9° (both for standard and certified aerodynamic devices)
Hash of input data	yes	no	
Tyres (per (semi-)trailer axle)			
Model	yes	no	
Certification number	yes	yes	
Tyre Dimension	yes	yes	Main tyre dimensions
RRC	yes	no	Declared Rolling Resistance Coefficient [N/N]
Fuel efficiency class	yes	yes	Efficiency class according to tyre RRC e.g. A,B,C, etc.
Hash	yes	no	
Twin tyres	yes	yes	Information if twin tyres are applied
Axle steered	yes	yes	Information if axle is steered
Axle liftable	yes	yes	Information if axle is liftable
Results			
Towing vehicle	yes	yes	Key information about the towing vehicle: <vehicle group, Model year, rated Power> e.g. <Group 5 (4x2 tractor), MY 2019/20, 325 kW>
Status	yes	no	Overall status if simulation was successful

Parameter information	Manufacturer's Records File (MRF)	Customer's Information File (CIF)	Comments
Results per mission profile and payload			
Status	yes	no	Simulation status per simulation run
Mission	yes	yes	
payload [kg]	yes	yes	
Total vehicle mass [kg]	yes	yes	
AirDrag [m²]			
CDxA yawAngle="0"	yes	no	CDxA value calculated for a wind yaw angle of 0°
CDxA yawAngle="3"	yes	no	CDxA value calculated for a wind yaw angle of 3°
CDxA yawAngle="6"	yes	no	CDxA value calculated for a wind yaw angle of 6°
CDxA yawAngle="9"	yes	no	CDxA value calculated for a wind yaw angle of 9°
Average speed [km/h]	yes	yes	
Fuel consumption [g/km]	yes	yes	
Fuel consumption [g/t-km]	yes	yes	
Fuel consumption [g/m³-km]	yes	yes	
Fuel consumption [l/100km]	yes	yes	
Fuel consumption [l/t-km]	yes	yes	
Fuel consumption [l/m³-km]	yes	yes	
CO_2 Emissions [g/km]	yes	yes	
CO_2 Emissions [g/t-km]	yes	yes	
CO_2 Emissions [g/m³-km]	yes	yes	
Efficiency-Ratio per km [-]	yes	yes	
Efficiency-Ratio per t-km [-]	yes	yes	
Efficiency-Ratio per m³-km [-]	yes	yes	
Reference-Ratio per km [-]	no	yes	
Results weighted			
payload [kg]	yes	yes	

Parameter information	Manufacturer's Records File (MRF)	Customer's Information File (CIF)	Comments
Fuel consumption [g/km]	yes	yes	
Fuel consumption [g/t-km]	yes	yes	
Fuel consumption [g/m³-km]	yes	yes	
Fuel consumption [l/100km]	yes	yes	
Fuel consumption [l/t-km]	yes	yes	
Fuel consumption [l/m³-km]	yes	yes	
CO_2 Emissions [g/km]	yes	yes	
CO_2 Emissions [g/t-km]	yes	yes	
CO_2 Emissions [g/m³-km]	yes	yes	
Efficiency-Ratio per km [-]	yes	yes	
Efficiency-Ratio per t-km [-]	yes	yes	
Efficiency-Ratio per m³-km [-]	yes	yes	
Software information			
Simulation tool version	yes	yes	
Date and time of the simulation	yes	yes	
Hash MRF	no	yes	
Hash CIF	no	yes	

Looking at the result section, one can see that also specific fuel consumption and CO_2 values are included besides the efficiency ratios to enable a comparison of trailers between different vehicle groups. Moreover, the CIF also contains the reference ratio allowing the customer to calculate the fuel / CO_2 consumption for his specific combination of lorry (with its allocated specific g/km value from VECTO) and trailer (the calculation must be done on a g/km basis).

Like all data in the regulated VECTO process, both files are written in XML format. To increase readability, especially for customers without an engineering or programming background, a web-based style sheet is provided for voluntary use to convert the content of the XMLs to a printable format (e.g. pdf).

<u>Output with engineering / analysis purpose:</u>

Additional information of the simulations is provided allowing the OEMs to get detailed insight into the calculations for each simulation run. These insights can then be used either for OEM specific analysis of the simulations or to report possible errors e.g. due to incorrect implementation of equations or data. Providing this information to OEMs is therefore crucial for efficient maintenance and high maturity of the tool and is done via two files, namely the "vmod" and the "vsum" file.

The vmod file contains time traces of simulation data with a resolution of roughly 2 [Hz] for each combination of:

- simulated vehicle (reference trailer, specific trailer)
- mission profile (Long Haul, Regional- and Urban Delivery) and
- payload condition (low, representative)

Such a file is created separately for every combination and each line in these files represents average values during the corresponding simulation time interval. Useful information provided by these files are for example vehicle and trip data like acceleration, vehicle speed, fuel consumption, selected gear, target speed, gradient and altitude of the mission profile, or data regarding power demands and individual power losses for every powertrain component.

The vsum file contains average and integral data for every simulation launched e.g. average speed, energy flows, fuel consumption or CO_2 emissions.
Unlike the vmod files, this file combines the results for each simulation executed in the same simulation run into one single vsum file (each simulation is represented in a separate row).

2.1.3.2 Output result

The most important results, beside the absolute CO_2 and fuel consumption figures, are the efficiency ratios defined in chapter **Error! Reference source not found.**. These ratios are calculated per combination of mission profile and payload and per km, t-km and m^3-km by applying the CO_2 emissions in the corresponding units according to the following equations.

$$EffRatio_{per\ km} = \frac{CO2_{spec\ (S)T}\left[\frac{g}{km}\right]}{CO2_{ref(S)T}\left[\frac{g}{km}\right]} \qquad (2\text{-}8)$$

$$EffRatio_{per\ t-km} = \frac{CO2_{spec\ (S)T}\left[\frac{g}{t-km}\right]}{CO2_{ref(S)T}\left[\frac{g}{t-km}\right]} \qquad (2\text{-}9)$$

$$EffRatio_{per\ m^3-km} = \frac{CO2_{spec\ (S)T}\left[\frac{g}{m^3 - km}\right]}{CO2_{ref(S)T}\left[\frac{g}{m^3 - km}\right]} \tag{2-10}$$

The payload and cargo volume to compute the individual CO_2 figures per t-km and m³-km are the total values for the whole vehicle (lorry + reference /specific trailer). To obtain final consolidated figures for CO_2 as well as for efficiency ratios the separate results per mission profile and payload must be weighted.

The following explanations show an example of the calculation process for determining the weighted figures:

First, the weighted results for payload and CO_2 emission in g/km are calculated by simply multiplying the specific value with the corresponding weight according to equation (3-9) and (3-10). [2] The values given in the Table 5 are exemplary values to further demonstrate the basic procedure.

$$CO2_{weighted} = \sum CO2_{Mission/Payload} * weighting \tag{2-11}$$

$$Payload_{weighted} = \sum Payload_{Mission} * weighting \tag{2-12}$$

Table 5. Example for weighting methodology

Parameters	Allocation of mission profile and payload scenario				
	Long Haul		Regional Delivery		
	low payload	representative payload	low payload	representative payload	weighted results
payload [kg]	2600	19300	2600	12900	13842
CO_2 reference trailer [g/km]	700	900	750	920	842.9
CO_2 specific trailer [g/km]	690	875	740	900	822.75
Weighting [-]	0.27	0.63	0.03	0.07	∑ 1

The weighted CO_2 results in g/t-km must be calculated by division based on the already weighted results for payload and CO_2 in g/km (last column). [3]

Finally, the weighted efficiency ratios can be calculated according to equations (3-6) to (3-8) by applying the corresponding weighted CO_2 values.

---

[2] A detailed explanation of the methodology used to determine the individual weighting factors can be found in chapter 2.4.3.1.

[3] The calculation based on direct weighting of the individual CO_2 values in g/t-km for each mission profile would be incorrect as the payload varies depending on the payload scenario and mission profile. In contrast, the weighted CO_2 results in g/m³-km can also be calculated by direct weighting, as the cargo volume is the same for any combination of mission and payload scenario of a given lorry + trailer configuration.

2.2 *Task 2.1: Definition of inputs to the tool*

A considerable set of inputs has been defined not only for calculation purposes, but of course also for documentation and classification purposes. Table 6 gives a general overview of the defined groups of input data including parameter examples for each group as well as a short description why these inputs are required. A detailed explanation of each defined input parameter is given in chapter 2.2.1.

Table 6. Overview of inputs to the tool

Input data group	Input parameters	Description
Documentation	- Manufacturer - Manufacturer Address - VIN - …	Parameters needed for documentation purposes e.g. allocation of results to the corresponding manufacturer
Classification	- Trailer type - Bodywork code - Number of axles	Parameters needed for complete classification of the trailer
Calculation	- Masses - Dimensions - Axle / tyre information - …	Parameters needed for calculating each individual trailer

It should be noted here that additional input parameters were proposed by stakeholders both in the 2020 survey and in subsequent consultations, aimed at taking into account additional trailer technologies. Section 0 lists the technologies not considered in this project, and thus in the first phase of trailer regulation, and provides the reasons for this.

2.2.1 Parameters foreseen to be covered in this project / in the first implementation stage of the trailer regulation

Table 7 to Table 33 below provide detailed information on every input parameter foreseen to be covered in this project including:

- Description of the parameter itself (name, unit, type, etc.),
- Reference to how the parameter must be determined and if it is already regulated somewhere
- Implementation status as well as an explanation why the parameter is needed in the tool

The first set of parameters include basic information about the manufacturer and trailer for documentation purposes.

Table 7. Parameter T001 - Manufacturer

Parameter name	Manufacturer
Parameter ID	T001
Type	token
Unit	[-]
Description	Name of trailer manufacturer
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

Table 8. Parameter T002 - Manufacturer Address

Parameter name	Manufacturer Address
Parameter ID	T002
Type	token
Unit	[-]
Description	Address of trailer manufacturer
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

Table 9. Parameter T003 - Model / Commercial Name

Parameter name	Model / Commercial Name
Parameter ID	T003
Type	token
Unit	[-]
Description	---
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

Table 10. Parameter T004 - VIN

Parameter name	VIN
Parameter ID	T004
Type	token
Unit	[-]
Description	Vehicle Identification Number
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

Table 11. Parameter T005 - Date

Parameter name	Date
Parameter ID	T005
Type	dateTime
Unit	[-]
Description	Date and time when input information and input data is created
Source of determination	---
Comments	This information is automatically generated by the VECTO Trailer Tool in case the input XML is generated via the Graphical User Interface.
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

Table 12. Parameter T006 - Legislative category

Parameter name	Legislative category
Parameter ID	T006
Type	string
Unit	[-]
Description	Allowed values: 'O3', 'O4'
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for documentation

The trailer classification is done depending on the number of axles, the trailer type and the bodywork type. Another important information for the classification is the orientation of the trailer (standard or volume orientation). A definition of the terms is contained in Annex I and this information is read in via a separate input parameter.

Table 13. Parameter T007 – Number of axles

Parameter name	Number of axles
Parameter ID	T007
Type	integer
Unit	[-]
Description	Allowed values: 1, 2, 3
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for classification

Table 14. Parameter T008 - Trailer type

Parameter name	Trailer type
Parameter ID	T008
Type	string
Unit	[-]
Description	Allowed values: 'DA', 'DB', 'DC'
Source of determination	---
Comments	DA (Semi-trailer) DB (Drawbar trailer) DC (Centre-axle trailer) In accordance with Regulation (EU) 2018/858
Status for trailer tool	Included in final Tool version
Justification	Needed for classification

Table 15. Parameter T009 - Bodywork type

Parameter name	Bodywork type
Parameter ID	T009
Type	string
Unit	[-]
Description	Allowed values: 'dry box', 'refrigerated', 'conditioned', 'curtain-sided', 'drop-side tarpaulin body'
Source of determination	In accordance with Table 3 of Annex III of the trailer Regulation
Comments	
Status for trailer tool	Included in final Tool version
Justification	Needed for classification

The next set of parameters need to be declared individually by the trailer manufacturer in order to obtain all the technical information for the simulation including masses, dimensions of the trailer, presence of aerodynamic devices and specific tyre and axle information.

Table 16. Parameter T010 – Volume Orientation

Parameter name	**Volume orientation**
Parameter ID	T010
Type	boolean
Unit	[-]
Description	Defines if trailer is volume or standard oriented
Source of determination	To be determined in accordance with Article 3, point 5
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 17. Parameter T011 – Corrected mass in running order

Parameter name	**Corrected mass in running order**
Parameter ID	T011
Type	integer
Unit	[kg]
Description	---
Source of determination	In accordance with Annex XIII, Part 2, Section A, point 1.3.(b) of Regulation (EU) 2021/535 In case of vehicles with 04 bodywork without an equipment to maintain the interior temperature, a generic mass of X[kg]=(850 kg/85m³)*cargo volume[m³] shall be added.
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Key parameter for VECTO simulations

Table 18. Parameter T012 - TPMLM trailer

Parameter name	TPMLM trailer
Parameter ID	T012
Type	integer
Unit	[kg]
Description	Technically Permissible Maximum Laden Mass of total trailer
Source of determination	In accordance with Annex XIII, Part 2, Section A, point 1.6. of Regulation (EU) 2021/535
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed for • Documentation • Limitation of total vehicle mass in simulation

Table 19. Parameter T013 - TPMLM axle assembly

Parameter name	TPMLM axle assembly
Parameter ID	T013
Type	integer
Unit	[kg]
Description	Technically Permissible Maximum Laden Mass of axle assembly
Source of determination	In accordance with Annex XIII, Part 2, Section A, point 1.13. of Regulation (EU) 2021/535
Comments	Input required only for trailers of type 'DA' and 'DC'
Status for trailer tool	Included in final Tool version
Justification	Additional parameter needed for classification for the cases 2-axle DAs and 2-axles DCs

Table 20. Parameter T014 - External length of the body

Parameter name	External length of the body
Parameter ID	T014
Type	double, 3
Unit	[m]
Description	---
Source of determination	To be determined in accordance with point 2(6)(a) of Annex III of the trailer Regulation
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 21. Parameter T015 - External width of the body

Parameter name	External width of the body
Parameter ID	T015
Type	double, 3
Unit	[m]
Description	---
Source of determination	To be determined in accordance with point 2(6)(b) of Annex III of the trailer Regulation
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 22. Parameter T016 - External height of the body

Parameter name	External height of the body
Parameter ID	T016
Type	double, 3
Unit	[m]
Description	---
Source of determination	To be determined in accordance with point 2(6)(c) of Annex III of the trailer Regulation
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 23. Parameter T017 - Total height of the trailer

Parameter name	Total height of the trailer
Parameter ID	T017
Type	double, 3
Unit	[m]
Description	---
Source of determination	To be determined in accordance with point 2(7) of Annex III of the trailer Regulation
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 24. Parameter T018 - Length from trailer front end to centre of first axle

Parameter name	Length from trailer front end to centre of first axle
Parameter ID	T018
Type	double, 3
Unit	[m]
Description	distance between front end of the trailer to centre of first axle; in case of 3-axle DB trailer: distance from the front end of the trailer to the centre of the last axle from the first set of axles
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 25. Parameter T019 - Length between centres of axles

Parameter name	Length between centres of axles
Parameter ID	T019
Type	double, 3
Unit	[m]
Description	distance between centres of first and last axle; in case of 3-axle DB trailer: distance from the centre of the last axle of the first set of axles to the centre of the first axle of the last set of axles
Source of determination	---
Comments	---
Status for trailer tool	Included in June ’21 tool release
Justification	Needed to calculate C_DxA

For the special case of DC trailers a separate input is needed on how the trailer is coupled to the towing vehicle (trailer coupling point). This has an effect on the gap between the body of the towing vehicle and the trailer and is considered in the air drag calculations.

Table 26. Parameter T020 - Trailer Coupling Point

Parameter name	Trailer Coupling Point
Parameter ID	T020
Type	string
Unit	[-]
Description	allowed values 'high', 'low'
Source of determination	To be determined in accordance with points 2(4) and 2(5) of Annex III of the trailer Regulation
Comments	only relevant for trailer type DC
Status for trailer tool	Included in final Tool version
Justification	Needed in case of trailer types DC to determine the gap between towing vehicle and trailer, which is of relevance for C_DxA

Table 27. Parameter T021 - Cargo volume

Parameter name	Cargo volume
Parameter ID	T021
Type	double, 3
Unit	[m^3]
Description	---
Source of determination	To be determined in accordance with points 2(8) of Annex III of the trailer Regulation
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate g/m^3-km

Table 28. Parameter T022 - Standard aerodynamic devices

Parameter name	Standard aerodynamic devices
Parameter ID	T022
Type	enum
Unit	[-]
Description	allowed values: 'side cover short', 'side cover long', 'rear flap short', 'rear flap long' Multiple entries allowed
Source of determination	Inputs to be declared in accordance with the provisions in Appendix 5 of Annex V of the trailer Regulation
Comments	The input of standard aerodynamic devices shall not be combined with input for a certified aerodynamic device
Status for trailer tool	Included in final Tool version
Justification	Needed to calculate C_DxA

Table 29. Parameter T023 – Certification number certified aerodynamic device

Parameter name	**Certification number certified aerodynamic device**
Parameter ID	T023
Type	token
Unit	[-]
Description	---
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Needed to check if aerodynamic device was certified for the trailer to be simulated

All the tyre information listed in Table 30 below is grouped together in a separate XML file already certified by the tyre OEM according to Annex X of Regulation (EU) 2017/2400. These files are then directly loaded into the tool, which is why the tyre parameters do not get an individual parameter ID in the VECTO Trailer Tool. The only exception is the parameter “Certification number” as it is used to identify the specific tyre XML used in the tool.

Table 30. Tyre XML – List of parameters (adapted from Annex X version second amendment of Regulation (EU) 2017/2400)

Parameter name	VECTO Trailer tool Param ID	Type	Unit	Description/Reference
Manufacturer	---	token		
Model	---	token		Trade name of manufacturer
CertificationNumber	T024	token		
Date	---	date		Date and time when the component hash is created.
AppVersion	---	token		Version number identifying the evaluation tool
RRCDeclared	---	double, 4	[N/N]	
FzISO	---	integer	[N]	
TyreSizeDesignation	---	string	[-]	Allowed values (non-exhaustive): "9.00 R20", "9 R22.5", "9.5 R17.5", "10 R17.5", "10 R22.5", "10.00 R20", "11 R22.5", "11.00 R20", "11.00 R22.5", "12 R22.5", "12.00 R20", "12.00 R24", "12.5 R20", "13 R22.5", "14.00 R20", "14.5 R20", "16.00 R20", "205/75 R17.5", "215/75 R17.5", "225/70 R17.5", "225/75 R17.5", "235/75 R17.5", "245/70 R17.5", "245/70 R19.5", "255/70 R22.5", "265/70 R17.5", "265/70 R19.5", "275/70 R22.5", "275/80 R22.5", "285/60 R22.5", "285/70 R19.5", "295/55 R22.5", "295/60 R22.5", "295/80 R22.5", "305/60 R22.5", "305/70 R19.5", "305/70 R22.5", "305/75 R24.5", "315/45 R22.5", "315/60 R22.5", "315/70 R22.5", "315/80 R22.5", "325/95 R24", "335/80 R20", "355/50 R22.5", "365/70 R22.5", "365/80 R20", "365/85 R20", "375/45 R22.5", "375/50 R22.5", "375/90 R22.5", "385/55 R22.5", "385/65 R22.5", "395/85 R20", "425/65 R22.5", "495/45 R22.5", "525/65 R20.5"";
TyreClass	---	string	[-]	“C2”, “C3” or “N/A”
FuelEfficiencyClass	---	string		“A”, “B”, “C”, “D”, “E”or “N/A”

Further information to be provided per axles are the parameters “Twin tyres”, “Steered axle” and “Lift axles”, as listed in Table 31 to Table 33 below. A method to consider the impact of steered and lift axles on the trailer performance was elaborated in this project. Those technologies are not yet considered in Regulation (EU) 2017/2400 for motor vehicles and thus no reference values were available. The methodology used to consider the impact of these technologies is described in chapter 2.4.3.2.

Table 31. Parameter T025 - Twin Tyres

Parameter name	Twin Tyres
Parameter ID	T025
Type	boolean
Unit	[-]
Description	Separate input per axle
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Key parameter for VECTO simulations

Table 32. Parameter T026 - Steered axle

Parameter name	Steered axle
Parameter ID	T026
Type	boolean
Unit	[-]
Description	Separate input per axle. This field shall be set to 'true' for both passively and actively steered axles.
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Trailer technology feature to be considered by the VECTO trailer tool, see section 2.4.3.2

Table 33. Parameter T027 - Liftaxle

Parameter name	Liftaxle
Parameter ID	T027
Type	boolean
Unit	[-]
Description	Separate input per axle
Source of determination	---
Comments	---
Status for trailer tool	Included in final Tool version
Justification	Trailer technology feature to be considered by the VECTO trailer tool, see section 2.4.3.2

2.2.2 Parameters / topics not foreseen to be covered in this project / in the first implementation stage of the trailer regulation

Stakeholders, in particular CLEPA, have provided a list of technologies and trailer features in the 2020 survey as well as in later position papers that they believe should be considered in trailer regulation and thus in the VECTO Trailer Tool. From this list, the technologies "lift axle" and "steered axle" - as mentioned above in the parameters and methodically described under chapter 2.4.4 - were selected for consideration in this project and thus for the first phase of the trailer legislation. Table 34 below contains the list of issues not taken up, a justification why the technologies have not been taken up at the moment and first suggestions for next steps. The selection of technologies was agreed with the Commission and also presented in the Task Force meetings.

Table 34. List of technologies / trailer features not yet covered by the VECTO trailer tool

Technology	Main effect on energy consumption	Consultants assessment
Tyre pressure monitoring systems (TPMS)	Reduced rolling resistance	A study performed by TNO and TUG in 2013 [1] showed a very low CO_2 reduction potential of this technology (which is also an important safety feature). From the results of the study some 0.2% maximum effect on CO_2 can be derived in case TPMLM is present on the trailer. TPMLM is also not considered a relevant CO_2 feature in Regulation (EU) 2017/2400. Thus this technology is currently not assessed to be considered in the trailer Regulation.
Automatic tyre inflation system (ATIS)	Reduced rolling resistance	The CO_2 reduction potential of ATIS is estimated to be only slightly higher than that of TPMS. Therefore, the assessment made above also applies here.
Wheel bearings	Reduced friction losses	The influence of wheel bearings is currently neglected in VECTO, even for motor vehicles. However, methods for consideration are being developed for the 3rd Amendment of Regulation (EU) 2017/2400. It is recommended that as soon as this process is completed, the same methods are also adopted in the trailer Regulation.

Technology	Main effect on energy consumption	Consultants assessment
E-axles	Energy recuperation, advanced systems allow for a full HEV vehicle operation	This technology is seen as one of the key challenges for the next levels of trailer Regulation. For this purpose, it is proposed to adopt the component certification and simulation models from Regulation (EU) 2017/2400, which are currently being developed, as a basis. On this basis, further trailer-specific elements are to be developed, such as.: * Classification of e-trailers into different technology classes (only passive recuperation, full HEV operation, others) * Consider electric energy use by auxiliary use, thus the implementation is suggested in a package with consideration of cooling demand from reefers (see also next item)
Optimised reefer technologies	Reduction of energy consumption from AC units by optimisation of insulation, efficiency of AC device and electrification	For refrigerated trailers, measures to optimise energy consumption are considered to be of major importance. However, the physical and technical mechanisms are complex and, according to current knowledge, there are no standards suitable for adoption in trailer regulation. In the project, initial discussions were held with stakeholders from the refrigerated trailer industry, but the topic was postponed due to its complexity. The associations were encouraged to develop their own drafts for approaches.
Solar panels	Generation of electric energy for use in auxiliaries or vehicle propulsion	With the increase in cost efficiency of solar cells in recent years, they represent an interesting technology for generating on-board electrical energy. This is especially true for the large areas available on box-bodies and box-trailers. For a robust consideration in VECTO, reference would have to be made to standards on how the power output of solar cells is determined. In addition, generic assumptions on solar radiation would have to be made. Following the basic principle that all provisions that are generally applicable to HDV (i.e. motor vehicles and trailers) should be included in Regulation (EU) 2017/2400, it is proposed that provisions for solar cells are first set out there and then referred to in the trailer regulation.

Technology	Main effect on energy consumption	Consultants assessment
Trailer telematics	Optimisations of logistics, trips etc.	Trailer telematics aims at logistical optimisation, i.e. reduction of trips and optimisation of vehicle utilisation/payload. The number of kilometres driven cannot be depicted in VECTO, optimisation of the payload would be very difficult to determine and could only be reflected in the weighting factors for mission profiles and payloads cycles and loads. At the current stage, this technology is considered to be of little relevance for consideration in VECTO.

2.3 *Task 2.2: Definition of the methodology including 3D vehicle model creation*

Computational Fluid Dynamics (CFD) plays an important role within this task as it is used to predict the aerodynamic resistance (C_DxA) of different vehicle configurations, as well as its evolution along the vehicle advancing direction.

A large collection of these C_DxA values are then used to build, evaluate and fine-tune the corresponding algorithms and equations that should be able to return an estimated drag resistance value for a given trailer or semitrailer without the need to run a CFD simulation and purely based on vehicle dimensions.

In order to validate the CFD methodology, an IVECO Stralis pulling a standard semitrailer with different aerodynamic devices has been tested at IDIADA facilities in Spain. This has been part of a 2nd CFD vs CST campaign, being the first campaign already documented in “Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005”.

2.3.1 IVECO Stralis correlation activities

CNH Industrial provided IDIADA with an IVECO Stralis Hi-Way from 2019 to be tested according to the test procedure described in the Annex 8 of the Commission Regulation (EU) 2017/2400 of 12 December 2017.

Figure 1. CST-tested IVECO Stralis Hi-Way 2019 model

In order to run the corresponding CFD analysis, CNH Industrial also provided IDIADA with the CAD geometry representing that tractor. All aerodynamically relevant exterior parts were included (mirrors, sun visor, roof spoiler, side deflectors, etc) and positioned as in the tests), as well as all engine compartment and chassis components. No treaded tyres and contact patch deformation were taken into account.

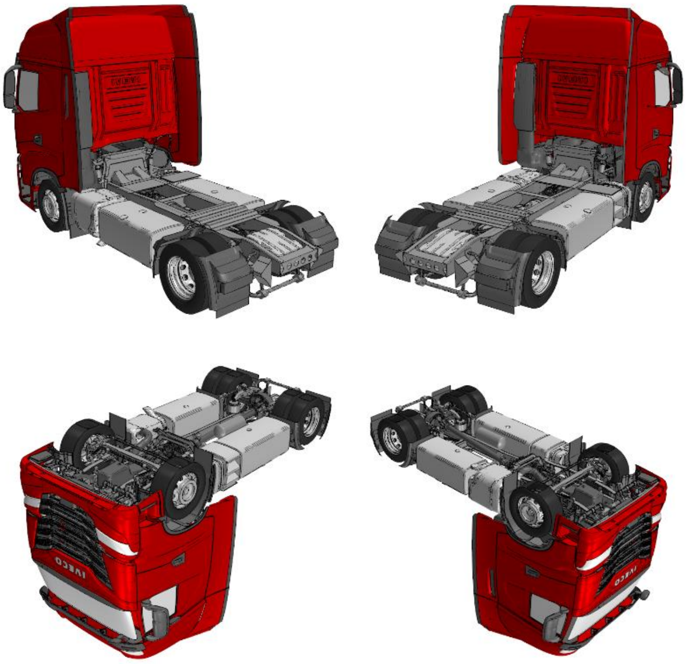


Figure 2. CAD model of the tractor IVECO Stralis Hi-Way 2019

2.3.1.1 Constant Speed Tests

The air drag measurements were performed according to the test procedure described in the Annex 8 of the commission regulation (EU) 2017/2400 of 12 December 2017. The several tests were performed at IDIADA Proving Ground facilities in Spain in August 2020 on a vehicle provided by CNH Industrial.

2.3.1.1.1 Test process

The test process is described hereby:

- Warm-up phase: The vehicle was driven 90 minutes at the target speed of the high speed test in order to warm-up the system. The warm-up was performed on IDIADA high speed track.

- Torque meters zeroing: After the warm-up phase the torque meters zeroing was performed lifting the instrumented wheels off the ground on the dynamic platform A.

- Low speed test warm-up: After the torque meters zeroing, another warm-up of 20 minutes at the target speed of the high speed runs was performed on the dynamic platform A before the beginning of the Air drag measurements.

- First low speed measurement: The vehicle was driven at the target speed of the low speed test in both directions during 20 minutes on the dynamic platform A.
- High speed test warm-up: After the first low speed measurement another warm-up of 5 minutes at the target speed of the high speed runs was performed before the beginning of the high speed measurements.
- High speed measurement: The vehicle was driven at the target speed of the high speed test in order to record 15 runs on each direction on the dynamic platform A.
- Second low speed measurement: The vehicle was driven at the target speed of the low speed test in both directions during 20 minutes on the dynamic platform A.
- Drift check of torque meters: After the second low speed measurement the torque meters drift check was performed lifting the instrumented wheels off the ground on the dynamic platform A and checking that the difference between both instrumented torque meters was less than 25Nm.

2.3.1.1.2 Vehicle specifications

The tested vehicle had the following specifications and characteristics.

Table 35. Specifications of the tested vehicle

VEHICLE CHARACTERISTICS	
Manufacturer	IVECO
Model	STRALIS 570
VIN	WJMM62AWZ0C425381
Class code	5
Vehicle maximum speed	90,0 km/h
Vehicle height	4,00 m
Axle ratio	3,360
Gear box type	MT_AMT
VEHICLE TEST CHARACTERISTICS	
Anemometer height	5,33 m
Gear at low speed	4
Gear ratio at low speed	7,670
Gear at high speed	12
Gear ratio at high speed	1,000

2.3.1.1.3 Vehicle test configurations

Figure 3. Baseline configuration (C00)

Figure 4. Pallet box configuration (C01)

Figure 5. Short rear flap configuration (C02)

Figure 6. Tall rear flap configuration (C03)

Figure 7. Side cover configuration (C04)

2.3.1.1.4 Vehicle test mass

Table 36. Vehicle's weight distribution

WEIGHT DISTRIBUTION

Axle	Left	Right	Total
1	3.117 kg	2.524 kg	**5.641 kg**
2	1.923 kg	1.773 kg	**3.696 kg**
3	1.161 kg	1.006 kg	**2.167 kg**
4	995 kg	1.088 kg	**2.083 kg**
5	1.110 kg	967 kg	**2.077 kg**
Totals	**8.306 kg**	**7.358 kg**	**15.664 kg**

2.3.1.1.5 Main results

Using the output of the VECTO Air drag module it is possible to compare the C_DxA obtained for every configuration. In the plot in Figure 8 it can be observed the reduction in C_DxA compared to the baseline configuration for each configuration, being the zero line the baseline configuration result:

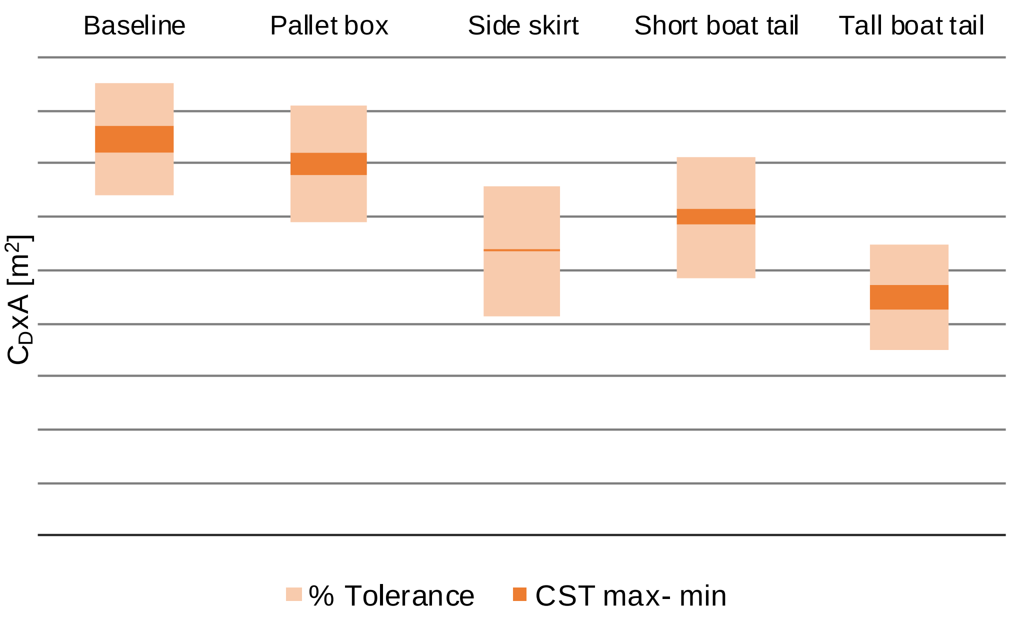


Figure 8. CST results with a 3,75% tolerance

The 3,75% tolerance represented in the plot here above refers to the repeatability of the different tests performed:

- in the same track,
- with the same instrumentation,
- same driver, and
- in similar weather conditions.

The value of 3,75% has been considered as a reference since it is half the value of what is accepted as tolerance margin in Commission Regulation (EU) 2017/2400. It must be noted that the same test performed in different test tracks and instrumentation may lead to a higher dispersion.

Figure 9 plots the potential effect of each device in $\Delta C_D xA$ after taking into account the 3,75% tolerance mentioned above.

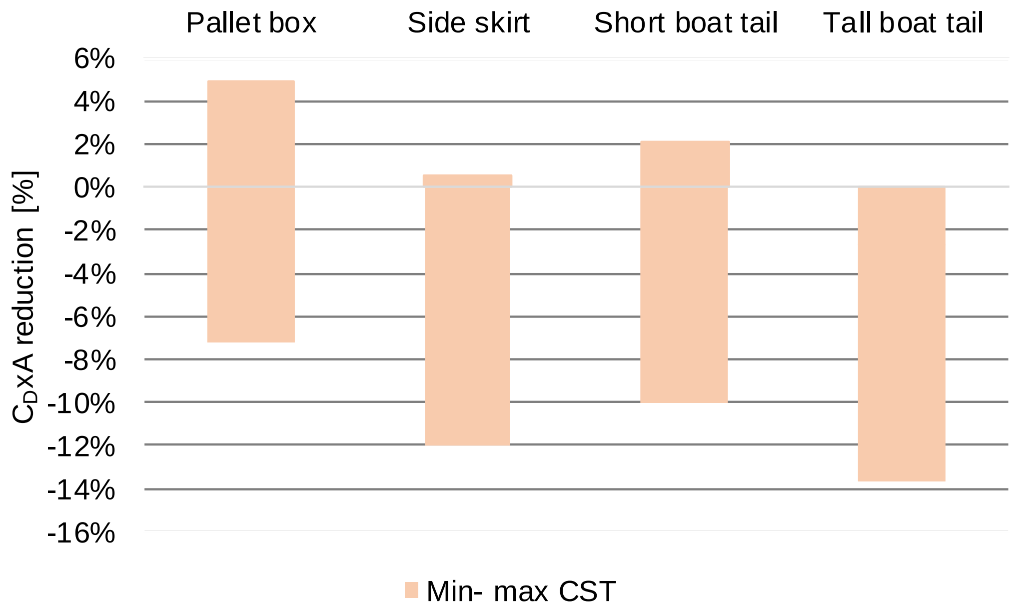


Figure 9. CST compared results

These results show that the effect of the pallet box on the $C_D xA$ at 0º of cross wind has not a significant effect in comparison with the baseline. The side cover presents very good results, because almost all the potential performance is on the negative percent side. On the other hand, both rear flap models show different results, being the tall rear flap better. In addition, the potential of the side cover is bigger than the short rear flap add-on. Furthermore, the tall version is the configuration that recorded the highest $C_D xA$ reduction in comparison with the baseline.

In the following representation of all configuration types with the add-ons painted in red, the bars depict the absolute result. This image clearly shows that the best solution in order to reduce $C_D xA$ is the configuration C04 with the tall rear flap.

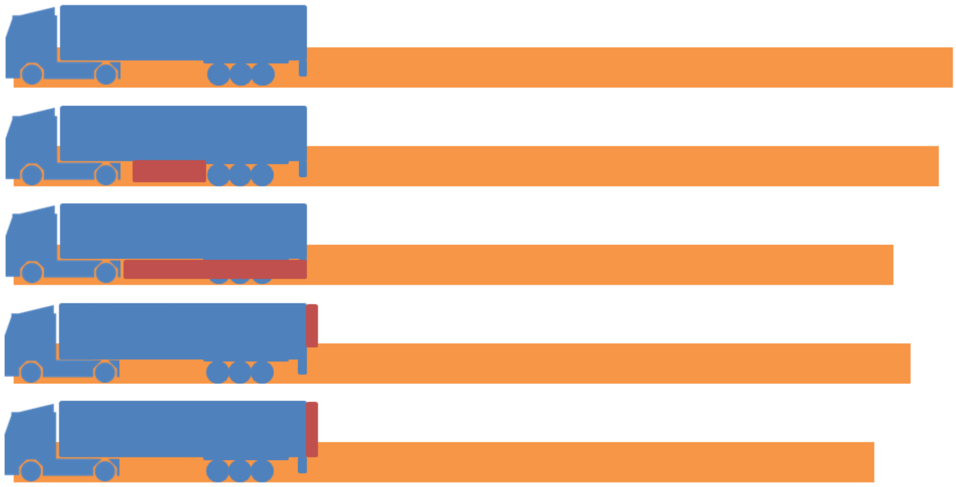


Figure 10. Representation of the worst cases for every configuration

2.3.1.1.6 Other measurements

2.3.1.1.6.1 Vehicle instrumentation

Table 37 shows the instrumentation that was used in order to perform the test and register all the required data.

Table 37. Instrumentation used

INSTRUMENTATION LIST

Channel Name	Inventory Number	Model	Maker	Sampling frequency
Position	26829	VBOX 3i RTK	Racelogic	100 Hz
Vehicle speed (DGPS)	26829	VBOX 3i RTK	Racelogic	100 Hz
Cardan speed	170705	Optical fibre	Omron	100 Hz
Asphalt temperature	10249	SA-IR200V6-002	2D	100 Hz
Tyre temperature	180553	SA-IR200V6-002	2D	100 Hz
Torque	181725	DX-RCI	Caemax	100 Hz
Anemometer	160455	86000-2AXES	YOUNG	100 Hz
Atmospheric temperature	180270	Thermocouple type K	RS Pro	100 Hz

2.3.1.2 CFD simulations

All five CST-tested configurations presented above have also been studied by means of CFD with the same mesh and boundary settings detailed in Section 5.3 CFD Settings of "Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005" and, as it was analysed back then, also both steady-state and transient methods have also been evaluated.

2.3.1.2.1 CFD Results on Iveco Stralis Hi-Way 2019

Absolute values obtained from the simulations are not reported due to confidentiality. Alternatively, only the difference with respect to the baseline configuration (C00) is presented according to the following formula:

$$Modification\ Effect\ (\%)_{CFD\_Method} = \left(\frac{C_D \cdot A^{Modified} - C_D \cdot A^{Baseline}}{C_D \cdot A^{Baseline}}\right)_{CFD\_Method} x\ 100$$

2.3.1.2.1.1 Steady-state results

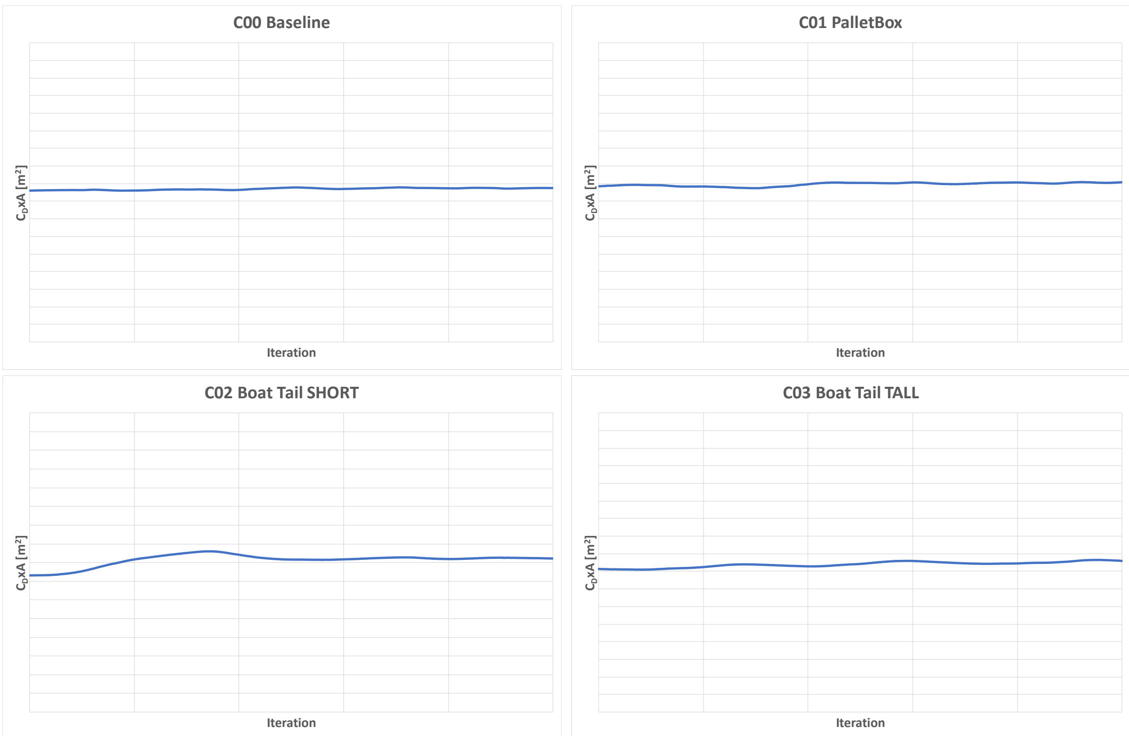
All cases have been run for enough iterations to ensure a full convergence of the most relevant engineering quantities. The following table reports the standard deviation (σ) of the last 500 iterations of C_D·A [m^2], calculated as follows:

$$\sigma = \sqrt{\frac{\sum(C_D \cdot A - \overline{C_D \cdot A})^2}{500}}$$

Table 38. C_DxA standard deviation [m^2] in the steady-state runs

Case	Last 500 iterations C_D·A standard deviation [m^2]
C00	0.00028
C01	0.00051
C02	0.00155
C03	0.00079
C04	0.00034

The following plots show the evolution of C_DxA [m^2] along the last 500 iterations. Absolute values of C_DxA [m^2] are hidden for confidentiality purposes, but the vertical axis is split with ΔC_DxA = 0.005 m^2 for a better understanding:



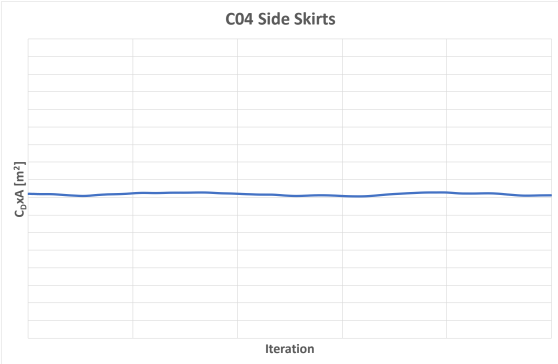


Figure 11. C_DxA [m^2] vs iteration for all 5 configurations

As far as the results is concerned, the following table presents the effect of the semitrailer modifications, with respect to the standard semitrailer, predicted by the CFD simulations resolved in a steady-state manner:

$$Modification\ Effect\ (\%)_{CFD\_Steady} = \left(\frac{C_D \cdot A^{Modified} - C_D \cdot A^{Baseline}}{C_D \cdot A^{Baseline}}\right)_{CFD\_Steady} x\ 100$$

Table 39. CFD Steady-state results

	C01 PalletBox	C02 Rear Flap Short	C03 Rear Flap Tall	C04 Side covers
Modification Effect	-0.9%	-4.5%	-6.3%	-2.3%

2.3.1.2.1.2 Transient results

All cases have been run for 12 seconds of simulation time, which is long enough to reach a rather constant oscillation behaviour of the C_DxA value and calculate the corresponding average.

The following plots show the evolution of C_DxA [m^2] along the last 8 seconds of simulation time, together with its average value. Absolute values of C_DxA [m^2] are hidden for confidentiality purposes, but the vertical axis is split with ΔC_DxA = 0.10 m^2 for a better understanding:

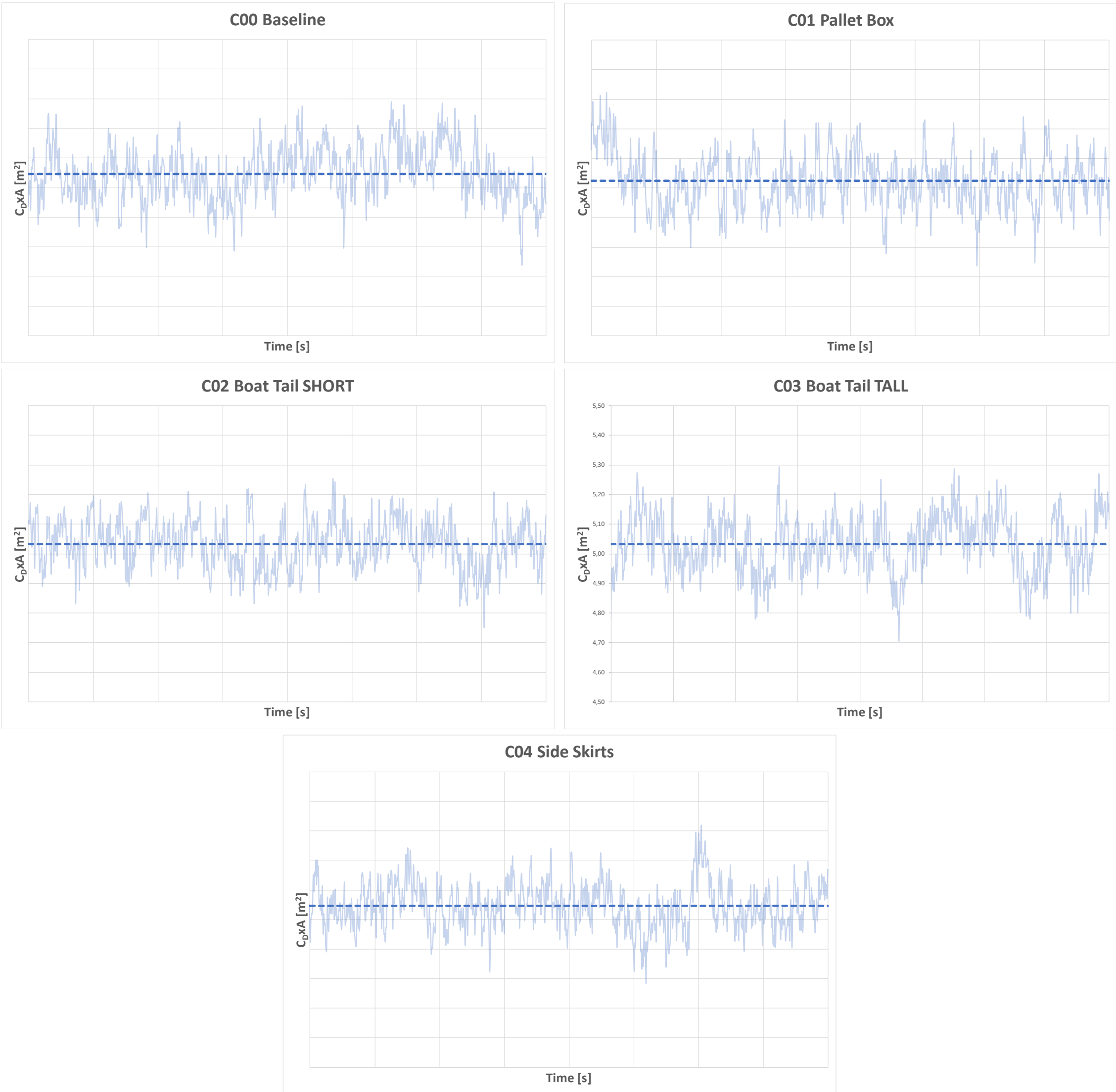


Figure 12. C_DxA [m^2] vs time for all 5 configurations

As expected, the variation of C_DxA over time is much larger than what was predicted by the steady-state methodology as it can be seen in Table 40.

Table 40. C_DxA standard deviation [m^2] in the transient runs

Case	Last 8 seconds $C_D \cdot A$ standard deviation [m^2]
C00	0.08793
C01	0.08933
C02	0.07996
C03	0.09445
C04	0.07681

Table 41 presents the effect of the semitrailer modifications, with respect to the standard semitrailer, predicted by the CFD simulations resolved in a transient manner.

$$Modification\ Effect\ (\%)_{CFD\_Transient} = \left(\frac{C_D \cdot A^{Modified} - C_D \cdot A^{Baseline}}{C_D \cdot A^{Baseline}}\right)_{CFD\_Transient} x\ 100$$

Table 41. CFD Transient results

	C01 PalletBox	C02 Rear Flap Short	C03 Rear Flap Tall	C04 Side covers
Modification Effect	-2.3%	-5.9%	-5.9%	-5.6%

2.3.1.3 CST vs CFD

Measured data in the CST tests and the CFD simulation results are merged into the plot seen in Figure 13.

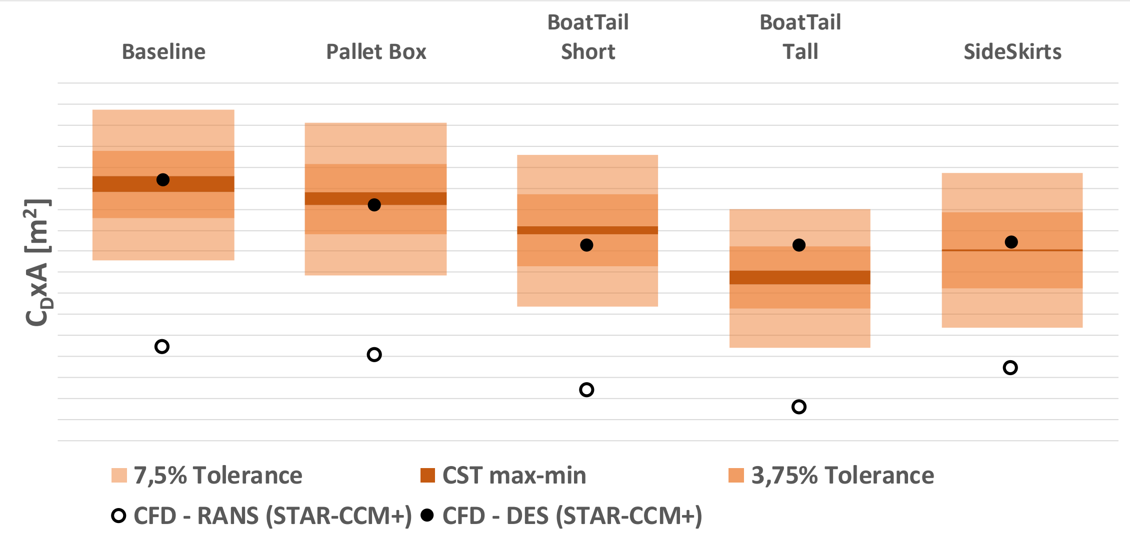


Figure 13. CST and CFD results absolute values compilation

While C_DxA values are hidden due to confidentiality reasons, it is clearly visible that the steady-state approach tends to underpredict air drag values. On the other hand, the transient approach prediction is much closer to what has been measured in the testing track, falling well within the tolerance margin of 7,5% specified in Commission Regulation (EU) 2017/2400.

The following table with normalized values quantifies the corresponding approximations and, while the steady-state method falls 11-15% short, the more computationally expensive approach of running a DES simulation, manages to predict C_DxA [m^2] within a deviation of less than 3% with respect to the average of the two CST runs.

Table 42. CST vs CFD data. Normalized values

	C00 Baseline	C01 Pallet Box	C02 Rear Flap Short	C03 Rear Flap Tall	C04 Side covers
CST (averaged**)**	1	1	1	1	1
CFD Steady-state	0.854	0.858	0.851	0.873	0.887
CFD Transient	1.004	0.994	0.986	1.031	1.008

While the data presented so far is focused the actual C_DxA [m^2] values for each configuration, CFD efforts within this project have been devoted to predicting the differences in aero performance between configurations: ΔC_DxA

Table 43. Aero performance differences in ΔC_DxA[%] wrt C00-Baseline

	C01 Pallet Box	C02 Rear Flap Short	C03 Rear Flap Tall	C04 Side covers
CST Min	0.0%	-3.0%	-7.0%	-5.1%
CST Max	-1.3%	-4.1%	-9.7%	-6.7%
CFD Steady-state	-0.9%	-4.5%	-6.3%	-2.3%
CFD Transient	-2.3%	-5.9%	-5.9%	-5.6%

Both methodologies provide similar results in terms air drag percentage reduction. It should also be noted that, for the studied configurations, the transient runs (more computationally expensive, but theoretically closer to reality as mentioned above) predict a slightly larger benefit of the trailer aerodynamic devices, with the exception of the tall version of a rear flap, where a slightly larger reduction in air drag is predicted when running in steady-state mode. This behaviour was also identified in previous project “Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005”.

Figure 14 contextualizes the results predicted by CFD with what was measured by CST. On top of that, the coloured columns indicate what CST could have measured considering a 2.5% repeatability tolerance, which is an acceptable range that one could expect in a testing campaign performed in the same testing track, very same vehicle, as well as the same testing equipment.

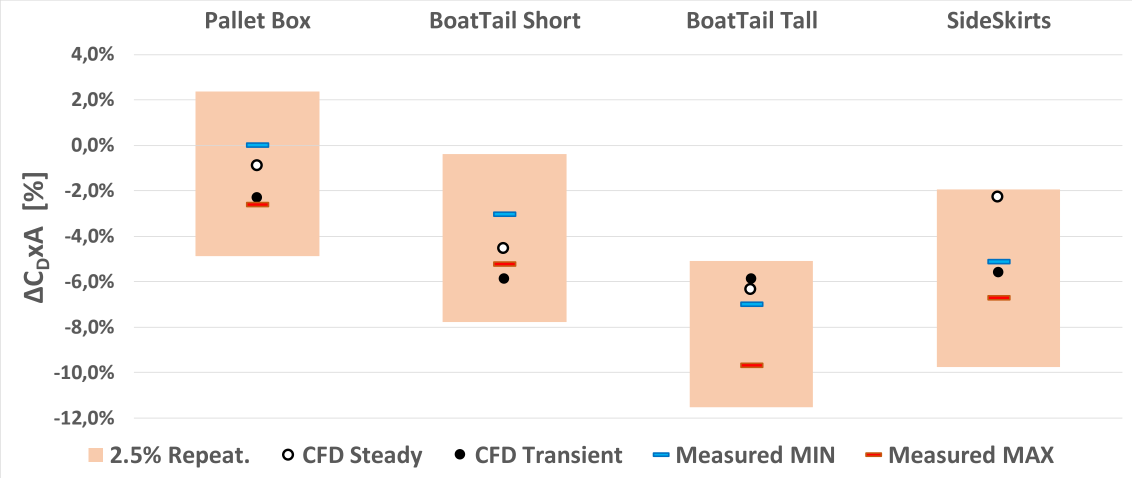


Figure 14. $\Delta C_D xA$[%] wrt C00-Baseline (Stralis MY19)

Taking such tolerance into account, it is clearly visible that both CFD methodologies, steady-state and DES, are well capable of predicting $\Delta C_D xA$ [%] with, at least, the same accuracy as CST.

2.3.2 Generic 3D Shapes

One of the main outcomes of the current project is a set of 3D CAD geometries that can be openly used by body and trailer manufacturers, as well as suppliers of aerodynamic solutions.

The development of such generic shapes aims to fill two well-known gaps:

- On the one hand, to have a common geometry for all stakeholders: Part of the work reported in "Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005" proved that cabin design does have an impact on the performance of a certain semitrailer modification (see following summary table). Hence, the existence of this common geometry aims to unify the criteria upon reporting.

Table 44. $\Delta(C_D xA)$[%] at yaw=0.0 depending on the tractor geometry

	FAT	FAT Extended	AEROFLEX
Rear Flap	-7.0%	-7.4%	-11.4%
Side covers	-4.1%	-4.4%	-8.4%

- On the other hand, the availability of a public 3D CAD model owned by the European Commission and not linked to any confidentiality issues: Virtual data is a highly sensitive piece of information within any company and, therefore, the option of using a real truck model to be provided by a European OEM was rapidly discarded.

Based on the classification matrix detailed within Task 1 of the current project, the following generic vehicles have been developed:

- 4x2 Tractor, corresponding to Group 5 in Category N
- 4x2 Rigid, corresponding to Group 4 in Category N
- 6x2 Rigid, corresponding to Group 9 in Category N
- Standard semitrailer ST1
- Standard Drawbar trailer
- Standard Centre-axle trailer

2.3.2.1 Generic 4x2 Tractor

Despite of being a simplified model, the 4x2 generic tractor has been designed taking into account most relevant features one can find in such vehicles currently circulating in European roads. Current regulation already allows certain changes into a truck cabin to make it more aerodynamic and, hence, to significantly reduce fuel consumption and CO_2 emissions. For example, replacing mirrors by cameras or the extension of the front end. While both options have been initially considered, they have been eventually discarded due to the insignificant number of vehicles currently implementing such solutions.

The chassis structure holds a rather simple powertrain and transmission unit, both front and rear axles with their suspension system, as well as the fifth gear and other plastic parts such as the side covers covering the tanks and the mudguards.

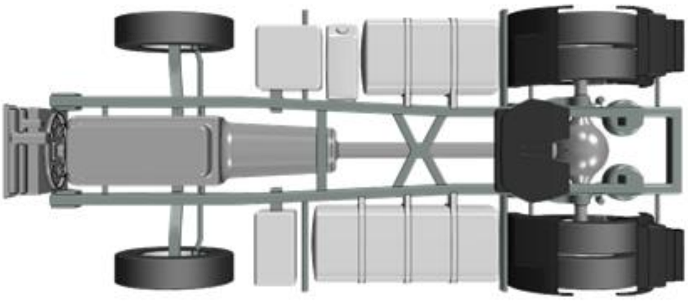


Figure 15. Chassis and other components of the 4x2 generic tractor model (Top view)

In the cabin, the front grille is divided in two parts (upper and lower) trying to mimic a real truck where the lower part is attached to the chassis and the upper one moves together with the cabin. Four sets of mirrors, a sun visor integrated into the roof line and a typical aerodynamic kit consisting of the roof spoiler and deflectors on both sides to help covering the tractor-trailer gap are all implemented.

Figure 16. Isometric view of the 4x2 generic tractor model

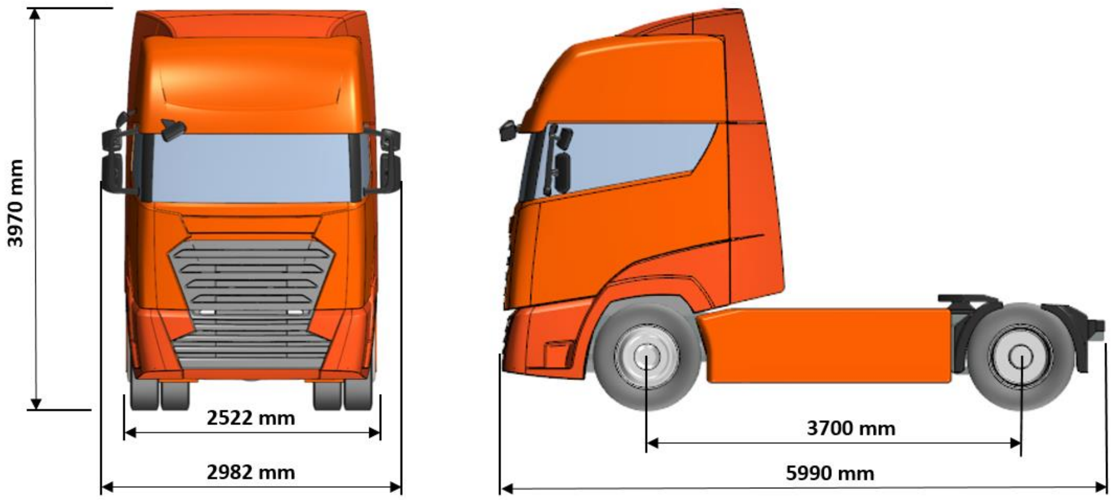


Figure 17. Front and side views with general dimensions

2.3.2.1.1 Powertrain cooling pack

The cooling pack, as in most real trucks, is made of three heat exchangers (condenser, charge air cooler and radiator) placed in series right upstream the fan shroud, which does not incorporate the actual fan.

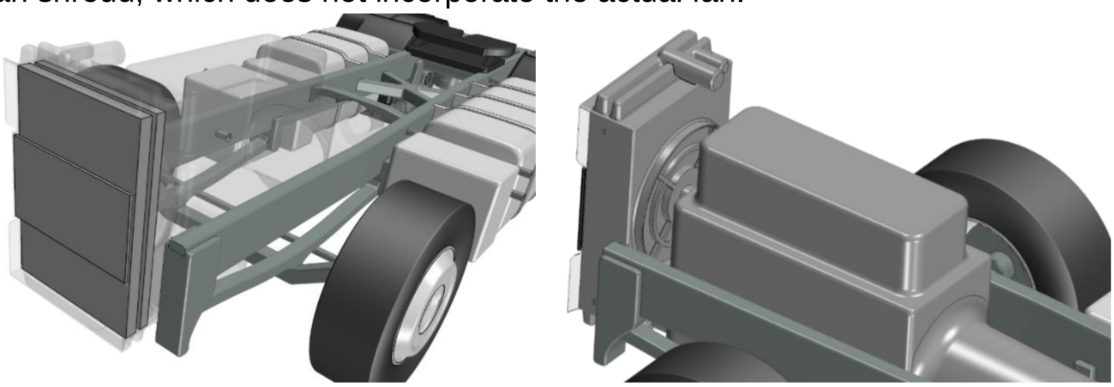


Figure 18. Cooling pack close view with all 3 heat exchangers

All heat exchanger dimensions are representative enough and close to what one can find in real trucks:

Table 45. Heat exchanger dimensions (in mm)

	Condenser	Charge Air Cooler	Radiator
Depth [dx]	14,0	60,0	46,0
Width [dy]	700,0	700,0	700,0
Height [dz]	400,0	1000,0	1000,0

The cooling performance (theoretical air pressure drop per unit length) is defined by the following equation:

$$\frac{\Delta P}{L} = -(P_i \cdot |v| + P_v) \cdot v$$

Where :

ΔP: pressure drop across the heat exchange core
L: core thickness
v: superficial velocity through the core
P_i: Inertial resistance coefficient defining the core's porous resistance
P_v: Viscous resistance coefficient defining the core's porous resistance

Both inertial and viscous resistance coefficients values are such that the corresponding performances are very similar to other OEM cooling pack, as it can be seen in Table 46.

Table 46. Porous resistance coefficients

	Condenser	Charge Air Cooler	Radiator
P_i [kg/m^4]	140,0	60,0	120,0
P_v [kg/m^{3}s]	450,0	300,0	450,0

Plots in Figure 19, Figure 20 and Figure 21 show the pressure drop versus air speed curves of two different OEMs (in blue and orange) and the EU generic vehicle (in gray) falling right in between.

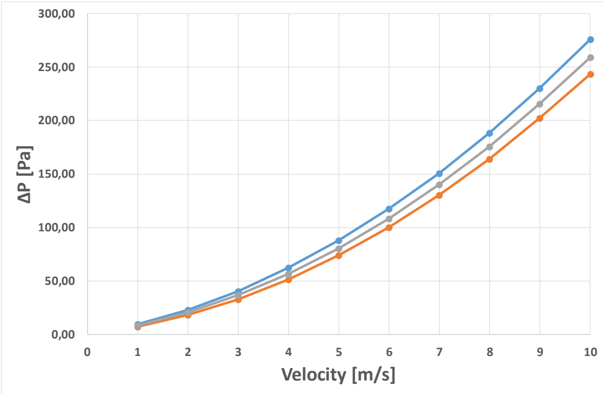


Figure 19. Condenser pressure drop vs speed curves

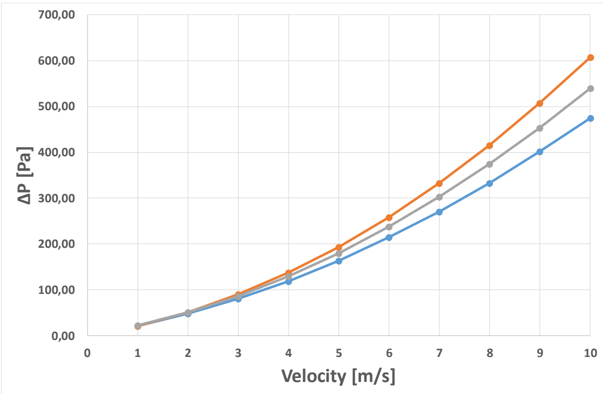


Figure 20. Charge Air Cooler pressure drop vs speed curves

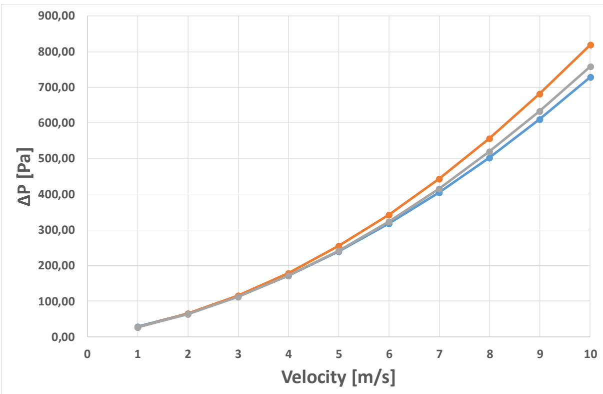


Figure 21. Radiator pressure drop vs speed curves

2.3.2.2 Generic standard semitrailer ST1

The semitrailer has been designed according to the current COMMISSION REGULATION (EU) 2017/2400 (Tables 14 and 15 of Annex VIII in Appendix 4).

For simplification reasons, the 2 back doors have not been included in the geometry model as they have no influence on the aerodynamic performance of the vehicle.

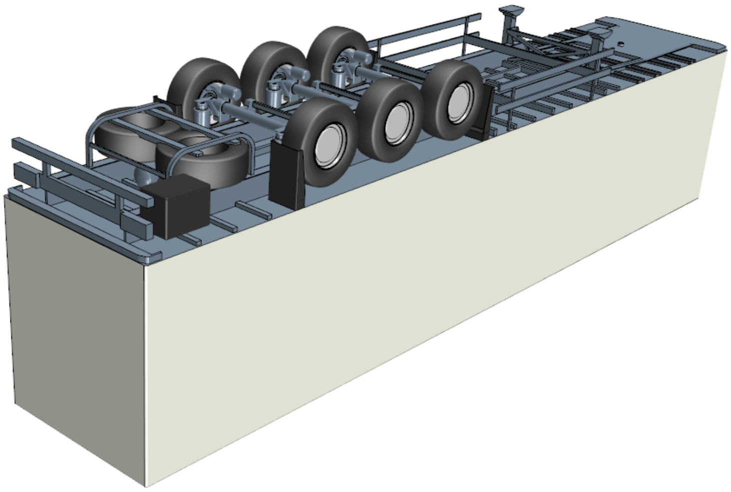


Figure 22. ST1 semitrailer underbody details

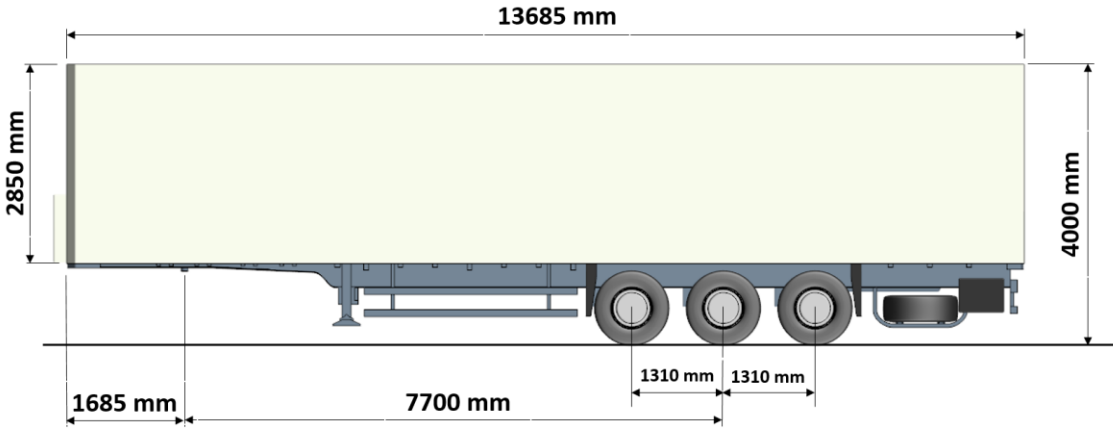


Figure 23. ST1 semitrailer general dimensions

2.3.2.2.1 Tractor and semitrailer combination

Assembling both tractor and semitrailer results in a vehicle with a total length of 13,685m and a total height of 4,000m over the ground. The vehicle frontal area, including the mirrors, is calculated to be 10,047 m^2, being very similar to conventional trucks.

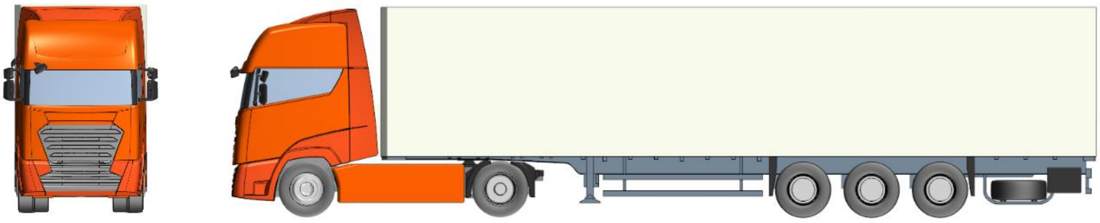


Figure 24. Tractor and semitrailer combination (front and side views)

The roof spoiler is well aligned with the semitrailer top edge and the side deflectors covering the tractor-trailer gap are also properly sketched to mimic current designs seen on real European trucks.

Figure 25. Tractor and semitrailer combination (isometric view)

2.3.2.3 Generic Rigid trucks

Both 4x2 and 6x2 rigid trucks share the very same cabin and powertrain with the articulated tractor presented here above. The aerokit (side deflectors and roof spoiler) has been modified to better fit the cargo box and the chassis and side panels have been extended accordingly.

2.3.2.3.1 4x2 Rigid

In accordance with Table 1 in Annex I of the current COMMISSION REGULATION (EU) 2017/2400, the generic 4x2 rigid truck is classified under group 4, carrying a B4 standard body, whose specifications are detailed in Table 12 of Annex VIII in Appendix 4.

The vehicle is equipped with 315/80 R22,5 tires in both front and rear axles and its frontal area, including the mirrors, is calculated to be 9,985 m^2, being very similar to conventional rigid trucks.

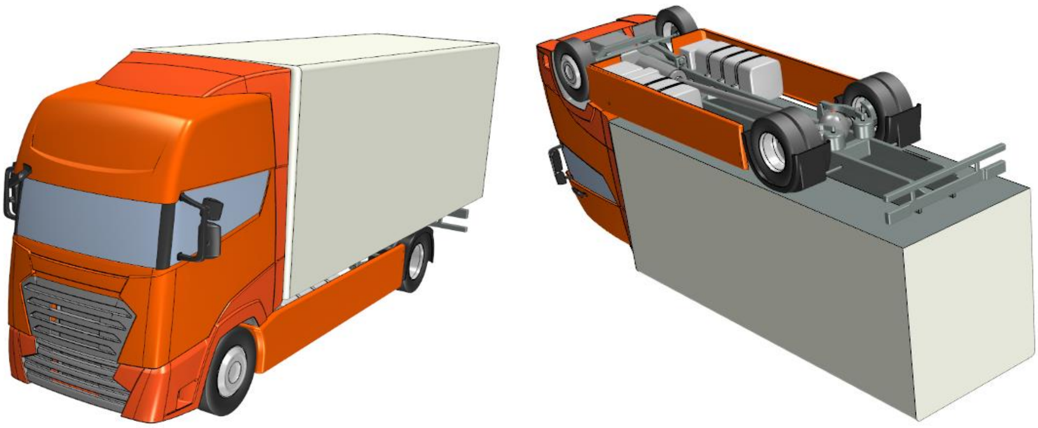


Figure 26. 4x2 Rigid Truck (isometric views)

The following images show some general dimensions:

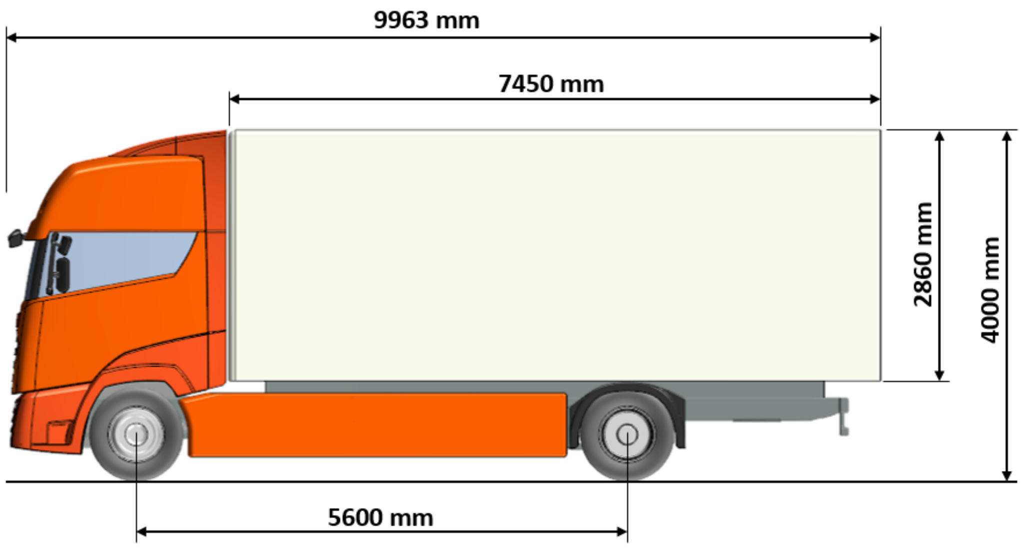


Figure 27. 4x2 Rigid Truck general dimensions

2.3.2.3.2 6x2 Rigid

In accordance with Table 1 in Annex I of the current COMMISSION REGULATION (EU) 2017/2400, the generic 6x2 rigid truck is classified under group 9, carrying a B5 standard body, whose specifications are detailed in Table 13 of Annex VIII in Appendix 4.

This 6x2 configuration shares the same tires and very same frontal area value with the 4x2 vehicle.

Figure 28. 6x2 Rigid Truck (isometric view)

The following images show some general dimensions:

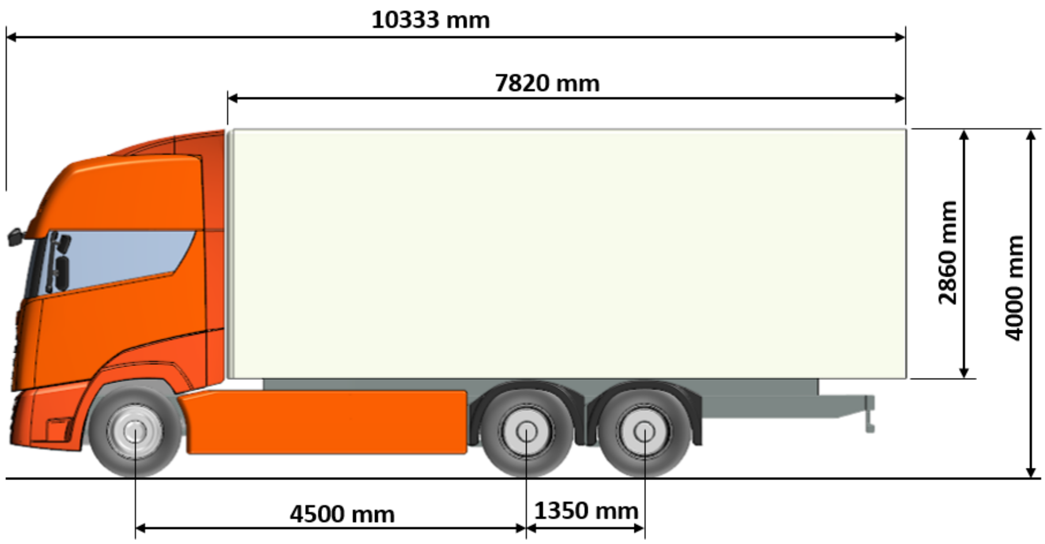


Figure 29. 4x2 Rigid Truck general dimensions

2.3.2.4 Generic standard drawbar trailer

The drawbar trailer has been designed following the guidelines provided by CLCCR:

Table 47. Standard drawbar trailer specs

Trailer Type	2-axle drawbar trailer
Body Type	Hard shell body (dry-out box design) With two rear doors Without side doors
Chassis specs	Lateral protection device (two strips or one plate per side) Rear underride protection Rear lamp holder plate Two spare wheels between the axles

	Toolbox between the axles (left or rear side) Mud flaps behind the axles Air suspension Disc brakes Tyre size: 385/65 R22.5

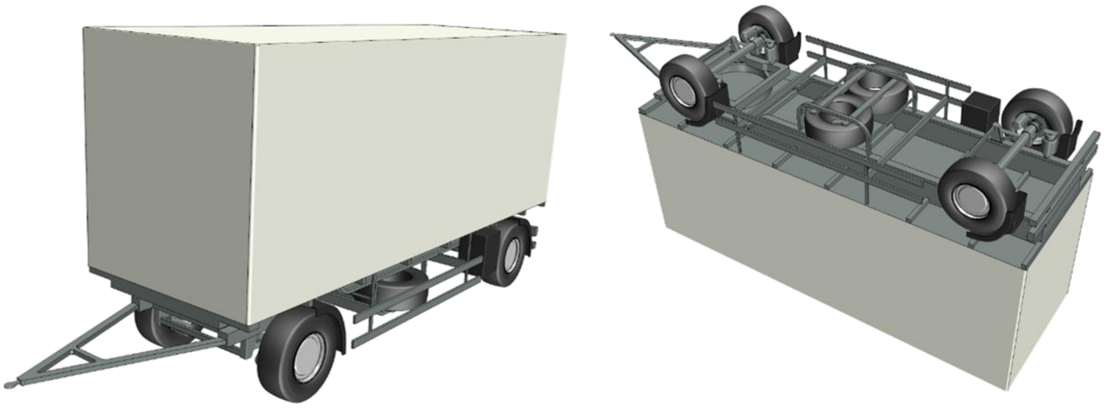


Figure 30. Standard Drawbar trailer (isometric views)

Table 48. Standard Drawbar trailer (General Dimensions)

	Dimensions [mm]
Total length	9.250,00
Body length	7.400,00
Total width (Body width)	2.550,00
Body height	2.730,00
Full height, unloaded	4.000,00
Wheelbase	5.300,00
Length drawbar eye – mid rotating assembly	3.000,00
Toolbox length	445,00
Toolbox cross section	655,00 x 493,00
Distance between truck and trailer body	1.550,00

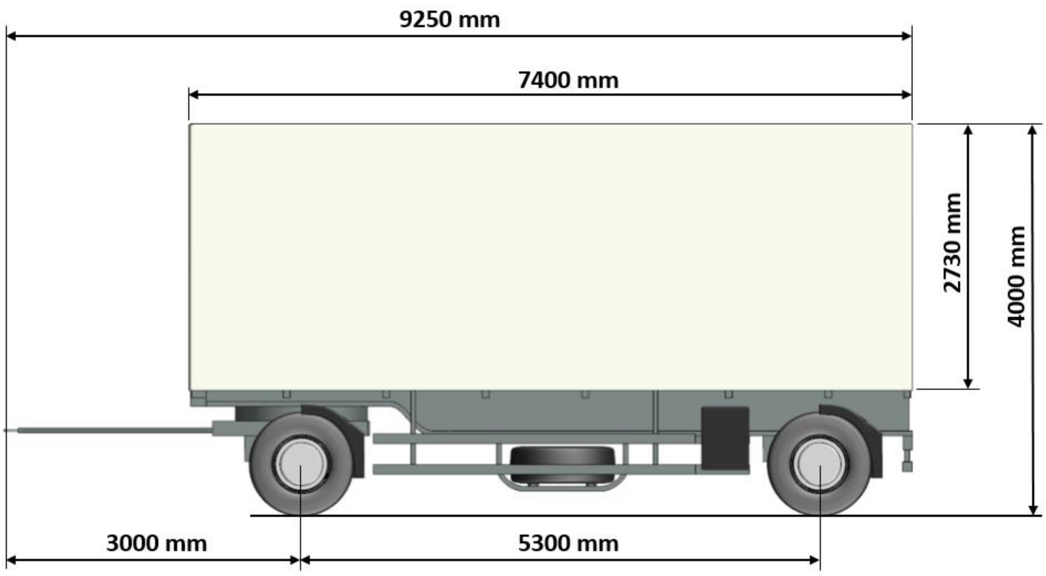


Figure 31. Standard Drawbar trailer. General Dimensions

It must be noted that with such trailer measurements, the resulting vehicle combination when being attached to the generic rigids presented above is longer than legally allowed:

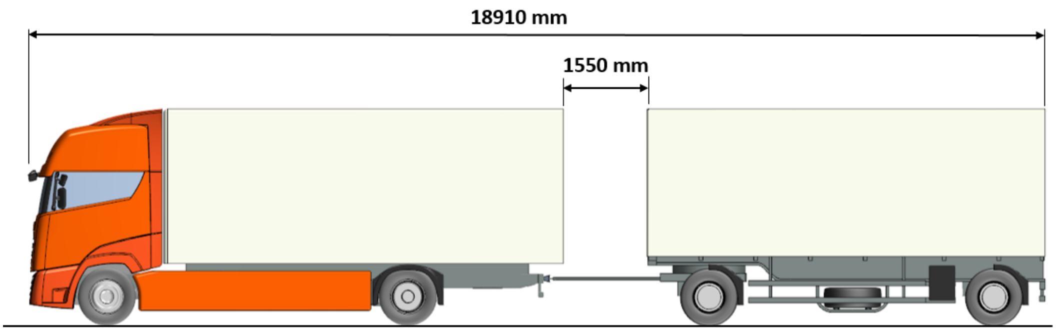


Figure 32. Generic Rigid 4x2 and Standard Drawbar Trailer combination

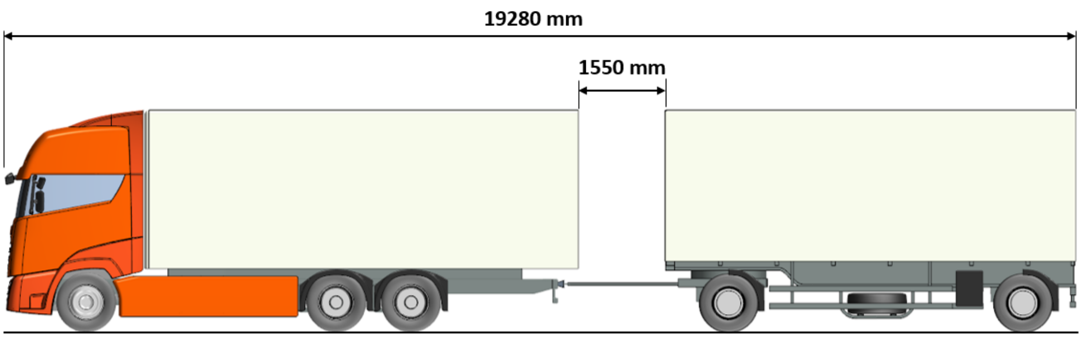


Figure 33. Generic Rigid 6x2 and Standard Drawbar Trailer combination

Nonetheless, this has been kept when running the corresponding CFD simulations because, aerodynamically speaking, the gap between the two boxes has a much more important effect on the final C_DxA value than those extra few centimeters above the legal limit.

2.3.2.5 Generic standard centre-axle trailer

The standard centre-axle trailer has also been designed to the specifications listed in CLCCR While Book which are summarised in Table 49.

Table 49. Standard centre-axle trailer specs

Trailer Type	2-axle centre-axle trailer
Body Type	Hard shell body (dry-out box design) With two rear doors Without side doors
Chassis specs	End to end ladder frame Frame w/o underfloor cover Drawbar, short coupling Two stripes at each side as underride protection Rear underride protection Rear lamp holder plate Two spare wheels after the 2nd axle One toolbox before the first axle (left or rear side) Mud flaps before and behind axle assembly Air suspension Disc brakes Tyre size: 385/65 R22.5

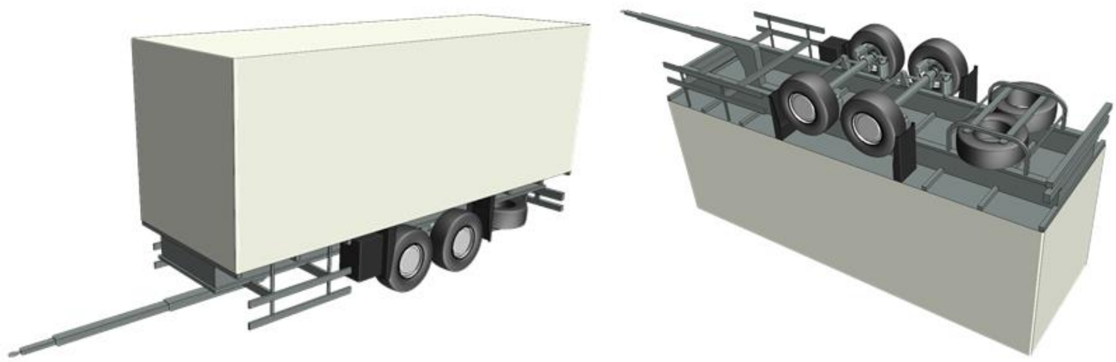


Figure 34. Standard Centre-axle trailer (isometric views)

Table 50. Standard Centre-axle trailer. General Dimensions

	Dimensions [mm]
Total length	10.310,00
Body length	7.820,00
Total width (Body width)	2.550,00
Body height	2.730,00
Full height, unloaded	4.000,00
Wheelbase	6.600,00
Axle distance	1.310,00
Drawbar length	2.490,00
Toolbox length	445,00
Toolbox cross section	655,00 x 493,00
Distance between truck and trailer body	750,00

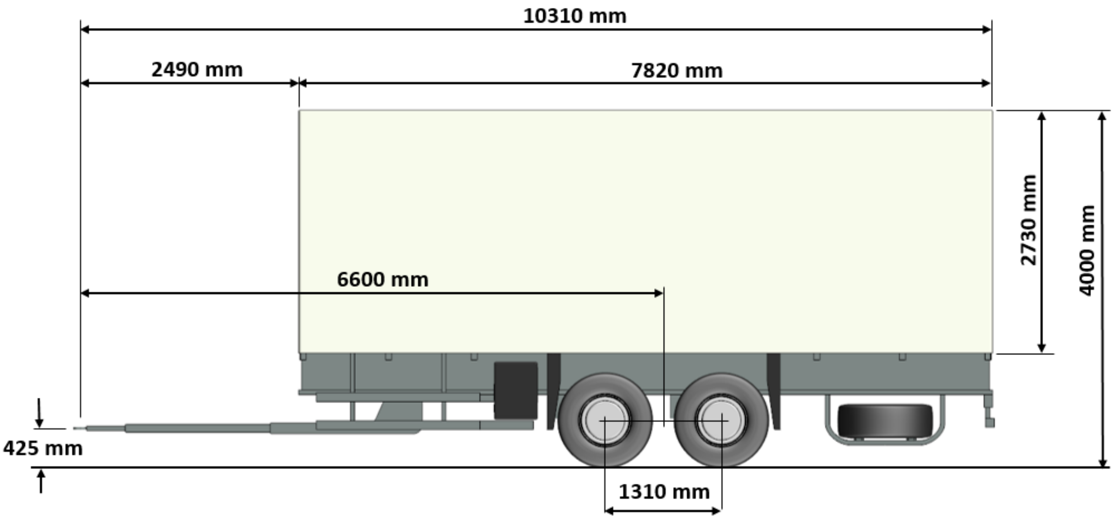


Figure 35. Standard Centre-axle trailer. General Dimensions

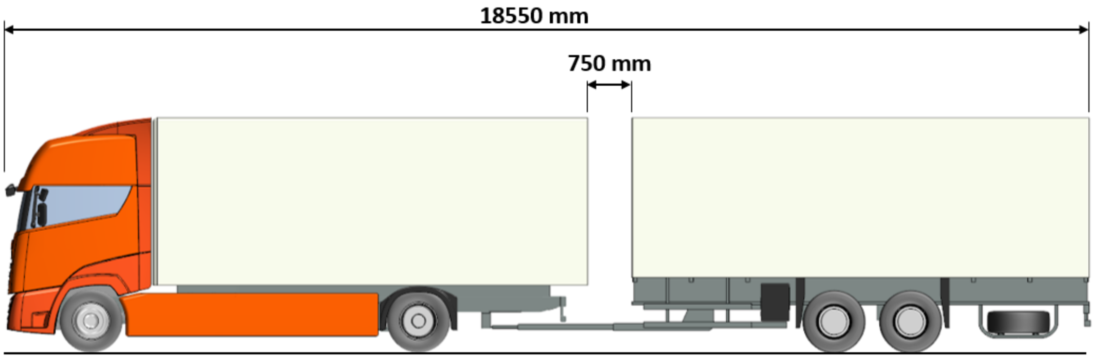


Figure 36. Generic Rigid 4x2 and Standard Centre-axle Trailer combination

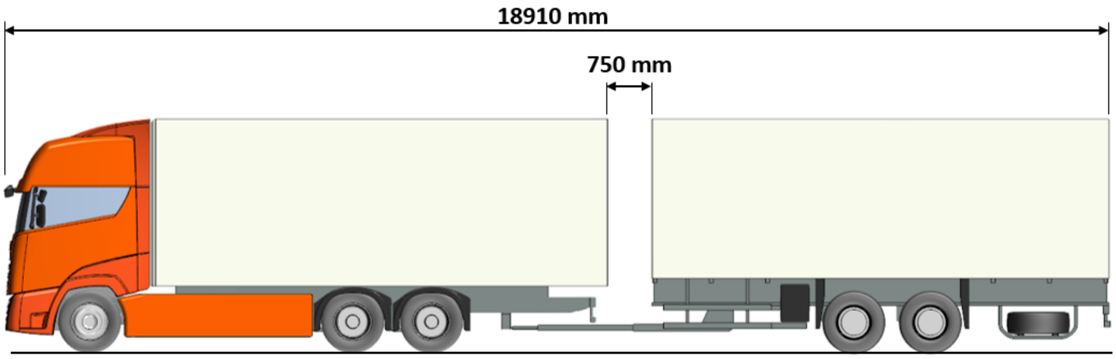


Figure 37. Generic Rigid 6x2 and Standard Centre-axle Trailer combination

2.3.3 CFD Method

The very same CFD methodology applied to the IVECO Stralis during the correlation phase against CST testing data has been used in all simulations using the generic vehicles presented above, as well as all their combinations.

The computational domain mimics open-road conditions and, hence, it has been made large enough to guarantee the blockage is below 0.5%. The large distance between the vehicle and the walls of the domain ensures the flow patterns around the vehicle do not get affected by the domain limits.

The cell count is close to 100 million cells, using a size between 5 and 25mm in close vicinity to the vehicle and steadily growing the size as the cells move away towards the domain limits. This figure is significantly lower than what was used in the IVECO Stralis, justified by the rather simple geometries that lack the details of a real truck (powertrain components, chassis brackets, cut lines, rubber sealings, etc). The cell count does increase slightly in the cases accounting for crosswind due to the mesh refinement in the leeward side of the vehicle.
The boundary layer has been resolved with enough prism layers and near wall cells resulting in y+ values between 1 and 5 in most of the vehicle in order to resolve the viscous sublayer.

All load cases (with or without side wind) apply the corresponding incoming flow velocity values so the vehicle travels at 25 m/s. The ground of the computational domain moves accordingly, and all wheels get their corresponding angular velocity with a tangential velocity boundary condition.

2.4 Task 2.3: Definition of algorithms, standard values and generic equations for the IT tool

2.4.1 Generic towing vehicles

Table 51 gives an overview on all elaborated generic vehicles and the allocation to trailer groups. The allocation is based on proposals from CLCCR and was fine-tuned in a number of working meetings with the Consortium.

Table 51. Overview towing vehicles and allocation to trailer groups

Generic towing vehicle			Allocated to trailer groups
Code	**Vehicle group**	**Config / body**	
A1	5-RD	day cab	1- axle DA
A2	5-LH	sleeper cab	2- and 3-axle DA
A3	10-LH	sleeper cab	Only for >3 axle vehicles, thus not yet relevant according to the planned coverage of the first stage of the trailer Regulation
R1	2-RD	day cab, B2 in specific variants	1- axle DC and 2 axle DC with a TPMLM axle assembly ≤ 13.5 tons
R2	9-LH	B4, B5 in specific variants	2- axle DB, 2 axle DC with a TPMLM axle assembly > 13.5 tons
R3	4-LH	B6 in specific variants	3- axle DB, DC

<u>Specifications of the bodies of the generic towing vehicles</u>

The B2, B4, B5 and B6 bodies assigned to the generic towing vehicles are partially modified compared to the standard bodies in Regulation (EU) 2017/2400. This concerns the mass and the cargo volume. In determining these values, it was assumed that the body has the same type of superstructure as the trailer and that the permissible overall lengths of the truck-trailer combinations may not be exceeded in accordance with the Road Traffic Act.

Table 52: Curb Mass and Cargo Volume of modified towing vehicle bodies

Trailer type	Number of trailer Axles	TPMLM Axle assembly	Volume orientation	Body type of generic towing vehicle	Curb Mass [kg]		
					Bodywork type		
					Dry box & Conditioned	Curtain-sided & Drop-side tarpaulin body	Refrigerated
DC	1	> 8 to	No	B2	1900	1350	---
			Yes	B2-V	2100	1550	---
	2	<= 13.5 to	No	B2	1900	1350	---
			Yes	B2-V	2100	1550	---
		> 13.5 to	No	B5	2200	1600	2950
			Yes	B5-V	2400	1850	---
	3	all weights	No	B6	1750	1300	2400
		all weights	Yes	B6-V	1900	1450	---
DB	2	all weights	No	B4	2100	1550	2800
		all weights	Yes	B4-V	2300	1750	---
	3	all weights	No	B6	1750	1300	2400
		all weights	Yes	B6-V	1900	1450	---

Trailer type	Number of trailer Axles	TPMLM Axle assembly	Volume orientation	Body type of generic towing vehicle	Cargo Volume [m³]		
					Bodywork type		
					Dry box & Conditioned	Curtain-sided & Drop-side tarpaulin body	Refrigerated
DC	1	> 8 to	No	B2	45.2	45.2	---
			Yes	B2-V	52.4	52.8	---
	2	<= 13.5 to	No	B2	45.2	45.2	---
			Yes	B2-V	52.4	52.8	---
		> 13.5 to	No	B5	51.9	51.9	47.4
			Yes	B5-V	55.4	56.0	---
	3	all weights	No	B6	41.4	41.4	38.0
		all weights	Yes	B6-V	44.1	44.6	---
DB	2	all weights	No	B4	49.4	49.4	45.0
		all weights	Yes	B4-V	52.6	53.2	---
	3	all weights	No	B6	41.4	41.4	38.0
		all weights	Yes	B6-V	44.1	44.6	---

In order to achieve most informative and robust results from the trailer Regulation, it is important that the generic vehicle models stored in the VECTO Trailer Tool are as representative as possible for typical towing vehicles in the fleet. Due to the availability of the data from the HDV CO_2 monitoring in accordance with

Regulation (EU) 2018/956[4], it was possible in this project to create such vehicle models in a high level of detail. The procedure and the resulting vehicle models are described below.

The vehicle models determined in this way represent the average state of vehicle technology of new vehicles in the above-mentioned "baseline" year. In reality, there is naturally a mix of old and new vehicles in the fleet, which continuously shifts to later years of construction. In the application in the VECTO Trailer Tool, however, it is not considered critical to use the generic vehicles created here for several years or at least a full legislative cycle. The efficiency ratio is assessed to be considerably robust against the shift towards increasingly fuel-efficient vehicles, and also for the comparison between two trailers from different groups on the basis of absolute consumption / emissions, it is above all important that the generic towing vehicles in the tool used for the trailers to be compared correspond to identical technology levels. If in 5 to 10 years the absolute fuel consumption level in the fleet of conventional vehicles has been reduced by a double-digit percentage, as to be expected from the HDV CO_2 standards, a need for an update will have to be considered.

Table 53 gives an overview on the information available from the 2019/2020 monitoring dataset. These data were provided for the vehicle subgroups 2, 4-LH, 5-RD, 5-LH, 9-LH, 10-LH and originate from the vsum-files of vehicles simulated.

Table 53. Information available from the 2019/2020 monitoring dataset

Vehicle / component specification	Data evaluation
Corrected actual curb mass (kg)	average
Engine rated power (kW)	average
Engine idling speed (1/min)	average
Engine rated speed (1/min)	average
Engine capacity (ltr)	average
Tyre dimension axle 1	most frequent
Specific rolling resistance coefficient (RRC) of all tyres on axle 1	average + most frequent (only measured, exclude standard values)
FZ_ISO of all tyres on axle 1	most frequent
Tyre dimension axle 2	most frequent
Specific RRC of all tyres on axle 2	average + most frequent (only measured, exclude standard values)
FZ_ISO of all tyres on axle 2	most frequent
Tyre dimension axle 3	most frequent
Specific RRC of all tyres on axle 3	average + most frequent (only measured, exclude standard values)
FZ_ISO of all tyres on axle 3	most frequent
Power take off (yes/no)	share of vehicles w. PTO
Gearbox type	most frequent and share of most frequent
Retarder type	most frequent
C_DxA [m2]	average (only measured, exclude standard values)

[4] Related evaluations were done by the DG JRC. For the purpose of this study data from vehicles produced from 1 October 2019 to 30 June 2020 has been evaluated

Transmission type	most frequent
Number of gears	most frequent
Transmission ratio final gear	average
Axle Ratio	average
Engine cooling fan	most frequent
Steering pump	most frequent
HVAC	most frequent
Electric System	most frequent
Pneumatic System	most frequent
Fuel consumption [g/km] (for all simulated mission profiles and payloads)	average for engine type “Diesel CI”
Engine WHTC CF Urban/Rural/Motorway	average for engine type “Diesel CI”
Engine efficiency [%] (for all simulated mission profiles and payloads)	average for engine type “Diesel CI”
Gearbox efficiency [%] (for all simulated mission profiles and payloads)	average (only measured, exclude standard values)
Axle-gear efficiency [%] (for all simulated mission profiles and payloads)	average (only measured, exclude standard values)

The data evaluated as described above were rounded to even numbers and incorporated into the corresponding vehicle models. Table 54 (for tractors) and Table 55 (for rigid lorries) give an overview of the vehicle specification of the generic vehicles.

Table 54. Vehicle specifications of generic tractors

Vehicle code	A1	A2	A3
Vehicle group	5-RD	5-LH	10-LH
TPMLM [t]	18.00	18.00	26.00
Engine power [kW]	311	350	370
Displacement [ccm]	11 500	12 700	13 000
Rated speed [rpm]	1 750	1 750	1 750
Idling speed [rpm]	550	550	550
Corrected actual mass [kg]	7 100	7 750	8 650
RRC [N/kN] (1^{st}-/2^{nd}-/3^{rd}-axle)	5.6/6.2	5.2/5.7	5.5/5.7/6.0
C_DxA [m2] with standard semitrailer	6.62	5.63	5.68
Tyre dimension steered axle	315/80 R22.5	315/70 R22.5	315/70 R22.5
Tyre dimension driven axle	315/80 R22.5 twin tyres	315/70 R22.5 twin tyres	315/70 R22.5 twin tyres
Total vehicle height with standard semitrailer [m]	4.0	4.0	4.0
Transmission type/gears	AMT/12	AMT/12	AMT/12
Overdrive gear	no	no	no
Axle Ratio	2.94	2.53	2.62
ADAS	Predictve Cruise Control (usecases 1, 2 and 3) with eco-roll (w/o engine stop-start)	Predictve Cruise Control (usecases 1, 2 and 3) with eco-roll (w/o engine stop-start)	none
Auxiliary technology:			
Engine cooling fan	Crankshaft mounted - Electronically controlled visco clutch	Belt driven or driven via transm. - Electronically controlled visco clutch	Belt driven or driven via transm. - Electronically controlled visco clutch
Steering pump	Fixed displacement	Variable displacement mech. controlled	Variable displacement mech. controlled
HVAC	Default	Default	Default
Electric System	Standard technology	Standard technology	Standard technology
Pneumatic System	Large Supply + ESS + AMS	Medium Supply 2-stage + ESS + AMS	Large Supply + mech. clutch + AMS

Table 55. Vehicle specifications of generic rigid lorries

Vehicle code	R1	R2	R3
Vehicle group	2-RD	9-LH	4-LH
TPMLM [t]	11.99	26.00	18.00
Engine power [kW]	170	350	325
Displacement [ccm]	6 000	12 500	11 800
Rated speed [rpm]	2 200	1 750	1 750
Idling speed [rpm]	650	550	550
Corrected actual mass (without superstructure) [kg]	4496	9000	7675
RRC [N/kN] (Steer/Drive/trailing)	6.2/6.6	5.4/6.1/5.4	5.2/5.8
C_DxA in combination with standard body [m2]	4.92	5.15	5.18
Tyre dimension steered axle	245/70 R17.5	315/70 R22.5	315/70 R22.5
Tyre dimension driven axle	245/70 R17.5 twin tyres	315/70 R22.5 twin tyres	315/70 R22.5 twin tyres
Total vehicle height [m] in combination with standard	3.75	4	4
Transmission type/gears	AMT/6	AMT/12	AMT/12
Overdrive gear	yes	no	no
Axle Ratio	3.7	2.72	2.56
ADAS	none	none	none
Auxiliary technology:			
Fan	Crankshaft mounted - Electronically controlled visco clutch	Belt driven or driven via transm. - Electronically controlled visco clutch	Crankshaft mounted - Electronically controlled visco clutch
Steering pump	Fixed displacement	Variable displacement mech. controlled	Variable displacement mech. controlled
HVAC	Default	Default	Default
Electric System	Standard technology	Standard technology	Standard technology
Pneumatic System	Medium Supply 1-stage + ESS + AMS	Large Supply + ESS + AMS	Large Supply + ESS + AMS

Furthermore, generic models for the components internal combustion engine, transmission and axle had to be created. The generic component models were created in such a way that they represent the average efficiencies by driving cycle and payload from the monitoring as well as possible. These generic component models are described below.

Generic internal combustion engine model

The generic engine model describes the fuel consumption map incl. WHTC correction factors and the engines full load curve. For the different engine ratings in the generic vehicles, a uniform method with standardised map formats was developed, with which the fuel consumption was calculated at the individual map points.

The generation of the vehicle specific engine FC map is based on normalised Diesel fuel consumption maps. There engine speed is normalised between idling (0) and rated speed (1); the engine power between zero (0) and rated power (1). The fuel consumption values in the FC map are denormalised by a multiplication with the rated power. The equations for denormalization are shown below.

$$P\ [kW] = P_{norm}[-] *\ P_{rated}[kW] \tag{2-13}$$

$$FC\ \left[\frac{g}{h}\right] = FC_{norm}\left[\frac{\frac{g}{h}}{kW_{rated}}\right] *\ P_{rated}[kW] \tag{2-14}$$

$$n\ [rpm] = n_{norm}[-] * (n_{rated}[rpm] - n_{idle}\ [rpm]) + n_{idle}[rpm] \tag{2-15}$$

Using this method, all maps have the same efficiency as the normalised base map. In order to consider the influence of different engine sizes on fuel consumption, two normalised basic maps were developed in this project. If the engine displacement is lower or equal than 8 litres, the efficiency map in Figure 38 is used. For engines with displacements above 8 litres, the map in Figure 39 is used.

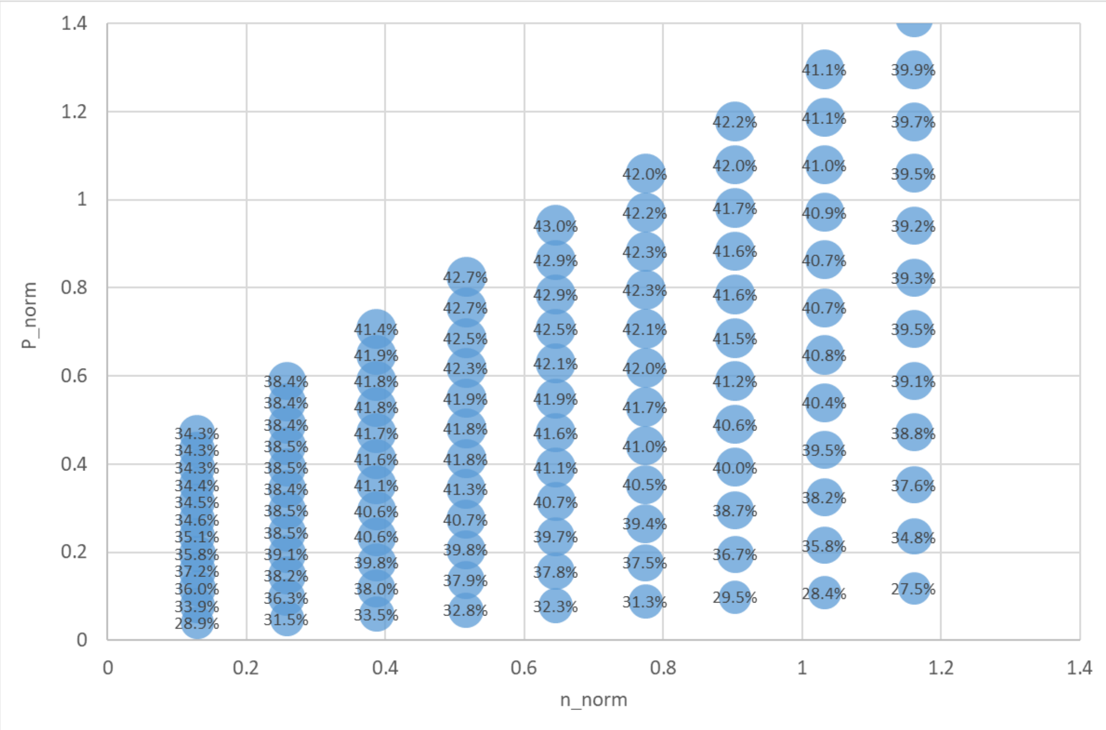


Figure 38. Generic engine map for engines with a displacement lower or equal than 8 litres

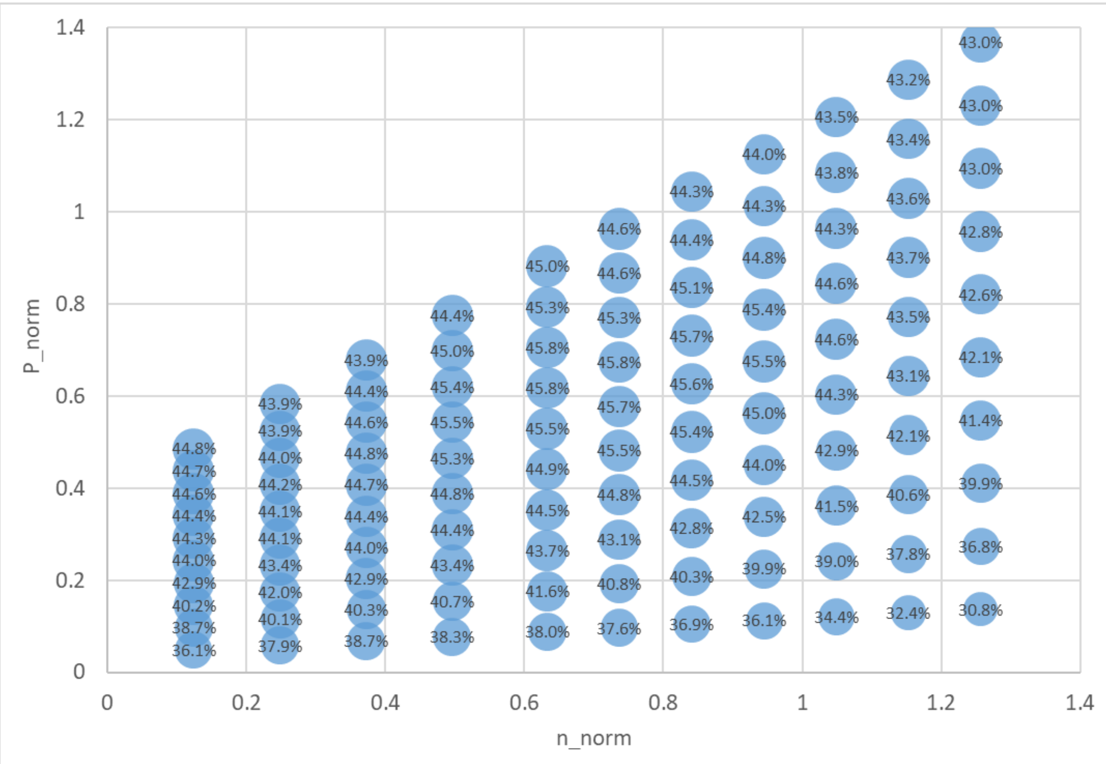


Figure 39. Generic engine map for engines with a displacement exceeding 8 litres

The corresponding WHTC weighting factors are shown in Table 56.

Table 56. WHTC weighting factors

	displacement ≤ 8 litre	displacement > 8 litre
WHTC CF urban	1.06	1.05
WHTC CF rural	1.02	1.02
WHTC CF motorway	1.00	1.00

Table 57 shows the deviation of the average engine efficiencies in percentage points between the generic engine model and the monitoring values. As one can see, the generic engine model achieves a very good agreement with the monitoring data.

Table 57. Deviation between generic efficiencies and average monitoring efficiencies of the engine

		$\eta_{generic} - \eta_{monitoring\ average}$ in %-P					
Mission profile	**Payload**	**2-RD**	**4-LH**	**5-RD**	**5-LH**	**9-LH**	**10-LH**
Long haul	reference	0.01	0.29	0.03	-0.02	-0.05	-0.09
Long haul	low	-0.14	0.62	0.20	0.35	0.16	0.14
Regional Del.	reference	0.19	0.73	-0.10	-0.19	0.13	-0.18
Regional Del.	low	0.24	0.89	0.16	0.18	0.23	0.03
Urban Del.	reference	0.14	0.57	-0.16	-0.15	---	---
Urban Del.	low	0.10	0.66	0.22	0.11	---	---
Weighted		**0.16**	**0.49**	**-0.01**	**0.08**	**0.03**	**-0.03**

The full load curve of the generic engine model is created using 5 characteristic points. This method is described in [2] and depends on the rated power, engine displacement, maximum torque, idle and rated speed.

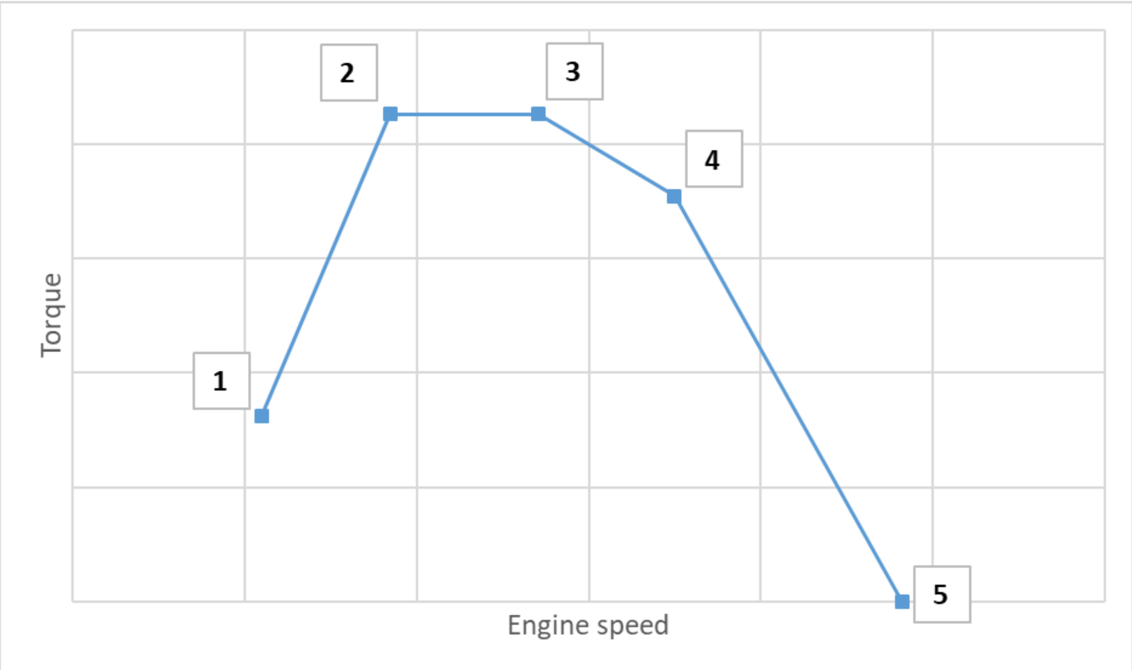


Figure 40. Full load curve of the generic engine model

Generic transmission losses

Constant efficiencies are assumed for the generic gear losses. All indirect gears are modelled to have an efficiency of 97% and all direct gears of 99%. Table 58 shows that despite this simplified assumption, there is good agreement with the monitoring efficiencies for the gearbox.

Table 58. Deviation between generic efficiencies and average monitoring efficiencies of the transmission

		$\eta_{generic}$ - $\eta_{monitoring\ average}$ in %-P					
Mission profile	**Payload**	**2-RD**	**4-LH**	**5-RD**	**5-LH**	**9-LH**	**10-LH**
Long haul	reference	-0.06	0.11	0.38	0.03	0.12	0.16
Long haul	low	0.13	0.46	0.93	0.56	0.57	0.68
Regional Del.	reference	0.61	0.51	0.13	-0.19	0.41	-0.09
Regional Del.	low	0.84	0.86	0.59	0.20	0.87	0.29
Urban Del.	reference	0.25	-0.28	-0.50	-0.61	---	---
Urban Del.	low	0.63	-0.01	-0.20	-0.41	---	---
Weighted*		**0.52**	**0.33**	**0.29**	**0.16**	**0.28**	**0.29**

Generic axle loss model

The calculation method is based on the general approach for standard losses according to Annex VII of Regulation (EU) 2017/2400. To better reflect typical components from the monitoring the drag loss coefficients have been reduced and an additional rotational speed dependency has been introduced. The generic parameters for the axle loss model are shown in Table 59.

Table 59. Generic model parameters

Generic efficiency	Drag torque (wheel side)
$\eta = 0.98$	$T_0 = 10.5$ $T_1 = 6$

The basic drag torque on wheel side T_d is calculated by

$$T_d = T_0 + i_{axle} * T_1 \qquad (2\text{-}16)$$

The rotational speed dependency in the model is based on the assumption that 25% of the drag torque occurs at 0 rpm and the remaining 75% increases linearly up to a speed of 500 rpm.

$$T_{d0'} = 0.25 * T_d \qquad (2\text{-}17)$$

$$T_{d500'} = 0.75 * T_d \qquad (2\text{-}18)$$

With the values from Table 59, the torque losses on wheel side can be calculated as follows:

$$T_{loss} = T_{d0'} + \frac{T_{d500'} * n_{out}}{500} + \frac{T_{out}}{\eta} - T_{out} \qquad (2\text{-}19)$$

The comparison of the generic axle losses with those of the monitoring data (Table 60) gives good agreement on average. There is a slight tendency that the efficiencies of axles in vehicles for regional delivery transport (2-RD, 5-RD) are overestimated and axle efficiencies in long haul traffic (4-LH, 5-LH, 10-LH) are underestimated. Overall, however, the error is small and could only have been eliminated by a more complicated model with significantly increased compilation effort.

Table 60. Deviation between generic efficiencies and average monitoring efficiencies of the axle

		$\eta_{generic} - \eta_{monitoring\ average}$ in %-P					
Mission profile	**Payload**	**2-RD**	**4-LH**	**5-RD**	**5-LH**	**9-LH**	**10-LH**
Long haul	reference	0.21	-0.29	0.40	-0.39	-0.20	-0.58
Long haul	low	0.31	-0.07	0.91	-0.10	0.08	0.53
Regional Del.	reference	0.56	0.11	0.32	-0.42	0.12	-0.24
Regional Del.	low	0.67	0.32	0.71	-0.22	0.41	0.00
Urban Del.	reference	0.58	-0.21	0.06	-0.45	---	---
Urban Del.	low	0.68	-0.09	0.22	-0.36	---	---
weighted		**0.60**	**-0.14**	**0.45**	**-0.31**	**-0.09**	**-0.23**

2.4.1.1 Validation of the generic towing vehicles

To check the overall behaviour of the generic vehicle models created from vehicle data and component data, the simulated fuel consumption values were compared with the fuel consumption data from the monitoring.[5] For this comparison, vehicles in the monitoring data that contained components mapped with standard values were removed.[6]

Table 61 shows the comparison of the fuel consumption of the generic VECTO models with the <u>average</u> consumption values from VECTO. There is a slight underestimation of the average monitoring data, which is explained by the fact that in the generic models for many parameters (e.g. auxiliary consumers, PTO) the most frequent technology was chosen and not the technology with an average energy consumption. Thus, the results with the generic VECTO models should primarily represent the most common or typical vehicle in the fleet (and not the average). This is confirmed by Table 62, where the comparison is made with the <u>median</u> fuel consumption from the monitoring. This is almost exactly matched by the generic models.

[5] The monitoring data referenced here according to Regulation (EU) 2018/956 contain the official fuel consumption values of the individual vehicles determined according to Regulation (EU) 2017/2400, which are also determined by simulations with VECTO with the individual vehicle and component data.

[6] Standard values are an option in Regulation (EU) 2017/2400 if the manufacturer does not want to perform a certification measurement for the component. Standard values represent the efficiency of a worst case component including penalty and are therefore not representative for the modelling of an average real vehicle.

Table 61. Deviation of fuel consumption VECTO generic models vs. monitoring average (only measured components)

		$(FC_{generic\ vehicles} - FC_{monitoring\ data}) / FC_{monitoring\ data}$					
Mission profile	**Payload**	**2-RD**	**4-LH**	**5-RD**	**5-LH**	**9-LH**	**10-LH**
Long haul	reference	0.6%	-1.1%	-2.7%	0.0%	-0.1%	-0.2%
Long haul	low	-0.2%	-2.5%	-5.0%	-1.6%	-1.3%	-1.5%
Regional Del.	reference	-3.0%	-3.3%	-1.9%	0.9%	-1.1%	0.6%
Regional Del.	low	-3.9%	-4.4%	-4.1%	-0.5%	-2.2%	-0.5%
Urban Del.	reference	-3.0%	-1.4%	0.3%	1.7%	---	---
Urban Del.	low	-4.3%	-2.2%	-1.1%	1.1%	---	---
weighted		**-3.3%**	**-1.9%**	**-2.6%**	**-0.3%**	**-0.4%**	**-0.4%**

Table 62. Deviation of fuel consumption VECTO generic models vs. monitoring median (only measured components)

		$(FC_{generic\ vehicles} - FC_{monitoring\ data}) / FC_{monitoring\ data}$					
Mission profile	**Payload**	**2-RD**	**4-LH**	**5-RD**	**5-LH**	**9-LH**	**10-LH**
Long haul	reference	0.8%	-0.7%	-2.7%	0.3%	0.4%	0.3%
Long haul	low	0.0%	-1.9%	-5.4%	-1.2%	-0.9%	-0.9%
Regional Del.	reference	-1.7%	-2.5%	-1.7%	1.2%	-0.4%	1.1%
Regional Del.	low	-2.4%	-3.7%	-3.8%	-0.2%	-1.6%	-0.1%
Urban Del.	reference	-0.6%	-0.8%	1.0%	2.4%		
Urban Del.	low	-1.3%	-1.7%	-0.6%	1.7%		
weighted		**-1.2%**	**-1.4%**	**-2.4%**	**0.0%**	**0.0%**	**0.0%**

2.4.2 Specifications of the reference trailers

As explained in chapter **Error! Reference source not found.** a reference trailer needs to be defined for each trailer group to be covered by the new Regulation. The majority of the specifications shown in this and the following chapter were provided by CLCCR after consultation of trailer manufacturers.

The main parameters describing reference trailer influencing the simulation are:

1. Curb mass
2. Cargo volume
3. Dimensions and C_DxA

In a late drafting phase for Annex I it was decided to merge the bodywork types “conditioned” with “drybox” and “drop-side tarpaulin body” with “curtain-sided” in the main classification table. Accordingly, identical reference trailers apply to the merged groups. The values already worked out for “conditioned” and “drop-side tarpaulin body” but not used in the final method are given in brackets in the following tables.

2.4.2.1 Curb mass

Since the reference trailers can be defined independently of the standard trailers as used in the Regulation (EU) 2017/2400, the curb masses were elaborated newly for each reference trailer configuration, see Table 63. The values highlighted in blue correspond to trailer configurations already included in Regulation (EU) 2017/2400 (3 axle DA (24 tons); 2 axle DC (18 tons)). Feedback from trailer manufacturers indicated to update the curb mass of both the reference box body semi-trailer and the reference box body centre axle trailer. As a result, the new reference trailers are now 200 kg heavier than the standard trailers in the motor vehicle Regulation. All other trailer configurations have no direct reference in the motor vehicle regulation and thus were elaborated newly in this project.

Table 63. Curb mass of the reference trailers

Trailer type	Number of trailer Axles	Volume orientation	TPMLM Axle assembly	Curb Mass [kg]				
				Bodywork type				
				Curtain-sided	Drop-side tarpaulin body*1	Dry box	Conditioned*2	Refrige-rated
DA	1	No	> 8 to	5400	5400 (5600)	6400	6400 (6500)	7250
		Yes	> 8 to	5650	5650 (5850)	6650	6650	---
	2	No	all weights	6050	6050 (6250)	7050	7050 (7300)	8050
		Yes		6350	6350 (6550)	7350	7350	---
	3	No	all weights	6700	6700 (6900)	7700	7700 (7950)	8700
		Yes	all weights	7000	7000 (7200)	8000	8000	---
DC	1	No	> 8 to	2850	2850 (3000)	3300	3300 (3400)	---
		Yes	> 8 to	3000	3000	3450	3450	---
	2	No	<= 13.5 to	2950	2950 (3100)	3400	3400 (3550)	---
		Yes		3100	3100	3550	3550	---
		No	> 13.5 to	5100	5100 (5200)	5600	5600 (5700)	6450
		Yes		5250	5250	5800	5800	---
	3	No	all weights	5800	5800 (5850)	6250	6250 (6450)	7200
		Yes	all weights	6150	6150	6450	6450	---
DB	2	No	all weights	4600	4600 (4650)	5100	5100 (5200)	5950
		Yes	all weights	4750	4750	5250	5250	---
	3	No	all weights	5450	5450 (5650)	6100	6100 (6250)	7000
		Yes	all weights	5750	5750	6400	6400	---

*1: Value for curtain-sided as this bodywork type is the reference in the vehicle group (value in brackets: data provided by CLCCR for drop-side tarpaulin body)
*2: Value for dry-box as this bodywork type is the reference in the vehicle group (value in brackets: data provided by CLCCR for conditioned)

2.4.2.2 Cargo volume

The cargo volume values for the corresponding trailer configurations are summarised in the table below. Again, the corresponding configurations of the motor vehicle regulation are marked in blue and in this case have the same cargo volume as the reference trailers of the trailer regulation.

Table 64. Cargo volume of the reference trailers

Trailer type	Number of trailer Axles	Volume orientation	TPMLM Axle assembly	Cargo Volume [m³]				
				Bodywork type				
				Curtain-sided	Drop-side tarpaulin body	Dry box	Conditioned*1	Refrige-rated
DA	1	No	> 8 to	73	73	73	73 (70.5)	67.7
		Yes	> 8 to	99.4	99.4	98.1	98.1	---
	2	No	all weights	91	91	91	91 (88)	85
		Yes		99.4	99.4	98.1	98.1	---
	3	No	all weights	91	91	91	91 (88)	85
		Yes	all weights	101	101	101	101	---
DC	1	No	> 8 to	52.7	52.7	52.7	52.7 (51.5)	---
		Yes	> 8 to	61.3	61.3	58.5	58.5	---
	2	No	<= 13.5 to	52.7	52.7	52.7	52.7 (51.5)	---
		Yes		61.3	61.3	58.5	58.5	---
		No	> 13.5 to	49.5	49.5	49.5	49.5 (47.7)	45.5
		Yes		56	56	55.8	55.8	---
	3	No	all weights	52.1	52.1	52.1	52.1 (50.6)	48.7
		Yes	all weights	68.4	68.4	58.8	58.8	---
DB	2	No	all weights	46.9	46.9	46.9	46.9 (45.5)	42.9
		Yes	all weights	53.5	53.5	53.5	53.5	---
	3	No	all weights	52.3	52.3 (52.4)	52.3	52.3 (50.9)	48.7
		Yes	all weights	60.9	60.9	60.9	60.9	---

*1: Value for curtain-sided as this bodywork type is the reference in the vehicle group (value in brackets: data provided by CLCCR for drop-side tarpaulin body)
*2: Value for dry-box as this bodywork type is the reference in the vehicle group (value in brackets: data provided by CLCCR for conditioned)

2.4.2.3 Dimensions and CdxA

All specifications relevant for the aerodynamic characteristics of the reference trailer (dimensions, C_DxA, polar curves) were taken from the work described in chapter 2.4.5). A complete list of all parameters used can be found in the MS Excel documentation of the VECTO Trailer Tool (“Masterexcel”) as distributed which each release in the subfolder “User Manual”.[7]

2.4.3 Generic operation conditions

For the simulations by the VECTO Trailer Tool, the following generic definitions of the typical operating conditions of trailers had to be made:

1. Mission profile allocation and weighting factors
2. Payloads
3. Axle load distributions

These generic operating conditions apply equally to the specific and the reference trailer in the simulations.

2.4.3.1 Mission profile allocation and weighting factors

Table 65 provides an overview on the mission profile allocation and the weighting factors applied by the tool to calculate a weighted result. These factors are intended to be as representative as possible of average real-world use. The values are based on the weighting factors from Regulation (EU) 2017/2400, which were readjusted using information from CLCCR. CLCCR has noted that there is little systematic and quantitatively reliable data available on the manufacturer side, and that the figures should therefore be regarded as expert estimates.

[7] The information regarding the base external dimensions and the tyres are located in the sheet “Reference Trailer” (columns G to N). The aero related information (CdxA and polar curves) can be found in the sheet “Reference Trailer Aero” (columns DT to ED).

Table 65. Weighting factors depending on mission and payload scenario

Vehicle sub-group	Number of trailer Axles	Bodywork type	TPMLM Axle assembly	Volume orientation	Mission Profile weightings*					
					LH		RD		UD	
					low payl.	rep. payl.	low payl.	rep. payl.	low payl.	rep. payl.
DA Semi-trailers										
5-RD	1	all	> 8 to	No / Yes	0.03	0.07	0.27	0.63	0	0
5-LH	2	all	all weights	No / Yes	0.27	0.63	0.03	0.07	0	0
	3	all	all weights	No / Yes	0.27	0.63	0.03	0.07	---	---
DC center axle trailer										
2-RD	1	all	> 8 to	No	0.03	0.07	0.27	0.63	0	0
		all	> 8 to	Yes	0.27	0.63	0.03	0.07	0	0
	2	all	<= 13.5 to	No	0.03	0.07	0.27	0.63	0	0
		all	<= 13.5 to	Yes	0.27	0.63	0.03	0.07	0	0
9-LH	2	all	> 13.5 to	No / Yes	0.27	0.63	0.03	0.07	0	0
4-LH	3	all	all weights	No / Yes	0.27	0.63	0.03	0.07	0	0
DB drawbar trailer										
9-LH	2	all	all weights	No / Yes	0.27	0.63	0.03	0.07	0	0
4-LH	3	all	all weights	No / Yes	0.27	0.63	0.03	0.07	0	0

* '0' …. mission profile/payload combination is simulated but has no influence on the weighted results
'---' ….mission profile/payload combination is not simulated

2.4.3.2 Payloads

The basic idea applied in the elaboration of generic payloads was to designate the payload values as a function of maximum gross combination mass (GCM) of the respective towing vehicle trailer combination and independent of the trailer-type (DA, DB or DC). With regard to the influence of bodywork type and volume orientation, it was finally decided that there were no sufficiently robust data on significant differences. Accordingly, identical payloads were defined for these types.

Table 66 provides an overview of the defined generic payloads depending on the respective lorry-trailer combination. It should be noted that the values displayed are defined as a lump sum (rigid + trailer), as VECTO does not take into account the exact load distribution between rigid and trailer in the calculations (the entire payload is distributed to each axle based on the specified axle load distributions).

Table 66. Payloads based on the vehicle + trailer configuration and mission for the reference / specific trailer

Vehicle sub-group	Number of trailer Axles	Trailer type	Max. GCM [kg]	Payloads [kg]			
				Long haul		Other mission profiles	
				Tractor+S-T/Rigid+trailer		Tractor+S-T/Rigid+trailer	
5-RD	1	DA	28000	1500	11200	1500	7500
5-LH	2	DA	36000	2200	16800	2200	11200
			38000	2400	18300	2400	12200
	3		40000	2600	19300	2600	12900
2-RD	1	DC	21990	1200	9200	1200	6100
	2		22490	1300	9500	1300	6300
9-LH	2	DC	40000	2600	19300	2600	12900
		DB	40000				
4-LH	3	DC	40000				
		DB	40000				

2.4.3.3 Axle load distributions

The axle load distribution influences fuel consumption and CO_2 emissions due to the impact on the total rolling resistance of the vehicle:

- Influence of different rolling resistance specifications of different tyre types on different axles
- Small influence of the non-linear rolling resistance behaviour depending on the vertical force on the tyre which is also covered in VECTO

In order to define the axle load distribution, the same approach as in Regulation (EU) 2017/2400 is pursued. This approach consists of fixed percentage-shares for the axle load distribution. The actual numbers were determined based on typical vehicles for the “representative” payload scenario. As for Regulation (EU) 2017/2400 no separate conditions were elaborated for the "low" payload scenario, as not only the influence on rolling resistance but also the weighting is lower compared to the "representative" payload condition.

Table 67 and Table 68 show the axle load distributions depending on the towing vehicle, the attached trailer and the mission profile. The values were elaborated based on the values used in the current VECTO regulation as well as proposals/adjustments by CLCCR. Similar to the payload definitions, it was concluded to use the same distribution for the specific body types and both the standard and volume orientation for each vehicle and trailer configuration, as either the necessary information was not available or the impact on the axle load distribution between the configurations was assumed to be negligible.

Table 67. Axle load distribution mission profile “long haul”

Vehicle sub-group	Number of trailer Axles	Trailer type	Max. GCM [kg]	Axle load distribution					
				Long haul					
				Towing vehicle			(Semi-)trailer		
				Axle 1 [%]	Axle 2 [%]	Axle 3 [%]	Axle 1 [%]	Axle 2 [%]	Axle 3 [%]
5-RD	1	DA	28000	25	40	---	35	---	---
5-LH	2	DA	36000	20	30	---	50/2	50/2	---
			38000						
	3		40000	20	25	---	55/3	55/3	55/3
2-RD	1	DC	21990	25	40	---	35	---	---
	2		22490	25	30	---	45/2	45/2	---
9-LH	2	DC	40000	15	30	15	40/2	40/2	---
		DB	40000						
4-LH	3	DC	40000	20	25	---	55/3	55/3	55/3
		DB	40000						

Table 68. Axle load distribution for other mission profiles than “long haul”

Vehicle sub-group	Number of trailer Axles	Trailer type	Max. GCM [kg]	Axle load distribution					
				Other Mission profiles					
				Towing vehicle			(Semi-)trailer		
				Axle 1 [%]	Axle 2 [%]	Axle 3 [%]	Axle 1 [%]	Axle 2 [%]	Axle 3 [%]
5-RD	1	DA	28000	30	40	---	30	---	---
5-LH	2	DA	36000	25	25	---	50/2	50/2	---
			38000						
	3		40000	25	25	---	50/3	50/3	50/3
2-RD	1	DC	21990	25	30	---	45	---	---
	2		22490	25	35	---	40/2	40/2	---
9-LH	2	DC	40000	15	30	15	40/2	40/2	---
		DB	40000						
4-LH	3	DC	40000	20	25	---	55/3	55/3	55/3
		DB	40000						

2.4.4 Methodology for liftable and steered axles

The basic principle for the consideration of lift and steered axles in the VECTO trailer tool is to apply bonus factors on fuel consumption/ CO_2 emissions for each of the technologies and additional special rules for combinations of both features.[8] The elaboration of those bonus factors and their application in the tool are described in this subchapter.

2.4.4.1 Liftable axles

In order to properly assess the impact of liftable axles, the main physical effects influencing vehicle drag and the corresponding consideration of those effects in VECTO were elaborated, see Table 69.

Table 69. Main physical effects of liftable influencing vehicle drag and FC/ CO_2

ID	Physical effects	Proposed consideration in VECTO
1)	Change in rolling resistance due to non-linear tyre behaviour	Non-linear RRC model is available in VECTO (elaboration of new axle load shares when liftable axle is “up”)
2)	Reduced wheel bearing drag	Use of a base power reduction when liftable axle is “up”
3)	Increased vehicle mass	Considered by default in VECTO as the mass of the trailer is a mandatory input to the tool
4)	Lower drag during cornering / manoeuvring	Such losses are not considered in VECTO (longitudinal dynamics only) → not suggested for consideration

The change in rolling resistance is considered automatically due to the non-linear RRC model used in VECTO when changing the axle load. Regarding typical values of the axle load distribution, no robust information was available on how the load shifts when lifting an axle for all the towing vehicle + trailer combinations. Hence, the assumption was made to keep the axle load on the towing vehicle constant and only reallocate the axle load on the trailer. Table 70 illustrates this process for a 3 axle DA trailer towed by a Group5 vehicle.

Table 70. Example for axle load allocation when liftable axle is "up"

Configuration	Mission profile	RR and axle load distribution				
		5,2 kg/t	5,7 kg/t	5,5 kg/t	5,5 kg/t	5,5 kg/t
		S1	D1	T1	T2	T3
Standard	Long Haul	20%	25%	18.3%	18.3%	18.3%
	Regional Delivery	25%	25%	16.7%	16.7%	16.7%
Lift axle "up"	Long Haul	20%	25%		27.5%	27.5%
	Regional Delivery	25%	25%		25%	25%

[8] Both effects could, of course, be simulated in greater physical and technical detail, as they both influence the rolling resistance and the overall driving resistance of the vehicle, which is also modelled directly in VECTO. Such approaches were not pursued further for the VECTO Trailer tool due to complexity reasons. For a possible consideration of these vehicle features in VECTO for the motor vehicle certification, it is recommended to resort to more complex methods. The main reason for this is that in the latter case, a wide range of towing vehicle technologies must be mapped with VECTO (and only the fixed generic vehicle models in the trailer tool).

This approach might slightly overestimate the reduction potential as in reality the load is expected to also shift towards the driven axle resulting in lower potential due to the higher RRC values. In addition, the influence of the position of the liftable axle was assumed to be negligible (in the simulations the first axle was always considered as the liftable axle).

The change in wheel bearing drag is considered using a generic power reduction of 500 W and represents a mean value of different wheel bearing technologies. The bonus factors calculated in this way can be seen in Table 71.

Table 71: Preliminary bonus factors simulated with VECTO

Trailer Classification				Liftaxle Bonus factor					
				Long haul		Regional Delivery		Urban Delivery	
Bodywork type	Volume orientation	Trailer type	Number of axles	payload low	payload rep.	payload low	payload rep.	payload low	payload rep.
all	No/Yes	DA	2	-1.03%	-1.23%	-1.06%	-1.11%	-1.13%	-1.07%
			3	-0.75%	-0.87%	-0.76%	-0.80%	-1.02%	-0.87%
		DC	2	-0.78%	-0.90%	-0.84%	-0.84%	-0.95%	-0.95%
		DB	3	-0.70%	-0.81%	-0.75%	-0.78%	-0.88%	-0.88%
		DC		-0.70%	-0.81%	-0.75%	-0.78%	-0.88%	-0.88%

The final reduction values were elaborated based on the simulated values and real world measurement data from FAT and BPW on a 3-axle semi-trailer which became available at the end of the project. The adjustments of the simulated values can be summarized as follows:

- The simulated effects of lift axles in straight driving conditions were rounded and reduced by 20%. The main reasons for this are that future trailers will have better RRCs (not label C) and the load will also shift slightly towards the driven axle in reality resulting in lower reduction potential.

- New insight from the measurement data of FAT/BPW, that with lift axles in raised condition on curvy roads approximately the same reduction effect in cornering resistance is achieved as by steered axles (see Table 74). Hence, this effect was added to the simulated effects of rolling resistance and wheel bearing losses for regional delivery and urban delivery.

Furthermore, the methodology also needs to consider the fact that the tool only simulates two distinctive payload scenarios (low, representative). In reality, however, the trailers are operated with a continuous load distribution. It has been analysed in which total weight ranges, that can be allocated to the two generic VECTO payloads, the liftable axles could be raised. Based on this analysis, a “usability factor” has been elaborated which corresponds to the share driven in this mission profile / payload scenario with liftable axle “up”, see Table 72.

Table 72. Usability factors for different mission profile and payload combinations

Mission Profile	Payload	Usability factor

LH	representative	1/3
RD / UD	representative	2/3
LH / RD / UD	low	1

These values are based on expert judgement and can be interpreted e.g. for the LH rep. payload that 1/3 of the time the payload is low enough to comply with the maximum axle load and thus the axle can be lifted. This of course only effects the representative payload scenario as the payload for the low scenario is always low enough to lift the axle (Usability factor = 1).

So, the reduction potential computed for lift axles as elaborated above is multiplied with these factors for the corresponding mission profile and payload scenario to get the final bonus factors, see Table 73.

Table 73. Final Bonus factors for liftable axles

Trailer Classification				Liftaxle Bonus factor					
				Long haul		Regional Delivery		Urban Delivery	
Bodywork type	Volume orientation	Trailer type	Number of axles	payload low	payload rep.	payload low	payload rep.	payload low	payload rep.
all	No/Yes	DA	2	-0.8%	-0.3%	-2.3%	-1.6%	-3.2%	-2.1%
			3	-0.6%	-0.2%	-3.6%	-2.4%	-5.3%	-3.5%
		DC	2	-0.6%	-0.2%	-2.2%	-1.5%	-3.1%	-2.0%
		DB	3	-0.6%	-0.2%	-2.1%	-1.4%	-3.0%	-2.0%
		DC		-0.6%	-0.2%	-3.6%	-2.4%	-5.2%	-3.5%

Due to the strong interaction of the influence of liftable and steered axles, the special cases of multiple liftable and/or steered axles on the same or different axles are elaborated in detail at the end of the next chapter.

2.4.4.2 Steered axles

The analysis regarding the impact of steered axles had to be much simpler as the main physical effect influencing vehicle drag / CO_2 (lower drag during cornering / manoeuvring), cannot be simulated in VECTO (longitudinal dynamics only, no curve profiles defined for the different mission profiles). Hence, the evaluated reduction potentials summarised in the table below are based on long term measurement data of a 3 axle DA provided by BPW, additional measurements regarding both liftable and steered axles commissioned by FAT, a derived proposal from CLEPA and considerations of the project team.

Table 74. Final CO_2 reduction potential for steered axles

Trailer Classification				Steered axle Bonus factor					
				Long haul		Regional Delivery		Urban Delivery	
Bodywork type	Volume orientation	Trailer type	Number of axles	payload low	payload rep.	payload low	payload rep.	payload low	payload rep.
all	No/Yes	DA/DC	1	-0%	-0%	-0%	-0%	-0%	-0%
			2	-0%	-0%	-1.5%	-1.5%	-2.3%	-2.3%
		DA%DC	3	-0%	-0%	-3%	-3%	-4.5%	-4.5%
		DB	3	-0%	-0%	-1.5%	-1.5%	-2.3%	-2.3%

The CO_2 reduction potential for 1-axle trailers and the LH mission profile in general was set to zero (marked in blue). For 1-axle trailers the wheels roll in direction of the vehicle movement even without steering mechanism just by the trailer rotation, thus no additional impact is considered.

Two- axle DB trailers have the first axle steered per default which is why they get no benefit as the bonus can only count for additional steered axles compared to the base axle configuration. This means that in case of DB trailers the first axle must be set to steered in order for the trailer to be valid according to the regulation and no bonus is applied.

The effect in the mission profile long haul can be neglected as there is practically only straight ahead driving and the steering function is typically only enabled at low speeds (e.g. < 35 km/h). The 3% reduction for 3-axle DAs/DCs in regional delivery was defined based on the measured reduction by BPW of 3.8% as the curve characteristics roughly correspond to the regional delivery. Based on this and the observation in the measurement data that the reduction potential increases with increasing curvature the reduction for urban delivery was defined to be 50% higher and therefore results in 4.5% bonus.

For 2-axle DAs and DCs the reduction rates assessed for the 3-axle variants were reduced by 50%. This reflects the effect that in a 2-axle assembly the lever of the lateral forces – which are reduced by a steered axle - in a trailer rotation is lower than in 3-axle assemblies. The same goes for the 3 axle DBs as the first axle is steered per default and hence only the rear axle tandem can contribute to an additional reduction.

Moreover, due to a lack of additional measurement data some assumptions were made regarding additional steering technologies. Therefore, it was concluded to use the same reductions for both passive and active steered axles as the active steered systems have their main additional impact in extreme cornering at low speeds (manoeuvring) which is not considered in VECTO and estimated to have negligible impact on total vehicle FC/ CO_2 performance.

Finally, due to the interaction of the influence of liftable and steered axle functions some special rules had to be evaluated on how to calculate the combined bonus factor depending on the specific trailer, payload and mission combination with regard to which technology is present on which axle.

- Special case #1: 1 liftable and 1 steered axle on different axles

  In this case both technologies can be active at the same time. However, when one axle is lifted the effect of the steered axle is reduced by 50% as already elaborated previously.

$$FC_{corr}, CO2_{corr} = FC, CO2 * \left(1 + \frac{bf_{lift}}{100}\right) * \left(1 + 0.5 * \frac{bf_{steer}}{100}\right) \qquad \text{(2-20)}$$

$FC_{corr}, CO2_{corr}$	Final fuel consumption, CO2 value
bf_{lift}	Lift axle bonus factor for the specific trailer, mission and payload combination
bf_{steer}	Steered axle bonus factor for the specific trailer, mission and payload combination

- Special case #2: 1 liftable and 1 steered axle on the same axle

  Since in this case both technologies are applied to the same axle the tool uses whichever reduction is higher based on the individual bonus factors per mission and payload combination.

$$FC_{corr}, CO2_{corr} = FC, CO2 * \left(1 + \frac{\max\left(bf_{lift}, bf_{steer}\right)}{100}\right) \qquad \text{(2-21)}$$

- Special case #3: 2 liftable axles

  Regarding the bonus factor to be applied in case of 2 liftable axles on the same axle (could be the case for 3-axle DA and DC trailers), the decision was made to scale the reduction potential depending on the payload. For the low payload scenario the bonus factor from Table 73 is multiplied by 1.5. For the representative payload scenario, the reduction remains unchanged assuming that the payload is always too high to lift a second axle.

  Payload “low”

$$FC_{corr}, CO2_{corr} = FC, CO2 * \left(1 + 1.5 * \frac{bf_{lift}}{100}\right) \qquad \text{(2-22)}$$

  Payload “representative”

$$FC_{corr}, CO2_{corr} = FC, CO2 * \left(1 + \frac{bf_{lift}}{100}\right) \qquad \text{(2-23)}$$

- Special case #4: 2 steered axles

The impact of 2 steered axles was discussed with CLCCR and BPW and concluded to be 20% higher than for 1 steered axle.

$$FC_{corr}, CO2_{corr} = FC, CO2 * \left(1 + 1.2 * \frac{bf_{steer}}{100}\right) \tag{2-24}$$

- Special case #5: In case more than 2 features are present on the vehicle (could theoretically only be the case for a 3-axle trailer and comprising at least a single steered axle), the rules for special case #1 are applied.

2.4.5 Determination of C_DxA

The starting value of any C_DxA calculation in the VECTO trailer tool, regardless of whether it is a specific trailer or the reference trailer, are base values for the assigned generic towing vehicles according to Table 75. These values are derived from data from the HDV CO_2 monitoring in accordance with Regulation (EU) 2018/956[9] by averaging all C_DxA values which are based on constant speed tests (i.e. for which the option to use standard values was not used). Those figures represent the aerodynamic characteristics of typical vehicles of construction year 2019/2020 in combination with a standard body and/or a standard trailer according to the definitions in Annex VIII of Regulation (EU) 2017/2400.

Table 75. Base CDxA values for the generic towing vehicles

Generic towing vehicle		C_DxA	Allocated to trailer groups
Code	Vehicle group		
A1	5-RD	6.62	1- axle DA
A2	5-LH	5.63	2- and 3-axle DA
A3	10-LH	5.68	Only for >3 axle vehicles, thus not yet relevant according to the planned coverage of the first stage of the trailer Regulation
R1	2-RD	4.92	1- axle DC and 2 axle DC with a TPMLM axle assembly ≤ 13.5 tons
R2	9-LH	5.15	2- axle DB, 2 axle DC with a TPMLM axle assembly > 13.5 tons
R3	4-LH	5.16	3- axle DB, DC

These basic values are converted in the correction steps (described in this section) to the specific aerodynamic configuration of the trailer under consideration.

This section and its conclusions are based on the CFD results obtained from each one of the simulated generic shapes and their modifications according to the CFD method described in section 2.3. In the current VECTO core code, air drag input data is split into two main parts:

- On the one hand, the aero resistance under no side wind: **C_DxA (0) [m^2]**
- On the other hand, the coefficients $\mathbf{a_1}$, $\mathbf{a_2}$ and $\mathbf{a_3}$ defining the Yaw Polar Curve:

$$C_DxA(\beta) - C_DxA(0) = a_1 \cdot \beta + a_2 \cdot \beta^2 + a_3 \cdot \beta^3$$

[9] Related evaluations were done by the DG JRC. For the purpose of this study data from vehicles produced from 1 October 2019 to 30 June 2020 has been evaluated

With this input data in mind, five different corrections have been identified, that can all be applied individually or in combination and, in case of applying more than one correction, they need to be applied in order they are presented here below.

2.4.5.1 Longitudinal and Axle Correction

This first correction not only considers the length of the semitrailer, but also the number of axles and their position.

The correction is based on the following equation extracted from CLCCR White Book:

$$C_D = C_{DR} + (L_f - L_{Rf}) * \Delta C_{Dmf} + (L_a - L_{Ra}) * \Delta C_{Dma} + (L_r - L_{Rr}) * \Delta C_{Dmr}$$

which returns the drag coefficient value (C_D) of the modified trailer thanks to the three main sections identified in the accumulated drag plot of the reference vehicle (generic 4x2 tractor pulling the generic ST1 semitrailer):

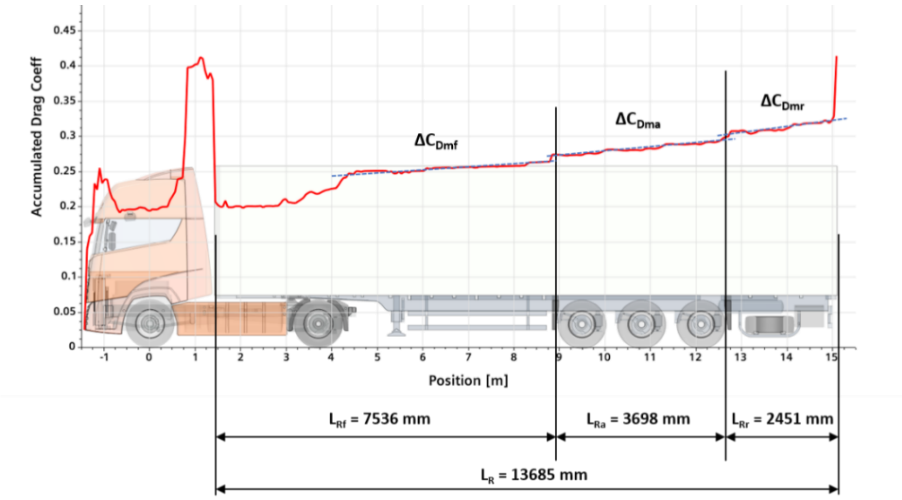


Figure 41. 4x2 tractor and ST1 semitrailer accumulated drag curve

where:

C_{DR}: Drag coefficient of the reference vehicle
L_{Rf}: Distance from the semitrailer front face to 1st wheel (7.536,00 mm)
L_{Ra}: Length of the semitrailer's wheel assembly (3.698,00 mm)
L_{Ra}: Distance from the semitrailer's 3rd wheel to box rear face (2.451,00 mm)

ΔC_{Dmf}: Slope or gradient of the first section
ΔC_{Dma}: Slope or gradient of the second section
ΔC_{Dmr}: Slope or gradient of the third section

As shown in the figure here below, the accumulated drag curve differs with the yaw angle.

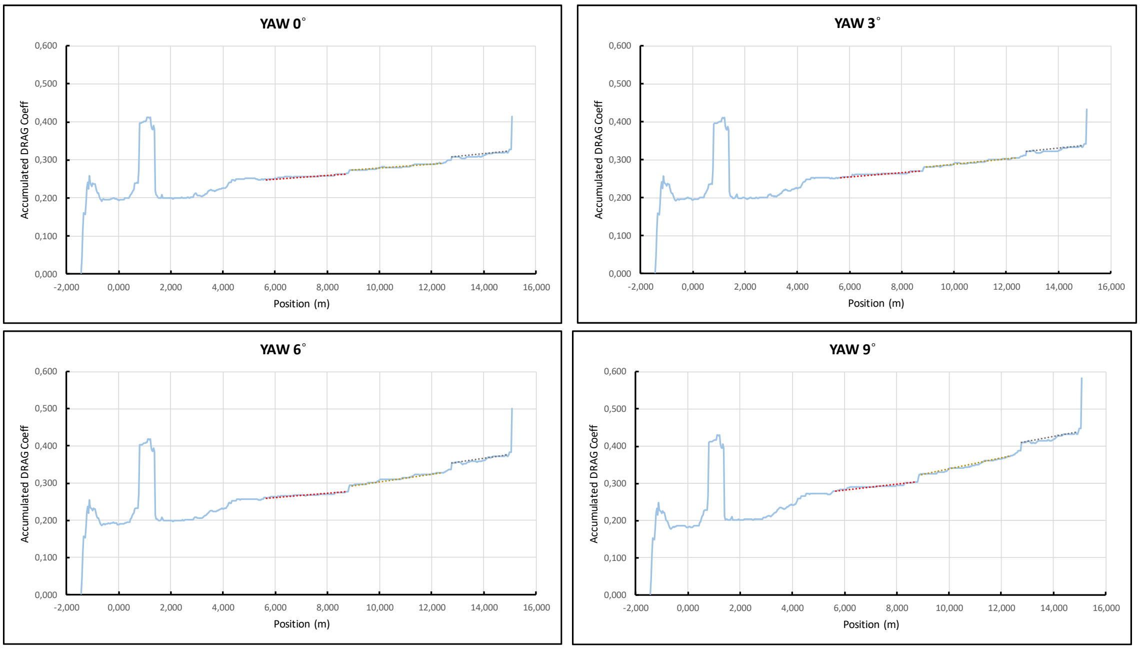


Figure 42. Accumulated drag plot for each yaw angle

Therefore, the values of C_{DR}, ΔC_{Dmf}, ΔC_{Dma}, and ΔC_{Dmr} are also depending on this variable.

Table 76. Longitudinal correction constants

Yaw Angle (β)	0.0	3.0	6.0	9.0
C_{DR}	0,414	0,433	0,500	0,584
L_{Rf} [mm]	7.536,00			
L_{Ra} [mm]	3.698,00			
L_{Rr} [mm]	2.451,00			
ΔC_{Dmf}	0,00516	0,00572	0,00523	0,00778
ΔC_{Dma}	0,00516	0,00676	0,01021	0,01464
ΔC_{Dmr}	0,00737	0,00671	0,01015	0,01406

In order to verify the applicability of these equations and their corresponding constants, the ST1 generic semitrailer has been modified resulting in five different semitrailers:

Table 77. Length and axle modifications. General specs

	Trailer Length [mm]	Num Axles	Axle Distance [mm]	Rear Overhang [mm]
Generic ST1	13.685	3	1.310	2.990
L01	13.685	2	1.310	2.990
L02	13.685	2	1.810	2.990
L03	13.685	1	-	2.990
L04	13.685	1	-	4.300
L05	12.375	1	-	2.990

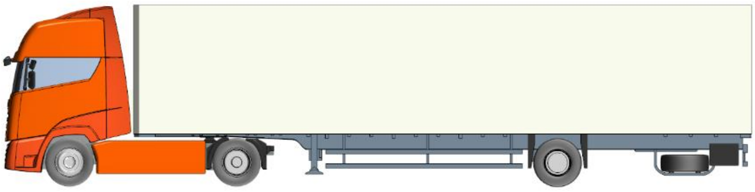


Figure 43. Modification L01

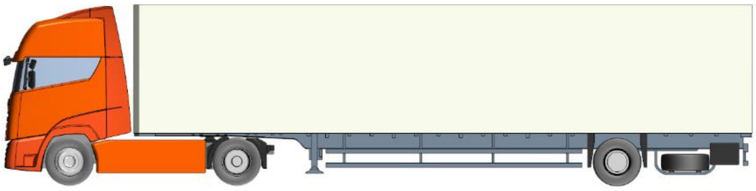


Figure 44. Modification L02

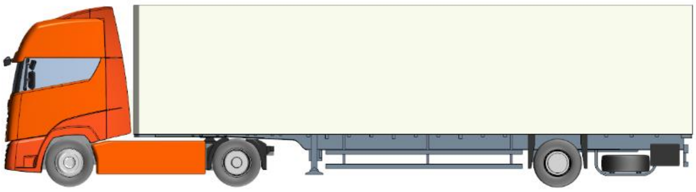


Figure 45. Modification L03

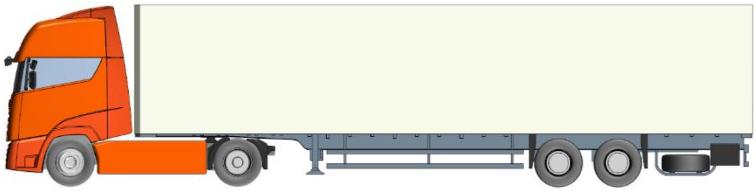


Figure 46. Modification L04

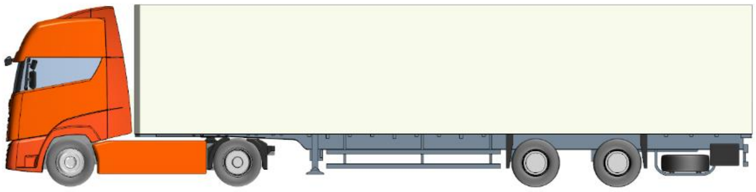


Figure 47. Modification L05

Each one of them has been CFD-simulated and the corresponding values compared against the result of applying the aforementioned equation:

Table 78. CFD vs Longitudinal correction equation

Modif	L_f [mm]	L_a [mm]	L_r [mm]	β = 0.0°			β = 3.0°		
				C_D (Eqtn)	C_D (CFD)	Error [%]	C_D (Eqtn)	C_D (CFD)	Error [%]
L01	8846	1078	3761	0,417	0,413	**0,86%**	0,432	0,436	**-0,92%**
L02	10156	1078	2451	0,414	0,413	**0,27%**	0,430	0,438	**-1,68%**
L03	8846	1078	2451	0,407	0,408	**-0,25%**	0,423	0,428	**-1,22%**
L04	8846	2388	2451	0,414	0,413	**0,12%**	0,432	0,432	**-0,19%**
L05	8346	2888	2451	0,414	0,413	**0,29%**	0,434	0,432	**0,47%**

Modif	L_f [mm]	L_a [mm]	L_r [mm]	β = 6.0°			β = 9.0°		
				C_D (Eqtn)	C_D (CFD)	Error [%]	C_D (Eqtn)	C_D (CFD)	Error [%]
L01	8846	1078	3761	0,494	0,500	**-1,20%**	0,574	0,573	**0,18%**
L02	10156	1078	2451	0,487	0,504	**-3,38%**	0,566	0,595	**-4,85%**
L03	8846	1078	2451	0,480	0,486	**-1,16%**	0,556	0,562	**-1,14%**

L04	8846	2388	2451	0,494	0,501	**-1,54%**	0,575	0,581	**-1,06%**
L05	8346	2888	2451	0,496	0,502	**-1,11%**	0,578	0,582	**-0,71%**

Except for the L02 modification at large angles of yaw, the computed errors with respect to the CFD values are quite low overall especially under no side wind conditions. Therefore, it is considered correct to use the longitudinal correction equation to calculate $C_DxA(0)$.

In order to further analyse the numbers when yaw applies, the polar curve expression $C_DxA(\beta) - C_DxA(0) = a_1 \cdot \beta + a_2 \cdot \beta^2 + a_3 \cdot \beta^3$ needs to be further assessed in order to choose the best fit for a_i coefficients.

The following set of plots in the left-hand side compare, for each one of the modifications, the curve obtained after applying the correction equations against what has been predicted by CFD. The secondary axis quantifies, in m^2, the difference between the two curves:

$$\text{Difference } [m^2] = [C_DxA(\beta) - C_DxA(0)]_{eqtn} - [C_DxA(\beta) - C_DxA(0)]_{CFD}$$

The same logic is implemented in the plots at the right-hand side, where the yaw polar curve obtained by CFD for each configuration is compared against the yaw polar curve of the ST1 semitrailer.

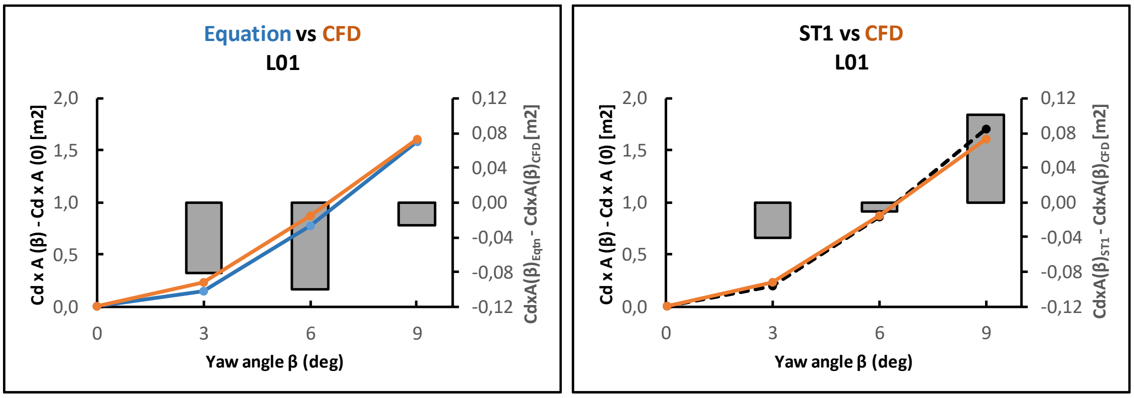


Figure 48. Yaw polar curves comparison. Modification L01

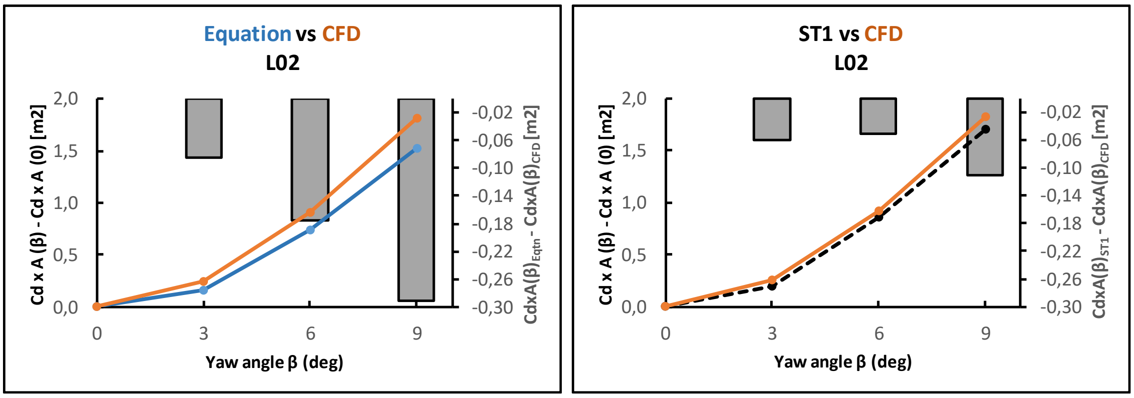


Figure 49. Yaw polar curves comparison. Modification L02

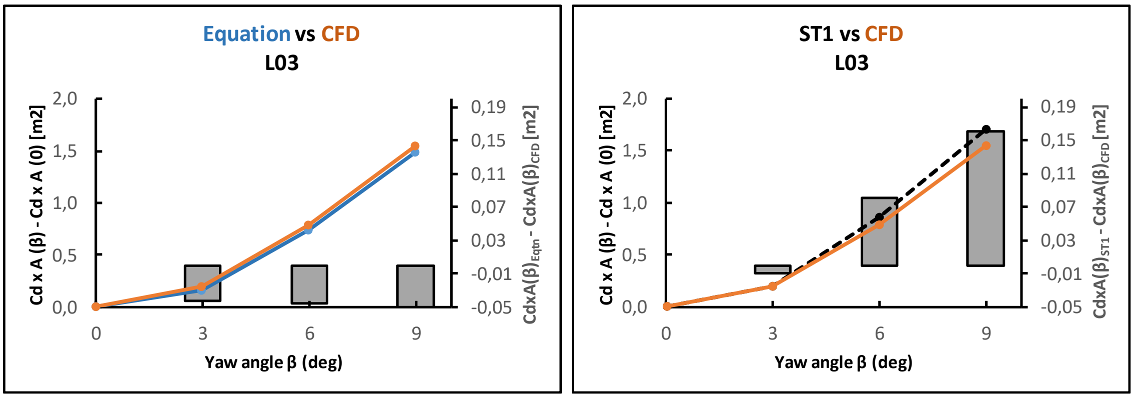


Figure 50. Yaw polar curves comparison. Modification L03

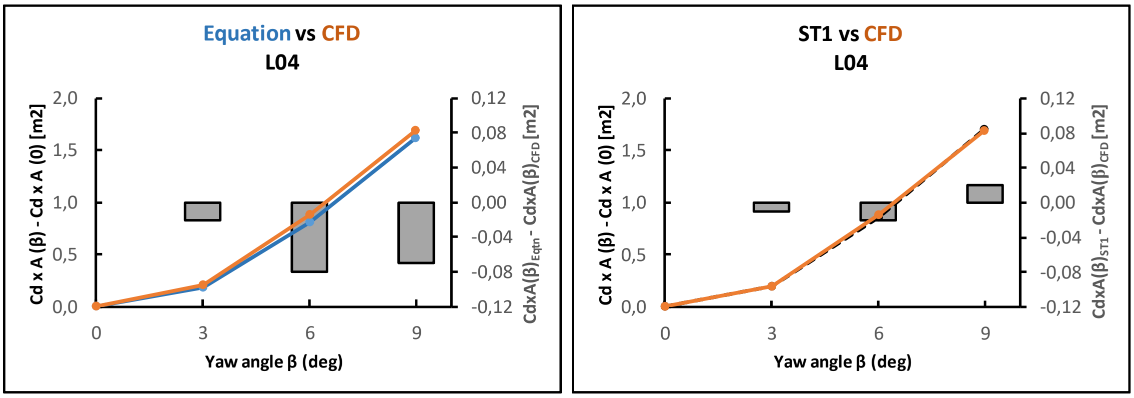


Figure 51. Yaw polar curves comparison. Modification L04

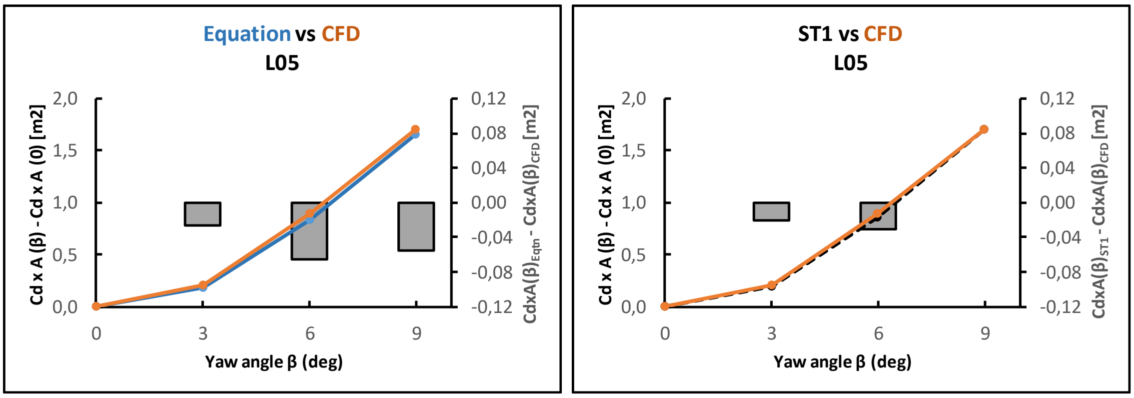


Figure 52. Yaw polar curves comparison. Modification L05

Overall, the ST1 polar curve seems to be a better fit than the one resulting from applying the longitudinal correction equation. In the attempt to quantify this fit, a long-haul cycle drag average value has been calculated for all the semitrailer modification and methods, both CFD and correction equation, using the following expression:

$$(C_D \cdot A)_{cycle\_avg} = \sum_{i=1}^{10} W_i \cdot [C_D \cdot A(\beta_i)]$$

where W_i are the shares in total air drag for a typical group 5 tractor and semitrailer configuration in the VECTO tool under a long-haul driving cycle. Source: “Bodies and trailers – development of CO_2 emissions determination procedure; CLIMA/C.4/SER/OC/2018/0005”.

The following table details the a_i coefficients for each configuration and calculation method:

Table 79. Polar Yaw Curve a_i coefficients

Configuration	Method	a_1	a_2	a_3
ST1	CFD	-0,05135	0,04409	-0,00192
L01	CFD	-0,02735	0,04075	-0,00198
	Corr. Equation	-0,06111	0,04243	-0,00179
L02	CFD	-0,00391	0,03237	-0,00105
	Corr. Equation	-0,03334	0,03306	-0,00117
L03	CFD	-0,01898	0,03237	-0,00124
	Corr. Equation	-0,04398	0,03679	-0,00150
L04	CFD	-0,05358	0,04689	-0,00223
	Corr. Equation	-0,04235	0,03880	-0,00157
L05	CFD	-0,04633	0,04521	-0,00211

	Corr. Equation	-0,04579	0,04098	-0,00172

The polar yaw coefficients are used to calculate the corresponding $C_DxA(\beta)$ for a complete sweep from 1 to 10 degree. The tables here below also include the final long-haul cycle average drag for each calculation method.

Table 80. Averaged long-haul cycle drag. Modification L01

Yaw Angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,15	4,16	4,24	4,38	4,56	4,78	5,02	5,27	5,52	5,76	5,97	**4,64**
Corr. Equation	4,19	4,17	4,22	4,34	4,51	4,72	4,96	5,22	5,50	5,77	6,03	**4,60**
Error (%)	0,88%	0,11%	-0,54%	-1,01%	-1,30%	-1,38%	-1,27%	-0,97%	-0,49%	0,17%	1,02%	**-0,89%**
$C_DxA(0)_{Eqtn}$ + ST1 Curve	4,19	4,18	4,24	4,38	4,56	4,79	5,05	5,33	5,61	5,89	6,16	**4,66**
Error (%)	0,88%	0,38%	0,06%	-0,09%	-0,04%	0,17%	0,53%	1,02%	1,64%	2,38%	3,24%	**0,35%**

Table 81. Averaged long-haul cycle drag. Modification L02

Yaw Angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,15	4,18	4,26	4,40	4,58	4,81	5,06	5,35	5,65	5,97	6,29	**4,67**
Corr. Equation	4,16	4,16	4,21	4,32	4,48	4,67	4,90	5,14	5,41	5,68	5,96	**4,56**
Error (%)	0,18%	-0,51%	-1,16%	-1,76%	-2,32%	-2,84%	-3,33%	-3,80%	-4,27%	-4,75%	-5,25%	**-2,33%**
$C_DxA(0)_{Eqtn}$ + ST1 Curve	4,16	4,15	4,22	4,35	4,53	4,76	5,02	5,30	5,58	5,86	6,13	**4,63**
Error (%)	0,18%	-0,70%	-1,11%	-1,20%	-1,10%	-0,94%	-0,84%	-0,90%	-1,18%	-1,73%	-2,59%	**-0,91%**

Table 82. Averaged long-haul cycle drag. Modification L03

Yaw Angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,10	4,11	4,18	4,30	4,46	4,66	4,88	5,13	5,38	5,65	5,91	**4,54**
Corr. Equation	4,09	4,08	4,14	4,25	4,41	4,60	4,83	5,07	5,33	5,58	5,83	**4,49**
Error (%)	-0,25%	-0,76%	-1,07%	-1,22%	-1,25%	-1,22%	-1,16%	-1,11%	-1,09%	-1,14%	-1,27%	**-1,09%**
$C_DxA(0)_{Eqtn}$ + ST1 Curve	4,09	4,08	4,15	4,28	4,47	4,69	4,95	5,23	5,52	5,80	6,06	**4,56**
Error (%)	-0,25%	-0,77%	-0,80%	-0,47%	0,09%	0,76%	1,44%	2,02%	2,44%	2,67%	2,64%	**0,46%**

Table 83. Averaged long-haul cycle drag. Modification L04

Yaw Angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,15	4,14	4,21	4,35	4,54	4,77	5,03	5,31	5,58	5,84	6,07	**4,63**
Corr. Equation	4,16	4,15	4,21	4,34	4,51	4,72	4,96	5,22	5,50	5,77	6,04	**4,60**
Error (%)	0,18%	0,27%	0,07%	-0,32%	-0,76%	-1,17%	-1,45%	-1,56%	-1,44%	-1,07%	-0,42%	**-0,78%**
$C_DxA(0)_{Eqtn}$ + ST1 Curve	4,16	4,15	4,22	4,35	4,53	4,76	5,02	5,30	5,58	5,86	6,13	**4,63**
Error (%)	0,18%	0,17%	0,08%	-0,06%	-0,19%	-0,26%	-0,25%	-0,14%	0,10%	0,47%	1,00%	**-0,10%**

Table 84. Averaged long-haul cycle drag. Modification L05

Yaw Angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,15	4,15	4,22	4,36	4,55	4,78	5,04	5,32	5,59	5,86	6,10	**4,64**
Corr. Equation	4,16	4,15	4,22	4,34	4,52	4,74	4,99	5,25	5,53	5,81	6,08	**4,61**
Error (%)	0,18%	0,10%	-0,13%	-0,43%	-0,73%	-0,99%	-1,15%	-1,19%	-1,09%	-0,82%	-0,38%	**-0,69%**
$C_DxA(0)_{Eqtn}$ + ST1 Curve	4,16	4,15	4,22	4,35	4,53	4,76	5,02	5,30	5,58	5,86	6,13	**4,63**
Error (%)	0,18%	0,04%	-0,13%	-0,29%	-0,41%	-0,47%	-0,45%	-0,35%	-0,16%	0,13%	0,52%	**-0,30%**

In all semitrailer modifications, the final averaged long-haul cycle drag obtained by applying the ST1 polar curve is closer to what has been predicted by CFD than the one obtained with the correction equation calculation.

Therefore, after analysing and comparing all these figures, <u>for semitrailer changes in length, number of axles and their position, it is suggested to use the</u>

correction equation to calculate $C_DxA(0)$ and extract the a_i coefficients from the standard ST1 semitrailer.

2.4.5.2 Width Correction

Whether a correction for semitrailer's width is required or not, the generic ST1 has been extended from 2.55m to 2.60m in order to transform it into a reefer-type. A generic cooling unit has also been added to the trailer front face to fit in the tractor-trailer gap.

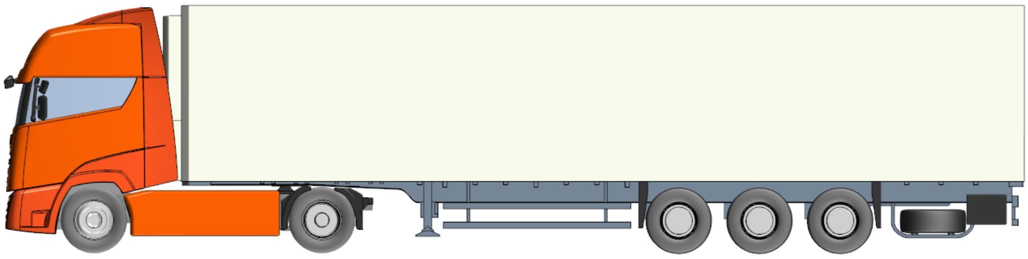


Figure 53. Semitrailer modification W01

This modification W01 results in a slightly larger frontal area:

Table 85. Vehicle frontal area. ST1 vs W01

Configuration	Frontal Area [m2]
ST1	10,047
W01	10,171

Submitting this geometry to the CFD methods previously validated returns the followings values:

Table 86. Aerodynamic resistance of the generic ST1

Yaw Angle [deg]	0,0	3,0	6,0	9,0
C_D	0,414	0,433	0,500	0,584
C_DxA [m^2]	4,16	4,35	5,02	5,87

Table 87. Aerodynamic resistance of the generic Reefer

Yaw Angle [deg]	0,0	3,0	6,0	9,0

C_D	0,411	0,428	0,496	0,570
C_DxA [m^2]	4,18	4,35	5,04	5,80

Three different correction approaches have been initially proposed in order to find the best fit:

2.4.5.2.1 No correction

Applying no correction at all assumes that the modified W01 semitrailer is submitted to the very same aero resistance than the generic ST1.

$$[C_D \times A]_{Reefer} = [C_D \times A]_{ST1}$$

2.4.5.2.2 Frontal Area Ratio

The frontal area ratio assumes that the modified W01 semitrailer shares the very same C_D value than the generic ST1, but the aero resistance C_DxA does consider the actual vehicle frontal area:

$$C_D \times A_{(Reefer)} = C_{D(ST1)} \times A_{(Reefer)}$$

2.4.5.2.3 Semitrailer Width Ratio

Given the difficulty to measure the frontal area of a vehicle with conventional methods and especially the fact that this frontal area is highly dependent on the pulling unit, a correction based purely on the semitrailer width is considered as a third options.

This width ratio correction assumes that the modified W01 semitrailer shares the very same C_D value than the generic ST1, but its area is corrected merely by the width:

$$C_D \times A_{(Reefer)} = C_{D(ST1)} \times A_{(ST1)} \times [W_{(Reefer)}/W_{(ST1)}]$$

The following table quantifies the error one would make depending on the width correction method to be applied:

Table 88. C_DxA [m^2] comparison. Modification W01. CFD vs Correction methods

Yaw Angle [deg]	0,0	3,0	6,0	9,0
CFD	4,18	4,35	5,04	5,80
No Correction	4,16	4,35	5,02	5,87
Error [%]	-0,50%	-0,07%	-0,43%	1,20%

Area Correction	4,21	4,40	5,09	5,94
Error [%]	0,73%	1,17%	0,81%	2,46%
Width Correction	4,24	4,44	5,12	5,98
Error [%]	1,45%	1,89%	1,53%	3,19%

By merely comparing the errors, one can already say that for this typical variation in semitrailer width, applying no correction at all seems to be the most accurate approach.

To further reinforce this assumption, the long-haul cycle average drag resulting from each method is presented here below:

Table 89. Polar Yaw Curve a_i coefficients. Modification W01

Method	a_1	a_2	a_3
CFD	-0,07967	0,05425	-0,00283
No Correction	-0,05135	0,04409	-0,00192
AreaRatio Correction	-0,05199	0,04464	-0,00195
WidthRatio Correction	-0,05236	0,04496	-0,00196

Table 90. Averaged long-haul cycle drag. Modification W01

β	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,18	4,15	4,22	4,35	4,55	4,78	5,04	5,31	5,57	5,80	5,98	**4,64**
NO Correct	4,16	4,15	4,22	4,35	4,54	4,76	5,02	5,30	5,59	5,87	6,13	**4,63**
Error (%)	-0,50%	-0,04%	0,06%	-0,07%	-0,27%	-0,42%	-0,43%	-0,20%	0,33%	1,20%	2,51%	**-0,24%**
RealArea Ratio	4,21	4,20	4,27	4,40	4,59	4,82	5,09	5,37	5,66	5,94	6,21	**4,69**
Error (%)	0,73%	1,19%	1,29%	1,17%	0,96%	0,81%	0,81%	1,04%	1,57%	2,46%	3,77%	**1,00%**
Width Ratio	4,24	4,23	4,30	4,44	4,63	4,86	5,12	5,41	5,70	5,98	6,25	**4,72**
Error (%)	1,45%	1,92%	2,02%	1,89%	1,69%	1,53%	1,53%	1,76%	2,29%	3,19%	4,52%	**1,72%**

While the error percentages are very low for all correction methods, applying no correction at all and assigning to this modified trailer the very same aerodynamic resistance than the generic ST1 returns the lowest difference of all three methods with respect to the CFD results. Therefore, <u>for semitrailer changes in width, it is suggested to use the very same values for $C_D xA(0)$, a_1, a_2 and a_3 than those of the generic ST1 semitrailer.</u>

2.4.5.3 Height Correction

To evaluate the influence of the trailer height and its effect on the aerodynamic resistance, the ST1 box top has been cut 22cm lower, resulting in a trailer total height of 3,78m. Besides the semitrailer modification, it has also been assumed that such semitrailer is being pulled by a low-roof tractor whose spoiler is properly aligned with the semitrailer upper edge.

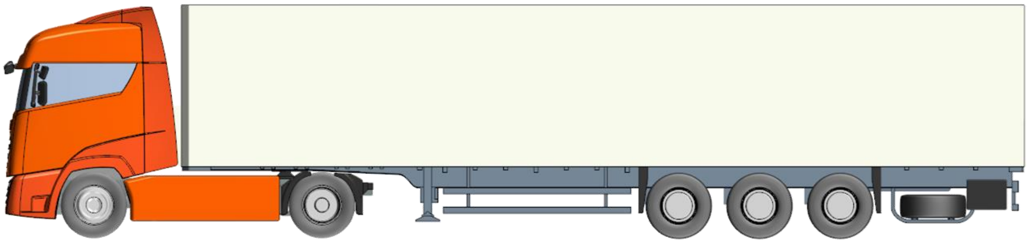


Figure 54. Semitrailer modification H01

Figure 55. ST1 (left) vs Modification H01 (right). Front View

This modification H01 clearly results in a smaller front area:

Table 91. Vehicle frontal area. ST1 vs H01

Configuration	Frontal Area [m2]
ST1	10,047
H01	9,488

And after submitting it to CFD, the following aero resistance values are predicted:

Table 92. Aerodynamic resistance of the H01 modification

Yaw Angle [deg]	0,0	3,0	6,0	9,0
C_D	0,422	0,444	0,510	0,590
C_DxA [m^2]	4,00	4,21	4,84	5,60

Similar to the width variation checks, three different correction approaches have also been assessed in order to find the best fit:

2.4.5.3.1 No correction

Assumes that the modified H01 semitrailer is submitted to the very same aero resistance than the generic ST1.

$$[C_D \times A]_{H01} = [C_D \times A]_{ST1}$$

2.4.5.3.1 Frontal Area Ratio

Assumes that the modified H01 semitrailer shares the very same C_D value than the generic ST1, but the vehicle's frontal area is, indeed, considered:

$$C_D \times A_{H01} = C_{D(ST1)} \times A_{H01}$$

2.4.5.3.2 Semitrailer Height Ratio

This correction assumes that the modified H01 semitrailer shares the very same C_D value than the generic ST1, but its area is corrected merely by the total height ratio:

$$C_D \times A_{H01} = C_{D(ST1)} \times A_{(ST1)} \times [H_{H01}/H_{ST1}],\ \text{where } H_{ST1} = 4{,}00\text{m}$$

The following table quantifies the error one would make depending on the width correction method to be applied:

Table 93. C_DxA [m^2] comparison. Modification H01. CFD vs Correction methods

Yaw Angle [deg]	0,0	3,0	6,0	9,0
CFD	4,00	4,21	4,84	5,60
No Correction	4,16	4,35	5,02	5,87
Error [%]	3,89%	3,27%	3,82%	4,82%
Area Correction	3,93	4,11	4,74	5,54
Error [%]	-1,90%	-2,48%	-1,96%	-1,02%
Height Correction	3,93	4,11	4,75	5,54
Error [%]	-1,83%	-2,41%	-1,89%	-0,95%

In this case, it seems obvious that a certain correction is necessary due to the large errors with respect to the CFD results obtained when not applying any correction.

Both area and height ratio corrections result in significantly lower errors. As previously justified, it is difficult to measure the vehicle's frontal area and it is also highly dependent on the tractor geometry. Therefore, the height ratio is the best candidate and it is also reinforced by the long-haul cycle figures as follows:

Table 94. Polar Yaw Curve a_i coefficients. Modification H01

Method	a_1	a_2	a_3
CFD	-0,0163	0,03900	-0,00176
No Correction	-0,05135	0,04409	-0,00192
AreaRatio Correction	-0,04849	0,04164	-0,00182
HeightRatio Correction	-0,04853	0,04167	-0,00182

Table 95. Averaged long-haul cycle drag. Modification H01

β	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,00	4,01	4,08	4,21	4,39	4,60	4,84	5,09	5,35	5,60	5,83	**4,47**
NO Correct	4,16	4,15	4,22	4,35	4,54	4,76	5,02	5,30	5,59	5,87	6,13	**4,63**
Error (%)	3,89%	3,51%	3,31%	3,27%	3,36%	3,55%	3,82%	4,13%	4,47%	4,82%	5,18%	**3,62%**
Area Ratio	3,93	3,92	3,98	4,11	4,28	4,50	4,74	5,01	5,28	5,54	5,79	**4,37**
Error (%)	-1,90%	-2,25%	-2,44%	-2,48%	-2,39%	-2,21%	-1,96%	-1,67%	-1,35%	-1,02%	-0,68%	**-2,15%**
Height Ratio	3,93	3,92	3,99	4,11	4,29	4,50	4,75	5,01	5,28	5,54	5,80	**4,38**
Error (%)	-1,83%	-2,18%	-2,37%	-2,41%	-2,32%	-2,14%	-1,89%	-1,60%	-1,28%	-0,95%	-0,61%	**-2,08%**

Given the figures here above, for semitrailer changes in height, it is suggested to use the height ratio method to correct the $C_D xA(\beta)$ values and calculate a_i coefficients from these corrected values.

2.4.5.4 Volume-Oriented Correction

This fourth correction takes into account whether the semitrailer is volume oriented or not. As in the previous height correction case, the geometry modifications applied to the generic shapes, not only apply to the semitrailer but also to the tractor.

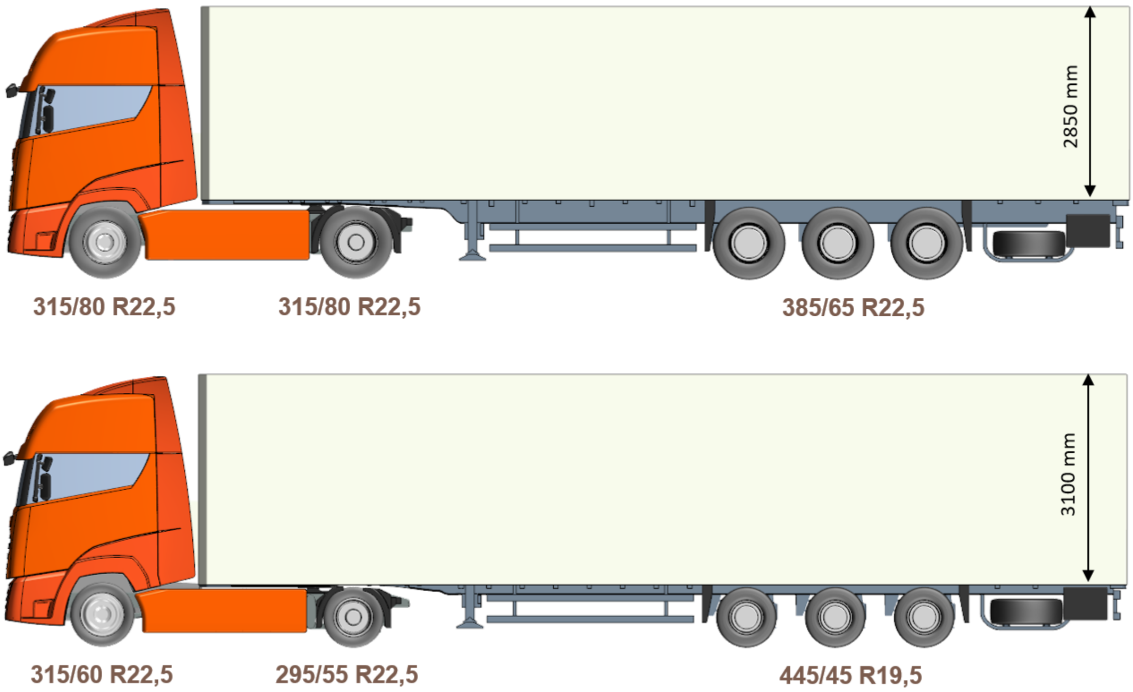


Figure 56. Generic 4x2 tractor and ST1 (top) vs modified volume-oriented solution (bottom)

The trailer body height has been extended form 2850mm to 3100mm. To accommodate this box body enlargement, the height of the chassis longitudinal beams has been reduced and the tyres have been replaced for the smaller 445/45 R19,5.

To accommodate the lower semitrailer chassis, the tractor chassis has also been lowered and the 315/80 R22,5 tyres have been replaced for 315/60 R22,5 in the front axle and 295/55 R22,5 in the rear axle.

Such modifications lead to slight increase of the vehicle frontal area:

Table 96. Vehicle frontal area. ST1 vs V01

Configuration	Frontal Area [m2]
ST1	10,047
V01	10,173

The following table summarizes the aero resistance values of this V01 modification submitted to CFD.

Table 97. Aerodynamic resistance of the V01 modification

Yaw Angle [deg]	0,0	3,0	6,0	9,0

C_D	0,411	0,458	0,536	0,612
C_DxA [m^2]	4,18	4,66	5,45	6,23

2.4.5.4.1 No correction

Following the very same approach of the previous modifications, a first no-correction approach is analysed assuming that the modified V01 semitrailer is submitted to the very same aero resistance than the generic ST1.

$$[C_D \text{ x } A]_{V01} = [C_D \text{ x } A]_{ST1}$$

2.4.5.4.2 Box Height Ratio

Using a well-defined dimension as the box height, it assumes that the modified V01 semitrailer shares the very same C_D value than the generic ST1, but the vehicle's frontal area is corrected by the ratio of the box heights.

$$[C_D \text{ x } A]_{V01} = C_{D(ST1)} \text{ x } A_{(ST1)} \text{ x } [H_{V01}/H_{ST1}], \text{ where } H_{ST1} = 2{,}85\text{m}$$

The error one would make using any of these two correction methods is shown in the following table:

Table 98. C_DxA [m^2] comparison. Modification V01. CFD vs Correction methods

Yaw Angle [deg]	0,0	3,0	6,0	9,0
CFD	4,18	4,66	5,45	6,23
No Correction	4,16	4,35	5,02	5,87
Error [%]	-0,52%	-6,63%	-7,87%	-5,76%
Box Height Corr.	4,52	4,73	5,46	6,38
Error [%]	8,21%	1,56%	0,21%	2,51%

While the aero resistance of both ST1 and V01 is very similar under no crosswinds, the CFD predictions at a yaw angle other than zero show that the V01 is submitted to larger aerodynamics effects. Consequently, the no-correction method falls very short at 3, 6 and 9 degree of yaw.

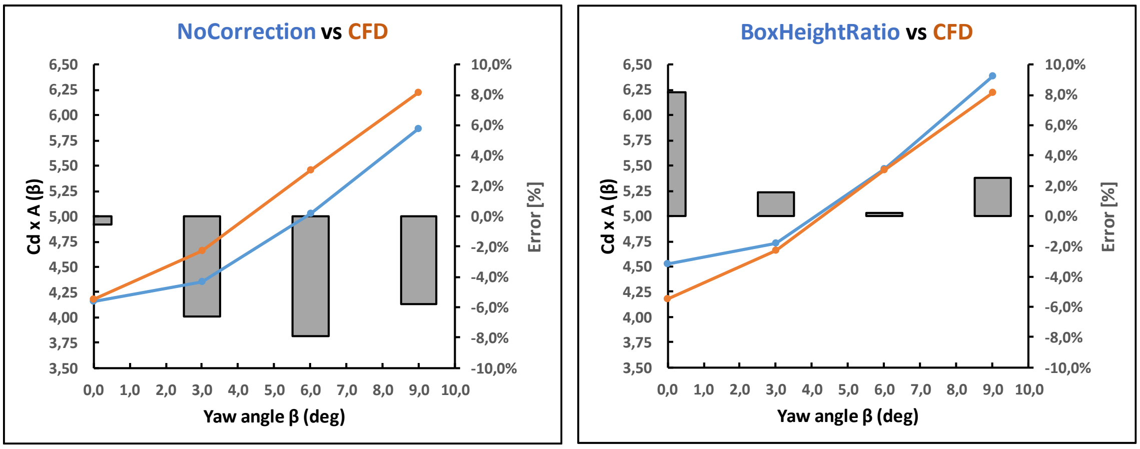


Figure 57. C_DxA(β) curves comparison. Modification V01

On the other hand, the box height ratio correction seems to fill the gap where the no-correction method fails.

2.4.5.4.3 Hybrid

Based on the values obtained from the previous two correction methods, it is proposed a hybrid approach consisting of:

- Not correcting C_DxA(0) and, as a consequence, assign the very same aerodynamic resistance than the ST1 configuration under no crosswind conditions.
- Applying the box height ratio correction for those load cases at 3.0, 6.0 and 9.0 degree of yaw.

Table 99. C_DxA [m^2] comparison. Modification V01. CFD vs Hybrid correction method

Yaw Angle [deg]	0,0	3,0	6,0	9,0
CFD	4,18	4,66	5,45	6,23
Hybrid approach	4,16	4,73	5,46	6,38
Error [%]	-0,52%	1,56%	0,21%	2,51%

To further compare the applicability of the methods, the tables here below report the long-haul cycle average drag:

Table 100. Polar Yaw Curve a_i coefficients. Modification V01

Method	a_1	a_2	a_3
CFD	0,06951	0,03617	-0,00207
No Correction	-0,05135	0,04409	-0,00192
Box Height Correction	-0,05586	0,04796	-0,00209
Hybrid Correction	0,16711	0,00742	0,00016

Table 101. Averaged long-haul cycle drag. Modification V01

β	0	1	2	3	4	5	6	7	8	9	10	Cycle AVG
CFD	4,18	4,28	4,45	4,66	4,91	5,17	5,45	5,73	5,99	6,23	6,42	**4,96**
NO Correct	4,16	4,15	4,22	4,35	4,54	4,76	5,02	5,30	5,59	5,87	6,13	**4,63**
Error (%)	-0,52%	-3,14%	-5,18%	-6,63%	-7,52%	-7,91%	-7,87%	-7,47%	-6,76%	-5,76%	-4,49%	**-6,54%**
BoxHeight Ratio	4,52	4,51	4,59	4,73	4,93	5,18	5,46	5,77	6,08	6,38	6,67	**5,04**
Error (%)	8,21%	5,36%	3,14%	1,56%	0,60%	0,17%	0,21%	0,65%	1,42%	2,51%	3,89%	**1,65%**
Hybrid	4,16	4,33	4,52	4,73	4,96	5,20	5,46	5,75	6,05	6,38	6,73	**5,00**
Error (%)	-0,52%	1,15%	1,72%	1,56%	1,06%	0,52%	0,21%	0,33%	1,05%	2,51%	4,87%	**0,78%**

The hybrid approach returns the lowest error of all methods. Therefore, <u>for volume-oriented semitrailers, it is suggested to use the very same $C_D xA(0)$ value than the ST1 and calculate the polar yaw coefficients a_1, a_2 and a_3 after applying the box height ratio correction.</u>

2.4.5.5 Aerodynamic appendices Correction

This fifth and last correction takes into account the aerodynamic resistance reduction provided by the standard aerodynamic parts described in Task 1 (and their combination) computed by CFD.

Table 102. Aerodynamic resistance reduction

Standard Aero Devices				**$\Delta C_D xA(\beta)$ [%]**			
SHORT Side cover	**LONG Side cover**	**SHORT Rear flap**	**TALL Rear flap**	**β=0.0**	**β=3.0**	**β=6.0**	**β=9.0**
-	-	-	-	0,0%	0,0%	0,0%	0,0%
X	-	-	-	-1,4%	-2,7%	-3,0%	-3,7%
-	X	-	-	-4,0%	-3,4%	-3,5%	-4,7%
-	-	X	-	-2,8%	-3,2%	-3,8%	-4,9%
-	-	-	X	-3,9%	-4,1%	-5,1%	-6,0%
X	-	X	-	-3,8%	-5,8%	-8,3%	-8,7%
X	-	-	X	-4,7%	-6,8%	-9,2%	-10,1%
-	X	X	-	-6,5%	-6,4%	-7,8%	-9,4%
-	X	-	X	-7,6%	-7,7%	-9,2%	-10,9%

It must be noted that the combination of two different aerodynamic parts should not necessarily lead to the very same drag reduction than the sum of those two individual parts. A slightly higher or lower drag is perfectly possible due to airflow pattern changes due to part 1 and its interaction with the vehicle and the corresponding aerodynamic part 2 further downstream.

2.4.6 Correction for trailers $C_D xA$

In this section both, centre axle trailers and draw bar trailers, have been under the spotlight. Like the previous section, this one aims to obtain a value of $C_D xA$ based on the geometry of the trailer with the aid of the CFD simulations.
Before analysing the different layers of corrections evaluated in the previous point, the interaction between the pulling vehicle and the trailer has been assessed. After this initial assessment, the five corrections identified for

semitrailers have been studied. Finally, since the gap between the trailer and the pulling unit has an important effect of the final C_DxA, it has also been included in the corrections.

2.4.6.1 Effect of the interaction between pulling unit and trailer

This first assessment studies, on one hand, the effect that different pulling units might have on the same trailer; and on the other hand, the effect that different trailers might have on the behaviour of the same pulling unit.

Clearly, different pulling units towing the same trailer will have a different total value of C_DxA, but the aim of this comparison is not focused on the final C_DxA, but the accumulated drag.

In the following plot it is shown the accumulated drag curves of the same drawbar trailer being pulled by two different lorries. The curve of the 4x2 variant has been moved to the right so the initial point of the trailer match on both cases.

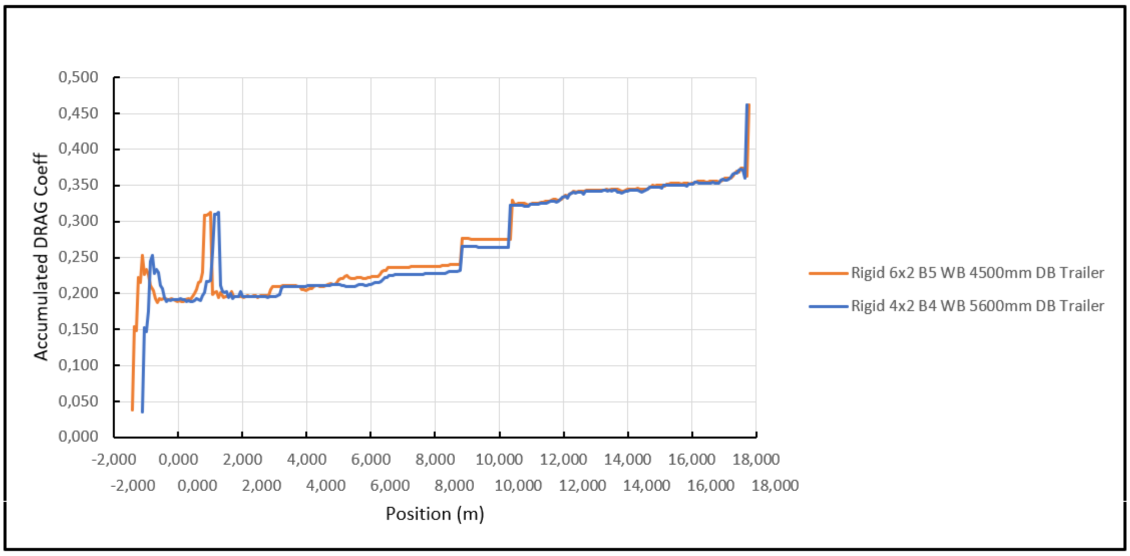


Figure 58. Accumulated drag curve of same trailer with different towing vehicles

When comparing the accumulated drag curve of the same trailer being towed by different lorries, there is no effect on the general behaviour of the trailer. It will be possible to establish general corrections to the trailer since they will not be dependent on the vehicle in front of them.

The effect of different trailers will result on different C_DxA total results, but again, in this case, the focus will be on the effect on the pulling unit accumulated drag instead of the final air drag result.

In this case, the following plot shows different trailers being pulled by the same 4x2 rigid lorry with a wheelbase of 5600mm.

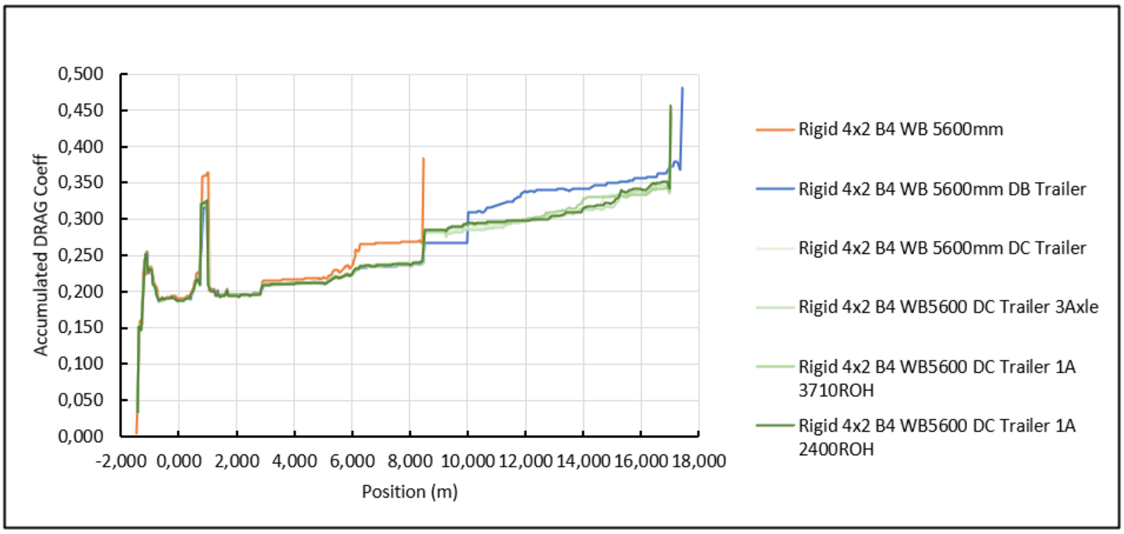


Figure 59. Accumulated drag curve of same lorry pulling different trailers

What can be concluded is that if the lorry is pulling a trailer it has a different accumulated drag curve than if it is not, but there is no effect attached to the kind of vehicle the lorry is pulling. Different trailers present different accumulated drag curves, which will be studied in future points, but the effect on the lorry is the same for all of them.

2.4.6.1.1 Longitudinal and Axle Correction

2.4.6.1.1.1 Centre axle trailers

The same idea to the semitrailers has been applied to the trailers based on the equation extracted from the CLCCR White Book:

$$C_D = C_{DR} + \left(L_f - L_{Rf}\right) * \Delta C_{Dmf} + (L_a - L_{Ra)} * \Delta C_{Dma} + (L_r - L_{Rr}) * \Delta C_{Dmr}$$

Where, for centre axle trailers:

C_{DR}: Drag coefficient of the reference vehicle

L_{Rf}: Distance from the trailer front face to the 1st wheels

L_{Ra}: Length of the trailer wheel assembly

L_{Rr}: Distance from the last wheel of the wheel assembly to box rear face

ΔC_{Dmf}: Slope or gradient of the first section

ΔC_{Dma}: Slope or gradient of the second section

ΔC_{Dmr}: Slope or gradient of the third section

While for centre axle trailers, the corrections are listed here below:

Table 103. Longitudinal correction constants for DC

Yaw Angle (β)	0.0	3.0	6.0
C_{DR}	0,462	0,503	0,560
L_{Rf} [mm]		2.895,00	
L_{Ra} [mm]		2.430,00	
L_{Rr} [mm]		2.495,00	

ΔC_{Dmf}	0,00727	0,00721	0,01243
ΔC_{Dma}	0,00743	0,00951	0,01367
ΔC_{Dmr}	0,04403	0,00146	0,06014

Just as with the semitrailers, the applicability of these equations and their constants have been tested with several modifications of centre axle trailers. The variations for centre axle trailers are as follow:

Table 104. Length and axle modifications for DC. General specs

	Trailer Length [mm]	Num Axles	Axle Distance [mm]	Rear Overhang [mm]
Generic DC	7.820	2	1.310	2.495
L01	7.820	3	2.747	2.400
L02	7.820	1	-	2.400
L03	7.820	1	-	3.710
L04	7.820	2	1.310	2.495

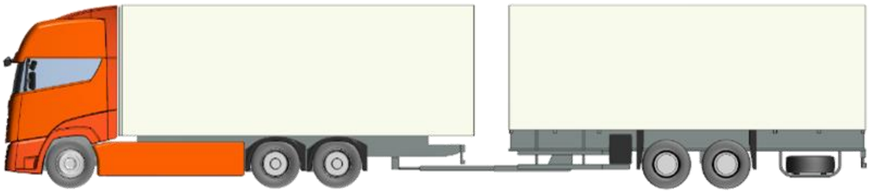


Figure 60. Generic DC pulled by 6x2

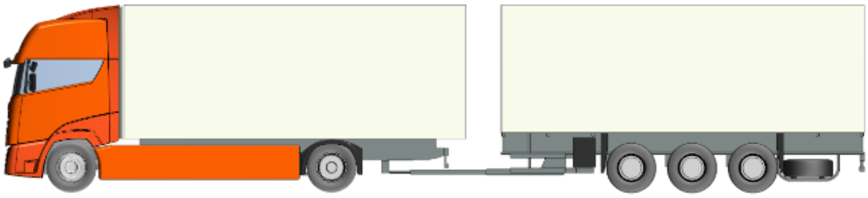


Figure 61. Modification L01

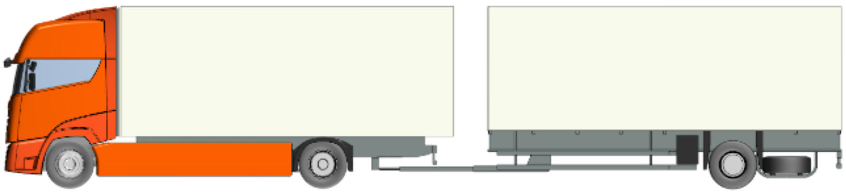


Figure 62. Modification L02

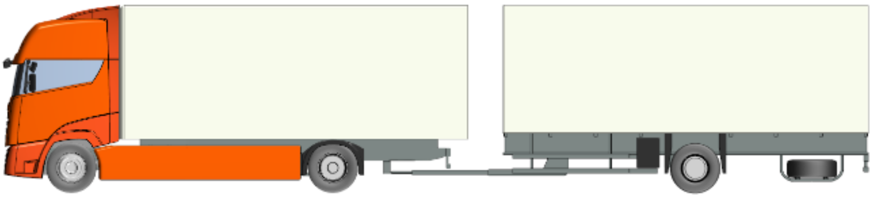


Figure 63. Modification L03

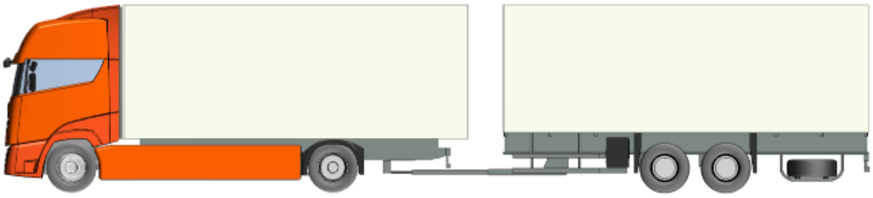


Figure 64. Modification L04

Each of these variants have been simulated using CFD and the results of these simulations have been compared to the calculated results obtained with the corrections:

Table 105. CFD vs Longitudinal correction equation for DCs

Modif	Lf [mm]	La [mm]	Lr [mm]	β = 0.0°			β = 3.0°		
				CD (Eqtn)	CD (CFD)	Error [%]	CD (Eqtn)	CD (CFD)	Error [%]
L01	2261	3698	1861	0.419	0.434	3.46%	0.464	0.446	4.04%
L02	**4881**	**1078**	**1861**	**0.418**	**0.441**	**5.22%**	**0.458**	**0.455**	**0.66%**
L03	3571	1078	3171	0.467	0.437	6.86%	0.450	0.447	0.67%
L04	**2895**	**2430**	**2495**	**0.442**	**0.434**	**1.84%**	**0.457**	**0.445**	**2.63%**

Modif	Lf [mm]	La [mm]	Lr [mm]	β = 6.0°		
				CD (Eqtn)	CD (CFD)	Error [%]
L01	2261	3698	1861	0.483	0.502	3.78%
L02	**4881**	**1078**	**1861**	**0.480**	**0.510**	**5.88%**
L03	3571	1078	3171	0.543	0.502	8.17%
L04	**2895**	**2430**	**2495**	**0.512**	**0.499**	**2.61%**

Despite showing big errors with some configurations at certain yaw angles, the final long-haul cycle average drag results in a more manageable error. Following the same method as per the semitrailer's calculation, the sweep between 0 and

10 º yaw has been calculated for each of the new configurations. The result obtained in each angle has been calculated both with the equation and using a reference curve obtained from the baseline model.

Table 106. Averaged long-haul cycle drag. Modification L01 DC

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,434	0,433	0,437	0,446	0,459	0,478	0,502	0,529	0,561	0,558	0,641	**0,470**
Corr. Equation	0,445	0,447	0,452	0,462	0,476	0,495	0,517	0,544	0,575	0,573	0,649	**0,485**
Error (%)	-2,53%	-3,12%	-3,48%	-3,62%	-3,75%	-3,45%	-3,09%	-2,78%	-2,42%	-2,66%	-1,25%	**3,28%**
CDxA(0)Eqtn + Reference Curve	0,445	0,446	0,451	0,460	0,474	0,492	0,515	0,542	0,574	0,610	0,651	**0,484**
Error %	-2,53%	-2,89%	-3,10%	-3,13%	-3,24%	-2,97%	-2,58%	-2,49%	-2,29%	-9,31%	-1,49%	**-2,90%**

Table 107. Averaged long-haul cycle drag. Modification L02 DC

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,441	0,440	0,446	0,455	0,469	0,488	0,510	0,538	0,571	0,565	0,649	**0,479**
Corr. Equation	0,441	0,440	0,444	0,454	0,468	0,488	0,514	0,543	0,578	0,575	0,665	**0,479**
Error (%)	0,09%	0,20%	0,45%	0,31%	0,26%	-0,02%	-0,83%	-0,84%	-1,33%	-1,75%	-2,40%	**-0,14%**
CDxA(0)Eqtn + Reference Curve	0,441	0,441	0,446	0,456	0,469	0,488	0,511	0,538	0,569	0,606	0,646	**0,479**
Error %	0,09%	-0,16%	-0,08%	-0,13%	-0,11%	-0,07%	-0,12%	0,09%	0,19%	-7,19%	0,44%	**-0,09%**

Table 108. Averaged long-haul cycle drag. Modification L03 DC

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,437	0,443	0,454	0,447	0,490	0,514	0,502	0,577	0,615	0,557	0,704	**0,489**
Corr. Equation	0,439	0,438	0,442	0,451	0,464	0,482	0,506	0,532	0,564	0,561	0,641	**0,475**
Error (%)	-0,42%	1,16%	2,64%	-1,01%	5,19%	6,21%	-0,82%	7,76%	8,30%	-0,67%	8,98%	**3,01%**
CDxA(0)Eqtn + Reference Curve	0,439	0,439	0,444	0,454	0,468	0,486	0,509	0,536	0,568	0,604	0,644	**0,477**
Error %	-0,42%	0,92%	2,21%	-1,52%	4,51%	5,49%	-1,36%	7,04%	7,63%	-8,40%	8,47%	**2,44%**

Table 109. Averaged long-haul cycle drag. Modification L04 DC

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,442	0,440	0,451	0,445	0,486	0,512	0,499	0,576	0,616	0,553	0,709	**0,487**
Corr. Equation	0,442	0,443	0,447	0,457	0,470	0,489	0,512	0,538	0,569	0,567	0,645	**0,480**
Error (%)	0,00%	-0,59%	0,71%	-2,70%	3,29%	4,50%	-2,61%	6,63%	7,54%	-2,53%	9,03%	**1,34%**
CDxA(0)Eqtn + Reference Curve	0,442	0,439	0,444	0,454	0,468	0,486	0,509	0,536	0,568	0,604	0,644	**0,478**
Error %	0,00%	0,12%	1,38%	-1,98%	3,84%	4,98%	-1,97%	6,95%	7,78%	-9,19%	9,12%	**1,86%**

Similar to what happen to the semitrailers, the method that presents the lowest difference among the studied variations is the one using the equations to calculate C_DxA(0) and later, apply the curve of the reference vehicle through a_1, a_2 and a_3.

2.4.6.1.1.2 Draw bar trailers

Just as in the previous section, the equation extracted from the CLCCR White Book has been applied:

$$C_D = C_{DR} + \left(L_f - L_{Rf}\right) * \Delta C_{Dmf} + (L_a - L_{Ra)} * \Delta C_{Dma} + (L_r - L_{Rr}) * \Delta C_{Dmr}$$

where, for draw bar trailer:

C_{DR}: Drag coefficient of the reference vehicle

L_{Rf}: Distance from the trailer front face to the end of the 1st set of wheels

L_{Ra}: Length between the two group of wheel assemblies

L_{Rr}: Distance from the beginning of the last set of wheels to box rear face

ΔC_{Dmf}: Slope or gradient of the first section

ΔC_{Dma}: Slope or gradient of the second section

ΔC_{Dmr}: Slope or gradient of the third section

Table 110.Longitudinal correction constants for draw bar trailers

Yaw Angle (β)	0.0	3.0	6.0
C_{DR}	0,462	0,503	0,560
L_{Rf} [mm]		1.962,00	
L_{Ra} [mm]		4.228,00	
L_{Rr} [mm]		1.210,00	
ΔC_{Dmf}	0,00505	0,00460	0,01928
ΔC_{Dma}	0,00442	0,00531	0,00901
ΔC_{Dmr}	0,00911	0,00911	0,01815

In this case, two variations to the geometry have been simulated to validate the length correction. The variations are as follow:

Table 111.Length and axle modifications for DB. General specs

	Trailer Length [mm]	Num Axles	Axle Distance [mm]	Rear Overhang [mm]
Generic DC	7.400	2	5.300	950
L01	7.400	2	3.990	950
L02	7.400	3	3.454	950

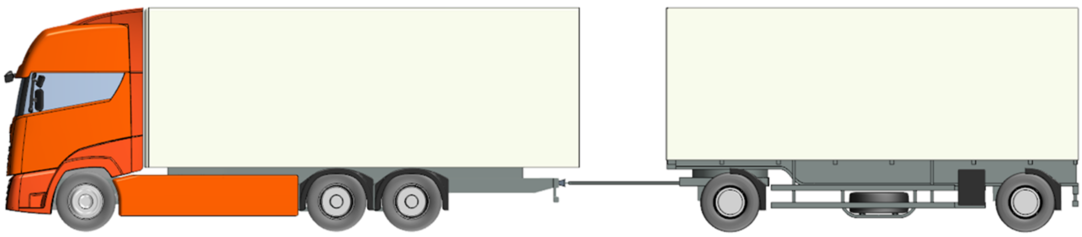


Figure 65.Generic DB pulled by 6x2

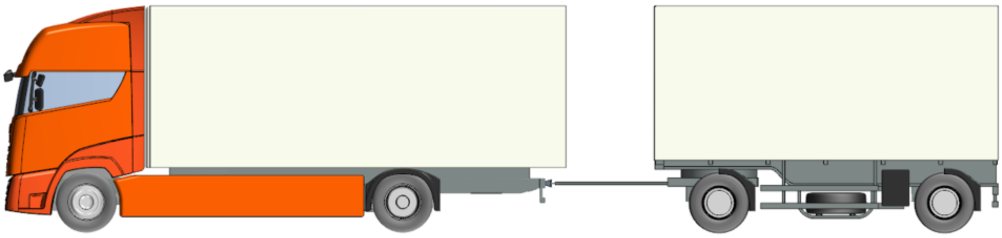


Figure 66. Modification L06

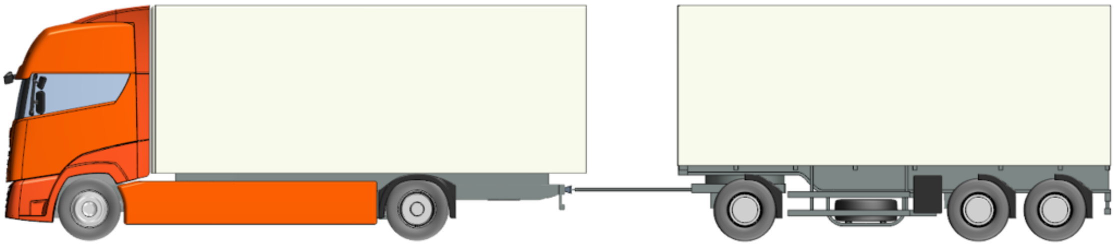


Figure 67. Modification L07

In this case, the simulations of the different variants have given the following results:

Table 112. CFD vs Longitudinal correction equation for DB

Modif	Lf [mm]	La [mm]	Lr [mm]	β = 0.0°			β = 3.0°			β = 6.0°		
				CD (Eqtn)	CD (CFD)	Error [%]	CD (Eqtn)	CD (CFD)	Error [%]	CD (Eqtn)	CD (CFD)	Error [%]
L01	1.962	2.918	1.210	0.461	0.461	0.02%	0.500	0.479	4.48%	0.567	0.529	7.14%
L02	1.962	2.382	3.056	0.476	0.463	2.71%	0.514	0.474	8.53%	0.595	0.532	11.92%

After applying the sweep from 0 to 10 degree yaw, and comparing the application of the generic curve from the baseline against the coefficients obtained through the interpolation of the CFD results, the following tables are obtained:

Table 113.Averaged long-haul cycle drag. Modification L05 DB

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,461	0,464	0,470	0,479	0,493	0,510	0,529	0,554	0,582	0,579	0,648	**0,500**
Corr. Equation	0,461	0,471	0,485	0,500	0,520	0,542	0,567	0,596	0,627	0,633	0,698	**0,526**
Error (%)	-0,02%	-1,68%	-3,17%	-4,48%	-5,54%	-6,40%	-7,14%	-7,47%	-7,72%	-9,33%	-7,73%	**-5,19%**
CDxA(0)Eqtn + Reference Curve	0,461	0,475	0,488	0,502	0,517	0,536	0,559	0,588	0,624	0,669	0,706	**0,508**
Error %	-0,02%	-2,53%	-4,02%	-4,82%	-5,05%	-5,20%	-5,69%	-6,12%	-7,29%	-15,56%	-8,91%	**0,53%**

Table 114. Averaged long-haul cycle drag. Modification L06 DB

Yaw angle (β) [deg]	0	1	2	3	4	5	6	7	8	9	10	Cyce AVG
CFD	0,463	0,461	0,465	0,474	0,488	0,507	0,532	0,561	0,596	0,590	0,681	**0,499**
Corr. Equation	0,476	0,484	0,497	0,514	0,536	0,563	0,595	0,630	0,671	0,676	0,766	**0,546**
Error (%)	-2,71%	-4,85%	-6,82%	-8,53%	-9,94%	-11,05%	-11,92%	-12,34%	-12,57%	-14,65%	-12,41%	**-9,44%**
CDxA(0)Eqtn + Reference Curve	0,476	0,490	0,503	0,517	0,532	0,550	0,574	0,602	0,639	0,684	0,720	**0,513**
Error %	-2,71%	-6,13%	-8,15%	-8,97%	-9,05%	-8,57%	-7,81%	-7,39%	-7,20%	-15,85%	-5,76%	**-2,68%**

In this case, the errors presented by the first analysed method (the one that obtains the coefficients a_1, a_2 and a_3 directly from the equations) are far greater than the errors shown by the method that uses the reference vehicle polar-yaw curve. Thus, as it has been seen in the two previous types of trailers, it is suggested to calculate the $C_DxA(0)$ with the equations and then, apply the curve of the reference vehicle through a_1, a_2 and a_3.

2.4.6.2 Height correction

The same approach as with the semitrailers have been applied to the centre axle trailers and the draw bar trailers when referring to the height correction. A direct height ratio is recommended to be used in those cases in which the height of the trailer is lower than the reference.

2.4.6.3 Width correction

Just as with the semitrailers, it is recommended to not apply any correction due to the width variation of trailers.

2.4.6.4 Volume correction

In this case, for centre axle trailers and draw bar trailers, when trying to apply the same solution as with semitrailers, the following results are obtained:

Table 115. Volume correction for draw bar trailers

DB Trailers	No correction		Box height ratio		Hybrid approach	
Yaw	Cd x A	Error	Cd x A	Error	Cd x A	Error
0	4,65	3,6%	5,28	4,3%	4,47	3,5%
3	5,05	4,0%	5,73	4,7%	5,22	4,2%
6	5,71	4,7%	6,49	5,5%	5,88	4,9%

Table 116. Volume correction for centre axle trailers

DC Trailers	No correction		Box height ratio		Hybrid approach	
Yaw	Cd x A	Error	Cd x A	Error	Cd x A	Error
0	4,45	3,4%	5,05	4,0%	4,45	3,4%
3	4,60	3,6%	5,23	4,2%	5,22	4,2%
6	5,15	0,0%	5,84	4,8%	5,88	4,9%

In this case, the values obtained when applying one correction or another at different angles, greater errors than not applying any correction. Considering this, it is recommended not to apply any correction due to the volume orientation.

2.4.6.5 Hinge position correction for centre axle trailers

The gap between the trailer and the body of the pulling vehicle is important when determining the effect of the C_DxA. Nonetheless, the length of the drawing bar can be adjusted. These adjustments cannot have a large variation and the distance is mainly defined by the position of the hinge in centre axle trailers. There are two possible positions (high hinged and low hinged). All the simulations so far have been done with the low hinged variant, so a high hinged correction has been simulated to study its effects.

Table 117. Hinge position correction

Yaw Angle [deg]	0,0	3,0	6,0	9,0
Low hinged	4.36	4.47	5.02	5.99
High hinged	4.82	5.08	5.92	7.33
Delta [%]	10.37%	13.48%	18.04%	22.35%

Since the effect of the hinge position is relevant, it is suggested to use a percentual correction at each angle via interpolation with a 3rd degree regression.

2.4.6.6 Aerodynamic appendices correction

Among the different aerodynamic appendices described in Task 1 report, only the rear flap tall has been considered for this study applicable to draw bar trailers and centre axle trailers. The effect of this device is described here below:

Table 118. Aerodynamic resistance reduction for DB

Standard Aero Devices							
SHORT Side Cover	**LONG Side Cover**	**SHORT Rear flap**	**TALL Rear flap**	**β=0.0**	**β=3.0**	**β=6.0**	**β=9.0**
-	-	-	-	-	-	-	-
X	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	X	-	-	-	-	-
-	-	-	X	-3,4%	-4,6%	-5,0%	-3,9%
X	-	X	-	-	-	-	-
X	-	-	X	-	-	-	-
-	-	X	-	-	-	-	-
-	-	-	X	-	-	-	-

Table 119. Aerodynamic resistance reduction for DC

Standard Aero Devices				$\Delta C_D xA(\beta)$ [%]			
SHORT Side Cover	**LONG Side Cover**	**SHORT Rear flap**	**TALL Rear flap**	**β=0.0**	**β=3.0**	**β=6.0**	**β=9.0**
-	-	-	-	-	-	-	-
X	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	X	-	-	-	-	-
-	-	-	X	-2,3%	-3,7%	-5,2%	-11,2%
X	-	X	-	-	-	-	-
X	-	-	X	-	-	-	-

-	-	X	-	-	-	-	-
Standard Aero Devices	$\Delta C_D xA(\beta)$ [%]	-	X	-	-	-	-

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