Bodies and trailers – development of CO2 emissions determination procedure

Procedure no: CLIMA/C.4/SER/OC/2018/0005

Date: 21/11/2019

This document contains 4 Task reports

Executive Summary

Task 1. Review of existing studies, data collection and identification of the characteristics and specific constraints of the sector

This Task report is part of the work developed in the project *Bodies and trailers – Development of CO2 emissions determination procedure,* for DG CLIMA under the contract CLIMA/C.4/SER/OC/2018/0005.

The overall objective of the project is to analyse the further application of the VECTO simulation tool, which addresses:

- Trailers for their effect on CO2 emissions of heavy-duty vehicles (HDV). Currently, trucks and tractors are certified with standard trailers and standard semi-trailers, non-motorised vehicles are not certified regarding their impact on fuel/energy consumption and CO2 emissions.

- Complete or completed HDV for CO2 emissions with their actual bodywork i.e., certain types of truck superstructures such as box types, curtain siders, flatbeds, etc. Currently, HDV are certified with standard bodies, regardless of their actual finish.

The overall objective of Task 1 is to understand the composition of and trends in the market for trailers, semi-trailers and bodies, its constraints and its impact on CO2 emissions. As part of this task, the objective of subtasks 1.1-1.3 is to analyse the current state of the market for trailers and bodies, in terms of fleet composition, registrations per body type, equipment use, and the different equipment manufacturers. Also, this report responds to the objective of subtask 1.4 from the Consortium Agreement, which is to analyse the status of the regulatory framework and to identify the regulatory gaps in the EU legislation.

Task 2. Identification and evaluation of the possible methodology options

The Task report describes the activities within Task 2 of the specific contract:
No 340201/2018/789725/SER/CLIMA.C.4 Bodies and trailers – development of CO2 emissions determination procedure

The report is analysing possibilities to determine the influence of specific bodies and trailers on the CO2 emissions from rigid lorries and tractors using the functionalities of the calculation tool VECTO, which is also the basic software for Regulation (EU) 2017/2400.

The current regulation is valid for rigid lorries and tractors and defines test methods for components, the input data for the VECTO tool, the result files and the responsibilities in certification.

Following this principle, the report on task 2 analyses the input data needed and possible methods to determine this input values for semi-trailers and trailers as well as for bodies of lorries. With this input data the CO2 emissions of the entire vehicle can be calculated with VECTO. In the case of tractor trailer combinations also a generic tractor has to be defined since the trailers and semi-trailers are not linked to specific makes and models of tractors.

The analysis was split in two main sub-tasks:

- Methods to create the input data for the simulation tool VECTO for bodies and trailers in an efficient way. The input data needed is air drag, mass and rolling resistance.
- Methods to handle the input data from the different companies involved in the multistage processes at rigid lorries for chassis-cab type HDVs and to produce CO2 results for trailers and for semi-trailers, which need to be linked to representative towing vehicle specifications.

Task 3: Detailed assessment and implementation plans for the most suitable and feasible methodology options

The interim report describes the activities within task 3 of the specific contract:
No 340201/2018/789725/SER/CLIMA.C.4 Bodies and trailers – development of CO2 emissions determination procedure

Task 3 evaluated the applicability and feasibility of the methodology options defined and selected in task 2, referring to producing body and (semi-)trailer specific CO_2 results for single heavy-duty vehicles in a possible extension of Regulation (EU) 2017/2400.

The task is split into three main sub-tasks and all shall work on bodies for rigid HDV and for trailers:

- Methodologies definition regarding certification. Specific methodology shall be defined for the three options (see sections 4.1, 4.2 and 4.3) to be created, focused on the applicability for certification, including test protocols and requirements in terms of equipment and software.

  Regarding the inputs for the certification options, the air drag resistance shall be taken into great consideration (excepting certification method A, see section 4.1). To model this resistance, the Cd*A value would be used as an input, and depending on the case, different ways to obtain this value would be used. These Cd*A values can be calculated using various methods (see 4.2 and 4.3); one of these methods, in order to simplify these calculations, are look-up tables.

  These look-up tables shall include standardised aerodynamic packages. These standards shall contain description of the aero parts, considering shapes, technical sizes and tolerances. Regarding this approach, Cd*A calculation would be based on deltas, with the baseline defined as the standard semi-trailer as per VECTO.

- Test protocols shall be evaluated in terms of complexity and manageability, while equipment shall be addressed in terms of availability, cost and accuracy. The goal of these evaluations is to achieve the reproducibility of the methodologies for all the stakeholders. This task must ensure objective decision-making when selecting methodologies.

- Definition of a roadmap for the implementation of measures, considering the previous inputs.

All of these tasks shall work on bodies for rigid HDV and trailers (including semi-trailers, draw-bar trailers, etc.). The work was supported by literature reviews.

Task 4: Feasibility analysis including simulations and/or measurements

This interim report describes the activities within task 4 of the specific contract:
No 340201/2018/789725/SER/CLIMA.C.4 Bodies and trailers – development of CO2 emissions determination procedure

Task 4 focuses on the aerodynamic benefits provided by two of the most popular drag reduction devices in trailers (boat tails and side skirts), as well as proving the applicability and feasibility of the CFD method analysed in Tasks 2 and 3 by comparing the values of Δ(Cd*A) predicted by the simulations against what has been measured in constant speed tests based on Regulation 2017/2400.

The following four trailer configurations have been tested at the IDIADA facilities using an IVECO Stralis with Hi-Way Cabin as a tractor:

- C00: Standard trailer
- C01: Standard trailer with a boat tail of 400mm length
- C02: Standard trailer with short side skirts
- C03: Standard trailer with boat tail and short side skirts

Out of the 5 different CFD methodologies presented in Task 2, two of them have been applied to a 3D model representative enough of the vehicle tested.

Bodies and trailers – development of CO2 emissions determination procedure

Procedure no: CLIMA/C.4/SER/OC/2018/0005

Task 1. Review of existing studies, data collection and identification of the characteristics and specific constraints of the sector

Task leader: Tim Breemersch
Date: 04/06/2019

This document contains 107 pages

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Acronyms and abbreviations

Acronym	Meaning
ABT	Averaging, Banking and Trading
ACEA	European Automobile Manufacturers Association
ATP	Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage (ATP)
CAFE	Corporate Average Fuel Economy
CLCCR	International Association of the Body and Trailer Building Industry
EPA	US Environmental Protection Agency
FE	Fuel Efficiency
GEM	Greenhouse Gas Emissions Model
GHG	Green House Gases
GVWR	Gross Vehicle Weight (Rating)
HDV	Heavy Duty Vehicles
ICCT	International Council on Clean Transportation
MY	Model Year
PCs	Passenger cars
SAC	Standardization Administration of China
TKm	Tonne kilometre (also referred to as tonne.km)
VECTO	Vehicle Energy Consumption Calculation Tool
Vkm	Vehicle kilometre (also referred to as vehicle.km)

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Executive Summary

Context and objectives

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Abstract of this deliverable

This report starts with an overview of the market for trailers and bodies: the market shares of different types (for semi-trailers, drawbar trailers and rigid truck bodies), and the competitive structure of the market and its suppliers. This is followed by an assessment of the use of different body types.

In addition, this report analyses the regulatory framework in different regions worldwide regarding their heavy-duty vehicles (HVD) CO2 emissions and Fuel Efficiency (FE) certification approaches. An introduction to the discussion groups related to transport emissions and pollution is presented. In this description, their structure, objectives and strategies are described.

Then, the analysis of the regulation framework in different regions is presented. The selected regions are: US, Canada, EU, Japan, China and Korea. All of them are compared but a specific comparison between the strategies followed in US and EU is considered.

Finally, key elements and factors for a harmonization of the regulations are presented as well as some conclusions and take away messages.

1 The characteristics of the trailer and body building sector

1.1 Data sources and methodology

The results presented below are based on an analysis of a dataset on the trailer market purchased from CLEAR International up to 2017, and on an earlier ICCT review of the trailer market based on the same dataset but only providing information up to 2016. The reason for this approach is that publication restrictions has to be applied to some of the purchased data, while the ICCT review did publish data of that nature. The analysis showed that the differences between 2016 and 2017 are negligible in terms of their impact on the results of this report.

The CLEAR dataset covers 30[1] countries in total, 24 of which are EU members. Not included are Cyprus, Greece, Malta and Luxemburg. An interview with representatives of the sector (CLCCR and ACEA) was conducted to collect additional insights in the sector.

Further updates of this chapter have been done based on input from a survey set up with trailer and body manufacturers.

In the following text the term "trailers" refers to the group of both semi-trailers and full trailers. When a statement refers to just one of those categories, the specific name is used.

1.1.1 Description of truck and trailer body types

This analysis covers the market for trailers (semi-trailers and full trailers) and rigid truck bodies. As terminology in theory (type approval legislation) and in practice does not necessarily align, this section will give a description of the different body types considered in this report, as well as the other distinctions made in this chapter. The digits used to supplement the codes to be used for various kinds of bodywork are in brackets.

1.1.1.1 Box Body types

1.1.1.1.1 Curtain-sided (06)

A curtain-sided trailer is essentially a flatbed trailer (which consists of only a platform) with a skeletal upper structure to hold the tarpaulin (the curtain) in place. Variants exist where the tarpaulin covers the entire upper structure, which can be moved to provide access for loading from all sides (top, side and back), or one where the tarpaulin only covers the side of the trailer, with a fixed roof and rear doors.

[1] EU 24 plus Turkey, Russia, Ukraine, Norway, Belarus, Switzerland

Figure 1. Curtain-sided semi-trailer (source: www.lawrencedavid.co.uk)

1.1.1.1.2 Dry Box (03)

A Dry Box trailer is a box body trailer with a hard shell that is closed from all sides, with a door on the back[2]. Compared to a curtain-sided, a dry box offers better protection from the weather, damage and theft.

Figure 2. Dry Box semi-trailer (source: www.ifa-forwarding.net)

1.1.1.1.3 Reefer: "Conditioned body with insulated walls and equipment to maintain the interior temperature" (04) and "Conditioned body with insulated walls but without equipment to maintain the interior temperature" (05)

A Reefer trailer is a box body trailer with a hard shell that is temperature-controlled. Typically, they are equipped with refrigerating units, but boxes that are only insulated also exist. They are mainly intended for the transport of perishable and temperature-sensitive goods like frozen foods, produce, pharmaceuticals or chemicals.

[2] Box trailers with side doors exist as well, but back doors are the most common.

Figure 3. Reefer semi-trailer (source: www.trucklocator.ie)

1.1.1.2 Non-box Body types

1.1.1.2.1 Flatbed (01)

A flatbed trailer is essentially just an even platform on wheels. It has no sides, roof, or doors. They are often used to transport construction equipment or materials and steel products and machinery.

Figure 4. Flatbed semi-trailer (source: www.nooteboomtrading.com)

1.1.1.2.2 Tank (11)/Tank intended for transport of dangerous goods (12)

Tanker trailers carry a tank that can be used to transport liquids, gases or dry bulk. The tanks could be insulated or non-insulated, pressurized or non-pressurized, and designed for single or multiple loads (using internal dividers). Some countries register tankers under 3 different categories: Dangerous goods, Foodstuffs, and Dry Bulk.

Figure 5. Tanker semi-trailer (source: www.autoline24.ie)

1.1.1.2.3 Swap Body (07)/Container Carrier (08)

Also known as simply a chassis, a swap body/container carrier is a minimal structure consisting of a frame with wheels, to which a container or swap body can be fixed.

Figure 6. Container carrier semi-trailer (source: www.krone-trailer.com)

1.1.1.2.4 Tipper (10)

A tipper trailer is equipped with an open-box bed, hinged at the rear and with hydraulic arms so that the front can be lifted and the material inside the box deposited on the ground. Typically, a tipper is used to transport heavy bulk materials such as sand or gravel, in the construction industry.

Figure 7. Tipper semi-trailer (source: www.autoline24.ie)

1.1.1.2.5 Vehicle Transporter (14)

Vehicle transporter trailers are used to carry cars, and consist of a skeletal frame and generally a double (uneven) platform on which vehicles can be loaded. Most vehicle carriers are open but boxed carriers exist as well.

Figure 8. Vehicle transporter truck-trailer (source: www.acea.eu)

1.1.1.2.6 Drop-side (02)

Drop side trailers are similar to tippers in the sense that they consist of an open-box bed structure, of which one or several sides can be dropped to ease the loading and unloading process. Sometimes a hydraulic arm can be used to lift the bed and allow the load to slide out onto the ground. Drop side trailers are mostly not as large as typical long-haul heavy trailers.

Figure 9. Drop-side semi-trailer (source: www.bedrijfsauto.com)

1.1.1.2.7 Low floor trailer (29)

Low-floor trailer are a special type of flatbed trailers with the platform as close to the ground as possible, so as to flexibly allow the carriage of the cargo (often big machinery). A low floor trailer could also be equipped with a light frame and covered with tarpaulin to create a curtain-sider with extra internal height.

Figure 10. Low floor semi-trailer (source: www.rac-germany.com)

1.1.1.2.8 Timber (17)

Timber trailers are another form of flatbed trailer with vertical stakes to hold the timber in place.

Figure 11. Timber semi-trailer (source: www.autoline.info)

1.1.1.2.9 Livestock carrier (13)

Livestock carriers are specially equipped for the transport of live cattle, pigs, chickens, etc. This includes equipment to improve the stability, the use of specific corrosion-resistant materials, a ramp for the animals to enter the vehicle, etc.

Figure 12. Livestock carrier semi-trailer (source: www.pezzaioli.co.uk)

1.1.1.2.10 Other

All other types of bodies and trailers according to Appendix 2 of annex I of Regulation 2018/858 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles. Many of these are vocational vehicles (vehicles that are not intended for the delivery of goods). According to Regulation (EU) 2017/2400 as amended by Regulation (EU) 2019/318 vocational vehicle means a heavy-duty vehicle that is not intended for the delivery of goods and for which one of the following digits is used to supplement the bodywork codes: 09, 10, 15, 16, 18, 19, 20, 23, 24, 25, 26, 27, 28, 31. However, trailers are not under the scope of the regulation and there is no official definition of "vocational trailers" in the sense of a set of technical criteria. The manufacturer is responsible for applying the designation. Vehicles generally considered vocational are indicated with a * in the list below.

- Vehicles fitted with hook lift (09); *
- Concrete mixer (15); *
- Concrete pump vehicle (16); *
- Refuse collection vehicle (18); *
- Street sweeper, cleansing and drain clearing (19); *
- Compressor (20); *
- Boat carrier (21);
- Glider carrier (22);

- Vehicles for retail or display purposes (23); *
- Recovery vehicle (24); *
- Ladder vehicle (25); *
- Crane lorry (26); *
- Aerial work platform vehicle (27); *
- Digger derrick vehicle (28); *
- Glazing transporter (30);
- Fire engine (31); *

Most of these types are generally not used in long haul and regional delivery transport (the main focus areas of the present report), but in more local (shorter distance) transport operations.

1.1.2 Description of CLEAR International data set

The dataset purchased from CLEAR International covers historic data of trailer registrations, fleet and production from 2012-2017 (2014-2017 for rigid trucks). Following splits are included:

- Everything per region for trailers: Western and Eastern Europe, further split into 15 countries each, including 24 EU countries
- Fleet and registrations per type of coupling: semi-trailer versus full trailer
- Registrations per body type: Curtain, Closed Box Van, Reefer, Chassis, Tank Bulk, Tipper, Other
- Registrations per body type of new rigid trucks for 12 European[3] countries
- Production volume for over 100 companies, split per country and per type of coupling

1.2 Production

The trailer and body building market is very heterogeneous. There are notable differences between the markets for semi-trailers and full trailers as well: the semi-trailer market is dominated by a few very large manufacturers delivering mainly standardized products, whereas non-standardized products are generally made to order by around 100 smaller manufacturers. In the full trailer market, the demand for non-standardized, non-box trailers is much greater; hence the differences between manufacturers are much smaller in terms of production volume.

[3] The countries are Germany, the Netherlands, France, Italy, Spain, Belgium, the UK, Poland, Finland, Sweden, Norway and Denmark

1.2.1 Semi-trailer market

Total semi-trailer production in 2016 was 215 000 units [1] – it increased slightly in 2017 (see Annex 1). There are 4 leading manufacturers with a production volume over 10 000 units: Schmitz Cargobull, Krone, Kögel (Humbaur) and Wielton S.A. Together, these 4 represent around 55% of the total European production volume. The 20 next-largest manufacturers represent another 25% of the market, leaving the remaining 20% for more than 75 smaller companies. The three largest manufacturers all have their main production facilities in Germany, with only Schmitz Cargobull also producing semi-trailers in other countries (Spain and Lithuania). Wielton S.A. has its origins in Poland but has production facilities in Italy and France as well.

In addition to these companies that are large at a European scale, several other countries have large local manufacturers with production volumes of several thousands of units. Examples include the UK (SDC), Belgium (Van Hool), Ireland (Dennison), Hungary (Schwarzmüller, which has its origins in Austria) and Spain (LeciTrailer).

While the sector is relatively consolidated at present, this is a recent phenomenon. In 2009, the top 5 largest manufacturers only accounted for around 27% of the market. The economic crisis has likely driven this evolution, as cost savings through mass production of standard type trailers made mergers and takeovers in the sector a necessity for survival.

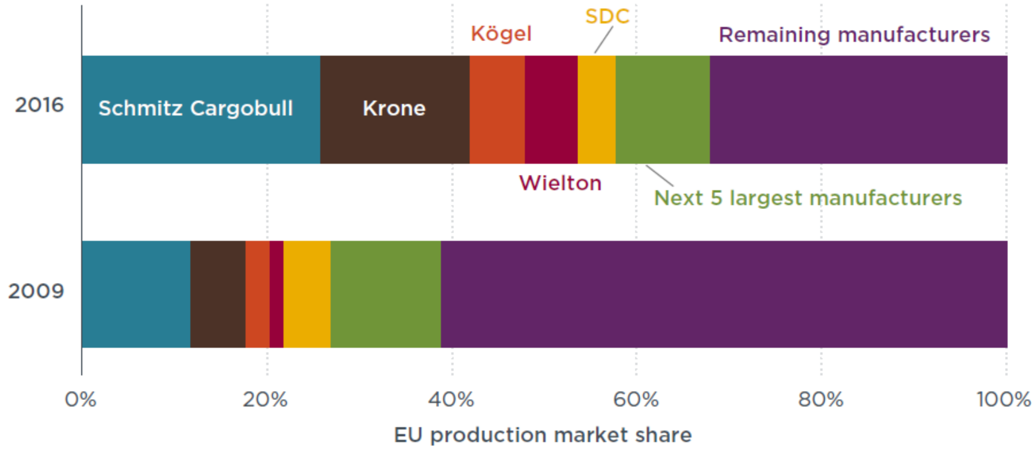

Figure 13. Consolidation in the semi-trailer manufacturing market [1]

1.2.2 Full trailer market

The market for full trailers is much smaller and much less consolidated than the one for semi-trailers. Total registrations of full trailers were around 25% of semi-trailer registrations; assuming a similar ratio for production volume, that puts drawbar trailer production at around 55 000 units. The 5 largest manufacturers (Schwarzmüller, Schmitz Cargobull, Fliegl, Wecon and Krone) have a total market share of just 23%, whereas the very small manufacturers (grouped together in the “Other” category in the dataset), represent over 40% of total European drawbar trailer production.

1.2.3 Country split

By far, Germany is the largest manufacturer of trailers, at 57% the EU countries included in the CLEAR dataset. The UK and France and the second and third largest manufacturers of trailers, both with shares of around 7.5%. Spain, Poland, Belgium, Austria, Italy and the Netherlands are the only other countries with a share over 2%. Together these eight countries account for 93% of total EU trailer production.

Table 1. Trailer production per country (source: CLEAR International)

Country	Trailer production	%
Germany	156 124	56.72%
France	20 732	7.53%
UK	20 631	7.49%
Spain	14 838	5.39%
Poland	12 939	4.70%
Belgium	9 240	3.36%
Austria	8 383	3.05%
Italy	7 539	2.74%
Netherlands	5 527	2.01%
Hungary	4 724	1.72%
Lithuania	3 265	1.19%
Czechia	2 454	0.89%
Ireland	2 226	0.81%
Finland	2 146	0.78%
Sweden	1 511	0.55%
Denmark	932	0.34%
Luxemburg	631	0.23%
Portugal	362	0.13%
Slovenia	350	0.13%
Bulgaria	303	0.11%
Estonia	169	0.06%
Romania	98	0.04%
Latvia	88	0.03%
Slovakia	27	0.01%
Croatia	25	0.01%
Total	**275 264**	

1.2.4 Profiles of manufacturers

Typically, the larger manufacturers produce a range of standardized equipment in large quantities, leaving specialized trailers to the smaller companies who offer highly customized products, in many cases building only a few trailers per year.

1.2.4.1 Product portfolio of manufacturers

Product ranges for the 8 largest European manufacturers:

- Schmitz Cargobull produces both semi-trailers and full trailers, but semi-trailers represent around 95% of total production. The product range includes dry boxes, curtainsiders, tippers and container/swapbody chassis (and also the swapbodies themselves), and cooling/insulation equipment is offered as an option to make reefers. Dollies are part of the product range as well.
- Krone’s production volumes show a similar full/semi-trailer ratio as Schmitz’s, and the product ranges are alike as well: box body types (curtainsider, dry box, reefer) and container/swapbody chassis. Its range also includes includes open trailers specifically tailored to building materials.
- Kögel (Humbaur) offers a mostly standardized product portfolio. Apart from box body types (curtainsider, dry box and reefer), Kögel’s range also includes dropside trailers, tippers, flatbed (low floor) trailers and container/swapbody chassis (swapbodies as well). Furthermore, Kögel also offers so-called Euro

trailer, elongated versions of its standard trailers (+1.3m length) for use in 11 of 16 German Bundesländer only.

- Wielton S.A.'s product portfolio covers, in addition to curtainsiders and dry box trailers (reefers are not offered specifically but could be part of the dry box range), a portfolio of container/swapbody chassis, tippers, flatbed (low floor) trailers and a specific range of trailers for use in the agricultural sector.
- SDC's range includes dry box and curtainsider trailers, in addition to container chassis, flatbed trailers (for the timber industry or the construction sector) and low floor trailers. It also offers a range of skeletal trailers, on which customized bodies can be installed (e.g tippers, tanks, timber). It is the UK's largest trailer manufacturer.
- Schwarzmüller, originally from Austria, offers the standard range of box body trailers (including reefers), but also has a range of tippers for both light goods (e.g. agricultural products) and heavier goods (for the construction sector). It is the largest manufacturer (in terms of total production volume) to also offer tankers (as a body on rigid trucks).
- LeciTrailer of Spain has a broad product portfolio, including the box types, container chassis, open (flatbed) trailers, low floor trailers, and tippers, but also offers special vehicles like concrete mixers and customized equipment (made to order).
- Fliegl's range covers curtain and dry box types, container chassis, flatbeds, tippers, timber carriers and low floor trailers.

Smaller manufacturers generally have a more diversified portfolio, offering greater degrees of customization or specializing in very specific market segments, like tankers or tippers. The CLEAR International dataset has information on 103 trailer manufacturing companies, with an important "Other" category covering around 15% of the market.
On average, companies outside the top 8 above have an average semi-trailer production volume of almost 600/year, though the median is 297. For companies outside the top 20, the average is 350 with a median of 240.

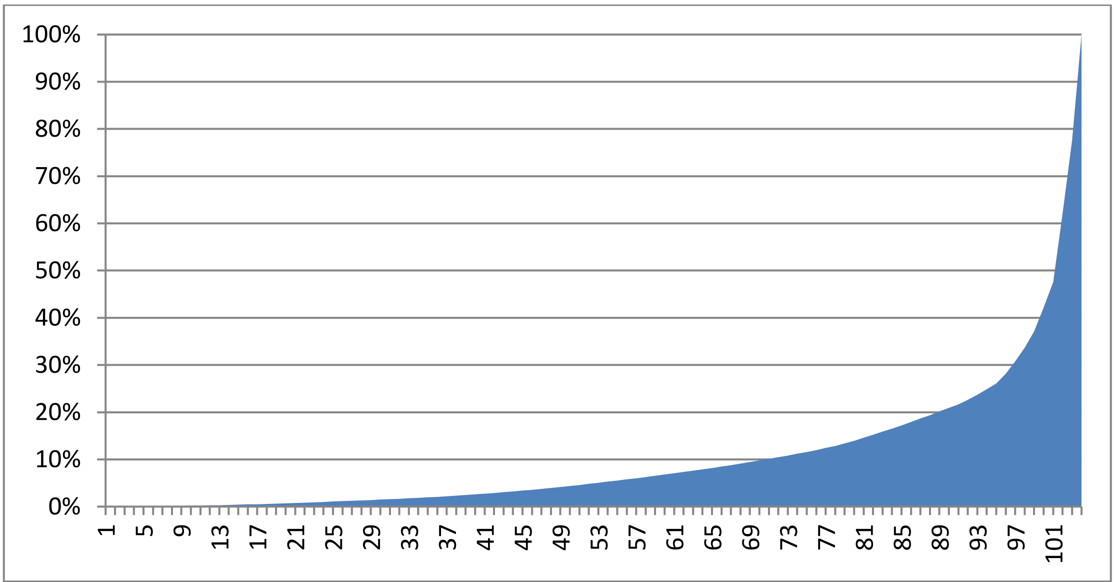

Figure 14. Cumulative market share of trailer production ranked from smallest to largest manufacturer (source: own calculation based on CLEAR International)

1.2.4.2 Economic parameters

This section provides information on the economic parameters of the different manufacturers: their annual turnover and the number of employees.
Schmitz Cargobull and Krone, Europe's largest manufacturers by a considerable margin, have a similar turnover at 2.17 billion € and 2.1 billion respectively. They provided no information in the survey regarding their profit margin.
79 other companies did provide information regarding both their profit margin and their annual turnover.

Table 2. Annual turnover and profit margin of survey respondents

Profit	0 - 1 mio euro	1 - 10 mio euro	10 - 100 mio euro	100 - 1000 mio euro	Total
Less than -5%		8	1	1	10
Between -5% and -2%	1	2			3
Between -2% and 0%		5	1		6
Between 0% and 2%		7	5		12
Between 2% and 5%	2	19	10	2	33
More than 5%	1	8	4	2	15
Total	**4**	**49**	**21**	**5**	**79**

Supporting the finding based on the number of trailers manufactured, most companies can be considered small, with 2/3 having an annual turnover under 10 million €. Companies with an annual turnover of more than 100 million € are uncommon.
Of the companies responding, 75% indicate that their business is profitable. Among manufacturers completing the survey, those with a turnover between 10 and 100 million € have the highest share of profitable companies.

The average number of employees in companies with an annual turnover between 1 and 10 million € is 32. The overall average is 358 employees per manufacturer.

Table 3. Trailer manufacturer turnover vs. number of employees (source: survey)

Turnover	# of Employees (average)	Standard deviation
0 - 1 mio euro	8.5	6.8
1 - 10 mio euro	32.4	24.8
10 - 100 mio euro	171.3	138.2
100 - 1000 mio euro	1 408.4	958.2
> 1000 mio euro	4 866.7	1 604.2
Total	**358.3**	**982.4**

1.3 Registrations and fleet

In this section, we present numbers on the distribution of trailer registrations per body type. We also provide figures on the total fleet size.

This section is based on the CLEAR International dataset, with some restrictions: splits between semi-trailers and full trailers are not included in this main report. The data collection survey was not sufficiently comprehensive to allow for a comparison with the information from the database on the number of trailers, but did deliver useful supporting information.

Additional information from the dataset will be presented in the confidential Annex 1.

1.3.1 Registrations per body type

In the 24 EU countries in the dataset, a total of over 238 000 trailers were registered in 2017, around 190 000 (80%) of which are semi-trailers. The majority are box types (curtainsiders, dry box trailers and reefers): 61%. [1] shows that 69% of semi-trailers are box types. From that we can then derive that among drawbar trailers, the share of box types is around 30%. Exact splits are presented in Annex 1.

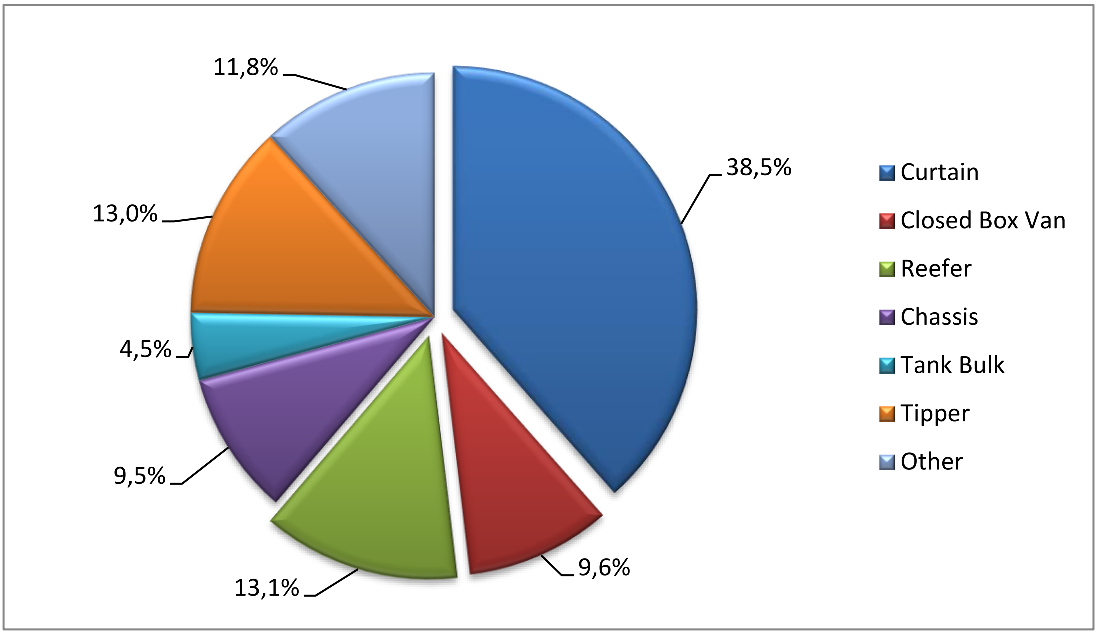

Figure 15. Registrations of new trailers in 2017 per body type (source: CLEAR International)

Curtainsiders represent the largest share of the market: 38.5% (almost 92 000 vehicles) of all newly registered trailers are of this type. Reefers are the second largest group at over 31 000 vehicles, followed by tippers (just under 31 000).

The trailer market has grown considerably over the past 5 years as economic recovery picked up: +53%. Market shares of the different body types have remained stable.

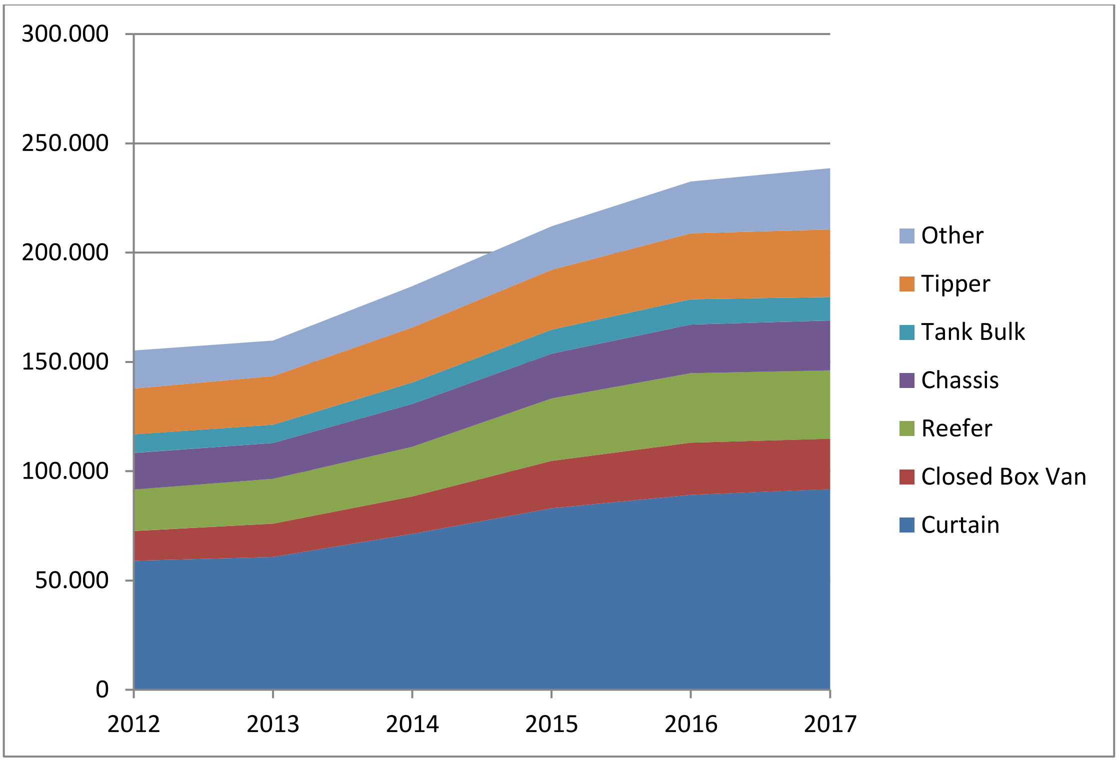

Figure 16. Evolution of trailer registrations in 24 EU countries, per body type (source: CLEAR International)

As for the split between semi-trailers and full trailers: in [1], we find the following figure for 2016 that includes this information. The corresponding table for 2017 based on the CLEAR International dataset is presented in Annex 1.

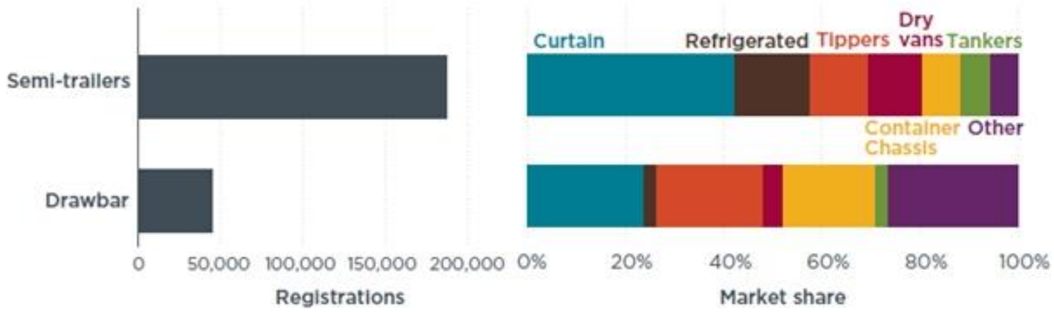

Figure 17. split of semi-trailer and full trailer fleet for 2016 (source: [1])

1.3.2 Comparison to survey results

The data collection survey generated similar splits of trailer production as the registrations from the CLEAR International data set. Curtainsiders and reefers are somewhat overrepresented in our sample, whereas namely fewer tankers and chassis are present in the production volumes of the companies that contributed to the survey.

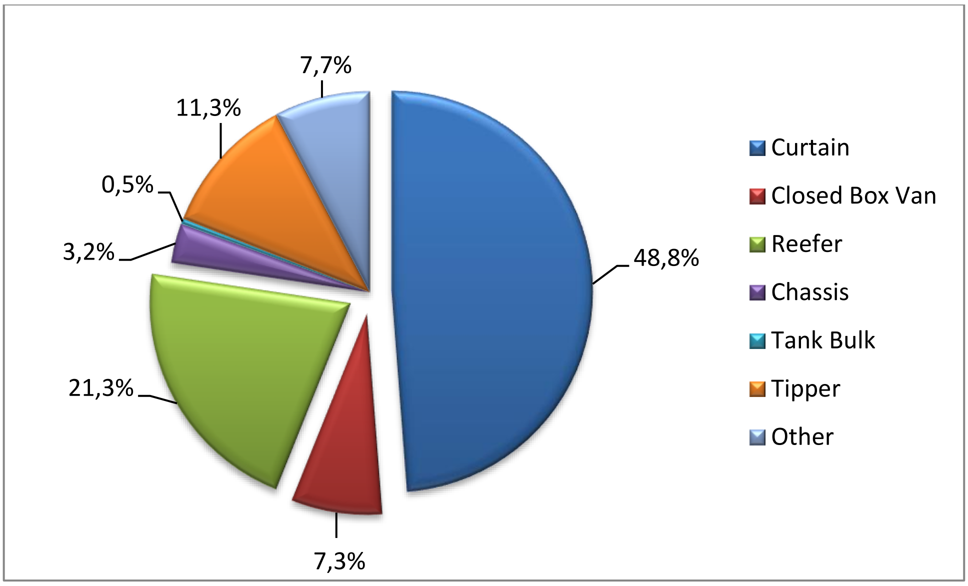

Figure 18. Production of new trailers in 2017 per body type (source: survey)

The main additional information we can draw from this is an indication of the split of the "Other" category, which covers around 7% of the semi-trailer registrations but 25% of new full trailers in the CLEAR International data set (derived from Figure 17).
These can be split as follows (rescaled based on rule-of-three):

Table 4. split of the "Other" category in CLEAR International data set based on survey input

	Semi-trailer	Full trailer
CLEAR "Other"	**7%**	**25%**
Survey	**3.3%**	**38.4%**
Flatbed	2.4%	5.5%
Vehicle transporter	0.1%	5.4%
Dropside	0.0%	4.8%
Low Floor	0.6%	3.8%
Timber	0.2%	1.5%
Livestock	0.5%	0.3%
Other	3.2%	3.7%

1.3.3 Split by weight class and type of trailer

The survey collected information for a total of 142 913 vehicles manufactured in 2017; 131 586 semi-trailers and 11 327 full trailers. It contained two additional levels of detail compared to the CLEAR dataset:

- All trailer types were split by weight: O3 (3.5-10 tonnes) and O4 (10+ tonnes);
- Full trailers were split by drawbar trailers and centre-axle trailers.

Regarding the split by weight category, the respondents of the survey manufacture almost only O4 trailers (99.5%). This applies to both semi-trailers and full trailers.
As for the split of the full trailer category, survey respondents produce nearly the same number of drawbar trailers (50.8%) as centre-axle trailers.

A third addition of the survey is the information on the axle configuration of the trailers. Respondents were asked to indicate the share of trailers with 2, 3 or 4 axles. For some of the more common body and coupling types, up to 30 companies provided an answer to this question, but for most, 3-10 manufacturers gave input.

Among O4 semi-trailers, a three-axle configuration was by far the most common, in some cases covering up to 99% of the market. The second most common are two-axle vehicles, with four-axle vehicles mostly non-existent. A notable exception are dry box trailers, where only 75% of the fleet has 3 axles. Vehicle carriers (mostly 2 axles) are the only O4 semi-trailer with a large majority of two-axles configurations. For drop side trailers, the market is more or less evenly distributed between four-axle and three-axle vehicles. In O3 semi-trailers, two-axle configurations are the most common.

Drawbar trailers generally have 2 axles, with the exception of dry box trailers, tippers and timber carriers, who mostly have 4. For centre-axle trailers, close to 99% of the vehicles manufactured by survey respondents have 2 axles.

Table 5. Axle configurations for trailer types (source: data collection survey)

Coupling	Class	Type	Body	Most common	%	2nd most common	%
Semi	O4	Box	Curtain	3	95%	2	4%
			Dry Box	3	75%	2	24%
			Reefer	3	97%	2	3%
		Non-Box	Flat bed	3	90%	2	9%
			Tank	3	98%	4	1%
			Chassis	3	99%	2	1%
			Tipper	3	95%	2	4%
			Vehicle transporter	2	95%	3	5%
			Drop-side	4	50%	3	45%
Semi	O3	Box	Curtain	3	95%	2	5%
			Dry Box	2	75%	3	25%
			Reefer	2	97%	3	3%
Drawbar	O4	Box	Curtain	2	92%	3	5%
			Dry Box	4	97%	3	2%
			Reefer	2	95%	4	5%
		Non-Box	Flat bed	2	95%	3	5%
			Tank	2	60%	3	40%
			Chassis	2	98%	3	2%
			Tipper	4	50%	3	35%
			Drop-side	2	50%	3	35%
			Timber	4	70%	3	20%
			Livestock carrier	3	55%	2	35%
Centre-axle	O4	Box	Curtain	2	99%	3	1%
			Dry Box	2	99%	3	1%
			Reefer	2	99%	3	1%
		Non-Box	Flat bed	2	99%	3	1%
			Chassis	2	99%	3	1%
			Tipper	2	99%	3	1%
			Vehicle transporter	2	85%	3	15%
			Drop-side	2	99%	3	1%

Another source of information on the axle configuration of trailer scan be found in research document by VDA [2].

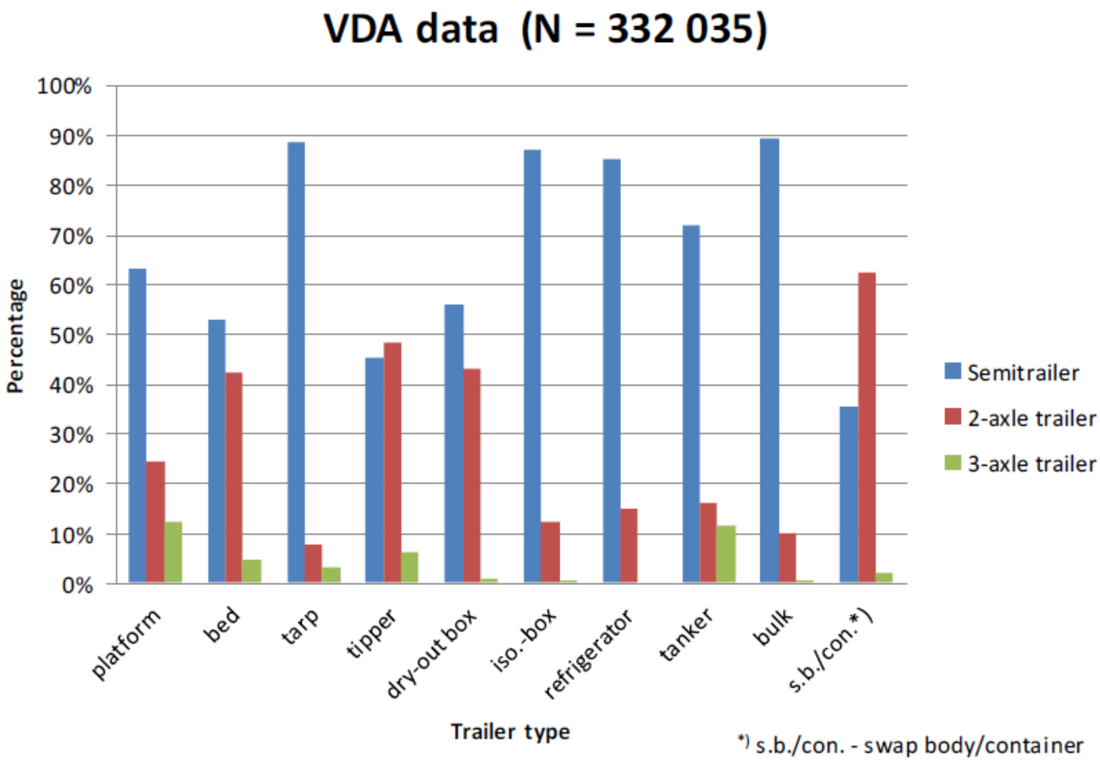

Figure 19. Trailer fleet split for Germany (2011)

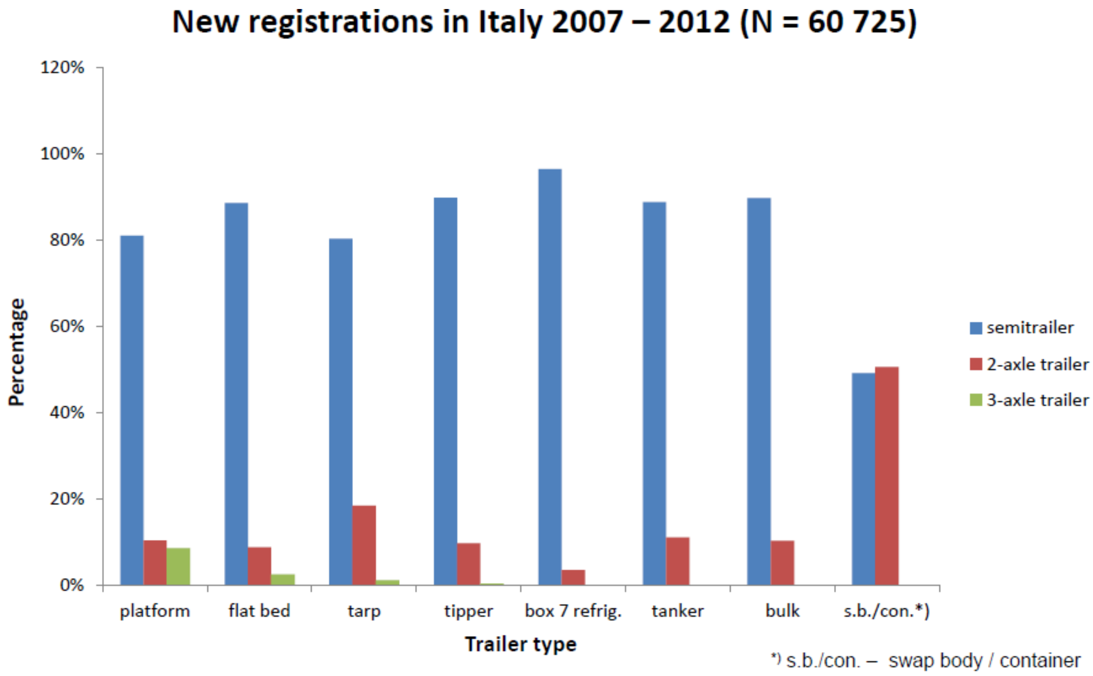

Figure 20. Trailer registrations split for Italy (2007-2012)

Traffic count data (HDV only) further reveal that tipper trailers in Germany mostly have a centre-axle configuration, but a 2 axle drawbar in Italy. Italian tanker trailers are also mostly 2 axle drawbar. Container/swap body chassis in Germany are mostly found as 2 axle drawbar trailers.

Among larger manufacturers, low rolling resistance tyres are requested by the client for 10-20% of trailers. Super single tyres are part of the standard equipment (70%+ of vehicles sold) for some large manufacturers, while it remains an exception for others.

1.3.4 Rigid trucks

For a selection of 12 countries (Germany, the Netherlands, France, Italy, Spain, Belgium, the UK, Poland, Finland, Sweden, Norway and Denmark), the CLEAR International dataset also has records on the registrations of rigid trucks per body type. The dataset metadata indicate that only vehicles with a maximum allowed mass of 6t and over are included.

In the 12 countries, a total of 154 000 rigid trucks were registered in 2017, up from 121 000 in 2014. Box types cover around 1/3 of the total, similar to the share for drawbar trailers. Of the non-box types, tippers are the most important category at 13% of the total, with flatbeds, container chassis and tankers the next most important. The "Other" category, which covers such types as refuse disposal trucks, construction vehicles, fire trucks, etc. is the largest at more than 53 000 registrations.

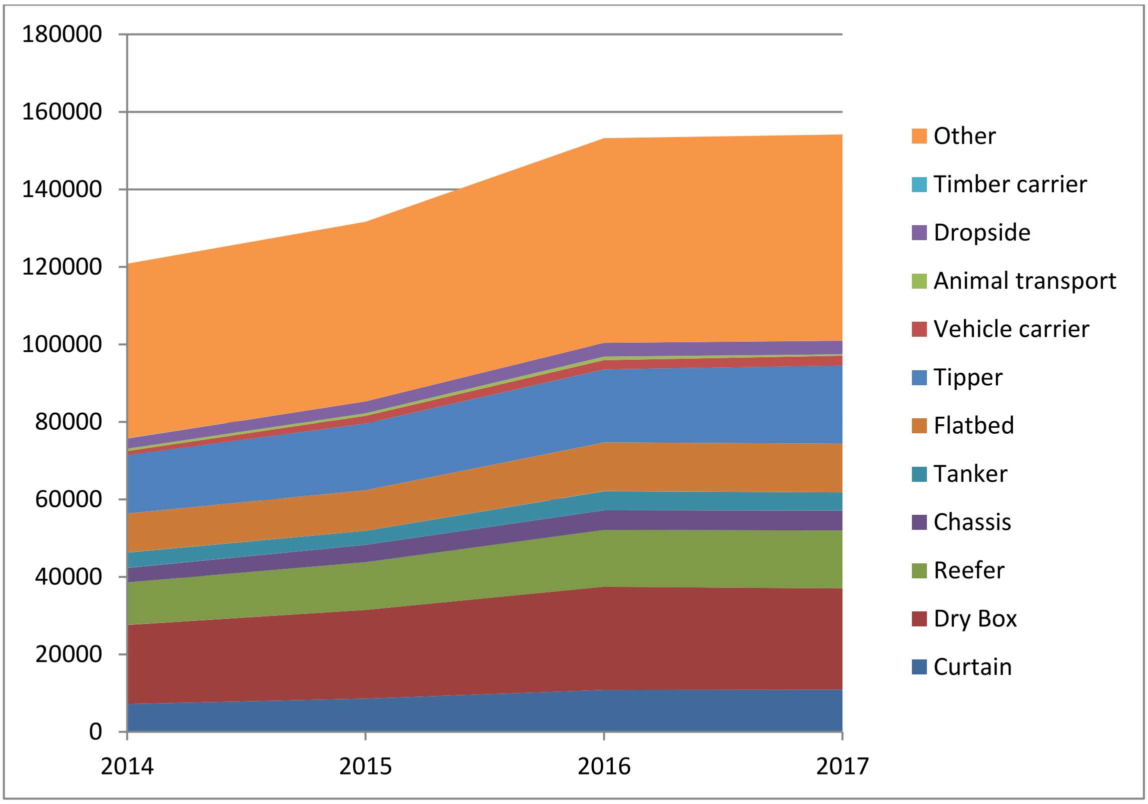

Figure 21. Evolution of rigid truck registrations in 12 EU countries, per body type

The survey also requested information on the production of rigid trucks, but it is not certain that results are representative of the market and comparable with those from the CLEAR dataset. The main addition is again a split between weight categories, in this case N2 (3.5-12 tonnes) and N3 (12+ tonnes).

Survey respondents manufactured 58 442 trucks in 2017; 23 674 N3 trucks (40.5%) and 34 768 N2 trucks (59.5%). The largest categories are flatbeds, dry box and tippers, each covering around 25% of the market. Flatbeds were by far the most common among N2 vehicles, where tippers, dry box trucks and livestock carriers were the most common N3 vehicles.

Among larger rigid truck manufacturers, trucks are mostly sold as a standalone vehicle. However, many smaller manufacturers indicate that 20-50% (for some as much as 95%) of their trucks are sold with a matching trailer, to form an articulated vehicle.

1.3.5 Specific remark concerning reefers

As was noted in paragraph 1.1.1.1.3, reefer trailers can be actively refrigerated (with a refrigerating unit) or passively cooled/insulated. The main data overviews of the CLEAR International data set do not distinguish between these categories, and structural data on the matter is not publicly available. However, the data set on rigid trucks does contain a split of refrigerated and insulated boxes for three large countries (Germany, Spain and Italy). The split of registrations for these countries is 95% refrigerated, 5% insulated. Those 5% insulated boxes are likely more similar to standard dry box bodies in terms of outside shape and dimensions than they are to reefers.

1.3.6 Fleet composition

The total trailer fleet consisted of 2.5 million units in 2017, up from 2.27 million in 2012 (+11%). Semi-trailers make up 76% of that. The share of semi-trailers in the fleet has remained stable since 2012.

It is noteworthy that the share of new semi-trailer registrations in total trailer registrations in 2012 was at 76% as well but has increased to 81% in 2017. This could suggest that the fleet of drawbar trailers is getting older relative to the semi-trailer fleet.
No figures are available on the composition of the fleet with regards to body types. However, based on consultation with CLEAR International and CLCCR, we can state that the share of body types in the fleet is roughly equal to the share of body types in new registrations. In [1], it is confirmed that market shares of different body types have remained stable over the past 9 years and will likely remain so for the foreseeable future.

1.3.7 Summary

To assess the importance of different trailer body types in the CO_2 emissions of the road freight, the first piece of information required is the split of the fleet over the different body types.
Based on input from stakeholders, it is assumed that the fleet share of different body types is the same as the share of registrations. The table below shows the split of registrations per body type and trailer type for 2016. Differences with 2017 are negligible. Therefore, this overview can be considered as representative for the fleet share of semi-trailers and full trailers.

Table 6. Share of new trailer registrations per body type for 2016 (based on [1])

Body type	Semi	Full
Curtain	42%	24%
Reefer	16%	3%
Tipper	11%	21%
Closed Box Van	12%	5%
Chassis	7%	19%
Tank Bulk	5%	3%
Other	7%	26%

1.4 The use of trailers

Different commodity types are transported under different circumstances, and this impacts how the equipment is being used. Relevant parameters are the annual mileage, lifetime mileage and the estimated life expectancy of a unit.

Primary data on this parameter likely exists with private parties (trailer fleet owners), but no regular publications on this are available. Mileages for trailers are generally not mentioned at all on websites for second-hand vehicles. Data collection would not be straightforward, as trailers are not equipped with odometers, so any efforts depend on the installation of specific tracking equipment or detailed documentation of vehicle missions. Information on these parameters was requested in the survey with trailer manufacturers and directly to a number of potential sources (large manufacturers, rental companies, transport operators' associations).

1.4.1 Indirect assessment

1.4.1.1 Eurostat

Eurostat is the primary comprehensive dataset on European Freight transport that can be used as a source of information. Table *road_go_ta_tcrg* contains values for the "Annual road freight transport by type of cargo and distance class (1 000 t, Mio tkm, Mio Veh-km, 1 000 BTO)". The types of commodities covered by the table are in line with the cargo type used by UNECE (Recommendation 21 – code between brackets) [2]:

- Liquid bulk goods (0)
- Solid bulk goods (1)
- Large freight containers (2)
- Other freight containers (3)
- Palletized goods (4)
- Pre-slung goods (5)
- Road mobile self-propelled units (6)
- Other Mobile units (7)
- Other cargo not elsewhere specified (9)
- Unknown

Several of these can be directly linked to a body type:

- Liquid bulk goods to tankers,
- Large and Other containers to Container Chassis,
- Road Mobile self-propelled units to Vehicle Carriers and Livestock Carriers.

Furthermore, we assume that Palletized goods and Pre-slung goods are generally transported in Box type trailers, whether they are curtainsiders, dry box vans or reefers. Dry bulk goods can be transported in bulk trailers (similar to tankers) or tippers (for e.g. construction materials).

The dataset contains values for the tonnage transported, tonne.km, vehicle.km and the amount of trips. Direct indications for the mileage per vehicle can thus not be derived from this dataset. It is noteworthy however that palletized goods and dry bulk goods represent 65% of the total tonnage transported in Europe, and 61% of the vehicle.km performed.

Table 7. Road freight transport performance per cargo type for 2017 (source: Eurostat table road_go_ta_tcrg)

Cargo type	Thousand tonnes	Million tonne-km	Million vehicle-km	Thousand trips
Liquid bulk goods	1 079 747	110 438	6 150	57 212
Dry bulk goods	5 764 430	371 419	20 132	329 898
Large containers	744 091	80 342	6 652	68 126
Other containers	358 237	28 366	3 212	56 226
Palletised goods	3 177 804	764 999	66 398	292 323
Pre-slung goods	306 181	62 676	4 054	22 113
Road mobile self-propelled units	258 583	41 028	4 585	27 762
Road mobile non-self-propelled units	134 799	17 997	2 024	14 730
Other cargo not elsewhere specified	1 774 597	304 079	27 832	173 357
Unknown	6 278	745	40	288
Total	**13 604 747**	**1 782 089**	**141 080**	**1 042 035**

A useful indicator for the use of the vehicle is the average trip length per cargo type (Table 8). Assuming a similar time for loading and unloading for all cargo types, a shorter trip means that in relative terms, more time is spent on loading/unloading activities than on driving, and that lower daily/annual distances can be achieved.

Table 8. Trip distance per cargo type for 2017 (source: own calculation based on Eurostat)

Cargo type	Trip distance = vkm/#trips
Liquid bulk goods	107.5
Dry bulk goods	61.0
Large containers	97.6
Other containers	57.1
Palletised goods	227.1
Pre-slung goods	183.3
Road mobile self-propelled units	165.2
Road mobile non-self-propelled units	137.4
Other cargo not elsewhere specified	160.5
Unknown	138.9
Total	**135.4**

The table reveals that palletized goods are transported over the longest distance per trip, while dry bulk goods and containers are transported over the shortest distances. For dry bulk, this is likely explained by the type of goods actually transported. Bulk goods are generally of low value, with a low value of time and are thus preferably moved over longer distances by other modes (rail or ship). Road transport thus represents only the last mile of the trip. A similar case can be made for container transport: as part of a multimodal chain, the role of road transport is limited. For dry bulk goods, another typical (short) trip would be the transport of raw materials (e.g. ores or construction materials) from a plant or storage area to a construction site.

We can thus conclude that if mileages differ per trailer body type, box types are likely to have higher annual mileages than most non-box types.

1.4.1.2 TRACCS

A secondary source of information that could provide a distinction between the use of truck-trailer combinations and that of tractor-semi-trailer combinations is the TRACCS project [2], which provides annual mileage estimates for "rigid trucks" and "articulated vehicles"[4]. The mileage for "rigid trucks" can be considered indicative for that of drawbar trailers (in a truck-trailer combination), while "articulated vehicles" are generally tractor-semi-trailers. Considering only the weight category with an upper limit of 40 tonnes, average annual mileage in 2010 for the EU28 is:

- Rigid truck (>32t): 54 867 km
- Articulated (34-40t): 102 998 km

1.4.1.3 Vehicle mileage to trailer mileage

A 1-to-1 conversion of annual mileages for vehicle combinations and trailers can however not be made. According to [3] and [4], the ratio of trailers to tractors is around 1.4 in Europe. However, the ratio of sales of tractors and trailers is close to and even slightly below 1 [1]. One reason for the discrepancy is the longer lifespan of trailers compared to towing vehicles.

Applying the 1.4 ratio of vehicles in use to the mileage of the vehicle combination, puts the average annual mileage of semi-trailers at 73 500 km. For drawbar trailers, such a conversion cannot be made as rigid trucks can functionally travel without a trailer (only carrying payload in the truck, or travelling empty), whereas tractors generally do not travel without a semi-trailer.

1.4.2 Results of consultation

In addition to the survey with trailer manufacturers, attempts were made to collect data on the use of different body types from large fleet owners. They were contacted by e-mail and invited to provide their input regarding the annual mileage and estimated life expectancy of certain vehicles. In practice, the data below is representative for semi-trailers only.

- One source noted that the average annual mileage of container chassis (in intermodal transport) is relatively low, around 60 000 to 70 000 km. Trailers used in pure road transport can have annual mileages of 120 000 to 140 000 km. The lifespan of vehicles is generally 8-9 years.

- Another source stated that there is little difference between different semi-trailer body types in the average annual mileage. Values around 120 000 km to 140 000 km were given. It was noted that if there is a difference, the price of the equipment drives the intensity of use: expensive reefers are driven more than relatively cheap container/swap body chassis.

- This source also suggested that the use profile depends greatly on the type of market in which the vehicle operates; e.g. container chassis in port areas likely spend much more time waiting for loading/unloading and only driving short distances between terminals, whereas those owned by operators further away

[4] The report does not provide a clear definition of these categories.

from port areas could still be involved in the transport of maritime containers but likely over longer distances.

- A third source indicates that the life expectancy of semi-trailer box body types is usually around 10 years, whereas container/swap body chassis can be used up to 15 years. The minimal structure of a chassis is of course less susceptible to damage and deterioration compared to more expensive equipment.

- This source also confirms that reefers are probably used around 20% more than other box body types.

- A fourth source provided information on the life expectancy of different semi-trailers only, and the figures are in line with those of other sources: chassis and flatbed trailers around 12-15 years, curtainsiders and dry boxes 7-10 years, and reefers only 6-8 years. If reefer lifespan is on the lower end of that range, it is because of ATP regulation[5].

An important caveat with these figures is that the use of trailers in a large fleet is not necessarily typical for the total fleet, and that large fleets tend to contain only the more standardized body types (box types and container/swap body chassis).

1.4.3 Survey results

A total of 9 companies provided estimates for the average mileage of their semi-trailers, though some for only one or two body types – which is sensible in a sector with such a high degree of specialization. The limited number of respondents results in a lower degree of confidence in the results in case there is a divergence in the values.

Table 9. Estimated annual mileage and lifespan of O4 semi-trailers based on survey input

Body Type		Annual mileage (km)	Confidence	Lifespan (years)	Confidence
Box	Curtain	120 000	high	10-15	high
	Dry Box	120 000	high	8-20	moderate
	Reefer	120 000	low	8-12	moderate
Non-Box	Chassis	120 000	moderate	15-20	moderate
	Tipper	75 000	high	15-20	moderate
	Flatbed	100 000	moderate	12-20	moderate

These values apply to large semi-trailers (O4, >10 tonnes). Only one mileage estimate was provided for smaller semi-trailers (O3, 3.5-10 tonnes), which put the value for curtainsided trailers at around half that of O4 curtainsiders.

1.4.4 Conclusion

Data on the average mileage of semi-trailers is scarce, especially for non-box types. Even for box types, the available information does not suggest that large differences exist between the mileages of the different body types.
Based on what is available, plus additional evidence from general freight transport statistics and combined with expert judgment, following table was compiled. However,

[5] Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage (ATP), see https://www.unece.org/trans/main/wp11/atp.html

these values should be considered as indicative only, given that the source data were not collected in a systematic manner.

Table 10. Average annual mileage of semi-trailer body types

Body type		Annual mileage (km)	Confidence
Box	Curtain	120 000	high
	Dry Box	120 000	high
	Reefer	130 000	moderate
Non-Box	Flat bed	100 000	low
	Tank	120 000	low
	Chassis	100 000	moderate
	Tipper	75 000	low
	Vehicle transporter	100 000	low
	Drop-side	100 000	low
	Low floor	75 000	low
	Timber	75 000	low
	Livestock carrier	90 000	low

For full trailers and rigids, mileage information per body type could not be found. Therefore, no split per body type will be provided. An estimate based on the TRACCS project puts the average at 55 000 km for N3 vehicles.

1.5 Specific issues and constraints of the sector

A dedicated meeting with representatives of CLCCR and ACEA was organized at the EC's premises on 8/2/2019 with the specificities of the trailer manufacturing industry as part of the road freight transport sector as the main topic. This section summarizes the results of that discussion.

The trailer sector is a follower of evolutions in the road freight transport sector, and hence subject to the changing requirements of this sector. Relevant trends include:

- The emergence of e-commerce and the need for smaller trucks, often highly customized but still in larger quantities.
- The promotion of intermodal transport by European and national authorities has not led to a large increase in the demand for container chassis trailers.
- The lack of drivers puts pressure on the market. This could lead to more trailers being left at loading/unloading points to be unloaded while drivers continue the journey to pick up a different trailer, and hence a higher demand for trailers.
- Load consolidation and the use of longer, heavier vehicle combinations can help improve fuel consumption but also concentrate the risk of cargo theft. Better security measures on the trailer itself will be an important mitigation measure (along with the use of secured parking areas).

Weights and dimensions regulation are also expected to impact the trailer market. There has always been a push for lower trailer weight, as this increases the max payload, but is also needed to compensate for the extra weight of certain equipment (e.g. modifications required to meet EURO VI standards). However, weight reduction has its limits with regard to the strength of the structure. Material can be removed from the

structure as long as it retains the minimal required strength. The use of innovative, lighter materials is an option, but cost-effectiveness is also an important consideration.
Further aspects mentioned include:

- The installation and deployment of rear flaps. These could be installed during the original manufacturing or as an aftermarket modification. This may cause some complexity with regard to the functionality of the rear doors of a trailer.
- Visibility of vulnerable road users: use of cameras?
- Lateral protection
- On board weighing equipment
- Rear Underrun protection

Technological evolution is also expected in the field of energy management. The use of trailers with built-in LNG tanks (as is being developed by Kögel according to [5]) allows for an easier deployment of this fuel technology in heavy duty vehicles. Electrified axles for semi-trailers can recover energy during braking and downhill driving, and thus contribute to fuel consumption reduction for the vehicle combination. Furthermore, the axle is driven so it can be used to power the trailer when it is not coupled to a towing vehicle.

1.6 *The impact of different body and trailer types on vehicle specific emissions*

This section provides an indication of the relative impact of different body and trailer types on distance specific CO_2 emissions. This information is used in section 1.7. to assess the contribution of the various kinds of HDV configurations as analysed in this report on overall HDV CO_2 emissions.

In the current HDV CO_2 determination based on Regulation (EU) 2017/2400 the CO_2 emissions of trucks are calculated by VECTO considering “standard bodies” and “standard (semi-)trailers”. Those are defined to be constructed as a “hard shell body in dry-out box design”. In the following analysis the specific CO_2 emissions of HDV configurations equipped with such “standard bodies” and “standard (semi-)trailers” are defined to be the “reference” - i.e. as 100% in the comparison. As the current analysis focuses on long haul and regional delivery operation, vehicle designs optimized for those mission profiles (i.e. including aerodynamic equipment on the cabin and “long” axle ratios optimized for highway speeds) were considered.

Differing specific CO_2 emission levels from HDV configurations with alternative body and (semi-)trailer types result from changes in various parameters:

a) Curb mass
b) Air Drag (C_dxA)
c) Rolling resistance
d) Different vehicle operation conditions (driving cycle)
e) Different drivetrain layouts (e.g. higher axle ratios for vehicles predominantly operated in off-highway conditions)
f) Different average payload conditions

Typical values for parameters for a) to c) for all body- and (semi-)trailer types have been investigated based on available literature ([7], [8]) data submitted by ACEA to TUG in the context of the VECTO development and internet research. The according values are given in Table 11 (curb mass), Table 12 (CdxA) and Table 13 (rolling resistance). It should be noted that the focus of this exercise is to analyse the general variability of the

CO_2 emission levels as input for the analysis in section 1.7. The analysis does not claim full representativeness of the parameters as shown below.

Table 11. Curb mass of body and/or (semi)-trailer

	Tractor + semi-trailer (group 5)	Truck only (group 9)	Truck + Trailer (group 9 plus T2 trailer)
Dry box (reference)	7500	2200	7600
Curtain-sided	7500	2200	7600
Reefer	9130	5180	11290
Flat bed	10100	---	7960
Tanker & Bulk	5950	3100	8050
Container chassis	10620	2700	9000
Vehicle transporter	12300	5000	11800
Tipper	6100	3230	8730
Drop side	7364	2160	6960
Low-floor	10100	---	5800
Timber	6700	1752	6052
Livestock	11400	4300	11300

CdxA values as presented in Table 12 refer to typical values as if measured by the constant speed test procedure. For “open body” types (e.g. flat bed) the contribution of a box-shaped payload was considered in the CdxA values. Several alternative vehicle configurations were found to have lower CdxA values than the reference vehicle, mainly due to a smaller frontal area (e.g. a typical tipper vehicle has a vehicle height of some 3.2 m compared to 4 m of the standard Dry box) and a smaller aerodynamic wake zone behind the vehicle.

Table 12. CdxA [m^2]

	Tractor + semi-trailer (group 5)	Truck only (group 9)	Truck + Trailer (group 9 plus T2 trailer)
Dry box (reference)	5.56	5.28	7.23
Curtain-sided	5.56	5.28	7.23
Reefer	5.67	5.39	7.37
Flat bed	7.00	---	9.10
Tanker & Bulk	4.20	3.99	5.46
Container chassis	5.98	5.68	7.77
Vehicle transporter	6.28	5.97	8.16
Tipper	4.80	4.56	6.24
Drop side	5.18	4.92	6.73
Low-floor	7.00	---	9.10
Timber	4.88	4.64	6.34
Livestock	5.28	5.02	6.87

Differences compared to reference in rolling resistance coefficients as shown in Table 13 result from either smaller wheel dimensions (associated with higher RRCs as standard 22.5 inch tyres) or higher traction requirements on the driven axle.

Table 13. Rolling resistance coefficients [kg/t] (steered / driven / trailer axle)

	Tractor + semi-trailer (group 5)	Truck only (group 9)	Truck + Trailer (group 9 plus T2 trailer)
Dry box (reference)	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Curtain-sided	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Reefer	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Flat bed	5.71 / 6.62 / 5.25	5.71 / 6.62	5.71 / 6.62 / 5.25
Tanker & Bulk	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Container chassis	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Vehicle transporter	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75
Tipper	5.71 / 6.62 / 5.25	5.71 / 6.62	5.71 / 6.62 / 5.25
Drop side	5.71 / 6.62 / 5.25	5.71 / 6.62	5.71 / 6.62 / 5.25
Low-floor	5.71 / 6.62 / 5.25	5.71 / 6.62	5.71 / 6.62 / 5.25
Timber	5.71 / 6.62 / 5.25	5.71 / 6.62	5.71 / 6.62 / 5.25
Livestock	5.21 / 6.12 / 4.75	5.21 / 6.12	5.21 / 6.12 / 4.75

For consideration of the impact of influence factors d) to f) (different vehicle operation conditions, drivetrain layouts and payload conditions) no systematic data could be gathered to make a complete and founded assessment on a quantitative level. A short sensitivity analysis on the influence of these factors is given later in this section.

Based on the parameters as shown in the tables above VECTO simulation have been carried out for each considered HDV configuration. Simulation results for CO_2 in grams per kilometer for the two considered mission profiles and payloads per have been weighted according to Table 13 and divided by the results for the reference vehicle configuration. The results for relative impact of curb mass, CdxA and rolling resistance of different body and trailer types on distance specific CO_2 emissions is shown in Table 15. The CO_2 levels vary in a relatively small range of some -10% to +15% compared to the reference vehicle configuration.

Table 14. Weighting factors

Long haul		Regional delivery	
low payload	**reference payload**	**low payload**	**reference payload**
0.15	0.35	0.15	0.35

Table 15. Relative impact of curb mass, CdxA and rolling resistance of different body and trailer types on distance specific CO_2 emissions

	Tractor + semi-trailer (group 5)	Truck only (group 9)	Truck + Trailer (group 9 plus T2 trailer)
Dry box (reference)	100%	100%	100%
Curtain-sided	100%	100%	100%

Reefer	104%	107%	106%
Flat bed	115%	---	110%
Tanker & Bulk	90%	94%	93%
Container chassis	108%	104%	105%
Vehicle transporter	113%	111%	110%
Tipper	96%	100%	100%
Drop side	100%	98%	98%
Low-floor	115%	---	110%
Timber	97%	97%	96%
Livestock	98%	103%	104%

In order to assess the possible magnitude of the impact of the remaining other influence factors, the tractor-semi-trailer vehicle with a tipper body was additionally simulated in the construction cycle, with 19 300 kg payload[6] and with a shorter axle ratio (3.7 instead of 2.64). In this scenario the relative CO_2 emissions increase to 152% (compared to 96% if only mass, CdxA and RRC are considered).
Thus it can be concluded that the influence factors which can currently not be quantified mainly determine the relative CO_2 emission levels (in g/km) of the alternative bodies and (semi-)trailer types compared to a reference dry box vehicle. **As a consequence, it was decided to use similar distance specific CO_2 emission values to quantify the contribution on overall CO_2 emissions in the fleet.**

1.7 The contribution of different trailer types to heavy duty road freight transport CO_2 emissions

In this section, we combine the impacts of all parameters discussed above:

- The composition of the equipment fleet (see Table 16. Share of new trailer registrations per body type for 2016 (based on)): this shows a very clear distinction between trailer types and body types;

- The differences in the use (mileage) of different trailer types, if available (see Table 10): based mainly on input from manufacturers and other stakeholders, differences between body types could not be identified with a sufficiently high degree of certainty. Therefore, this parameter is not suitable for weighting;

- The impact of different trailer types on the specific emissions of different trailer types (section 1.6): it was found that the impact of the design and dimensions of the trailer impacted the specific vehicle emissions much less than the operational cycle in which the vehicle is used. Therefore, this parameter can also not be used for weighting.

The conclusion from this section is thus that the contribution of different body types to emissions of heavy duty road freight transport vehicles can only be based on their shares in the vehicle fleet. Semi-trailers represent around 80% of the fleet, full trailers 20%. The annual mileage for semi-trailers is probably around 120 000km, while that for

[6] This value refers to "reference payload in the long haul cycle with a payload factor of approx. 75%. For comparison : The average payload for the tractor semi-trailer combination in the mix as shown in Table 14 is 12 050 kg.

full trailers is just under half that. However, it is likely that there are large differences in the use of full trailers.

Body type	Semi	Full
Curtain	42%	24%
Reefer	16%	3%
Tipper	11%	21%
Closed Box Van	12%	5%
Chassis	7%	19%
Tank & Bulk	5%	3%
Other	7%	26%

Table 16. Share of new trailer registrations per body type for 2016 (based on [1])

2 Review of the existing legislation

Rulemaking activity related to fuel efficiency and emissions has been very active in the recent years.

Some countries, like EU, US, Japan or China have already completed their own legislation on Fuel Efficiency, with different rules among each area. Furthermore, evolutions of local rules are ongoing in almost all the above areas, but until now no activity for FE Harmonization is yet started among the governments.

2.1 Discussion groups

The agreements of vehicles characteristics are being discussed by several groups in Geneva and Brussels. Some of them are just regulatory groups which are continuously improving their agreements and others are discussing groups looking for the implementation of new technologies in the official framework.

In order to have a wide understanding of their structure, a brief introduction to them will be presented in the following lines.

2.1.1 Harmonization of Vehicle Regulations (WP.29) UNECE

The Inland Transport Committee (ITC) is the highest policy-making body of the UNECE in the field of transport. Together with its subsidiary bodies, the ITC has provided a pan-European intergovernmental forum, where UNECE member countries come together to forge tools for economic cooperation and negotiate and adopt international legal instruments on inland transport.

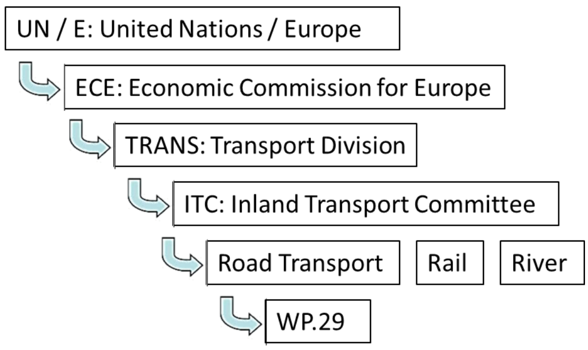

Figure 22. Hierarchical chart of the United Nations Transport committee

To deal with the transport issues, the ITC is assisted by several Subsidiary Bodies. One of them is the World Forum for Harmonization of Vehicle Regulations (WP.29).

The WP.29 is assisted in its work by six specialized Working Parties (GRs) covering specific regulatory areas of vehicles as seen in Figure 22. Their aim is to incorporate into its regulatory framework the technological innovations of vehicles to make them safer and more environmentally sound:

- Noise and Tires (GRBP)
- Lighting and Light-Signalling (GRE)
- Pollution and Energy (GRPE)
- Automated Driving (GRVA, former GRRF)
- General Safety Provisions (GRSG)

- Passive Safety (GRSP)

This group of experts conducts research and analysis to develop noise, active safety (specifically on braking and running matters), light, general safety and passive safety requirements. The World Forum convenes officially three times per year and entrusts informal groups with specific problems that need to be solved urgently or that require special expertise. More than 120 representatives participate at the sessions of the World Forum.

To include any novelty, modification or extension in the regulatory acts of the vehicle type approval, a new technical necessity should be announced in the WP.29 (directly by their members or as a suggestion coming from the Ad Hoc working groups). Once the discussion about this necessity is accepted, the technical requirements for the new regulation are developed in a specific working group (Ad Hoc Working group). Finally, it is presented to the correspondent responsible GR. After the proposal has been discussed and accepted in technical terms it is sent to the WP29 where its practicability will be discussed and accepted.

Together with the WP.29 the administrative committees AC.1 AC.2 and AC.3 (council about the 1998 Geneva agreement, 1958 Geneva agreement and the 1997 Vienne agreement) will give their approval (see Figure 23).

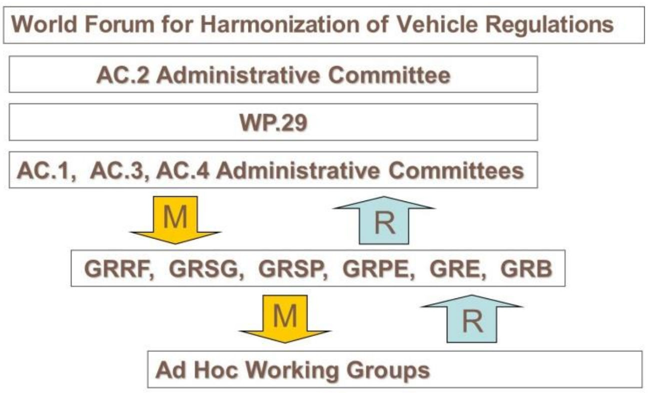

Figure 23. Regulation acts approval process

2.1.1.1 UNECE Working Groups (GR) regulatory analysis

In Table 17, a list of the regulations discussed in the different working groups is presented. These regulations have or will have direct relation to CO2 emissions regulations.

Table 17. List of regulations that might be affected by a CO2 regulation for bodies and trailers

Regulation	Brief description	GR discussion	Comments
Regulation (EU) …/…	Amendment of Regulation (EU) No. 1230/2012 Type-approval requirements for certain motor vehicles fitted with elongated cabs and for aerodynamic devices and equipment for motor vehicles and their trailers	DG MOVE, EC	At some point, the future regulation will have to take into account that motor vehicles and their trailer might be fitted with aerodynamic devices.
UN Regulation No 49	Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines and positive ignition engines for use in vehicles	GRPE of the WP.29 (UNECE)	At this moment, CO2 emissions are not considered in Regulation 49. But, if later on this is introduced, it could be used the "future" VECTO Certificate as a certified value for Regulation 49.
Regulation (EC) No 595/2009	Emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC	DG GROW HDV CO2 Editing Board, EC	The results of this tender will be used for the amendment of this regulation.
Regulation (EU) 2018/858	On the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC	EC	The requirements for vehicles of type O would change. Thus, this regulation should be amended accordingly.

2.1.2 G20 Transport Task Group

The Transport Task group is a voluntary platform for G20 countries. The objective is to share experiences and work together to improve the energy and environmental performance of motor vehicles, especially HDV. Participants are EU, USA, Argentina, Australia, Brazil, Canada, China, Germany, India, Italy, Japan, Mexico, Russia, and the United Kingdom.

The current activities of the G20 Transport Task Group are focused on:

1. Deep dive projects:

   Build domestic support and enhance capability for action to reduce the energy and environmental impacts of motor transport, especially HDVs. These “Deep Dive Projects” were 6 month in-depth webinar series on HVD CO2 certification. [7]

2. Policy Exchanges:

   In order to identify and exchange best practices among G20 countries on the implementation of cost-effective energy efficiency and emission control measures in the transportation sector.

3. Research Agenda

   Conduct analysis and outreach to assess the opportunities, barriers, costs and benefits of HDV programs, and subsequently recommend a course of action for participating G20 countries.

2.1.3 DG CLIMA

The Directorate-General for Climate Action (DG CLIMA) leads the European Commission's efforts to fight climate change at EU and international level.[8]

The mission of DG CLIMA is to formulate and implement climate cost-effective policies and strategies, such as the EU’s Emissions Trading System (EU ETS) and monitor national emissions by EU member countries.

The objective is to implement new policies in order to meet its climate targets for 2020 and beyond regarding greenhouse gas emissions and the ozone layer.
Other mission of DG CLIMA is to ensure that other EU policies and measures consider climate change and to not increase the EU’s vulnerability.

DG CLIMA also promotes the development of low-carbon technologies and adaptation measures, including carbon capture & storage, cutting emissions of fluorinated gases, cutting use of ozone-depleting substances and standards for vehicle-efficiency and fuel quality.

DG CLIMA has a staff of around 220 people. It was set up in 2010, climate change having previously been handled by the Commission's DG Environment.

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[7] The “Deep Dive” webinar presentations are available online, see https://www.theicct.org/heavy-duty-vehicle-efficiency

[8] For more information about DG CLIMA, see https://ec.europa.eu/clima/about-us/mission_en

2.1.4 DG GROW

The Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs is the European Commission service responsible, among other objectives for completing the Internal Market for goods and services.

In order to reach such targets, the work of DG-GROW is focused in:

- Ensuring an open internal market for goods and services in the EU
- Improving the range, quality, and competitiveness of products and services on the internal market
- Strengthening the industrial base in Europe
- Providing sector-specific and business-friendly policies

With regards to HDV CO2 emissions and FE, DG-GROW is responsible for the creation of standards, based on the technical input from DG-CLIMA work.

Examples of this Works are:

- Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information
- Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information
- Commission Regulation (EU) 2017/2400 of 12 December 2017 implementing Regulation (EC) No 595/2009 of the European Parliament and of the Council as regards the determination of the CO2 emissions and fuel consumption of heavy-duty vehicles

2.2 Overview of HDV CO2/FE certification approaches around the globe

This chapter reviews the approach of different countries around the globe regarding CO2/FE certification.

Table 18 and Table 19 show the strategy followed by each country. Each strategy is analysed considering the type of certification (Fuel Efficiency/ CO_2 emissions/ Corporate Average Fuel Economy/ others), the vehicle scope (minimum gross vehicle weight), the expect implementation, the certification procedure and other considerations, the enforcement mechanism and the software used for the certification if existing.

Some of the countries have not completely defined its strategy but are in its way of defining it.

Table 18. Adapted and updated from: White, B., & Hill, N. (2017). Analysis of fuel economy & GHG emission reduction measures from HDVs in other countries and of options for the EU. Ricardo Energy & Environment

	USA, Canada	**China**	**Japan**	**EU**
Type	FE & CO_2 (ex. Canada); CAFE	FE; individual vehicle	FE; CAFE (Corporate Average Fuel Economy)	FE & CO_2; Individual Vehicle
Vehicle scope	GVWR > 3.85t	GVW > 3.5t	GVW > 3.5t The current scope does not cover trailers	Vehicle groups for vehicles of category N (N2 GVW > 7500kg; N3) Scope to be extended in the future to other N vehicles, as well as buses, coaches and trailers
Sub-groups	Vehicle sub-groups included in each country are detailed in Annex 3 of this report			
Timeframe (full implementation)	MY= Model Year MY2014 Phase 1 MY2018 Phase 2	MY2014 China I MY2016 China II MY2021 China III	MY2015 MY2025 (proposal)	Published in 2017 and mandatory from 2019. Further stages implementation dates TBC
Certification	Engine dyno + component testing + whole vehicle simulation	Chassis dyno (base vehicles) or whole vehicle simulation (variants)	Engine dyno + whole vehicle simulation Aero/Rolling tests (proposal)	Engine dyno + component testing + whole vehicle simulation
Flexibilities	ABT scheme	None	Averaging. Initial credit system; now reduced at half.	None
Enforcement	Type Approval	Type approval ~Inspection / maintenance	Type approval	Type approval
Software	GEM			VECTO
Regulation	CANADA: *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations, phased-in 2014-2018* USA: Regulation *Greenhouse Gas Emission and Fuel Efficiency Standard for Medium- and Heavy-Duty Engines*	Second stage of national standards (GB 30510-2014) Third stage of national standard of China (GB 30510-2018)	2015 Fuel Efficiency Targets (Ministry of Economy, Trade and Industry) 2020 Targets: 2020 Top Runner Program	Regulation (EU) 2017/2400 of 12 December 2017 implementing Regulation (EC) No 595/2009 of the European Parliament and of the Council as regards the determination of the CO2 emissions and fuel consumption of heavy-duty vehicles and amending

	and Vehicles-Phase 2		Directive 2007/46/EC of the European Parliament and of the Council and Commission Regulation (EU) No 582/2011

Table 19. Adapted from: White, B., & Hill, N. (2017). Analysis of fuel economy & GHG emission reduction measures from HDVs in other countries and of options for the EU. Ricardo Energy & Environment.

	India	Brazil	Mexico	Korea
Type	FE	**Undecided**; possibly FE	**Undecided**; likely both FE and CO_2	**Undecided**; likely FE
Vehicle scope	>12t Segmentation on GVW, number of axles, and truck type (rigid – tractor)	>3.85t Undecided	>3.85t Undecided	>3.5t 4 sub-categories by duty cycle
Timeframe (full implementation)	Steering group since 2014 CSFC standards: 2018-21	Undecided	Undecided	Undecided
Certification	Track testing at 40/60km/h	Undecided	As US Phase 2	Undecided
Flexibilities		Undecided		Under development
Enforcement		Undecided		
Evaluation		Undecided		
Comments	In force from April 2018	Proposal for HDV F/CO2 timeline: Phase 1 (2018-22). Phase 2 (2023-27) Phase 3 (2028-32):	2012 General Law on Climate Change requires vehicle efficiency standards	Official announcement expected in near term

Most of the certification procedures are a combination of testing and simulation. Some input data is required, such as the specifications of the vehicle, and then, results of the testing and the modelling are combined, using a correction factor depending on the type of vehicle or using a mission profile defined for each vehicle specification. The final output is the fuel consumption value and/or the CO2 emissions value.

The image below (see Figure 24) shows the different input data used in the simulation model. Most countries use the values from the rolling resistance, the aerodynamic drag, the engine mapping and the value of the test cycles.

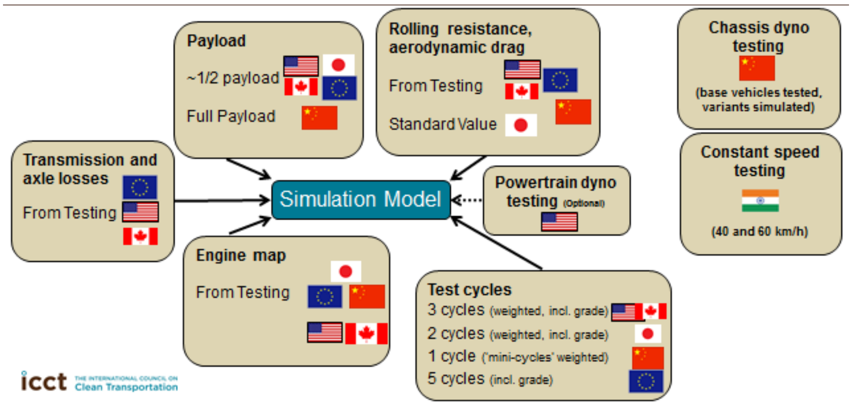

Figure 24. Inputs used in the simulation model per country [6]

2.2.1 US & Canada

In US and Canada, a declared CO2 and fuel consumption value is declared using the software GEM (Greenhouse Gas Emissions Model).

The enforcement mechanism is through type approval under the regulation *Greenhouse Gas Emission and Fuel Efficiency Standard for Medium- and Heavy-Duty Engines and Vehicles- Phase 2,* which has been updated in 2019[9].

This rule is the continuation of the phase 1, published in September 2011, *Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles.* Phase 1 covered new trucks and HDV in model year 2014 and later. It was developed by the agencies through close consultation with industry and other stakeholders.

Phase 2 standards, however, include technology advancing standards that will phase in over the long-term (through model year 2027). Phase 2 standards will maintain the underlying regulatory structure developed in the Phase 1 program, but it will consider technologies now under development and HGH and FE standards for trailers.

GEM is a free, desktop computer application that estimates the GHG emissions and fuel efficiency performance of specific aspects of HDV. It can be downloaded in the United States Environmental Protection Agency website.[10]

The input data used for the simulation are the results from drag area CdA test, tires test, transmission and axle test, as well as off cycle technologies. Also, the results from the engine testing are introduced to the GEM together with the engine dyno mapping.

The drag area CdA of both tractors and trailers are obtained according to 40 CFR 1037 – Subpart F. For tractors, the primary procedure for calculating drag area CdA is the coastdown test. For trailers, the primary procedure is the wind-tunnel test, however coastdown test, CFD test and other tests can be used as alternative.

[9] For latest version (v2019) of Part 1037 of 40 CFR and the alternative procedures to obtain the drag area CdA, see https://ecfr.io/Title-40/pt40.36.1037#se40.36.1037_1526
[10] For more information about GEM, see https://www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty

The image below (see Figure 25) shows the certification procedure's schema for a tractor.

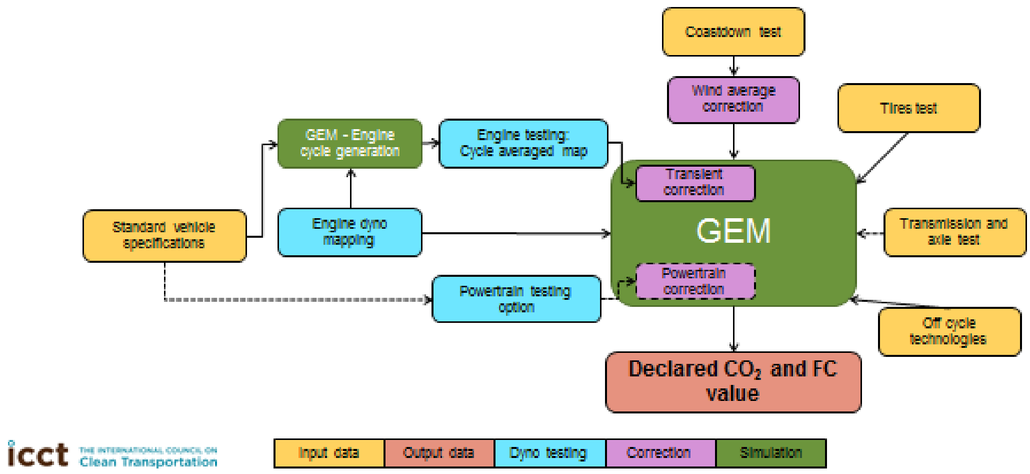

Figure 25. US and Canada HDV fuel consumption certification [6]

This standard, applicable for trailers from MY 2018 describes to trailer manufacturers how to use a simple equation to determine the GEM equivalent GHG emissions without actually using GEM.

This equation replicates GEM results, based on inputting certain trailer values into the equation. Manufacturers insert their tire rolling resistance level, wind-average change in drag area and weight reduction value when applicable. Through the following equation, a certified CO2 value is obtained:

Certified CO2 value (grams/ton-mile) = $[C_1 + C_2 \times C_{RR} + C_3 \times (DC_DA) + C_4 \times WR] \times C_5$
where

- C_{RR}= tire coefficient of rolling resistance, in kg/ton
- ΔC_DA = change in aerodynamic drag area
- *WR = weight reduction, in pounds*

This value corresponds to the simulated GHG emissions of the trailer in combination with a reference tractor (see Table 20).

Table 20. GEM equation coefficients

Trailer subcategory	C_1	C_2	C_3	C_4	C_5		
					No tire pressure system	Automatic tire inflation	Tire pressure monitoring system
Long dry van	76.1	1.67	-5.82	-0.00103	1	0.988	0.99
Long refrigerated van	77.4	1.75	-5.78	-0.00103			
Short dry van	117.8	1.78	-9.48	-0.00258			
Short refrigerated van	121.1	1.88	-9.36	-0.00264			

The agencies adopted Phase 2 standards that phased-in beginning in MY 2018 and be fully phased-in by 2027. These standards are predicated on use of aerodynamic and tire improvements, with trailer OEMs making incrementally greater improvements in MYs 2021 and 2024 as standard stringency increases in each of those model years.

Many of these technologies have already been introduced into the market through EPA's voluntary SmartWay program and California's tractor-trailer greenhouse gas requirements.[11]

The agencies adopted special provisions to minimize the impacts on small business trailer manufacturers. These provisions provide additional lead time for small business manufacturers, as well as simplified testing and compliance requirements. This standard can be achieved and demonstrated by manufacturers who lack prior experience implementing such standards. Bearing this in mind, this standard has been designed considering the limitations of small business (less than 1000 employees).

However, next standard (standards for MY2021) will be more stringent. These provisions provide additional lead time for small business manufacturers, as well as simplified testing (e.g: the simplified equation) and compliance requirements. For instance, small business manufacturers (1000 or fewer employees) had a 1-year delay in implementation to January 1, 2019 instead of 2018.

A workshop on GHG emissions and CO2 emissions for trailers was held in November 2016, and as an outcome, a FAQ document was issued, clarifying the responsibilities for trailer manufacturers.[12] (see question 1 of the FAQ document). For instance, if a small manufacturer wants to take advantage of the 1-year delay, it must notify EPA and submit a declaration describing how the company meets the employee threshold. Also, the trailer excluded under the small business flexibility must include a label saying; "This vehicle is excluded under 40 CFR 1037.150 (c)".

2.2.1.1 Categorisation of vehicles and tests performed

With the intention of understanding different vehicle categories and applicable tests, the following tables on this document will analyse and give an overview of what tests apply to each category of vehicles. The order of such tables will be: heavy-duty pickups and vans, tractors, trailers and vocational vehicles.

2.2.1.1.1 Heavy-duty pickup trucks and vans

Heavy-duty pickup trucks and vans are pickup trucks and vans with a gross vehicle weight rating between 8,501 pounds and 14,000 pounds (Class 2b through 3 vehicles) manufactured as complete vehicles by a single or final stage manufacturer or manufactured as incomplete vehicles as designated by a manufacturer (see Figure 26).

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[11] For further information, see Chapter IV. Trailers of the Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2, available online https://ecfr.io/Title-40/pt40.36.1037#se40.36.1037_1526

[12] FAQ document is available on https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100QWHL.pdf

Figure 26. HD Pick up (left) and van (right). (Source: https://www.kbb.com/ford/transit-350-hd-van/2016/ and https://www.gmc.com/previous-year/choose-your-sierra-heavy-duty-pickup-truck)

In Table 21 the Applicable tests for pickups and vans are described.

Table 21. Applicable tests for pickups and vans

Tests for HD pickups and vans	HD Pickups & Vans
• City fuel economy test cycle (FTP) • Highway fuel economy test cycle (HFET)	Class 2b-3

Note: The vehicles will continue to be tested using the same heavy-duty chassis test procedures currently used by EPA for measuring criteria pollutant emissions from these vehicles, including the ones mentioned above.

2.2.1.1.2 Tractors

Tractors are classified into three categories: day cab, sleeper cab and heavy-haul.

2.2.1.1.2.1 Day cab tractor

A type of tractor cab that is not a sleeper cab or a heavy-haul tractor cab (see Figure 27).

Figure 27. Day cab (Source: https://www.udtrucks.com/philippines/croner/productivity)

2.2.1.1.2.2 Sleeper cab tractor

Means a type of tractor cab that has a compartment behind the driver's seat intended to be used by the driver for sleeping, and is not a heavy-haul tractor cab. This includes cabs accessible from the driver's compartment and those accessible from outside the vehicle (see Figure 28).

Figure 28. Sleeper cab (Source: ref-https://freightliner.com/trucks/new-cascadia/)

2.2.1.1.2.3 Heavy-haul cab tractor

Means a tractor with GCWR (Gross Combined Weight Rating) greater than or equal to 120,000 pounds. A heavy-haul tractor is not a vocational tractor in Phase 2 (see Figure 29).

Figure 29. Heavy-haul (Source: https://wwwb.autohebdo.net/a/Kenworth/C500+58"+Sleeper+Tri-Drive+Heavy+Haul+Truck+Tr/Nisku/Alberta/5_38112677_2005629103257706/)

Table 22 summarizes the tests performed for each categories of tractor.

Table 22. Applicable tests for tractors

	Tractors			
	Day Cab		Sleeper Cab	Heavy-haul
Test	Class 7	Class 8	Class 8	Class 8
ARB*	19%	19%	5%	19%
55mph	17%	17%	9%	17%
65mph	64%	64%	86%	64%
Idle	x	x	x	x
Tire testing	x	x	x	x

Coast down test	x	x	x	x
Wind tunnel	x	x	x	x
CFD	x	x	x	x
Chassis Dynamometer testing	x	x	x	x

* ARB= Air Resource Board

2.2.1.1.3 Heavy-duty trailers

Phase 2 of the standard introduces also GHG emission standards for certain types of trailer. The agencies considered the wide variety of trailers and decided to focus on the most common types: dry and refrigerated box vans.

According to the definitions described in 49 CFR 571.3, a trailer means a "*motor vehicle with or without motive power, designed for carrying cargo and for being drawn by another motor vehicle*".

2.2.1.1.3.1 Dry box vans

Dry box vans are trailers with enclosed cargo space that is permanently attached to the chassis, with fixed sides, nose, and roof. Tank trailers are not box vans (see Figure 30).

Figure 30. Dry box trailer (Source: https://www.greatwesternleasing.com/used-semi-trailers/dry-vans)

2.2.1.1.3.2 Refrigerated box van

Refrigerated box van with front-mounted HVAC systems are refrigerated vans (see Figure 31 and Figure 32).

Figure 31. Refrigerated truck-trailer (Source: http://flatbed-semi-trailer.quality.chinacsw.com/iz67dc34b-80000l-40ft-3-axles-refrigerated-semi-trailer-enclosed-box-reefer-trailer-images.html)

Figure 32. Refrigerated Box Van Trailer (Source: https://www.truckpaper.com/listings/trailers/for-sale/32308141/2012-utility-reefer?ACTY=houston&ST=texas&CTRY=usa)

2.2.1.1.3.3 Non-box trailers

Trailers that are not box vans are non-box trailers. Note that the standards for non-box trailers in 49 CFR 535.5(e)(2) apply only to flatbed trailers, tank trailers, and container chassis (see Figure 33, Figure 34 and Figure 35).

Figure 33. Flatbed trailer (Source: https://hire.maunmotors.co.uk/hire-vehicle-midlands-nottingham-derby-sheffield/hgv-trailer-rental-flatbed-40-foot-moffett/#.XN6PE8gzblU)

Figure 34. Tanker trailer (Source: https://amthorinternational.com/tanks/tanker-trailers/)

Figure 35. Container chassis (Source: http://prattinc.com/products/tank-and-container-chassi)

2.2.1.1.3.4 Summary of the trailer categorisation

The following table (Table 23) is a summary of all the subcategories of trailers considered in Phase 2 standard:

Table 23. Trailer classification

Trailers								
Box Van						Non-Box Trailers		
Dry			Refrigerated			Tank trailers	Flatbed trailers	Container chassis
Long & Short Vans*			Long & Short Vans*					
Full aero	Partial aero	Non-aero	Full aero	Partial aero	Non-aero			

* Box van with a length greater than 50 feet (15.24m) are long box vans. Other box vans are short box vans.
Note: Heavy-duty trailers excluded can be found on "49 CFR 535.3".

2.2.1.1.4 Vocational vehicles

Vocational vehicles are classified according to Table 24:

Table 24. Vocational vehicles classification

Vocational Vehicles									
Light heavy-duty (class 2b-5)			Medium heavy (class 6-7)			Heavy-duty class 8 (CI only)			Vocational tractor
Regional	Multi-purpuse	Urban	Regional	Multi-purpuse	Urban	Regional	Multi-purpuse	Urban	

Test for vocational vehicles:

- ISO 28850 test method (rolling resistance for each tire)
- Transmission Efficiency Test: GEM will accept as inputs results of this test. The test will allow manufacturers to reduce the CO2 emissions and fuel consumption by designing better transmissions with lower friction due to better gear design and/or mandatory use of better lubricants.

2.2.2 EU

In EU, the Commission has set that, since 1st January 2019, truck manufacturers have to declare the CO2 emissions and fuel consumption of new vehicles they produce for the EU market.

The instrument to calculate their emissions is the Vehicle Energy Consumption Calculation Tool (VECTO). The calculated CO2-Emissions and fuel consumption information is declared for the registration of vehicles under the EU type-approval legislative framework, in application of the EU Regulation 2017/2400 implementing EU Regulation No 595/2009 and amending Directive 2007/46/EC and EC Regulation No 582/2011.

The Commission has published a proposal for a new regulation, 2018/0143 (COM) final, which will set CO2 emission performance standards for new heavy-duty vehicles. The aim of this proposal is to address the targets of CO2 emissions reduction from the European Commission.

This proposal is waiting for Parliament first reading. According to the letter written by the Chairman of the Permanent Representatives Committee on the 22nd February 2019, the European Parliament could adopt its position at first reading.[13]

Next steps include the extension of the current scope to other types of HDV, such as buses, coaches and trucks under 7,5T of GVW.

As it is today, the input data used in VECTO is air drag test results, transmission and axle test results; tires test results and auxiliary's standard results; in combination with the engine dyno mapping.

The image below (see Figure 36) shows the schema of the certification procedure.

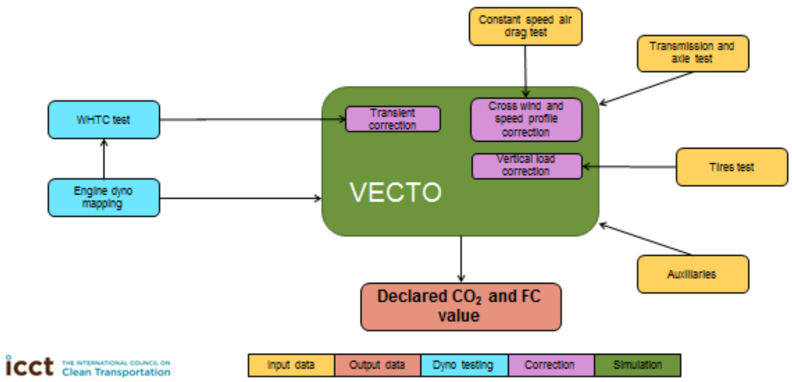

Figure 36. Europe HDV fuel consumption certification [6]

[13] A letter addressed to the Chairwoman of the European Parliament Committee for Environment, Public Health and Food Safety the 22nd February 2019 by the Chairman of the Permanent Representatives Committee is available on http://www.europarl.europa.eu/RegData/commissions/envi/lcag/2019/02-22/ENVI_LA(2019)001750_EN.pdf

2.2.3 Comparison of EU and US methodologies

2.2.3.1 Vehicle Simulations: VECTO vs GEM

The ICCT has published recently a report where it compares the approach and the limitations of the EU strategy for the fuel consumption simulation of HDV [7].

2.2.3.2 Differences regarding their input data

In this report, the architecture model of VECTO is analysed and compared to the GEM one. Also, other aspects such as the input needed for each model is compared. Table 25 shows the results of the comparison carried out in this report.

Table 25. Input comparison between GEM and VECTO [7]

Component	VECTO input	GEM input
Engine	Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, brake-specific fuel consumption over the Worldwide Harmonized Transient Cycle (WHTC)	Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, fuel consumption over the ARB Transient Drive Cycle for 9 different vehicle configurations
Transmission	Transmission type, gear ratios, torque loss map as a function of torque and speed for each gear, maximum torque and speed per gear	Transmission type, gear ratios, and maximum torque per gear. Optional: Power loss map as a function of torque and speed for each gear
Axle	Axle ratio and torque loss map as a function of torque and speed	Axle ratio Optional: Power loss map as a function of torque and speed
Aerodynamic drag	Air drag area as determined during the constant speed procedure. For rigid trucks, a standard box-body is used. For tractors, a standard trailer is used.	Air drag area as determined by the coastdown methodology. Standard trailers are used for tractor modelling.
Tires	Tire dimensions, rolling resistance coefficient (Crr), and load applied during the rolling resistance test for each axle	Rolling resistance coefficient (Crr) for each axle, and drive tire revolutions per mile
Vehicle	Curb vehicle weight, gross vehicle weight rating, and axle configuration	Vehicle weight reduction (sum of standardized weight reductions per component), vehicle regulatory subcategory (e.g., Class 8, sleeper cabin, high roof), and axle configuration
Other	Auxiliaries: Technology used for the following auxiliaries: cooling fan, steering system, electric system, pneumatic system, A/C system (whether it is present or not), and power take-off	Off-cycle technologies: Improvements through the application of the following technologies: Speed-limiter, neutral-idle, intelligent controls, accessory load reduction, extended idle reduction, tire pressure system, and other technologies.

Taking into account the equation and the trailer subcategories (see point 2.2.1 US & Canada), manufacturers determine the CO2 emissions and fuel consumption results for partial- and full-aero trailers using the equations and technologies specified in 40 CFR part 1037, subpart F of the US Regulation. Manufacturers can use testing to determine input values in accordance with 40 CFR 1037.515 of the US Regulation.

From the equation results, manufacturers can use the CO2 family emissions level (FEL) to calculate equivalent fuel consumption FELs are expressed to the nearest 0.0001 gallons per 1000 ton-mile:

- For families containing multiple subfamilies, manufacturers cab identifies the FELs for each subfamily

- Then, to calculate the equivalent fuel consumption FEL values for trailer families, they can use the expression:

  CO2 FEL value (grams per 1000 ton-mile)/10,180 grams per 1000 ton mile of diesel fuel) × (103) = Fuel consumption FEL value.

2.2.3.3 Differences regarding their model architecture

In the one hand, the GEM's model does not feature a graphical user interface. It was developed in Matlab Simulink as a forward-looking model: The simulation runs from the accelerator pedal to the wheels.

The GEM architecture is comprised of four main modules: Powertrain, Vehicle, Driver (which is a closed-loop controller), and Ambient. The image below (Figure 37) shows the schema of its architecture.

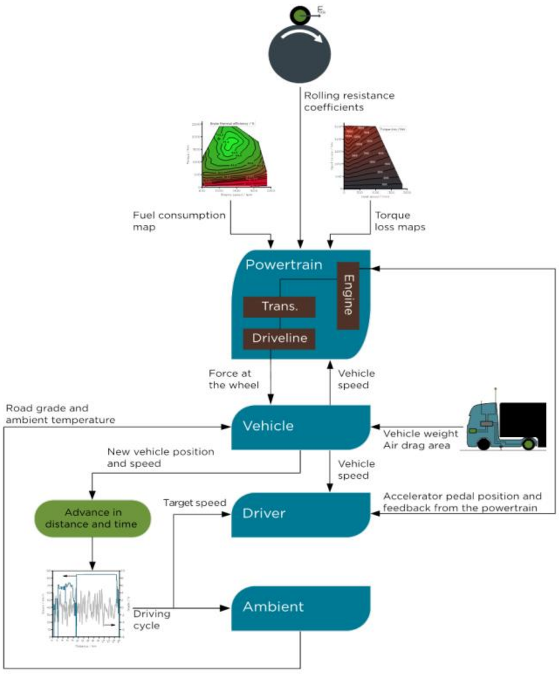

Figure 37. GEM's model architecture [6]

On the other hand, VECTO was developed in C# as a backward-looking model: the simulation flow occurs in the opposite direction to the way it takes place in the actual vehicle. The Driver Model converts the drive cycle information into an acceleration request, to ultimately locate an appropriate operating point in the engine fuel map. Once a valid engine operating point is found, the simulation moves to the next point in the driving cycle.

The image below (Figure 38) shows its model architecture.

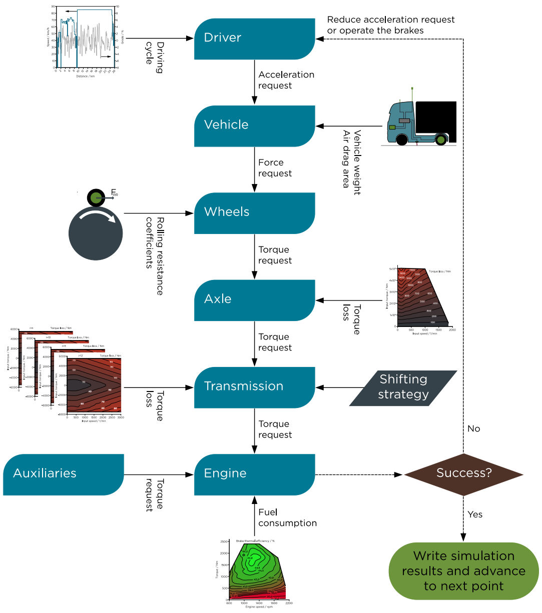

Figure 38. VECTO's model architecture [6]

2.2.3.4 Air Drag Certification

The other main difference between the US and the EU certification model is the way to determine the air drag value.

In EU, the air drag measurement method consists on a constant speed test. EU's air drag test procedure (see EU 2017/2400 Annex VIII) measures the torque at the wheel at a high and a low speed to determine the air drag area (CdA in m^2). The methodology requires the measurement of the torque at the wheel, the vehicle position, and the wind speed and angle as observed by the vehicle. Vehicles measured in the constant speed test according R(EU)2017/2400, shall fulfill the requirements on standard bodies and standard semi-trailer as described in Appendix 4 of Annex VIII of the regulation, where the bodies (Bx) and semi-trailers (STx) are stated with their own measurement requirements for each vehicle group.

In the US, the air drag measurement methods are described in 40 CFR 1037 – Subpart F. For tractors, the primary procedure for measuring the air drag is the coastdown test. An alternative method can be the constant speed test.
On the other hand, the primary procedure for measuring the air drag for trailers is the wind-tunnel test; however coastdown test and CFD test can be used as alternative.

Due to the fact that the purpose of this analysis is comparing the air drag measurement methods in EU and US, wind-tunnel test has not been taken as the primary procedure for trailers. Coastdown test have been considered instead, in order to be able to perform a proper comparison of the different methods.

The data measured in the coastdown test are the vehicle speed, the air speed and direction as observed by the vehicle. Furthermore, the road grade, wind speed and direction, ambient temperature, and atmospheric pressure as measured from a stationary weather station are also recorded.

The table below (Table 26) summarizes the main differences between the US and the EU methods.

Table 26. Comparison of key points between US and EU air drag tests [7]

Parameter	EU (constant speed test)	US (constant speed test) – only for tractors	US (coast-down test)
Torque meter	Hub, rim or half shaft torque meter	Hub or rim torque meter	None
Vehicle warm up	90 minutes at high-speed target speed before zeroing torque meters	At least 30 minutes at 80 km/h before zeroing torque meters	At least 30 minutes at 80 km/h
Low-speed test	Between 10 and 15 km/h	16 km/h ± 1,6 km/h	From 35 km/h to 12 km/h
High-speed test	Between 85 and 95 km/h	112 km/h ± 1,6 km/h	From 116 km/h to 93 km/h
Torque drift	Must not exceed 25 Nm	Must not exceed ± 1%	N/A
Anemometer calibration	Run test for anemometer calibration misalignment	No anemometer calibration for misalignment. Use of stationary weather station	No anemometer calibration for misalignment. Use of stationary weather station
Tire rolling resistance (RRC) influence	The RRC is assumed to be constant and the same at high and low speed	The post-processing takes into account the speed dependence of the RRC	The post-processing takes into account the speed dependence of the RRC
Spin axle losses	Torque measured at wheel, powertrain losses are irrelevant	Torque measured at wheel	The spin axle losses are estimated using a quadratic regression on the tire rotational speed.
CdA yaw angle correction	Correction to zero yaw based on generic formula	Correction to a yaw angle of 4.5° using CFD or wind tunnel testing	Correction to a yaw angle of 4.5° using CFD or wind tunnel testing
Cross wind correction	VECTO applies correction internally	GEM does not perform any further crosswind correction	GEM does not perform any further crosswind correction

According to US 40 CFR 1037, there are other alternative methods to measure the air drag CdA. All the methods available are listed below:

- §1037.528 – Coastdown test
- §1037.530 – Wind-tunnel test
- §1037.532 – Using computational fluid dynamics (CFD)
- §1037.534 – Constant-speed test (only for tractors, not for trailers)

2.2.3.5 Harmonization possibilities for HDV CO2/FE Certification

In this chapter, the overall conditions needed to harmonize the HVD CO2/FE Certification are reviewed.

In general, CO2 certification methodology requires certain regions specific adaptations like fleet segmentation, duty cycles, payloads or standard bodies.

VECTO and GEM are physic based models that does not require major specific adaptations to be used by other regions.

In particular, component testing procedures developed by the EU are applicable to other regions without modifications. Nowadays, the five certified component that are needed as an input for the simulation tool are: engine, transmission and driveline, aerodynamic drag, tire rolling resistance and vehicle characteristics.

<u>Tire rolling resistance measurement</u>
In the US, the tire rolling resistance is measured using the test procedure defined by the standard ISO 28580.

In the EU, the rolling resistance is measured according to UN/ECE R117. The provisions established in UN/ECE R117 are largely equivalent to those in ISO 28580.

The determination of the rolling resistance can be done by measuring the horizontal reaction force, the torque input at the drum, the tire-drum system deceleration, or the power input at the drum.

ISO 28580 / UN/ECE R117 include provisions for an inter-laboratory alignment procedure using a control tire, to allow direct comparison between different test rigs and methods.

<u>Engine</u>
The strategy followed by VECTO Engine and Gem cycle generation are a bit different.

The images below (Figure 39 and Figure 40) show the schema/strategy followed by the US and the EU.

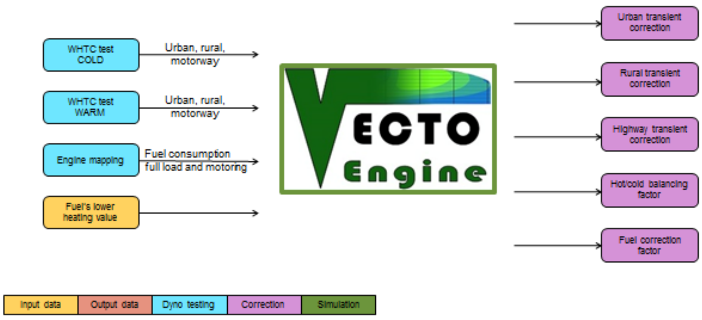

Figure 39. Engine transient correction procedure in the EU [6]

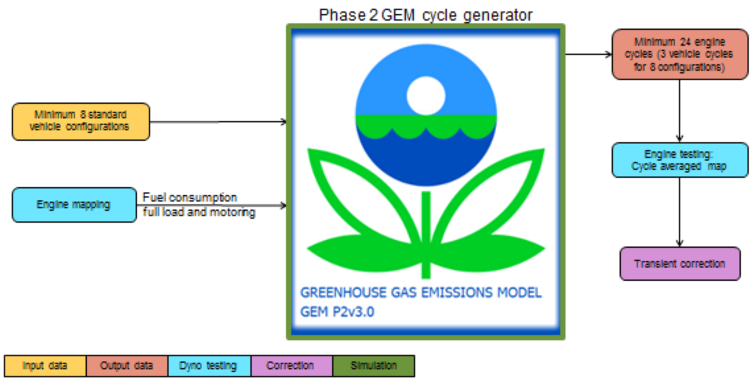

Figure 40. Engine transient correction procedure in the US [6]

Measurement of transmission and axle losses

In the EU, the measurement procedure of the torque losses of transmissions and axles is described in regulation EU 2017/2400, Annexes VI and VII.

For transmissions and other torque transferring components, three measurement options are possible, with increasing degrees of complexity.

In the US, the measurement of the power losses of transmission and axles is an optional procedure. Transmissions and axles shall be divided into transmission and axle families, which may include both driven and non-driven axles.

The measurement procedure of the power losses of transmissions and axles is described in §1037.565 and §1037.560 respectively.

In general, it can be seen that the US and EU component certification methodologies have several common points. In particular, axles, tires and engine mapping procedures are similar. Key differences include the aerodynamic drag determination.

There are many advantages to consider the harmonization of the component certification:

1. It facilitates transparent comparison of performance between different markets and brands

2. Facilitates the implementation of future regulatory measures

3. Facilitates adapting GEM/VECTO to country-specific needs

4. Streamlines processed and reduced cost of compliance for international manufacturers

2.2.4 Japanese FE Standard

2.2.4.1 Background

In Japan, CO2 emissions from automobiles account for 15% of total emissions in Japan, and these from heavy-duty vehicles account for 30% of automobiles. It is important to reduce CO2 from heavy-duty vehicles to achieve Japan's CO2 reduction target, which consists of a reduction of 25% by 2030 compared to 2013.

Japan already started to develop its standard for HDV in 2006, but in 2017 they started to develop a new standard as it can be seen in Table 27.

Table 27. Regulatory timeline in Japan [6]

Year	Action
2006	Development of a FE standard for HDV Target year: 2015 Objective: to improve FE by 12,2% from 2002 Test method: Simulation Combining JE05 mode (simulated urban area) and high-way mode
2010	Add the test method of Idle stop and AT
2012	Start to consider the new FE for further CO2 emission reduction
2017	Development of the new standards Target year: 2025 Strengthen regulation by 13,5% compared to 2015 standard Amendment of the test method: running resistance end engine map measurement method

2.2.4.2 Outline of Standard

Japanese standard for HD applies to vehicles using diesel fuel and exceeding 3.5 t (such as trucks, tractors and buses). The limit was set for each category according to the vehicle weight for each type. In Table 28 and Table 29 more detailed information is given.

Table 28. "2025 Limit Value" for trucks and tractors [6]

Category				2025 Limit Value [km / L]
Truck	T1	3.5t<GVW<=7.5t	PL<=1.5t	13.45
	T2		1.5t<PL<=2t	11.93
	T3		2t<PL<=3t	10.59
	T4		3t<PL	9.91
	T5	7.5t<GVW<=8t		8.39
	T6	8t<GVW<=10t		7.46
	T7	10t<GVW<=12t		7.44
	T8	12t<GVW<=14t		6.42
	T9	14t<GVW<=16t		5.89
	T10	16t<GVW<=20t		4.88
	T11	20t<GVW<=25t		4.42
Tractor	TT1	GVW<=20t		3.31
	TT2	20t<GVW		2.32

Table 29. "2025 Limit Value" for buses [6]

Category			2025 Limit Value [km / L]
Route Bus	BR1	3.5<GVW<=8t	7.15
	BR2	8t<GVW<=10t	6.30
	BR3	10t<GVW<=12t	5.80
	BR4	12t<GVW<=14t	5.27
	BR5	14t<GVW	4.52
Tour Bus	B1	3.5t<GVW<=6t	9.54
	B2	6t<GVW<=8t	7.73
	B3	8t<GVW<=10t	6.37
	B4	10t<GVW<=12t	6.06
	B5	12t<GVW<=14t	5.29
	B6	14t<GVW<=16t	5.28
	B7	16t<GVW	5.14

The 2025 fuel efficiency limit for trucks is 7.63 km/L on average for the all categories. This standard is strengthened by 13.4% compared to 2015 standard.

The 2025 fuel efficiency limit for buses is 6.52 km/L on average for the all category. This standard is strengthened by 14.3% compared to 2015 standard.

2.2.4.3 Test Method

In HDV, there are many kinds of power train depending on difference of engine power, transmission and differential. There are also many types of body depending on difference of wheelbase and tire size, which are covered in this regulation.

In the trucks which account for about 90% of the number of heavy duty vehicles, these are shipped mainly in semi-finished state, and the rear body is selected by the user to be a completed vehicle.

Therefore, it is difficult to measure with real vehicles which have many patterns. Thus, the Japanese approach to calculate fuel efficiency has been using simulation since 2006 (see Figure 41 and Table 30 for more test details).

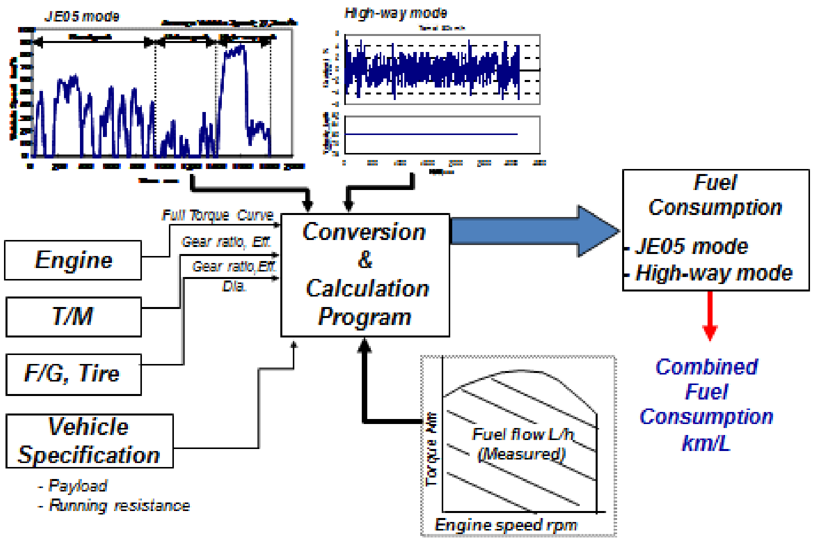

Figure 41. Outline of test method [6]

Table 30. Input data for the simulation [6]

Item	Amendment from 2025 standard
Aero drag	Introduction of aerodynamic resistance coefficient of individual car
Tire rolling resistance	Reflecting tire rolling resistance coefficient
Shift Logic	Update shift point
Rotational inertial mass	Equivalent rotating mass inertial mass review
Standard vehicle specifications	Update the standard vehicle specifications
Transient compensation	Introduction of transient compensation coefficient
Fuel consumption map measurement	Increase measuring point
Weighting factor (High-way ratio and Payload ratio)	Update high-way ratio and payload ratio

Aero drag measurement method

The Cd coefficient to determine the air drag can be measured by constant speed test (CST) or coast down with correction using wind flow meter. The CST of Japan is more similar to the method used in EU (with VECTO) than the coast down used in the US.

Tire rolling resistance measurement method

The tire rolling resistance is measured under the standard ISO28580. Regarding the test tire selection method, tires are selected based on market share, to simplify the selection process in view of the many tire supplies, tire models and tire sizes in the market.

Engine mapping

Steady state engine map (see Figure 42): number of points, measuring order, and measuring process like sweep time and measuring time, etc.

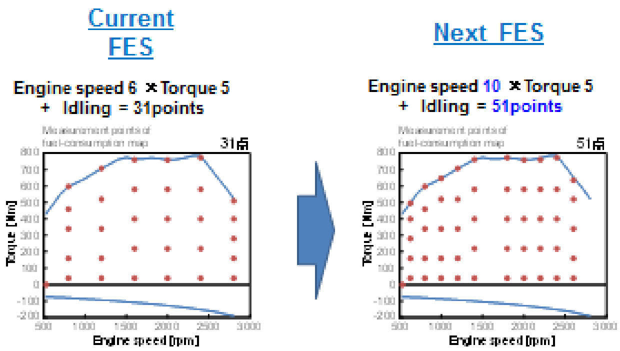

Figure 42. Engine mapping [6]

2.2.5 China FE Regulation

2.2.5.1 Background

In China, a Medium- and Long-Term Development Plan was set in 2017. In this plan, two objectives were set (see Figure 43):

- First step: the average fuel consumption for new passenger cars (PCs) needs to reach the target of 5.0L/100km, commercial vehicles (CVs) approach the international advanced level by 2020.

- Second step: the average fuel consumption for new PCs need to reach the target of 4.0L/100km, CVs reach the international advanced level by 2020.

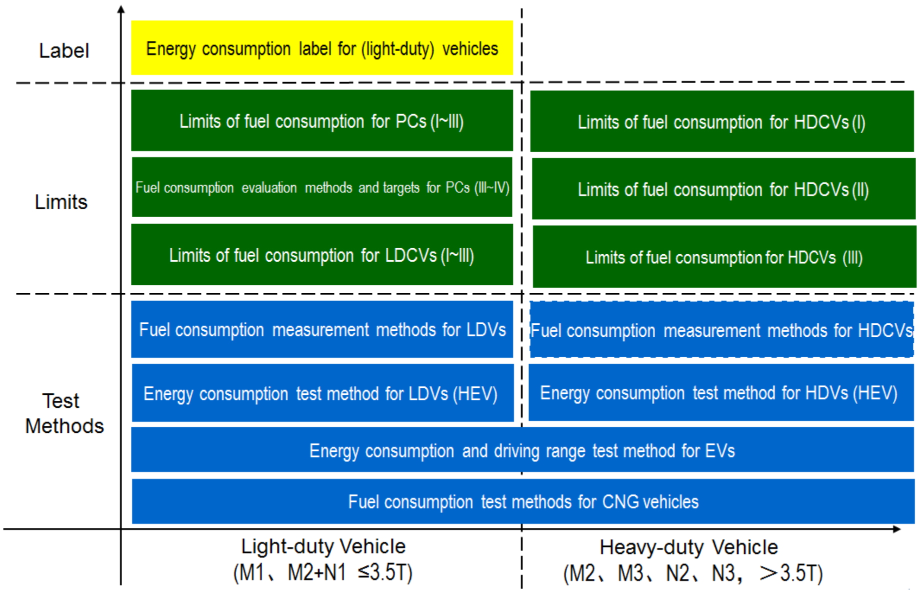

Figure 43. Overall standard system [6]

Regarding bodies and trailers, they are not covered in the Chinese regulation so far.

2.2.6 Timeline for Fuel Consumption (FE) standards for HDVs

The image below (Table 31) shows the timelines of the FE standards for HVDs in China.

Table 31. Timelines of FE Standards implementation in China [6]

Year	Action
2011	Test method, establishing issued
2011	Fuel Consumption limits (1st stage), establishing issued
2014	Fuel Consumption limits (2nd stage), establishing issued
2018	Fuel Consumption limits (3rd stage), establishing issued

The first stage of the standards applies to trucks, buses, semi-trailer tractor and special transport vehicles. While the second stage of the standards applies to all of them plus city bus and dumper. Other vehicles like special work vehicles would be out of the scope at this first and second stage.

According to their strategy, fuel consumption of basic types and HEVs is tested according to chassis dyno testing. For variant types, fuel consumption is calculated. Based on the engine data, fuel consumption is calculated by inputting resistance and other parameters. Figure 44 shows the strategy followed to determine the value of the fuel consumption for basic and variant types. In Table 32 the Basic Types and the Variant types are shown.

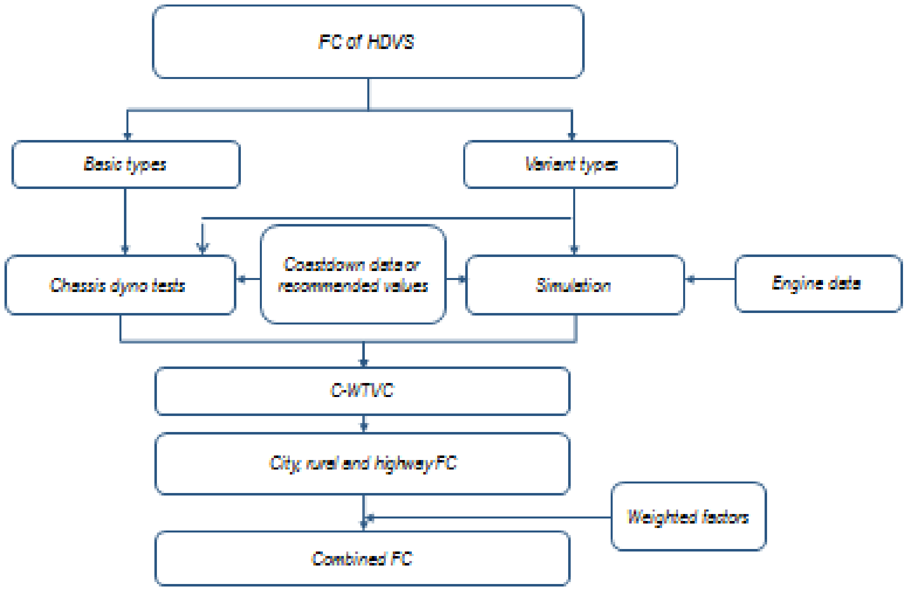

Figure 44. Strategy for fuel consumption determination value [4]

Table 32. Vehicle Types (Basic types) and its Variant types table

Vehicle type	GVW/GCW	City	Rural	Motorway
Semi-trailer tractor	9t-25t	0	40%	60%
	27t above	0	10%	90%
Dumper	3.5t above	0	100%	0
Truck	3.5-5.5t	40%	40%	20%
	5.5-12.5t	10%	60%	30%
	12.5-25t	10%	40%	50%
	25 above	10%	30%	60%
Bus	3.5-5.5t	50%	25%	25%
	5.5-12.5t	20%	30%	50%
	12.5above	10%	20%	70%
City bus	3.5t above	100%	0	0

In February 2018, the Standardization Administration of China (SAC) issued the GB 30510-2018 *Fuel consumption limits for heavy-duty commercial vehicles* (Phase 3).

This standard sets the energy-saving target for 2020. China proposes that fuel consumption of HDVs will approach the international advanced level by 2020.

The evaluation system is consistent with the Phase 2 limits: the L/100km is taken as the evaluation unit, the fuel consumption limits are determined by different groups based on the GVW (see Table 33).

In case of trucks, the limits decline 11.5~15.4% to the phase 2 limits. A percentage of 5.0~16.8% (avg. 9.5%) of current vehicle types can meet the limits.

Table 33. Example of China Standards of Phase 3 limits [6]

Truck	Phase 2	Phase 3	Variation
3 500＜GVW≤4 500	13.0	11.5 [a]	-11.5%
4 500＜GVW≤5 500	14.0	12.2 [a]	-12.9%
5 500＜GVW≤7 000	16.0	13.8 [a]	-13.8%
7 000＜GVW≤8 500	19.0	16.3 [a]	-14.2%
8 500＜GVW≤10 500	21.5	18.3 [a]	-14.9%
10 500＜GVW≤12 500	25.0	21.3 [a]	-14.8%
12 500＜GVW≤16 000	28.0	24.0	-14.3%
16 000＜GVW≤20 000	31.5	27.0	-14.3%
20 000＜GVW≤25 000	37.5	32.5	-13.3%
25 000＜GVW≤31 000	43.0	37.5	-12.8%
31 000＜GVW	45.5	38.5	-15.4%
a: For gasoline vehicles, the limit is the corresponding limit in the table multiplied by 1.2, and the value obtained is rounded to one decimal place.			

2.2.6.1 Future Work

Currently, the driving cycle is inconsistent with the characteristics of the actual driving condition in China and the differences will become larger and larger. Furthermore, current regulations can't accurately evaluate new technology, such like technologies for new energy vehicle.

Table 34 shows the plan of China regulatory implementation.

Table 34. China Regulatory forecast [4]

Year	Action
2019-2021	Phase 3 limits implements
2020-2021	New method issues
202X	- New method implements for new vehicle types - New method implements for all vehicle types - Phase 4 limits establish based on new method
2025	Phase 4 limits implements

2.2.7 Korean HDV CO2 Regulation

2.2.7.1 Regulatory timeline

In Korea, the rulemaking process regarding HDV emissions started in 2016 with the development of the simulation model. A draft version of the regulation is expected to be ready in 2020, for its implementation in 2021 (see Table 35).

Regarding bodies and trailers, they are not going to be covered at this first stage.

Table 35. Regulatory timeline for Korea [6]

Year	Action
2016	Start of the simulation model development First distribution of the simulation model to manufacturer
2017	Second distribution of the simulation model to manufacturer
2019	Start of the HDV CO2 emission monitoring Input data submission (OEMs) Accurate calculation of CO2 emission from HDVs
2020	Star of the legislation process: creation of a draft regulation in order to set CO2 reduction target, super credit, eco innovation technology, draft regulation
2021-20XX	Start of the CO2 emission Regulation from HDVS

2.2.7.2 Model structure

The Korean simulation model is known as HES - Heavy-duty vehicle Emission Simulation (see Figure 45).

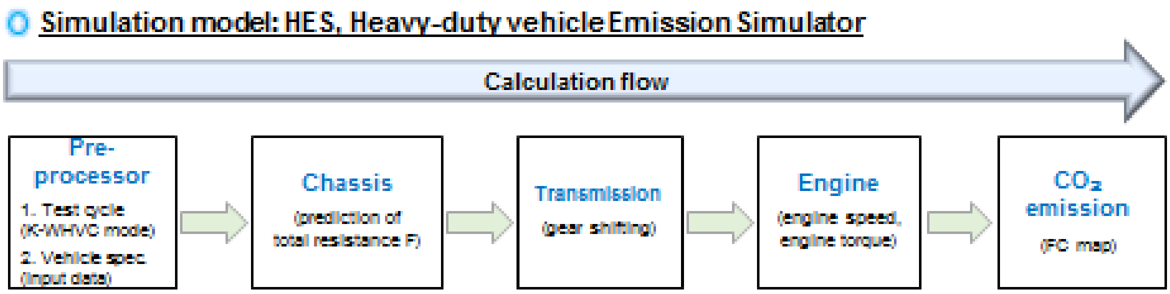

Figure 45. Basic model structure [6]

The simulation model in composed by 5 elements:

1. Pre-processor module: reading input data (vehicle specifications and velocity profile)
2. Chassis module: calculating total resistance force acting on vehicle
3. Transmission module: predicting gear position at each time step based on engine operating condition
4. Engine module: determining engine torque & speed at each time step
5. CO_2 emission module: predicting CO_2 emission based on fuel map & CO_2 emission factor of fuel

The calculation program is set as “backward type” from wheel to engine.

2.2.7.3 Future work

The roadmap is described below:

- 2019: HDV CO_2 emission monitoring
    - Vehicle data submission (OEMs)
    - Accurate calculation of CO_2 emission from HDVs
- 2020: Legislation process
    - Public hearing about CO_2 emission regulation
    - Determination of CO_2 reduction rate
- 2021: Start of CO_2 emission regulation from HDVs

2.3 HD FE Harmonisation

2.3.1 Introduction

There are several aspects of HDV that must be considered. Categories N2, N3, M2, M3 include wide variety of size and weight of vehicle. There is a lot of variation for same vehicle weight like wheel base, number of axis, different tire size, etc. Also, the usage of the vehicle is quite different depending on the kind of vehicle.

Furthermore, there are many applications of the vehicle in the market like cargo, garbage truck, etc. In addition, almost all vehicles are shipped out without body from vehicle manufactures; therefore, there is difficulty for the measurement using real vehicle.

In Table 36 the main differences between regions when talking about regulation are analysed.

Table 36. Elements of a Fuel Efficiency regulation including measurement method [6]

Elements	Sub-Elements	Issues	Examples
FE Unit	-	Transport efficiency or easily understand able unit	- km/L (Japan) - ton.km/L (EU) - L/100 km (China) - gal/100 bhp-hr or gal/1000ton-mile (US) - CO2 (g/bhp-hr) or g CO2/ton-mile (US)
Others	Criteria	Limit of FE value or average value	- Averaged by number of sales (CAFE)
Vehicle classification	-	Simpler category is desired, but needs to reflect to real world complexity	- Vehicle type (Tractor, bus….etc) - GVW, type of cabin
Items of FE effect	-	Accuracy vs. cost of measurement Contribution for FE	- Engine, T/M - Aero dynamic and rolling resistance
Driving Mode	-	Vehicle speed base or road data base Less complexity vs real world reflection	- Combination of two cycles - Unique mode for each vehicle type
Measurement Method	Chassis dynamometer	Chassis dynamometer measurement requires real vehicle	
	Simulation	Driver model is required for simulation	- Common calculation logic - Difference of steady and transient
	Engine measurement	Number of measurement points Transient operation effect	- CO2 measurement by engine - Engine FE map and simulation
	Aero dynamic measurement	Measurement methods Selection of vehicle type, rear body	- Coast down, steady speed drive - CFD - Wind tunnel
	Tyre rolling resistance	Measurement method, labeling	- Common tyre measurement method - How to handle a number of axis
	Others	Measurement method	- Driveline drag, Auxiliary drag, etc

2.3.2 Categorisation

As it has been mentioned before in this report, it is difficult to define a categorisation of the different vehicles. A huge range of variants, together with the fact that, in most cases, the base vehicle is built without body leads to a different categorisation in each region.

Also, the existing regulatory framework in each region defines the vehicle categories in a different way, which is also a burden for harmonisation (see Table 37).

Table 37. Vehicle categorization [6]

Elements	US	EU	Japan	China
Vehicle Type	Vocational Tractor	Rigid Tractor	Truck Tractor City bus General bus	Truck Dumper City bus Coach
Vehicle Weight	Based on Vehicle weight Classification 2b - 8	Based on GVW > 7.5 ton	Based on GVW> 3500kg	Based on GVW> 3500kg
Others	Cab type Roof type	Number of axles and axle configuration		

2.3.3 Method of FE Evaluation

Even if there are similarities between the different approaches, each region has developed their own method for the FE and CO2 emissions evaluation as it can be seen in Table 38.

Table 38. Method of FE Evaluation [6]

Elements	US	EU	Japan	China	India
Simulation with engine FE map	✔	✔	✔	✔	
Real vehicle measurement with chassis dyno.				✔	
Real vehicle measurement In test course				✔	✔
Powertrain measurement	✔				

2.3.4 Key Elements of FE Measurement

2.3.4.1 Driving Cycle

Driving cycle defines the driving conditions to evaluate the fuel consumption. Two types of driving cycle are adopted (see Table 39):

A: Time and vehicle speed

B: Distance and target speed

Table 39. Driving cycle [6]

Item	Status of each region				Remarks
	EU	US Phase Ⅱ	China	Japan FES 2025	
Type	B Distance and target speed	A Time and speed	A Time and speed	A Time and speed	B Requires more realistic driver model
Number of cycle types	10	4	3	2	Although there are few types of cycles other than EU, weighting factor is changed for each vehicle category.
Details of cycle	Trucks:5 City Bus:3 Bus:2	• ARB tangents • 55 mph • 65 mph • Idle Above four kinds of weighting factor depending on the category of the vehicle.	C-WHVC • Urban • Suburban • Highway Above three kinds of weighting factor depending on the category of the vehicle.	JE05 Intercity (80km/h) Above two kinds of weighting factor depending on the category of the vehicle.	

2.3.4.2 Simulation

Simulation is introduced to evaluate HDV with fuel efficiency. Mathematical method of simulation seems similar for each software. Input data differs because of the difference of concept or FE items as it can be seen in Table 40.

Table 40. Comparison of the simulation method [6]

Classification	Item	EU	US Phase Ⅱ	China	Japan FES 2025	Remarks
		Status of each region				
Vehicle Parameters	Vehicle Category	✔	✔	✔	✔	
	Curb Weight	✔	✔	✔	✔	
	Gross Vehicle Weight	✔	✔	✔	✔	
	Maximum Payload	✔	✔	✔	✔	
	Gross Combination Weight	✔	✔	✔	✔	
	Rated Passenger Capacity	✔	✔	✔	✔	
	Axle Configuration	✔	—	✔	—	
	Axle Number	✔	—	✔	—	
	Aero drag (Cd)	✔	✔	✔	✔	
	Auxiliary	(✔) *	—	—	—	* By spec. of technology
Engine Parameters	Engine Fuel Map	✔	✔	✔	✔	
	Full Load Engine Torque	✔	✔	✔	✔	
	Motored Engine Torque	✔	✔	✔	✔	
	Idling Speed	✔	✔	✔	✔	
	Rated Engine Speed	✔	✔	✔	✔	
	Maximum Engine Speed	✔	✔	✔	—	
	Transient Engine Map	—	✔	—	—	
Drive train	Transmission type	✔	✔	—	✔	MT, AT, AMT
	Number of gear	✔	✔	✔	✔	
	Transmission gear ratio	✔	✔	✔	✔	
	Transmission drag	✔	✔	—	✔	
	Final reduction gear ratio	✔	✔	✔	✔	
	Drive axle drag	✔	✔	—	✔	
Tire	Rolling radius	✔	✔	✔	✔	
	Rolling resistance	✔	✔	✔	✔	

FE map measured by steady state operation is commonly used to take account engine performance (see Table 41). However, US Phase II introduced new method called "Cycle averaging map".

Table 41. Engine measurement [6]

Item	Status of each region EU	US Phase II	China	Japan FES 2025	Remarks
Steady state Engine Map	100 points	70 points for 55,65 mph	81 points	51 points	Difference in concept
Transient Engine Map	NA	Cycle averaging map	NA	NA	
Transient coefficient	WHTC correction factor tool	Include Cycle averaging map	NA	Table value 3%	

2.3.4.3 Driving Resistance

There are two types of methods for measuring Air Drag, "Coast down test" and "Constant speed test". One of these or both is adopted in each area. Tire RRC measurement uses ISO 28580 which is a tire bench test method common to each region (see Table 42).

Table 42. Driving resistance measurement [6]

Item	Sub-item	Status of each region EU	US Phase II	China	Japan FES 2025	Remarks
Aero Drag	Aero Drag measurement	Constant speed Calculation	Coast down Wind tunnel CFD	Table value (Opt. Wind tunnel or coast down)	Coast down Constant speed	
Tire RRC	Resistance measurement	(EC) 1222/2009 = ISO28580	ISO28580	Table value	ISO28580	Method of measuring tire RRC is common in individual areas in the unit test by ISO method.
	Resistance select Method	Direct input of tire RRC for each vehicle	Direct input of tire RRC for each vehicle	-	Averaging RRC to be used	

In Table 43 a summary of FE elements in each region can be observed.

Table 43. Summary of the FE elements in each region [6]

Item		Sub-item	EU	US Phase Ⅱ	China	Japan (Next FES)
			Status of each region			
Categorize			Axles, Configurations, Weight	Weight Cab type	Vehicle type Weight	Vehicle type Weight
FE Unit			CO_2 g/ton-km g/passenger-km	gal/1000ton-mile CO_2 g/ton-mile	L/100km	km/L
FE Criteria			Consider after labeling	Becomes strict every 3 years	Becoming strict in 2019	FES value around 2025 is decided this year
Mode			10type	ARB tangents 55,65 mph	C-WHVC	JE05, Inter city
Measurement method	**Engine**	Steady state Engine Map	100 points	70points for 55,65 mph	81 points	51 points
		Transient Engine Map	NA	Cycle average map	NA (Include chassis dyno)	NA
		Transient coefficient	WHTC correction factor tool	Include Cycle average map	NA (Include chassis dyno)	Table value 3%
	Powertrain	FE map with powertrain	For Hybrid, AT, AMT by simulation	For Hybrid, AT, AMT by powertrain test	NA	For Hybrid and AMT by simulation
	Gear	T/M efficiency	Table value or Measurement	Table value or Measurement	NA (Include chassis dyno)	Table value
		AT parts efficiency	Table value or Measurement	Include powertrain test method	NA (Include chassis dyno)	Table value or Measurement
		Axle efficiency	Table value or Measurement	Table value or Measurement	NA (Include chassis dyno)	Table value

	Aero Drag	Aero Drag measurement	Constant speed Simulation	Coast down Wind tunnel CFD	Table value (Opt. Wind tunnel or coast down)	Coast down or Constant speed
		Vehicle select method	Family Concept	?	?	Family Concept
	Tire	Resistance measurement	(EC) 1222/2009 = ISO28580	ISO28580	Table value	Ranking by ISO28580
		Resistance select Method	Direct input of tire RRC for each vehicle	Direct input of tire RRC for each vehicle	-	Averaging tire RRC to be used
	auxiliary parts		Generic or OEM-specific	?	NA	Only installed when measuring engine
Determine FE value	Simulation	Input data & Logic	Input data and driver model is different based on item above			
	Chassis dyno		NA	NA	Shall be a family-representative vehicle	NA

2.3.4.4 HD FE Regulatory Schedule in each area

As it has been seen in the previous chapters in this report, HD FE regulatory schedule differs in each area analysed. In Figure 46, all the important dates for each region can be observed.

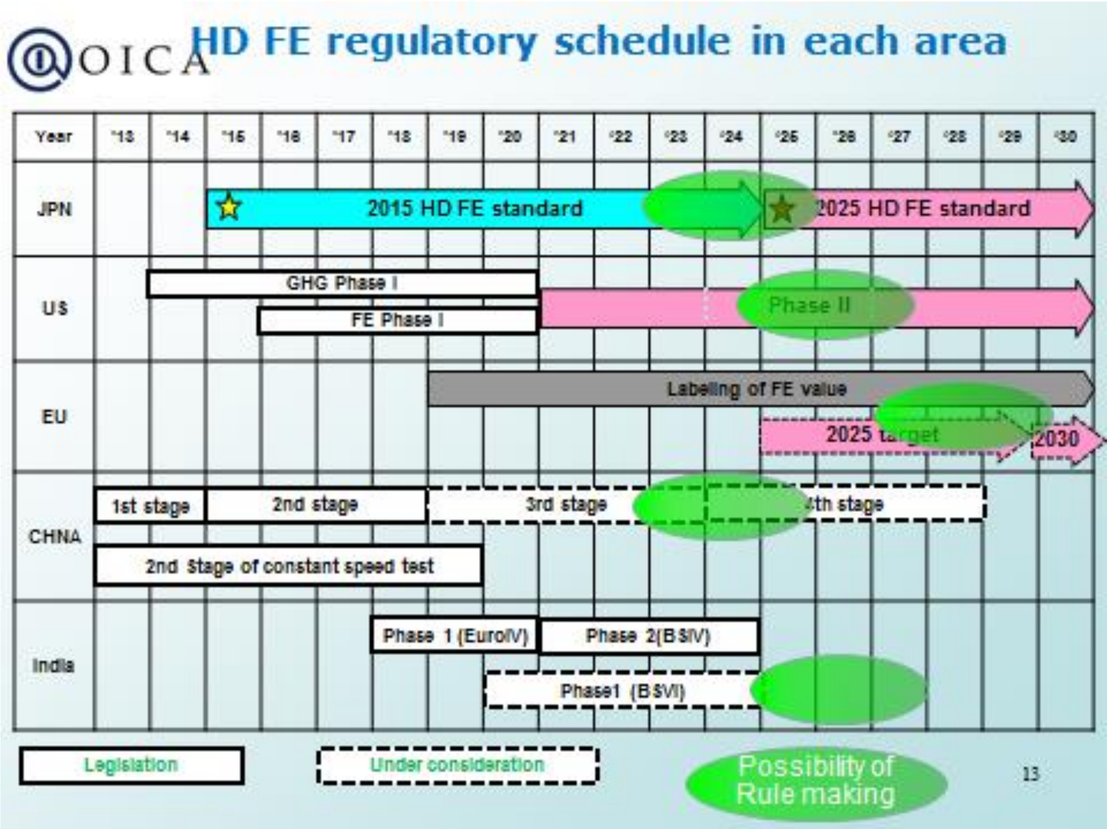

Figure 46. Rulemaking timeline for each region [6]

3 Summary and conclusions

In the following lines, some comments have been summarised considering the different countries analysed:

- Most new semi-trailers registrations (almost 2/3) are box-body types (curtainsider, dry box, reefer). For drawbar trailers and rigid trucks, box-body types represent only 1/3 of the market. Tippers and Container/Swap Body Chassis are the most registered non-box types.

- The total trailer fleet consists of around 2.5 million units. New registrations in 2017 were 240 0000. Semi-trailers represent 80% of new registrations.

- The semi-trailer market is dominated by 4 big companies, who account for 55% of the European market. Over the past decade, there has been a trend toward consolidation: the top 5 manufacturers had a combined market share of 27% in 2009. The drawbar trailer market is less consolidated. At least 100 companies are active in the market, most of which produce less than 1000 trailers per year.

- A limited data sample reveals that box body types are used more (in terms of annual mileage) than non-box types. Reefers appear to have the highest annual mileage, but also the shortest lifespan.

- Heavy Duty Vehicles (HDV) have a lot of variation and are frequently shipped without body.

- Due to this wide range of variants, FE regulation and measurement method have different feature from LD regulation, for example use of simulation.

- HD regulations in each area have different feature based on its policy or vehicle usage, but there are many common parts especially on measurement method.

- It seems that FE measurement method has less difficulty to harmonize.

- OICA/GEPE recommends starting from the harmonization of measurement method as first step.

- Several Stakeholders see (significant) benefits on analysing what level of harmonization could be achieved globally on Fuel Efficiency regulation.

- Categorization of heavy-duty vehicles in each region may prove to be challenging to harmonize, also fuel efficiency cycles and simulation approaches.

- If contracting parties would agree to proceed with harmonization, existing methodologies and regulations should be analysed and studied thoroughly and should be used as a basis to define global approach.

- Deviations where necessary to accommodate the regional conditions or technical differences or in the interests of improving currently set methodologies must be considered. Any such developments should be guided by robust technical analysis

- Implementing a harmonised approach could help countries/ regions interested in introducing FE legislation for HDV.

- Industry suggests a two-step approach to have an effective effort that would allow to start harmonisation efforts, these efforts should begin as soon as possible.

- Contracting Parties should consider, in order to make the different regulatory approaches comparable, whether efforts should begin with the harmonisation for system/component measurement methodologies and/or simulation approach for the whole vehicle.

Improvements in the different methodologies shall be considered in order to take into account new technologies, especially with regards to those regulations based in simulation methods.

4 Bibliography

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[10] F. Rodríguez, Fuel consumption simulation of HDVs in the EU: Comparisons and limitations. Internal Council on Clean Transportation, ICCT, 2018.

Regulation	**Link**
UN Regulation No. 83	https://www.unece.org/trans/main/wp29/wp29regs81-100.html
UN Regulation No. 49	https://www.unece.org/trans/main/wp29/wp29regs41-60.html
UN Regulation No. 96	https://www.unece.org/trans/main/wp29/wp29regs81-100.html
UN Regulation No. 101	https://www.unece.org/trans/main/wp29/wp29regs101-120.html
Regulation (EC) No 715/2007	http://data.europa.eu/eli/reg/2007/715/oj
Regulation (EC) No 595/2009	http://data.europa.eu/eli/reg/2009/595/oj
Commission Regulation (EU) 2017/2400	https://eur-lex.europa.eu/eli/reg/2017/2400/oj
Proposal for Regulation 2018/0143 (COM)	https://eur-lex.europa.eu/procedure/EN/2018_143

Annex 1 Information from CLEAR International database

Disclaimer: *For reasons of confidentiality, the information included in Annex 1 has been removed from this report.*

Annex 2 Survey

This section includes the contents of the survey that was held among trailer manufacturers in April 2019, with the support of CLCCR.

The data will be used as a supporting source to assess the contribution of different body types to the CO2 emissions of the road freight transport sector. The individual data will not be shared with third parties. Aggregated data could be included in a public report to be delivered to the European Commission. The information we collect is used expressly to provide the services requested and is not shared with other organisations for commercial purposes. The data will be stored in our database until 1 year after the end of the project. The current prospective end date of the project is 15/11/2019. A note on privacy - The data collected about you during this study will be anonymised before it is submitted for publication. - You are in control of the personal data you provide to us. You can contact us at all times to have your information changed or deleted. You can find our full Privacy Policy here.

Section A: General information

In this first section, we want to ask general questions with regard to your company.

A1. **What is the name of your company?**

A2. **What is the country of the head office?**

A3. **What is your name?**

A4. **What is your position at the company?**

A5. **What is your e-mail address?**

A6. **What is your phone number?**

A7. **What do you produce?**

Trailers and/or semi-trailers? ☐

Rigid truck bodies? ☐

A8. Do you collect information on the use of your products by your customers (annual and lifetime mileage, and estimated life expectancy) that you are willing to share?

Yes ☐

No ☐

A9. Do you offer other goods and/or services than this (e.g. manufacturing custom structures for sectors other than road freight transport)?

Yes ☐

No ☐

A10. How many people are employed at your company?

In the trailer and body building activities (including all branches: manufacturing, management, support, ... ☐☐☐☐☐☐☐☐☐☐

In total ☐☐☐☐☐☐☐☐☐☐

A11. What was your company turnover in euro in 2017?

0 - 1 mio euro ☐

1 - 10 mio euro ☐

10 - 100 mio euro ☐

100 - 1000 mio euro ☐

> 1000 mio euro ☐

Other ☐

Other

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

A12. What was your company operating profit in 2017?

Less than -5% ☐

Between -5% and -2% ☐

Between -2% and 0% ☐

Between 0% and 2% ☐

Between 2% and 5% ☐

More than 5% ☐

Other ☐

Other

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Section B: Portfolio and production volume (number of trailers produced)

In this section, we want to learn more about your portfolio and production volume (number of of trailers produced). Please indicate your production volume for the full year 2017. Here we ask information on semi-trailers, drawbar trailers, and centre-axle trailers, each time for mass classes O4 (> 10 tonnes) and O3 (between 3.5 and 10 tonnes).

B1. Please provide information on your semi-trailers, mass class O4 (> 10 tonnes).

Production volume:

- Box body: Curtain sider ☐
- Box body: Dry box ☐
- Box body: Reefer (conditioned / refrigerated) ☐
- Non-box body: Flat bed ☐
- Non-box body: Tanker ☐
- Non-box body: Swap body / container carrier ☐
- Non-box body: Tipper ☐
- Non-box body: Vehicle transporter ☐
- Non-box body: Drop side ☐
- Non-box body: Low-floor trailer ☐
- Non-box body: Timber ☐
- Non-box body: Livestock carrier ☐
- Non-box body: Other ☐

Percentage with 2 axles:

- Box body: Curtain sider ☐
- Box body: Dry box ☐
- Box body: Reefer (conditioned / refrigerated) ☐
- Non-box body: Flat bed ☐
- Non-box body: Tanker ☐
- Non-box body: Swap body / container carrier ☐
- Non-box body: Tipper ☐
- Non-box body: Vehicle transporter ☐
- Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 3 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 4 or more axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

B2. Please provide information on your semi-trailers, mass class O3 (between 3.5 and 10 tonnes).

Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 2 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 3 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 4 or more axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

B3. Please provide information on your drawbar trailers, mass class O4 (> 10 tonnes).

Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 2 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 3 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 4 or more axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

B4. Please provide information on your drawbar trailers, mass class O3 (between 3.5 and 10 tonnes).
Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 2 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 3 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 4 or more axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

B5. Please provide information on your centre-axle trailers, mass class O4 (> 10 tonnes).

Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber

Non-box body: Livestock carrier

Non-box body: Other

Percentage with 2 axles:

Box body: Curtain sider

Box body: Dry box

Box body: Reefer (conditioned / refrigerated)

Non-box body: Flat bed

Non-box body: Tanker

Non-box body: Swap body / container carrier

Non-box body: Tipper

Non-box body: Vehicle transporter

Non-box body: Drop side

Non-box body: Low-floor trailer

Non-box body: Timber

Non-box body: Livestock carrier

Non-box body: Other

Percentage with 3 axles:

Box body: Curtain sider

Box body: Dry box

Box body: Reefer (conditioned / refrigerated)

Non-box body: Flat bed

Non-box body: Tanker

Non-box body: Swap body / container carrier

Non-box body: Tipper

Non-box body: Vehicle transporter

Non-box body: Drop side

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 4 or more axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

B6. Please provide information on your centre-axle trailers, mass class O3 (between 3.5 and 10 tonnes).

Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 2 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Percentage with 3 axles:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper

Non-box body: Vehicle transporter

Non-box body: Drop side

Non-box body: Low-floor trailer

Non-box body: Timber

Non-box body: Livestock carrier

Non-box body: Other

Percentage with 4 or more axles:

Box body: Curtain sider

Box body: Dry box

Box body: Reefer (conditioned / refrigerated)

Non-box body: Flat bed

Non-box body: Tanker

Non-box body: Swap body / container carrier

Non-box body: Tipper

Non-box body: Vehicle transporter

Non-box body: Drop side

Non-box body: Low-floor trailer

Non-box body: Timber

Non-box body: Livestock carrier

Non-box body: Other

Section C: Portfolio and production volume (number of rigid truck bodies produced)

In this section, we want to learn more about your portfolio and production volume (number of rigid truck bodies produced). Please indicate your production volume for the full year 2017. Here we ask information on rigid truck bodies, for mass classes N2 (between 3.5 and 12 tonnes) and N3 (> 12 tonnes).

C1. Please provide information on your rigid truck bodies, mass class N2 (between 3.5 and 12 tonnes).

Production volume:

Box body: Curtain sider

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

C2. Please provide information on your rigid truck bodies, mass class N3 (> 12 tonnes).

Production volume:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

C3. What percentage of your rigid trucks is sold in a package with a trailer?

☐☐☐☐☐☐☐☐☐

Section D: Annual and lifetime mileage for semi-trailers

In this section, we want to learn more about the annual and lifetime mileages of semi-trailers, as well as their estimated life expectancy.

D1.

Annual mileage:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Lifetime mileage:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Estimated life expectancy:

Box body: Curtain sider ☐

Box body: Dry box ☐

Box body: Reefer (conditioned / refrigerated) ☐

Non-box body: Flat bed ☐

Non-box body: Tanker ☐

Non-box body: Swap body / container carrier ☐

Non-box body: Tipper ☐

Non-box body: Vehicle transporter ☐

Non-box body: Drop side ☐

Non-box body: Low-floor trailer ☐

Non-box body: Timber ☐

Non-box body: Livestock carrier ☐

Non-box body: Other ☐

Section E: Tyres, 3D/CFD, extra information, and privacy.

E1. Which % of (semi) trailer customers request the fitting of:

Low rolling resistance tyres ☐

Super single tyres ☐

Annex 3 HDV CO2/FE certification – Vehicle scope and sub-groups

<u>USA, CANADA</u>

Vehicle scope GVWR > 3,85 tn

Type/Sub-groups Combination tractors

Trailers used in combination with those tractors

Heavy-duty pickup trucks and vans

Class 2b-8 Vocational vehicles

Table 44. Vehicle categorisation for USA and Canada

Class	**2b**		**3**		**4**		**5**		**6**		**7**		**8**
GVWR (lb.)	8501	10000	10001	14000	14001	16000	16001	19500	19501	26000	26001	33000	33000
GVWR (tn)	3,86	4,54	4,54	6,35	6,35	7,26	7,26	8,85	8,85	11,79	11,79	14,97	14,97

<u>CHINA</u>

Vehicle scope GVW > 3,5 tn

Table 45. Vehicle categorisation for China

Sub-groups

Type	**GVW (kg)**
Straight trucks	3501 - 4500
	4501 - 5500
	5501 - 7000
	7001 - 8500
	8501 - 10500
	10501 - 12500
	12501 - 16000
	16001 - 20000
	20001 - 25000
	25001 - 31000
	31000 <
Type	**GCW (kg)**
Tractor-trailers	≤ 18000
	18001 - 27000
	27001 - 35000
	35001 - 40000
	40001 - 43000
	43001 - 46000
	46001 - 49000
	49000 <
Type	**GVW (kg)**

Coaches	3501 - 4500
	4501 - 5500
	5501 - 7000
	7001 - 8500
	8501 - 10500
	10501 - 12500
	12501 - 14500
	14501 - 16500
	16501 - 18000
	18001 - 22000
	22001 - 25000
	25000 <
Type	**GVW (kg)**
Dump trucks	3501 - 4500
	4501 - 5500
	5501 - 7000
	7001 - 8500
	8501 - 10500
	10501 - 12500
	12501 - 16000
	16001 - 20000
	20001 - 25000
	25001 - 31000
	31000 <
Type	**GVW (kg)**
City buses	7001 - 8500
	8501 - 10500
	10501 - 12500
	12501 - 14500
	14501 - 16500
	16501 - 18000
	18001 - 22000
	22000 - 25000
	25000 <

JAPAN

Vehicle scope GVW > 3,5 tn

Table 46. Vehicle categorisation for Japan

Type/Category

<table>
<tr><th colspan="2">Heavy-Duty Transit Buses</th></tr>
<tr><th>Category</th><th>GVW (kg)</th></tr>
<tr><td>1</td><td>3501 - 8000</td></tr>
<tr><td>2</td><td>8001 - 10000</td></tr>
<tr><td>3</td><td>10001 - 12000</td></tr>
<tr><td>4</td><td>12001 - 14000</td></tr>
<tr><td>5</td><td>14000 <</td></tr>
<tr><th colspan="2">Heavy-Duty General (Non-Transit) Buses</th></tr>
<tr><th>Category</th><th>GVW (kg)</th></tr>
<tr><td>1</td><td>3501 - 6000</td></tr>
<tr><td>2</td><td>6001 - 8000</td></tr>
<tr><td>3</td><td>8001 - 10000</td></tr>
<tr><td>4</td><td>10001 - 12000</td></tr>
<tr><td>5</td><td>12001 - 14000</td></tr>
<tr><td>6</td><td>14001 - 16000</td></tr>
<tr><td>7</td><td>16000 <</td></tr>
<tr><th colspan="3">Heavy-Duty Trucks (excluding Tractors)</th></tr>
<tr><th>Category</th><th>GVW (kg)</th><th>Max. Load (kg)</th></tr>
<tr><td>1</td><td rowspan="4">3501 - 7500</td><td>≤ 1500</td></tr>
<tr><td>2</td><td>1501 - 2000</td></tr>
<tr><td>3</td><td>2001 - 3000</td></tr>
<tr><td>4</td><td>3000 <</td></tr>
<tr><td>5</td><td>7501 - 8000</td><td></td></tr>
<tr><td>6</td><td>8001 - 10000</td><td></td></tr>
<tr><td>7</td><td>10001 - 12000</td><td></td></tr>
<tr><td>8</td><td>12001 - 14000</td><td></td></tr>
<tr><td>9</td><td>14001 - 16000</td><td></td></tr>
<tr><td>10</td><td>16001 - 20000</td><td></td></tr>
<tr><td>11</td><td>20000 <</td><td></td></tr>
<tr><th colspan="2">Heavy-Duty Tractors</th></tr>
<tr><th>Category</th><th>GVW (kg)</th></tr>
<tr><td>1</td><td>≤ 20000</td></tr>
<tr><td>2</td><td>20000 <</td></tr>
</table>

EU

Vehicle scope Vehicle groups for vehicles of category N (N2 > 7500kg; N3)

Table 47. Vehicle categorisation for the EU

Sub-groups

Description of elements relevant to the classification in vehicle groups			Vehicle group	Allocation of mission profile and vehicle configuration						
Axle configuration	Chassis configuration	Technically permissible maximum laden mass (tons)		Long haul	Long haul (EMS)	Regional delivery	Regional delivery (EMS)	Urban delivery	Municipal utility	Construction
4 × 2	Rigid lorry	> 3,5 –7,5	(0)							
	Rigid lorry (or tractor) (**)	> 7,5 – 10	1			R		R		
	Rigid lorry (or tractor) (**)	> 10 – 12	2	R+T1		R		R		
	Rigid lorry (or tractor) (**)	> 12 – 16	3			R		R		
	Rigid lorry	> 16	4	R+T2		R		R	R	
	Tractor	> 16	5	T+ST	T+ST+T2	T+ST	T+ST+T2	T+ST		
	Rigid lorry	> 16	4v (***)						R	R
	Tractor	> 16	5v (***)	T+ST						
4 × 4	Rigid lorry	> 7,5 – 16	(6)							
	Rigid lorry	> 16	(7)							
	Tractor	> 16	(8)							
6 × 2	Rigid lorry	all weights	9	R+T2	R+D+ST	R	R+D+ST		R	
	Tractor	all weights	10	T+ST	T+ST+T2	T+ST	T+ST+T2			
	Rigid lorry	all weights	9v (***)						R	R
	Tractor	all weights	10v (***)							T+ST
6 × 4	Rigid lorry	all weights	11	R+T2	R+D+ST	R	R+D+ST		R	R
	Tractor	all weights	12	T+ST	T+ST+T2	T+ST	T+ST+T2			T+ST
6 × 6	Rigid lorry	all weights	(13)							
	Tractor	all weights	(14)							
8 × 2	Rigid lorry	all weights	(15)							
8 × 4	Rigid lorry	all weights	16							R
8 × 6 / 8 × 8	Rigid lorry	all weights	(17)							

(*) EMS — European Modular System

(**) In these vehicle classes tractors are treated as rigid lorries but with specific curb weight of tractor

(***) Sub-group 'v' of vehicle groups 4, 5, 9 and 10: these mission profiles are exclusively applicable to vocational vehicles

T = Tractor

R = Rigid lorry & standard body

T1, T2 = Standard trailers

ST = Standard semitrailer

D = Standard dolly

Bodies and trailers – development of CO2 emissions determination procedure

Procedure no:

CLIMA/C.4/SER/OC/2018/0005

Task 2. Identification and evaluation of the possible methodology options

Task leader: Stefan Hausberger

Date: 18/03/2019

This document contains 78 pages

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Acronyms and abbreviations

Acronym	Meaning
A/C	Air conditioning
Avrg	Average
CFD	Computational Fluid Dynamics
CO_2	Carbon dioxide
CoP	Conformity of Production
CST	Constant Speed Test
Curb weight	total weight of a vehicle in driving condition but without loading and without driver
DES	Detached Eddy Simulation
ECU	Electronic control unit
EMS	European Modular System (trailer combinations for 60t TPMLM vehicles)
EU	European Union
η (Eta)	Efficiency, usually defined here as ratio from output work to input work of a component
FC	Fuel consumption
GEM	Greenhouse Gas Emissions Model, c/o USEPA
Gen.	Generic values used in VECTO (see table with definitions below)
GHG	Greenhouse gas
GUI	Graphical user interface
GVW	Gross vehicle weight…..curb weight plus payload and driver.
HDH	Heavy Duty Hybrid vehicle
HDV	Heavy-duty vehicle
HEV	Hybrid electrical vehicle
HVAC	Heating, Ventilation and Air Conditioning
LBM	Lattice Boltzmann Method
LES	Large Eddy Simulation
NA	North America
NS	Navier-Stokes
OEM	Original Equipment Manufacturer
RNG	Renormalization Group
RRC	Rolling resistance Coefficient
Std.	Standard values used in VECTO (see table with definitions below)
TPMLM	Total permissible maximum laden mass
TT	Tractor-semi-trailer combination
VECTO	Vehicle Energy Consumption calculation Tool
w/o	without

Definitions

Term	Definition
Chassis-cab	An incomplete vehicle with a cabin (complete or partial), chassis rails, power train, axles and tyres which is intended to be completed with bodywork, customised to the needs of the transport operator according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
CO_2-Factor	Ratio of two CO2-values as results from VECTO for vehicles with the the final body and equipment in the nominator and the results for the generic body and equipment in the denominator.
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]
HDE	Heavy Duty Engine with type approval according to Regulation (EC) 595/2009 and its amending Regulations”
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
RM	Reference Mass = mass in running order -75kg (driver) +100kg according to Reg. (EU) 715/20107
TPMLM	Technically permissible maximum laden mass
Van	A lorry with the compartment where the driver and cargo area is located within a single unit, according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
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)
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

Term	Definition
Heavy Lorry	N2 exceeding 7.4 tons maximum mass and N3 with engine type approval according to Regulation (EU) 595/2009
Light Bus	M1 and M2 not exceeding 5 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Medium Bus	M3 not exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009
Heavy Bus	M3 exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009
Definitions introduced for differentiation of steps in CO2 determination:	
Primary Lorry	Lorry with complete chassis, engine, transmission, axles, tyres and auxiliaries but with standard body or semi-trailer for declaration of the vehicles CO2-value
Complete(d) Lorry	Lorry with its final body and equipment for declaration of the CO2-Factor
Primary Van	A Primary lorry of the category van with generic data for body and equipment for declaration of the vehicles CO2-value.
Complete(d) Van	Van with its final body and equipment for declaration of the CO2-factor.
Primary Bus	“Bus chassis” with at least engine, transmission, axles and tyres but with generic data for the body for declaration of the vehicles CO-value.
Complete(d) Bus	Bus with its final body, interior and auxiliaries for declaration of the CO2-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.
Generic value	Input values for the CO_2 calculation tool for components where no component testing is foreseen (e.g. auxiliaries). Generic values reflect performance of average component technology.
Standard value	Input values for the CO_2 calculation tool in case that a component is not measured. Standard values reflect performance of worst case component plus a certain tolerance margin.
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 CO2 calculation tool

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Figures

Tables

1 Introduction

The report describes the activities within task 2 of the specific contract:

No 340201/2018/789725/SER/CLIMA.C.4
Bodies and trailers – development of CO2 emissions determination procedure

The report is analysing possibilities to determine the influence of specific bodies and trailers on the CO_2 emissions from rigid lorries and tractors using the functionalities of the calculation tool VECTO, which is also the basic software for Regulation (EU) 2017/2400.

The current regulation is valid for rigid lorries and tractors and defines test methods for components, the input data for the VECTO tool, the result files and the responsibilities in certification.

Following this principle, the report on task 2 analyses the input data needed and possible methods to determine this input values for semi-trailers and trailers as well as for bodies of lorries. With this input data the CO_2 emissions of the entire vehicle can be calculated with VECTO. In the case of tractor trailer combinations also a generic tractor has to be defined since the trailers and semi-trailers are not linked to specific makes and models of tractors.

The analysis was split in two main sub-tasks:

- Methods to create the input data for the simulation tool VECTO for bodies and trailers in an efficient way. The input data needed is air drag, mass and rolling resistance.
- Methods to handle the input data from the different companies involved in the multistage processes at rigid lorries for chassis-cab type HDVs and to produce CO2 results for trailers and for semi-trailers, which need to be linked to representative towing vehicle specifications.

2 Overview

To determine the fuel consumption and CO2-values of vehicles with VECTO, a set of input data is needed. The set and the formats are defined in Regulation (EU) 2017/2400 for heavy primary lorries. For all other vehicles, the same structure of input data can be used but the source for the input data will partially differ.

For primary lorries and tractors, all CO_2 relevant input data has to be produced by component tests within certification procedures. Only auxiliary technologies are not based on measurements of specific components but are standard values for different technology levels. For certification of the air drag values and for definition of the total vehicle mass, standard bodies and standard semi-trailers are used.

For complete(d) rigid lorries with their specific bodies the same calculation method should be used as for the primary lorries to ensure comparable results. Using the same structure also has the advantage, that no parallel method and software development and – more important – later on no parallel maintenance and update of different software is needed.

A limitation is the transfer of VECTO input data from 1st stage OEMs to 2nd or later stage manufacturers, which is needed if the complete(d) vehicle shall be simulated with all specific input data in a single simulation step. Since efficiency maps for engine, transmission and axles are confidential data, an exchange of this data between 1st and final stage manufacturer is not preferred. Main reason is, that OEMs often sell complete vehicles including bodies to fleet operators while selling the same vehicle as chassis-cab to 2nd stage manufacturers, who have the same fleet operators as customers. Thus, a data transfer from 1st to 2nd stage manufacturer or vice versa would disturb the competition since one of the two manufacturers then knows the fuel efficiency from the competitor.

Since CO_2-results for all rigid lorries should be based on the same methods independently if produced in single or in multistage processes, a different method was developed. This is the “CO2-factor” method described in chapter 4.3.1. In this method, the confidential data is not forwarded to the 2nd stage OEM but replaced by generic values representing average technologies.

Consequently, for the production of the CO_2 and fuel consumption values with VECTO for complete(d) rigid lorries, the results from the primary lorry and the values influenced by the specific body are needed, which are:

- Mass of the body or of the complete(d) vehicle
- Air drag of the complete(d) vehicle
- Auxiliaries which are mounted after the primary stage manufacturer

Possible methods to determine this input data are discussed in chapters 3.1 and 0.

For specific semi-trailers and trailers, no direct link to a specific tractor or rigid lorry is given, since any trailer can be carried by any HDV designed to tow such a trailer. Thus, the calculation of CO_2 and fuel consumption values for trailers and semi-trailers with VECTO needs the definition of standard tractor and standard rigid lorry properties as “reference vehicles”. These reference vehicles can be used to virtually tow the trailers in the VECTO simulation. Reference vehicles shall reflect typical vehicles in the corresponding vehicle group. Properties of the reference vehicles could be defined based on the monitoring data for the lorries with regular updates (e.g. average of two years monitoring, updated every three years). The reference vehicle data set can be used to directly simulate the specific trailers in VECTO, to calculate the ratio of CO2-emissions compared to the standard trailer or semi-trailer or to produce some look-up tables in a pre-processing step, as discussed in chapter 4.

Table 1 summarises the components, for which input data has to provided and where standard values should be used. Underlined text indicates that new methods have to be developed to produce this input data for bodies and trailers on basis of certification or similar procedures. The possible methods are discussed in the next chapters.

Table 1. Overview on components for which input data has to be provided and on data qualities needed for different vehicle categories

	Vehicle category		
Component	**Primary lorry**	**Complete(d) lorry**	**(Semi-)Trailer(2)**
Engine map	Spec.(1)	Gen.	Gen.
Engine full load curve and rated power	Spec.	Spec.	Gen.
Gear box loss map	Spec.	Gen.	Gen.
Transmission ratios	Spec.	Spec.	Gen.
Axle loss map	Spec.	Gen.	Gen.
Rolling resistance coefficients	Spec.	Spec.	Spec. for trailer Gen. for towing vehicle
Tire dimensions	Spec.	Spec.	Spec.
"Corrected actual mass" (defined w/o superstructure)	Spec.	-	-
Vehicle curb mass	-	Spec. (based on specific body)	Spec. for trailer Gen. for towing vehicle
Vehicle air drag (C_d*A)	Spec. with Std. body	Spec. (based on specific body)	Spec. for trailer with gen. towing vehicle
Auxiliaries	Technologies from chassis-cab	Technologies from chassis-cab	Gen. for tractor Spec. for trailer(3)

(1) "Spec." … specific data for the individual vehicle

(2) "Trailer" in this column shall cover all design types as identified relevant by the analysis from task 1, i.e. semi-trailers, centre axle trailers and possible also drawbar-trailers

(3) Specific trailer technologies may e.g. be hybrid axles for brake energy recuperation of cooling systems.

3 Methods to provide the VECTO input data

This chapter describes options to generate VECTO input data according to the current Regulation (EU) 2017/2400 as well as alternative methods suitable for bodies and trailers.

3.1 Methods for vehicle mass

A simple weighing of the entire vehicle without loading seems to be sufficient to produce the necessary VECTO input data. A differentiation of the weight into single components is not relevant for the VECTO results.

The vehicle mass for primary rigid lorries is defined in Annex III of Regulation (EU) 2017/2400 in paragraph 2:

"(4) 'corrected actual mass of the vehicle' shall mean the mass as specified under the 'actual mass of the vehicle' in accordance with Commission Regulation (EC) No 1230/2012 (1) with an exception for the tank(s) which shall be filled to at least 50 % of its or their capacity/ies, without superstructure and corrected by the additional weight of the non-installed standard equipment as specified in point 4.3 and the mass of a standard body, standard semi-trailer or standard trailer to simulate the complete vehicle or complete vehicle-(semi-)trailer combination. All parts that are mounted on and above the main frame are regarded as superstructure parts if they are only installed for facilitating a superstructure, independent of the necessary parts for in running order conditions."

The mass of the complete(d) rigid lorry thus would be the corrected actual mass of the primary lorry plus the mass of the specific body mounted. Definitions of the components counting to the weight of the specific body need to be discussed with ACEA and CLCCR and then fixed for a possible future regulation for bodies. E.g. refrigerating sets may or may not count, depending on the intentions of the regulation. For the customer information including all components of the complete(d) vehicle seems to be advantageous. For introduction of limit values for complete(d) vehicles this may cause unfair conditions for specialised bodies and/or a complex regulation with many sub-segments per vehicle group and/or artefacts, when e.g. all heavy components are mounted after vehicle certification as retrofit. As a minimum list, the accessories according to the actual definition in Annex VIII, Appendix 4 for the standard bodies and trailers can be used. Body and trailer families may be introduced to allow the use of a calculated weight difference to a measured parent body for smaller parts which are added on customer demand.

As alternative to weighting, a calculation of the weight based on part lists is an option. Nevertheless, the possibility of errors and the efforts seem to be higher for a calculation-based method for those manufacturers who do not have a detailed data base on the properties of all parts they use in the manufacturing process. Pros and cons of each option should be discussed with CLCCR and ACEA.

Independently of the method selected, the resulting weight should comply with the tolerance provisions. Annex Xa[1] of Regulation (EU) 2017/2400 defines the accuracy to verify the entire vehicle mass with +/- 50 kg or maximum 0,5 % of the maximum

[1] Annex Xa describes the Verification Test Procedure (VTP), which verifies if all input data used for VECTO is correct. In this context also the entire vehicle mass for tractors and rigid lorries is verified, which is done by weighting of the vehicle.

calibration of the balance, whichever is smaller. This definition seems to be sufficient for a certification of the entire vehicle weight as VECTO input data.

For trailers and semi-trailers, also a weighing of the entire vehicle is suggested. The accessories to be on board for weighting can also be defined according to the list for standard semi-trailers and trailers in Annex VIII, Appendix 4 of the current regulation. The questions if and which possibly existing additional components of specific trailers should be included have to be discussed as for the bodies mentioned before.

Recommendation:

The entire vehicle mass for rigid lorries and the mass of the trailers and semi-trailers could be certified by weighting on vehicle balances with accuracies according to Annex Xa of the current regulation. Accessories to be on board can be defined according to Annex VIII, Appendix 4, if results shall be comparable to the standard bodies and trailers. For customer information additional components, such as refrigerating sets, may also be considered in the total mass.

3.2 Methods for rolling resistance

For the primary rigid lorries and the primary tractors, the tyre rolling resistances are obtained from tyre drum tests. The same test method is used as for the tyre label values. The method is defined in Annex X of the current regulation:

"The tyre rolling resistance coefficient shall be the value measured and aligned in accordance with Regulation (EC) No 1222/2009, Annex I part A, expressed in N/kN and rounded to the first decimal place, according to ISO 80000-1 Appendix B, section B.3, rule B (example 1)."

Using this method also for trailers seems to be the most reasonable approach. It needs to be discussed with ETRMA if they see any issues in providing the rolling resistance coefficients (RRC) also for trailer manufacturers. If the numeric RRC values of the tyres are not available for trailers, the average RRC value of the label class (+ 0.3 N/kN as tolerance) of the tyres may be used as fall-back option.

For rigid lorries the tires shall be selected already by the manufacturer of the primary lorry (possibly selected according to the order of a 2nd stage manufacturer). The 2nd stage manufacturer should not be allowed to change tyres to avoid loopholes in the CO_2 limit regulation between primary and complete(d) vehicles.

Recommendation:

The tyre rolling resistance coefficients shall be defined according to Annex X of the existing regulation also for trailers. For rigid lorries the manufacturer of the primary vehicle shall be responsible for tyre selection.

3.3 Methods for Air Drag

For primary lorries the current regulation allows air drag measurements only with the so called "Constant Speed Test (CST)", which is defined in Annex VIII of Regulation (EU) 2017/2400. Since the CST seems to be a rather expensive method for smaller companies, alternatives are discussed also in this chapter.

3.3.1 Physical measurements

In the Constant Speed Test the primary rigid lorries are equipped with standard bodies and the tractors are equipped with standard semi-trailers. The standard semi-trailers and bodies are defined in Appendix 4 of Annex VIII of Regulation (EU) 2017/2400.

The vehicles are then driven on a flat test track at constant low speed followed by constant high speed and a low speed phase again. During the measurement the torque and rotating speed at the driven axle as well as the vehicle speed relative to the air and other parameters are recorded. From these test data, the air drag is computed from the difference in the forces measured at the wheels in high and low speed. For a high accuracy several corrections as e.g. for side wind are included in the evaluation routine.

The resulting air drag (C_d*A in [m²]) is representing the entire vehicle, i.e. the rigid lorry with the standard body or the tractor and semi-trailer combination. For the test a test track with sufficiently long straight and flat lanes has to be rented and various test equipment is needed. Especially the torque meter rims are a quite costly device, which will rather not be purchased by smaller manufacturers for a few tests per year. Thus, physical air drag tests for small volume manufacturers would rather be assigned to consultants, such as technical services.

Basically, the tests for specific bodies or semi-trailers could be made just with the specific body or trailer but this option seems not to be very promising since:

- For any type of trailer the air drag depends to a large extent also on the geometry of the towing vehicle (chapter 3.3.2), which is however not fixed for a given (semi-)trailer.
- For rigid lorries the C_d*A value of the combination of chassis-cab and specific body is a meaningful value but the reproducibility of the CST is rather not sufficient to provide reliable differences between different bodies with similar shape[2].
- If a body or a (semi-)trailer shall be used for different lorries or tractors, a C_d*A result is needed, which can be transferred to any lorry in the corresponding vehicle group. Such a family concept would reduce the number of tests needed.

Consequently, it is suggested to measure the difference in the air drag between the specific and the standard body or standard (semi-)trailer. To obtain the difference, the tests have to be performed both with the specific and with the standard body or standard (semi-)trailer. One may also use the certified C_d*A results from the primary vehicle

[2] The reproducibility is expected in a range of +/-5 to 7.5% unless either many repetitions are made or the ambient conditions (temperature, wind conditions) are defined even narrower than in Annex VIII of Regulation (EU) 2017/2400. Thus a body may get more than 10% different C_dxA values if tested at different boundary conditions by different personnel.

manufacturer of the specific lorry, but due to the aforementioned limited reproducibility, this may be too inaccurate to produce reliable numbers for the difference in air drag. The most robust method seems a measurement with both, the standard body or trailer and with the specific body or trailer using the same lorry at the same test track at the same ambient conditions ("double testing").

To elaborate data as basis for further discussion, if double testing is needed, task 4 of this project may use a tractor for which already certified air drag data with the standard semi-trailer is available and run tests with standard- and alternative semi-trailer configurations. Results with the standard trailer can then be compared with the certified value. Test on more than one tractor-trailer combination to validate the robustness would be necessary before such a procedure could be applied in a regulation.

Recommendation:

Tests with a tractor for which already certified C_d*A values are available are suggested with a standard semi-trailer and with an alternative semi-trailer to make a first analysis of the accuracy and robustness of possible physical test methods. Further physical tests for verification of the method are necessary before putting it into a regulation.

3.3.2 CFD Simulation

Computational Fluid Dynamics (CFD) is widely used within the automotive industry in different application areas such as aerodynamics, thermal management or passenger comfort, among others. In the truck industry in particular, CFD tools are used extensively when optimizing the aerodynamic performance of such large vehicles throughout the entire development phase (from early conceptual sketches to the final designs ready for production) by the vast majority of OEMs, like DAF Trucks [1] [2], DAIMLER Trucks North America [3] [4], FORD OTOSAN [5] [6], MAN Trucks [7], SCANIA [8] [9] [10] or VOLVO Trucks [11] [12] [13].

On top of that, current regulations already allow the use of CFD tools in order to demonstrate the selection of the parent vehicle within a family [14] to be tested by the constant speed procedure.

Such evidences make CFD methods, a priori, a good alternative to Constant Speed Test (CST) when determining aerodynamic resistance values (C_DxA). However, it must be noted that, after a literature research, no evidences that CFD being used by trailer and bodies manufacturers have been found.

3.3.2.1 Standardization of CFD settings

SAE document J2966 [15] provides general requirements in CFD to simulate aerodynamics of medium and heavy commercial vehicles such as minimum computational domain dimensions to avoid blockage effects, minimum cell count to properly capture relevant flow structures, prism layer resolution to properly resolve the boundary layer, turbulence intensity of the incoming flow or convergence criteria, for instance. These recommendations are valid for both Navier-Stokes (NS) and Lattice-Boltzmann (LBM) based solvers, which are the most common in this industry sector.

Following these recommendations, together with IDIADA own best practices and past experience on simulating the aerodynamics of heavy-duty vehicles, an extensive list of different configurations cases have been simulated in order to:

- analyse the effect of different tractor geometries over trailer aero improvements

- Evaluate the effect of side wind depending on the trailer aero enablers
- Understand the effect of trailer aero enablers (boat tails and side skirts) once mounted alone or in combination

The baseline geometry used at this stage of the project is the one created by FluiDyna GmbH [16] and provided by the research department FAT (*Forschungsvereinigung Automobiltechnik*) associated to the German Automotive Association (VDA) for the purpose of this report.

It is a generic truck geometry resulting from the combination of six European OEMs (Daimler, Iveco, MAN, Kögel, Krone and Schmitz-Cargobull) that keeps the main features of the source vehicles and, at the same time, makes this report OEM design independent.

The tractor geometry consists of a hybrid MAN / IVECO / DAIMLER cabin. See figures below:

Figure 1. Tractor geometries. Daimler (left), Iveco (centre) and MAN (right) [16]

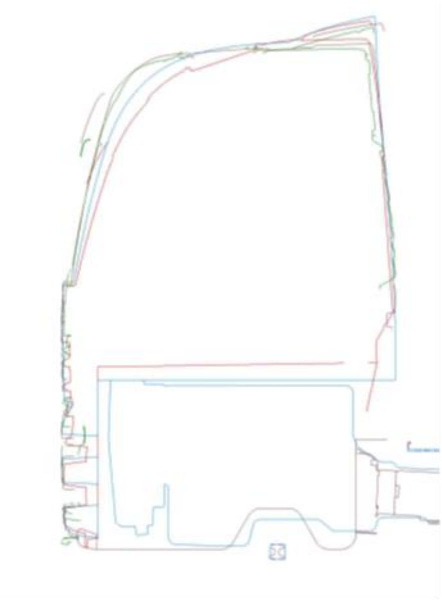


Figure 2. Symmetry plane cut. Hybrid (blue); Daimler (green); Iveco (red); MAN (brown) [16]

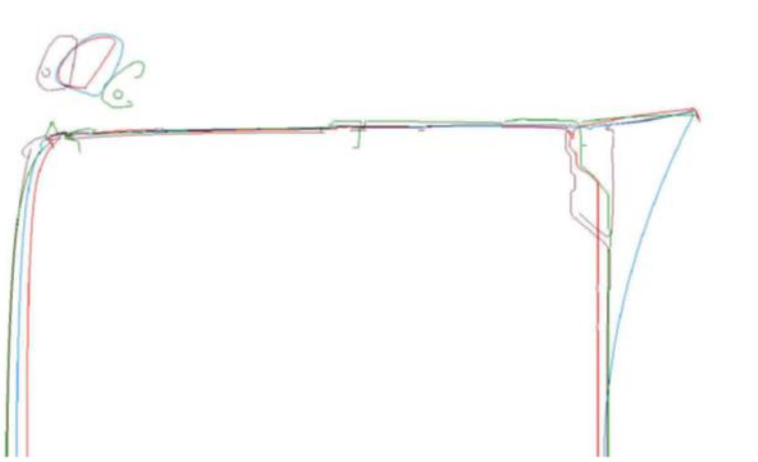


Figure 3. Cut in the Z-axis. Hybrid (blue); Daimler (green); Iveco (red); MAN (brown) [16]

Figure 4. Views of the resulting hybrid geometry [16]

The trailer geometry consists of a hybrid KÖGEL / KRONE / SCHMITZ standard 3-axle semitrailer without steering axle(s). See figures below:

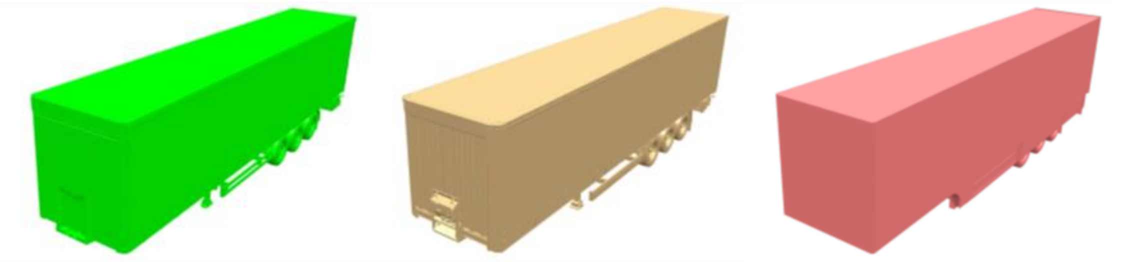
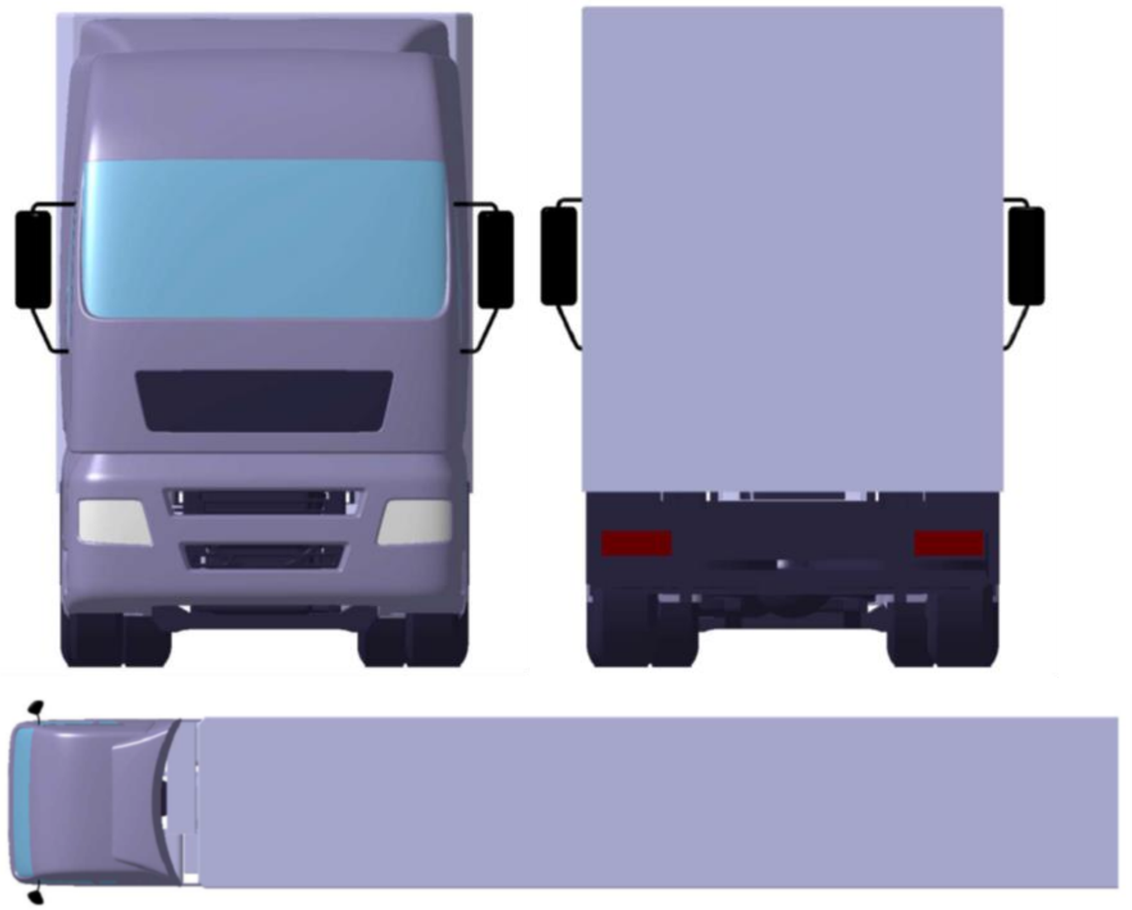


Figure 5. Trailer geometries. Kögel (left), Krone (centre) and Schmitz (right) [16]



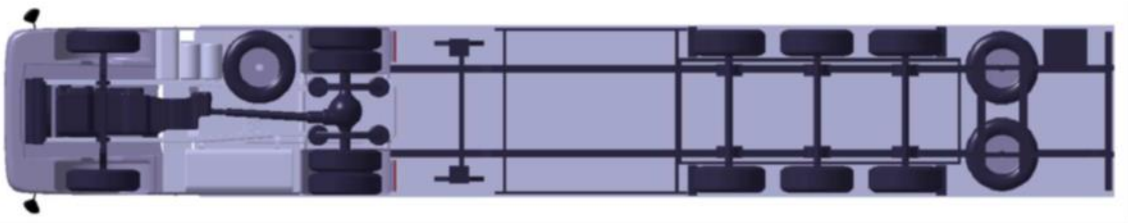


Figure 6. Orthogonal views of the entire hybrid vehicle [16]

Figure 7. Isometric views of the entire hybrid vehicle [16]

The following tables summarize what are the criteria, according to the Commission Regulataion 2017/2400 [14], met by the hybrid trailer:

Table 2. Type and chassis configurations of standard semitrailer "ST1"

End to end ladder frame	OK
Frame w/o underfloor cover	OK
2 stripes at each side as underride protection	OK
Rear underride protection (UPS)	OK
Rear lamp holder plate	OK
w/o pallet box	OK
Two spare wheels after the 3rd axle	OK
One toolbox at the end of the body before UPS (left or right side)	OK
Mud flaps before and behind axle assembly	OK
Air suspension	N/A
Disc brakes	N/A
Tyre size: 385/65 R 22,5	NOK[3]

[3] Hybrid trailer tyre width is 395mm

2 back doors	N/A
w/o side door(s)	OK
w/o tail lift	OK
w/o front spoiler	OK
w/o side fairings for aero	OK

Table 3. Specifications standard trailer "ST1"

Specification	Unit	External dimension (tolerance)	Hybrid trailer compliance
Total length	[mm]	13685	13675
Total width (body width)	[mm]	2550 (-10)	2550
Body height	[mm]	2850 (±10)	2863
Full height, unloaded	[mm]	4000 (-10)	3960
Trailer coupling height, unloaded	[mm]	1150	1150
Wheelbase	[mm]	7700	7605
Axle distance	[mm]	1310	1310
Front overhang	[mm]	1685	1665
Front wall	[mm]	flat wall with attachments for compressed air and electricity	Flat wall without attachments
Corner front/side panel	[mm]	Broken with a strip and edge radii ≤ 5	OK
Remaining corners	[mm]	Broken with radius ≤ 10	r = 25
Toolbox dimension vehicle x-axis	[mm]	655	650
Toolbox dimension vehicle y-axis	[mm]	445	665
Toolbox dimension vehicle z-axis	[mm]	495	500
Side underride protection length	[mm]	3045	2865
Stripe profile	[mm^2]	100 x 30	150 x 37,5

Despite the minor differences between the specifications of a standard trailer "ST1" and the hybrid geometry used for the CFD simulations, it can still be considered aerodynamically valid for this report.

The commercial software STAR-CCM+ from SIEMENS AG has been used as CFD simulation tool to run all reported cases.

STAR-CCM+ uses the Finite-Volume Method (FVM) which solves the Navier-Stokes equations in a discretized computational domain. Out of the different turbulence models available within the tool, the k-ω SST model [17] [18] has been chosen based on its proven accuracy in ground vehicle aerodynamic applications [16] [19] [20] [21] [22] [23] [24] and second order discretization has bet set for all solvers. The computational domain has been made large enough in order to reduce blockage effects down to a minimum. The largest blockage ratio measured (corresponding to the 9º yaw angle cases) falls below 0.5%, which is very close to what is recommended in [25]. The computational domain has been discretized with approximately 160 million cells (mostly hexahedral) with the smallest cells (between 1.5mm and 25mm) located in close vicinity to the vehicle.

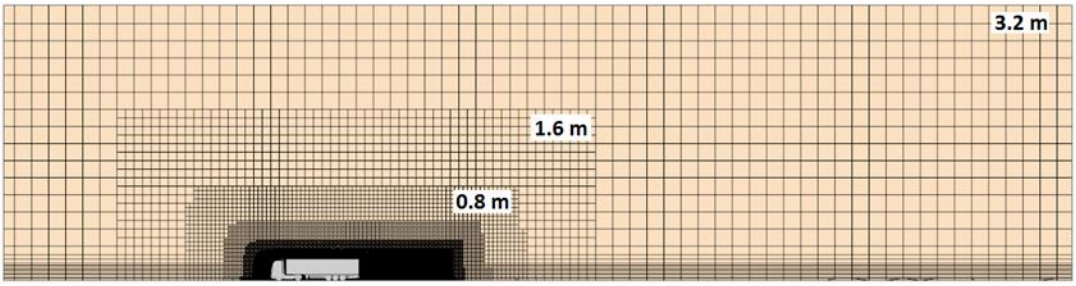


Figure 8. Cell distribution at the Y=0 section

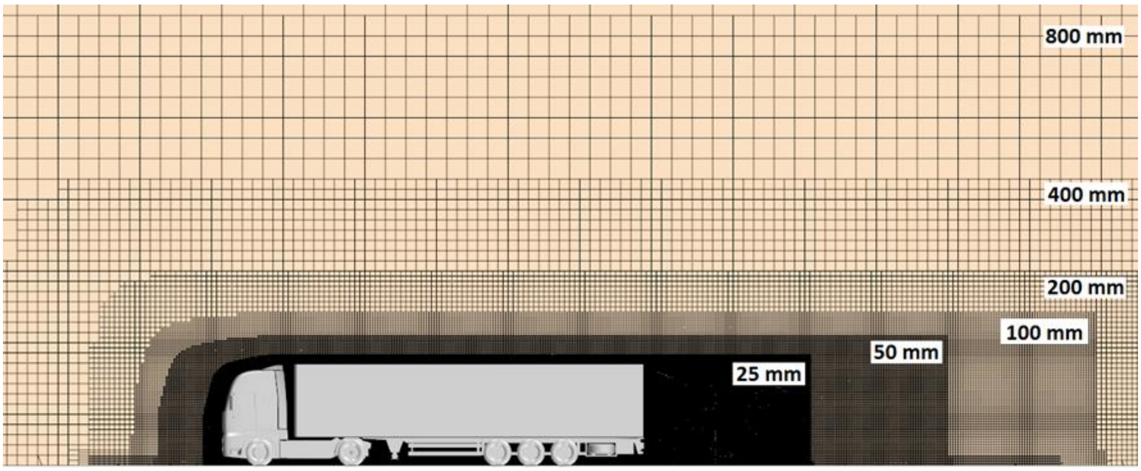


Figure 9. Cell distribution at the Y=0 section near the vehicle

The boundary layer has been resolved with sufficient prism layers and near wall cells resulting in y+ values between 1 and 5 in the vast majority of the vehicle in order to resolve the viscous sublayer. See Figure 10.

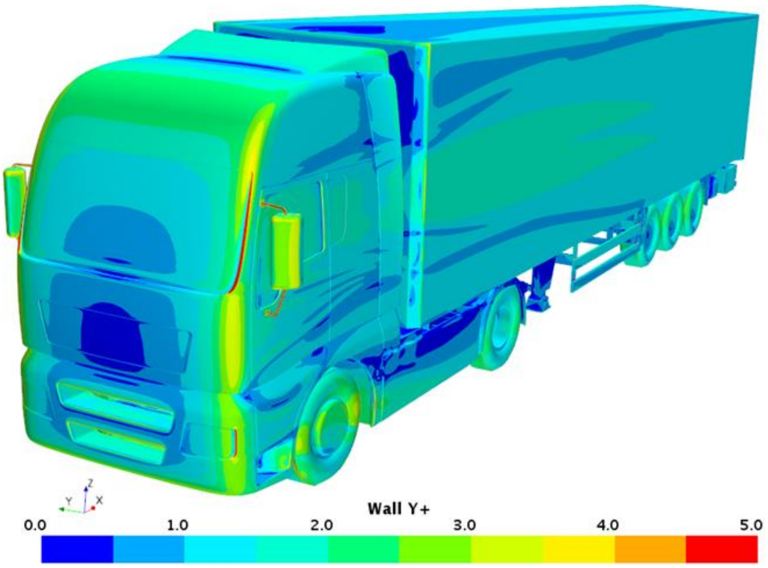


Figure 10. Wall Y+ values on the standard vehicle configuration at 0 deg of yaw

The incoming flow is such that the vehicle is always travelling at 25 m/s (90 km/h). The ground of the computation domain is modelled with a tangential velocity and all wheels are rotating.

3.3.2.2 Influence of tractor geometry

Three different cabins have been used to report the effect that the tractor geometry might have over different trailer improvements:

- Standard FAT cabin: Described in the previous section.
- Extended FAT cabin: Modification of the standard cabin consisting of an extension of 500mm upstream. Provided also by VDA *Forschungsvereinigung Automobiltechnik.* See Figure 12
- AEROFLEX cabin: Provided by the AEROFLEX European project consortium (https://aeroflex-project.eu/highlights-first-phase/). See Figure 13

Figure 11. Standard FAT tractor geometry

Figure 12. Extended FAT tractor geometry

Figure 13. AEROFLEX tractor geometry

In order to limit the number simulations to be run to an acceptable number, and given the fact that the results of the survey from Task 1 were not available at this stage of the work, a simple benchmarking task had been carried out in order to identify the two most common trailer aerodynamic devices. The following table summarizes what the different suppliers, found after a quick search on the internet, offer on their websites:

Table 4. Trailer aerodynamic device suppliers

	Boat Tail	Side Skirts	Inter-wheel panel	Leading edge add-on	Underbody deflectors	Diffuser	Vortex Generators	Rear Fairings	Wheel Covers
AEROTECHCAPS (NA) [26]	X	X					X	X	X
AIRTAB (NA) [27]							X		
BETTERFLOW (EU) [28]	X	X		X					
FLOWBELOW (NA) [29]			X						X
SMARTTRUCK (NA) [30]	X			X	X	X		X	
STEMCO (NA) [31]	X	X							
WABASH (NA) [32]	X	X		X					
WABCO (NA & EU) [33]	X	X							
WINDYNE (NA) [34]		X							

Most of the suppliers are located in North America (NA), probably as a result of being a more mature market in this field, while only a couple of them have been found in Europe (EU).

Figure 14. Side and top fairings provided by AeroTechCaps [26]

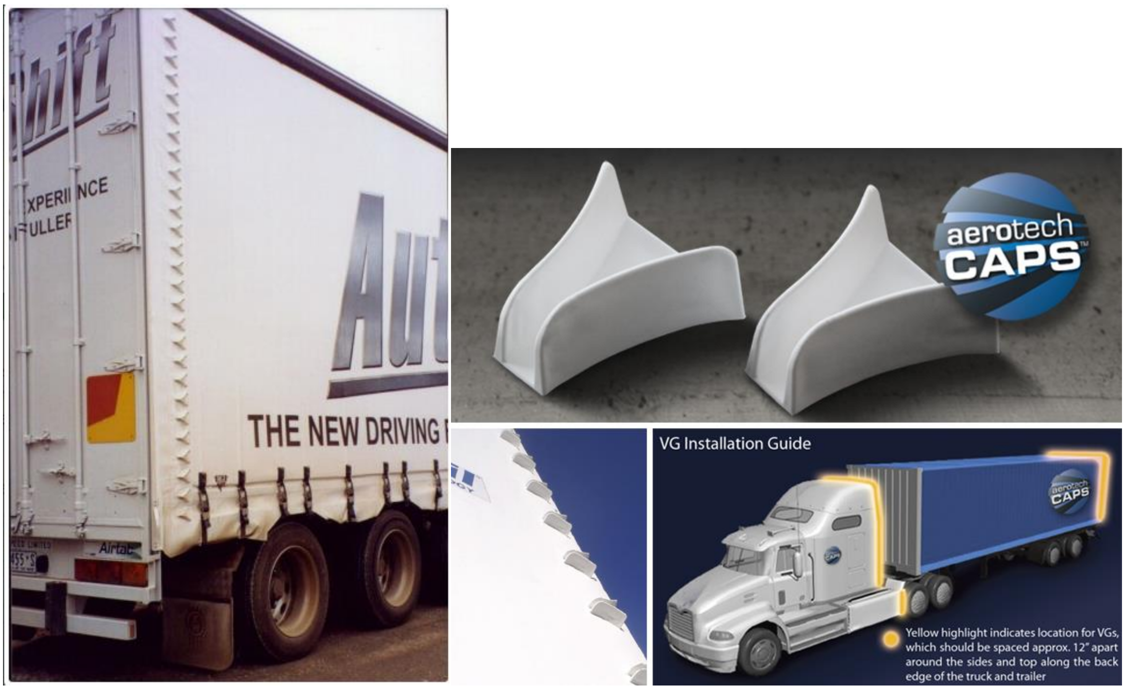


Figure 15. Vortex generators provided by AirTab [27] (left) and AeroTechCaps [26] (right)

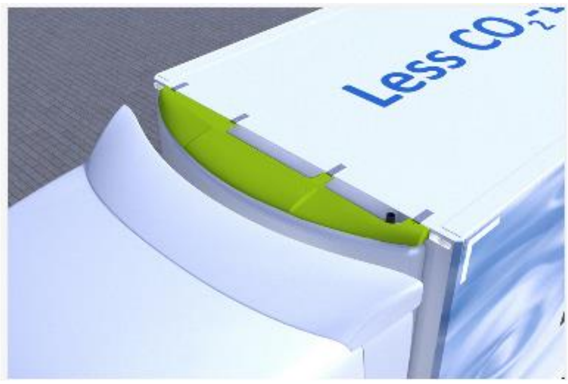


Figure 16. Trailer leading edge add-on provided by BetterFlow [28]

Figure 17. Wheel covers and inter-wheel panel of FlowBelow [29]

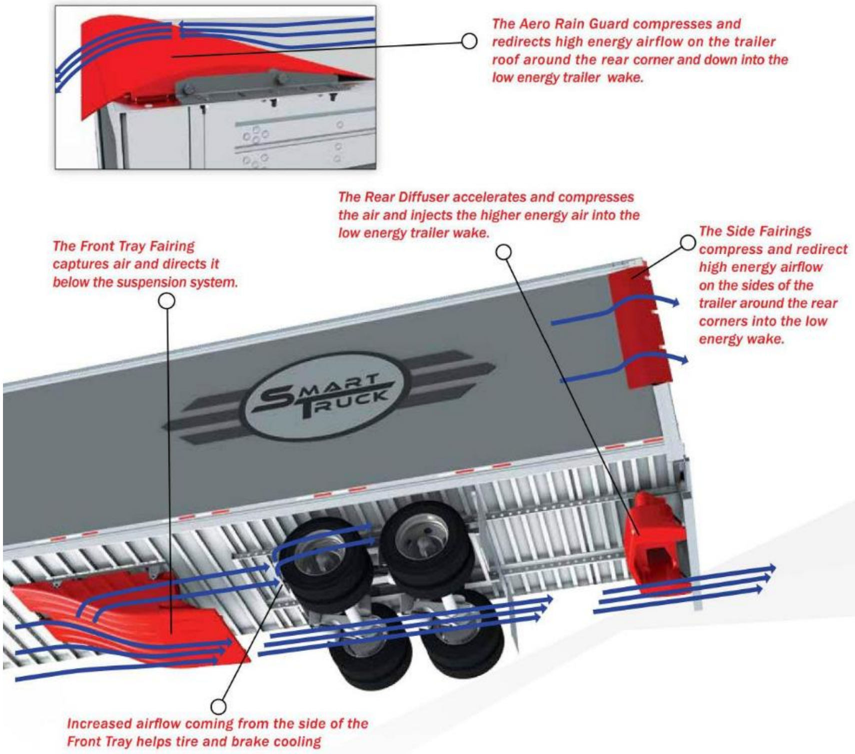


Figure 18. Underbody deflector, diffuser and rear fairings provided by SmartTruck [30]

Figure 19. Boat tail solution prived by Stemco [31]

Figure 20. Side skirts and leading edge add-ons provided by Wabash [32]

Figure 21. Side skirts solution provided by Wabco [33]

Figure 22. Side skirts solution provided by Windyne [34]

As reflected in the table, the two most popular devices are boat tails and side skirts. Therefore, similar devices have been sketched and mounted on the FAT reference semitrailer (see Figure 23) in order to evaluate their effect.

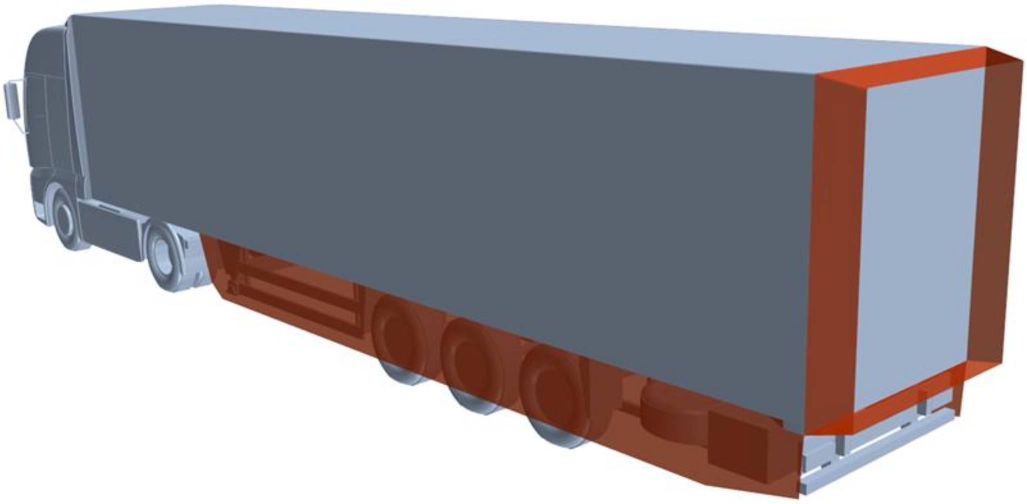


Figure 23. Side skirts and boat tail mounted on the FAT semitrailer geometry

The boat tail design has been mimicked from [24], consisting of four plates inclined 13º (α) with respect to the geometry and 400mm long (L).

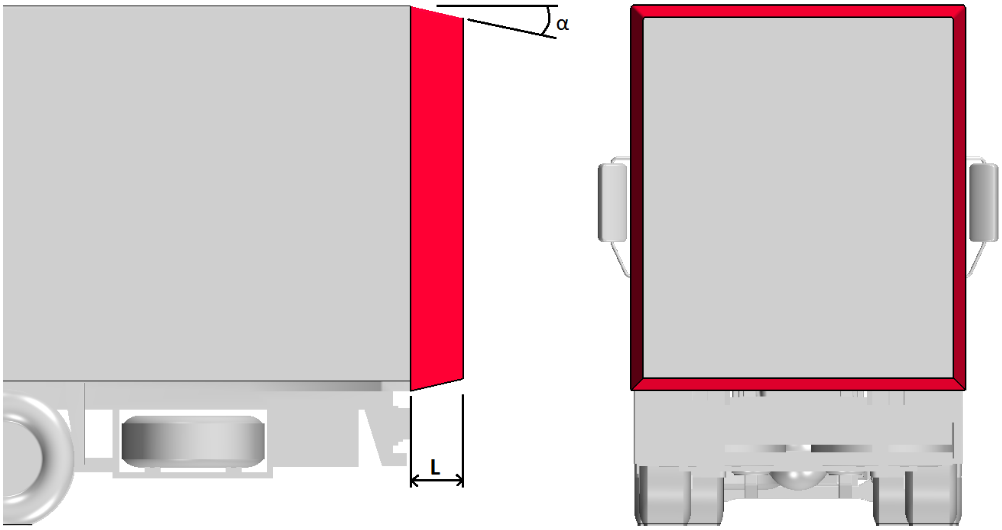


Figure 24. Boat tail specifications

As far the side skirt is concerned, the overall dimensions are L = 10100 mm (aligned with the landing gear at the front and the rear underride protection) and H = 850mm.

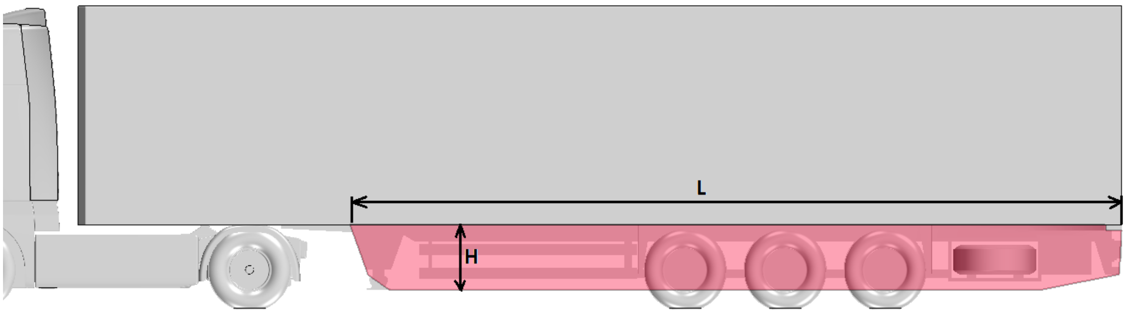


Figure 25. Side skirts specifications

A total of 48 cases, as detailed in the following matrix, have been simulated.

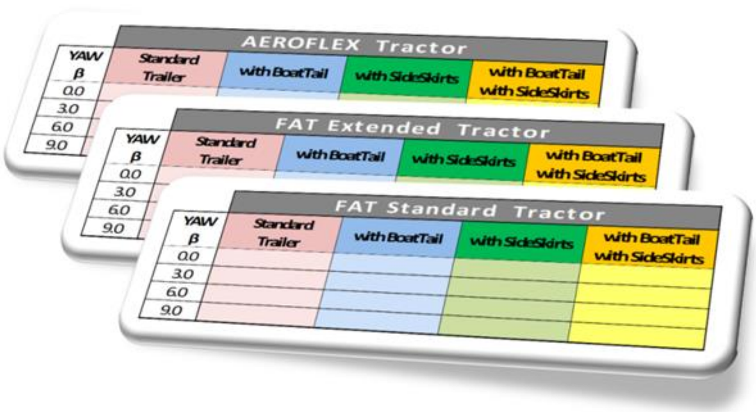


Figure 26. Cases matrix

Table 5, Table 6 and Table 7 show the values predicted by the CFD runs for each one of the tractors when implementing different aerodynamic improvements to the trailer by mounting a boat tail, side skirts or both devices at the same time. The reported values correspond to the difference in C_DxA of the entire vehicle between the standard semitrailer case and the corresponding aerodynamic device(s) addition.

Table 5. $C_D xA_{AeroEnabler}$ - $C_D xA_{StandardTrailer}$ [m²] for FAT standard tractor

YAW β	+BoatTail	+SideSkirts	+BoatTail +SideSkirts
0.0	-0.313	-0.182	-0.495
3.0	-0.303	-0.233	-0.607
6.0	-0.526	-0.576	-1.062
9.0	-0.576	-0.849	-1.436

Table 6. $C_D xA_{AeroEnabler}$ - $C_D xA_{StandardTrailer}$ [m²] for FAT extended tractor

YAW β	+BoatTail	+SideSkirts	+BoatTail +SideSkirts
0.0	-0.303	-0.182	-0.495
3.0	-0.303	-0.233	-0.667
6.0	-0.384	-0.445	-0.940
9.0	-0.546	-0.748	-1.304

Table 7. $C_D xA_{AeroEnabler}$ - $C_D xA_{StandardTrailer}$ [m²] for AEROFLEX tractor

YAW β	+BoatTail	+SideSkirts	+BoatTail +SideSkirts
0.0	-0.416	-0.307	-0.703
3.0	-0.347	-0.267	-0.604
6.0	-0.406	-0.426	-0.861
9.0	-0.546	-0.653	-1.208

It should be noted that the reported values in the tables above correspond to the drag benefits provided by the designs in Figure 24 and Figure 25. Different designs are likely to lead to different results.

It is well known that different tractors will lead to different aero resistance values of the complete tractor + semitrailer configuration. Therefore, the focus is on the difference with respect to the standard semitrailer configuration, with the corresponding tractor, in order to evaluate whether the very same aero device will provide similar air drag benefit independently of the tractor geometry pulling the semitrailer.

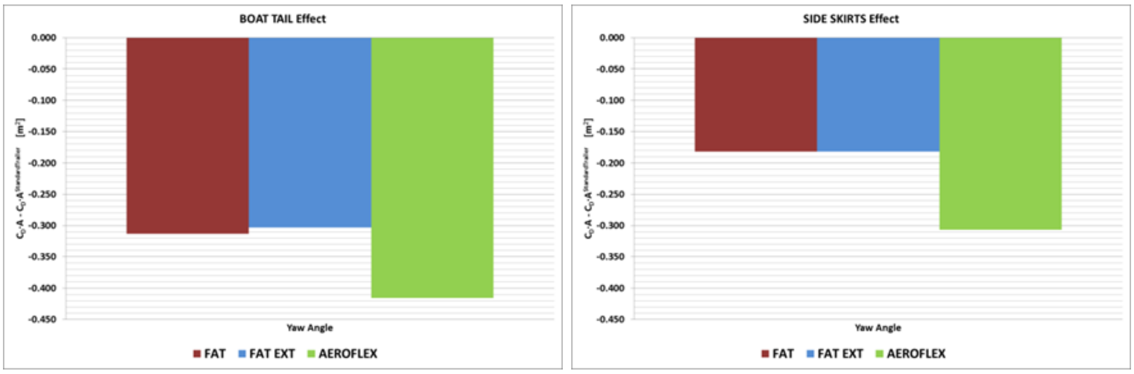


Figure 27. Aerodynamics benefit of boat tail (left) and side skirts (right) under no side wind influence

Based on Figure 27, boat tail and side skirts seem to provide the same aero benefit to the FAT cabins, making the device tractor-independent. However, a more streamlined cabin, such as AEROFLEX, leads to cleaner airflow towards the semitrailer. This is due to mainly the following differences:

- larger radius at the front-end edges of the cabin,
- smaller tractor-trailer gap
- removal of the side mirrors

Such modifications, help reducing the tractor losses and as a consequence, the air flow further downstream is less turbulent, enhancing the benefits of the aero enablers implements on the trailer and hence, a more significant drag reduction of the overall vehicle.

3.3.2.3 Side wind influence

Traditionally, the aerodynamic resistance of a vehicle is obtained at pure forward driving conditions. In wind tunnel tests, this is achieved by perfectly aligning the vehicle in the longitudinal direction with the incoming flow. In coast-down or constant speed tests, this is ensured by performing such tests when no wind blowing. The VECTO CST procedure, for instance, requires the average wind speed to be below 5 m/s [14][4].

Unfortunately, ground vehicles not only travel through standing still air conditions, but they are also exposed to cross winds. Several publications show that the effect of the side wind on vehicle aerodynamics cannot be neglected [19] [35] [36] [37]. This effect is also taken under consideration in VECTO by applying a generic yaw polar curve (Equation 1), as a correction to the C_D value obtained from the Air Drag test.

[4] In the VECTO software, based on the $C_d{}^*A$ value at zero yaw angle, the influence of side winds is considered by generic curves (yaw polar curve) reflecting the effect of different yaw angles on the air drag.

$$C_d A(\beta) - C_d A(0) = a_1\beta + a_2\beta^2 + a_3\beta^3$$

Equation 1. Yaw polar polynomial

where the constants a_1, a_2 and a_3 vary depending on the type of vehicle configuration.

It is known that, under cross wind, the drag coefficient is dependent on the side the wind is blowing, which is reflected by a non-symmetrical polar curve. This is due to geometric properties of the overall vehicle and, in particular, the underbody [19]. Despite such constrain and, in order to limit the total number of CFD runs, only one side of the polar curve (yaw angles of 0°, 3°, 6° and 9°, as suggested in [25], has been simulated for each vehicle configuration. It has been selected the side corresponding to crosswind coming from the left, as it is dominant over flow coming from the right, probably due to oncoming traffic [37] [19].

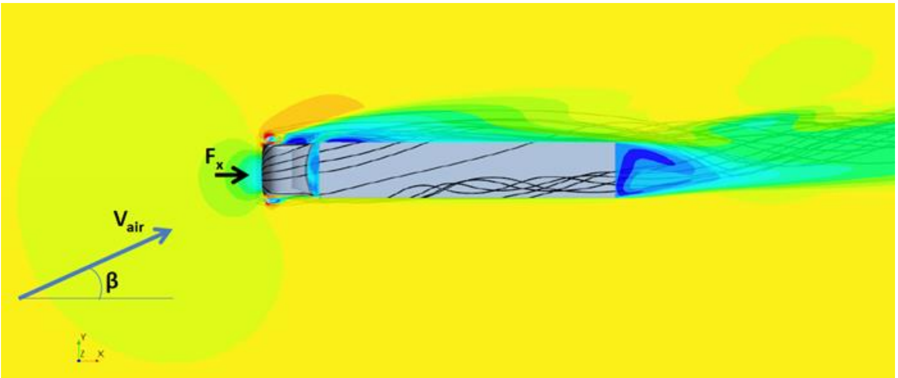


Figure 28. Simulated crosswind direction

The following figures show, in a more visual way, the results reported in Table 5, Table 6 and Table 7. The polar curve used by VECTO is also displayed as a reference.

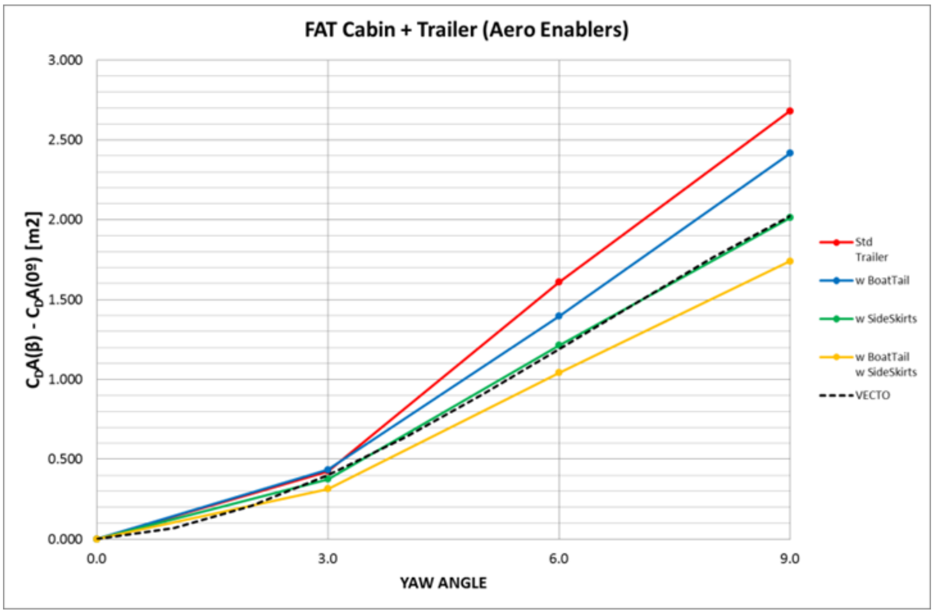


Figure 29. Polar curves of the FAT standard tractor. $C_D xA(\beta)$ - $C_D xA(0°)$ [m^2]

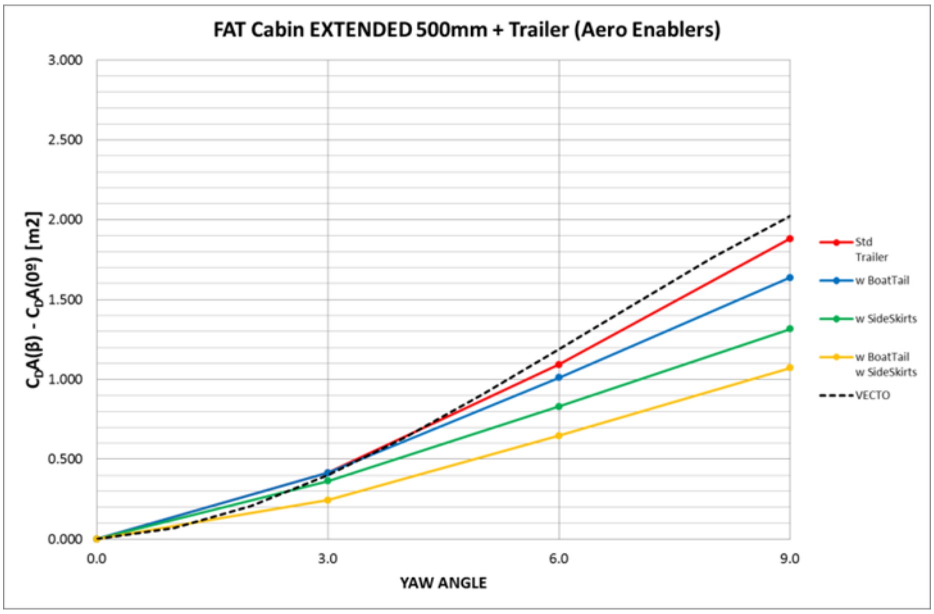


Figure 30. Polar curves of the FAT extended tractor. $C_D xA(\beta)$ - $C_D xA(0°)$ [m^2]

Figure 31. Polar curves of the AEROFLEX tractor. $C_D xA(\beta)$ - $C_D xA(0°)$ [m^2]

The main take away from the plots above is that, not only the aero appendices on the trailer have significant impact on the shape of the polar curve, but also the tractor geometry itself.

Figure 32 and Figure 33 show the ranges predicted by the CFD runs for each trailer aero device considering all three tractor geometries simulated.

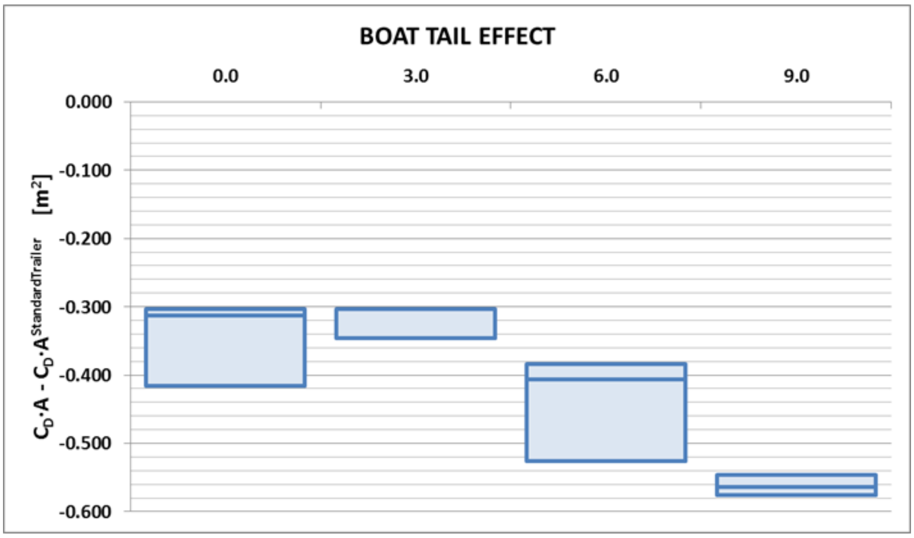


Figure 32. Aero benefit of the boat tail for all 3 tractors simulated. $C_D xA_{BoatTail}(\beta)$ - $C_D xA_{StdTrailer}(\beta)$ [m^2]

Figure 33. Aero benefit of the side skirts for all 3 tractors simulated. $C_DxA_{SideSkirts}(\beta)$ - $C_DxA_{StdTrailer}(\beta)$ [m^2]

CLCCR Working Group [25] suggests, in page 40, the use of analytical equations to compute ΔC_DxA values depending on trailer length, see Figure 34.

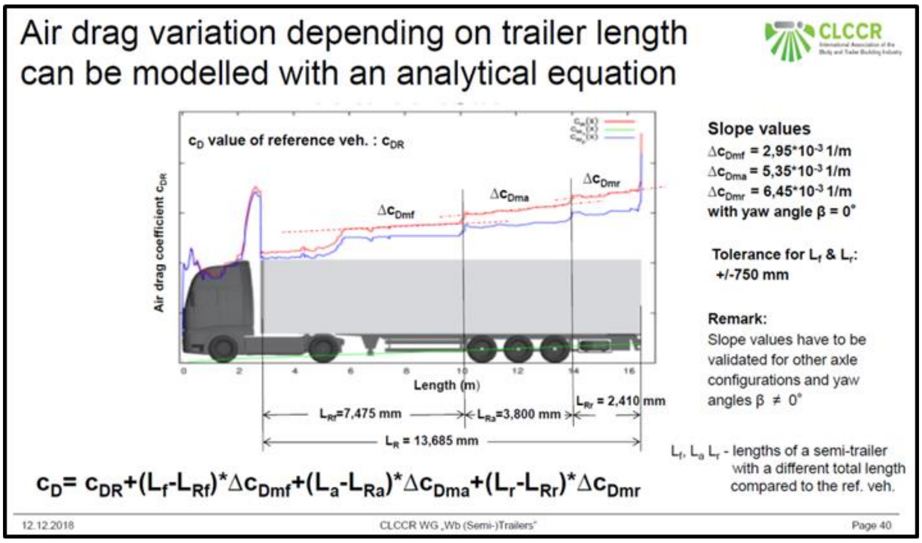


Figure 34. CLCCR proposal for air drag variation calculation depending on trailer length

The total reference (R) trailer length, L_R, is divided in 3 sections:

- L_{Rf}: From the trailer front end to the first wheel
- L_{Ra}: Including all wheels
- L_{Rr}: From the last wheel to the rear end

CLCCR's White Book already indicates the dependency on yaw angles of the slope values C_{Dmx} to be used in Equation 2.

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

Equation 2

Without going deeper into the actual slope values, the set of cases reported so far confirms CLCCR's assumption (see Figure 35) where the main differences between yaw angles are predicted in the trailer axles section, C_{Dma}.

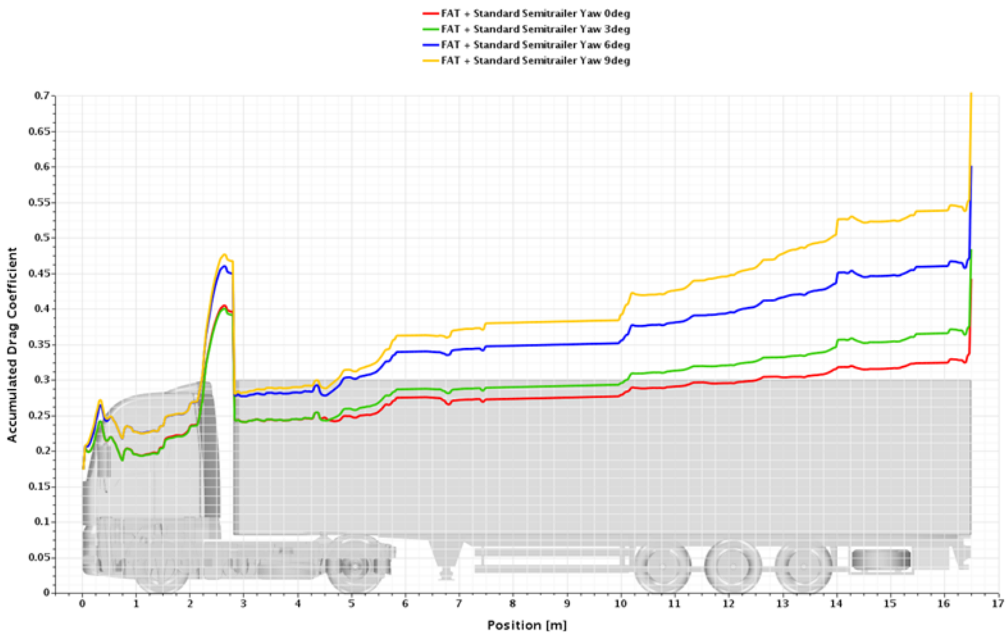


Figure 35. Accumulated drag plot. FAT standard tractor with standard trailer. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

Similar phenomena have been predicted for all other tractor geometries:

- FAT extended tractor (Figure 36), and
- AEROFLEX tractor (Figure 37).

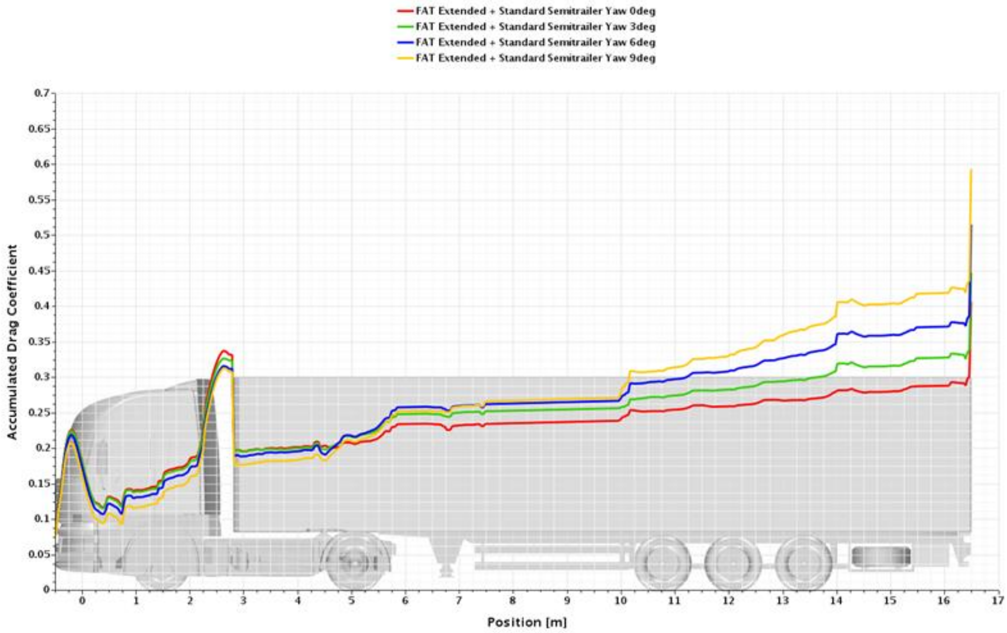


Figure 36. Accumulated drag plot. FAT extended tractor with standard trailer. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

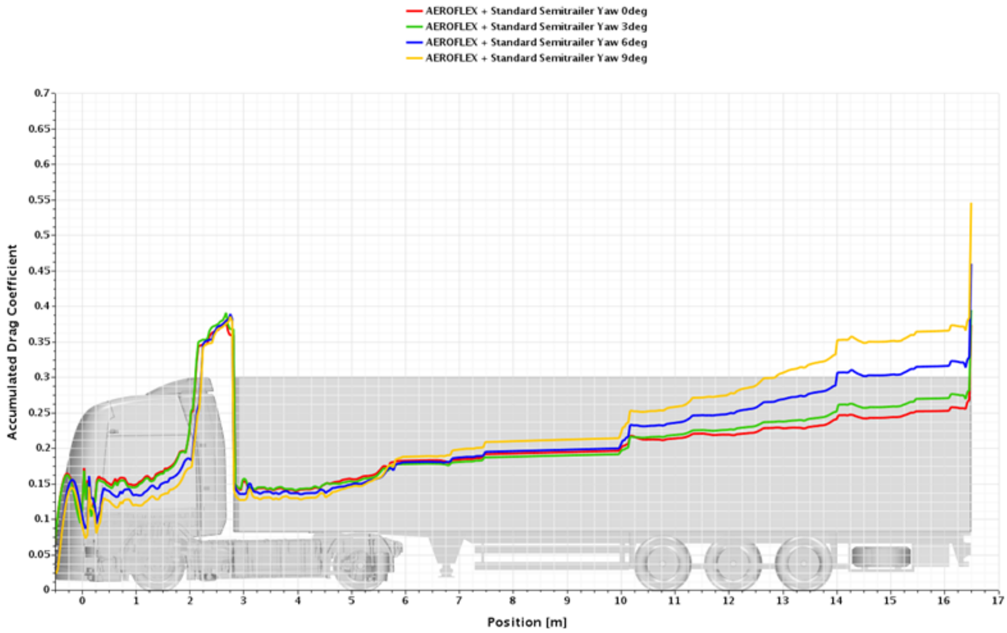


Figure 37. Accumulated drag plot. AEROFLEX tractor with standard trailer. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

As seen in the previous plots, the section L_a is clearly impacted by the cross wind. Covering them with the side skirts shows a clear benefit since the slope C_{Dma} is smoothed out. This effect is clearly visible in all three tractors:

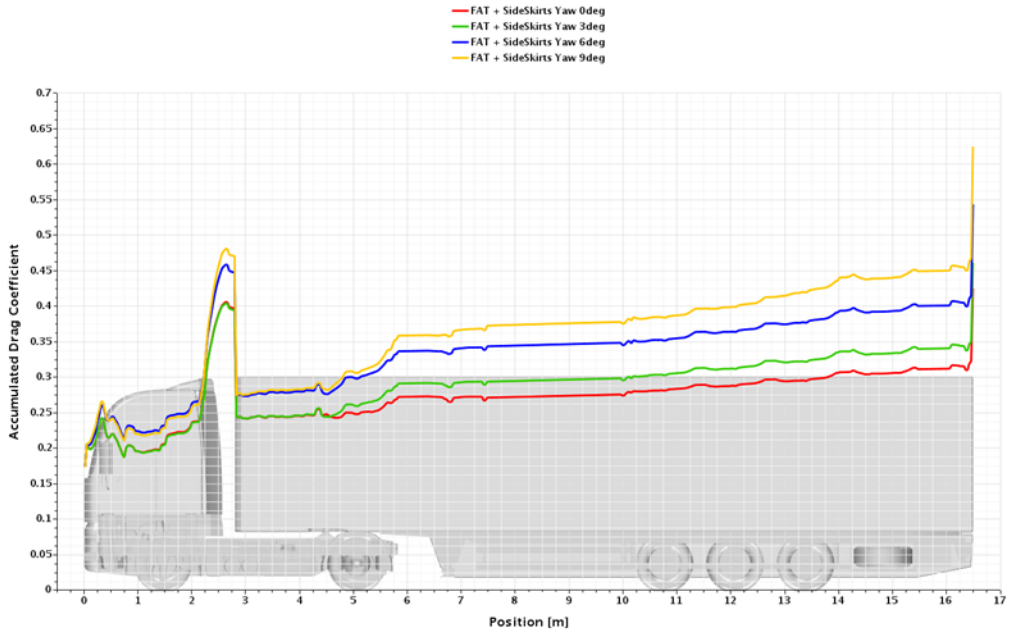


Figure 38. Accumulated drag plot. FAT standard tractor with trailer and side skirts. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

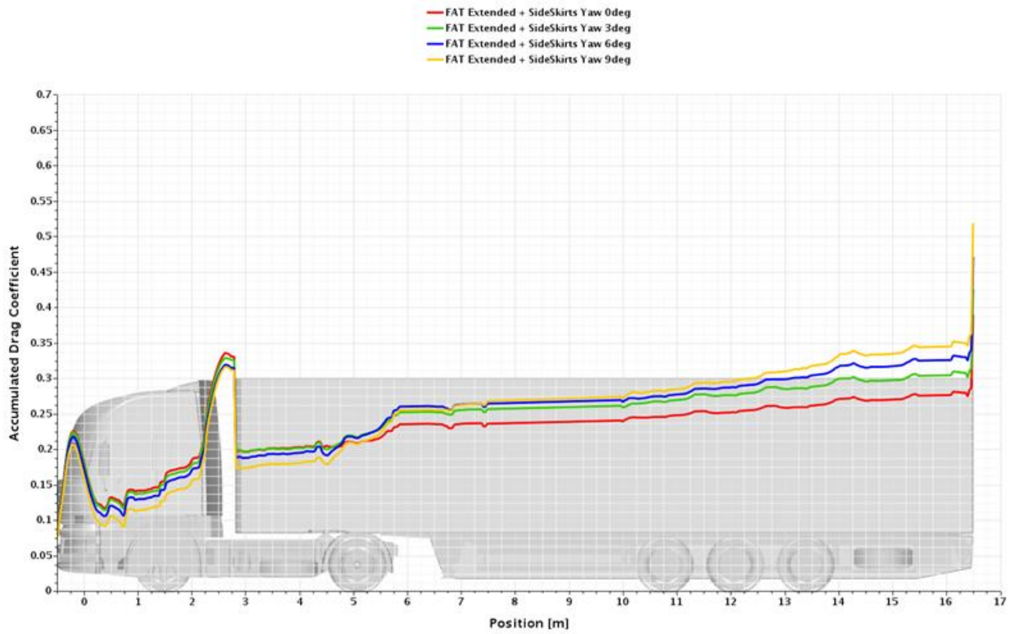


Figure 39. Accumulated drag plot. FAT extended tractor with trailer and side skirts. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

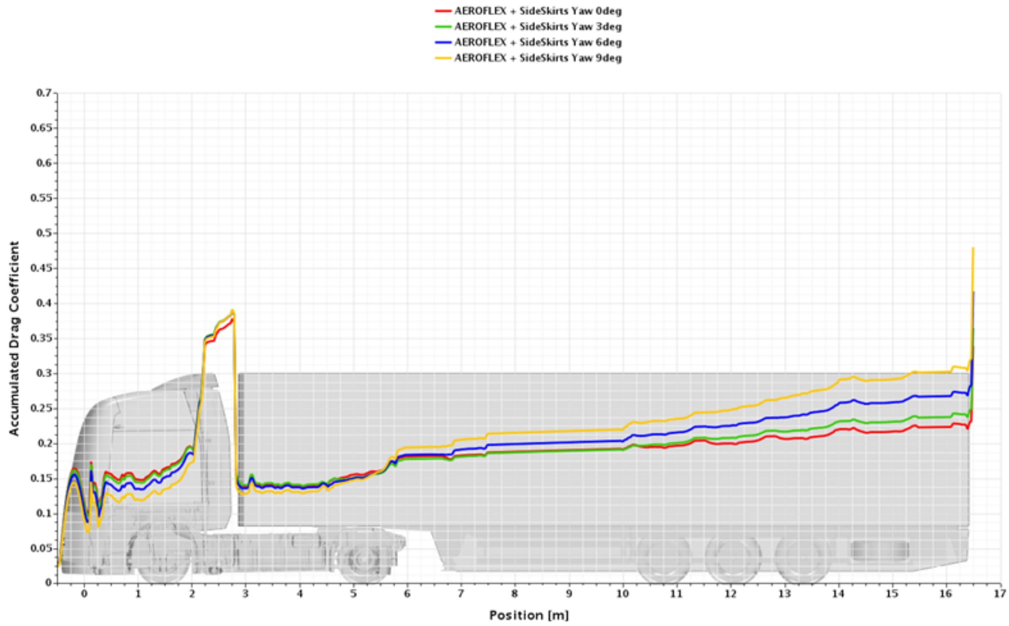


Figure 40. Accumulated drag plot. AEROFLEX tractor with trailer and side skirts. Yaw of 0° (red); 3° (green); 6° (blue) and 9° (yellow)

When comparing the predicted accumulated drag plots (see Figure 41) for the same semitrailer but different cabin, it can be seen that slopes C_{Dmf}, C_{Dma} and C_{Dmr} run fairly parallel to each other in all four yaw angles simulated.

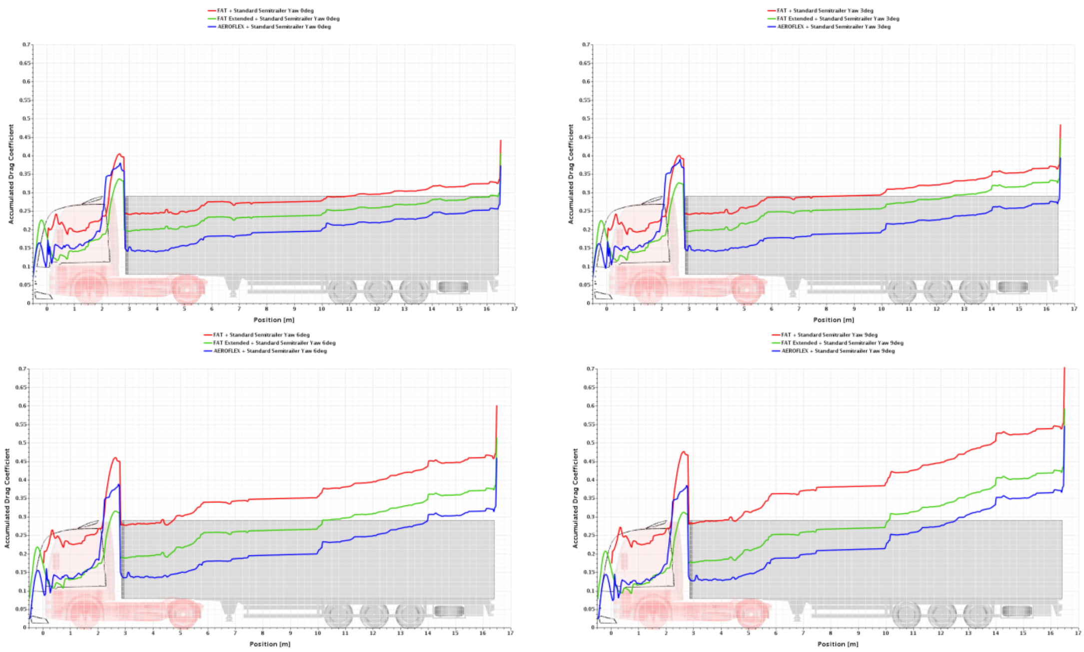


Figure 41. Accumulated drag plots at yaw 0°, 3°, 6° and 9°. Standard trailer pulled by FAT standard (red); FAT extended (green); AEROFLEX (blue)

Similar conclusion can extracted from Figure 42 where the semitrailer has side skirts implemented.

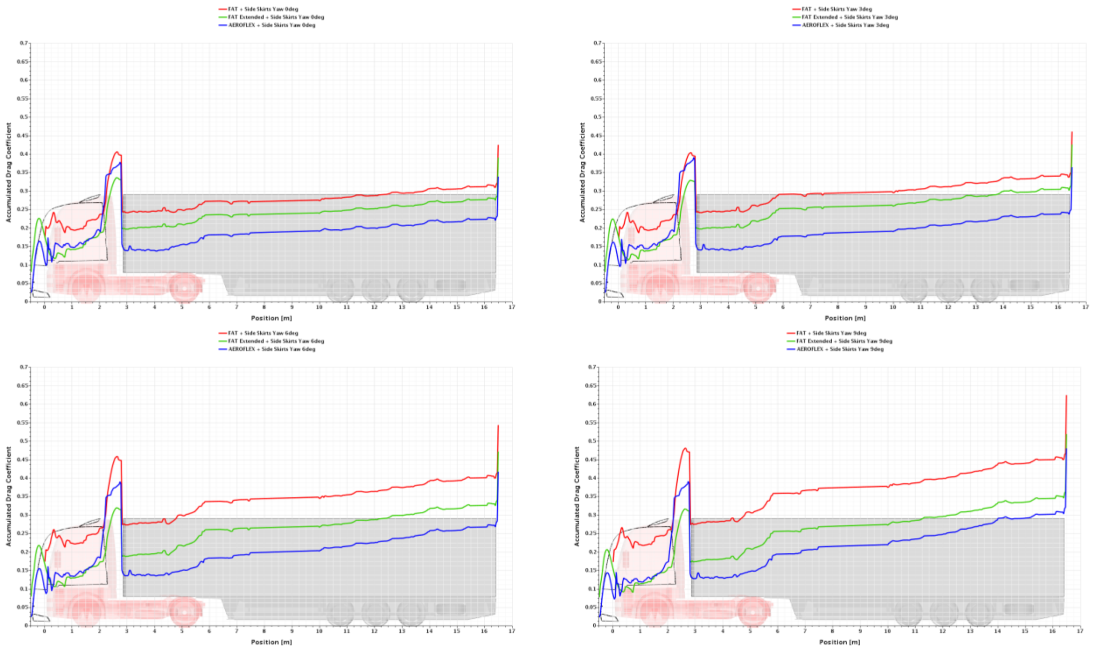


Figure 42. Accumulated drag plots at yaw 0°, 3°, 6° and 9°. Trailer with side skirts pulled by FAT standard (red); FAT extended (green); AEROFLEX (blue)

3.3.2.4 Interaction between trailer aero enablers

Simulating the effect of the trailer aero devices first separately and finally the two together, allows the extra analysis of the interaction between the two (Table 8 to Table 10).

Table 8. $C_DxA_{AeroEnabler}(\beta)$ - $C_DxA_{StandardTrailer}(\beta)$ [m^2] for FAT standard tractor. Combination effect

YAW β	Boat Tail Effect		Side Skirts Effect	
	Alone	With Side Skirts	Alone	With Boat Tail
0.0	-0.313	-0.313	-0.182	-0.182
3.0	-0.303	-0.374	-0.233	-0.303
6.0	-0.526	-0.485	-0.576	-0.536
9.0	-0.576	-0.586	-0.849	-0.859

Table 9. $C_DxA_{AeroEnabler}(\beta)$ - $C_DxA_{StandardTrailer}(\beta)$ [m^2] for FAT extended tractor. Combination effect

YAW β	Boat Tail Effect		Side Skirts Effect	
	Alone	With Side Skirts	Alone	With Boat Tail
0.0	-0.303	-0.313	-0.182	-0.192
3.0	-0.303	-0.435	-0.233	-0.364
6.0	-0.384	-0.495	-0.445	-0.556
9.0	-0.546	-0.556	-0.748	-0.758

Table 10. $C_DxA_{AeroEnabler}(\beta)$ - $C_DxA_{StandardTrailer}(\beta)$ [m^2] for AEROFLEX tractor. Combination effect

YAW β	Boat Tail Effect		Side Skirts Effect	
	Alone	With Side Skirts	Alone	With Boat Tail
0.0	-0.416	-0.396	-0.307	-0.287
3.0	-0.347	-0.337	-0.267	-0.257
6.0	-0.406	-0.436	-0.426	-0.455
9.0	-0.546	-0.554	-0.653	-0.644

Same values are plotted in Figure 43 and Figure 44. As previously mentioned, both boat tail and side skirts seem to provide the same aero benefit to the FAT cabins, making the device tractor-independent under no cross-wind conditions (yaw angles of 0°). This statement, however, differs when adding the AEROFLEX cabin to the comparison. Nonetheless, the drag reduction of each device, at 0° of yaw, seems to be independent of whether the other aero devices is mounted on the trailer or not.

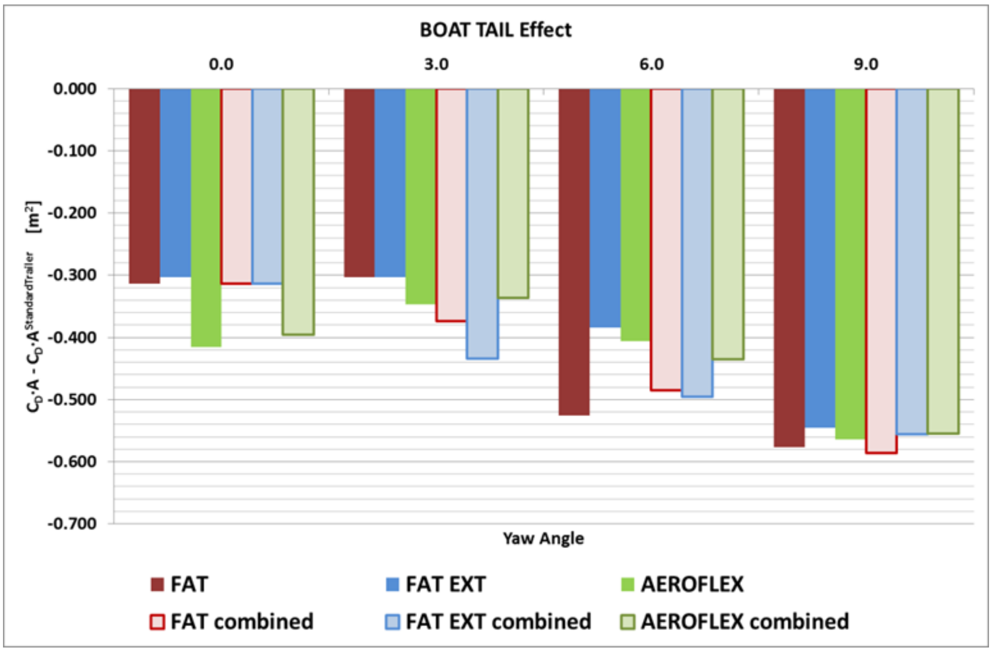


Figure 43. Boat tail effect on drag coefficient. Alone and in combination with side skirts.
$C_D x A_{BoatTail}(\beta) - C_D x A_{StdTrailer}(\beta)$ [m^2]

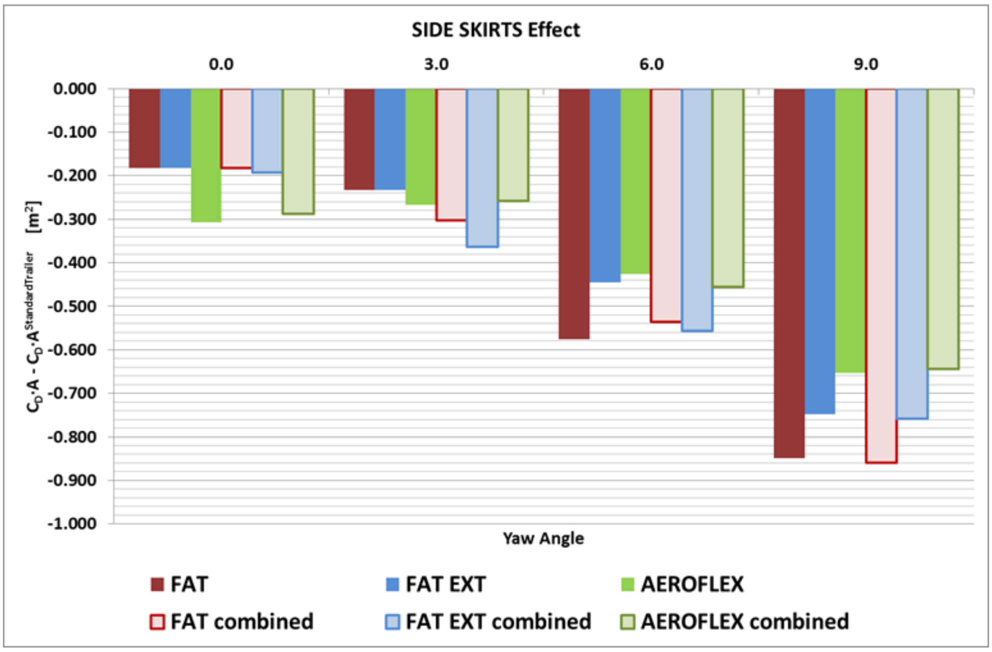


Figure 44. Side skirts effect on drag coefficient. Alone and in combination with boat tail.
$C_D x A_{SideSkirts}(\beta) - C_D x A_{StdTrailer}(\beta)$ [m^2]

As soon as the side wind comes into play, the conclusions extracted from the 0° yaw results are no longer applicable. This demonstrates the importance of cross winds on ground vehicles, especially large ones such as tractor and semitrailer configurations.

The following box plots show a clear trend where the higher the yaw angle, also the higher the reduction in drag coefficient, regardless of the tractor geometry pulling the trailer.

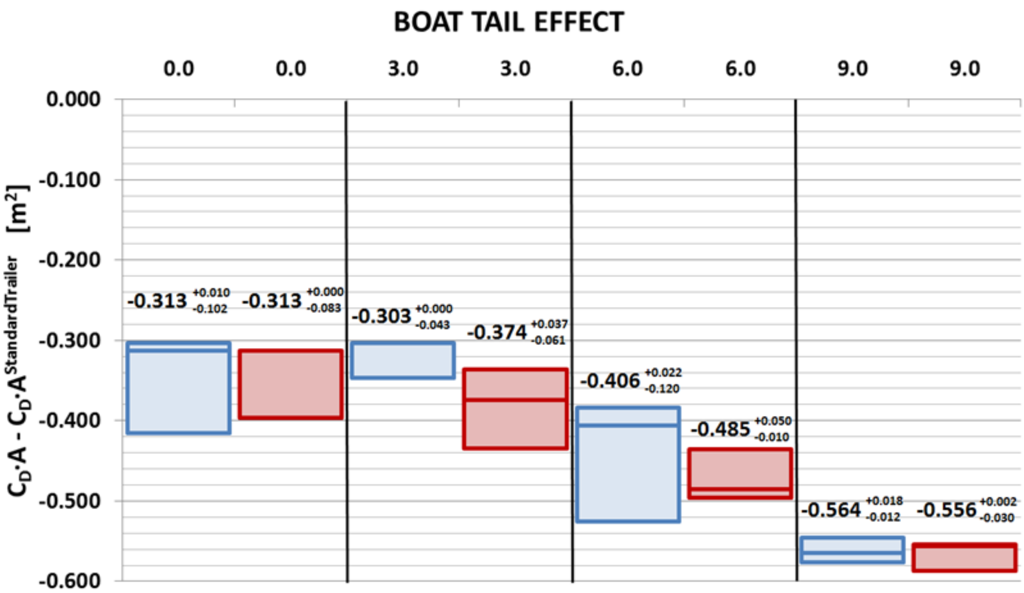


Figure 45. Boat tail aero effect. On its own (blue) and in combination with side skirts (red).
$C_DxA_{BoatTail}(\beta)$ - $C_DxA_{StdTrailer}(\beta)$ [m^2]

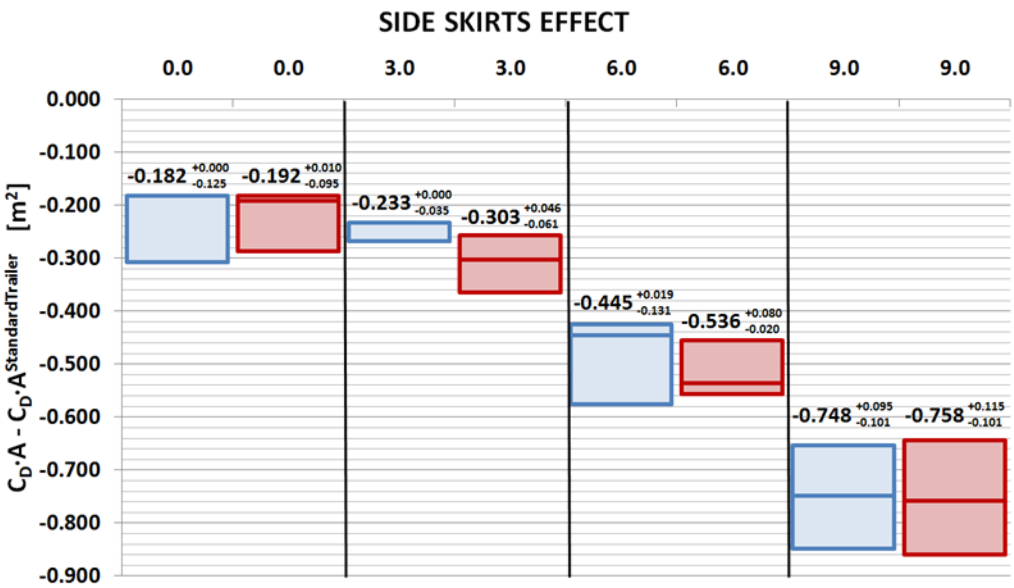


Figure 46. Side skirts aero effect. On its own (blue) and in combination with a boat tail (red).
$C_DxA_{SideSkirts}(\beta)$ - $C_DxA_{StdTrailer}(\beta)$ [m^2]

Comparing both Figure 45 and Figure 46 one can notice that the effect of the boat tail is more depending on whether side skirts are mounted or not, whereas the effect of the side skirts is a bit more independent.

In chapter 4.3.1 the yaw angle calculation method from VECTO is applied to identify the distribution of yaw angles and to get an average yaw angle weighted for the total air drag contribution. The analysis shows "averages" between approx. 3 and 4°, depending on the geometry of the vehicle. In general, from this exercise the conclusion is, that air drag values at different yaw angles should be considered according to the frequency of occurrence in real traffic.

3.3.2.5 CFD methods comparison

With the goal to identify necessary CFD standard settings, different CFD technologies and methodologies have been assessed. In this initial stage, a common geometry (FAT standard tractor and standard trailer, together with the side skirts and boat tail geometries) has been shared with the interested parties in order for them to run a series of cases and, after analysing the results, estimate the uncertainty one could expect from virtual simulations.

Three different software vendors have collaborated in this subtask:

- SIEMENS AG with their Simcenter STAR-CCM+ tool,
- ALTAIR with their Hyperworks ultraFluidX code, and
- DASSAULT SYSTEMES with their EXA PowerFLOW software.

While both EXA PowerFlow and ALTAIR ultraFluidX are based on Lattice-Boltzmann methods (LBM), which are inherently transient, STAR-CCM+ is a finite volume method (FVM), which can resolve in a steady-state manner (as it has been done in all cases reported above) or in transient mode.

This list, together with the simulations already discussed above and other exisiting data from past publications, provides five different methodologies/softwares to be compared:

Table 11. CFD methods comparison

Software	STAR-CCM+	OpenFOAM [19]	STAR-CCM+	UltraFluidX	PowerFLOW
Time dependency	Steady-state	Steady-state	Transient	Transient	Transient
Turbulence Model	RANS k-ω SST (Menter)	RANS k-ω SST (Menter)	DES k-ω SST (Menter)	Smagorinsky LES	RNG k-epsilon
Compressibility	Constant Density	Constant Density	Constant Density	Constant Density	Constant Density
Discretization	150 million cells approx	60 million cells approx	150 million cells approx	300 million voxels approx	100 million voxels approx
Solution Time-Averaging	N/A	N/A	15 seconds	3 seconds	4 seconds

While it is believed that such broad portfolio covers all softwares and methodologies used by any European OEMs, it must be emphasized that the simulations have been performed using the corresponding software vendor best practices, not the OEMs settings. Nonetheless, the most relevant boundary conditions and mesh refinements areas have been properly fulfilled and are common in all methods:

- Vehicle speed
- Wheels rotation rate
- Tangential velocity applied to the ground
- Mesh refinement areas:
    - Vehicle wake
    - Side mirrors wake
    - Tractor-trailer gap
    - Underbody

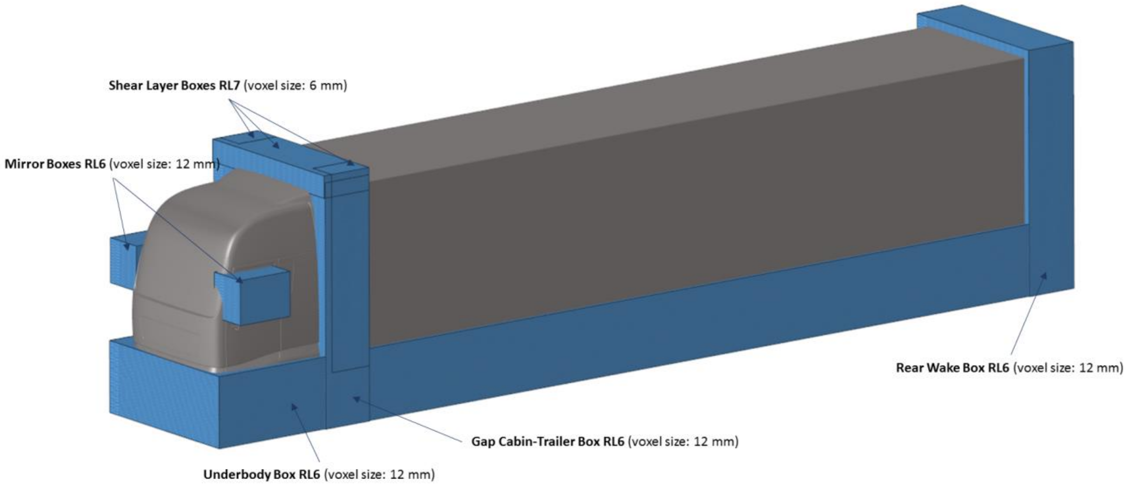


Figure 47. Spatial discretization in UltraFluidX

One might suspect that OEMs settings might differ in, for instance, mesh refinement levels of certain key areas, turbulence levels at the domain inlet, modelling of the cooling pack (heat exchangers and fan), wheel motion modelling approach, etc. Unfortunately, the details are not available due to confidentiality and their own know-how.Rather than simulating the entire matrix for a given tractor, which would require 16 different runs, 6 configurations have been tagged as high priority instead. Those 6 configurations that have been simulated by the CFD collaborators, providing values that are relevant enough to judge what might be the uncertainty expected from virtual methodologies.

Table 12. Cases matrix with priority cases

YAW β	Standard Trailer	+BoatTail	+SideSkirts	+BoatTail +SideSkirts
0.0	Low	Low	Low	Low
3.0	**High**	**High**	Low	**High**
6.0	**High**	**High**	Low	**High**
9.0	Low	Low	Low	Low

As explicitly expressed by some of the participants, the values are reported anonymously and rather than comparing absolute values of C_DxA, the focus is always on ΔC_DxA, of two different configurations, instead.

Table 13. Values of $C_DxA(6°)$ - $C_DxA(3°)$ [m^2] obtained by the five different methods

		$C_DxA(6°)$ - $C_DxA(3°)$ [m^2]
Method A	Standard Trailer	1.183
	with Boat Tail	0.960
	with Boat Tail and Side Skirts	0.728
Method B	Standard Trailer	0.738
	with Boat Tail	0.698
	with Boat Tail and Side Skirts	0.516
Method C	Standard Trailer	0.761
	with Boat Tail	0.726
	with Boat Tail and Side Skirts	0.461
Method D	Standard Trailer	0.475
	with Boat Tail	0.485
	with Boat Tail and Side Skirts	0.324
Method E	Standard Trailer	0.866
	with Boat Tail	0.765
	with Boat Tail and Side Skirts	0.529

Figure 48 clearly shows that Method A is always providind the largest value of $C_DxA(6°)$-$C_DxA(3°)$ [m^2], while Method D is always reporting the smallest value.

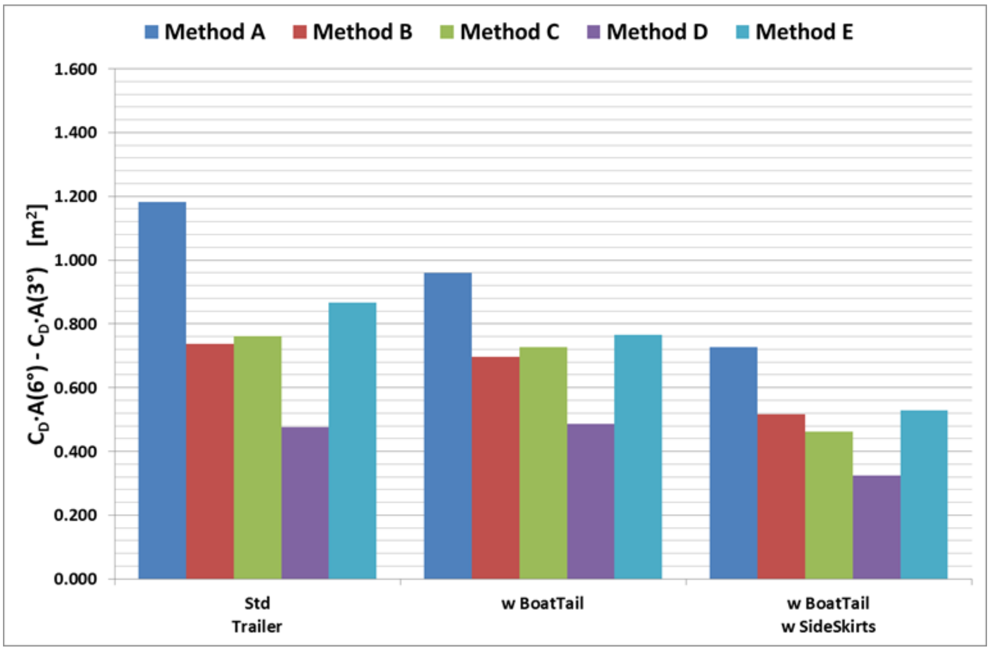


Figure 48. Values of $C_DxA(6°)$ - $C_DxA(3°)$ [m^2] obtained by the five different methods

Following figure displays the ranges obtained from the different methodologies, cleary proving that the minimum and maximum values are significantly different:

- 0.422+0.286 = 0.708 m^2 for the standard trailer case,
- 0.234+0.241 = 0.475 m^2 for the case with the boat tail, and
- 0.212+0.192 = 0.404 m^2 for the side skirts.

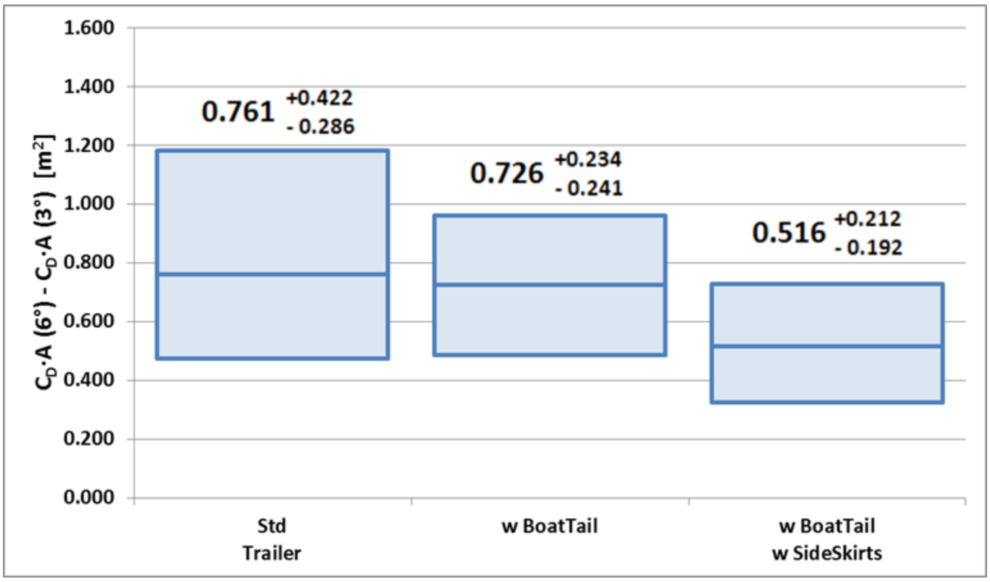


Figure 49. Range of $C_DxA(6°)$ - $C_DxA(3°)$ [m^2] values

This could lead to significantly different yaw polar curves depending on the CFD method to be used. Nonetheless, and in order to further quantify these discrepancies, it should be necessary to run the additional cases marked as low priority in Table 12.

As far as the effect of the different aerodynamic devices is concerned, the tolerances predicted by the different methods is significantly reduced. See following figures.

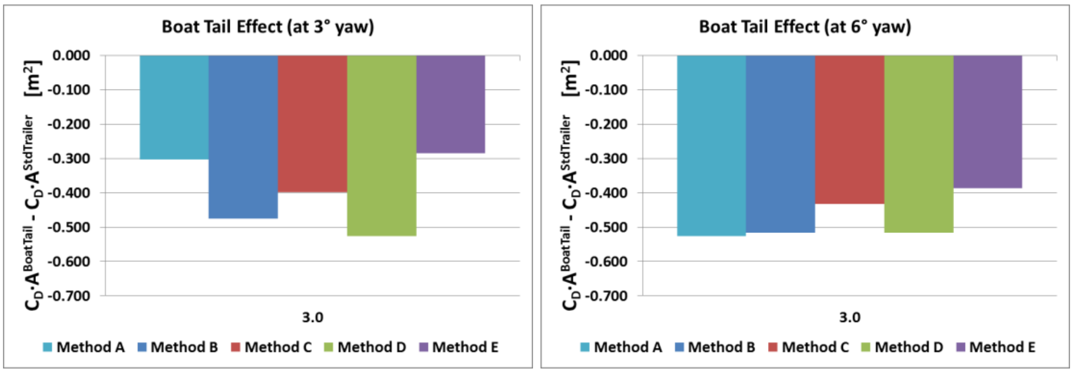


Figure 50. Boat tail effects at 3º and 6º of yaw

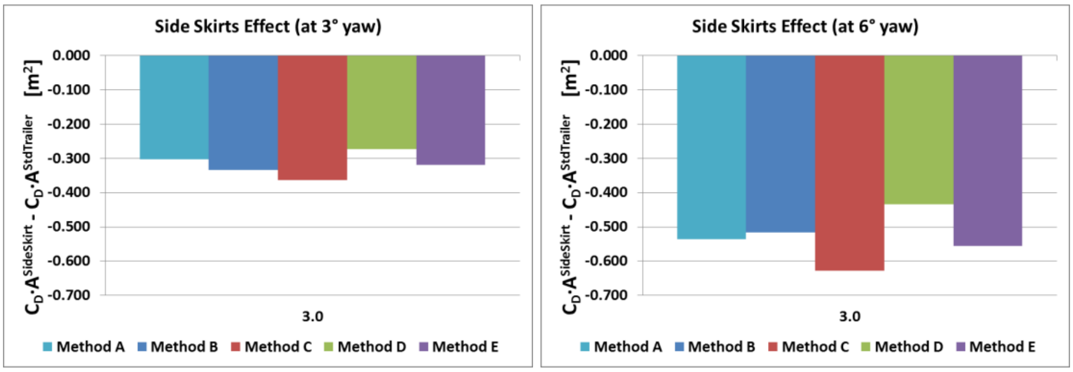


Figure 51. Side skirts effect at 3º and 6º of yaw

Analysing the box plots in Figure 52, the predicted ranges are:

- Boat Tail effect:
    - 0.113+0.128 = 0.241 m^2 at 3º yaw
    - 0.130+0.010 = 0.140 m^2 at 6º yaw
- Side skirts effects:
    - 0.047+0.044 = 0.091 m^2 at 3º yaw
    - 0.101+0.093 = 0.192 m^2 at 6º yaw

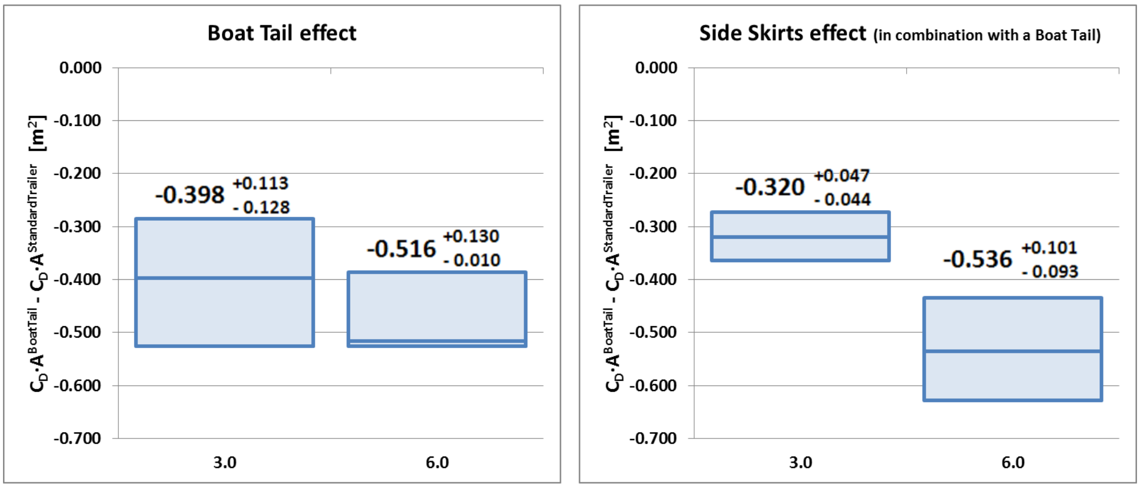


Figure 52. Range of $C_D xA(\beta)$ - $C_D xA(\beta)$ [m[2]] values corresponding to the effects of the boat tail (left) and the side skirts (right)

Figure 53 to Figure 58 show a comparison of the accumulated drag plots of methods A, C and D (such data for methods B and E is not available). It can be seen that they show very similar patterns along the trailer length and with the three sections L_f, L_a and L_r, clearly identified in the case of not mounted side skirts and nearly identical slopes C_{Dmf}, C_{Dma} and C_{Dmr}. (See definitions of L_f, L_a, L_r, ,C_{Dmf}, C_{Dma} and C_{Dmr} above, defined by CLCCR proposal).

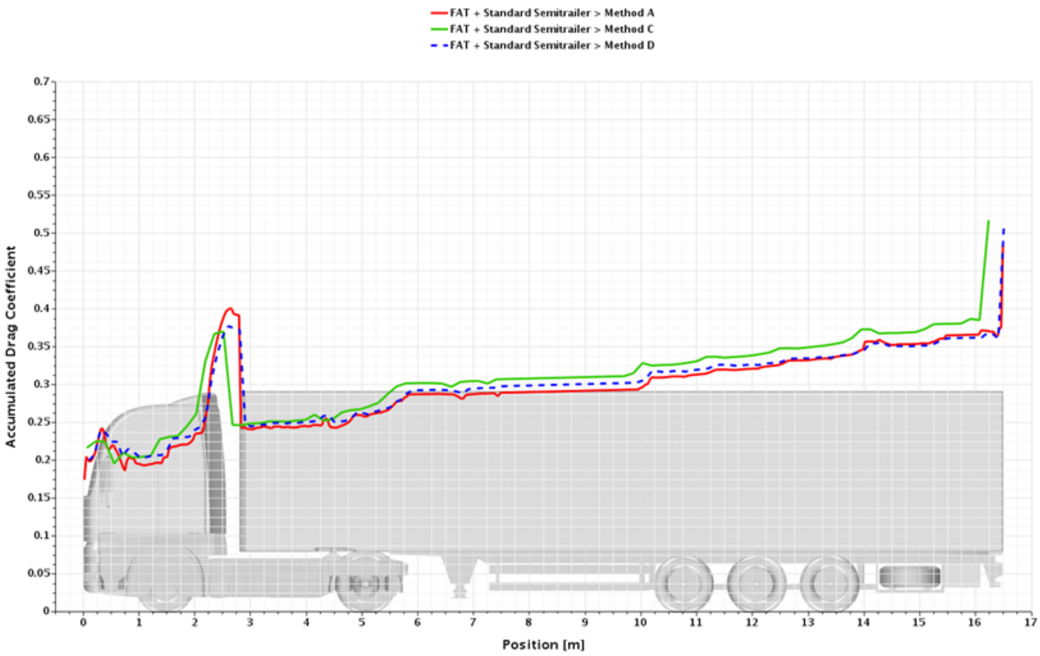


Figure 53. Accumulated drag plot. Standard semitrailer at yaw = 3°. Methods A (red); C (green); D (blue)

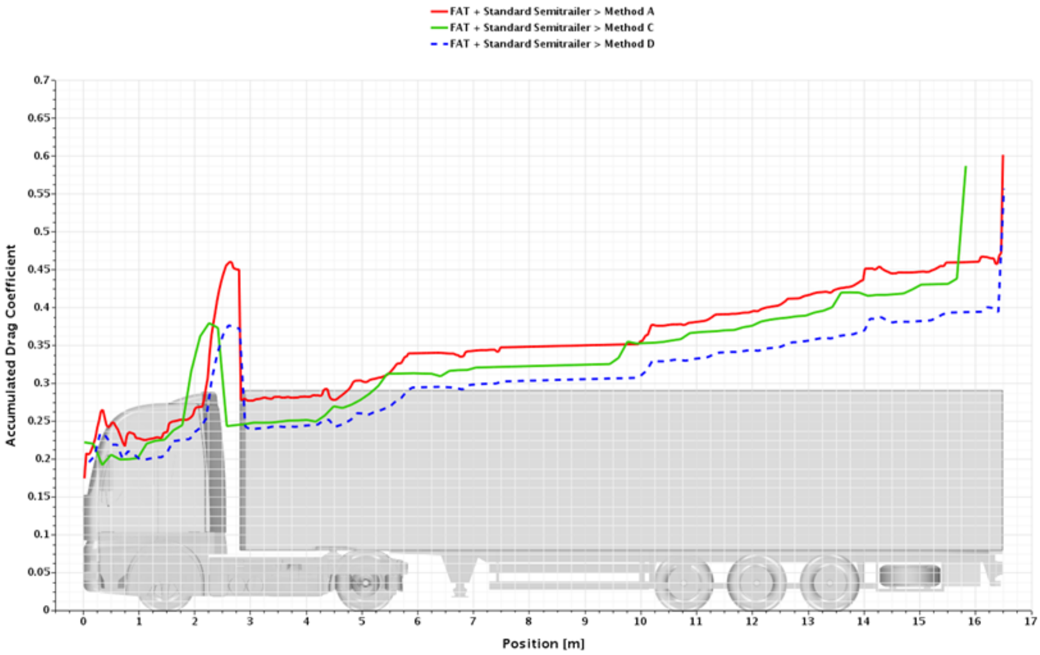


Figure 54. Accumulated drag plot. Standard semitrailer at yaw = 6°. Methods A (red); C (green); D (blue)

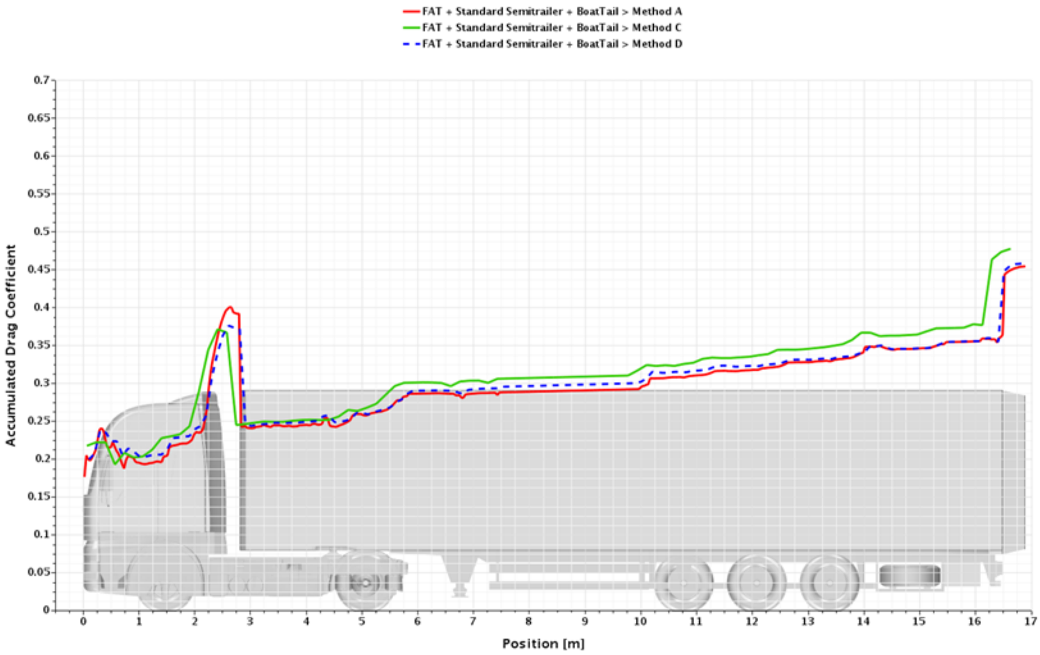


Figure 55. Accumulated drag plot. With Boat Tail at yaw = 3°. Methods A (red); C (green); D (blue)

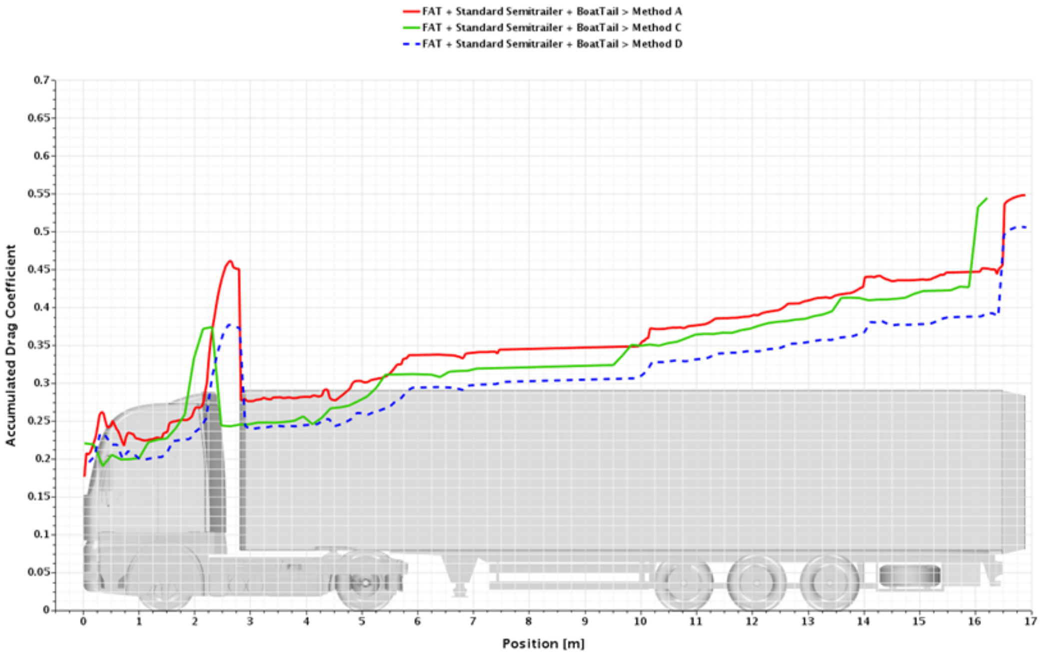


Figure 56. Accumulated drag plot. With Boat Tail at yaw = 6°. Methods A (red); C (green); D (blue)

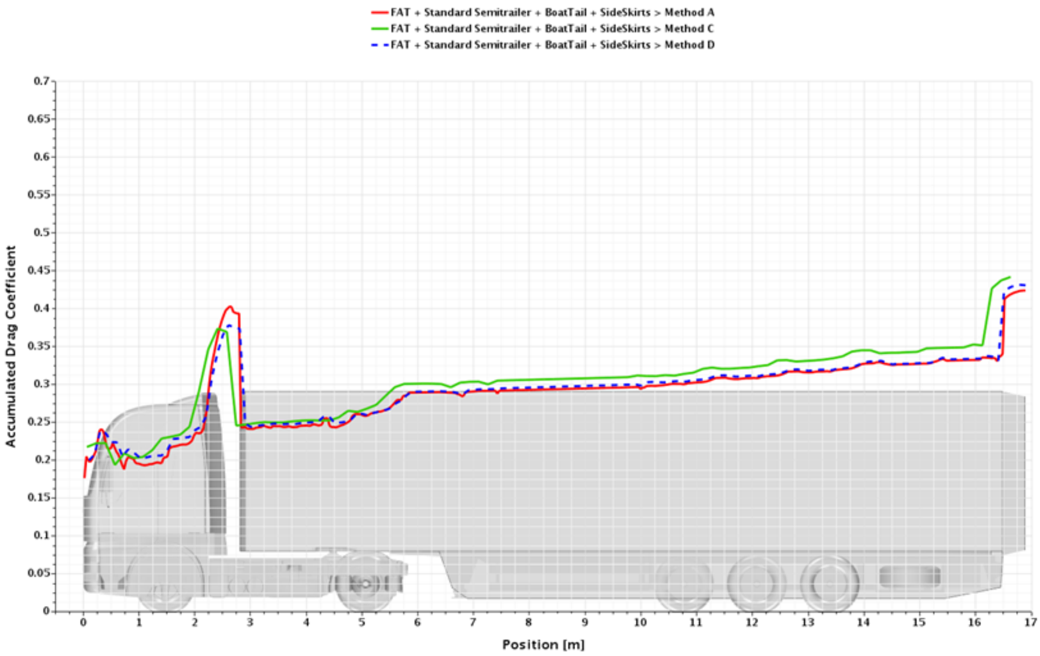


Figure 57. Accumulated drag plot. With Boat Tail and Side Skirts at yaw = 3°. Methods A (red); C (green); D (blue)

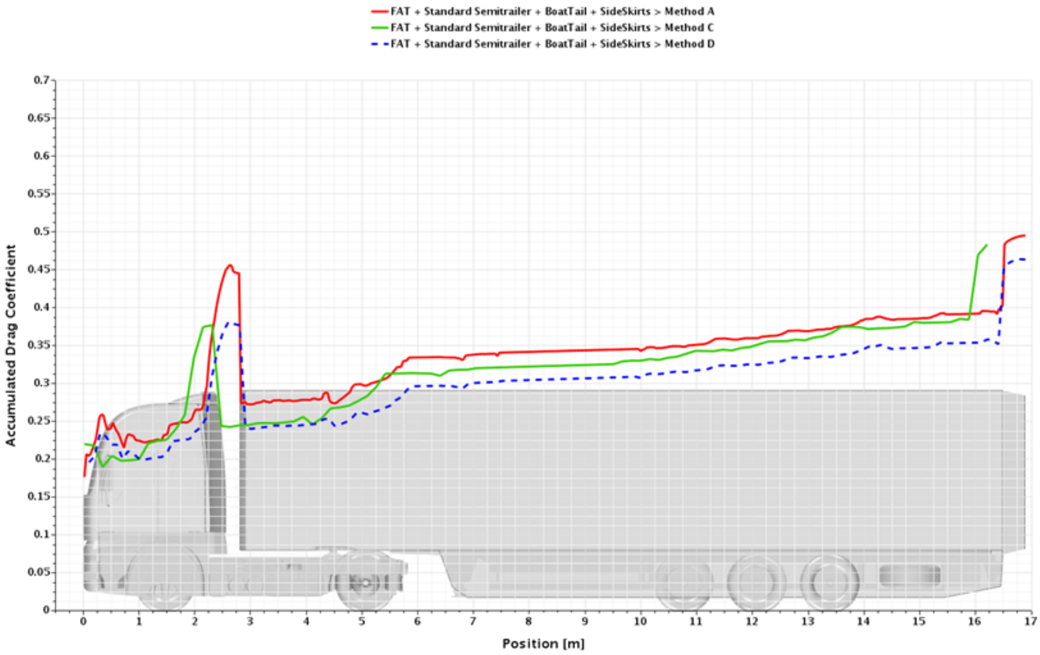


Figure 58. Accumulated drag plot. With Boat Tail and Side Skirts at yaw = 6°. Methods A (red); C (green); D (blue)

Recommendation:

It is suggested to use – at least in the long term – a CFD based method for certification of bodies and trailers which provides also air drag results for different yaw angles to incentivise all relevant areas of aerodynamic optimisation. The CFD models should be used to generate differences in the air drag to standard bodies or trailers. In order to make CFD more reliable, several aspects need to be addressed:

First of all, in the case of trailers and semi-trailers representative CAD models for the lorries, own by the Commission, should be provided. The CAD models should be adjusted to the representative vehicle designs e.g. every 3 years to consider the rather high influence of the design of the towing vehicle on the effect of improved trailers (chapter 3.3.2.2). The AEROFLEX geometry could be used as a base for such model, especially considering ACEA and CLCCR vision on this: *“Interest is shown from ACEA & CLCCR to use the reference model for future CO2 regulations.”* (source: https://aeroflex-project.eu/highlights-first-phase/)Those “public” models of a tractor and rigid lorries would also offer a common geometry to work with to all trailer manufacturers and other interested parties.

In all cases a set of test cases with tolerances allowed or a comparable quality check system for certification of CFD vendors is suggested. 3rd party CFD simulations or physical vehicle tests could serve for independent verifications of the CFD results.

Given the uncertainty that constant speed tests currently offer, wind tunnel testing seems to be the only sensible approach as it offers a much more controlled environment. This wind tunnel testing campaign could cover many different topics currently open:

- It should use the tractor geometry provided by the Commission
- Despite covering the influence of cross winds quite extensively, only two trailer aerodynamic devices have been evaluated within with work and, ideally, this list should be extended further in order to evaluate other aspects, such as:
  - Variations of L_f, L_a and L_r to confirm whether CLCCR's suggested approach is accurate enough (See Figure 34 and Equation **2**)
  - More trailer aerodynamic devices
  - Modifications of the existing trailer aero devices (i.e. influence of the side skirts length, influence of the boat tail angle, etc)
  - Variation in the trailer underbody (tool boxes, side protections, etc)
  - Others
- The resulting test data would be used to narrow down the differences in the results between the CFD methods, as it would allow the corresponding CFD vendors to tune the relevant solver settings. The CFD methods comparison carried out in this work miss this point and merely general best practices have been applied by each participant.
- The wind tunnel testing campaign should use a scale model because:
  - There is one facility in Europe that could perform full scale test (https://www.dnw.aero/wind-tunnels/llf/)
  - Full scale testing has certain limitations:
    - Rotation of the wheels is not allowed
    - Moving ground effect is not allowed
    - Large yaw angles (typically above 5 degree) are not allowed.
  - There are many more wind tunnels in Europe that could be used to accommodate a model scale, some of them allowing the modelling of wheel rotation.
  - The EU-funded project AEROFLEX does involve model scale wind tunnel
    - Assuming that the mock-up especially built for this wind tunnel campaign is owned by the Commission, only a low budget would be necessary to allocate for an additional campaign (or to extend the AEROFLEX campaign, if it has not happened yet)

It should be noted that CFD models used for reproducing wind tunnel environment are usually set up differently to models simulating open road conditions. Modelling of the wheels, ground or the size of the computational are typical examples of those differences. In order to address such uncertainties, it is suggested to still validate the CFD methodology (reproducing the wind tunnel environment) against wind tunnel results. This certified CFD method would then be allowed to be used for open road simulations with certain limitations/restrictions that should be further defined.

3.3.3 Use of standard values and generic functions

Since physical tests are expensive, and the method development for the use of CFD simulation in a certification process may not be mature enough in near future, alternative options may be better suited for a first step of a certification of the efficiency of alternative bodies or trailers.

As alternative, simple look up tables may be used, covering the most relevant add-on parts for improving aerodynamics of bodies or trailers. The corresponding reduction rates in air drag may be gained by certification of such components (chapter 3.3.4) and/or by physical tests of by CFD simulation. Table 14 shows an example of such a look up table for semi-trailers. The values provided are not verified and for demonstration only.

Table 14. Schematic picture of a look up table for standard reduction rates against the air drag of a group 5 vehicle with the standard semi-trailer

Aero component	ΔC_d*A [m²]
Covers for trailer wheels	-0.10
Rounded front edges of trailer	-0.10
Side panels at trailer chassis	-0.25
Underbody panels at trailer chassis	-0.15
Short boat tail	-0.35
Long boat tail	-0.45

Using such a look up table for certification or declaration of an air drag value for bodies and trailers would need well defined descriptions of minimum properties a component has to fulfil to get the air drag bonus. Otherwise any add-on component at the rear end may be called a boat tail. E.g. a short boat tail may be defined based on a drawing showing the allowed length (e.g. 300 to 500 mm) but also the ranges of angles between the side plates. Furthermore, maximum protrusion levels for articulations needed to open the boat tail for loading the trailers may have to be defined and a minimum flexural stiffness to prevent collapsing of the boat tail at higher wind pressure.

Such regulatory definitions for component designs may hinder the R&D of better aerodynamic designs, thus such look up tables should only be introduced together with the possibility to extend the list by certified parts (chapter 3.3.4). Consequently, the reduction rates in the generic part of the look up table should be rather conservative to ensure that certified values do not have disadvantages against generic values of similar components.

For some components listed in Table 14 an explicit and robust definition seems to be difficult, e.g. for underbody panels. Thus, the components to be covered by such a look-up table have to be elaborated together with component manufacturers and with OEMs of trailers and bodies.

If also different length of bodies should be considered, generic equations could be introduced which most likely can be gained from CFD simulation results of some bodies with different length (see chapter 3.3.2). A correction for height and width seems straightforward based on scaling on the frontal area.

For alternative bodies, such as tankers or flat-beds, the use of standard values to provide a base C_d*A value for such body types may be useful. The aim of such an exercise would be rather customer information since CO_2 limits for complete(d) lorries with such specialised bodies based on generic air drag values are not very meaningful[5]. For such body types, consequently the look-up tables may already provide the difference in fuel consumption to be expected compared to the value declared for the combination with the standard body or semi-trailer. These values can be calculated using VECTO with a set of generic lorries and the $\Delta C_d xA$ results summarised in look-up tables gained from CFD simulation and/or from physical CST. Factors to account for effects of accumulated aero devices on a trailer may be included separately in the look up tables. An example for combined effects from boat-tails and side skirts is shown in chapter 3.3.2.4.

Recommendation:

Look up tables for reduction rates of the air drag value against the design of the standard semi-trailers is an interesting approach at least for a first phase of a certification to provide cost efficient options to certify major improvements due to add on parts. The look-up table has to be open to add certified components to incentivise R&D and to be technology neutral.

Generic functions can furthermore be used to scale ΔCdxA values e.g. from CFD for a certain body type to other dimensions of the body or the trailer within a family concept.

3.3.4 Certification of add-on parts

Certified components may complement the look-up tables described in chapter 0. Certainly, certified air drag reduction rates for specific components could be used also without look up tables for standard values. If a sufficient number of manufacturers is willing to certify their products, standard values are not needed. With a suitable certification process, the resulting air drag reduction rates will be more reliable than with the standard value method.

Candidates for component certification are add-on-pieces as boat tails, side and underfloor panels. The certification should provide the air drag reduction rate compared to a standard body or trailer without the add-on-piece.

Thus, the options for certification of such components are the same as for the entire body or trailer, i.e.

a) Physical measurement in the CST with standard body or trailer without and with the product to be certified,

b) CFD simulation of generic lorries with standard body or trailer without and with the product to be certified.

Option b) would be applicable, if CFD is also introduced for the entire bodies and trailers. Option a) is always a fall-back option if no fast progress in CFD based certification for bodies and trailers is made. The CFD-based approach has the big advantage against the CST method to be able to provide also effects of the yaw angle on the air drag in form of yaw polar curves. These curves can be used as input to the VECTO simulation. Since first CFD analysis showed for several components a high relevance of the yaw

[5] The main CO2 reduction potential due to improved air drag is expected at bodies and trailers which drive rather high velocities and have rather high shares in the fleet. Thus, semi-trailers and trailers used in long haul operation on highways are the main candidate for the consideration of air drag in a certification process.

angle, the use of a yaw polar curve based on the simulation of some yaw angles between 0 and 9°C would increase the accuracy of the results (chapter 3.3.2.2). In case of certification of single components, the reduction rates against the standard trailer will be available. Factors to account for effects of accumulated aero devices on a trailer may be included separately in the look up tables.

Recommendation:

It is suggested to use – at least in the long term – a CFD based method for component certification which provides air drag results for different yaw angles to incentivise all relevant areas of aerodynamic optimisation. As fall-back option the physical CST is applicable but has limited accuracy to identify small changes in $C_d{}^*A$. CFD or CST should be used to generate the differences in the air drag to standard bodies or trailers caused by the certified add-on piece. The recommendations made for CFD and for CST testing are applicable also here.

3.4 Components not related to the body or trailer

The input data for VECTO has to be completed with all component data representing the lorry (engine, transmission, axle, retarder, auxiliaries and tyres).

The most representative CO_2 reduction rates for specific bodies and trailers are expected, if the lorry related input data is representative for the real-world situation. Thus, no “standard value” but a “generic value” approach should be used to define the representative lorries. Since aero packages are meaningful in long haul operation, typical long-haul configurations of the lorries should be selected. These are typically better than the average in a group [38] and may be defined by a vehicle in or below the median of the future monitoring data base per vehicle group. The way forward to set up standard vehicles could be to use first the set of generic vehicle data already available in VECTO for software testing [39], [40]. These data could be adjusted e.g. every 3 years based on an evaluation of the monitoring data to meet the median of the reported component efficiencies of the last one or two years.

Due to the limited influence of the input data of the lorry for the VECTO simulation on the percent change of CO_2-emissions and fuel consumption from specific body and trailer designs, more sophisticated methods seem not to be necessary.

4 Methods to calculate the CO_2 results

Different methods are discussed here to calculate the differences in CO_2-emissions and fuel consumptions for a vehicle with specific body or trailer design and the primary vehicle with the standard body or trailer. Different options exist in following parts:

- Selection of input data
- Vehicle groups to be covered
- Calculation method

4.1 Selection of input data

Mass, rolling resistance and specific air drag of the body or trailer as well as extra energy saving devices, such as electric axles for regenerative braking have to be included in a certification process to cover the full potential for CO_2 reduction.

However, such a complete coverage of all parameters influencing fuel efficiency is complex and also costly. Thus, it is worth considering also simpler options, especially for a first phase and/or for vehicle groups with lower sales numbers and smaller shares in the energy consumption of the HDVs in Europe.

Table 15 shows typical shares in total energy consumption of HDVs to identify the coverage of relevant energy consumers if simpler certification methods exclude single parts. E.g. for group 5 vehicles (semi-trailer-tractor combination) air drag has 35% share in the long-haul mission. With approx. 50% of air drag caused by the trailer some 17% of total energy consumption are related to the semi-trailer. Assuming 30% Cd*A reduction potential at the semi-trailer, this gives some 5% CO_2 reduction potential[6]. In comparison, energy lost in braking is 17% in this mission with some 50% share also in braking, maximum energy recuperation from braking at a semi-trailer with an electric axle is less than 8%.

Table 15. Typical shares in total energy consumption of HDVs (reference payload)

Vehicle	Cycle	Gear-box	Retarder drag	Axle losses	Rolling resistance	Air drag	Auxiliaries	Braking
Group 2 (Rigid lorry, 12t TPMLM)	Long Haul	3%	0%	5%	30%	46%	4%	12%
	Region. Del.	4%	0%	5%	22%	49%	6%	13%
	Urban Del.	4%	0%	5%	22%	25%	11%	34%
Group 5 (tractor semi-trailer)	Long Haul	3%	1%	4%	35%	35%	4%	17%
	Region. Del.	4%	1%	5%	30%	31%	4%	25%

[6] Values represent only the orders of magnitude.

4.1.1 (A) Simplified method based on mass and RR only

The mass of the vehicle and the rolling resistance of the tires can be determined easier and more accurate compared to the air drag. For bodies, only weight would remain as variable input parameter for VECTO and measures for mass reduction are rather expensive and limited in the reduction potential. Thus, it seems not to be an attractive approach for bodies. However, the mandatory consideration of mass and RRC would be a cost-efficient way to incentivise more fuel-efficient trailers and may be used in a first phase.

Candidates for such a regulation are the box-body trailers for tractors in hard shell and as curtain siders. Nevertheless, since air drag is not covered, which causes more than 30% (update with new results) of the total driving resistances and has also a quite high reduction potential, this option has limited potential for CO2-reduction in long haul transport. Thus, it is not a preferable option for a long-term strategy. Table 16 summarises the input data needed for Option (A)

Table 16. Input data needed for option (A) for bodies and trailers compared to the primary vehicles

	Primary vehicle	Complete(d) vehicle
Mass	Calculated with standard body or trailer	Weighing of total vehicle
RRC	RRC values of specific tyres according to Annex X	As for primary vehicle
Cd*A	CST test with standard body or trailer according to Annex VIII	none
Others	All input defined for the manufacturers record file	None
Coverage of reduction potential		<50% (1)

(1) Potential for air drag reduction similar as for RRC, potential for mass reduction is limited, brake energy recuperation not covered.

4.1.2 (B) Method based on mass, RRC and C_dxA influences of add-on parts

In addition to the mandatory consideration of mass and RRC also the effect of add-on pieces on the air drag could be considered quite cost-efficient using look-up tables and/or certified aero-devices (see chapters 0 and 3.3.4). Since this approach covers a broader range of CO_2 reduction potentials especially relevant for semi-trailers, it seems to be the better way to incentivise more fuel-efficient trailers compared to a pure mass and RRC based approach.

Table 17. Input data needed for option (B) for bodies and trailers compared to the primary vehicles

	Primary vehicle	Complete(d) vehicle
Mass	Calculated with standard body or trailer	Weighing of total vehicle
RRC	RRC values of specific tyres according to Annex X	As for primary vehicle
Cd*A	CST test with standard body or trailer according to Annex VIII	C_d*A reduction from look up tables for add-on pieces (1)
Others	All input to the simulation tool defined in Annex III	None
Coverage of reduction potential		<80% (2)

(1) See chapters 0 and 3.3.4 for details. In addition, alternative bodies, such as tankers or flat-beds may be covered if needed.

(2) Only part of potential for air drag reduction covered (the one from add-on pieces), brake energy recuperation not covered

4.1.3 (C) Method considering all parameters

If the air drag reduction is measured or simulated for the entire body or trailer, an overall optimisation of the aerodynamic design is incentivised. This includes the shape of the body, underfloor, wheel houses, wheels and tyres, accessories like spare tyre and toolbox etc. Thus, a broader potential for C_d*A reduction exists with method (C).

The consideration of extra energy saving parts, such as an electric axle would lead to a complete coverage of the potentials for trailers. Such additional fuel saving components may be covered by a separate certification process or by direct simulation in VECTO.

An electric axle may be simulated in VECTO similar to the hybrid vehicle model currently developed in [41]. How the method to be developed for hybrid lorries and busses can be applied for trailers needs to be analysed when the method is ready.

Nevertheless, the use of electric energy in a trailer depends very much on the electrified auxiliaries mounted on the trailer as long as the electric system and its controllers are not aligned with the tractors electric system[7]. Thus, a separate certification process may be the better approach for the beginning. For components which produce electric energy as an output and which do not need deep integration with other components, the test

[7] To develop standards for common electric systems of hybrid lorries and hybrid trailers may take quite long and seems to be realistic only if higher shares of hybrid lorries are on the road.

procedure could just measure the electric energy for the VECTO mission profiles. The electric energy produced could be converted by generic alternator and combustion engine efficiency values to a fuel and CO_2 saving value.

The ideal procedure would take place on a chassis dyno, where braking events from the VECTO missions can be reproduced, since in on-road tests a standard braking power trajectory can hardly be followed. If existing chassis dynos could be used for such tests needs to be analysed. As an alternative, the electric power produced as function of the brake power may be tested to interpolate the overall effects later based on the braking power simulated for generic vehicles in VECTO.

Table 18 summarises the input data needed for option C. If ambitious efficiency standards for bodies and trailers are introduced, option (C) seems to be the most suitable method, since a high number of possible technologies to reduce energy consumption can be covered.

Table 18. Input data needed for option (C) for bodies and trailers compared to the primary vehicles

	Primary vehicle	Complete(d) vehicle
Mass	Calculated with standard body or trailer	Weighing of total vehicle
RRC	RRC values of specific tyres according to Annex X	As for primary vehicle
Cd*A	CST test with standard body or trailer according to Annex VIII	C_d*A reduction from simulation or CST
Others	All input to the simulation tool defined in Annex III	Energy recuperation from standard tests procedures
Coverage of reduction potential		<100% (2)

(1) The experience with lorries showed, that always new technologies to be covered show up, especially when CO2 limits are introduced and make pressure on R&D of fuel saving technologies. The same can be expected for trailers if a CO2 limit scheme is introduced.

Recommendation:

If a determination of influences of bodies, semi-trailers and trailers on the CO2 emissions from lorries shall be implemented before a cost efficient and robust method for air drag determination is elaborated, the “Option B) Method based on mass, RRC and CdxA influences of add-on parts” is a good compromise since mass and RRC can be determined with low efforts and effects of side skirts, boat-tails etc can be attributed either by generic values or by certification of such components.

Due to the high influence of air drag, the complete method (Option C) will bring the highest incentives to optimise bodies, trailers and semi-trailers and should be the longer-term target.

4.2 Vehicle groups to be covered

Figure 59 gives an overview on the combinations of rigid lorries, trailers and semi-trailers covered in regulation (EU) 2017/2400. The specific bodies and trailers may be classified according to the same system if they shall be covered by an efficiency regulation in future. The combinations show, that e.g. boat tails for bodies and trailers are reasonable only, if not a trailer is added after the body or semi-trailer.

In the group of rigid lorries, a lot of different types of bodies exist, the annual mileage on highways is rather low, the tire RRC is already fixed from the primary lorries. Thus, the CO_2-reduction potential for these vehicle groups due to improved bodies is limited, especially since rigid lorries which are running more on long haul operation typically carry a trailer.

The conditions for semi-trailers and trailers are much more favourable for improving the energy efficiency by a regulation. Tires from the semi-trailers are selected by the trailer manufacturers or their customers, more options exist to reduce air drag - at least if the semi-trailers are not used in EMS – and also electrified axles could be mounted.

Mass reduction certainly is an option for all bodies and trailers but is a rather expensive measure for CO_2-reduction. In [42] for weight reduction on trailers approx. 700 € per % CO_2 reduction, for improved tires 30€/% and for boat tails 260€/% are given.

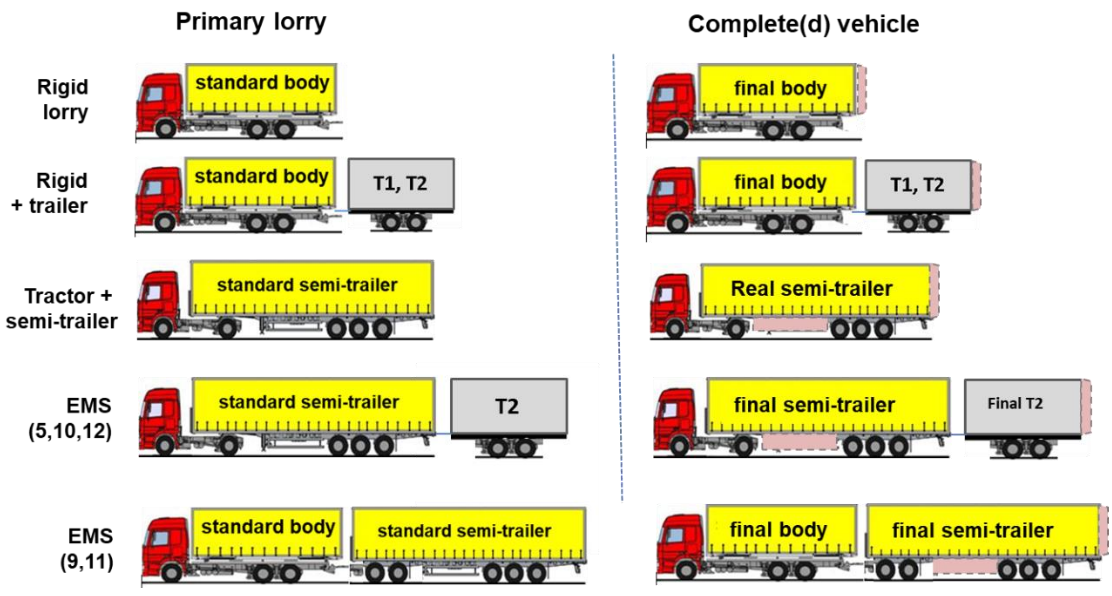


Figure 59. Overview on relevant vehicle configurations considered in Regulation (EU) 2017/2400 for primary vehicles and possible extension to complete(d) vehicles

Table 19 gives an overview on bodies, trailers and semi-trailers categories for which standard dimensions etc. are defined (Annex I of Regulation (EU) 2017/2400). Here also “B II” bodies are included, which are allocated to medium lorries from 5t to 7.4t TPMLM. The currently drafted vehicle group definitions for lorries are listed in Annex I.

Table 19. Overview on standard bodies, trailers and semi-trailers defined in Annex I of Regulation (EU) 2017/2400 (draft including medium lorries also)

Abbrev.	Vehicle	Corresponding lorry groups
R	Rigid & standard body	1, 2, 3, 4, 9, 11, (16) (1)
BII	ML2, ML3, ML4	
B1		1
B2		2
B3		3
B4		4
B5		9, 11
		2, 4
T1	Standard trailer	2
T2 (2)	Standard trailer	4, 5, 9, 10, 12
	Tractor + semi-trailer	
ST	Standard semitrailer	5, 9, 11
D	Standard dolly	9, 11

(1) Vehicle group 16 (8x4 vehicles) are in VECTO allocated only to the construction cycle and are simulated with a generic CdxA.

(2) In Regulation (EU) 2017/2400 the standard trailer T2 is defined as a center axle trailer with 18t TPMLM. For a Co2 certification of trailers it is reasonable to cover other types of trailers (e.g. drawbar trailers) in this mass segment as well.

(3) To be completed with results from task 1, when available

The share of the different trailer types in the total fleet of trailers and semi-trailers is shown in Table 20 as a results from task 1. Since more trailers and semi-trailers than tractors are registered, the average annual mileages and mission profiles of the different types cannot be estimated with reasonable accuracy with existing data and thus the shares in the overall CO2 emissions cannot be assessed. Nevertheless, the semi-trailers with a box type body (curtain, reefer and closed box) have certainly the highest share in mileages and also high reduction potentials and thus are first candidates for inclusion into a regulation.

Table 20: shares of different trailer types in the fleet of trailers and semi-trailers in EU 28 (source: task 1 report)

Body type	Semi	Full
Curtain	32%	6%
Reefer	12%	1%
Closed Box Van	9%	1%
Tipper	8%	5%
Chassis	5%	5%
Tank & Bulk	4%	1%
Other	5%	7%

For rigid trucks the vehicles with box-bodies seem to be first candidates, since for these the CO2-factor method would be applicable.

4.3 Calculation method

As mentioned before, the input data for possible VECTO simulations should provide the differences in mass, air drag and RRC to the standard (semi-) trailers or bodies.

Consequently, the results provided by VECTO for specific bodies and (semi-)trailers could show the difference in CO_2 emissions to a vehicle equipped with the standard bodies or (semi-)trailers. Absolute CO_2 values are not very meaningful for trailers and semi-trailers, since the absolute value depends a lot on the lorry.

The "CO2-Ratio"[8] would define the VECTO result with the specific body or trailer divided by the result with the standard body or standard trailer.

$$\boldsymbol{CO2_{ratio}} = \frac{\boldsymbol{CO2_{Real\ body\ or\ trailer}}}{\boldsymbol{CO2_{Std.\ body\ or\ trailer}}}$$ [-] **Equation 3**

$$CO2_{reduction} = (1 - CO2_{ratio}) * 100$$ [%] **Equation 4**

Different options to calculate the "CO2-ratio" have been analysed.

For buses the "CO2 Factor Method" was developed. This method multiplies the CO2 value of the primary bus with a "CO2-Factor". The CO2-Factor is calculated similar to the CO2-ratio shown above (see Equation 3 below).

To differentiate between the application for a complete(d) vehicle and trailers, we use following definition for the time being:

CO2-Ratio .... Ratio of the CO2-value from real trailer to standard trailer use

CO2-Factor...... Ratio of the CO2-value from real bodies to standard body use

CO2-factor method…application of CO2-Factor or CO2-Ratio

The CO2-Factor seems to be the most flexible option applicable to all types of vehicles. The "CO2 Factor Method" will most likely also be used for buses [43].

4.3.1 CO2 Factor Method

The "CO2-Factor Method" is the result of 3 VECTO runs. One with the real body or (semi-) trailer, the other with the standard body or (semi-) trailer.

Depending on the vehicle group, the input data for the vehicle differs.

[8] With this definition, the "CO2-Ratio" is similar to the "CO2-Factor", introduced for buses but may be calculated with different methods. To differentiate between the application for buses and for bodies and trailers, for the time being a different nomenclature is used.

4.3.1.1 Rigid lorries

VECTO would calculate the CO_2-value for the primary motor vehicle using all component input data available at this specific stage together with the standard bodies as input for the simulation tool. The simulation is performed as already done for lorries exceeding 7.5t TPMLM in Regulation (EU) 2017/2400. This method would be similar for primary lorries and for primary buses.

Since confidential data, i.e. the engine fuel map and the loss maps from the transmission, shall not be forwarded to 2nd stage manufacturers (see chapter 2), the CO2-Factor method is applied. The CO2-Factor is the ratio of the CO_2 value the vehicle has with the final body to the CO_2 value the vehicle has with the standard body. For the CO2-Factor calculation instead of the confidential data generic values are used. All other lorry related data remains the same (rated engine power, transmission ratios, tyres RRC, etc.). Since the same generic data is used to calculate the denominator and the enumerator, the CO2-Factor shows the relative fuel efficiency between real body and standard body with quite high accuracy.

$$CO2_{Ratio} = CO2_{Factor} = \frac{CO2_{GenChassis,RealBody}}{CO2_{GenChassis,GenBody}}$$ **Equation 5**

For rigid trucks the calculation of the CO_2 and fuel consumption values of the complete(d) vehicle would be a valuable customer information. This result can be produced by multiplication of the CO_2 and fuel consumption values from the primary vehicle with the CO2-Factor.

$$CO2_{final} = CO2_{primary\ vehicle} \cdot CO2_{Factor}$$ **Equation 6**

with

$CO2_{final}$ .... CO_2 value in [g/km] for the vehicle equipped with his real chassis and final body and equipment. Values in [g/t-km] and [g/pass.-km] can be derived from this value in the software.

$CO2_{primary\ vehicle}$ .... CO_2 value in [g/km] for the vehicle equipped with his real chassis and with standard body

$CO2_{GenChassis,RealBody}$ ..... CO_2 value in [g/km] for the vehicle equipped with the final body and equipment but with generic data for the confidential data from the primary lorry.

$CO2_{GenChassis,GenBody}$ ..... CO_2 value in [g/km] for the vehicle equipped with the standard body and with generic data for the confidential data from the primary lorry

$CO2_{Factor}$ .... Ratio of $CO2_{GenChassis,RealBody}$ to $CO2_{GenChassis,GenBody}$ representing the relative change in CO_2 emissions caused by using the final body instead of the standard body in the CO_2 calculation.

To calculate the CO_2-Factor the relevant, and non-confidential input data for the simulation tool from the Primary vehicle can be forwarded to the final stage manufacturer in a standardised file format in the “Primary vehicle Information File (PIF)” and has to be completed by vehicle specific input data on mass and air drag of the complete(d) vehicle.

4.3.1.2 Trailers and Semi-Trailers

While the body is directly connected to the chassis of a rigid lorry, any lorry fitting for the trailer design can carry trailers and semi-trailers.

Consequently, the data from the primary rigid lorry used in the CO2-Factor method for rigid trucks, should be replaced by generic data for a typical lorry carrying the specific trailer. Certainly, also no final CO_2 value should be produced but only the CO2-Factor which is named here CO2-Ratio.

An advantage of using VECTO to calculate the CO2-Ratio is, that the results will always be in line with future updates of the VECTO software. Thus, also hybrid functions, waste heat recovery etc. would be available. Furthermore, updates of the generic lorries can be made with rather low efforts (e.g. reduce air drag values etc. approx. every 3 years to maintain representative vehicle technologies for the lorries, see chapter 2).

$$CO2_{Ratio} = \frac{CO2_{GenChassis,RealBody}}{CO2_{GenChassis,GenBody}}$$ **Equation 7**

4.3.1.3 Application

For a later regulation, the VECTO software can be extended by a GUI for bodies and trailers, where only the relevant data has to be entered (total mass, RRC of the tyres and air drag changes compared to the standard body or trailer). Also vehicle VIN, some technology information and certainly the manufacturer, production date etc. can be entered to produce a VECTO result file complete for certification. For bodies from rigid lorries, also the PIF has to be loaded to VECTO, which has to be provided by the manufacturer of the primary vehicle. For trailers and semi-trailers, VECTO could allocate the generic data automatically. Such an integrated software solution seems to be more robust against errors from the manufacturers than the need to do several VECTO calculations or manual interpolations from table values.

The accuracy of the method was tested using following data set:

Generic vehicle for HDV group 4 with following variations:

- 2 different sets of fuel maps and torque loss maps for the gear box and the axle (“Spec1” better than the values used for the generic vehicle, “Spec 2” which is worse than the generic vehicle)
- Mass reduced by 800kg compared to the generic vehicle
- C_d*A reduced by 0.5m² compared to the generic vehicle

The variations in mass and C_d*A have been considered in the upper range of a realistic difference between an individual body compared to the generic body. Thus this analysis gives an estimation of the worst case accuracy of the CO2-Factor method for the analysed vehicle configuration. In the VECTO simulation, the CO2-Factor method was executed in 3 consecutive VECTO calculation to produce the “$CO2_{primary\ vehicle}$“, the “$CO2_{GenChassis,RealBody}$“ and the “$CO2_{GenChassis,GenBody}$“. The results are compared to the VECTO calculation using the vehicle data of the complete lorry. Deviations were below 0.3% in all combinations of settings and missions (Table 21).

Table 21. Deviation of the CO2 [g/km] calculated with the CO2-Factor method to the result from a direct VECTO calculation

Efficiency data	Body	Deviation extended factor method to full VECTO								Average
		LH-L	LH-R	RD-L	RD-R	UD-L	UD-R	MU-L	MU-R	
Spec 1	-800 kg	0.0%	-0.1%	-0.1%	-0.1%	0.2%	0.0%	0.2%	-0.1%	**0.0%**
Spec 2	-800 kg	0.1%	0.0%	0.0%	0.0%	-0.1%	0.3%	0.1%	-0.1%	**0.0%**
Spec 1	-0.5 m²	-0.2%	-0.2%	-0.4%	-0.2%	0.0%	0.0%	0.3%	-0.1%	**-0.1%**
Spec 2	-0.5 m²	0.0%	0.0%	-0.2%	-0.1%	-0.2%	0.0%	0.2%	-0.1%	**0.0%**

4.3.1.4 Comparison with the draft method for buses

In a parallel project for DG Grow, the calculation methods for buses are elaborated, [41]. For the buses the "CO_2-Factor" method was introduced as calculation method into the draft amendment of Regulation (EU) 2017/2400. Figure 60 gives an overview on the stages of vehicle completions relevant for CO_2 determination. The figure includes buses to demonstrate the possibility to apply similar methods for bodies of rigid lorries and for buses.

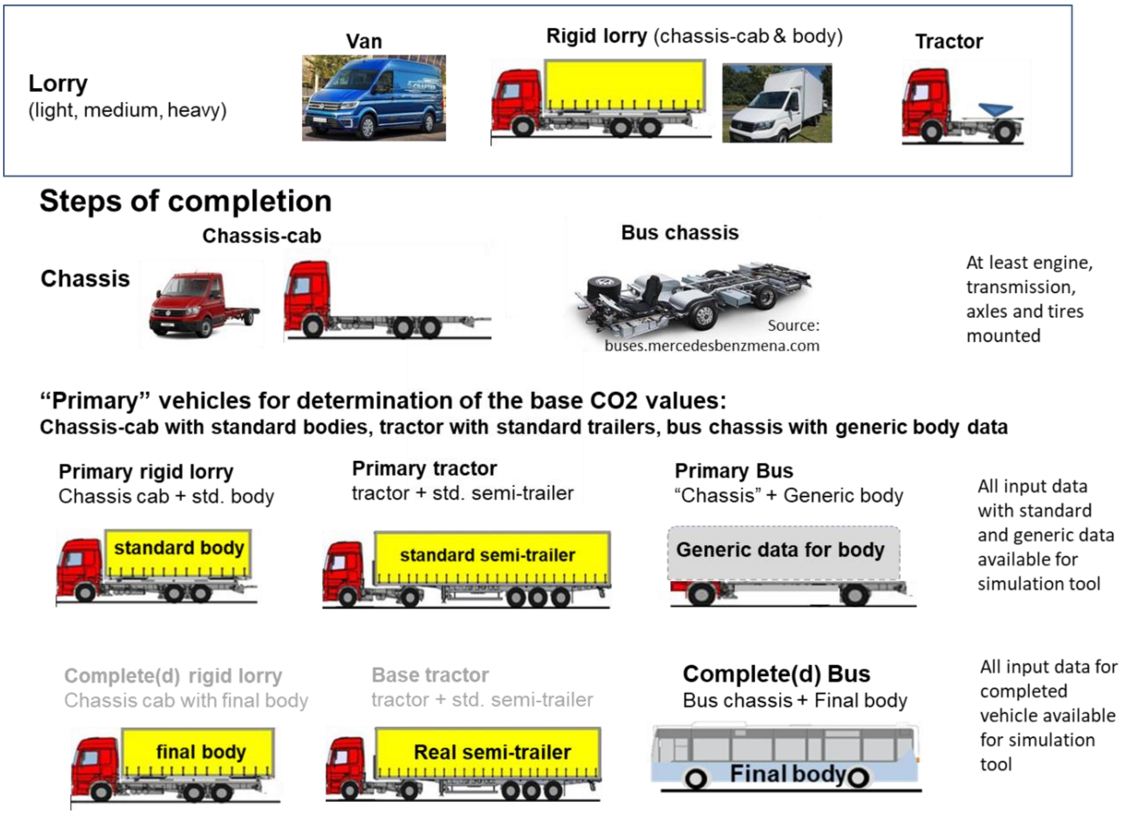


Figure 60. Schematic picture of the vehicle class definitions described above

A significant part of the aerodynamic drag force of a vehicle configuration is influenced by the cross-wind sensitivity of the geometry, i.e. how much the C_d*A value is affected by the change in yaw angle ("polar curve", chapter 3.3.2). This physical influence is fully modelled in the VECTO software, assuming an average wind of 3 m/s flowing uniformly distributed from all directions and currently using a generic polar per main type of vehicle geometry (rigid lorry, rigid lorry and trailer, tractor-semitrailer, bus). Table 22 exemplarily depicts the distribution of yaw angles weighted according to the shares in total air drag in the VECTO long haul cycle. Yaw angles cover a range of up to 10° with the average value at some 4°.

Table 22. Yaw angle distribution simulated for a typical group 5 (tractor semitrailer) vehicle in the VECTO long haul cycle

yaw angle distribution [°]										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
5.6%	11.7%	9.8%	12.7%	15.3%	15.8%	17.1%	10.7%	1.0%	0.2%	0.1%

Using an extended VECTO software for bodies and for (semi-)trailers could take into account the specific polar curves as determined via CFD. Polar curves could be generated by performing simulations for the angles 0°, 3°, 6° and 9° (as done in the work described in section 3.3.2 of this report) to determine the 3rd order polynomial as input to VECTO.

Table 23 gives a comparison of change in CO2 from semi-trailers with boat tail and/or side-skirts calculated by two versions of the FAT tractor geometry and both using the generic VECTO polar curve and the specific polar curve from CFD as well. Especially the effect of a combination of both aero-devices is underestimated if CO2 is not simulated in VECTO based on the specific polar curve of the total vehicle.

Table 23. CO2 Emissions of semi-trailer variants determined based on generic or specific polar curves determined by CFD

Description vehicle	**CO2 [g/km]**		**CO2 vs. Standard vehicle**	
	polar curve		polar curve	
[-]	generic	specific	generic	specific
Standard FAT	897.9	906.4	= basis value (0%)	
Standard FAT + BT	883.8	888.4	**-1.6%**	**-1.1%**
Standard FAT + SK	889.8	889.7	**-0.9%**	**-0.9%**
Standard FAT, BT+SK	875.2	870.8	**-2.5%**	**-3.0%**
FAT-Extended, Standard	897.9	896.5	---	
FAT-Extended, BT	884.2	881.2	**-1.5%**	**-1.9%**
FAT-Extended, SK	889.8	881.9	**-0.9%**	**-1.8%**
FAT-Extended, BT+SK	875.2	861.4	**-2.5%**	**-4.1%**
BT … Boat tail, SK … Side skirts				

4.3.2 Matrix Interpolation

To avoid the mandatory application of VECTO for a CO2-Ratio between real bodies and trailers and the standard ones, also interpolations from look-up tables are an option.

Since CO_2 emissions in [g/km] show a quite linear dependency on mass, RRC and air drag some grid points are sufficient to interpolate the CO_2 reduction rates for a body or trailer as function of the mass, RRC and air drag. This method is also quite accurate but manual interpolations by the body manufacturer from 3-dimensional tables may lead to several errors in the result. Thus, also such look-up tables should be packed into a software. Such a software basically can have the same functionalities as described in chapter 4.3.1.3. Just the computation time would be shorter for the interpolation than for two full VECTO runs.

If the CO2-Ratio should be produced for all combinations of loading and missions for each vehicle group, a high number of interpolation tables are needed. All of them have to be calculated as pre-processing work with VECTO using in principle the generic input data needed also for the CO2-Factor method. Thus additional effort is needed to produce and to maintain the look-up tables compared to the CO2-Factor method.

In addition, the influences of the yaw angle on the air drag of bodies and trailers cannot be considered accurately with the matrix interpolation method unless some post-processing of CFD results (chapter 3.3.2) is made to calculate the air drag for the average yaw-angle distribution[9].

Therefore, the matrix interpolation seems to be less practical than the CO2-Factor method but would also be sufficient for the demands.

The accuracy of the method was tested using a 8-point matrix with only minimum and maximum values as grid points with the corresponding CO2-emission values calculated with VECTO for the generic group 6 vehicle from the data set in [38].

When interpolating CO_2 values for different target vehicle properties (reasonable combination of Cd*A, mass and RRC), the difference to the result calculated with VECTO directly was 0.3% (Table 24).

Table 24. Matrix for air drag, mass and RRC and interpolated properties ("Target")

	C_d*A [m²]	curb mass [kg]	RRC [-]	Deviation
Target	5.57	7500	0.0055	-0.30%
Matrix max.	8.70	10000	0.0080	
Matrix min.	4.18	4000	0.0030	

4.3.3 Efficiency Classification

If the rolling resistance values would be available only as averages for the tyre label value and if also the air drag measurement or simulation proves to be not very reliable

[9] VECTO calculates the yaw angle distribution for an average ambient wind of 3m/s and an uniform 360 distribution of the wind direction for the various vehicle speeds. In the CO2-Factor method, this functionality of VECTO could be used directly by entering the yaw polar curve gained for the body or trailer as software input, as described in chapter 4.3.1. For the matrix interpolation, the calculation needs to be done in an extra software.

in showing small changes, a classification may reflect such limitations in the accuracy better than a detailed calculation.

Efficiency classes may be defined for bins of C_d*A, RRC and mass differences to standard trailers or bodies. The overall efficiency class could then be allocated according to the average of the single component efficiency classes of the body or trailer.

A corresponding regulation for e.g. semi-trailers could be the demand of minimum efficiency class levels to certify semi-trailers (e.g. better than class D(=4) from 2025 on, better than class B(=2) from 2030 on,..).

Recommendation:

The CO_2-Factor method seems to be a suitable method for bodies, trailers and semi-trailers. For trailers and semi-trailers, the method would deliver the ratio of CO_2 emissions compared to the standard trailers, for rigid lorries the CO_2 emissions of the complete(d) vehicle can be calculated with this method. The matrix interpolation method has a similar accuracy but some shortcomings in coverage of possibly more complex future technologies. If the CO_2-Factor method is selected for buses in future, using the same approach also for bodies and trailers would reduce the complexity of the regulation and of the corresponding software VECTO.

5 Responsibilities

Depending on the aims of a regulation for bodies and trailers, responsibilities have to be defined for:

a) Getting a certificate for the use of the VECTO software (for CO2-Factor, Matrix interpolation or for any other method to produce CO2-Ratios)

b) Getting a certificate for CFD simulations

c) Declaring or certifying other relevant vehicle data (mass, RRC)

d) Producing CO_2 values (for rigid trucks) or CO2-Ratios (for trailers) for the vehicle certification

e) Proving the production standards e.g. by CoP testing

f) Delivering the resulting CO2 values or CO2-Ratios to a data base for monitoring of the fleet development

g) Running and analysing the monitoring data base

h) Meeting standards for minimum or fleet average efficiencies

i) Possible independent 3rd party tests

The responsibilities for several certification steps may be outsourced by small manufacturers. Nevertheless, the responsibility for the process and for the CO2 results in the vehicles certification documents is seen at the manufacturer of the trailer or at the (final stage) body manufacturer. Thus, also the related additional costs have to be covered by the manufacturer and thus finally by the customers.

For trailers and bodies, where large numbers of similar models are produced, these extra efforts most likely can be overcompensated by fuel savings due to more efficient vehicle operation.

For an efficient operation of a body and trailer certification and depending on the methods selected, the Commission may provide:

- Table values for add-on pieces reducing aerodynamic drag of bodies and trailers
- A certification process of add-on pieces reducing aerodynamic drag of bodies and trailers
- Generic CAD models for the lorries needed for CFD simulation together with reference results for several aerodynamic adjustments
- A method and the related infrastructure to certify providers of CFD-simulation work
- A software with a user-friendly GUI and an interface to data base systems to allow an efficient calculation of the CO_2 results for small and for large manufacturers of bodies and trailers.

6 Summary and Conclusion

Several options for the determination of CO_2 values for bodies and trailers were analysed. We draw following conclusion from the work:

- For bodies and trailers a relative change of CO_2-emissions compared to the standard bodies and trailers is the most practical output
- For bodies of rigid lorries, also the final CO_2 and fuel consumption values for the complete(d) vehicle can be provided for customer information
- These the final CO_2 and fuel consumption values can be calculated by the CO_2-Factor method. The matrix-interpolation method shows similar accuracy but seems to need more efforts for elaboration and maintenance and has limits in covering side wind effects on the air drag and including additional features like electric axles.
- The input data can be produced with low extra efforts for the mass (weighing of the vehicle) and for the rolling resistance (RRC values according to Annex X of regulation (EU) 2017/2400
- The change of the air drag compared to the standard bodies and trailers could be assessed by look-up tables and/or by component certification for add-on pieces such as boat tails from trailers with rather low efforts for the manufacturers of the bodies and trailers
- To incentivise the aerodynamic optimisation of the entire design of the bodies and trailers, a CFD based method seems to be more attractive than physical tests. CFD can provide also influences of side wind on the air drag with a reasonable effort, which is a relevant area for future improvements of vehicle designs. The methods for using CFD to produce certified air drag results for bodies and trailers should to be further elaborated.

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Annex 1 – Vehicle groups in Regulation (EU) 2017/2400

Vehicle groups for "Medium Lorries"

Description of elements relevant to the classification in vehicle groups			Allocation of mission profile and vehicle configuration						
Axle configuration	**Chassis configuration**	**Vehicle group**	Long haul	Long haul (EMS)	Regional delivery	Regional delivery (EMS)	Urban delivery	Municipal utility	Construction
RWD	Rigid Lorry (or tractor)	**ML2r**	R		R		R		
	Van	**ML2van**	I		I		I		
AWD	Rigid Lorry (or tractor)	**ML3r**	R		R		R		
	Van	**ML3van**	I		I		I		
FWD	Rigid Lorry (or tractor)	**ML4r**	R		R		R		

R	=	Standard body (BII for 4.1 to 7.4 tons)
I	=	Van with his integrated body
FWD	=	Front Wheel Driven
RWD	=	Single driven axle at rear
AWD	=	More than one driven axle

Vehicle groups for "Heavy Lorries"

Description of elements relevant to the classification in vehicle groups			**Vehicle group**	**Allocation of mission profile and vehicle configuration**						
Axle configuration	**Chassis configuration**	**P (tons)**		Long haul	Long haul (EMS)	Regional delivery	Regional delivery (EMS)	Urban delivery	Municipal utility	Construction
4x2										
	Rigid lorry (or tractor) **	> 7.4 – 7.5	**1s**[10]			R		R		
	Rigid lorry (or tractor) **	> 7.5 – 10	**1**			R		R		
	Rigid lorry (or tractor) **	> 10 – 12	**2**	R+T1		R		R		
	Rigid lorry (or tractor) **	> 12 – 16	**3**			R		R		
	Rigid lorry	> 16	**4**	R+T2		R		R	R	
	Tractor	> 16	**5**	T+ST	T+ST+T2	T+ST	T+ST+T2	T+ST		
	Rigid lorry	> 16	**4v*** **						R	R
	Tractor	> 16	**5v*** **							T+ST
4x4	Rigid lorry	> 7,5 – 16	**(6)**							
	Rigid lorry	> 16	**(7)**							
	Tractor	> 16	**(8)**							
6x2	Rigid lorry	all weights	**9**	R+T2	R+D+ST	R	R+D+ST		R	
	Tractor	all weights	**10**	T+ST	T+ST+T2	T+ST	T+ST+T2			
	Rigid lorry	all weights	**9v*** **						R	R
	Tractor	all weights	**10v*** **							T+ST
6x4	Rigid lorry	all weights	**11**	R+T2	R+D+ST	R	R+D+ST		R	R
	Tractor	all weights	**12**	T+ST	T+ST+T2	T+ST	T+ST+T2			T+ST
6x6	Rigid lorry	all weights	**(13)**							
	Tractor	all weights	**(14)**							
8x2	Rigid lorry	all weights	**(15)**							
8x4	Rigid lorry	all weights	**16**							R
8x6 8x8	Rigid lorry	all weights	**(17)**							

* EMS - European Modular System

** in these vehicle classes tractors are treated like rigid lorries but with specific curb weight of tractor
*** sub-group "v" of vehicle groups 4, 5, 9 and 10: these mission profiles are exclusively applicable to vocational vehicles

T	=	Tractor
R	=	Rigid lorry & standard body
T1, T2	=	Standard trailers
ST	=	Standard semitrailer
D	=	Standard dolly".

[10] Explanation: lorries with 7.4 to 7.5 tons are typically identical to those slightly above 7.5t

Bodies and trailers – development of CO_2 emissions determination procedure

Procedure no: CLIMA/C.4/SER/OC/2018/0005

Task 3: Detailed assessment and implementation plans for the most suitable and feasible methodology options

Report v4

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Date: 27/11/2019

This document contains 52 pages

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Acronyms and abbreviations

Acronym	Meaning
A/C	Air conditioning
Avrg	Average
CFD	Computational Fluid Dynamics
CO_2	Carbon dioxide
CoP	Conformity of Production
CST	Constant Speed Test
Curb weight	Total weight of a vehicle in driving condition but without loading and without driver
DES	Detached Eddy Simulation
ECU	Electronic control unit
EMS	European Modular System (trailer combinations for 60t TPMLM vehicles)
EU	European Union
η (Eta)	Efficiency, usually defined here as ratio from output work to input work of a component
FC	Fuel consumption
GEM	Greenhouse Gas Emissions Model, c/o USEPA
Gen.	Generic values used in VECTO (see table with definitions below)
GHG	Greenhouse gas
GUI	Graphical user interface
GVW	Gross vehicle weight…..curb weight plus payload and driver.
HDH	Heavy Duty Hybrid vehicle
HDV	Heavy-duty vehicle
HEV	Hybrid electrical vehicle
HVAC	Heating, Ventilation and Air Conditioning
LBM	Lattice Boltzmann Method
LES	Large Eddy Simulation
NA	North America
NS	Navier-Stokes
OEM	Original Equipment Manufacturer
RNG	Renormalization Group
RRC	Rolling resistance Coefficient
Std.	Standard values used in VECTO (see table with definitions below)
TPMLM	Total permissible maximum laden mass
TT	Tractor-semi-trailer combination
VECTO	Vehicle Energy Consumption calculation Tool
w/o	without

Definitions

Term	Definition
Chassis-cab	An incomplete vehicle with a cabin (complete or partial), chassis rails, power train, axles and tyres which is intended to be completed with bodywork, customised to the needs of the transport operator according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
CO_2-Factor	Ratio of two CO_2-values as results from VECTO for vehicles with the the final body and equipment in the nominator and the results for the generic body and equipment in the denominator.
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]
HDE	Heavy Duty Engine with type approval according to Regulation (EC) 595/2009 and its amending Regulations”
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
RM	Reference Mass = mass in running order -75kg (driver) +100kg according to Reg. (EU) 715/20107
TPMLM	Technically permissible maximum laden mass
Van	A lorry with the compartment where the driver and cargo area is located within a single unit, according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
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)
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
Light Bus	M1 and M2 not exceeding 5 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Medium Bus	M3 not exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009
Heavy Bus	M3 exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009

Term	**Definition**
Candidate body/ (semi-) trailer	Body or trailer to be analysed using the methods described in this document
Custom candidate body/ (semi-) trailer	Candidate body/ (semi-) trailer that differ from a Standard Body or Standard Trailer in in geometry, mass or tyres as defined in the Annex VIII of the Regulation (EU) 2017/2400
Definitions introduced for differentiation of steps in CO_2 determination:	
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
Primary Van	A Primary lorry of the category van with generic data for body and equipment for declaration of the vehicles CO_2-value.
Complete(d) Van	Van with its final body and equipment for declaration of the CO_2-factor.
Primary Bus	“Bus chassis” with at least engine, transmission, axles and tyres but with generic data for the body for declaration of the vehicles CO-value.
Complete(d) Bus	Bus with its final body, interior and auxiliaries 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.
Generic value	Input values for the CO_2 calculation tool for components where no component testing is foreseen (e.g. auxiliaries). Generic values reflect performance of average component technology.
Standard value	Input values for the CO_2 calculation tool in case that a component is not measured. Standard values reflect performance of worst case component plus a certain tolerance margin.
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

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Figures

1 Introduction

The interim report describes the activities within task 3 of the specific contract:

No 340201/2018/789725/SER/CLIMA.C.4

Bodies and trailers – development of CO_2 *emissions determination procedure*

Task 3 evaluated the applicability and feasibility of the methodology options defined and selected in task 2, referring to producing body and (semi-)trailer specific CO_2 results for single heavy-duty vehicles in a possible extension of Regulation (EU) 2017/2400.
The task is split into three main sub-tasks and all shall work on bodies for rigid HDV and for trailers:

- Methodologies definition regarding certification. Specific methodology have been defined for the three options (see sections 4.1, 4.2 and 4.3), focused on the applicability for certification, including test protocols and requirements in terms of equipment and software.

  Regarding the inputs for the certification options, the air drag resistance shall be taken into great consideration (excepting certification method A, see section 4.1). To model this resistance, the C_DxA value would be used as an input, and depending on the case, different ways to obtain this value would be used. These C_DxA values can be calculated using various methods (see 4.2 and 4.3); one of these methods, in order to simplify these calculations, are look-up tables.

  These look-up tables shall include standardised aerodynamic packages. These standards shall contain description of the aero parts, considering shapes, technical sizes and tolerances. Regarding this approach, C_DxA calculation would be based on deltas, with the baseline defined as the standard semi-trailer as per VECTO.

- Test protocols have been evaluated in terms of complexity and manageability, while equipment has been addressed in terms of availability, cost and accuracy. The goal of these evaluations is to achieve the reproducibility of the methodologies for all the stakeholders. This task must ensure objective decision-making when selecting methodologies.

- Analysis of the implementation of measures, considering the previous inputs.

2 Literature review

Task 1 in this project (*review of existing studies, data collection and identification of the characteristics and specific constraints of the sector*) had as an objective to research the bodies and trailers market in the EU. This research had its base in two main topics: the characteristics of the trailer and body building sector and the review of the existing legislation.

With regard to the certification of trailers, the existing regulations in the US, Canada, EU, Japan, China and Korea were compared, looking for the best approach possible for the EU. The model which might fit best the EU is the one in the US, which allows trailer manufacturers to use a simple equation. The equation uses as inputs the results from a coastdown test, tyre test, transmission and axle test, as well as off-cycle technologies, and has as the objective of determining the GEM equivalent GHG emissions without actually using GEM. This value corresponds to the simulated GHG emissions of the trailer in combination with a reference tractor.

Considering the work done in task 1, task 2 of the project (*identification and evaluation of the possible methodology options*) had the objective of elaborating options to produce body and (semi-)trailer specific CO_2 results for single heavy-duty vehicles. To achieve this objective, methods are defined to create the input data for the simulation tool VECTO for bodies and trailers in an efficient way; this input data being air drag, mass and rolling resistance.

In task 2, several options for the determination of CO_2 values for bodies and trailers were analysed, and found that a relative change of CO_2-emissions compared to the standard bodies and trailers is the most practical output.

The CO_2 Factor Method offers a solution similar to the one introduced for buses. The Factor for bodies and trailers is different from the one introduced for buses and thus, it has been called as CO_2 Ratio. The CO_2-Factor Method is the result of 2 VECTO runs, one with the real body or (semi-) trailer, the other with the standard body or (semi-) trailer. The calculation of this ratio differs whether the candidate vehicle is a rigid lorry or a trailer:

- Should a body is to be certified, the CO_2 Ratio would be calculated through the division of a VECTO CO_2 value obtained using a combination of generic data and real data of the candidate vehicle with a standard box divided by the same data modifying the values of mass and/or C_DxA (depending on the method used, see point…). In this case, the CO_2 Ratio can be multiplied times the CO_2 of the primary vehicle declared, which would lead to the CO_2 final value.

- If the vehicle to be assessed is a trailer, a similar procedure would be followed, using standard values for the denominator and real data for the enumerator. This would give a CO_2 Ratio.

The matrix-interpolation method is quite accurate as well, but seems to need more efforts for elaboration and maintenance and has limits in covering crosswind effects on the air drag and including additional features like electric axles.

The Efficiency Classification proposes that, if the measurements or simulations of the C_DxA show small changes or prove to be not reliable, and the rolling resistance values of the tyres are only available as averages for the tyre label, a classification would reflect such limitations. The classification would include the differences of the candidate vehicle from the standard.

To incentivise the aerodynamic optimisation of the entire design of the bodies and trailers, a CFD-based method seems to be more attractive than physical tests. CFD can also provide influences of crosswind on the air drag with a reasonable effort, which is a relevant area for future improvements of vehicle designs. The methods that are using CFD simulations to produce certified air drag results are now a days discussed in ACEA proposals and other Regulation proposals.

3 Overview

Three methods for the determination of the CO_2 emissions contribution of bodies and trailer were proposed in task 2. In order to materialise these testing methodologies, further explanations are needed. In this task 3, these methods are completely defined with many details, with their main aspects explained for the complete definition of testing procedures. The main aspects defined for each method are:

- Description of the testing method
- Inputs needed for the calculations
- Calculation method used
- Outputs generated in the calculations
- Roles and responsibilities

Some of the methods defined have, as part of the procedure, the utilisation of look-up tables for the definition of the C_DxA differences generated by certain add-ons. Regarding the generation of these look-up tables, the existing add-ons in the market shall be identified and analysed with the objective of defining their effect on the air drag resistance of the vehicle. These analysed add-ons do not necessarily have to improve the air drag resistance of the vehicle, as some of the add-ons provide the trailer with functionalities, but they have a negative effect on the aerodynamicity of the vehicle.

With regard to these add-ons, a standard add-ons catalogue is developed, with an eye on defining look-up tables for the ones with biggest effects on the air drag resistance of the vehicle. This catalogue differentiates between functional add-ons and air drag reduction add-ons.

If a manufacturer wants to certificate its own air drag improvement devices, apart from the existing add-on catalogue, it can be done by performing certified CFD (CFD simulation specifications still to be defined, see 4.3.3) or CST tests (per Annex VIII of the R (EU) 2017/2400). With these tests, manufacturers would be able to generate their own look-up tables with the related C_DxA improvements on the vehicle.

It is not enough simply to determine the effect of the individual add-ons, it is necessary to evaluate their contribution as a standalone system and their combined effect as part of a set of aero-features. This requirement is necessary because the change in C_DxA when mounting several of these add-ons altogether is likely to be different from the value resulting from the summation of each of those add-ons' individual contribution.

The different test methods defined are considered to be used in different situations, depending on the vehicle characteristics and the manufacturer. In order to facilitate the choice of the method which best suits the situation, a framework analysis was made with the definition of the different factors considered for the certification. Once these factors are defined, the methods are evaluated and classified considering these factors.

4 Test procedure

This section develops the three methods initially mentioned in the previous task to obtain the contribution on the mass, the RRC and the C_DxA of the body/trailer. The final goal of these methods though is to calculate a final CO_2 emission reduction of the candidate body or trailer as defined in section 5.3 of task 2. To this end, three different approaches are proposed, these are the CO_2 factor method, the interpolation method and the efficiency classification.

The interpolation method proposes a three-axis matrix including the mass, the RRC and the C_DxA. The body or trailer manufacturer has to interpolate the value of their candidate body or trailer to obtain a final value of CO_2 reduction.

On the other hand, the efficiency classification method proposes not to give a reduction in CO_2 but to give an overall efficiency class based on the differences from standard trailers or bodies.

The absolute CO_2 values are not very meaningful for trailers and semi-trailers, since the absolute value depends a lot on the motor vehicle that is used for the test. Furthermore, most of the aerodynamic improvements that a trailer or a body can get are more effective under crosswind conditions. Considering all of the above and considering that the CO_2 factor method will most likely also be used for buses, this method is the most developed herein.

The CO_2 ratio is obtained by the division of the VECTO result of a generic lorry with the candidate trailer or the body installed with the VECTO result of the same generic body with a standard box or trailer.

$$CO_{2\ Ratio} = \frac{CO2_{Candidate\ body\ or\ trailer}}{CO2_{Generic\ \ body\ or\ trailer}} \qquad [-]$$

It is assumed that the required data to obtain the generic VECTO result or PIF (Primary vehicle Information File) would be provided by the OEM and would be one of the inputs necessary for the certification (in the case of bodies) or would be directly allocated in the application (in the case of trailers and semitrailers).

In order to take into account the aerodynamic improvements at different yaw angles, these VECTO simulations should include the possibility of including a polar-yaw curve so the CO_2 reduction would be more noticeable.

Standard bodies and trailers for each vehicle class are defined in Annex 8 of the Regulation (EU) 2017/2400, with all the dimensions which are considered representative for the standardisation. Being so, a candidate trailer or body with the same specification as the standard body or trailer would have a CO_2 ratio of 1. Thus, any bodies or trailers that differ in geometry, mass or tyres (in case of a trailer) would be considered as a custom candidate. Custom candidates may vary in the kind of enclosure, curtain sider for instance, or the number of axles.

This reduction in emissions and consumption can also be provided as a percentage:

$$CO_{2_{reduction}} = (1 - CO_{2_{Ratio}}) * 100 \qquad [\%]$$

This method can be used for rigid lorries and for trailers and (semi-) trailers, and is of great utility as it overrides the effect of the parts of the vehicle which are not being analysed (e.g. the tractor in the case of trailers).

European Modular System (EMS) configurations shall also be considered. In these configurations, the contribution of the trailer can be insulated from the contribution of the pulling unit (whether it is a rigid lorry or a tractor-semitrailer combination.

For every different calculation method defined in this task follow the same process. Schematically, the process diagram for the certification shall be:

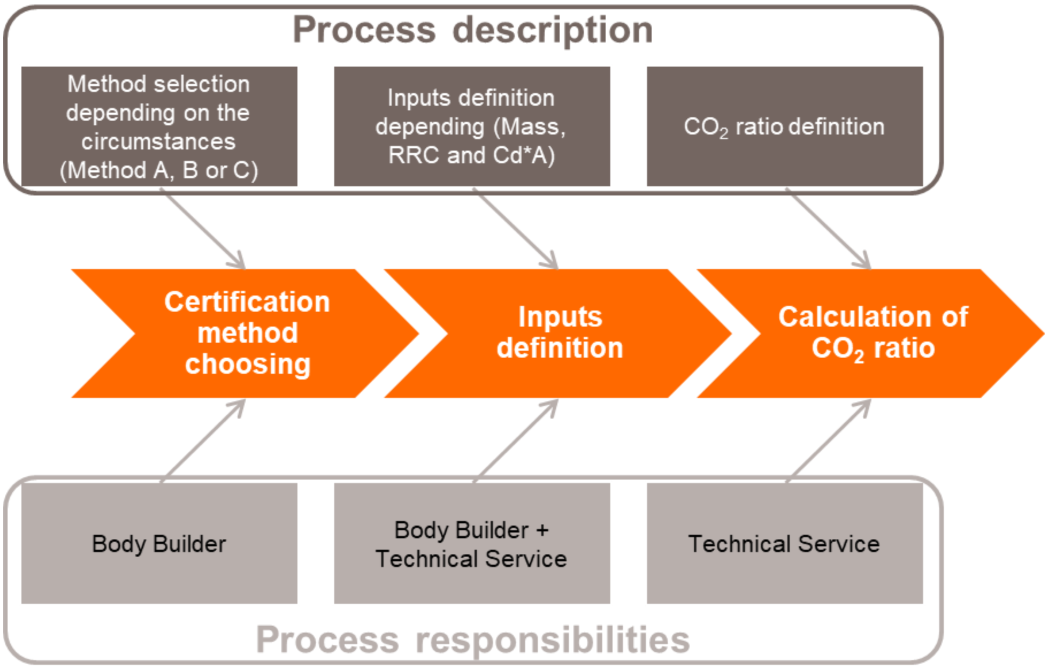

Figure 1: Certification process diagram

Similar to cases where the manufacturer is producing the CO_2 emissions value, the OEM has to be able to calculate the CO_2 ratio, but first a type-approval authority have to approve that the VECTO is used correctly. This shall simplify the calculations for different body or trailer variants, also reducing the costs for the OEM.

The evaluation of the correct use of the calculation tool by the manufacturer may be performed by means of a system based in an initial system of the internal procedures of the manufacturer, together with periodical random checks of calculations issued by the manufacturer. The responsible for this assessment and supervision shall be the Approval Authority, which may delegate this activity on their designated technical services. This procedure is similar to the one in place according to Regulation (EU) 2017/2400.

4.1 *(A) Simplified method based on mass and RRC only*

4.1.1 Description

This is the simplest method involving only the RRC for trailers and the mass for both bodies and trailers. As stated in the previous task, since the improvements in weight have small margin and are expensive, this method may not be the most suitable for bodybuilders. For instance, according to the work performed in the support for preparation of the impact assessment for CO_2 emissions standards for Heavy Duty Vehicles; Final Report [1], vehicles of group 5 show the following CO_2 reductions based on mass reductions:

Curb mass tractor [kg]	Curb mass semitrailer (standard) [kg]	Curb mass semitrailer (lightweight) [kg]
8229	7500	6500

Cycle	**Payload**	**Fuel consumption (standard) [l/100km]**	**Fuel consumption (lightweight) [l/100km]**	**Reduction [l/100km]**	**Reduction [%]**
Long Haul	low	25.3	24.8	0.49	1.9%
Long Haul	representative	33.5	33.0	0.49	1.5%
Regional Delivery	low	27.8	27.0	0.76	2.7%
Regional Delivery	representative	35.7	34.9	0.77	2.1%
weighted (group 5-LH)		31.3	30.8	0.52	1.7%

Since this method does not consider the option of including the variation of C_DxA, the files used in the CO_2 ratio calculation would include the C_DxA of the standard trailers or bodies. In order to reduce the error of the final CO_2 ratio, it would be preferred to apply this method only to dry freight, curtain siders and refrigerated trailers due to its geometric similarities with the Standard Bodies and Trailers.

4.1.2 Inputs

4.1.2.1 Mass

In the previous task, two different methods of obtaining the weight were presented. The first and most accurate one is a simple weighting while the second one is a calculation based on parts list. Currently, manufacturers declare a range of masses on their vehicle type-approval, together with the mass of the optional equipment. When a single vehicle is built, manufacturers usually calculate the masses on the basis of the theoretical calculation depending on the specifications of the vehicle. Other manufacturers may weigh every single unit. In any case, the mass declared in the COC is an official value, and is subject to control during the COP procedures, so it shall be representative enough of the actual mass.

Should the simple weighting be chosen as recommended, the trailer would be weighed directly while in the case of a body, the mass would be calculated through the difference between the corrected actual mass of the primary body and the final weight of the complete(d) lorry (as per paragraph 2 of Annex III of Regulation(EU) 2017/2400).

The list of accessories proposed to be considered at the time the weighting is performed is included in Appendix 4 of Annex VIII as follows:

- Side and rear underride protection

- Rear lamp holding plate
- Pallet box
- Spare wheels under the third axle
- One tool box at the end of the body
- Frame underfloor cover
- Mud flaps before and behind axle assembly
- Air suspension
- Disc brakes
- Tail lift
- Front spoiler
- Side fairings for aero

4.1.2.2 RRC

As specified in task 2, it is recommended to use the same method as described in Annex X of Regulation (EU) 2017/2400. Should the tyre manufacturers not wish to share the values of the RRC, the average RRC value used is the one of the label class plus a 0.3 N/kN.

4.1.3 Calculation

This method does not include any calculation to produce the input data for VECTO or for the matrix interpolation. The declared values can already be introduced in VECTO directly to obtain a CO_2 consumption value for the body or trailer.

If considering an EMS, the values of mass and the RRC would be added to the final sum of the trailer.

4.1.4 Outputs

This method provides as intermediate results a mass and an RRC. Once these intermediate results are defined, they can be used as inputs for the calculation of the CO_2 emission reduction value as the main output of the process.

4.1.5 Implementation

The implementation and maintenance would be very easy for this certification method, as there is no need of previous work and investment, and the method can be implemented practically instantaneously.

The existing VECTO simulation tool could be used with specific inputs for mass and RRC and standard inputs for the other blocks.

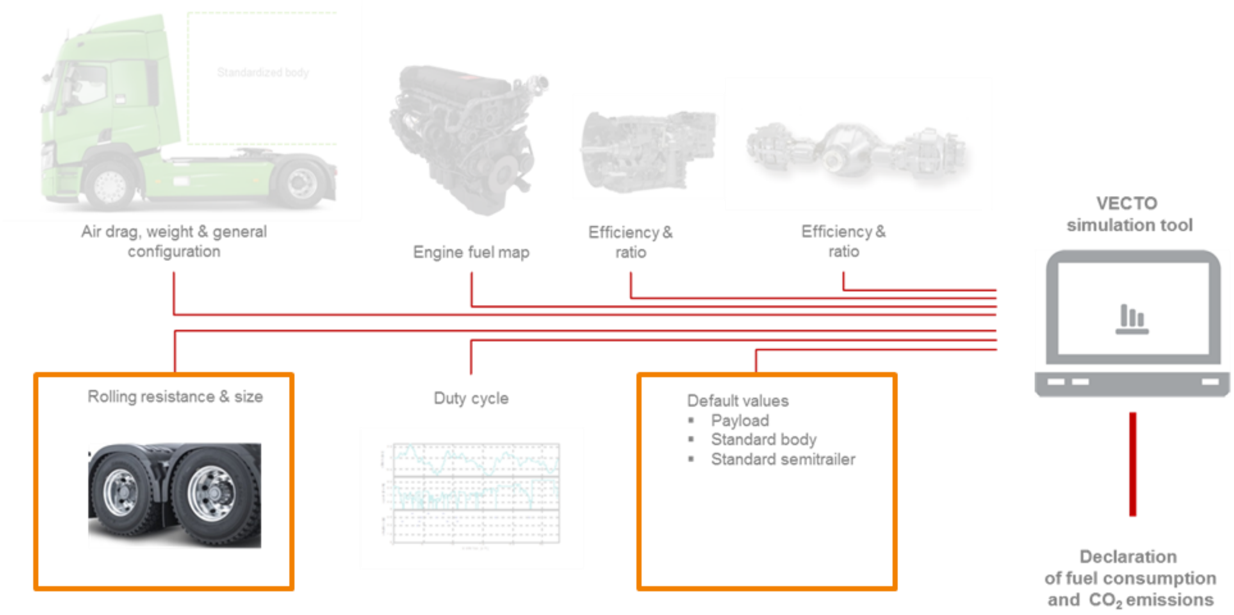

Figure 2: VECTO simulation tool diagram (Method A)

4.2 *(B) Method based on mass, RRC and C_DxA influences of add-on parts*

4.2.1 Description

This method includes the already mentioned mass and RRC, but it also considers the use of generic functions and look-up tables for certified aero-devices to evaluate the contribution of the C_DxA of the body/trailer. In order to consider different body lengths, it is proposed to use generic functions for each kind of custom body/trailer. If no custom body/trailer equation is defined for the candidate vehicle, a generic value should be used to evaluate the C_DxA contribution.

4.2.2 Inputs

4.2.2.1 Mass

Mass input as per 4.1.2.1.

4.2.2.2 RRC

RRC input as per 4.1.2.2.

4.2.2.3 Vehicle dimensions

The dimensions which need to be provided as inputs for the calculations depend on the vehicle type and are defined in Appendix 4 of Annex VIII. For bodies, depending on the mass and these dimensions, the vehicle can be classified along 5 different standards. For bodies, the needed dimensions are:

- Length
- Width
- Height

- Side & roof corner radius of the front panel
- Side corner radius of the roof panel
- Remaining corner radius

For (semi-)trailers, these dimensions are:

- Total length
- Total width
- Body height
- Full height, unloaded
- Trailer coupling height, unloaded
- Wheelbase
- Axle distance
- Front overhang
- Front/side panel corner radius
- Remaining corner radius
- Toolbox dimension vehicle x-axis
- Toolbox dimension vehicle y-axis
- Toolbox dimension vehicle z-axis
- Side underride protection length

In both cases (standard bodies and standard trailers), these dimensions are used to define if the candidate vehicle can be considered as a standard or a custom vehicle. Depending on this, one calculation method or another shall be used (See Figure 2: C_DxA contribution flowchart (Method B)).

4.2.2.4 Add-ons

A set of look-up tables of standardised add-ons affecting the aerodynamic performance may be addressed in the Regulation. The tables may include the improvement of the aero-device mounted alone or together with other aero-devices.

If an aero-device manufacturer wants to certify that its devices achieve better aerodynamic performance than those defined in the look-up tables, an option to certificate these devices should be given. In order to certify these devices, a series of tests or simulations shall be made considering their stand-alone behaviour and the possible cross-interactions with other standard aero-devices included in the add-on standard catalogue. If the improvements are proved, the bodybuilder or trailer manufacturer should be able to use the certified air drag reduction value instead of that addressed in the regulation look-up tables for that specific add-on. The possibility of enhancing the add-on reduction should encourage manufacturers to improve and certify their products.

4.2.3 Calculation

In order to apply this method, it is necessary to identify the variations of the custom candidate trailer from the standard body/trailer defined in Appendix 4 of Annex VIII in terms of C_DxA.

Each kind of custom candidate should have its own function that defines its C_DxA contribution before the application of the aero-devices effect based on its geometry. The initial custom trailer equations should cover the most standard body/trailer geometries that differ from the standard box/trailer of the Regulation. These functions shall be obtained once through CFD simulation results of some bodies with different lengths (see Task 2, section 4.3.3).

After the calculation of the contribution to the air drag based on the geometry, the look-up tables of the standardised add-ons can add the contribution of the aero-devices or the functional features that affect the Air Drag and the polar-yaw curve.

If an EMS configuration is being calculated, the contribution to the mass and the RRC would be done as described in the previous method. The C_DxA contribution of the final trailer shall be evaluated either with a standard value for each kind of trailer or with a formula that takes into account the configuration of this last vehicle and the gap between the first vehicle and the second.

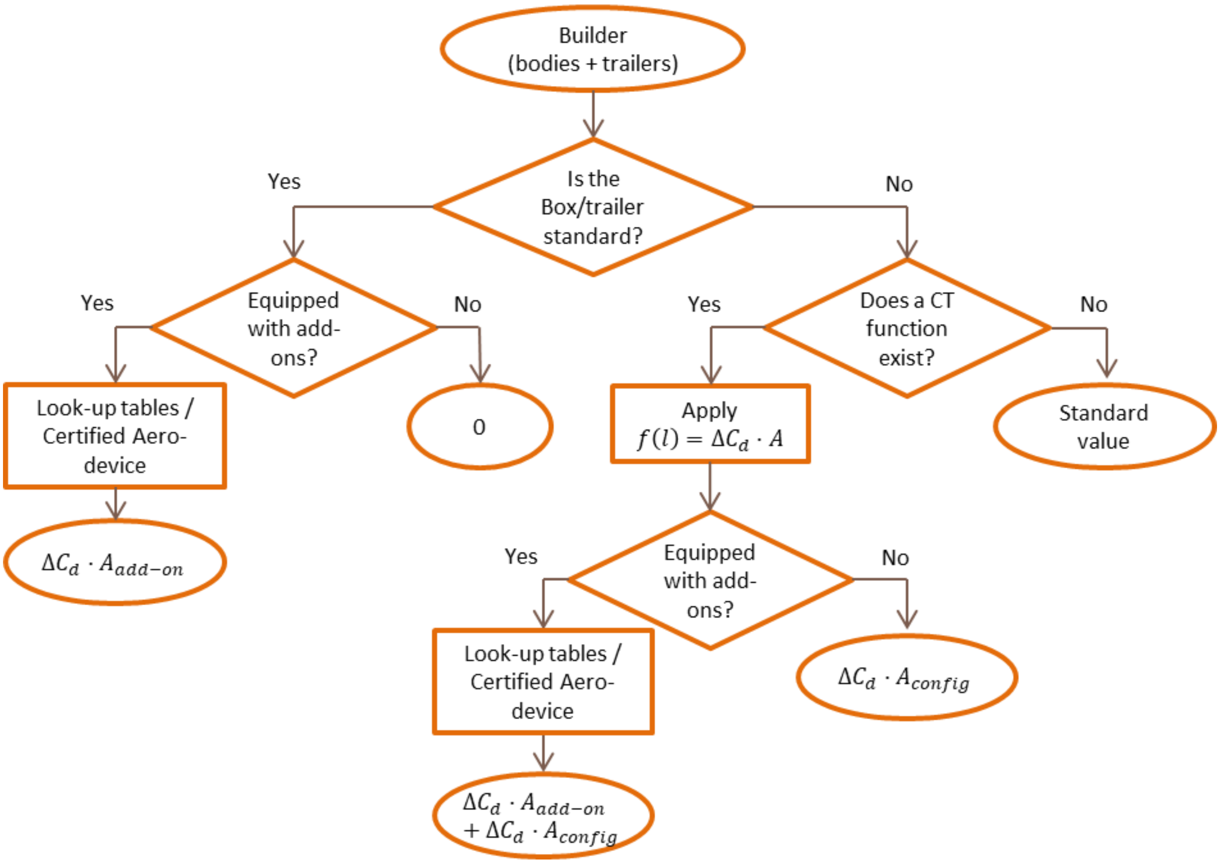

Figure 3: **C_DxA** contribution flowchart (Method B)

4.2.4 Outputs

This method provides as intermediate results a mass, an RRC and a delta of C_DxA for trailers. For bodies, it would provide mass and delta C_DxA.

Once these intermediate results are defined, they can be used as inputs to obtain a CO_2 emission value. If the CO_2 factor approach is chosen, the VECTO GUI shall include the possibility of selecting the add-ons included in the vehicle so the polar-yaw curve can be modified accordingly.

4.2.5 Implementation

The implementation and maintenance of the B certification method is the main issue. The required preliminary work is considerable.

Apart from method A requirements, the VECTO simulation tool should be operated through a graphic user interface for collecting the equations inputs depending on the geometry and look-up tables for the equipped aerodynamic appendices according to the standard add-ons catalogue.

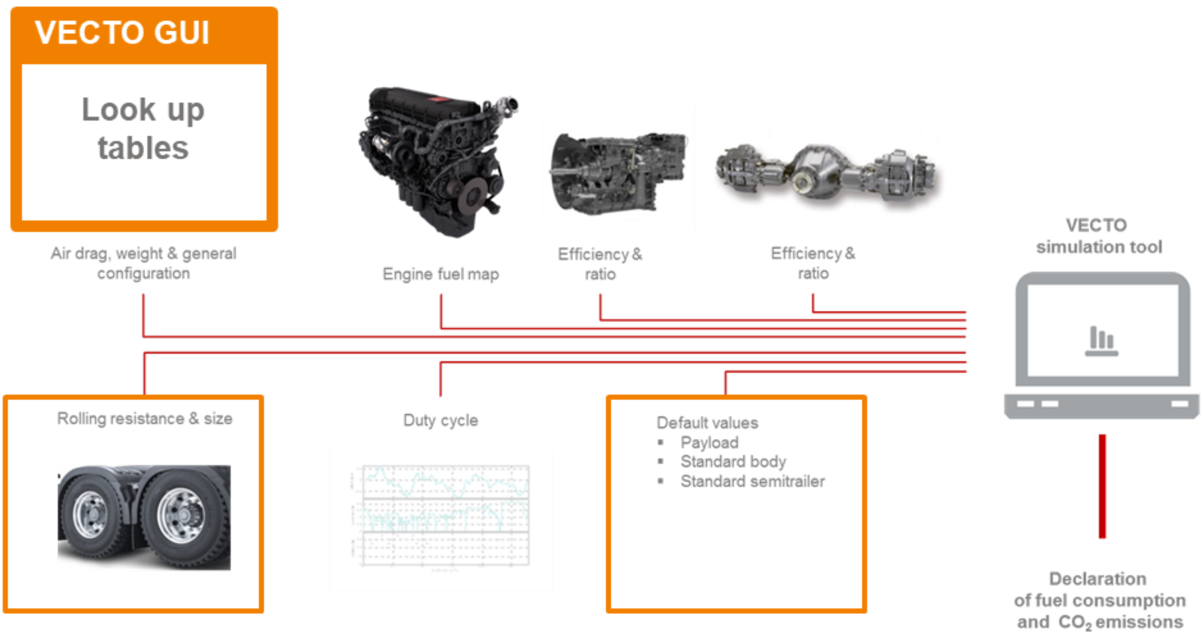

Figure 4: VECTO simulation tool diagram (Method B)

The proposed steps for implementing the B certification method are listed below:

1. Determination of a classification system for O3 and O4 category vehicles and rigid lorry bodyworks
2. Standardization of add-ons specifications
3. Look-up tables fill-up through CFD simulations based on method 3 procedures
4. Custom Trailers functions development

5. Development and validation of the IT tool(s) to be used for certification

6. Definition of a certification methodology

Moreover, a periodic update of look-up tables to include the new trends of the aerodynamic add-ons may be needed in future.

4.3 (C) Method considering all parameters

4.3.1 Description

This method considers almost every parameter for the determination of CO_2 emissions. As the air drag reduction is measured (or simulated) for the entire body or trailer, an optimisation in this subject is incentivised, which can lead to a reduction of CO_2 emissions of up to 5% (considering that there is a 30% reduction potential in the (semi)trailer, and that 17% of total energy consumption is related to it).
Energy saving parts, such as electric axles, shall be also considered as they have a positive effect on energy consumption. The consideration and modelling of these systems is very complex and might require a specific simulation similar to the VECTO module for hybrid vehicles. This way, the electric energy produced can be converted by generic alternator and combustion engine efficiency values to a fuel and CO_2 saving value.
Certification method C covers almost 100% of energy consumption in lorries, which is directly related to CO_2 emissions and fuel consumption. The counterpoint of this method is the high complexity and cost of the method and its test processes.
This method is mainly conceived for bodies and trailers which are very different from their respective standard body or trailer according to Annex VIII.

4.3.2 Inputs

4.3.2.1 Mass

Mass input as per 4.1.2.1.

4.3.2.2 RRC

RRC input as per 4.1.2.2.

4.3.2.3 C_DxA

Regarding the aerodynamic forces generated by the vehicle, a C_DxA value is needed. In the case of primary vehicles, a CST (Constant Speed Test) shall be performed on standard body or trailer, in order to get a representative C_DxA value. This value shall be used as base value for the calculation of the standard body or trailer's emissions and consumption calculation.

As certification method is conceived for bodies and trailers which are very different from their respective standards, and which cannot be certified reliably with methods A and B, for the completed vehicles a CFD simulation or a CST is required to obtain a representative C_DxA reduction and its specific value.

4.3.2.4 Geometry data

Either for the CST or for the CFD simulations, vehicle geometry data shall be needed. Depending on the case, the next data are demanded:

- For CST tests, the dimensions defined in Annex VIII of R (EU) 2017/2400 shall be needed, these dimensions being the total height and width.

- For CFD simulations, a CAD model of the vehicle shall be needed. This CAD model shall vary depending on the case, and normalized cabins can be used (see Task 2, section 4.3.2.2).

4.3.2.5 Others

For the calculations, all the data required in R (EU) 2017/2400 Annex III shall be collected at least for the standard bodies and trailers.
In cases where the vehicle is equipped with energy recovery devices, these should be taken into account and considered for the calculations regarding the CO_2 emissions and fuel consumption. For the lorries, VECTO is currently extended to cover hybrids and waste heat recovery (WHR). The development of a CO_2-Factor method which also considers energy recovery at trailers can use methods from lorries, however, it has not considered in the scope of this project.

These energy recovery systems shall be simulated apart from the rest of the vehicle, with the VECTO module for hybrid vehicles. This simulation's main objective is to get a CO_2 reduction directly related to the energy recovery system.

4.3.3 Calculation

The calculation used in this certification method is directly related to the VECTO results. The results provided by VECTO for specific bodies and (semi-)trailers could show the difference in CO_2 emissions to a vehicle equipped with the standard bodies or (semi-)trailers.
In (C) certification method, CST or simulations are used to model the real body or trailer to be certified. With these CST or simulations, the C_DxA are defined, along with the dimensions, mass, RRC and others, and once all the data defined as inputs is collected, the CO_2 emissions shall be calculated with VECTO. The CST shall be made as they are defined in Annex 8 of R (EU) 2017/2400.

With regard to the CFD simulations, some technical features shall be met. These specifications have been defined considering the proposal done by the CLCCR and with engineering criteria, the most important being:

- A maximum blockage ratio of 0.5%.
    - Blockage is defined as the ratio $\frac{Vehicle\ Frontal\ Area}{Simulation\ Domain\ cross\ Area}$

- A yaw angle in the simulation of 0º. This is selected to simplify, as CST results in air drag are normalized to 0º yaw angle. Also, yaw angle corrections could be made in the VECTO long haul calculations for the CO_2 consumption calculation.

- Both tyres and ground set in motion.

- A vehicle speed of between 80 and 90 km/h.

- A minimum number of 65,000,000 volume elements.

- A minimum size of 5 mm in regions of high flow gradient and smaller-geometry features, such as A-pillar, mirrors, grilles, leading and trailing edges, etc

- Mesh refinement (with engineering criteria) in key aerodynamic areas:
  - Vehicle wake
  - Side-mirror wake
  - Tractor-trailer gap
  - Underbody

Although these specifications are enough to make simulations, it would be preferable that the European Commission provided technical services (or manufacturers) with a more complete guidance document, similar to what CLCCR suggests in [2].

Considering that the C_DxA results are normalized to 0º, correction curves depending on the yaw angle are used to obtain C_DxA values for different angles. These correction curves are already considered in Annex VIII of R (EU) 2017/2400, considering the vehicle class to be certified, but in some cases manufacturers might want to use their own correction curves alleging that their results would be better than the ones specified in the regulation. In this case, manufacturers could be allowed to use their curves if they can prove these improvements with certified CFD software and simulation specifications.

Also, in cases where an energy recovery device is installed, the CO_2 reduction directly related to the energy recovery system could be calculated, which can be done with a hybrid vehicle VECTO module.

4.3.4 Outputs

This method provides as intermediate results a mass, an RRC and a delta of C_DxA for trailers. For bodies, it would provide mass and delta C_DxA. Also, if an energy recovery device is installed, its CO_2 reduction can be applied directly to the CO_2 factor calculation.

Once these intermediate results are defined, they would be used as inputs to obtain a CO_2 emission value. If the CO_2 factor approach is chosen, the VECTO GUI should include the possibility to include the calculated polar-yaw curve obtained through CFD or, as in the previous case, the possibility of selecting the add-ons included in the vehicle so the polar-yaw curve can be modified accordingly.

4.3.5 Implementation

In case of obtaining the C_DxA though CST, there should be no implementation time for this method since these tests already exist. Therefore, no investment either should be necessary in this field.

In case of obtaining the C_DxA through CDF, implementation and maintenance might require an investment for the definition of certain minimum requirements for the simulations and validation of CFD software/procedure.

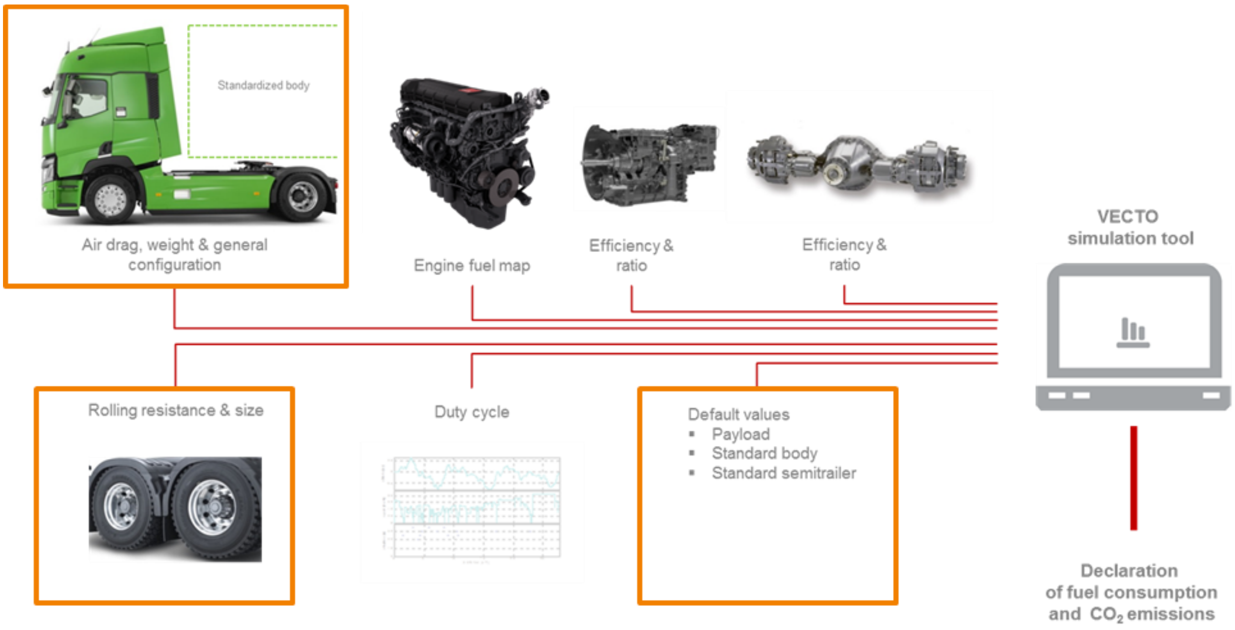

Figure 5: VECTO simulation tool diagram (Method C using CST)

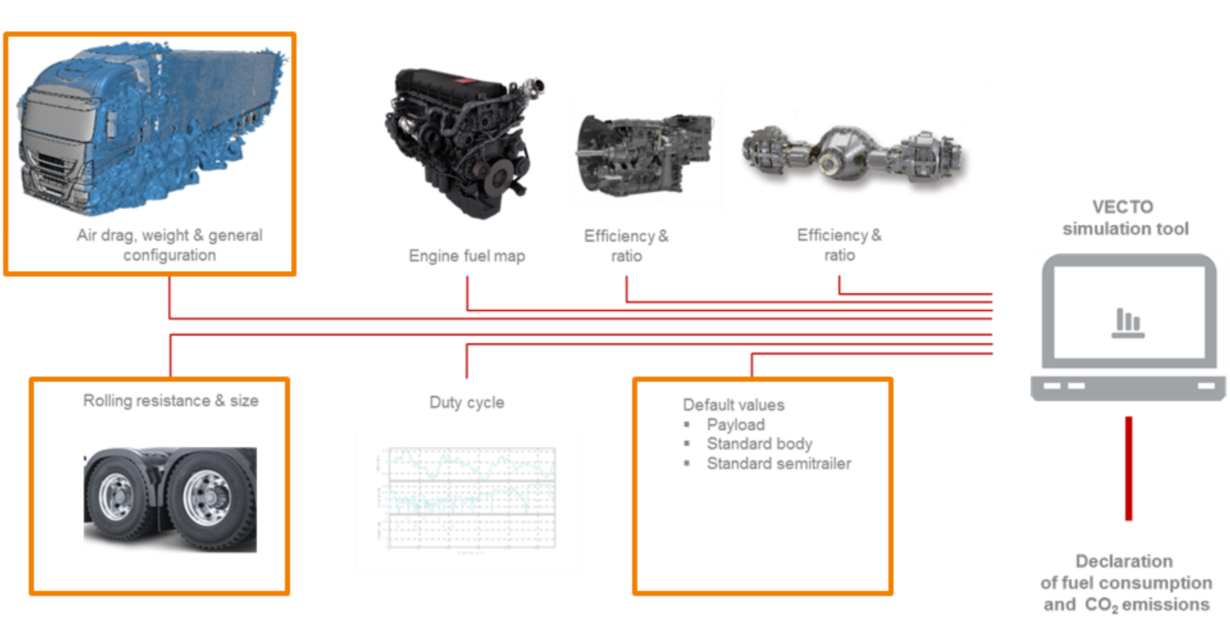

Figure 6: VECTO simulation tool diagram (Method C using CFD)

5 Framework analysis

Once the possible certification methods, with their inputs and procedures, have been defined, an analysis has been done to provide the European Commission with hints about the most suitable method in each case. With this purpose, a framework analysis has been done, in which the proposed methods' most important features were objectively analysed and classified.

Therefore, the proposed certification methods have been analysed measuring the Key Performance Indicators (KPIs) that have been considered as most significant for the method classification. The selected KPIs have been classified in six axes considering the main concerns for the manufacturers and technical services, and the main interests for the European Commission for the implementation of the certification method. These groups shall be:

- Software & Equipment
- Complexity
- Implementation & Maintenance
- Body type
- Accuracy
- Cost

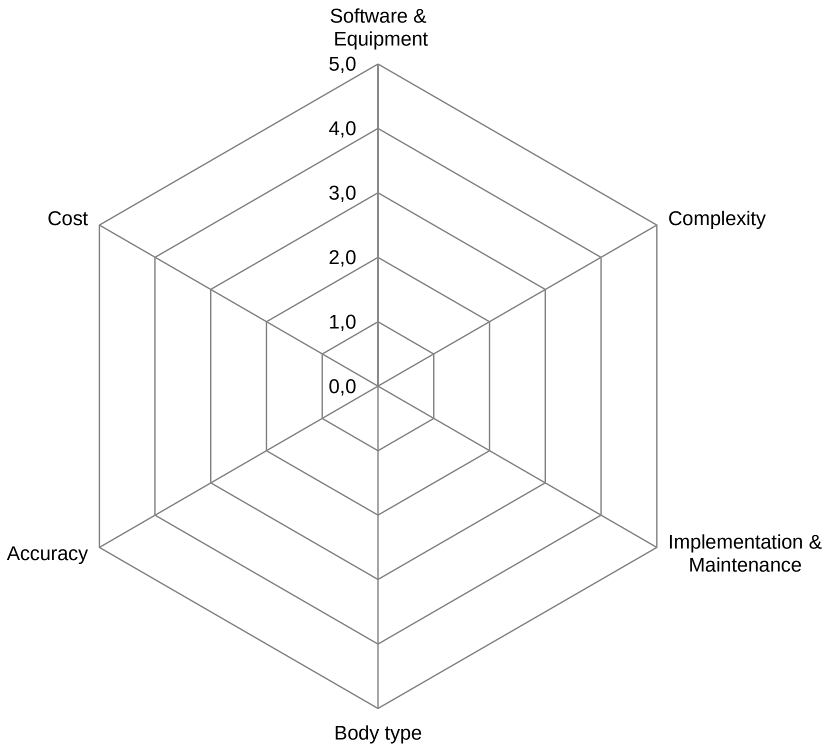

Figure 7: 6 axis spider plot

This six-axis classification shall be made within a range of 5 steps, the worst achieved value being a 1 and the best a 5.

In order to correctly apply and measure these KPIs, they shall be defined as specific as possible and minimizing the risk of subjective considerations. Avoiding this subjectivity, the analysis of this certification method selection shall provide the European Commission with the most suitable approach.

As discussed, in the following sections the pertinent KPIs and their groups have been defined. These definitions must be as specific as possible, and the measurement system for each KPI shall be determined.

For each factor, their KPIs have been weighted considering their relative importance for the factor and a weighted average shall be calculated. This way, a value from 1 to 5 has been achieved for each considered factor.

With regard to the certification methods, three were defined in the previous sections (A, B and C), but for the frameworks analysis the C method has been split in two variants. The differential factor between the two variants is that in one case a Constant Speed Test (CST) is performed in order to achieve the C_DxA value, and in the other one CFD Simulations are executed with the same purpose.
Therefore, the four certification methods that have been analysed are:

- **(A) certification method**: Mass + RRC
- **(B) certification method**: Mass + RRC + C_DxA through equations + Look-up tables for aero devices
- **(C1) certification method**: Mass + RRC + C_DxA through CST
- **(C2) certification method**: Mass + RRC + C_DxA through CFD

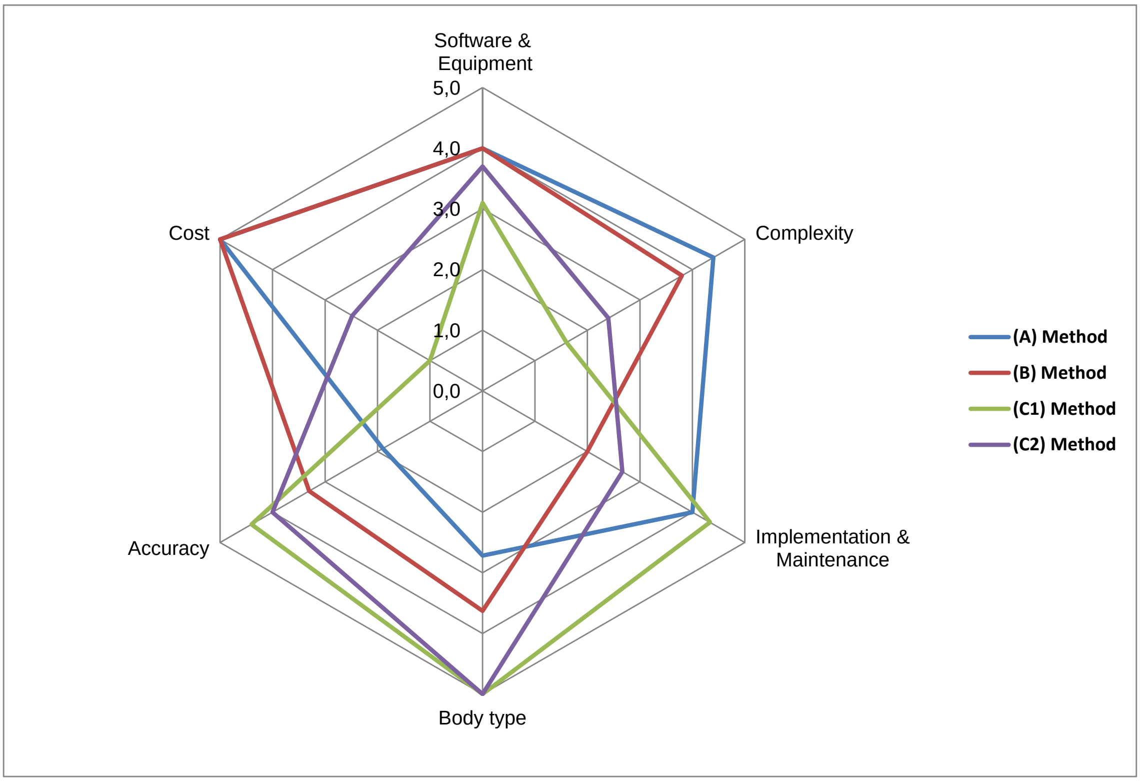

Figure 8: 4 method summarized results for the framework analysis

Even though the spider graphic provides all the information of the analysis, it is hard to reach some conclusions with it. In order to evaluate the methods, the following plots show the most concerning axes of the main stakeholders of this project. These plots represent three axes, in which the bubble diameter represents the cost for the target stakeholder.

In the first place, the point of view of the legislator, where the amount of body types to be evaluated, the accuracy of the method and the implementation costs are the most relevant axes. It is shown that method A is the worst being the most inaccurate and is only applicable to a limited number of bodies and trailers. It is also clear that both branches of method C would be the best option under this perspective. Finally, method B would be suspended in a middle term, with a rather high cost of implementation.

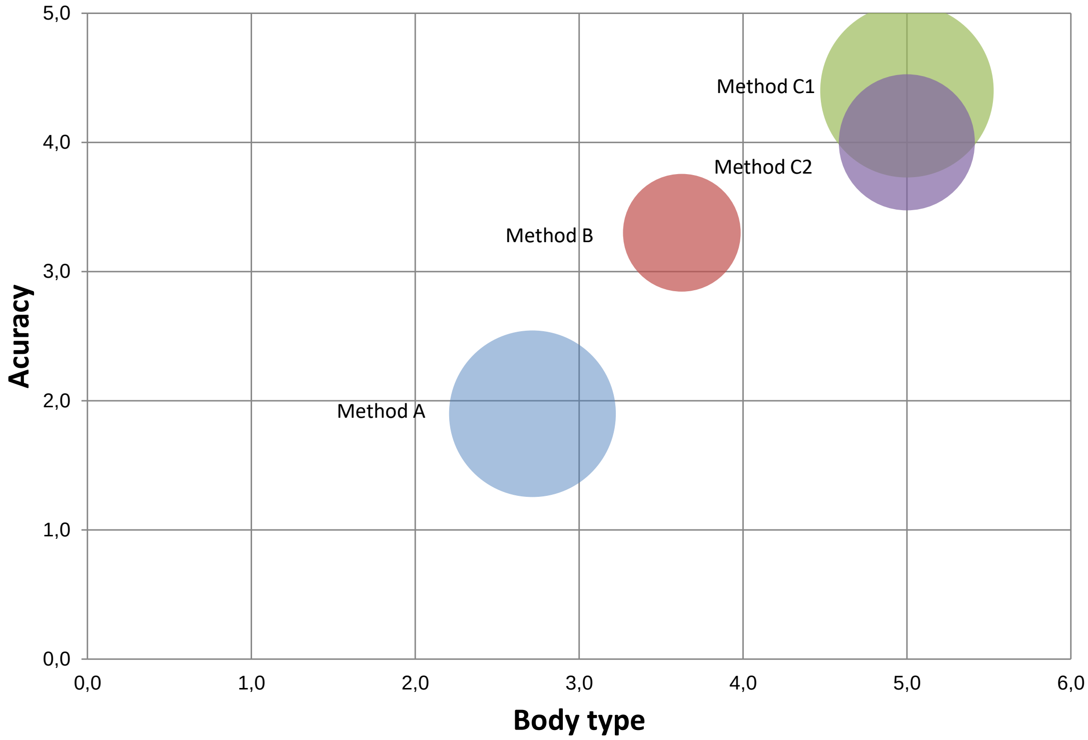

Figure 9: Legislator concerning most relevant parameters plot

When the point of view is changed and focused to the manufacturers, the axes to evaluate the methods have been the complexity, the software and equipment and the cost. From the manufacturers standpoint, methods A and B are those that show better results, being cheap, easy to implement and with low requirements of tools. On the other hand, methods C1 and C2 not only are more complex but way more expensive. Specially, method C1 that is left in the bottom of the plot is the most expensive and thus, the most inappropriate.

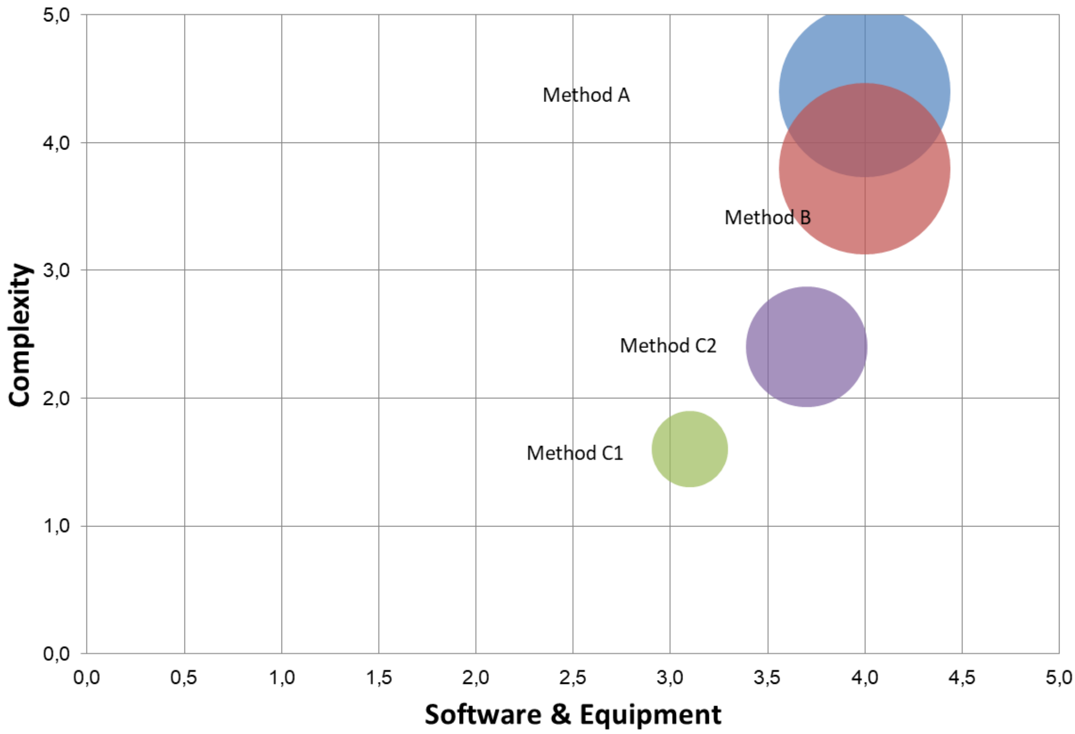

Figure 10: Manufacturer concerning most relevant parameters plot

Therefore, it is clear that if great accuracy is to be achieved, an investment will have to be made, which shall not be an option for small manufacturers. For this reason, a balance shall be found among all the fields considered for the certification method selection, even if its implementation requires preliminary work and an investment by the European Commission in order to start up this certification procedure. Regarding this, the best method considering this balance between fields shall be option B. For this method, a considerable preliminary investment and a lot of preliminary work is needed. This should aim the creation of equations and look-up tables for the approximation of the C_DxA value, in order to simplify the certification of the bodies and trailers.

In addition, if the manufacturer requires a more accurate method and can afford a more expensive method, the option of C certification methods could be offered.

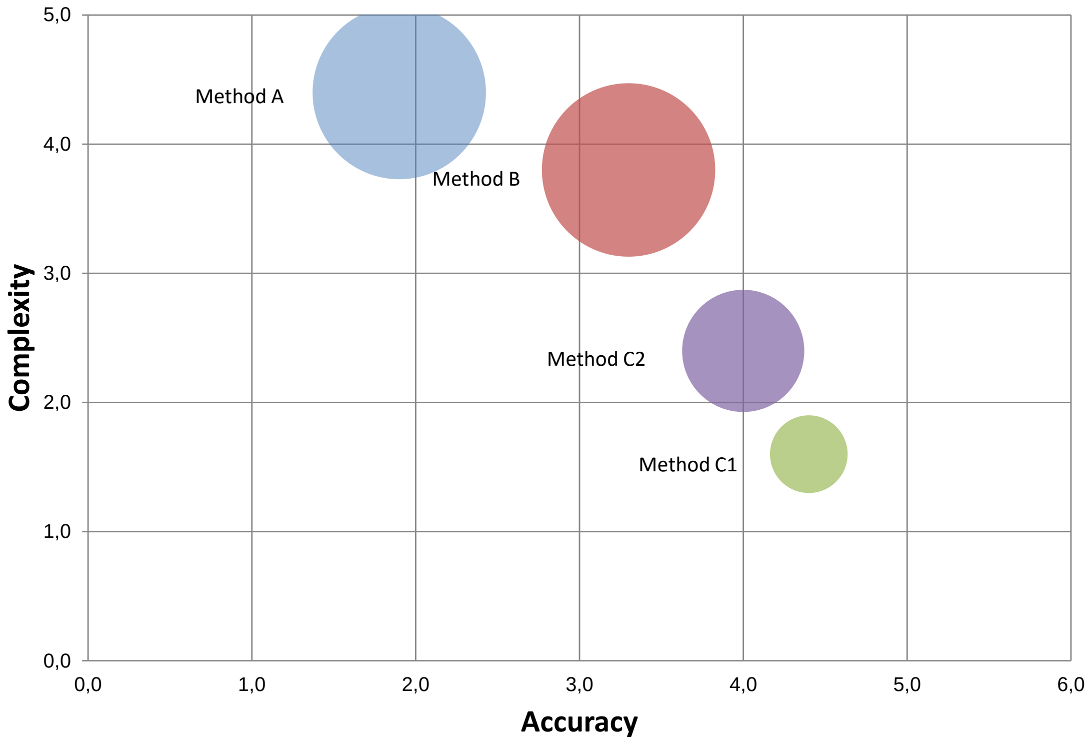

Figure 11: Accuracy-Complexity-Cost plot

Overall, each certification method has its own advantages and disadvantages, but there are two possible grouping:

- Simplicity, low cost and low accuracy (methods A and B).
- Complexity, high cost and high accuracy (methods C1 and C2).

Nonetheless, bearing in mind the sensibilities of the different stakeholders in the project, the two main methods to be considered shall be C2, and chiefly method B.

5.1 (A) Method evaluation

The achieved results for the (A) certification are the expected ones. The following evaluation about the method has been performed:

- The requirements in Software & Equipment are very few, as the needed calculations can be made with a simple software. **(4/5)**
- The Complexity is not very restrictive as the calculations to be made are just a few, and the required tests are very simple. **(4,4/5)**
- The Implementation & Maintenance would be very easy for this certification method, as there is no need of previous work and investment, and the method can be implemented practically instantaneously. Moreover, there is almost no need for any maintenance for the method to update it by the Commission. **(4/5)**
- Regarding the Body Types covered, this is the main weakness of this certification method. This certification method is only able to cover the dry freight, the curtain siders and the reefers, which represents 54,3% of the new registrations, so it might be a problem as almost the half of the vehicles cannot use this certification method. **(2,7/5)**

- The other main problem of the method is that its Accuracy is low, as the results obtained in the calculations are not completely representative of the vehicle certificated. The eventual aerodynamics improvements on the standard trailer (e.g. aero parts) cannot be evaluated using this method. So it is assumed that the value would be a worst case. **(2,2/5)**

- The cost of the certification is very low. This low price is the main advantage of this certification method, as it makes it affordable for any size of manufacturer. Moreover, it is a fast certification method, which affects the cost positively. **(5/5)**

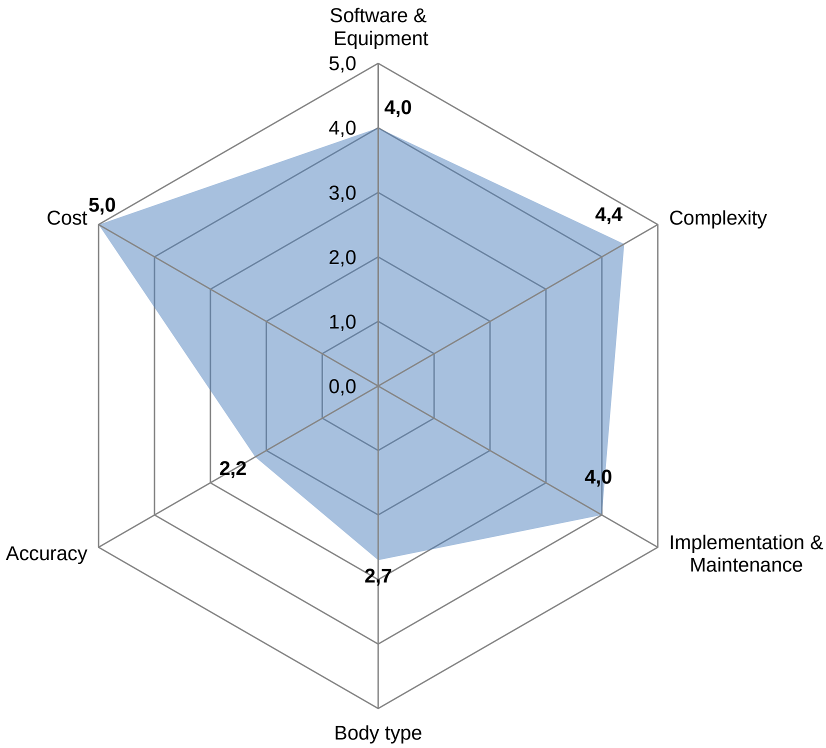

Figure 12: Method A 6-axis spider plot

5.2 *(B) Method evaluation*

The result of the evaluation of this certification method is the most interesting one, as its characteristics are in the average values in almost all the factors, making it the most regular. This is important for the method as, apart from the implementation & maintenance, there is no main weakness which can impact its validity very negatively. Considering the analysis, the following evaluation was made:

- Regarding the Software & Equipment all the requirements would be disposed in the regulation. **(4/5)**

- The Complexity of the process is similar to the A certification method. The calculations required for the certification are simple, but the needed in-house skills are a bit more complex. **(3,8/5)**

- The Implementation & Maintenance of the B certification method is the main issue. The required preliminary work is considerable because of the number of tests necessary for the aerodynamic add-on characterization in order to fill the look-up tables, and the validation of the accumulated air drag equations.

Moreover, maintenance is needed for the look-up tables to update them to include the new trends of the aerodynamic add-ons. **(2/5)**

- This certification method covers about a 72,5% of the new registrations, because of the Body Types which are valid for this process (curtain-sider, close van box, reefer, tanker and tipper). Furthermore, it has to be said that the only body or trailer types, which are not covered, are the ones that do not belong to a big group. **(3,6/5)**

- The Accuracy of the method is good, but it has to bear in mind that the values of the look-up tables are approximations and these approximations may not fit every case in the same way. Anyway, the representativeness of the method is acceptable. **(3,6/5)**

- The cost of the certification is low. This low price is the main advantage of this certification method, as it makes it affordable for any size of manufacturer. Moreover, it is a fast certification method, which affects the cost positively. **(5/5)**

Figure 13: Method B 6-axis spider plot

5.3 (C) Method evaluation

5.3.1 (C1) Method evaluation

This certification method's main characteristic is the utilisation of Constant Speed Tests (CST) to obtain the C_DxA value. The result of the evaluation of this method is quite irregular, as it achieves the best grades in some factors, but very poor grades in some other ones. This method may suit large body and trailer manufacturers, but for small ones it may be prohibitive as the costs are too great to deal with. The next evaluation was made considering the analysis:

- The Software & Equipment mark is low. This is mainly because of the need for test tracks in which Constant Speed Tests can be performed. Even if traceability of the used equipment in terms of equipment is good, the low availability of the proving ground and torque meters for body builders has a big impact on the grade. **(3,1/5)**

- The Complexity of the process is very high as the needed calculations and skills are very complex. Moreover, the duration of the process is very long because of the vehicle logistics and tests needed. **(1,6/5)**

- No Implementation time shall be needed as the regulations for these tests already exist, so no investment shall be needed in this field. The only Maintenance needed shall be the updating of the VECTO Air Drag software. This updating shall consist in periodic software revisions and error fixings. **(4,3/5)**

- This certification method covers every possible Body type because every single unit must be tested, so it gets the best possible grade in this area. **(5/5)**

- The Accuracy of the method is very good, as even if the repeatability is not the best among the options, the representativeness is the best as the tests are performed with the real vehicle to be certified. **(4,4/5)**

- The Cost of this certification method is by far the most expensive one, so it gets the worst grade possible in this field. **(1/5)**

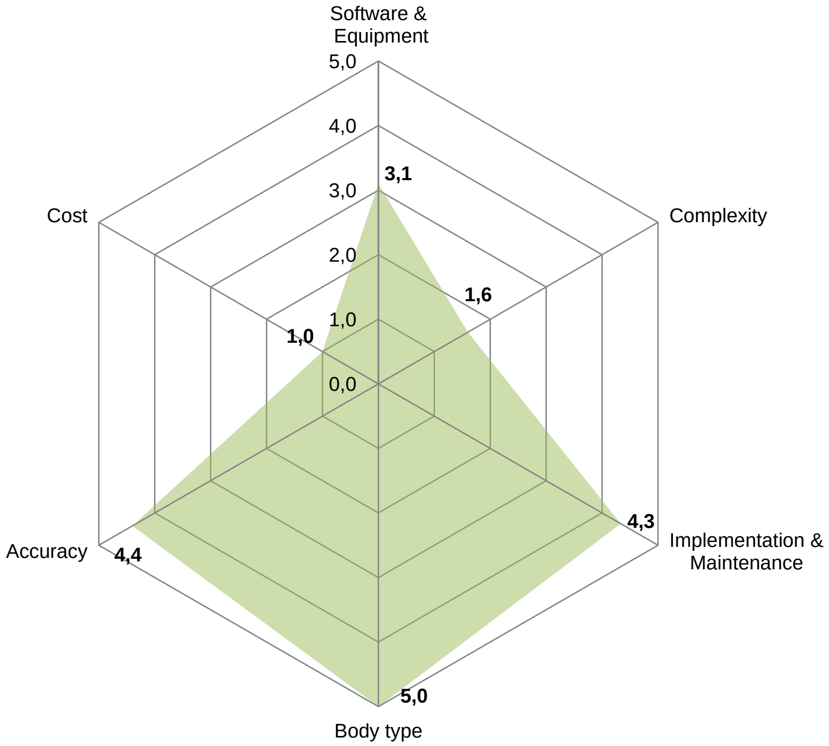

Figure 14: Method C1 6-axis spider plot

5.3.2 (C2) Method evaluation

The main characteristic of this certification method is the utilisation of Computational Fluid Dynamics (CFD) for the obtaining of the C_DxA value. The main benefits and weaknesses of this certification method are more or less the same as for the C1 method, but the differences between benefits and weaknesses are not so marked.

- The required Software & Equipment shall not be so critical as nowadays the availability for CFD software is very high and its traceability is usually good. CST data would only be needed once during the implementation process for setting the delta between the baseline tractor and trailer C_DxA through CST and CFD. Then, CST tests would be omitted by the body builders. **(3,7/5)**

- It is a method of regular Complexity, as many inputs are needed (including the CAD model of the vehicle to certificate) and the required skills for a CFD simulation are considerable. On the other hand, the duration of this certification shall be shorter than the C1 method. **(2,4/5)**

- The Implementation & Maintenance shall be a factor to be considered, as it might require an investment for the definition of some minimum requirements for the simulations and validation of CFD software (such as minimum cell number, yaw angle, etc…). The duration of the certification process shall not be too long. **(2,7/5)**

- This certification method covers every possible Body type, so it gets the best possible grade in this area. **(5/5)**

- This method has a fairly good Accuracy, as the representativeness of the method is very high (considering that the CAD model is accurate) and the CFD simulations tend to achieve great repeatability. **(4/5)**

- For this certification method the Cost is also high, but not as much as C1 method. This shall be a problem for small manufacturers. **(2,5/5**

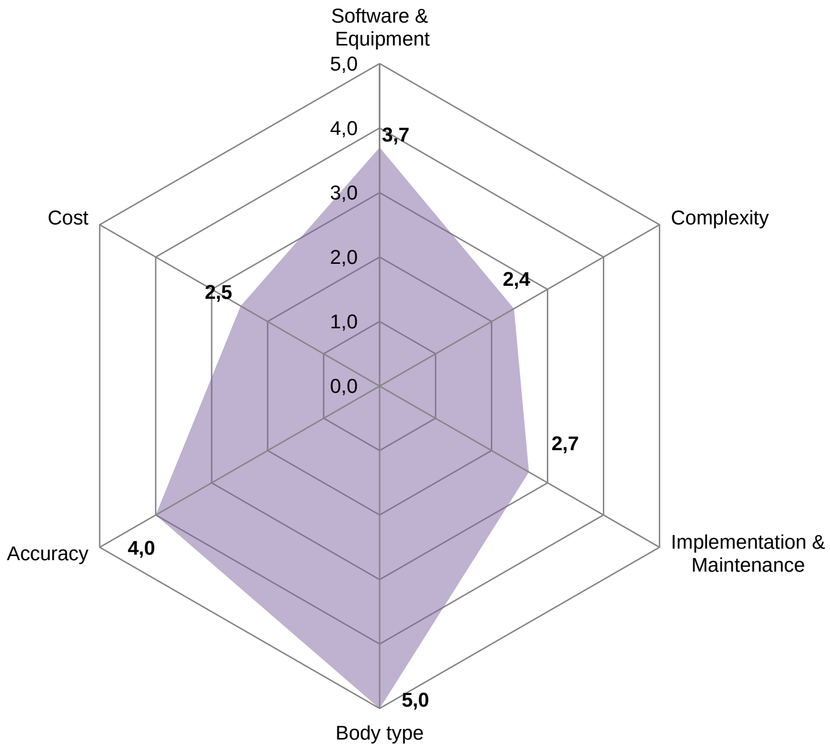

Figure 15: Method C2 6-axis spider plot

5.4 Definitions

5.4.1 Software & Equipment

The first factor that shall be taken into account is the necessary software and equipment for the certification method procedure. These requirements are directly related to the tests and calculations that need to be performed in the certification method. It can be stated that if the certification procedure is more complex, the requirements in this factor would be more specific.
If the method only requires basic calculations (methods A and B), the requirements in software would be very basic and the equipment needed should not be a restrictive factor for its application. On the other hand, with regard to certification methods in which tests or simulations are done (C1 and C2 methods) these requirements could be very restrictive for manufacturers or technical services with limited resources. In these cases, the necessary software (telemetry, data processing, CFD...) and equipment (sensors, data acquisition hardware, proving grounds…) can be very expensive, difficult to find or possess and complex to use. During the all the analysis, the higher the value given to a specific KPI, the better the punctuation is. In some cases like the cost, it seems counterintuitive since a higher value means a lower cost.

Two Key Performance Indicators (KPIs) have been selected, and for each of them a relative weight (in percentage) has been assigned considering its importance for the software and equipment factor. In the next table, these KPIs and their weights are displayed:

KPI	Weight
Availability	30%
Traceability	70%

Hereunder, each of the analysed KPIs is defined specifically:

- Availability: The ability to acquire the necessary software and equipment is important when choosing the certification method. In some cases, it might be difficult to acquire the needed software or to buy the required equipment, not to mention a proving ground to perform constant speed tests.

- Traceability: The traceability of the used equipment is of great importance as it has to be traceable by technical services or authorities. The person responsible for the certification must keep the calibration certificates of all the equipment used in the process. This KPI is also important regarding the Conformity of Production (CoP) tests that might be done after the certification.

In the next table the values for each KPI in each method are displayed, along with the overall value for the Software & Equipment factor:

	Availability	Traceability	**Software & Equipment**
(A) Method	4	4	**4,0**
(B) Method	4	4	**4,0**
(C1) Method	1	4	**3,1**
(C2) Method	3	4	**3,7**

5.4.2 Complexity

The process´ complexity has been considered, as a more complex method can lead to possible issues because of human mistakes, delayed processes or price rises. The complexity of the certification method would depend on the number of tests, the required inputs, the processes and the needed data processing.
In cases where not many calculations would be made and there is a low number of inputs (methods A and B), the complexity would be low, but while the required accuracy is higher, the number of inputs, the processes and the complexity of the calculations rise significantly.
For some manufacturers, the required skills and knowledge needed for complex methodologies might be prohibitive. For example, the data acquisition and processing in CST tests requires knowledge about the installed sensors and the data processing needed for VECTO simulations, and the CFD simulations, which meet the minimum specifications defined in method C (See section 4.3.3.) require wide knowledge and skills in CAD/CFD field.

As for the rest of the factors, the Key Performance Indicators have been selected considering their importance and assigning them relative weights in order to get to the overall value for the complexity factor. These KPIs are displayed in the next table:

KPI	Weight
Inputs	40%
Duration	40%
In-house skills	20%

Below, each of the analysed KPIs is defined specifically:

- Inputs: The number of inputs and their accuracy are of great importance regarding the complexity of the certification method. In cases where the inputs are a few and their collecting is simple (Method A), it will simplify widely the complexity of the calculations and the process itself.

- Duration: The duration of the certification method is also an important part of the complexity of the process. If the process is too long, it will negatively affect the complexity.

- Required in-house skills: As commented before, depending on the certification method the skills required for the test certification planners and verifiers will vary. The higher the number of inputs, calculations and tests, the higher the skills required for the staff.

In the next table the values for each KPI in each method are displayed, along with the overall value for the Complexity factor:

	Inputs	Duration	In-house skills	**Complexity**
(A) Method	5	4	4	**4,4**
(B) Method	4	4	3	**3,8**
(C1) Method	2	1	2	**1,6**
(C2) Method	2	3	2	**2,4**

5.4.3 Implementation & Maintenance

The certification method implementation is a key factor for the process selection. Some methods can be very suitable for the project achievement, but if its implementation is too long, too expensive or if the maintenance requires too much money it can be counterproductive.

If there is no need for preliminary work, this would minimise the investment and the time needed for the certification process to be implemented properly. For example, CST and CFD methods (C1 and C2) need very little preparatory work, so they achieve a very good grade in the classification.

It has to be taken into account that, for some certification methods, a maintenance would be needed (look-up tables actualization, for example), so that might suppose a regular update.

Three Key Performance Indicators have been selected for this axis. Along with the KPIs, their relative weights have been also defined for the classification to be done as objectively as possible. These KPIs are displayed in the next table:

KPI	Weight
Initial investment	33%
Maintenance	33%
Implementation time	33%

Below, each of the analysed KPIs is defined specifically:

- Initial investment: The initial investment needed has to be taken into account as a key factor for the classification, as we assume that the budget destined for the implementation is limited. In cases like B method, in which look-up tables would be defined and equations modelled, the initial investment might be considerable.

- Maintenance: Depending on the method, maintenance may be necessary. This maintenance could be rather table or equation updating (B method), CFD model verification (C2 method) or program development (C1 method), but every method will require updating by the European Commission).

- Implementation time: The implementation time for the new certification method cannot be too large, as the actual analysis has been done considering the actual framework of the bodies & trailers in Europe. The best case would be a fast implementation of the new method, but for that, a very simple method should be implemented. Moreover, a longer implementation time would affect negatively the initial investment in the project.

In the next table the values for each KPI in each method are displayed, along with the overall value for the Implementation & Maintenance factor:

	Initial investment	Maintenance	Implementation time	**Implementation & Maintenance**
(A) Method	4	4	4	**4**
(B) Method	1	3	2	**2,0**
(C1) Method	4	4	5	**4,3**
(C2) Method	2	3	3	**2,7**

5.4.4 Body type

The analysed certification methods are not necessarily suitable for every trailer and body on the market, so the variants covered should a factor to be considered for the method classification. Among the many different models, there are some which have a bigger representation in the market and in total registrations. Because of that, some variants have a bigger importance in percentages than others depending on the number of vehicles of that type in the road.
The grades given to the body type factor are directly proportional to the percentage of vehicles covered by the certification method.

Percentage	Grade
20,0%	1
40,0%	2
60,0%	3
80,0%	4
100,0%	5

The data used for the definition of these percentages are the bodies & trailers new registrations in 2017 analysed in the Task 1 (section 1.3.1.).

	Trailers	Rigid	Aggregate	**Percentage**
Curtain	91.858	10.885	102.743	**28,15%**
Closed Box Van	22.994	26.155	49.149	**13,47%**
Reefer	31.347	14.932	46.279	**12,68%**
Tanker	10.718	4.743	15.461	**4,24%**
Tipper	30.906	20.163	51.069	**13,99%**
Other	28.058	72.173	100.231	**27,47%**
	215.881	149.051	364.932	

- The A certification method covers curtain siders, closed boxes and reefers due to its geometric similarities with the Standard Bodies and Trailers.
- B method covers the same as A certification method, plus tankers and tippers.
- Certification methods C1 and C2 can cover every vehicle type that is being analysed.

So, the covered percentages and the grades obtained shall be:

	Percentage covered	Body type
(A) Method	54,30%	**2,7**
(B) Method	72,53%	**3,6**
(C1) Method	100,00%	**5,0**
(C2) Method	100,00%	**5,0**

5.4.5 Accuracy

The accuracy of the certification method is a key factor to be considered. The accuracy of the method will vary depending on the process itself, the equipment´s accuracy and the calculations executed to obtain the results.
Firstly, the process and the tests performed will have a deviation in the results achieved. In addition, the used equipment and software are mandatory to be accurate in order to

obtain reliable results. This might be also problematic for some manufacturers, as for higher accuracy of the used equipment the prices raise exponentially.
The preparatory work by the European Commission would also affect the achieved results' accuracy with regard to the equation characterisation and look-up tables' generation. More types of vehicles with different geometries tested and/or simulated, will lead to more accurate equations that would predict the effect of these geometry variations on the air drag. Similarly, the more aero devices tested at different yaw angles and with different combinations, the more accurate the look-up tables would be.
Just as for the other factors, the Key Performance Indicators have been defined. In this case, the characteristic KPIs for accuracy have been selected.

KPI	**Weight**
Repetitivity	50%
Representativity	50%

Below, each of the analysed KPIs is defined specifically:

- Repeatability: It is important for the process to have good repeatability with regard to the results obtained. This ability to repeat results will define the accuracy of the method concerning the tests and calculations performed. This KPI shall be graded taking into account the errors that can be achieved for each certification method.

- Representativeness: The representativeness of the method must be as good as possible. As far as possible, the tests should be similar to the real case of study. For example, in method C the CAD of the process should be done as detailed as possible.

In the next table the values for each KPI in each method are displayed, along with the overall value for the Accuracy factor:

	Repeatability	Representativeness	**Accuracy**
(A) Method	5	1	**2,2**
(B) Method	5	3	**3,6**
(C1) Method	3	5	**4,4**
(C2) Method	4	4	**4,0**

5.4.6 Cost

The last key factor for the certification method characterisation is the cost of certification procedure itself. The cost of the procedure is of great importance, as the big differences in budget between manufacturers have to be taken into account.
As can be seen in task 1, the 4 biggest manufacturers have a 55% share of the total production of bodies and trailers in the European Union. Therefore, it can be concluded that for these big manufacturers there shall be no problem to afford expensive certification methods. On the other hand, for small manufacturers a certification which is too expensive could make the manufacturing of vehicles unaffordable for them, leading them to closure or bankruptcy.

Bearing in mind these factors, for the chosen certification method(s) a balance should be found in order to give the same opportunities for both small and big manufacturers and avoid giving advantages.
Instead of defining KPIs for this factor, the grades are going to be in consequence of the cost of each method:

- The A certification method shall have a price corresponding to the homologation cost.

- The B certification method shall have a price corresponding to the homologation cost.

- C1 certification method shall have a price corresponding to the homologation cost, and the Constant Speed Test (CST).

- C2 certification method shall have a price corresponding to the validation of the simulation tool, the CAD generation and the homologation cost.

The grades obtained for each certification method are proportional to the prices obtained. In the next table, the grade corresponding to the proportional price is displayed.

	Cost
(A) Method	**5,0**
(B) Method	**5,0**
(C1) Method	**1,0**
(C2) Method	**2,5**

6 Standard add-ons catalogue

6.1 Introduction (What is considered an add–on?)

Since the main objective of this project is to define the differences between different configurations of trailer and semitrailer, any add-on feature which implies a modification of the outside shape of the vehicle has to be considered. These add-ons may have a positive or negative affect on the vehicle´s drag resistance, and both of them need to be considered and defined for their correct implementation in the different test procedure methods proposed.
Every add-on installed on a trailer/semitrailer will have to be considered as a modification of the standard or custom trailer, and its influence will have to be considered and calculated to obtain the complete air drag coefficient for the vehicle.
For some aerodynamic add-ons the position they are installed in should be considered, as their impact on the air drag resistance can show differences. For instance, in the case of European Modular Systems (EMS), the effect of a boat tail can be different if it is installed between the trailer and the dolly or right behind the dolly (in the first case the positive impact would be very low, even negative). For such reasons, some add-ons should be analysed in different positions of the trailer/semitrailer/dolly.

6.2 Functional add-ons

The add-ons which have improvement of the functionality of the trailer as an objective have been considered as functional add-ons. These add-ons do not have as an objective to improve the vehicle's air drag resistance, and they will usually have a negative effect on it.
In this section, the most common functional add-ons have been listed and defined with regard to their analysis and implementation in the different test procedure methods.
Regarding the large number of manufacturers, synergies should be defined for simplifying and reducing the number of look-up tables.

6.2.1 Pallet boxes

In order to transport pallets in the trailer without consuming any space at the cargo compartment, it is very usual to see groups of pallets piled under the trailer/semitrailer chassis. These spaces where these groups are stored are named pallet boxes, and can be either open or closed. The expected results shall be better for the closed boxes than for the open ones, because of the irregular shapes in a group of pallets. These add-ons can be classified by their storing capacity and will usually be of 24 or 36 pallets.

Figure 16: Example of a closed pallet box

Figure 17: Example of an open pallet box

6.2.2 Storage boxes

Storage boxes can be also installed in trailers and semitrailers with the objective of transporting various items such as repair tools, first-aid kits or machinery. These boxes are usually installed under the chassis, facing the sides of the vehicle and their sizes depend on their purpose. To sort out these add-ons, a classification by size could be made, sorting them in two groups (small or big). This classification by size could be done by the full storage volume for the box, as follows:

Small	< 0.35 m^3
Big	> 0.35 m^3

Apart from the classification considering the size of the storage box, the position and quantity of boxes should also be considered. Taking this into account, the next two classifications can be done:

- Position:
    - Between the kingpin and the semitrailer axles
    - Behind the semitrailer axles
- Quantity:
    - One storage box (in one side)
    - Two storage boxes (in both sides)

Therefore, when designing the matrix for the influence of these add-ons, three characteristics should be clearly defined for the vehicle certification: the size, the position and the quantity of boxes.

Figure 18: Example of a storage box

6.2.3 Slider lifts

These devices are destined to make the task of loading and unloading the goods easier. They work as elevators which can move vertically between floor and trailer height, and when they are not needed can be folded against the rear wall of the trailer or below it. There are many different slider lift manufacturers with different models, but seemly all of them will have a very similar influence on the air drag resistance of the vehicle.
Regarding these slider lifts, when obtaining the impact on the air drag resistance of the add-on, the ones which are folded below the semitrailer chassis should be considered over those which are folded behind.

Figure 19: Example of a slider lift folded under the chassis

6.2.4 Refrigeration system

Reefer trailers require the installation of a refrigeration unit in the front wall of the trailer. Because of its size, shape and position this might have an important impact on the vehicle's air drag resistance.
There are many different refrigeration units depending on the manufacturer, but they all seem to have the same effect on the air drag resistance (which shall not necessarily be bad, as the gap between trailer and tractor is reduced). For this reason, each refrigeration unit should be treated as if it had the same effect on the aerodynamic resistance of the trailer.

Figure 20: Refrigeration system in a reefer trailer

6.2.5 Fire extinguisher

Fire extinguishers are mandatory only in trucks, but can also be installed on trailers and semitrailers. These fire extinguishers can be either simply installed or inside a box, but their effect on the air drag resistance should be very similar.

Figure 21: Example of a fire extinguisher mounted inside a box

6.3 Dedicated Air Drag reduction add-ons

The add-ons that aim to reduce the air drag resistance of the vehicle have been considered as dedicated Air Drag reduction add-ons. These add-ons should prove their positive effect on the drag coefficient, in order to define the look-up tables to be used. The following list includes all the aerodynamic improvements for trailers that have been found in the market. The possible benefit of each of them has not been proven in this project.

6.3.1 Rear air drag reducing devices

6.3.1.1 Boat tail

The purpose of this feature is to reduce the depression behind the trailer by maintaining the air flow attached to the vehicle surface. Minimising this depression, the impact on the air drag resistance will be positive because of the lower pressure differential between the front and the rear of the vehicle.

Boat tails usually have the same dimensions as the trailer in width and height, and a length of between one or two meters, with small differences between the different manufacturers.

These systems use to be foldable in order not to interfere with the loading and unloading of the cargo.

Regarding the certification of the boat tail systems, some limitations should be met regarding the existing legislations for the trailer and semitrailer dimensions:

- The length of the whole semitrailer with the boat tail installed shall not exceed 12 meters.
- The length of the whole vehicle (tractor + trailer/semitrailer) with the boat tail installed shall not exceed 16.5 meters.

In order to consider the installed add-on as an air drag reducing device, some criteria should be met. Once this criteria are met the device is considered a boat tail, and possible concerns regarding the validity of the system will be avoided. The dimension requirements for the boat tail shall be:

- The length should be in accordance with the existing regulation and ensure a minimum improvement.
- The width of the boat tail has to be the same as the semitrailer in which the device is installed.

- There should be a minimum of free height from the boat tail to the road surface (for safety reasons).

With regard to the materials used for the boat tail manufacturing, it is rather complicated to set some minimums for the expected materials without restricting the possible innovation that shall be made by aero device manufacturers. Because of that, the acceptance criteria for the materials should be:

- The engineering criteria of the certificating authority should approve that the material and its mechanical properties are valid for the system.

Figure 22: Example of a trailer equipped with a foldable boat tail

6.3.1.2 *Vortex generators*

Vortex generators produce solid body vortices that rotate at high speeds, it is claimed to help to reduce turbulence and suction. This system consists of the installation of many of these vortex generators around the rear edges of the trailer, which help to minimize the high drag wake behind the trailer.
The size of these vortex generators is small, with a width of about 10-15 centimetres. That is the reason for the installation of many of them around the rear edges.
The installation of this add-on could be classified considering the number of edges the vortex generators are installed on (two or three edges).

Figure 23: Example of a vortex generator system

6.3.2 Side air drag reducing devices

6.3.2.1 Side skirts

This add-on's main objective is to prevent the air flow from getting under the trailer body. Less air flow in the underbody of the vehicle means a lower aerodynamic drag resistance because of its structured construction.
This type of add-on has been widely adopted because of its simplicity and easy installation, and has proved to achieve reductions of fuel consumption of between 3 and 7 per cent. Moreover, its efficiency improves under high angle crosswind conditions.
The size and shape of these add-ons are highly dependent on the type of side skirt mounted on the vehicle. The most common side skirt types are:

- Simple side skirt: This type of side skirt extends from the kingpin to the trailer/semitrailer´s rear group of axles. The length of these side skirts is around 3-4 meters.

Figure 24: Example of simple side skirt

- Full side skirt: This side skirt type goes all the way from the kingpin to the rear end of the trailer/semitrailer. The length of these side skirts will be around 10 meters. Among these full side skirts, there are two possible models:
    - Covered wheels full side skirt

Figure 25: Example of a covered wheels full side skirt

- Open-wheel full side skirt

Figure 26: Example of an open-wheel full side skirt

Seemingly, the full side skirts will have a more effective impact on the aerodynamic efficiency of the vehicle, and among these, the covered wheels device shall be the one with the best impact on the air drag resistance, as the turbulence generated by the wheels is avoided.

Just as with the boat tail devices, these air drag reducing systems shall meet some criteria in order to be considered a valid and certifiable system which would impact positively on the air drag resistance of the trailer/semitrailer. Firstly, the size requirements to be met shall be:

- The length of the side skirts is limited, as they cannot exceed the rear end of the trailer/semitrailer.
- The width of the vehicle with the side skirt devices installed cannot exceed the maximum dimensions defined by the regulation. (2.55 meters for regular trailer/semitrailers and 2.60 meters for refrigerated trailers).
- For the height of the side skirt there is not a minimum size, but with the device installed, at least 60% of the wheel height has to be covered (not literally, at least for the simple side skirt, but the free height under the side skirt cannot exceed 40% of the total wheel diameter).

With regard to the materials used for the device, just as for boat tails, the acceptance criteria for the materials shall be:

- The engineering criteria of the certifying authority should approve that the material and its mechanical properties are valid for the system.

Finally, with regard to the side underrun protection regulation, the same characteristics with regard to the mechanical strength of the side underrun should be met even with the side skirts installed.

6.3.2.2 Inter-wheel panels

This add-on is designed to reduce the turbulence generated by the rotating wheels by covering the spaces between wheels and chassis, where turbulent air can get stuck negatively affecting the air drag resistance of the vehicle. These add-ons are usually installed in tractors, but their application in trailers and semitrailers is also possible. They are made of reinforced plastic and they are not widely used because of the complete side skirts that can cover those zones too.

Inter-wheel panels cannot be easily classified, as they will usually have the same size, so only one class should be defined.

Figure 27: Example of inter-wheel panels (installed on a tractor)

6.3.2.3 Wheel Covers

These add-ons are installed inside the wheels of the trailer, and their main objective is to remove the turbulences generated by the wheel rims. Their operation is fairly simple, as with this system the rims are completely covered.

As these wheel covers are designed for heavy-duty vehicles, their size is related to the usual rim size in these vehicles. Usually, these rims have a radius of 22.5 inches, which corresponds to a diameter of 1.143 meters.

There is no possible classification for these covers as they have the same size in commercial vehicles (22,5” radius).

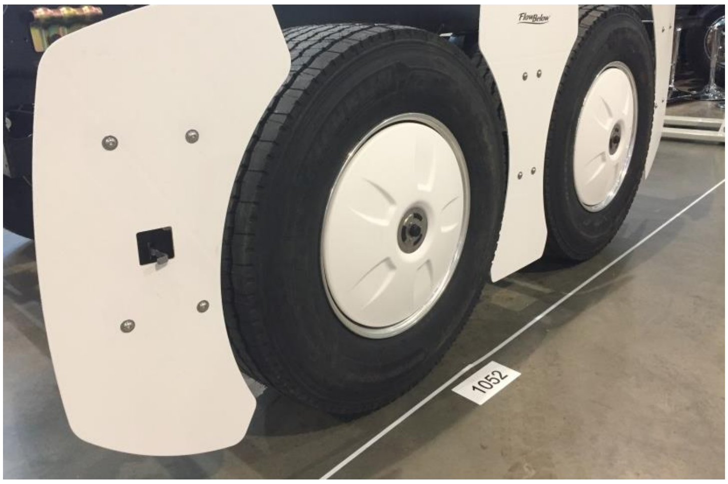

Figure 28: Example of wheel covers installed in a tractor

6.3.3 Front air drag reducing devices

6.3.3.1 Leading edge add-on

The objective of this add-on is to minimise the distance between the tractor and the semitrailer by bridging it with a hard plastic part, reducing the turbulence generated in that gap. Sizes and shapes are usually very similar for different manufacturers, as they are influenced by the gap size between the tractor and the trailer/semitrailer. In case of

the gap reducer is reached by means of a sliding fith wheel, the two set-ups should be considered as geometry data inputs and only test method C2 may apply.
The criteria to be met by this add-on in order to be valid for its certification shall be:

- The leading edge must cover at least 60% of the gap between the tractor and the trailer.
- The width of the leading edge cannot exceed the maximum dimensions for the vehicle defined by the regulation. (2.55 meters for regular trailer/semitrailers and 2.60 meters for refrigerated trailers).

Finally, it has to be considered that the manufacturing material meets some characteristics which ensure the correct functioning of the aero device. These characteristics will be defined by the certificating authority engineering criteria.

Figure 29: Example of a leading edge

6.3.4 Underbody air drag reducing devices

6.3.4.1 Underbody deflectors

This aerodynamic add-on is not very extended in the market since only one manufacturer who sells this system has been found.
This add-on has as the objective of redirecting the airflow under the rear suspension system, in order to avoid the possible turbulences generated by those parts. Its installation is fairly simple and can be done in about less than an hour.

It is a quite large part, with a length of about 3 meters, a height of 1 meter and a width of about 2 meters.
Regarding the certification of this aero device, there are not many restrictions for the dimensions of the add-on as long as the maximum permissible width is not exceeded. Also, the height of the device shall not compromise the safety of the vehicle, so the free space must be enough to go through inclination changes without the device touching the floor.
As actually there is only one manufacturer which sells this add-on, there is no possible classification.

Figure 30: Example of an underbody deflector

6.3.4.2 Diffusers

The diffuser's main objective is to accelerate and compress the underbody air and to inject this high energy air into the low energy trailer wake. This way, the wake will generate less drag resistance on the vehicle.

There are not many manufacturers who sell this add-on, so it is not widely used in the trailer and semitrailer market. The size of this device shall meet some characteristics in order to be valid for installation on the vehicle:

- Its length shall not exceed the rear end of the trailer/semitrailer.
- Its width shall not exceed the width of the trailer/semitrailer.

As currently there is only one manufacturer which sells this add-on, there is no possible classification. Anyway, its effect on the air drag resistance of the vehicle seems to be considerable, so it should be taken into account for the look-up tables.

Figure 31: Example of a rear diffuser installed on a trailer

6.4 Considered add-ons for the look-up tables

In order to simplify the design and lower the complexity of the look-up tables, not every listed add-on is going to be taken into account for the building of these tables. So, the devices with the lowest impact on the air drag resistance of the vehicle should be

considered as negligible, simplifying the look-up tables for both technical service and first and second stage manufacturers.
Taking this into account, the add-ons which are going to be considered for the add-ons would be:

Functional add-ons
1. Pallet boxes (open, closed)
2. Storage boxes (size, position, quantity)
3. Slider lifts
4. Refrigeration systems

Dedicated Air Drag reduction add-ons
5. Boat tails
6. Side skirts (simple, full)
7. Wheel covers
8. Leading edge add-ons
9. Underbody deflectors
10. Difussers

Therefore, as can be seen, the number of add-ons considered for building the look-up tables is 10, simplifying as far as possible the design of the tables and their usage by both the technical service and manufacturers.

7 Summary and Conclusion

All the options conceived in task 2 were grouped in four methods. Considering that weighting is the most suitable option for the mass calculation and the tyre label given by the tyre manufacturer the best option to assess the rolling resistance coefficient, the main difference between the four methods is the way the C_DxA is evaluated.

The first method (Method A) considers that the effect on the air drag depending on the body can be neglected. This approach is the cheapest and could only be considered applicable to dry freight and curtain siders due to their similarities to the Standard Body or Trailer used in the certification process of the pulling unit or the rigid lorry

The second method (Method B) considers using equations to determine the effect of the geometry for each category of body (dry freights would have an equation, tankers would have a different equation, etc.) and look-up tables including the delta reductions based on the aerodynamic appendixes. This method would open the door to aero-appendix manufacturers to certify their own products with certified deltas. After a deep analysis, this method seems to be the most suitable for all the stakeholders.

The third and fourth methods foresee the direct measurement of the C_DxA whether with Constant Speed Test (Method C1) or via CFD (Method C2). These methods are the most accurate but also the most expensive. Method C1 has an inherent uncertainty that may difficult the appreciation of small improvements. Furthermore, the polar-yaw curves used to correct the final value of these tests are generic ones. Considering that some of the aero-appendixes are focused on modifying this curve instead of reducing the C_DxA at 0º yaw, this method shall not be used. The only method to be considered among these two would be Method C2. However, this option implies that the Commission should provide some standard CAD for rigid lorries and tractor cabs in order to all manufacturers can simulate their products on the same basis.

8 Bibliography

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Bodies and trailers – development of CO_2 emissions determination procedure

Procedure no: CLIMA/C.4/SER/OC/2018/0005

Task 4: Feasibility analysis including simulations and/or measurements

Report v2

Task leader: Marc Soler

Date: 13/11/2019

This document contains 42 pages

Document information

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Acronyms and abbreviations

Acronym	Meaning
CFD	Computational Fluid Dynamics
CO_2	Carbon dioxide
CST	Constant Speed Test
DES	Detached Eddy Simulation
LBM	Lattice Boltzmann Method
NS	Navier-Stokes
RANS	Reynolds Averaged Navier Stokes

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1 Introduction

The interim report describes the activities within task 4 of the specific contract:

No 340201/2018/789725/SER/CLIMA.C.4
Bodies and trailers – development of CO_2 emissions determination procedure

Task 4 focuses on the aerodynamic benefits provided by two of the most popular drag reduction devices in trailers (boat tails and side skirts), as well as proving the applicability and feasibility of the CFD method analysed in Tasks 2 and 3 by comparing the values of $\Delta(C_D xA)$ predicted by the simulations against what has been measured in constant speed tests based on Regulation 2017/2400.

The following four trailer configurations have been tested at the IDIADA facilities using an IVECO Stralis with Hi-Way Cabin as a tractor:

- C00: Standard trailer
- C01: Standard trailer with a boat tail of 400mm length
- C02: Standard trailer with short side skirts
- C03: Standard trailer with boat tail and short side skirts

Out of the 5 different CFD methodologies presented in Task 2, two of them have been applied to a 3D model representative enough of the vehicle tested.

2 Literature review

Task 1 in this project (*review of existing studies, data collection and identification of the characteristics and specific constraints of the sector*) had as an objective to research the bodies and trailers market in the EU. This research had its base in two main topics: the characteristics of the trailer and body building sector and the review of the existing legislation.

With regard to the certification of trailers, the existing regulations in the US, Canada, EU, Japan, China and Korea were compared, looking for the best approach possible for the EU. The model which fits best the EU might be the one in the US, which allows trailer manufacturers to use a simple equation. This equation uses as inputs the results from a coastdown test, tyre test, transmission and axle test, as well as off-cycle technologies, and has as the objective of determining the GEM equivalent GHG emissions without actually using GEM. This value corresponds to the simulated GHG emissions of the trailer in combination with a reference tractor.

Considering the work done in task 1, task 2 of the project (*identification and evaluation of the possible methodology options*) had the objective of elaborating options to produce body and (semi-)trailer specific CO_2 results for single heavy-duty vehicles. To achieve this objective, methods are defined to create the input data for the simulation tool VECTO for bodies and trailers in an efficient way; this input data being air drag, mass and rolling resistance.

In task 2, several options for the determination of CO_2 values for bodies and trailers were analysed, and a relative change of CO_2-emissions compared to the standard bodies and trailers is the most practical output.

The CO_2 Factor Method offers a solution similar to the one introduced for buses. The Factor for bodies and trailers is different from the one introduced for buses and thus, it has been called as CO_2 Ratio. The CO_2-Factor Method is the result of 2 VECTO runs, one with the real body or (semi-) trailer, the other with the standard body or (semi-) trailer. The calculation of this ratio differs whether the candidate vehicle is a rigid lorry or a trailer:

- Should a body is to be certified, the CO_2 Ratio would be calculated through the division of a VECTO CO_2 value obtained using a combination of generic data and real data of the candidate vehicle with a standard box divided by the same data modifying the values of mass and/or C_DxA (depending on the method used, see point…). In this case, the CO_2 Ratio can be multiplied times the CO_2 of the primary vehicle declared, which would lead to the CO_2 final value.

- If the vehicle to be assessed is a trailer, a similar procedure would be followed, using standard values for the denominator and real data for the enumerator. This would give a CO_2 Ratio.

The matrix-interpolation method is quite accurate as well, but seems to need more efforts for elaboration and maintenance and has limits in covering crosswind effects on the air drag and including additional features like electric axles.

The Efficiency Classification proposes that, if the measurements or simulations of the C_DxA show small changes or prove to be not reliable, and the rolling resistance values of the tyres are only available as averages for the tyre label, a classification would reflect such limitations. The classification would include the differences of the candidate vehicle from the standard.

To incentivise the aerodynamic optimisation of the entire design of the bodies and trailers, and based on the 6-axis plots reported in Task 3, a CFD-based method seems to be more attractive than physical tests. On top of that, CFD can also provide influences of crosswind on the air drag with a reasonable effort, which is a relevant area for future improvements of vehicle designs. The methods for using CFD to produce certified air drag results for bodies and trailers shall be further developed.

In task 3, all the options conceived in task 2 were grouped in four methods. Considering that weighting is the most suitable option for the mass calculation and the tyre label given by the tyre manufacturer the best option to assess the rolling resistance coefficient, the main difference between the four methods is the way the C_DxA is evaluated.

The first method (Method A) considers that the effect on the air drag depending on the body can be neglected. This approach is the cheapest and could only be considered applicable to dry boxes and curtain siders due to their similarities to the Standard Body or Trailer used in the certification process of the pulling unit or the rigid lorry.

The second method (Method B) considers using equations to determine the effect of the geometry for each category of body (dry boxes would have an equation, tankers would have a different equation, etc.) and look-up tables including the delta reductions based on the aerodynamic appendixes. This method would open the door to aerodynamic device manufacturers to certify their own products with certified deltas. After a deep analysis this method seems to be the most suitable for all the stakeholders.

The third and fourth methods foresee the direct measurement of the C_DxA whether with Constant Speed Test (Method C1) or via CFD (Method C2). These methods are the most accurate but also the most expensive. Method C1 has an inherent uncertainty that may difficult the appreciation of small improvements. Furthermore, the polar-yaw curves used to correct the final value of these tests are generic ones. Considering that some of the aero-appendixes are focused on modifying this curve instead of reducing the C_DxA at 0º yaw (side skirts, for example), this method shall not be used. The only method to be considered among these two would be Method C2. However, this option implies that the Commission should provide some standard CAD models for rigid lorries and tractor heads, so all manufacturers can simulate their products on the same basis.

3 Overview

The applicability and feasibility of the methods that consider the evaluation of the air drag, the effect of the aero-devices and its interaction are proven by performing laboratory tests and CFD simulations.

In order to do so, the same vehicle is tested in four different configurations:

- C00: Baseline consisting off a tractor head with a Standard Trailer 1 as per Regulation 2017/2400
- C01: Baseline with boat tail
- C02: Baseline with simple side skirts
- C03: Baseline with both side skirts and boat tail

The laboratory test method to determine the air drag is based on Regulation 2017/2400 and consists of constant speed tests (CST), performed in both directions of a straight line with sufficient distance to road side obstacles. The running resistance torque is measured with strain gauges installed on the driveshafts and the vehicle speed is measured with DGPS. The output is the C_DxA for the complete vehicle as per VECTO specification. The application of VECTO Air Drag Module will introduce an error in those cases in which aero-appendixes are introduced since the polar-yaw correction used by the program does not include the benefit of these devices. Nonetheless, all the tests are performed under low wind speed conditions, and thus, the difference between one polar-yaw curve and another are of the order of less than 0.1 m^2.

For each aerodynamic configuration at least two repetitions of the CST are performed.

In parallel, the same vehicle configurations measured on the test laboratories are simulated. The Consortium uses the methodology proposed in task 2 based on its potential advantages regarding accuracy, robustness and cost.

This activity should confirm the applicability of CFD methods to assess the effect of trailer designs on the air drag. The consortium reports its conclusions focussing on the CFD method accuracy, robustness and cost.

4 Constant Speed Tests (CST)

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 on a vehicle provided by CNH Industrial.

4.1 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 10 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.

4.2 Vehicle specifications

Table 1. Specifications of the tested vehicle

VEHICLE CHARACTERISTICS	
Manufacturer	IVECO
Model	STRALIS 460 E
VIN	WJMM1VTH60C251283
Class code	5
Vehicle maximum speed	95,0 km/h
Vehicle height	4,00 m
Axle ratio	2,850
Gear box type	MT_AMT
VEHICLE TEST CHARACTERISTICS	
Anemometer height	5,30 m
Gear at low speed	2-H
Gear ratio at low speed	7,435
Gear at high speed	6-H
Gear ratio at high speed	1,000

4.2.1 Vehicle test configurations

Figure 1. Baseline configuration, left hand side (C00)

Figure 2. Boat tail configuration, left hand side (C01)

Figure 3. Side Skirts configuration, right hand side (C02)

Figure 4. Boat tail and Side skirts configuration, right hand side (C03)

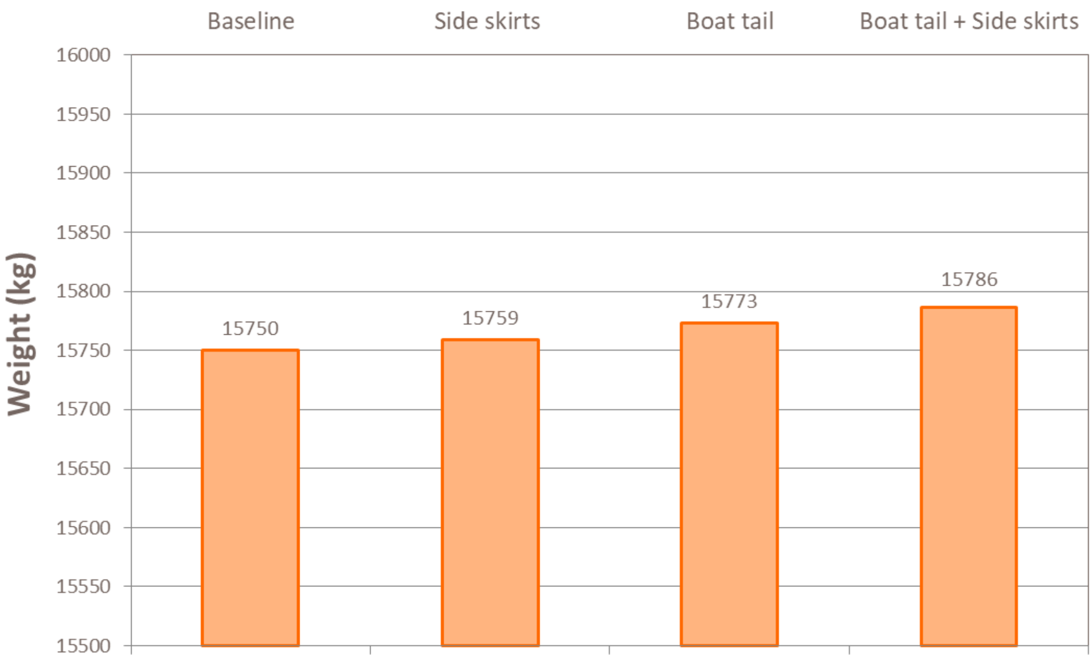


Figure 5. Weights of the different configurations

4.3 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 following plot 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 6. 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.

In the following plot it can be observed the potential effect of each device in ΔC_DxA after taking into account the 3,75% tolerance mentioned above.

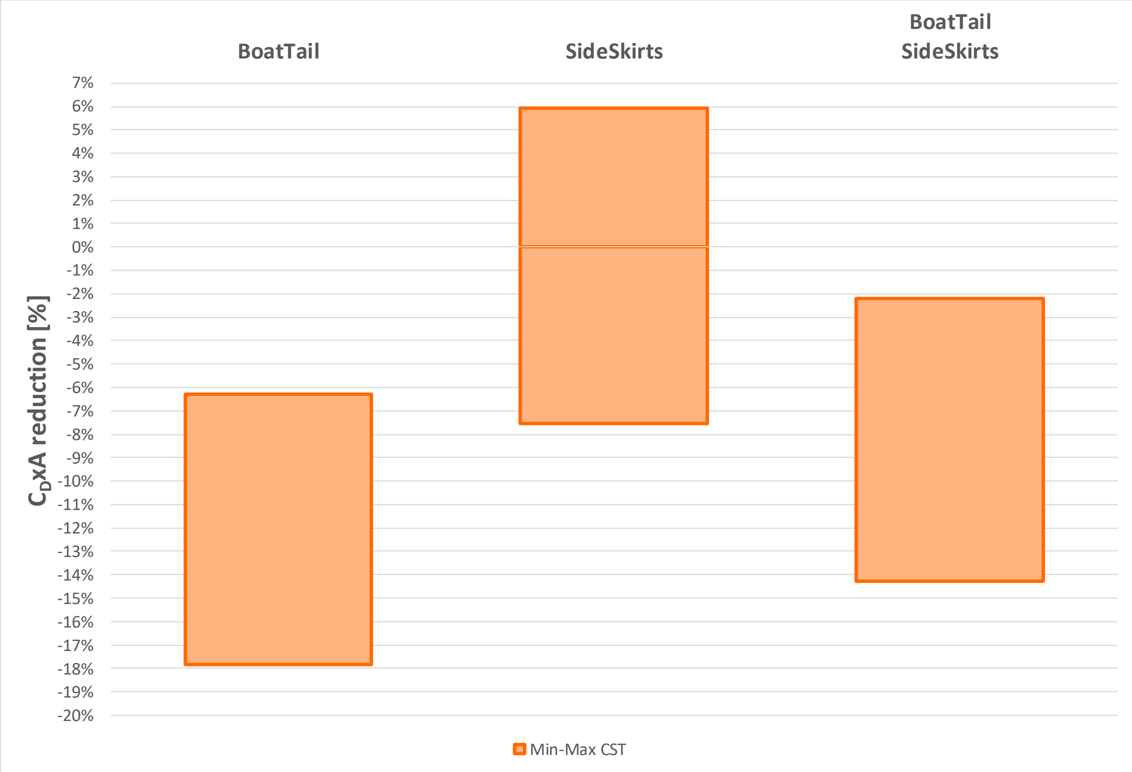


Figure 7. CST compared results

These results show that the effect of the side skirts on the C_DxA at 0º of cross wind has no effect in both tested configurations while the boat tail has an important impact. As assessed in task 3, due to the uncertainty of the test, it is difficult to assign a delta value to the aerodynamic appendixes.

4.4 *Other Measurements*

4.4.1 Tyre configuration

Axle*:* ***1*** ***2*** ***3*** ***4*** ***5***

Table 2. Tire distribution and pressure

	Left Model	Left Pressure	Right Model	Right Pressure
Axle 1	Michelin XLine Energy	130 psi	Michelin XLine Energy	130 psi
Axle 2 Inner	Michelin XLine Energy	130 psi	Michelin XLine Energy	130 psi
Axle 2 Outer	Michelin XLine Energy	130 psi	Michelin XLine Energy	130 psi
Axle 3	Formula Trailer	130 psi	Sava Cargo 4	130 psi
Axle 4	Next Tread NT242	130 psi	Good year KMAX T	130 psi
Axle 5	Sava Cargo 4	130 psi	Next Tread NT242	130 psi

4.4.2 Vehicle instrumentation

Table 3. Instrumentation used in the test

INSTRUMENTATION LIST

Channel Name	Inventory Number	Model	Maker	Acquisition rate
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

4.4.3 Other measurements

The drag force on wheel gives information useful if the test is to be repeated.

Table 4. Drag force on wheel of the pulling unit [N]

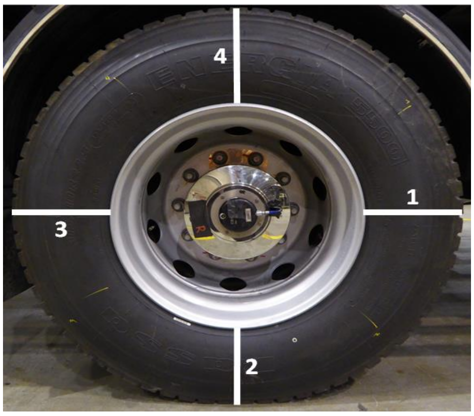
DRAG FORCE WHEEL PULL MEASUREMENTS [N]		
	Front Left	**Front Right**
Maximum	34.00	38.00
Minimum	15.00	22.00
	Rear Left	**Rear Right**
Maximum	34.00	40.00
Minimum	20.00	25.00

Tyre tread depth and wheel alignment are requirements of the regulation 2400/2017

Table 5. Tyre tread depth

TIRE TREAD DEPTH MEASURMENT [mm] (See pic. 1 & 2)						
Tire	Front Left			Front Right		
Mark[1]	E	C	I	I	C	E
1	4,3	4,8	4,6	4,7	5,1	4,8
2	4,6	4,9	4,7	4,4	4,6	4,2
3	4,5	4,9	4,6	4,4	4,6	4,3
4	4,5	4,9	4,8	4,8	5,1	4,5
Mean	**4,5**	**4,9**	**4,7**	**4,6**	**4,9**	**4,5**
	4,7			**4,6**		
Tire	Rear Inner Left			Rear Inner Right		
Mark[1]	E	C	I	I	C	E
1	5,0	4,2	4,2	6,0	5,3	6,1
2	5,2	4,5	4,1	6,0	5,2	5,6
3	5,5	5,5	5,0	6,0	5,6	6,1
4	5,4	5,2	5,0	5,7	5,5	6,3
Mean	**5,3**	**4,9**	**4,6**	**5,9**	**5,4**	**6,0**
	4,9			**5,8**		
	Rear Outer Left			Rear Outer Right		
Mark[1]	E	C	I	I	C	E
1	6,0	5,1	5,8	5,4	5,0	5,6
2	6,0	5,3	5,7	5,7	5,1	5,8
3	6,6	5,4	6,1	5,3	4,7	5,4
4	6,3	5,4	5,8	5,0	4,7	5,5
Mean	**6,2**	**5,3**	**5,9**	**5,4**	**4,9**	**5,6**
	5,8			**5,3**		

[1]Marks: Inner (I), central (C) & outer (E)



Pic. 1.- Radial marks for tire tread depth measurement

Pic. 2.- Transversal marks for tire tread depth measurement

Remark: Pictures only for information. They do not represent the sample tested.

The wheel alignment has been adjusted as per the manufacturer's recommendation.

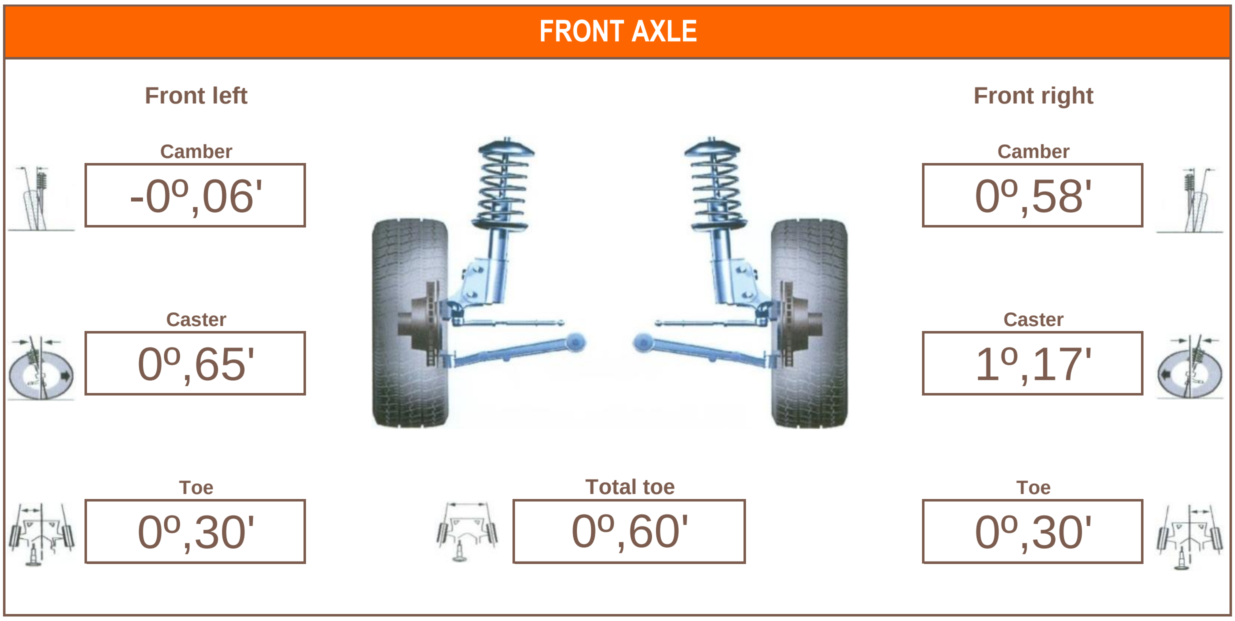


Figure 8. Front axle wheel alignment

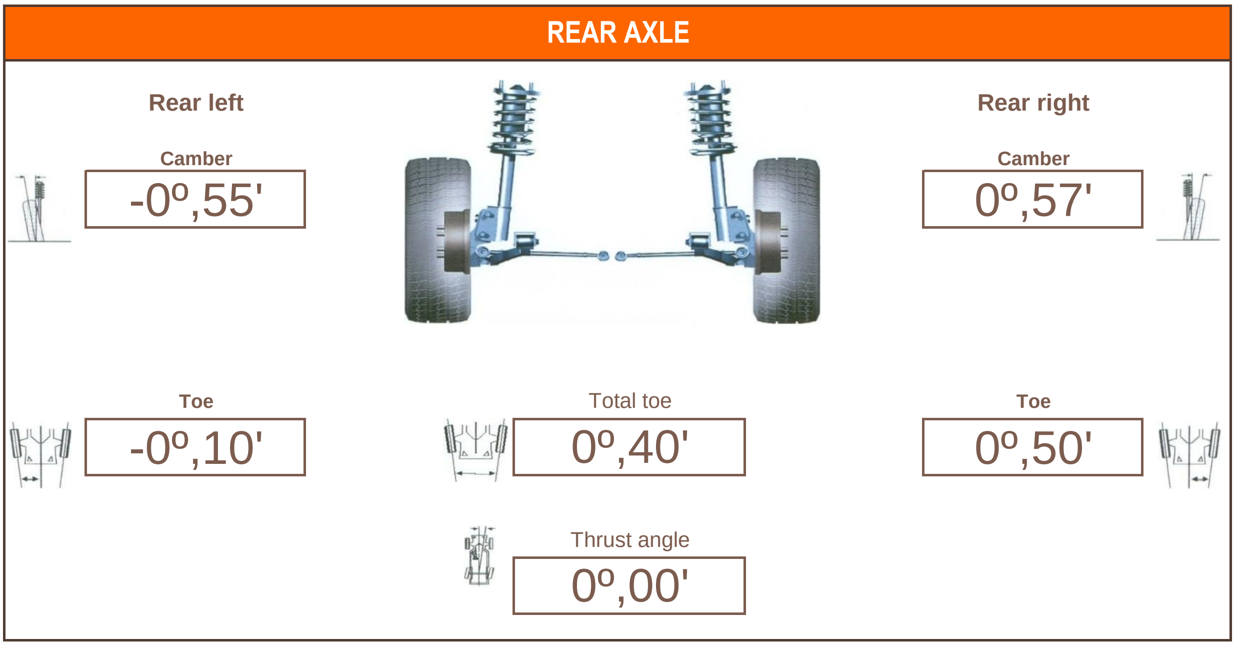


Figure 9. Rear axle wheel alignment

5 Computational Fluid Dynamics simulations

Computational Fluid Dynamics (CFD) is widely used within the automotive industry in different application areas such as aerodynamics, thermal management or passenger comfort, among others. In the truck industry in particular, CFD tools are used extensively when optimising the aerodynamic performance of such large vehicles throughout the entire development phase (from early conceptual sketches to the final designs ready for production) by the vast majority of OEMs, like DAF Trucks [1] [2], DAIMLER Trucks North America [3] [4], FORD OTOSAN [5] [6], MAN Trucks [7], SCANIA [8] [9] [10] or VOLVO Trucks [11] [12] [13].

On top of that, current regulations [14] already allow the use of CFD tools in order to demonstrate the selection of the parent vehicle within a family to be tested by the constant speed procedure.

Such evidences make CFD methods, a priori, a good alternative to Constant Speed Test (CST) when determining aerodynamic resistance values (C_DxA). However, it must be noted that, after a literature research, no evidence have been found that CFD is used by trailer and body manufacturers and the answers provided to the survey sent out during Task 1 did not identify any CFD users either. Nonetheless, and to the authors' knowledge, suppliers of drag reduction devices for trailers do make intensive use of CFD methods to further develop their products.

5.1 Standardization of CFD settings

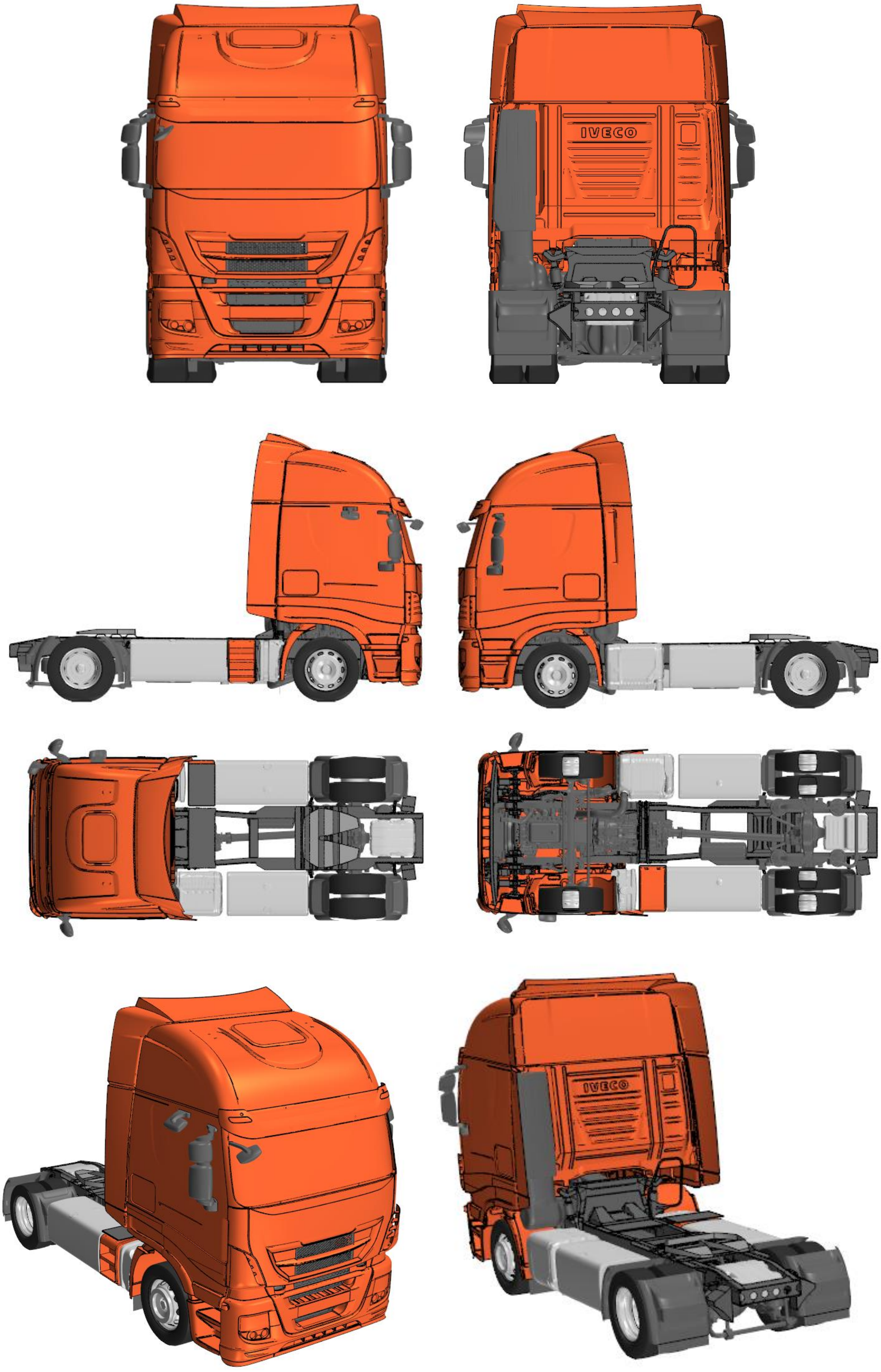
SAE document J2966 [15] provides general requirements in CFD to simulate aerodynamics of medium and heavy commercial vehicles such as minimum computational domain dimensions to avoid blockage effects, minimum cell count to properly capture relevant flow structures, prism layer resolution to properly resolve the boundary layer, turbulence intensity of the incoming flow or convergence criteria, for instance. These recommendations are valid for both Navier-Stokes (NS) and Lattice-Boltzmann (LBM) based solvers, which are the most common in this industry sector.

Following these recommendations, together with IDIADA own best practices and past experience on simulating the aerodynamics of heavy-duty vehicles, including all the CFD activities performed within Task 2, all four configurations tested (C00 to C03) have also been studied by means of CFD.

5.2 Virtual Geometry Model

5.2.1 Tractor Unit

The 3D model of the tractor, a Stralis 460E Hi-Way Cabin, was provided by IVECO. All aerodynamically relevant exterior parts are included (mirrors, sun visor, roof spoiler and side deflectors at their corresponding position as in the tests), as well as all engine compartment and chassis components. Tyres are completely treadless and contact patch deformation is taken into account.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IVECO

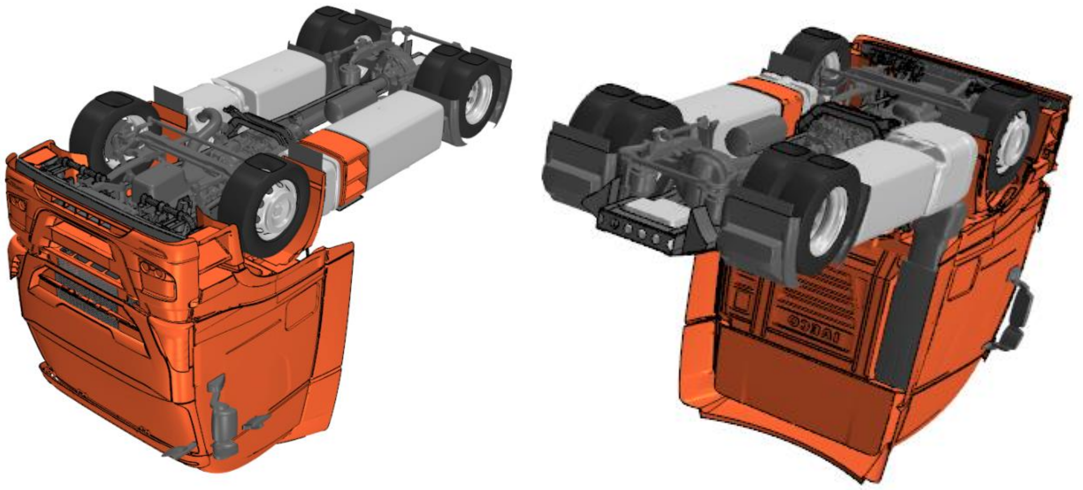
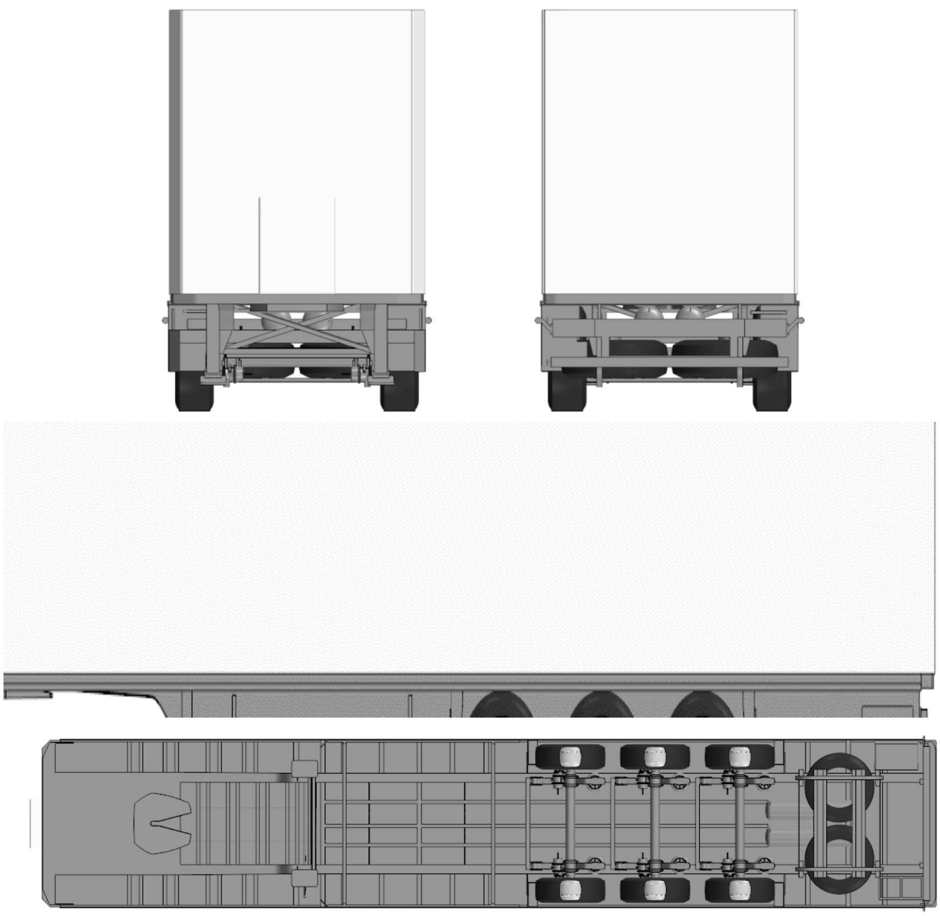


Figure 10. CAD model of the tractor IVECO Stralis 460E Hi-Way

5.2.2 Semitrailer Unit

The Schmitz-Cargobull semitrailer available at IDIADA facilities, which fulfils the standards of a ST1 trailer according to Commission Regulation (EU) 2017/2400, has been translated to a virtual 3D model.



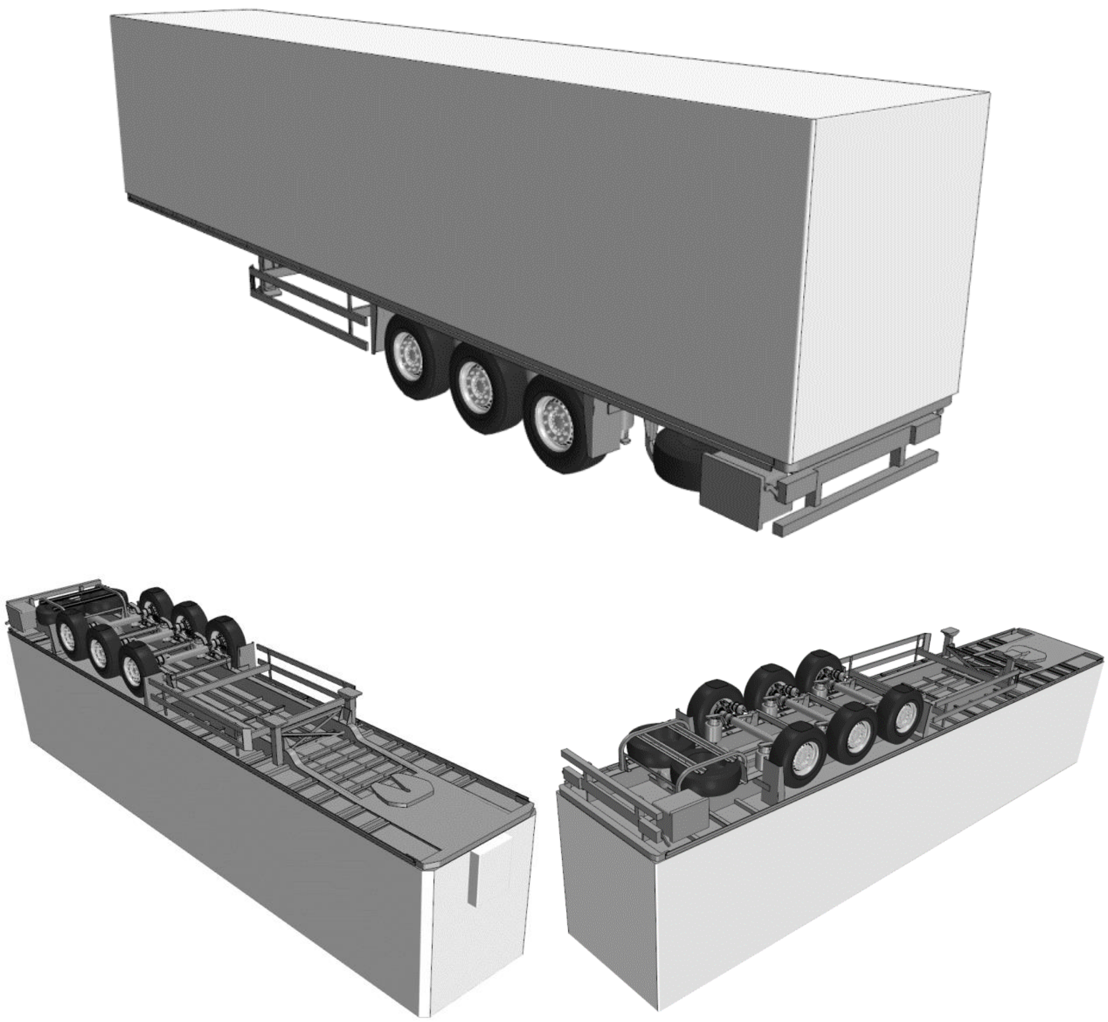


Figure 11. CAD model of the Schmitz-Cargobull trailer available at IDIADA

5.2.3 Complete Vehicle

The combination of both tractor and trailer presented here above result in a total vehicle length of 16.50 m and height of 4.0m

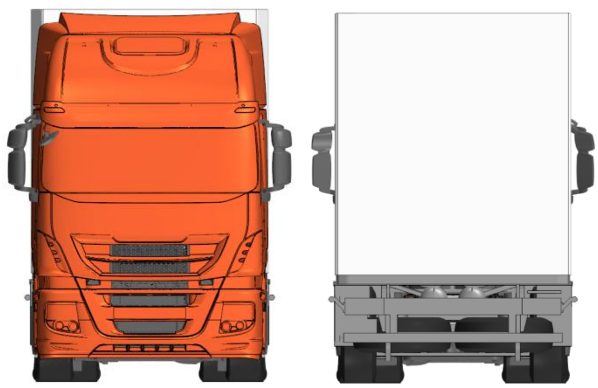


Figure 12. CAD model of the complete vehicle

The vehicle has a frontal projected area of 10.25m^2, which remains unchanged when any of the drag-reduction devices analysed here (side skirt and boat tail) is implemented onto the trailer.

Table 6. List of simulated cases

Case	Boat Tail	Side Skirts
C00	NO	NO
C01	YES	NO
C02	NO	YES
C03	YES	YES

C00 – Standard semitrailer w/o aero devices

C01 – Standard semitrailer with Boat Tail

C02 – Standard semitrailer with short Side Skirts

C03 – Standard semtrailer with Boat Tail and short Side Skirts

Figure 13. Semitrailer configuration cases

5.3 CFD Settings

Five different CFD methods were applied to the FAT and AEROFLEX geometries in Task 2:

Table 7. CFD methods compared in Task 2

Software	STAR-CCM+	OpenFOAM	STAR-CCM+	UltraFluidX	PowerFLOW
Time dependency	Steady-state	Steady-state	Transient	Transient	Transient
Turbulence Model	RANS k-ω SST (Menter)	RANS k-ω SST (Menter)	DES k-ω SST (Menter)	Smagorinsky LES	RNG k-epsilon
Compressibility	Constant Density	Constant Density	Constant Density	Constant Density	Constant Density
Discretization	150 million cells approx	60 million cells approx	150 million cells approx	300 million voxels approx	100 million voxels approx
Solution Time-Averaging	N/A	N/A	15 seconds	3 seconds	4 seconds

The commercial software STAR-CCM+ from SIEMENS AG has been used and both steady-state and transient approaches have been applied to all four configurations reported in this Task 4.

The computational domain has been made large enough in order to work with a very small blockage of around 0.2%, which fulfils the requirements reported in both [15] and [16]. A small blockage, or in other words, placing the computational domain boundaries far away from the vehicle, allows to better simulate the vehicle in open road conditions as the interaction between the domain walls and the vehicle are minimized.

Also, the cell count is significantly higher (~250 million cells vs 65 million cells recommended in Task 3) mainly due to the finer details and geometrical features one can find in a real cabin such as the IVECO Stralis with respect to the FAT and AEROFLEX cabins. Cell size in close vicinity to the vehicle falls within the range 3 – 25mm, applying refinement in key aerodynamic areas such as tractor deflectors, mirrors, wheels, etc. It must be noted that such small sizes of 3mm is not a requirement for future regulations. Such small size was used in certain very detailed areas of the tractor where high flow gradients are expected. A more simplified cabin, such as FAT, would not require such refinement levels.

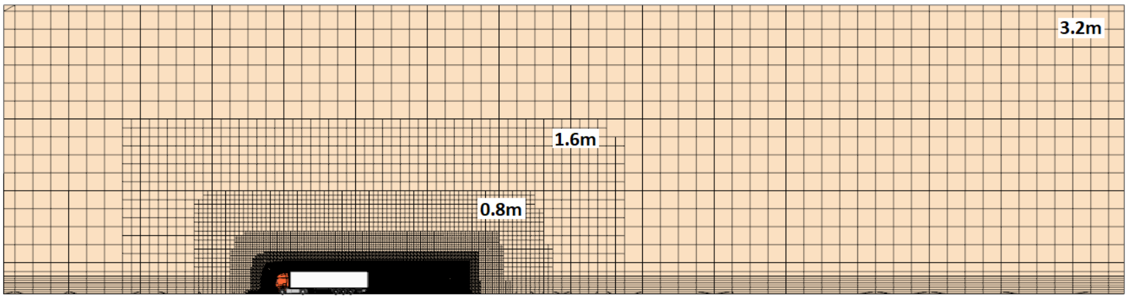


Figure 14. Cell distribution at the Y=0 section

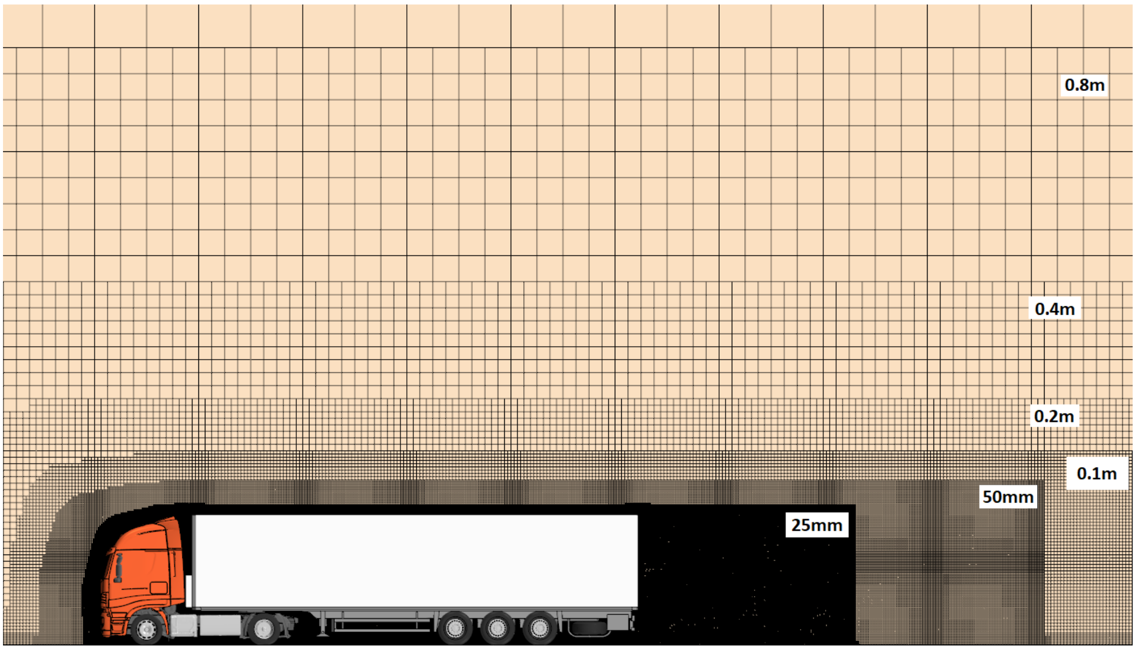


Figure 15. Cell distribution at the Y=0 section near the vehicle

The boundary layer has been resolved with enough prism layers and near wall cells resulting in y+ values between 1 and 5 in the vast majority of the vehicle in order to resolve the viscous sublayer.

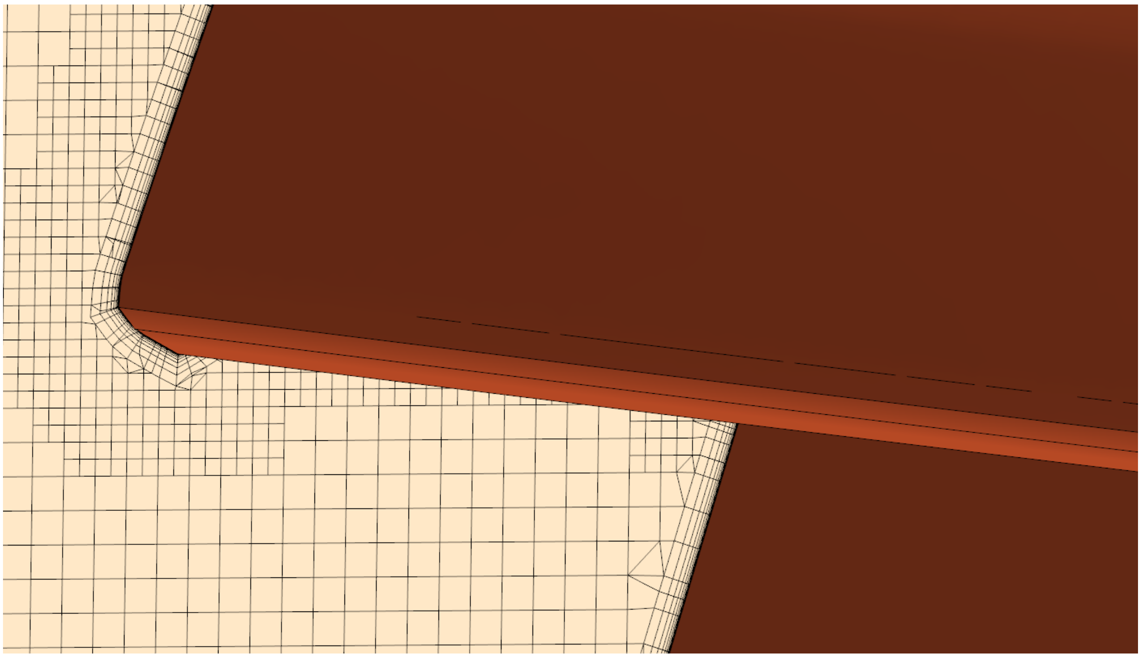


Figure 16. Detail of the generated prism layer

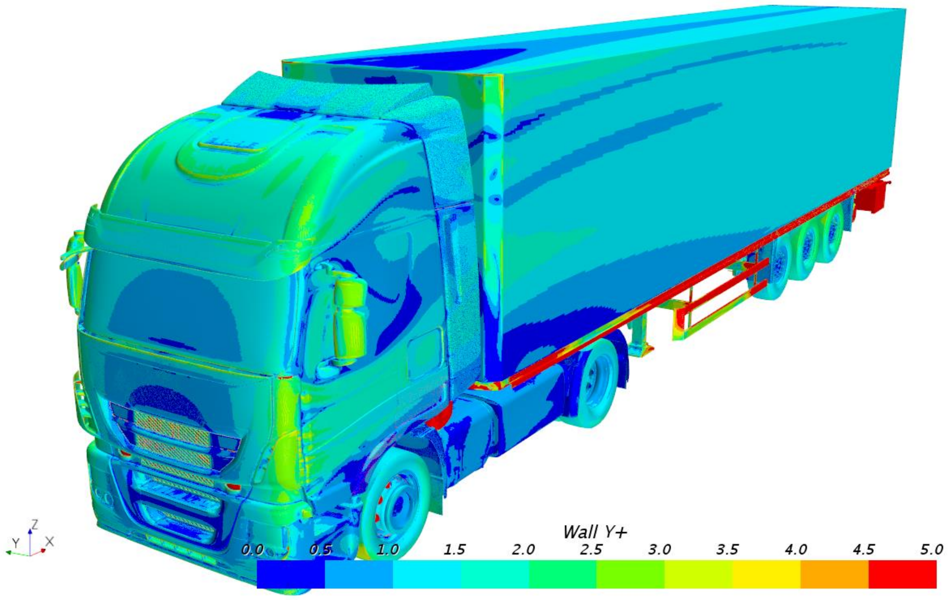


Figure 17. Wall Y+ values

The incoming flow is such that the vehicle is simulated to be travelling at 25 m/s (90 km/h), which corresponds to the high-speed phase of the test measurements. The ground of the computation domain is modelled with a tangential velocity and all wheels are rotating.

Finally, the pressure losses across the cooling pack (condenser, charge air cooler and radiator) in the engine compartment are characterised with the Darcy-Forchheimer model.

5.4 CFD Results

The absolute values obtained from the simulations are not reported due to confidentiality. Alternatively, only the difference with respect to the baseline configuration (semitrailer without any aerodynamic appendix) is presented, according to the following formula:

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

5.4.1 Steady-State results

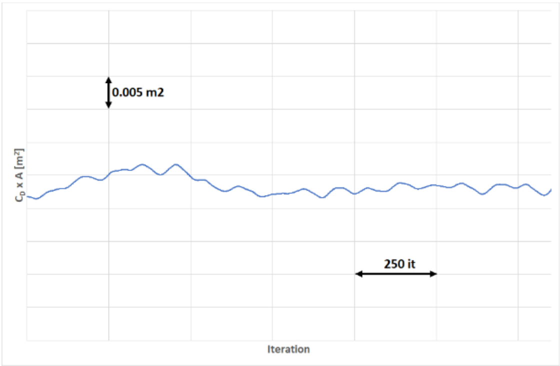
All four cases have been run for enough iterations to ensure a full convergence of the most relevant engineering quantities. The following table reports the standard deviation (σ) of the last 500 iterations of C_D·A [m^2], calculated as follows:

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

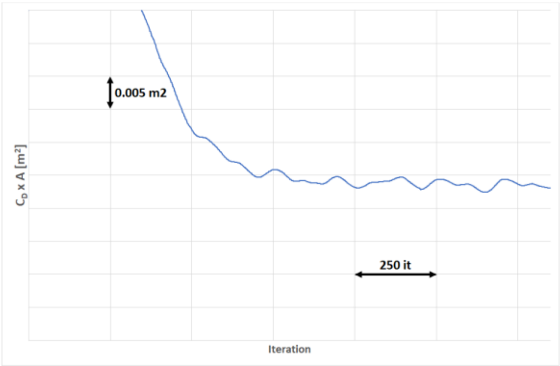
Table 8. C_DxA standard deviation [m^2] in the steady-state runs

Case	Last 500 iterations C_D·A standard deviation [m^2]
C00	0.00053
C01	0.00051
C02	0.00050
C03	0.00049

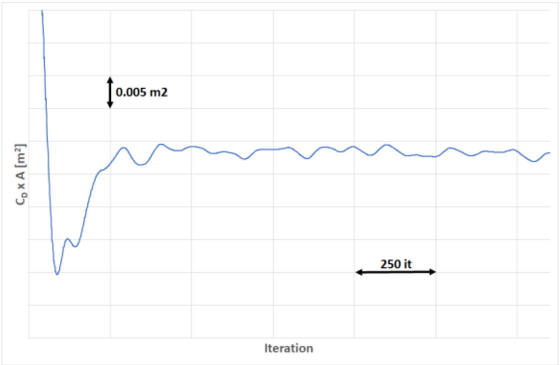
In a more visual way, the following plots show the evolution of C_DxA [m^2] vs iteration. Absolute values of C_DxA [m^2] are hidden for confidentiality purposes, but Δ C_DxA() [m^2] and Δ(iteration) are displayed for a better understanding.



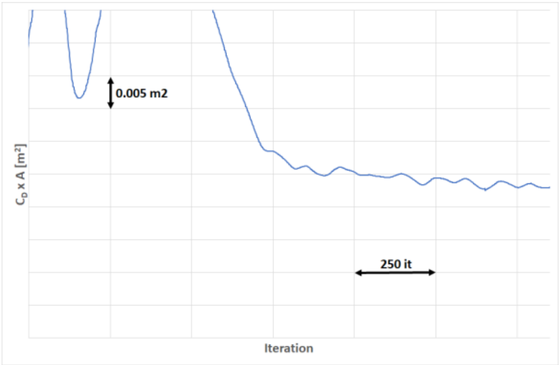
Case 00



Case 01



Case 02



Case 03

Figure 18. C_D·A [m^2] vs iteration

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

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

Table 9. CFD Steady-state results

	C00 w/ Boat Tail	**C01 w/ Side Skirts**	**C02 w/ Boat Tail w/ Side Skirts**
Aero Device Effect	-8.0%	-0.4%	-7.7%

As shown in the following plot, the main benefit of the **boat tail** lies in the flow pattern changes at the rear part of the trailer, which leads to a significant reduction of the sudden drag coefficient (C_D) jump that occurs in the rear end with such a blunt closing.

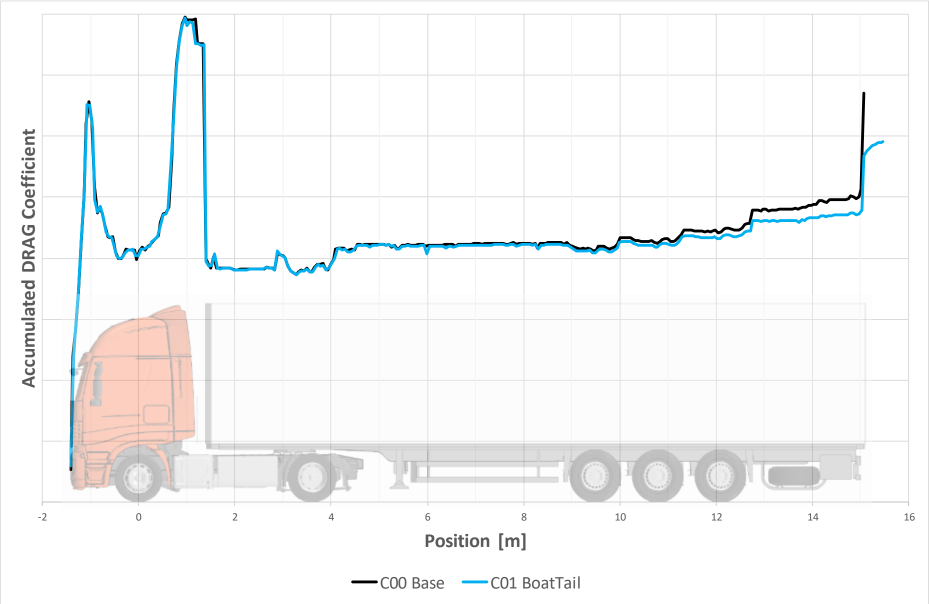


Figure 19. Accumulated Drag Coefficient. C00 vs C01. Steady-state results

Total pressure coefficient (Cp_{tot}) isosurfaces are useful to easily identify areas where flow kinetic energy is lost, which is translated to a worse aerodynamic performance or, in other words, a higher C_DxA value.

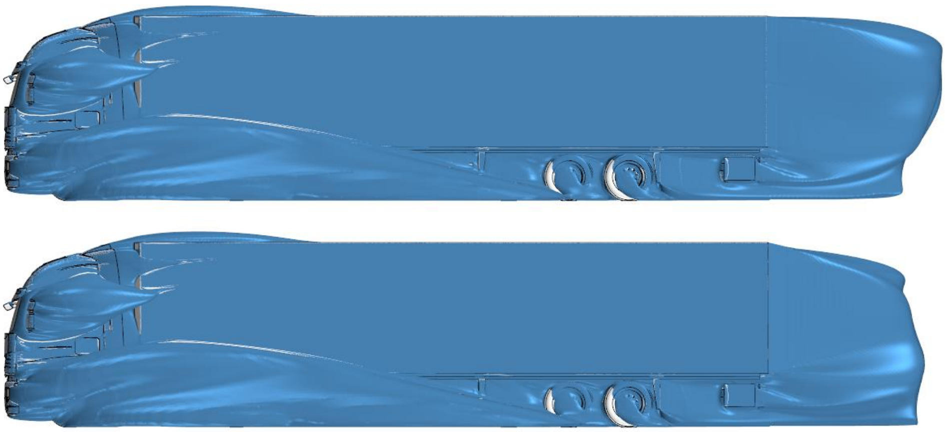
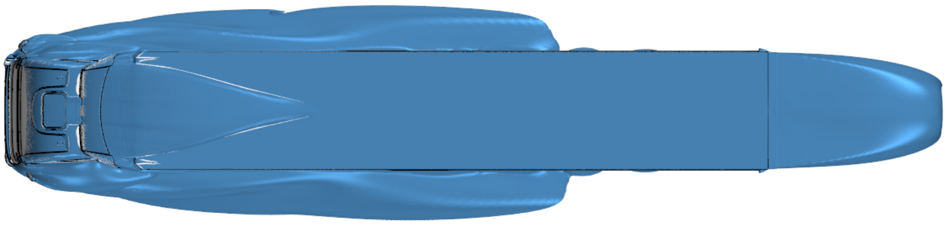


Figure 20. Cptot=0 isosurface. Side view of C00 (top) vs C01 (bottom)



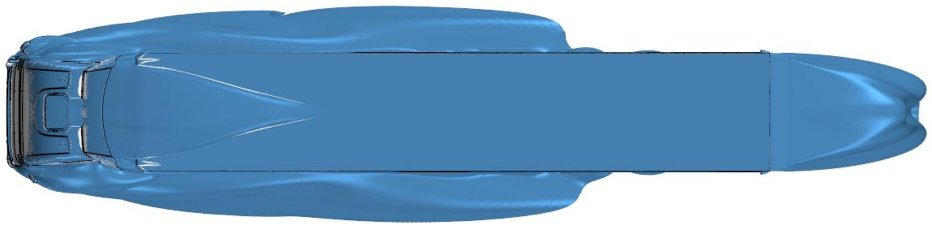


Figure 21. Cptot=0 isosurface. Top view of C00 (top) vs C01 (bottom)

Images above show how the boat tail helps reducing the wake size behind the vehicle by tapering and pushing the wake downwards. Following images zoom into the trailer wake area for a better comparison:

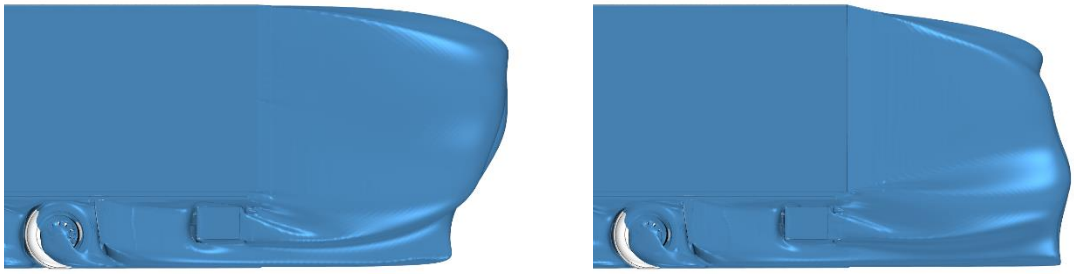


Figure 22. Cptot=0 isosurface. Zoomed side view of C00 (left) vs C01 (right)

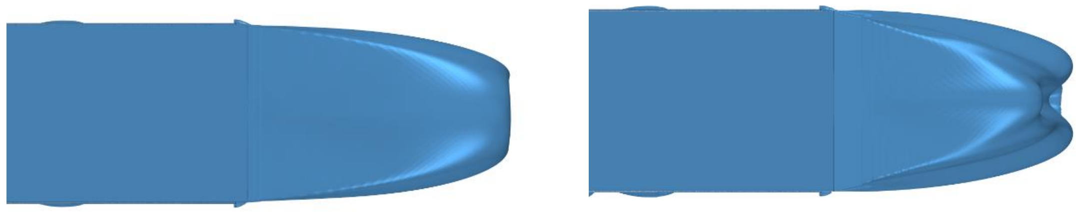


Figure 23. Cptot=0 isosurface. Zoomed top view of C00 (left) vs C01 (right)

The reduction of the recirculation zone behind the vehicle is also translated into a higher base pressure. A higher pressure on the rear of a vehicle acts as a pushing forward phenomena and, hence, reducing drag.

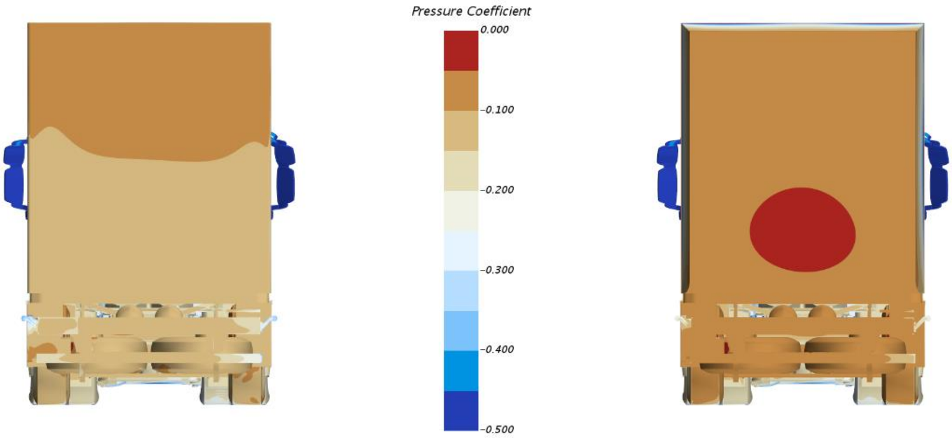


Figure 24. Pressure Coefficient (C_p) distribution at the rear. C00 (left) vs C01 (right)

As far as the **side skirts** is concerned, their effect is minimum under straight wind conditions. The accumulated drag plot here below shows only minor differences between the two configurations around the trailer wheels, which is then propagated further downstream.

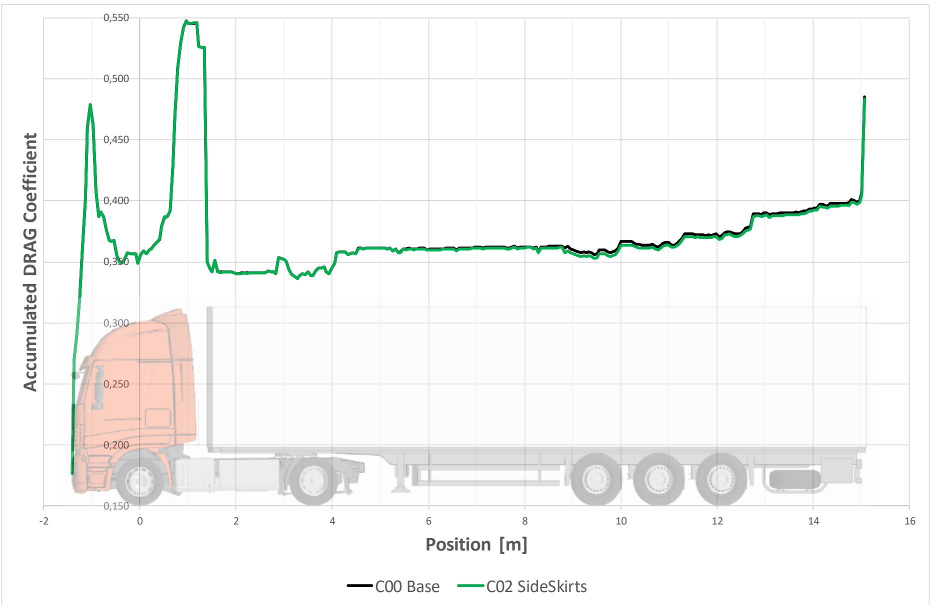


Figure 25. Accumulated Drag Coefficient. C00 vs C02. Steady-state results

The following accumulated drag plot considers only drag forces acting on the trailer underbody. It clearly shows that side skirts alter the flow structures in such way that axles, wheels and underbody components reduce their contribution on the overall drag resistance.

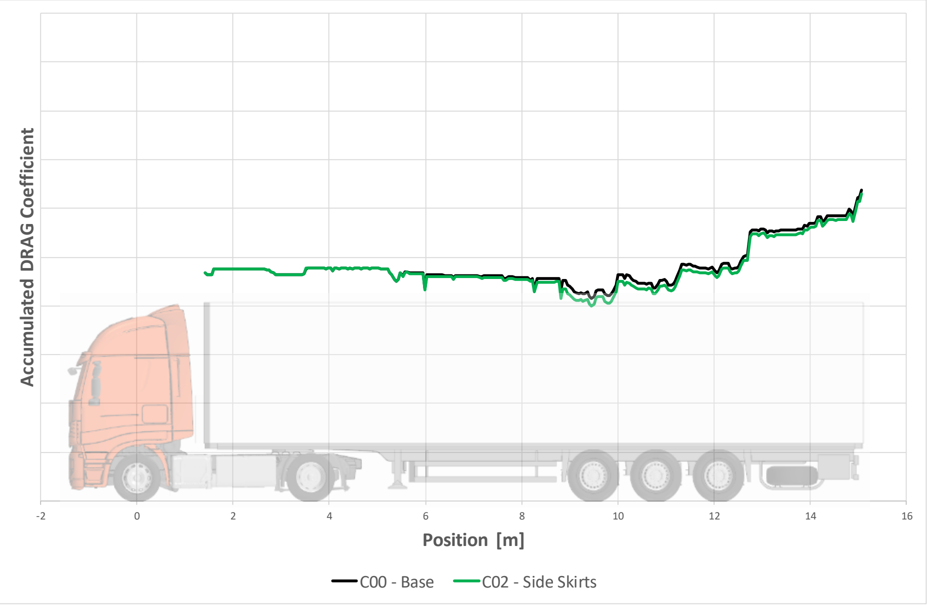


Figure 26. Accumulated Drag Coefficient in trailer underbody. C00 vs C02

A better understanding of the real contribution to overall drag by different components can be achieved by looking at their surface orientation and the pressure acting on that surface. Taking this into account, one could face the following scenarios:

- Forward-facing surfaces with positive pressure values contribute to drag
- Forward-facing surfaces with negative pressure values reduce drag
- Backward-facing surfaces with positive pressure values reduce drag
- Backward-facing surfaces with negative pressure values contribute to drag

The product of Pressure Coefficient (C_p) and surface orientation, called Drag Normal, is displayed in the following images:

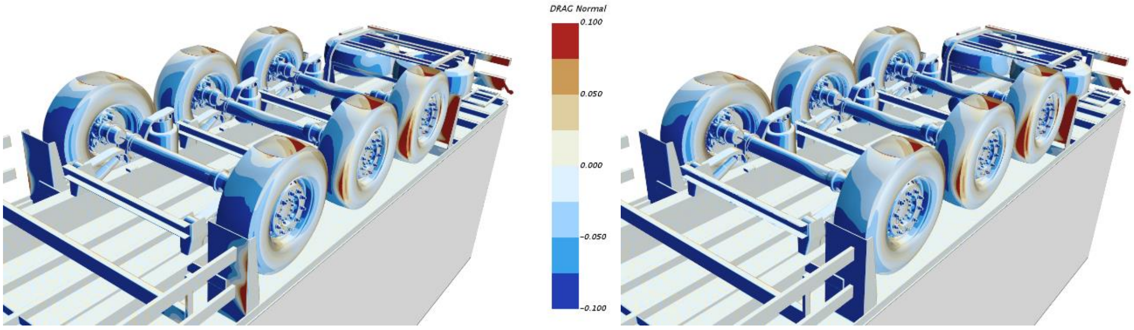
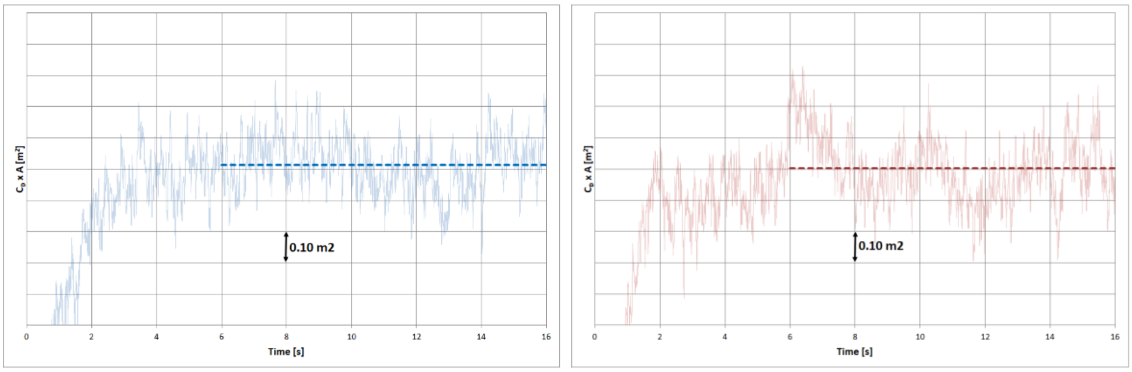


Figure 27. Drag Normal in trailer underbody. C00 (left) vs C02 (right)

The differences are very subtle, but a clear effect of these side skirts is identified in the forward-facing surfaces of the mudguards, where pressure built-up occurs.

5.4.2 Transient results

All cases have been run for 16 seconds of simulation time. Within this time, the drag coefficient values reach a rather constant oscillation behaviour, as It can be seen in the following plots, that allows to extract an average of the last 10 seconds:



Case 00 Case01

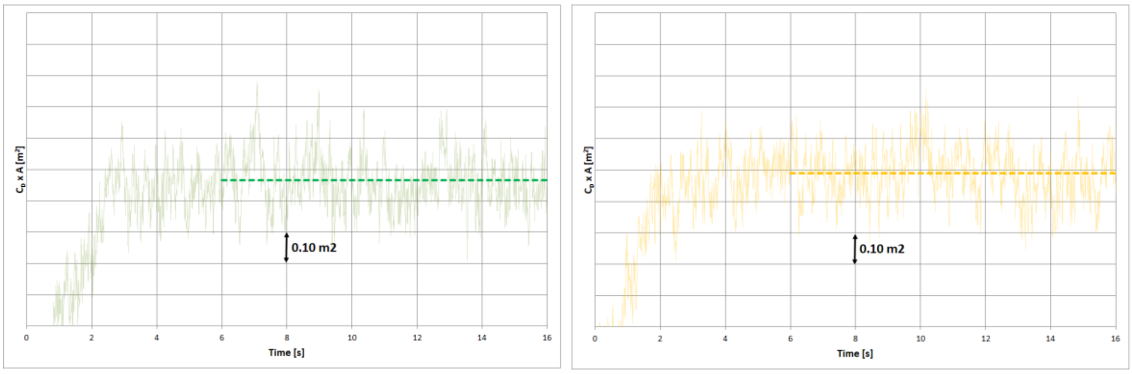


Figure 28. $C_D \cdot A$ [m^2] vs time

As expected, the variation of C_DxA over time is much larger than what was predicted the steady-state methodology:

Table 10. C_DxA standard deviation [m^2] in the transient runs

Case	**Last 10 seconds** $C_D \cdot A$ **standard deviation [m^2]**
C00	0.0875
C01	0.1063
C02	0.0849
C03	0.0808

Among other things, such larger variations with respect to the steady-state results are mainly because a transient methodology is capable of capturing the vortex shedding phenomena, specially occurring at the trailer rear end, as well as resolving different turbulence length scales of certain flow structures:

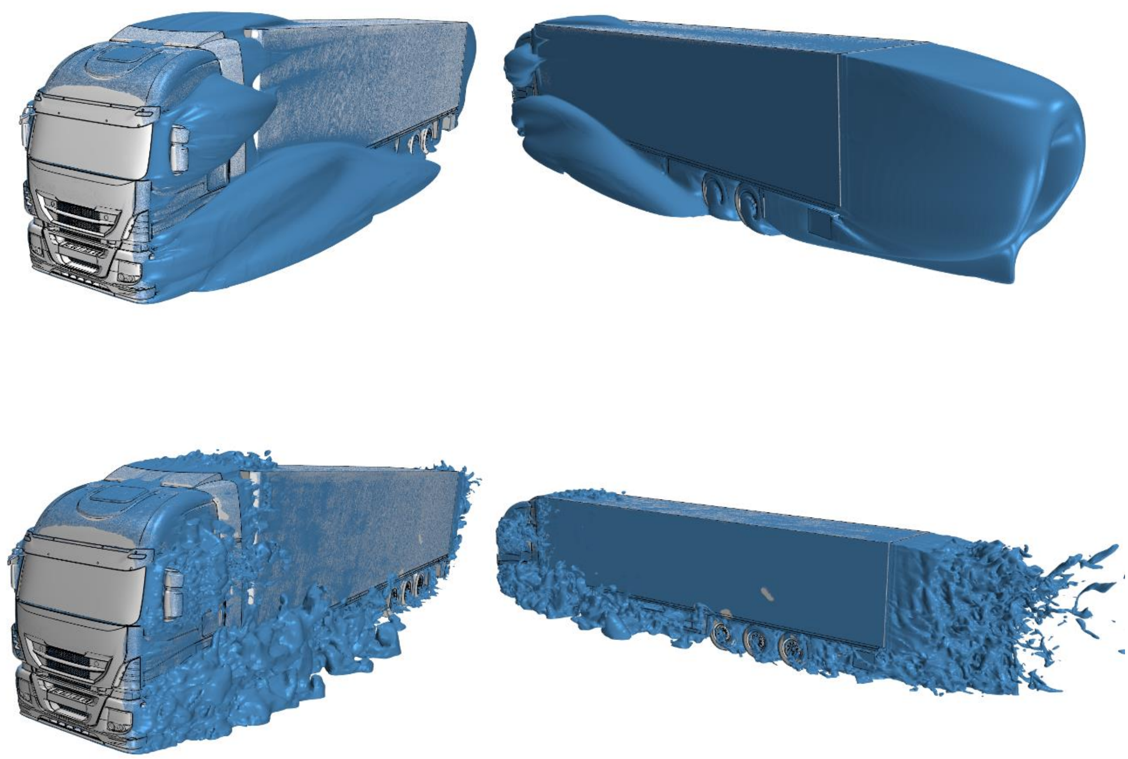


Figure 29. Isosurface of CpTot = 0 in the C00 configuraiton. Strady-state (top) and DES (bottom)

The following table presents the effect of the semitrailer aerodynamic devices, with respect to the standard semitrailer, predicted by the CFD simulations resolved in a transient manner:

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

Table 11. CFD Transient results

	C01 w/ Boat Tail	C02 w/ Side Skirts	C03 w/ Boat Tail w/ Side Skirts
Aero Device Effect	-7.4%	-0.9%	-8.9%

5.4.3 Steady-state vs Transient results

In the following plot the results of the CST tests and the CFD simulations are merged. 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 and the transient approach prediction is much closer to what has been measured in the testing track and it even falls within the tolerance margin of 7,5% specified in Commission Regulation (EU) 2017/2400.

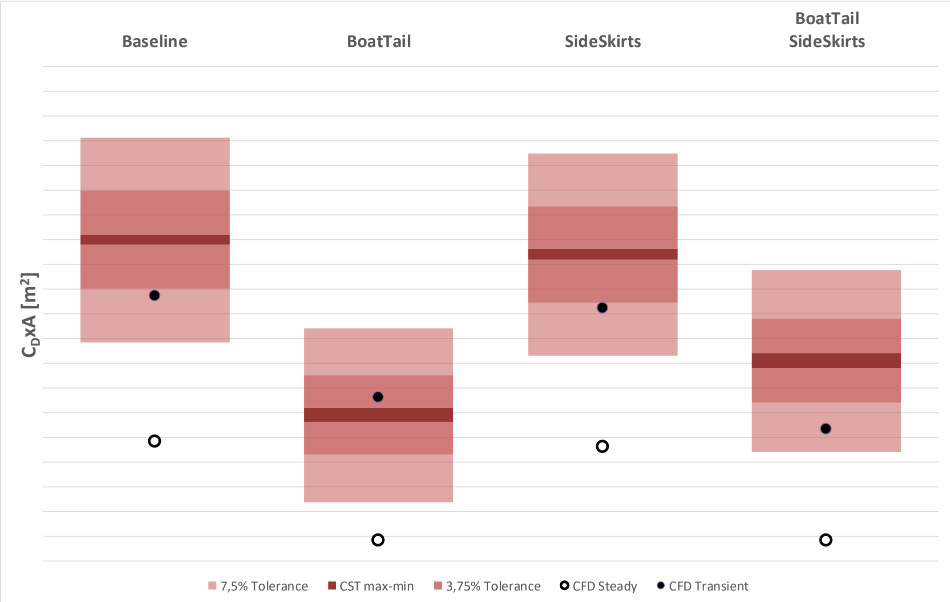


Figure 30. CST and CFD results absolute values compilation

Table 12. CST vs CFD data. Normalized values

	C00 Baseline	C01 w/ Boat Tail	C02 w/ Side Skirts	C03 **w/ Boat Tail** w/ Side Skirts
CST (averaged**)**	1	1	1	1
CFD Steady-state	0.86	0.90	0.86	0.86
CFD Transient	0.96	1.01	0.95	0.96

The following table summarises the results of both CFD methodologies:

Table 13. CFD Steady vs Transient results

Aero Device Effect **------** **Method**	**w/ Boat Tail**	**w/ Side Skirts**	**w/ Boat Tail** **w/ Side Skirts**
CFD – Steady	-8.0%	-0.4%	-7.7%
CFD - Transient	-7.4%	-0.9%	-8.9%

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 mounting the boat tail as stand-alone device, where a larger reduction in air drag is predicted when running in steady-state mode.

Additional data corresponding to the effect the trailer devices have when mounted alone or in combination with a second device are reported in the following tables:

Table 14. Aerodynamic resistance reduction predicted by the two CFD methods

Aero Device Effect ------ Method	Boat Tail (stand-alone)	Boat Tail (when Side Skirts are on)	Side Skirts (stand-alone)	Side Skirts (when Boat Tail is on)
CFD – Steady	-8.0%	-7.7%	-0.4%	0.0%
CFD - Transient	-7.4%	-8.9%	-0.9%	-2.5%

While the steady-state approach predicts similar effects of each device regardless of being mounted alone or with a second device, the DES method is predicting an extra reduction when in combination.

5.4.3.1 Computational Cost

Besides the different formulation in terms of turbulence modelling, the main difference between the steady-state and transient approach lies on the solving times. While the steady-state runs converged within 2.000-3.000 iterations, the transient (DES) ones required more than 40.000 iterations for those 16 seconds of simulation time.

6 Comparison CST vs CFD

As already detailed in section 4, two constant speed tests were performed with each vehicle configuration. Therefore, a minimum and maximum values are reported according to the following expressions:

$$MIN\ Effect\ (\%)_{CST} = \left(\frac{MIN\left[C_D \cdot A^{AeroDevice}\right] - MAX\left[C_D \cdot A^{Baseline}\right]}{MAX\left[C_D \cdot A^{Baseline}\right]} \right)_{CST} x\ 100$$

$$MAX\ Effect\ (\%)_{CST} = \left(\frac{MAX\left[C_D \cdot A^{AeroDevice}\right] - MIN\left[C_D \cdot A^{Baseline}\right]}{MIN\left[C_D \cdot A^{Baseline}\right]} \right)_{CST} x\ 100$$

The table here below summarizes the aerodynamic resistance reduction (in percentage) with respect to the baseline (C00) configuration, according to the following expression:

$$AeroDevice\ Effect\ (\%)_{Method} = \left(\frac{C_D \cdot A^{AeroDevice} - C_D \cdot A^{Baseline}}{C_D \cdot A^{Baseline}} \right)_{Method} x\ 100$$

Table 15. Aero resistance reduction measured in CST and predicted by CFD

Aero Device Effect ------ Method	**C01 w/ Boat Tail**	**C02 w/ Side Skirts**	**C03 w/ Boat Tail w/ Side Skirts**
CST [MAX]	-13.1%	-1.7%	-9.3%
CST [MIN]	-11.4%	-0.3%	-7.6%
CFD – Steady	-8.0%	-0.4%	-7.7%
CFD - Transient	-7.4%	-0.9%	-8.9%

Both steady-state and transient approaches predict very similar results to what has been measured in the tests, especially for configurations C02 and C03. Nonetheless, the predicted values when mounting the boat tail only (C01) are slightly off with respect to the actual measured values.

Nonetheless, it must be noted that considering a tolerance of 3,75% (half the value of what is required by Commission Regulation (EU) 2017/2400) on the measured data in the CST tests, all predicted data from both steady-state and transient CFD are well captured within the testing data.

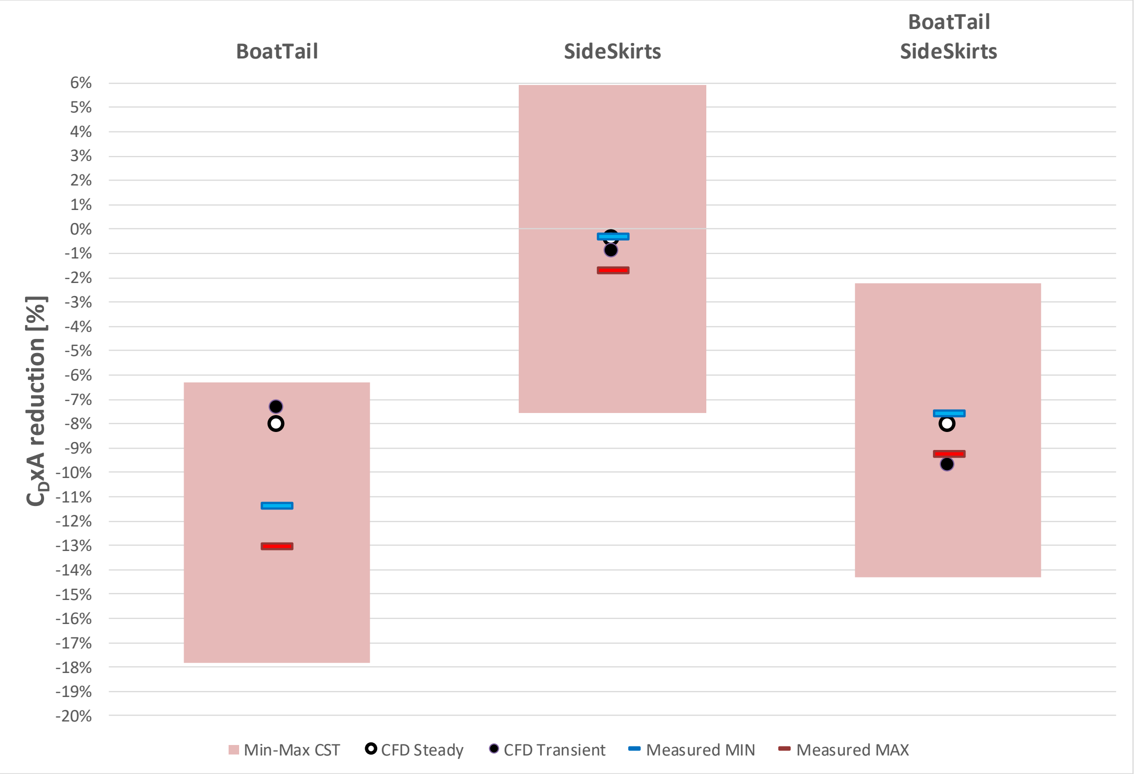


Figure 31. Trailer aero devices effect measured by CST and CFD

Assuming a measurement tolerance of 3.75% in the CST test, the effect of the boat tail, for instance, could vary between ~6% and ~18% (first column in the plot above)

7 Conclusions, Recommendations and Future Work

The effect of a boat tail with a length of 400m and side skirts mounted in the trailer between the landing gear and the 3rd axle have been deeply studied by means of air drag measurements, as well as two different CFD methodologies, steady-state (RANS) and transient (DES), both run with the commercial software STAR-CCM+ by SIEMENS AG.

After a thorough analysis of the data obtained from such activities, it can be stated that CFD is a suitable tool for predicting the impact that those two devices have on the aerodynamic resistance of the overall vehicle.

While the steady-state methodology clearly underpredicts the absolute air drag values in comparison with what was measured during the CST campaign, a more computationally expensive CFD approach such as DES, is capable of predicting those values within an error of approximately 4% or lower, which is a very good approximation considering the tolerance that CST have on its own, which can be estimated at around 3% when the same vehicle, same track, same personnel, etc are involved and way lower than the 7,5% stated in Commission Regulation (EU) 2017/2400.

Also, considering that the main outcome of the activities performed within this Task 4 is not the prediction of the actual air drag values, but the effect that the studied boat tail and side skirts have on the overall aerodynamics of the vehicle, both CFD methodologies accurately predict such effect with differences of around 1% between the two options. On top of that, both fall within a margin of tolerance of the CST as low as 3%.

It must be noted that all activities performed within this Task 4 only apply to the four different configurations presented above. Therefore, the authors suggest that commercial boat tails and side skirts (preferably a version that covers also the wheels) as well as other aerodynamic devices, such as tractor-trailer gap reducers and/or trailer underbody panels should be analysed in a similar manner.

On the other hand, previous activities performed within Task 2 demonstrated that certain elements (mainly side skirts) have a larger benefit under cross wind conditions. Such conditions are not properly captured in laboratory measurements according to the test procedure described in the Annex 8 of the Commission Regulation (EU) 2017/2400 of 12 December 2017 due to the very low ambient air velocities required. Consequently, CFD is the recommended approach to, not only predict their effect under small yaw angles (where CST might not be able to capture their effect due to its own margin of tolerance, as seen in this Task 4), but also to provide the corresponding polar curve. Currently, VECTO uses one single polar curve for all configurations when correcting side wind effects.

As far as the polar curve is concerned, it must be noted that further investigations are required in order to identify the best approach to define it. Leaving CST out due to its own limitations regarding side wind, only CFD and wind tunnel testing remain. Task 2 already proved that the five different methods presented returned significantly different polar curves. Therefore, the authors suggest either a CFD campaign focused on side wind sensitivity and/or a wind tunnel testing phase.

Finally, the consortium suggests the application of the air drag reduction factor in terms of percentage, with respect to a baseline configuration, rather than the addition or subtraction of $\Delta(C_D xA)$ in m^2.

8 Bibliography

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