Support for aerodynamic modelling of heavy-duty trailers

Procedure no:

090203/2022/882079/SER/CLIMA B3

Determination of standard values for the DA-vol semitrailers and the DB, DB-vol, DC and DC-vol trailers.

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Document information

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Acronyms and abbreviations

Acronym	Meaning
EU	European Union
CO_2	Carbon dioxide
VECTO	Vehicle Energy COnsumption calculation TOol
HDV	Heavy Duty Vehicle
OEM	Original Equipment Manufacturer
CFD	Computational Fluid Dynamics
CST	Constant Speed Test
TRF	Tall Rear Flaps
SRF	Short Rear Flaps
LSC	Long Side Covers
SSC	Short Side Covers

Definitions

Term	Definition
DA	Code for semi-trailer according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DB	Code for Drawbar trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DC	Code for Centre-axle trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DA-vol	Volume-oriented version of a DA semitrailer
DB-vol	Volume-oriented version of a DB trailer
DC-vol	Volume-oriented version of a DC trailer

Executive Summary

Climate change and environmental degradation are an existential threat to Europe and the world. The European Commission adopted a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. The European Green Deal set the blueprint for this transformational change. The CO_2 emission Standards for heavy-duty vehicles are a key EU policy instrument in this area.

VECTO (Vehicle Energy Consumption calculation TOol) is a simulation tool developed by the European Commission for determining CO_2 emissions and fuel consumption from Heavy Duty Vehicles (HDV's). The inputs for VECTO are parameters to determine the energy consumption of every vehicle component. The CO_2 emissions and fuel consumption of the motor vehicle is determined using the so-called standard (semi-)trailers during certification.

Current semitrailers and trailers can differ from the standard ones. The adoption of the first (semi-)trailer certification legislation, Regulation (EU) 2022/1362, sets out the rules for certifying certain (semi-)trailers based on their impact on the CO_2 emissions and fuel consumption of the towing motor vehicle and, therefore, compare different vehicles and enable faster market uptake of more efficient trailers.

One of VECTO input parameters is the aerodynamic performance of the vehicle. Traditionally, OEMs have been optimizing the vehicle cabin to bring the air drag values down by means of spoilers, air deflectors and other panelling techniques.

The recently adopted Regulation (EU) 2022/1362 allows vehicle manufacturers to use standard air drag reduction values when using certain aerodynamic devices. At present, the VECTO Trailer Tool does not contain such values for all aerodynamic devices configurations and should therefore be replaced in order to ensure the proper application of the Regulation.

The aim of this project is the determination of the air drag reduction standard values for the rear flaps and side covers on the following (semi-)trailer types,.

- Volume-oriented semitrailers (DA-vol)
- Drawbar trailers (DB)
- Centre-axle trailers (DC)
- Volume-oriented drawbar trailers (DB-vol)
- Volume-oriented centre-axle trailers (DC-vol)

Abstract of this deliverable

This report is part of the work developed in the project *Support for aerodynamic modelling of heavy-duty trailers,* for DG CLIMA under the contract 090203/2022/882079/SER/CLIMA B3.

The aim of this project is the determination of standard air drag reduction values provided by certain (semi-)trailer aerodynamic devices like rear flaps and side covers of different sizes when implemented in drawbar (DB) and centre-axle (DC) trailers as well as volume-oriented DA semi-trailers and volume-oriented DB and DC trailers for which such values are not yet available in current Regulation (EU) 2022/1362.

All air drag reduction values ($\Delta C_D xA$) have been predicted by means of a Computational Fluid Dynamics (CFD) methodology previously validated and described within this report.

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Tables

1 CFD Methodology

Siemens' Simcenter™ STAR-CCM+™ v16.04 Multiphysics CFD software has been used to develop a CFD methodology capable of predicting the corresponding $\Delta C_D xA$ values within the required tolerances.

Besides the software vendor own guidelines and best practices documents to simulate road vehicle aerodynamics, literature research has been made to further complement IDIADA's own methods.

SAE document J2966 [1] 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.

The application of IDIADA CFD methodology has also been validated against Constant Speed Test (CST) data several times. For instance, on an IVECO Stralis 460E Hi-Way Cabin model from 2016 pulling a standard Schmitz Cargobull semitrailer [2] [3]:

Figure 1. Iveco vehicle form 2016 (top) and its digital twin (bottom)

Or an IVECO Stralis 570 Hi-Way Cabin model from 2019 pulling the same semitrailer [4]:

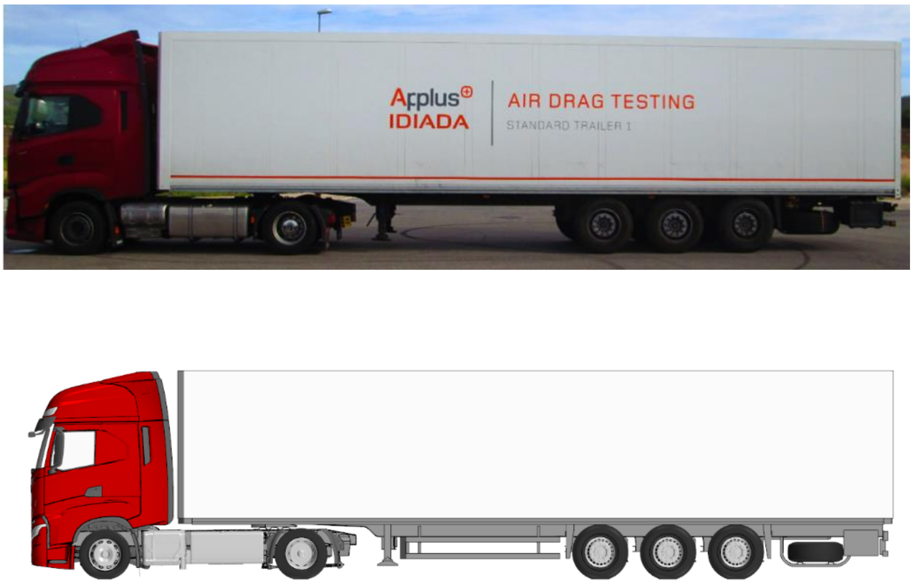


Figure 2. Iveco vehicle form 2019 (top) and its digital twin (bottom)

1.1 *Mesh settings and simulation domain*

The computational domain mimics open-road conditions and, hence, it has been made large enough, 200.0m x 100.0m x 50.5m, to guarantee the blockage is below 0.5%. The large distance between the vehicle and the tunnel walls of the domain ensures the flow patterns around the vehicle do not get affected by the domain limits.

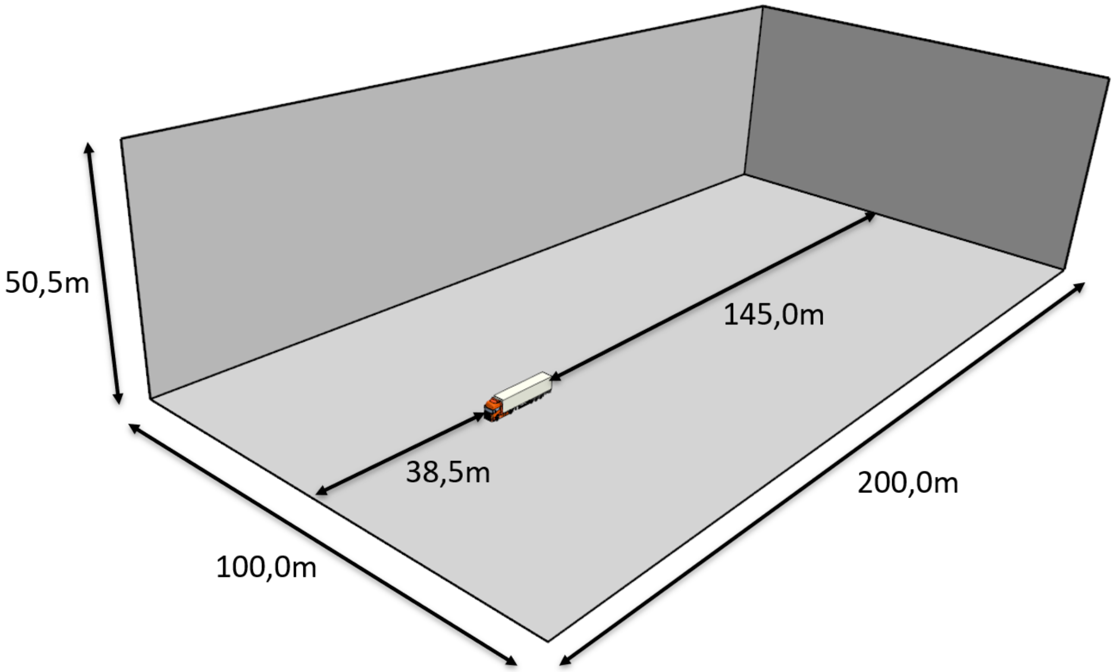


Figure 3. General domain dimensions and vehicle positioning

The cell count is close to 100 million cells, using a size between 5 and 25mm in close vicinity to the vehicle and steadily growing the size as the cells move way towards the domain limits.

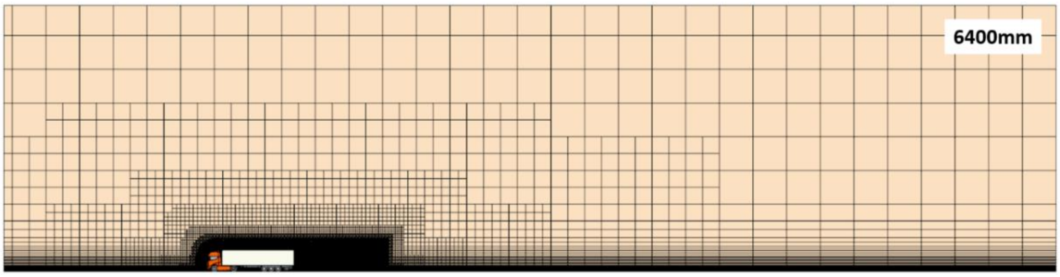


Figure 4. XZ plane section at Y=0 across the entire simulation domain

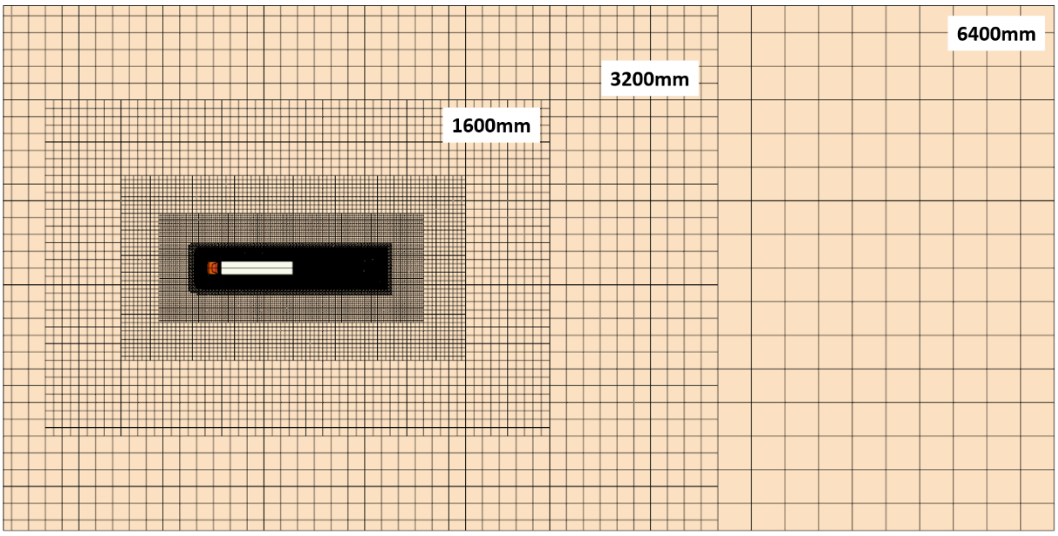


Figure 5. XY plane section at Z=0 across the entire simulation domain

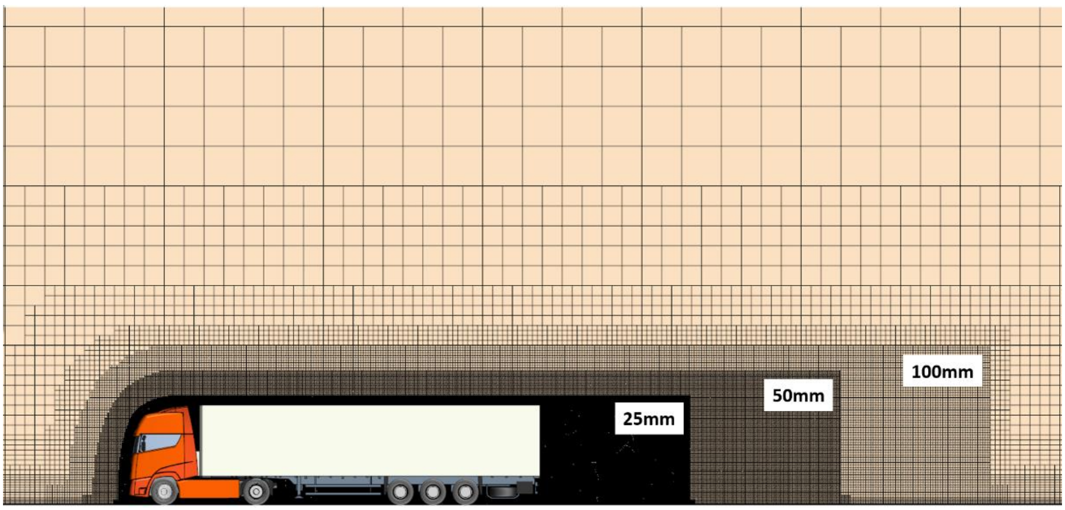


Figure 6. XZ plane section detail at Y=0

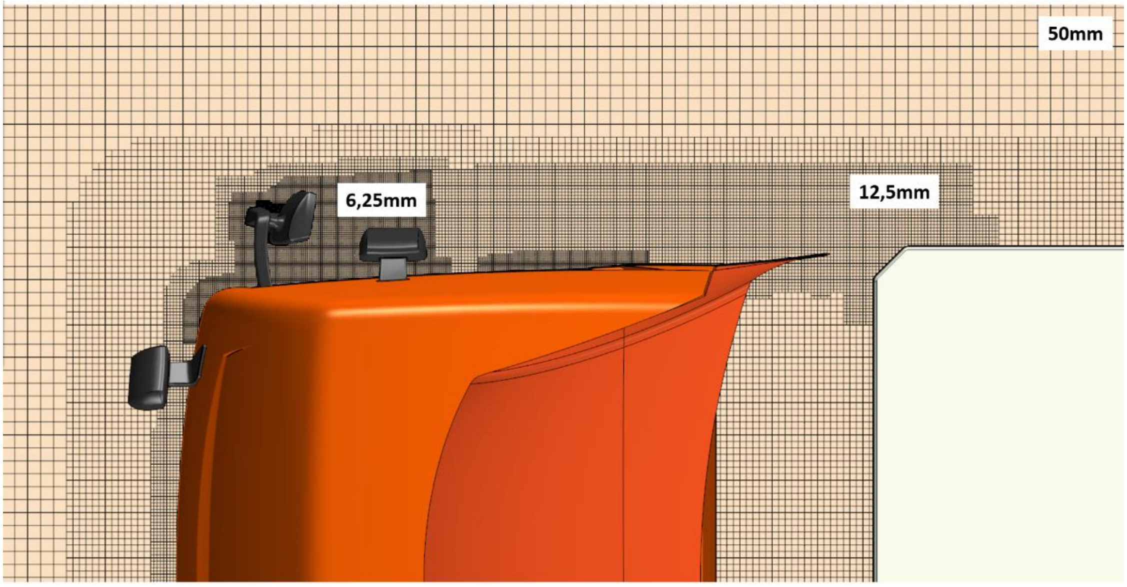


Figure 7. XY plane section detail at Z=1820mm

The cell count does increase slightly in the cases accounting for crosswind due to the mesh refinement in the leeward side of the vehicle.

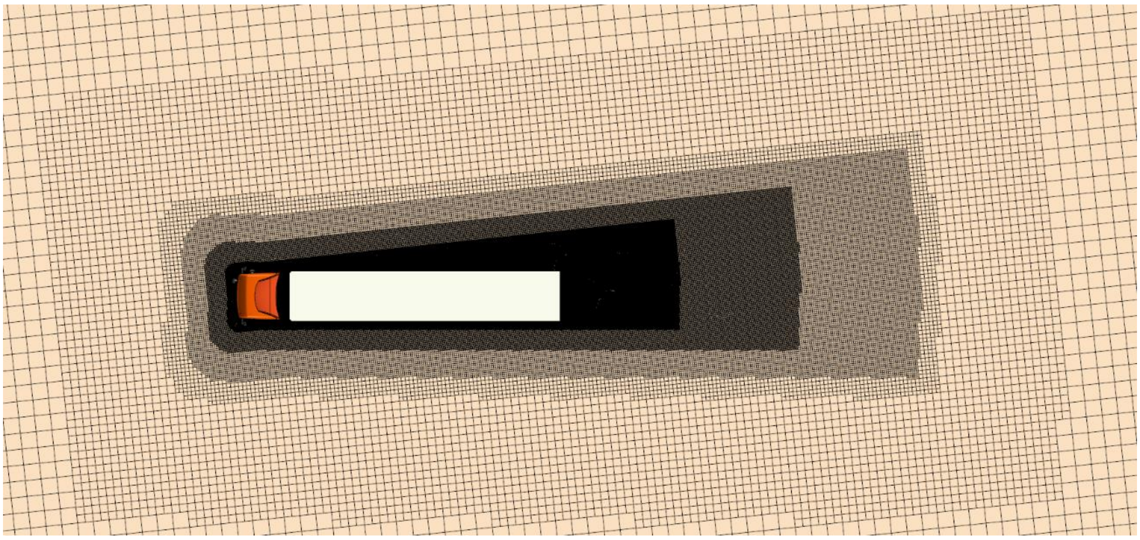


Figure 8. XY plane section detail at Z=0 across the rotated simulation domain

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

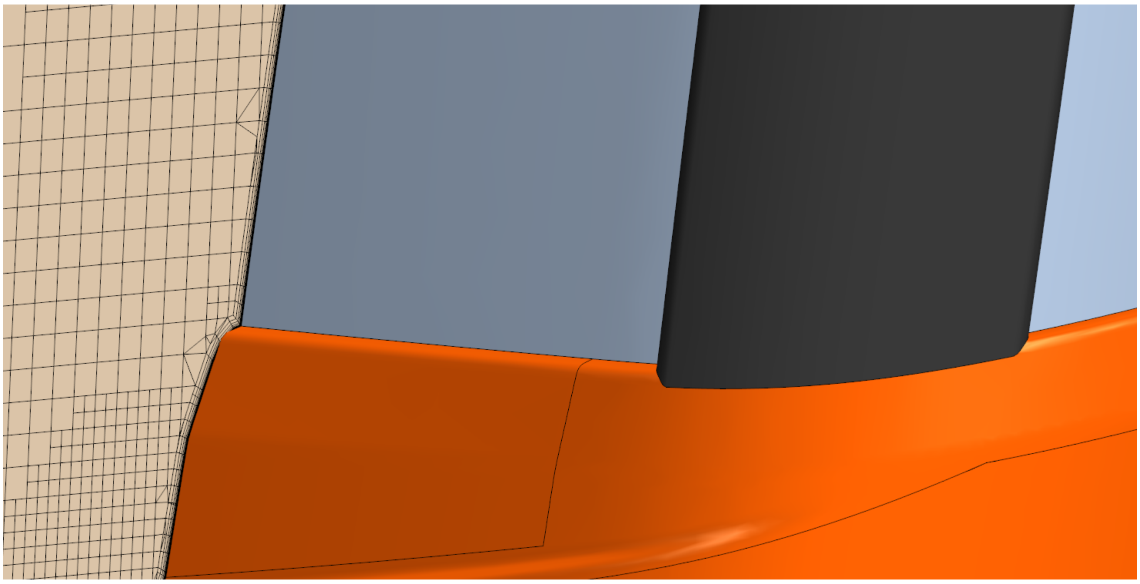


Figure 9. Prism layer detail at the base of the windshield

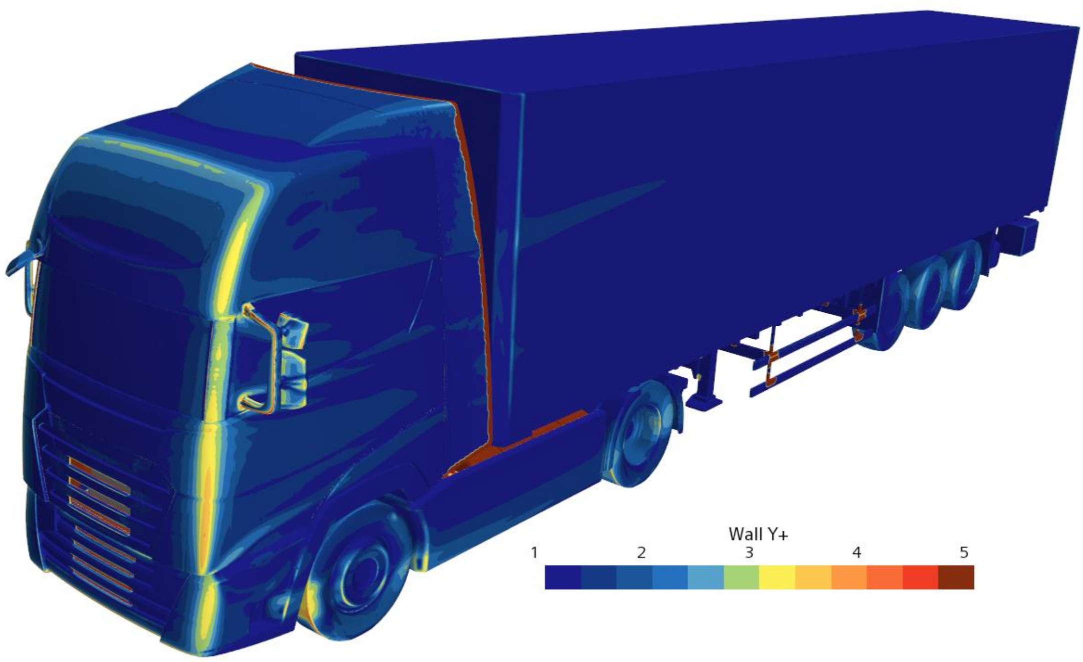


Figure 10. Wall Y+ values over the vehicle surfaces

1.2 *Physics Settings and Boundary conditions*

All simulations have been solved in a steady-state manner and out of all different turbulence models available in the CFD software, the well-known k-ω SST turbulence model has been selected based on its proven accuracy in ground vehicle aerodynamic applications. No compressibility effects are considered (air's density remains constant), and all solvers have been set to use second order discretization schemes.

The pressure losses across the different heat exchangers conforming the cooling pack (condenser, charge air cooler and radiator) have been characterized with the Darcy-Forchheimer model with the viscous and inertial resistance coefficients stated in the tender specifications.

The incoming flow boundary condition is such that the vehicle is simulated to be travelling at 25 m/s (90.0 kph). To take the yaw angle (β) into account, the entire simulation domain is rotated accordingly and, therefore, the incoming flow velocity depends on the yaw angle:

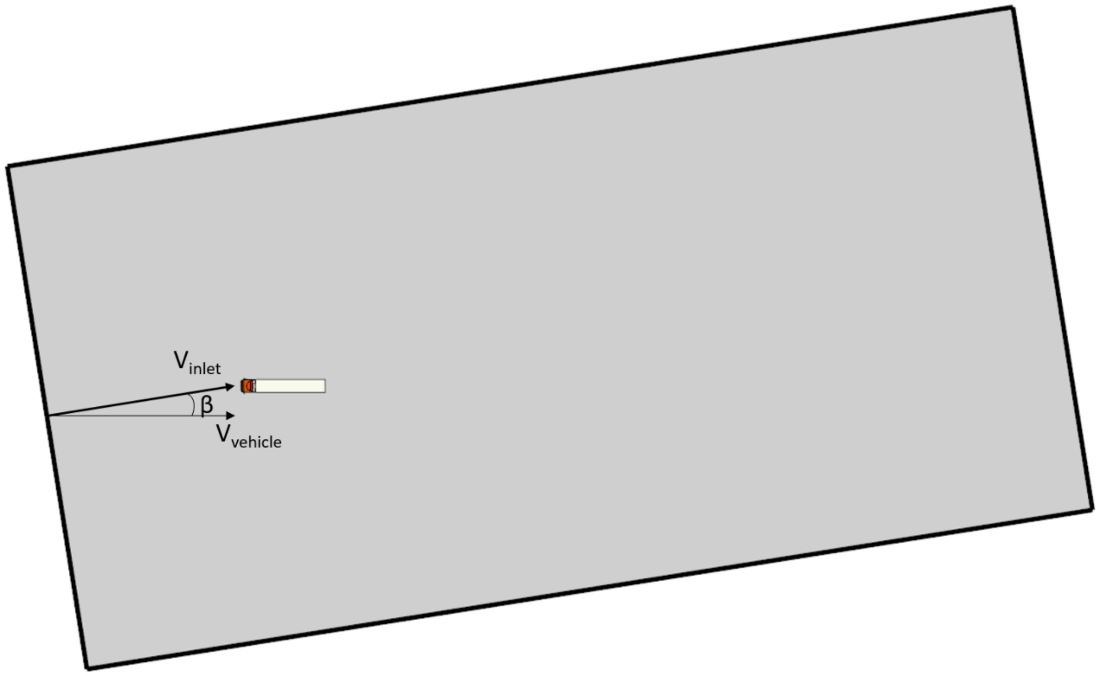


Figure 11. Simulation domain with yaw angle

Table 1. Incoming air velocity vs Yaw angle

Yaw angle [deg]	0.0	3.0	6.0	9.0
$V_{vehicle}$ [m/s]	25.0	25.0	25.0	25.0
V_{inlet} [m/s]	25.000	25.034	25.138	25.312

The back face of the computational domain is defined as a flow outlet with atmospheric pressure and the ground is modelled with a tangential velocity of 25.0 m/s in the vehicle advancing opposite direction. Side and top boundaries are set to be walls with slip wall shear stress to avoid boundary layer build-up.

The vehicle wheels are also modelled with a tangential velocity to account for their rotation based on the wheel radius:

Table 2. Wheel rotation rates

Wheels	Radius [m]	Vehicle Velocity [m/s]	Wheel Angular Velocity [rad/s]	Wheel Angular Velocity [rpm]
Tractor	0.538	25.0	46.468	443.741
Semitrailer	0.539	25.0	46.382	442.917

1.3 Results

All nine cases have been solved for enough iterations to ensure a full convergence of the most relevant engineering quantities. The following tables report the average C_DxA [m^2] values of the last 400 iterations predicted by the previously described CFD methodology, as well as the corresponding standard deviation (σ), calculated as follows:

$$\sigma = \sqrt{\frac{\sum(c_D \cdot A - \overline{c_D \cdot A})^2}{400}}$$

Table 3. C_DxA [m^2] values predicted by CFD

Simulation set	Yaw Angle – β [deg]		
	0.0	**3.0**	**6.0**
BASE	4.16	4.35	5.02
TRF	3.93	4.15	4.59
LSC	3.92	4.22	4.83

Table 4. C_DxA [m^2] standard deviation (σ) of the last 400 iteration

Simulation set	Yaw Angle – β [deg]		
	0.0	**3.0**	**6.0**
BASE	0.00077	0.00189	0.00192
TRF	0.00130	0.00129	0.00201
LSC	0.00064	0.00269	0.00085

The standard deviation values are very small, which reinforces the fact that the solution is well converged, and the magnitude of the oscillations of the C_DxA [m^2] value along the iterative process can be seen in figures below:

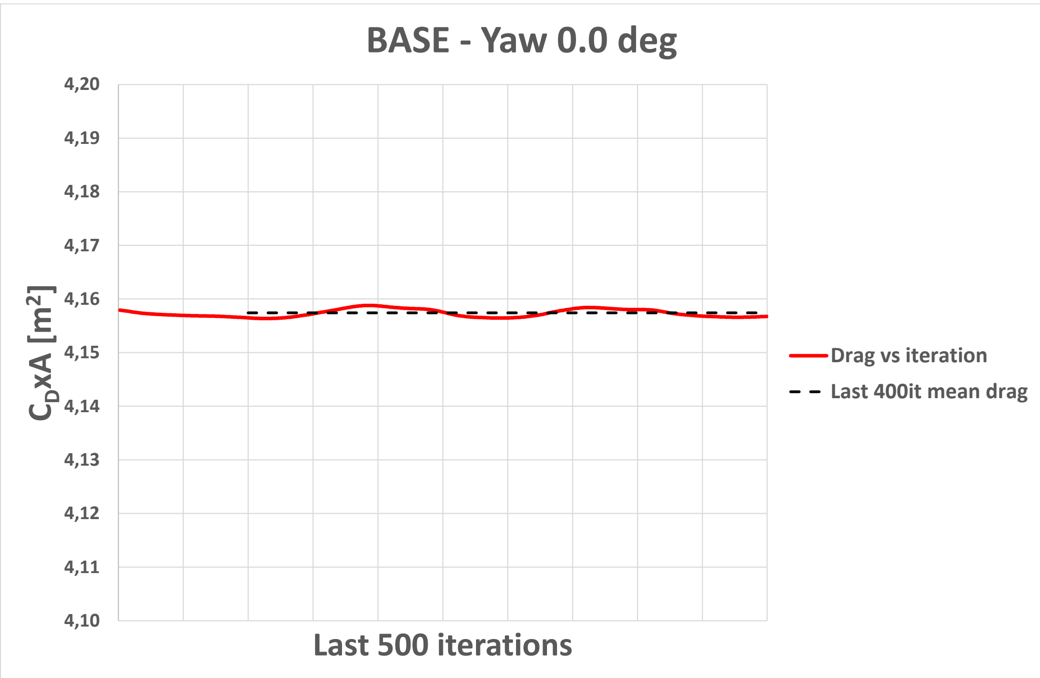


Figure 12. Drag vs iteration. Base at Yaw=0.0deg

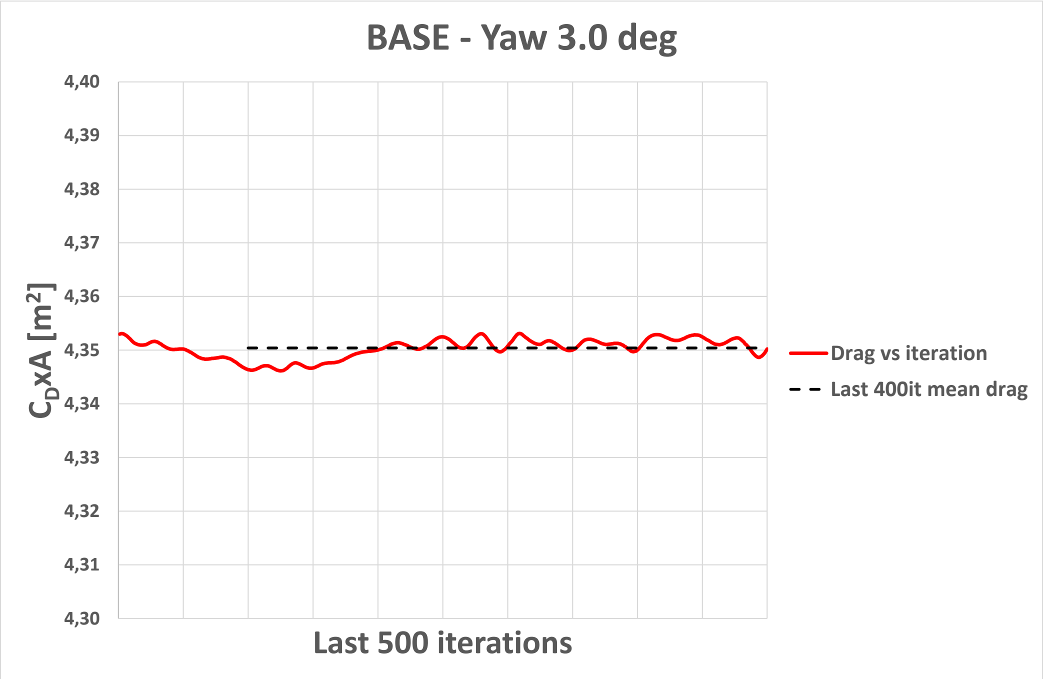


Figure 13. Drag vs iteration. Base at Yaw=3.0deg

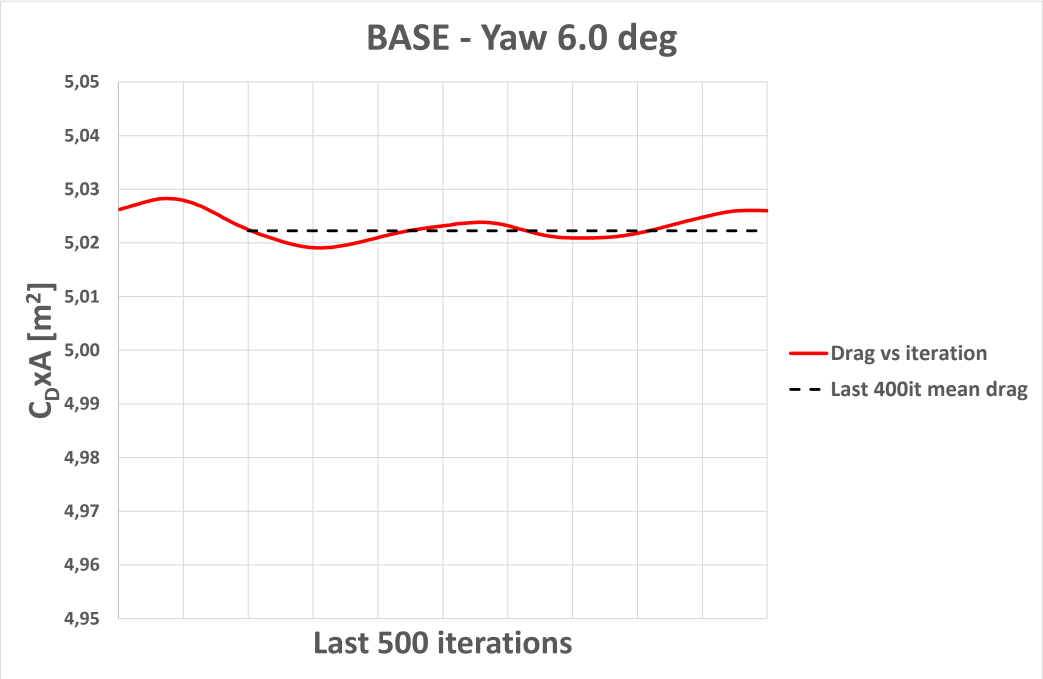


Figure 14. Drag vs iteration. Base at Yaw=6.0deg

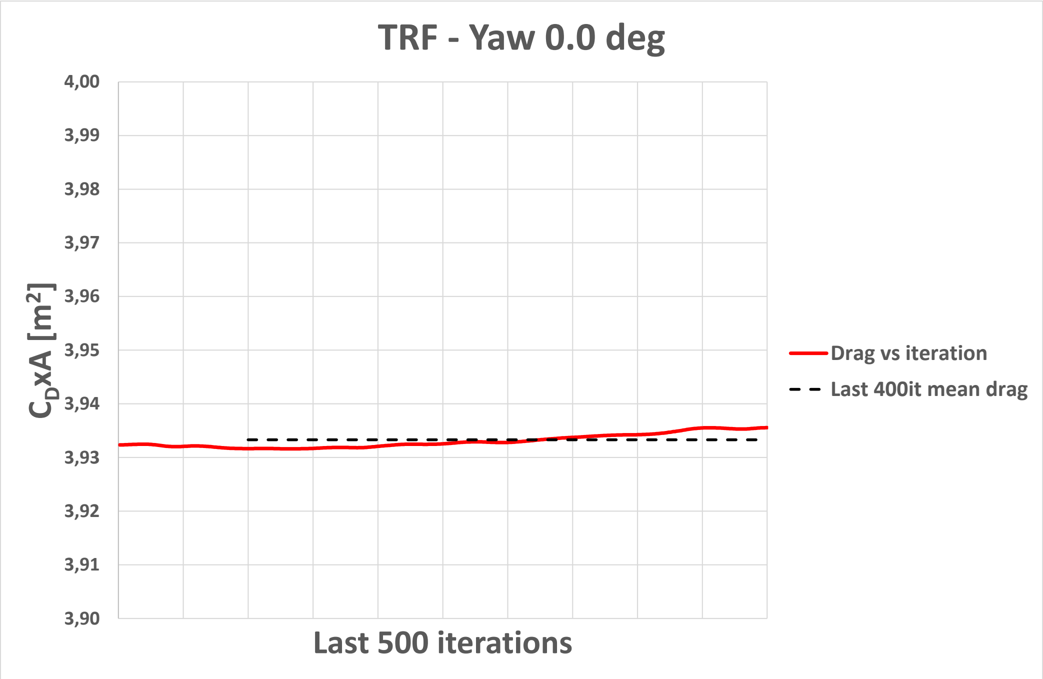


Figure 15. Drag vs iteration. TRF at Yaw=0.0deg

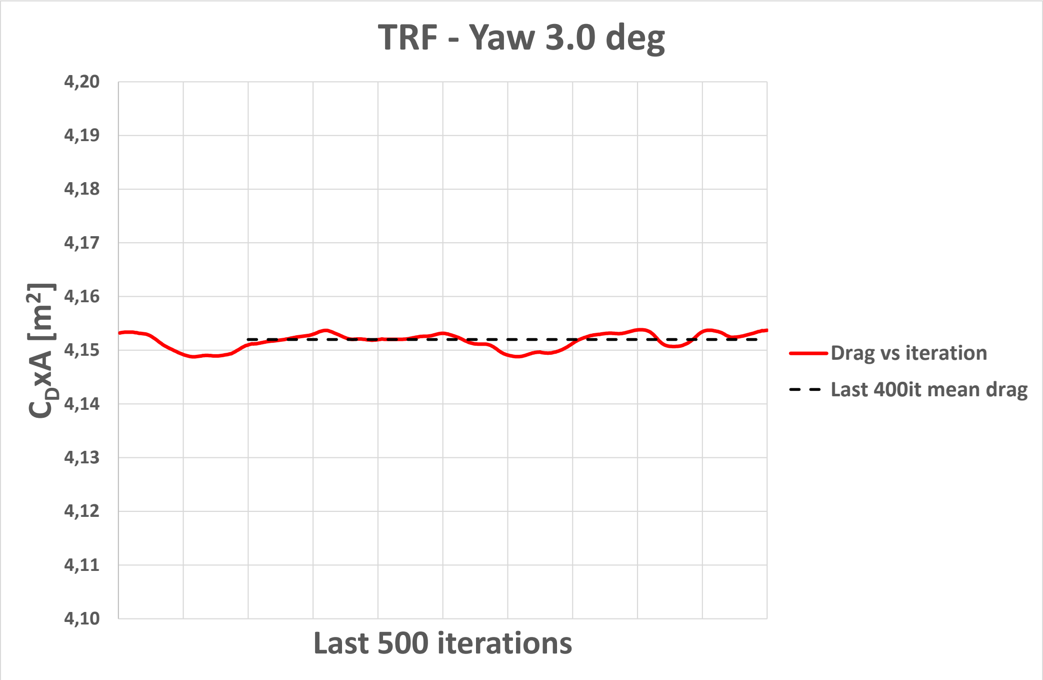


Figure 16. Drag vs iteration. TRF at Yaw=3.0deg

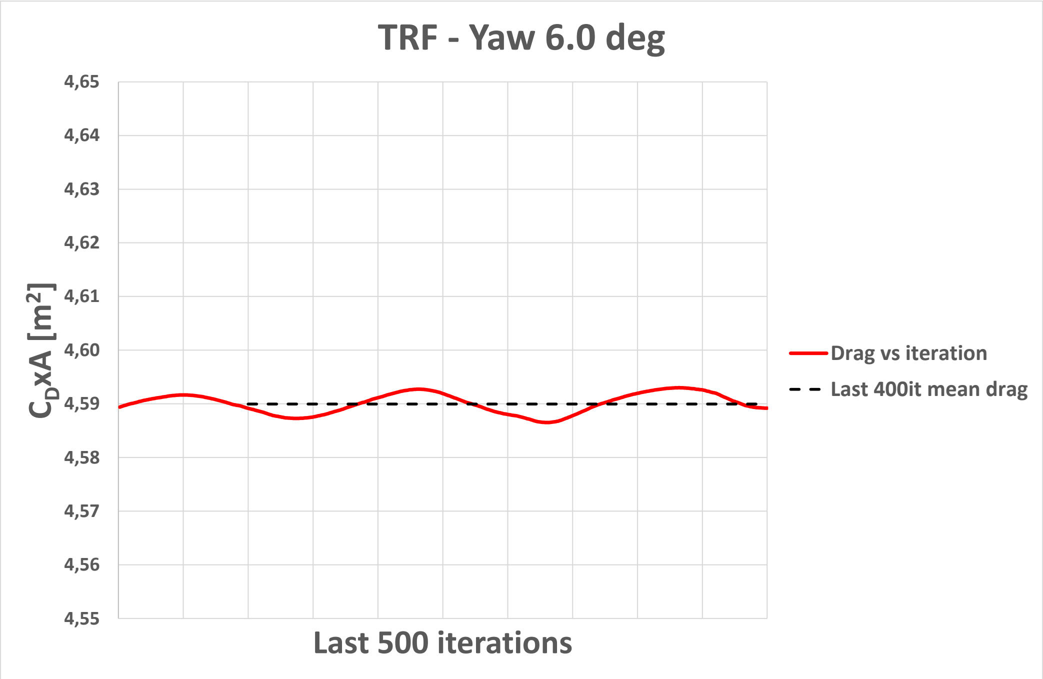


Figure 17. Drag vs iteration. TRF at Yaw=6.0deg

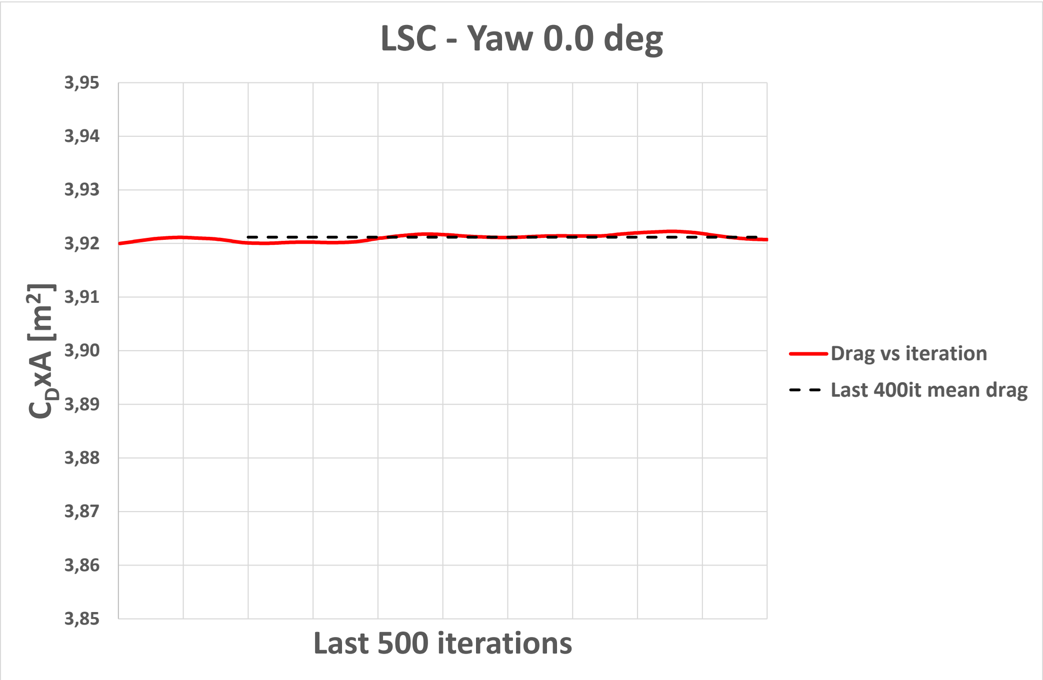


Figure 18. Drag vs iteration. LSC at Yaw=0.0deg

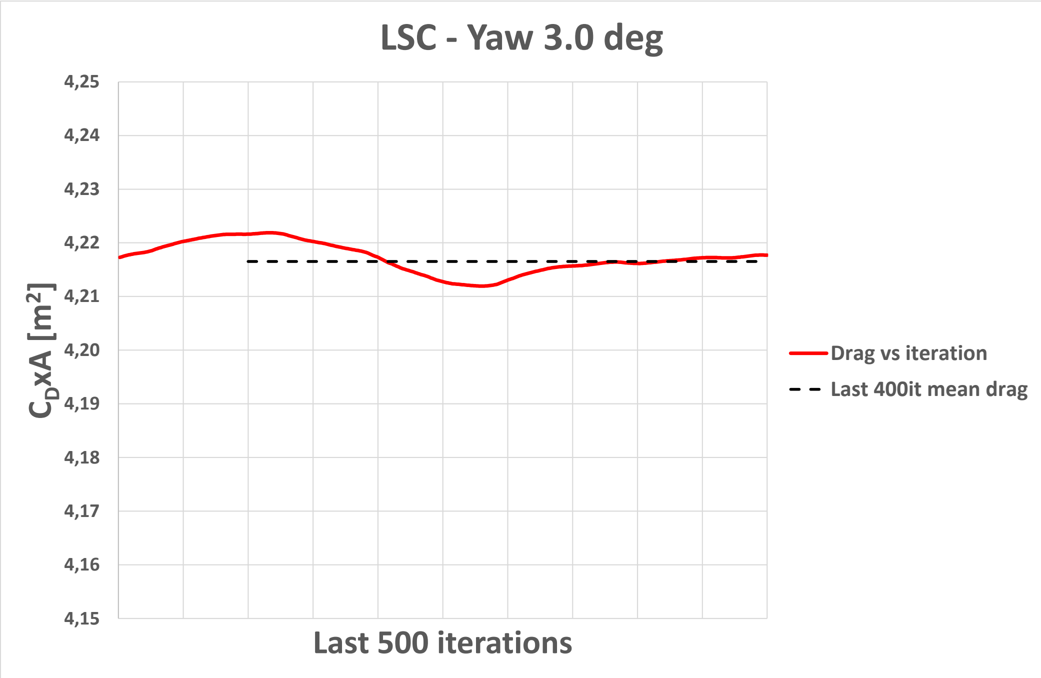


Figure 19. Drag vs iteration. LSC at Yaw=3.0deg

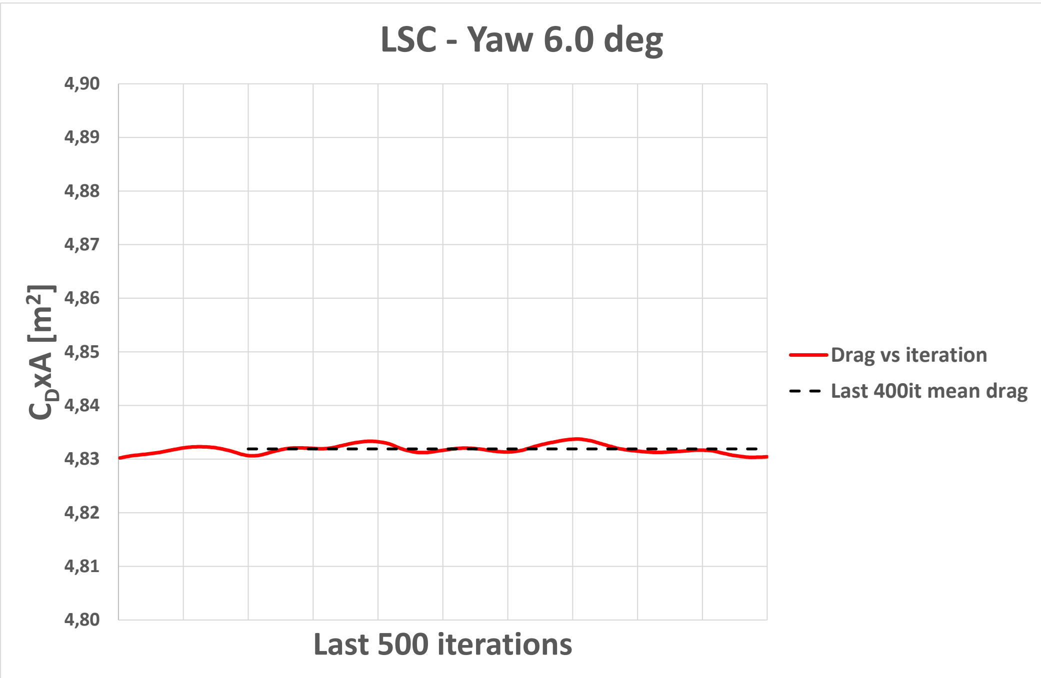


Figure 20. Drag vs iteration. LSC at Yaw=6.0deg

The aerodynamic effect of the tall rear flaps (TRF) and the long side covers (LSC) is expressed, in percentage reduction, as follows:

$$Aero\ Device\ Effect\ (\%) = \frac{c_D \cdot A^{AeroDevice} - c_D \cdot A^{Base}}{c_D \cdot A^{Base}} x\ 100$$

Table 5. $\Delta C_D xA$ [%] wrt to BASE predicted by CFD

Simulation set	Yaw Angle – β [deg]		
	0.0	**3.0**	**6.0**
TRF	-5.56%	-4.62%	-8.60%
LSC	-5.80%	-3.00%	-3.80%

All values fall well within the required ± 2.5% accuracy specified in the tender specifications:

Table 6. Aerodynamic reduction accuracy for CFD method validation

Simulation set	Yaw Angle – β [deg]		
	0.0	**3.0**	**6.0**
TRF	-5.1% ± 2.5%	-5.5% ± 2.5%	-6.8% ± 2.5%
LSC	-5.3% ± 2.5%	-4.5% ± 2.5%	-4.6% ± 2.5%

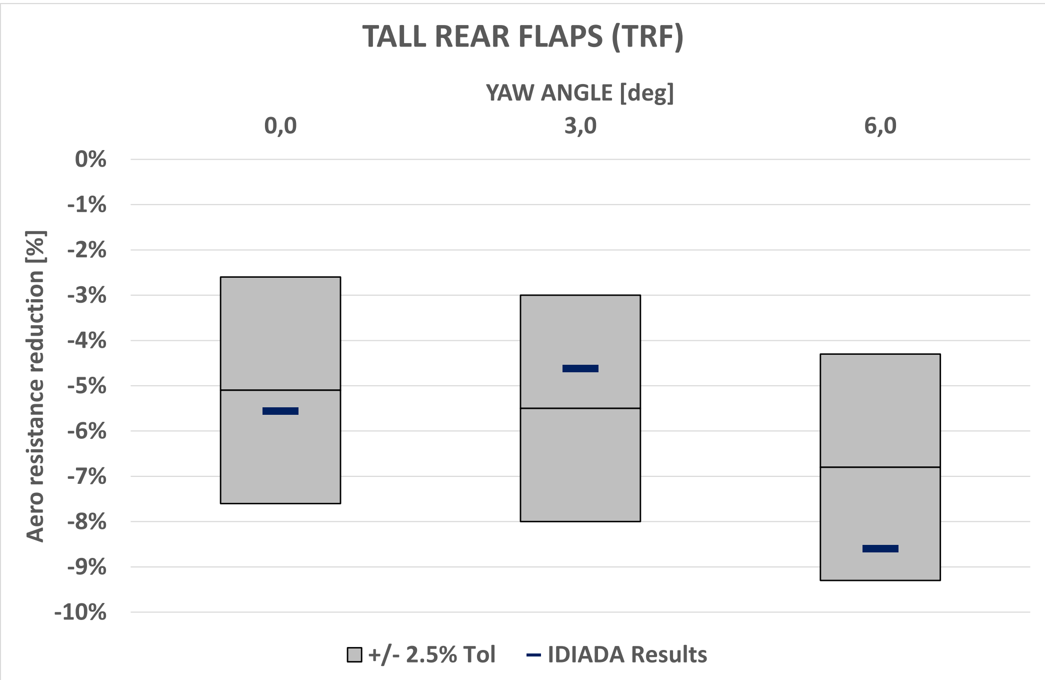


Figure 21. TRF predicted results within expected tolerance

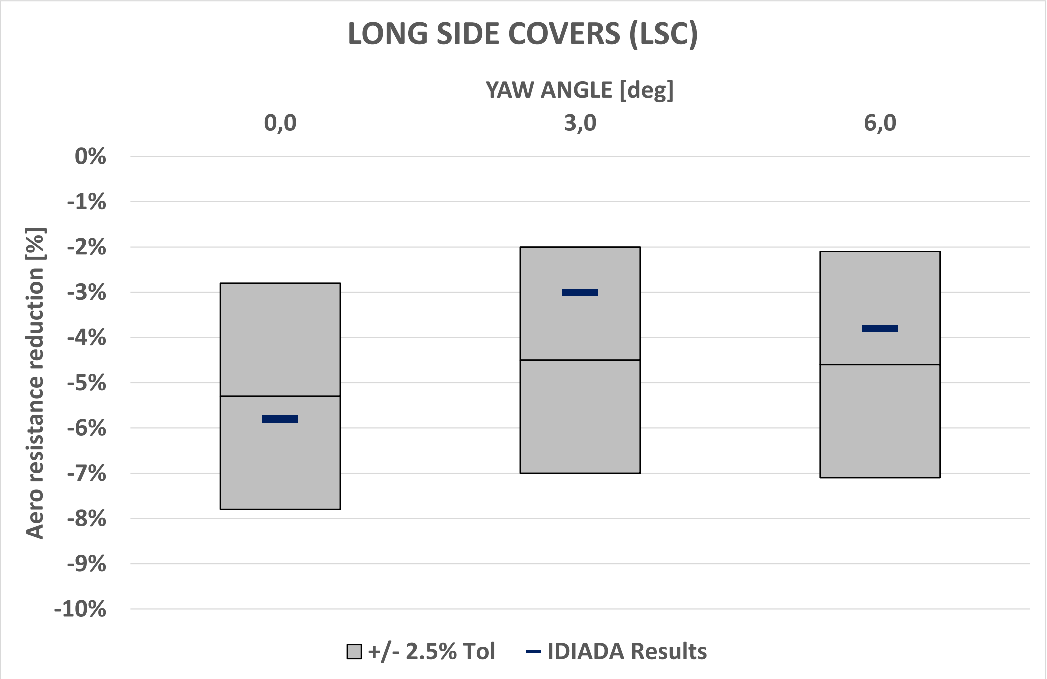


Figure 22. LSC predicted results within expected tolerance

2 Vehicle Configurations

The following table summarizes all vehicle configurations requested in the Tender specifications, where the corresponding aerodynamic device is adapted to the cargo box dimensions of each vehicle and every single configuration is simulated under 4 different scenarios of crosswind, resulting in angles of 0, 3, 6 and 9 degrees of yaw.

Table 7. Vehicle configuration matrix

Vehicle Configuration	BASE	TRF	SRF	LSC	SSC	TRF LSC	TRF SSC	SRF LSC	SRF SSC
DA-vol	✓	✓	✓	✓	✓	✓	✓	✓	✓
DB	✓	✓	✓	N/A	✓	N/A	✓	N/A	✓
DB-vol	✓	✓	✓	N/A	✓	N/A	✓	N/A	✓
DC	✓	✓	✓	N/A	✓	N/A	✓	N/A	✓
DC-vol	✓	✓	✓	N/A	✓	N/A	✓	N/A	✓

2.1 *Volume-Oriented Semitrailer (DA-vol)*

The DA-vol semitrailer is simulated being pulled by a 4x2 tractor with a lower chassis and smaller wheels with respect to the standard 4x2 tractor.

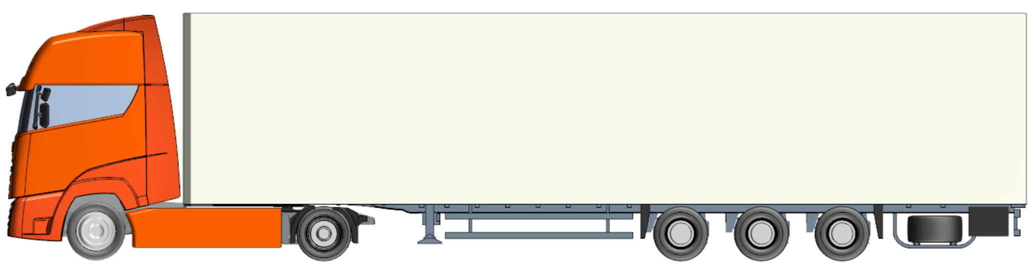


Figure 23. DA-vol Baseline

The cargo box is 3.100mm high and its standard aerodynamic devices are characterized with the following dimensions:

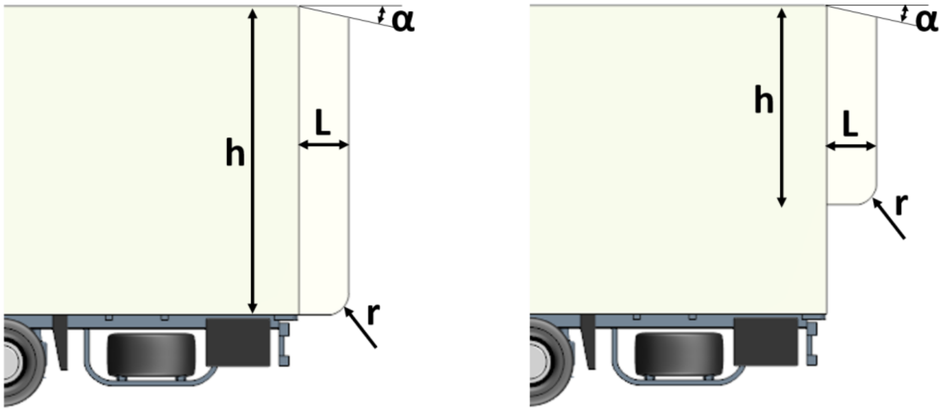


Figure 24. DA-vol standard rear flaps dimensions. TRF (left) and SRF (right)

Table 8. DA-vol standard rear flaps dimensions

Specification	Symbol	Unit	External dimension
Tapering angle	α	[deg]	13 (for top and side panels)
Length	L	[mm]	400
Height	h	[mm]	3100 (TRF) 2000 (SRF)
Fillet radius	r	[mm]	200

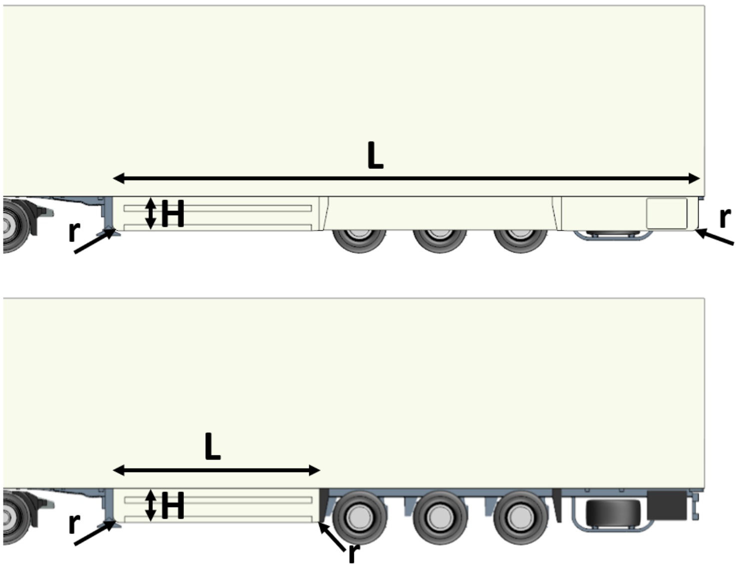


Figure 25. DA-vol standard side covers dimensions. LSC (top) and SSC (bottom)

Table 9. DA-vol standard side covers dimensions

Specification	Symbol	Unit	External dimension
Length	L	[mm]	9.520 (LSC) 3.355 (SSC)
Height	H	[mm]	560
Fillet radius	r	[mm]	100

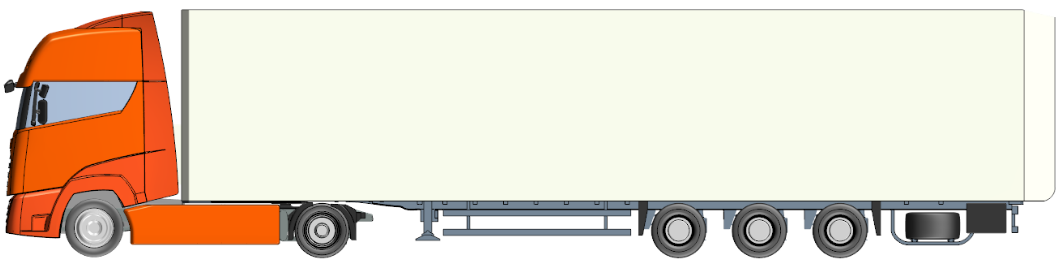


Figure 26. DA-vol Baseline + TRF

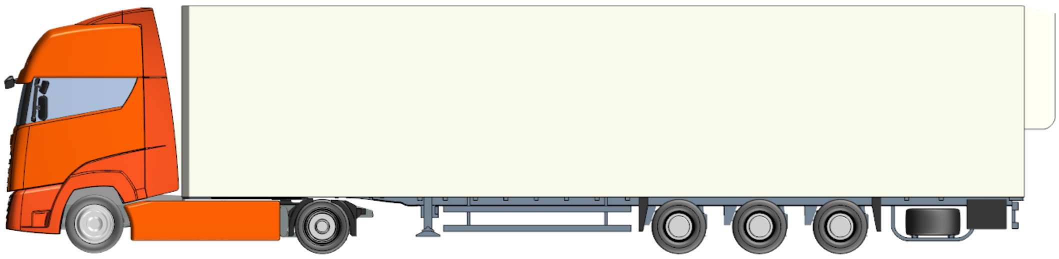


Figure 27. DA-vol Baseline + SRF

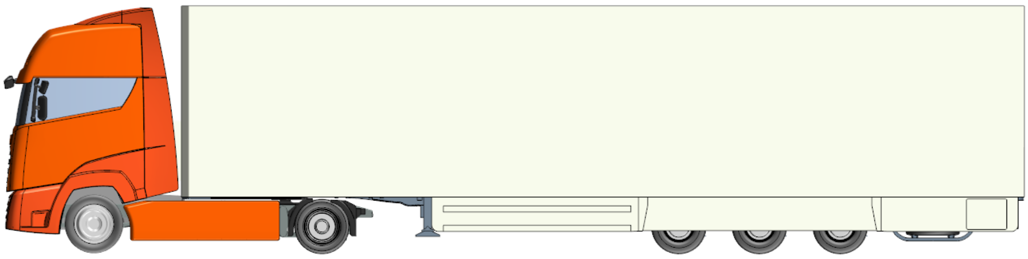


Figure 28. DA-vol Baseline + LSC

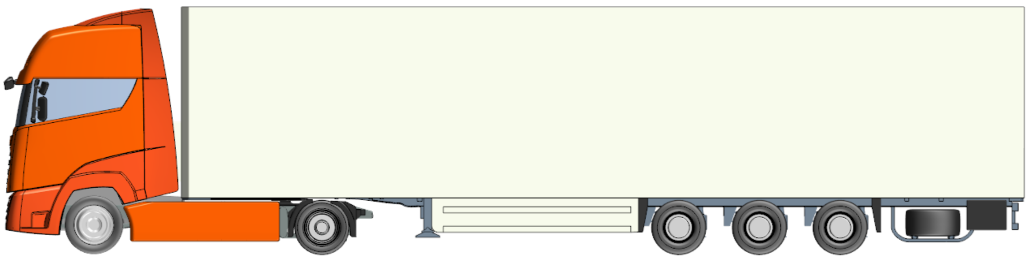


Figure 29. DA-vol Baseline + SSC

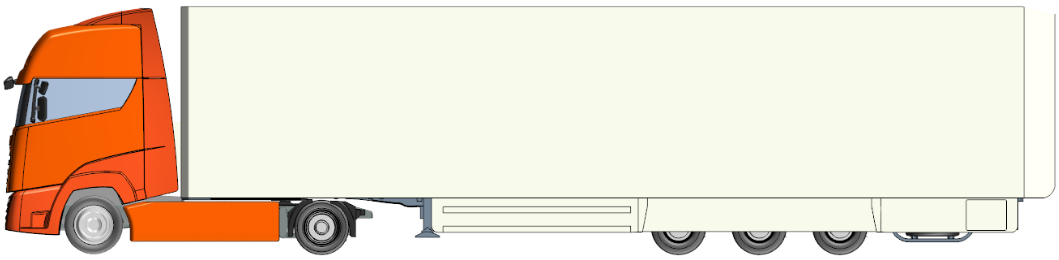


Figure 30. DA-vol Baseline + TRF + LSC

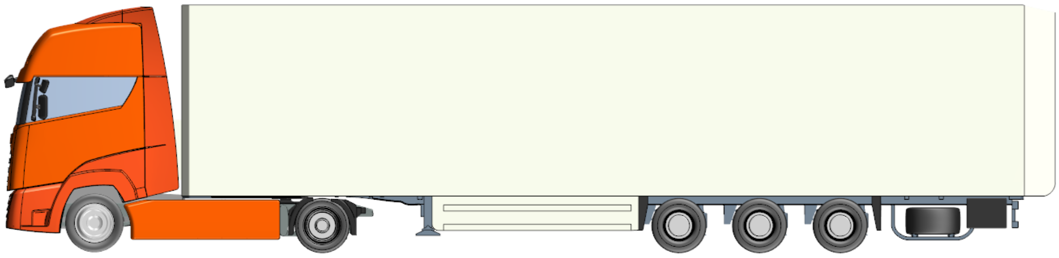


Figure 31. DA-vol Baseline + TRF + SSC

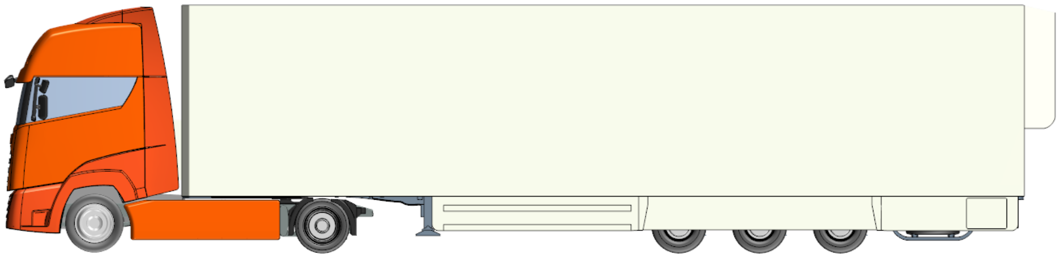


Figure 32. DA-vol Baseline + SRF + LSC

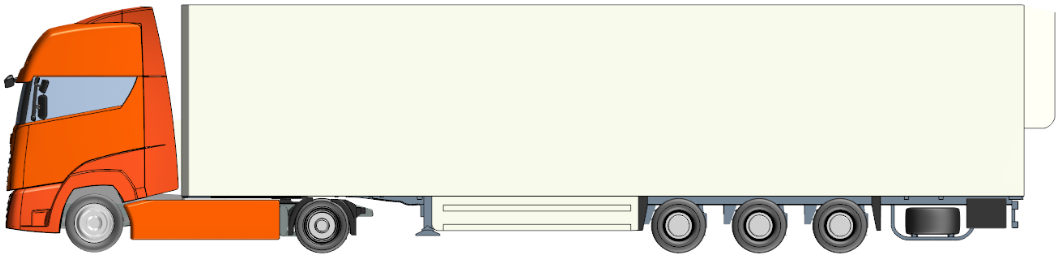


Figure 33. DA-vol Baseline + SRF + SSC

2.2 *Drawbar Trailer (DB)*

The standard drawbar trailer is simulated being pulled by a 6x2 rigid truck.

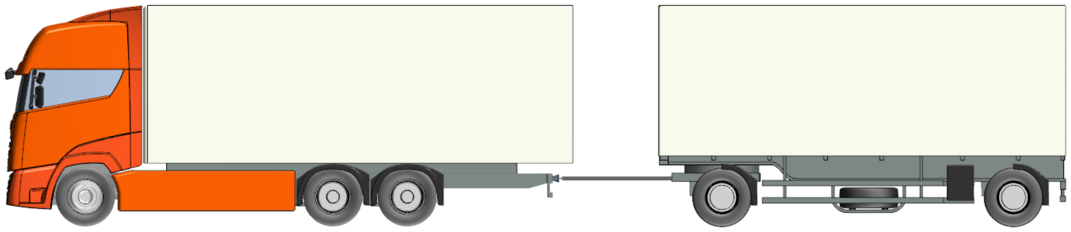


Figure 34. DB Baseline

The cargo box is 2.730mm high and its standard aerodynamic devices are characterized with the following dimensions:

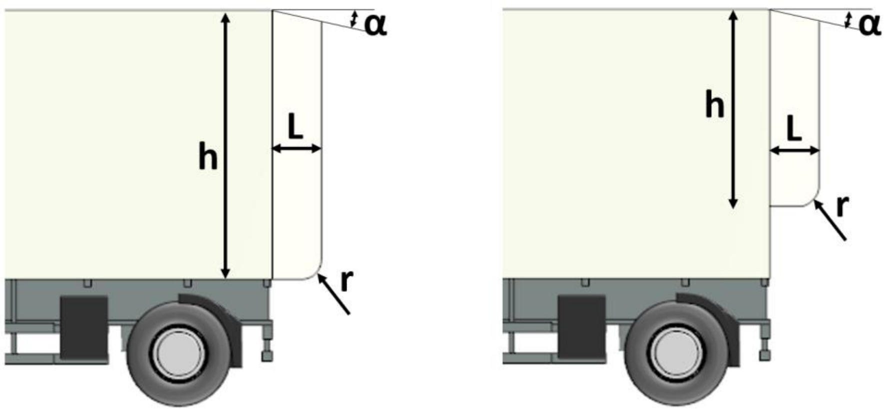


Figure 35. DB standard rear flaps dimensions. TRF (left) and SRF (right)

Table 10. DB standard rear flaps dimensions

Specification	Symbol	Unit	External dimension
Tapering angle	α	[deg]	13 (for top and side panels)
Length	L	[mm]	400
Height	h	[mm]	2730 (TRF) 2000 (SRF)
Fillet radius	r	[mm]	200

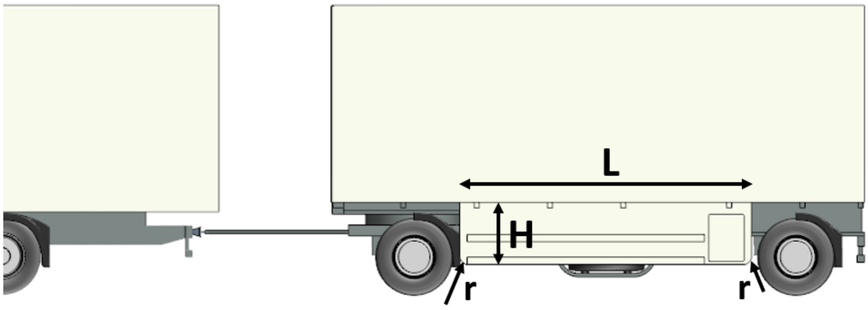


Figure 36. BD standard short side covers dimensions

Table 11. DB standard short side covers dimensions

Specification	Symbol	Unit	External dimension
Length	L	[mm]	4.050
Height	H	[mm]	860
Fillet radius	r	[mm]	100

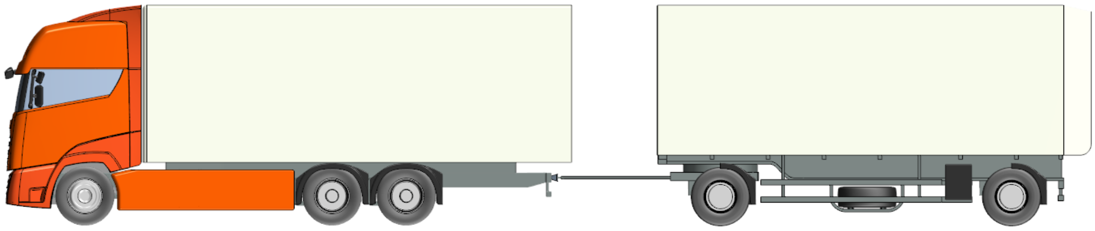


Figure 37. DB Baseline + TRF

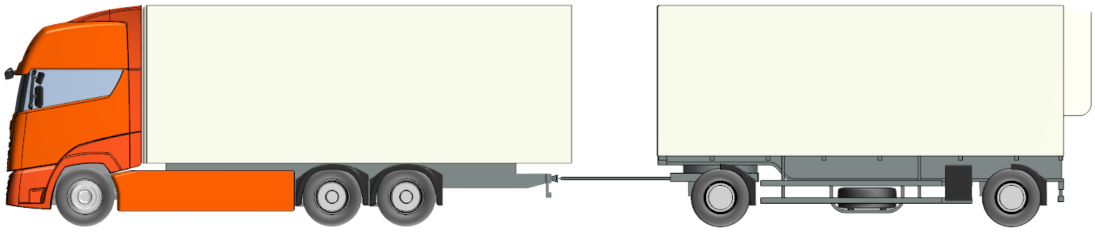


Figure 38. DB Baseline + SRF

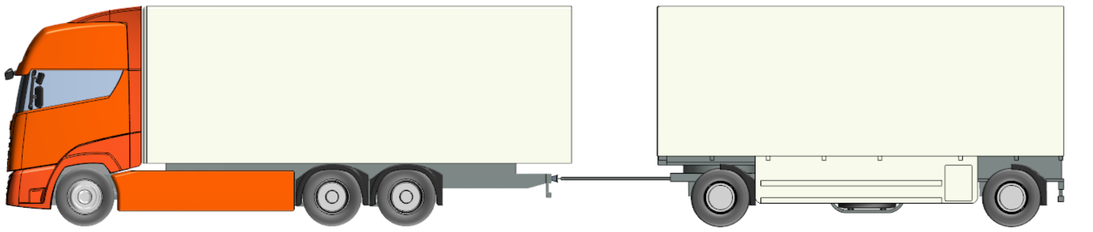


Figure 39. DB Baseline + SSC

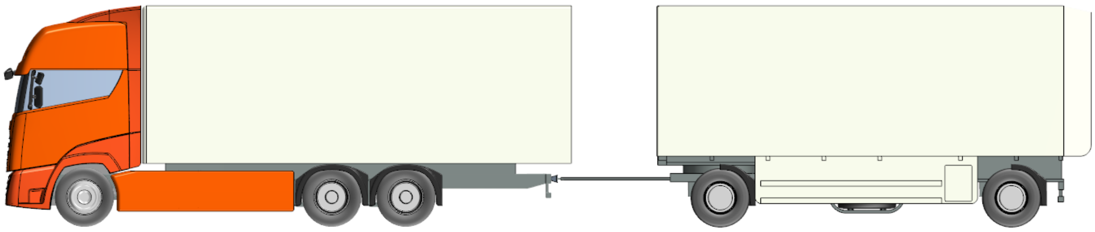


Figure 40. DB Baseline + TRF + SSC

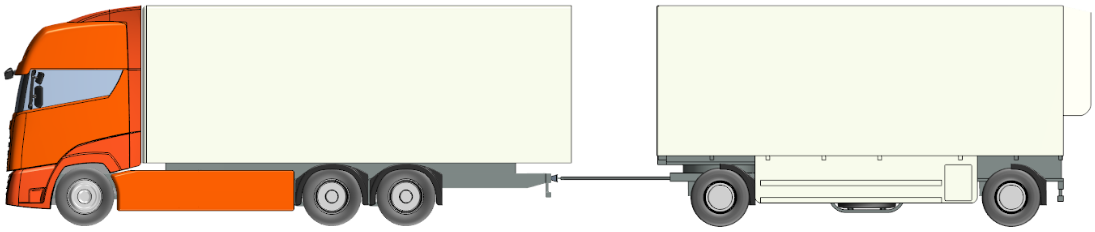


Figure 41. DB Baseline + SRF + SSC

2.3 *Volume-Oriented Drawbar Trailer (DB-vol)*

The standard volume-oriented drawbar trailer is simulated being pulled by a 6x2 rigid truck.

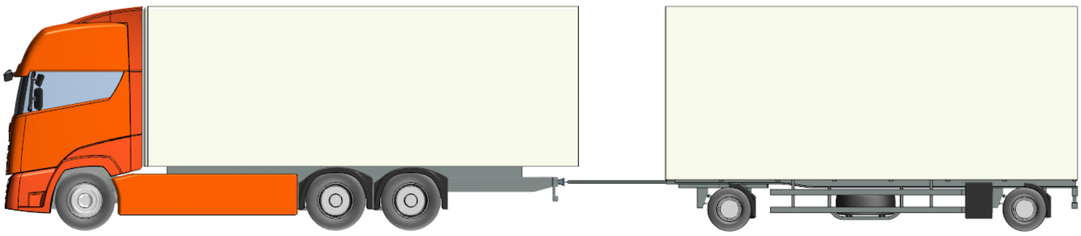


Figure 42. DB-vol Baseline

The cargo box gets enlarged with respect to the DB up to a height of 3100mm and its standard aerodynamic devices are characterized with the following dimensions:

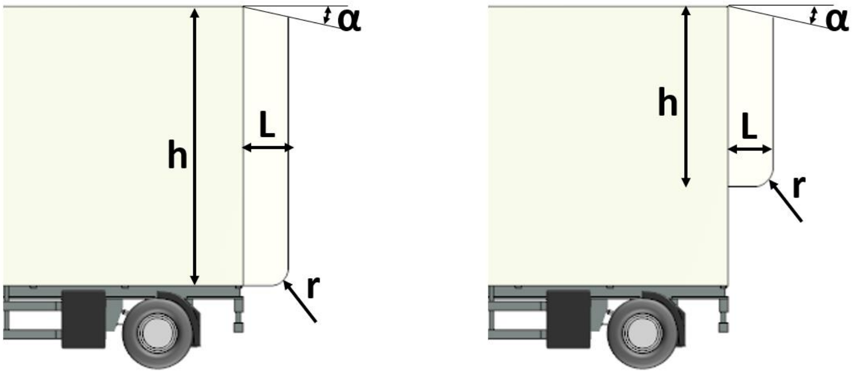


Figure 43. DB-vol standard rear flaps dimensions. TRF (left) and SRF (right)

Table 12. DB-vol standard rear flaps dimensions

Specification	Symbol	Unit	External dimension
Tapering angle	α	[deg]	13 (for top and side panels)
Length	L	[mm]	400
Height	h	[mm]	3100 (TRF) 2000 (SRF)
Fillet radius	r	[mm]	200

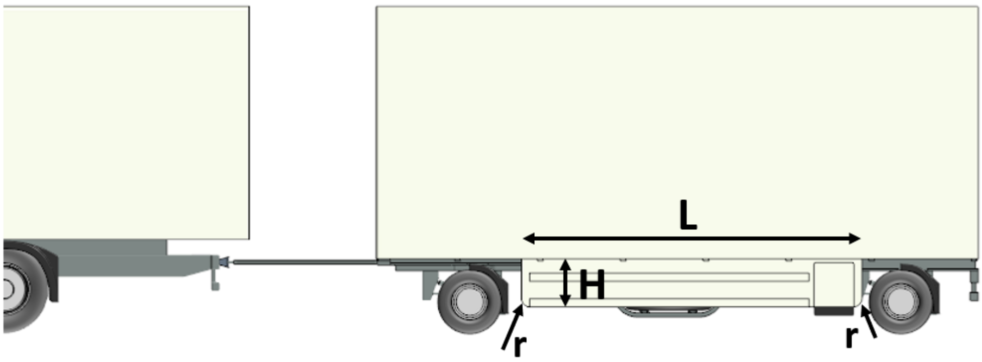


Figure 44. DB-vol standard short side covers dimensions

Table 13. DB-vol standard short side covers dimensions

Specification	Symbol	Unit	External dimension
Length	L	[mm]	4.190
Height	H	[mm]	590
Fillet radius	r	[mm]	100

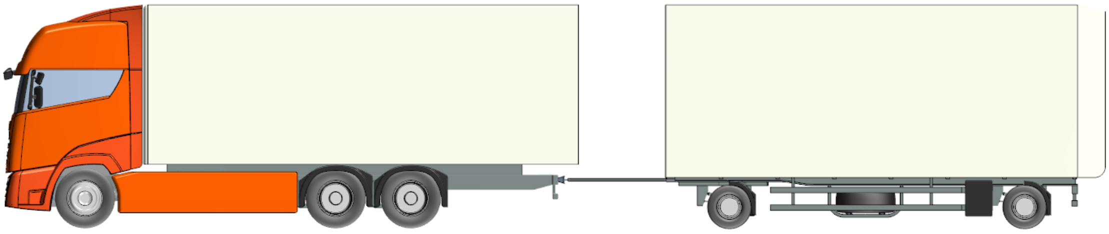


Figure 45. DB-vol Baseline + TRF

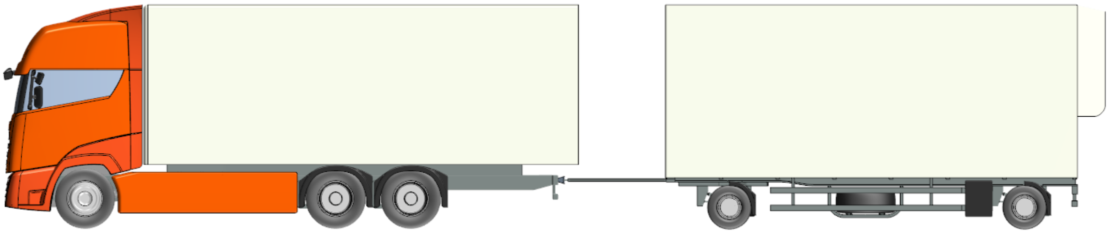


Figure 46. DB-vol Baseline + SRF

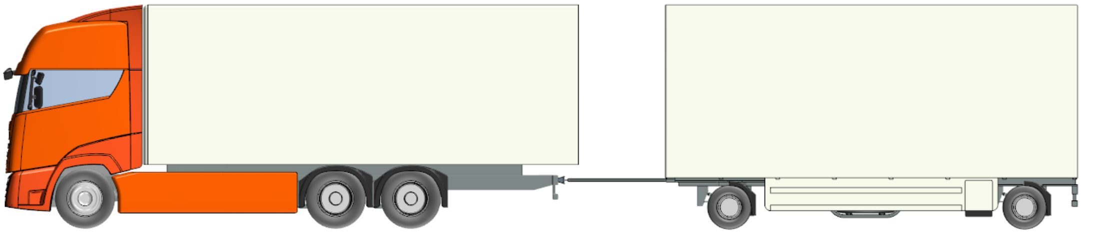


Figure 47. DB-vol Baseline + SSC

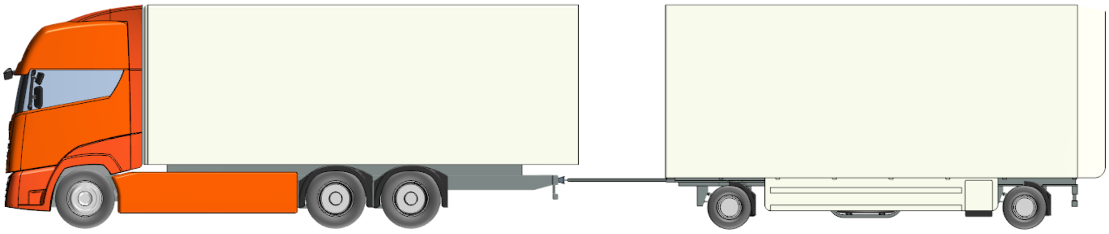


Figure 48. DB-vol Baseline + TRF + SSC

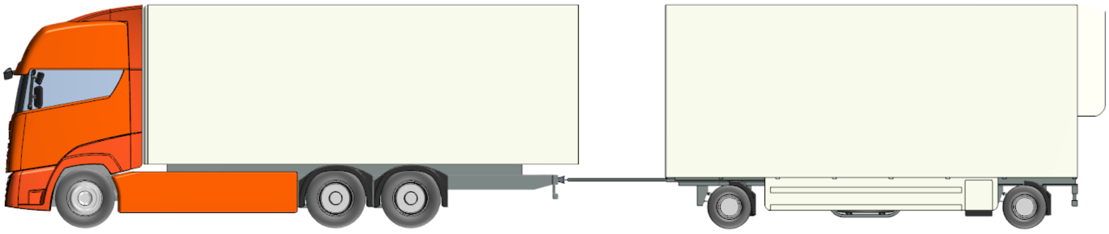


Figure 49. DB-vol Baseline + SRF + SSC

2.4 Centre-axle Trailer (DC)

The standard centre-axle trailer is simulated being pulled by a 6x2 rigid truck.

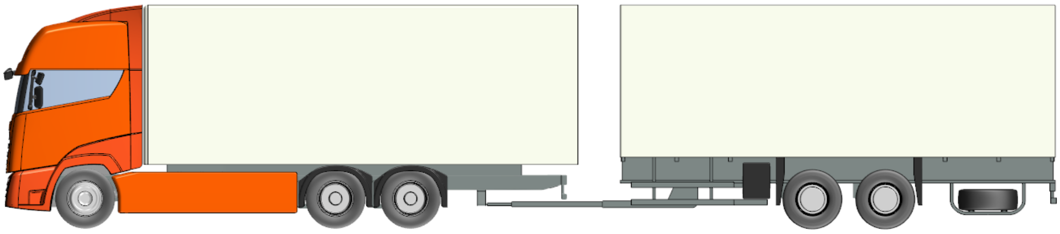


Figure 50. DC Baseline

As in the DB, the DC cargo box is 2.730mm high and its standard aerodynamic devices are characterized with the following dimensions:

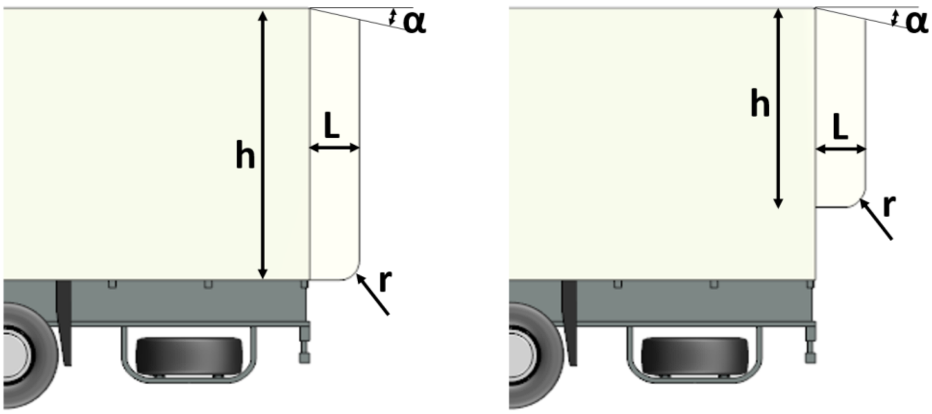


Figure 51. DC standard rear flaps dimensions

Table 14. DC standard rear flaps dimensions

Specification	Symbol	Unit	External dimension
Tapering angle	α	[deg]	13 (for top and side panels)
Length	L	[mm]	400
Height	h	[mm]	2730 (TRF) 2000 (SRF)
Fillet radius	r	[mm]	200

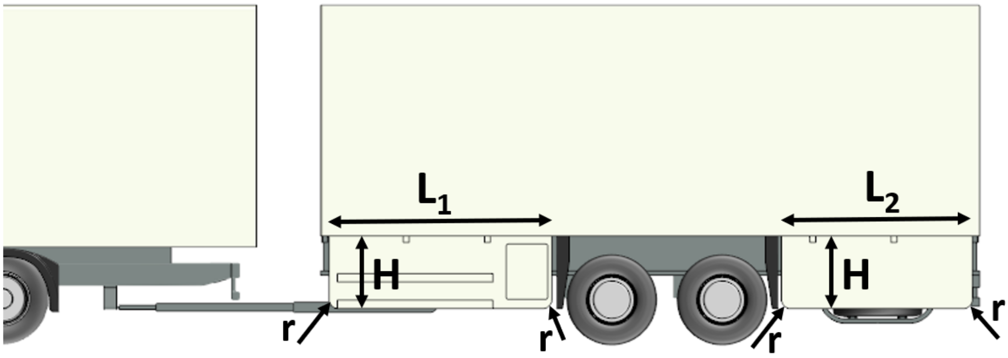


Figure 52. DC standard short side covers dimensions

Table 15. DC standard short side covers dimensions

Specification	Symbol	Unit	External dimension
Length	L_1 L_2	[mm]	2.645 2.265
Height	H	[mm]	860
Fillet radius	r	[mm]	100

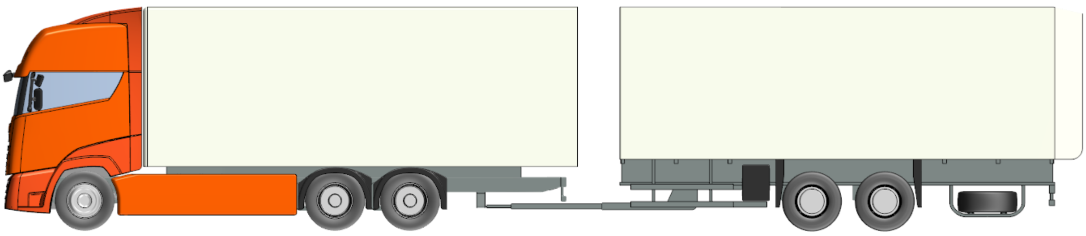


Figure 53. DC Baseline + TRF

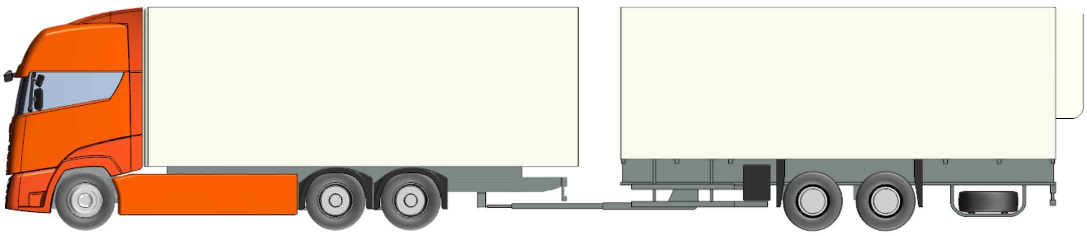


Figure 54. DC Baseline + SRF

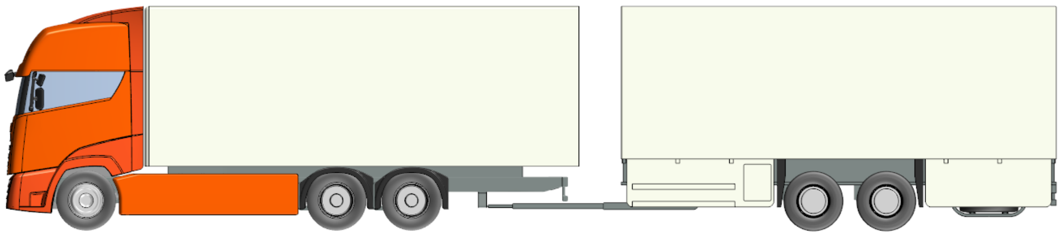


Figure 55. DC Baseline + SSC

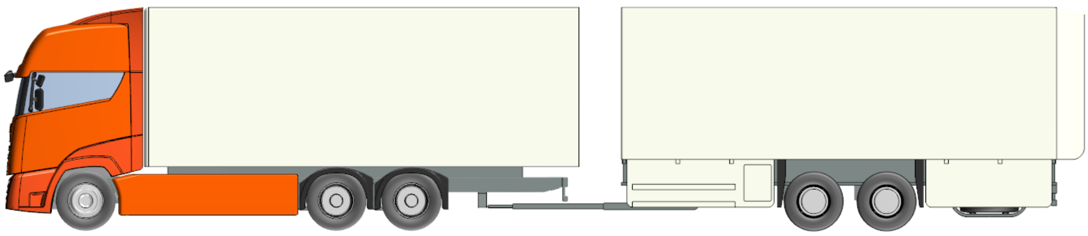


Figure 56. DC Baseline + TRF + SSC

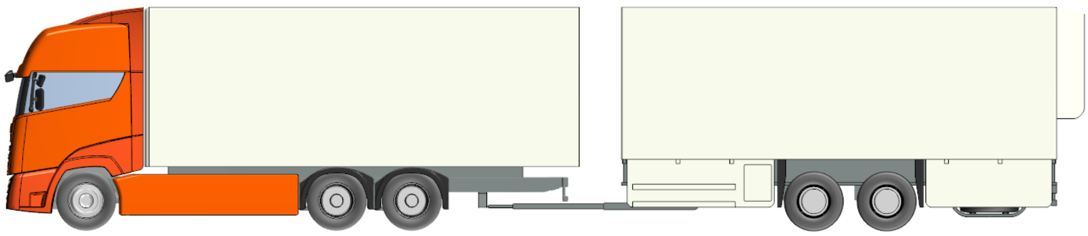


Figure 57. DC Baseline + SRF + SSC

2.5 Volume-Oriented Centre-axle Trailer (DC-vol)

The standard volume-oriented centre-axle trailer is simulated being pulled by a 6x2 rigid truck.

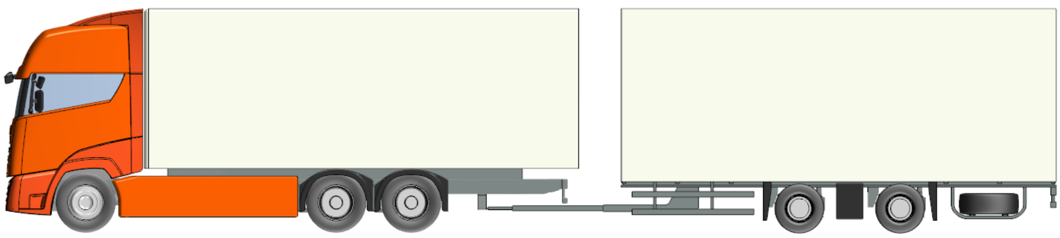


Figure 58. DC-vol Baseline

The cargo box gets enlarged with respect to the DC up to a height of 3100mm and its standard aerodynamic devices are characterized with the following dimensions:

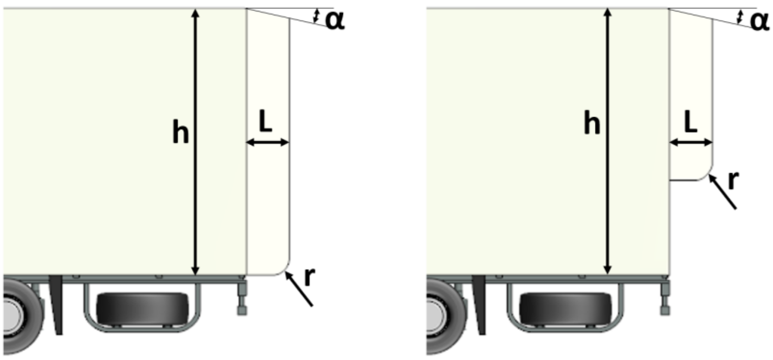


Figure 59. DC-vol standard rear flaps dimensions

Table 16. DC-vol standard rear flaps dimensions

Specification	Symbol	Unit	External dimension
Tapering angle	α	[deg]	13 (for top and side panels)
Length	L	[mm]	400
Height	h	[mm]	3100 (TRF) 2000 (SRF)
Fillet radius	r	[mm]	200

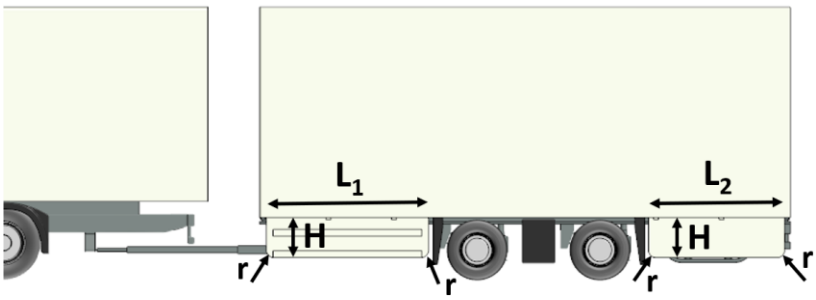


Figure 60. DC-vol standard short side covers dimensions

Table 17. DC-vol standard short side covers dimensions

Specification	Symbol	Unit	External dimension
Length	L_1 L_2	[mm]	2.390 2.000
Height	H	[mm]	590
Fillet radius	r	[mm]	100

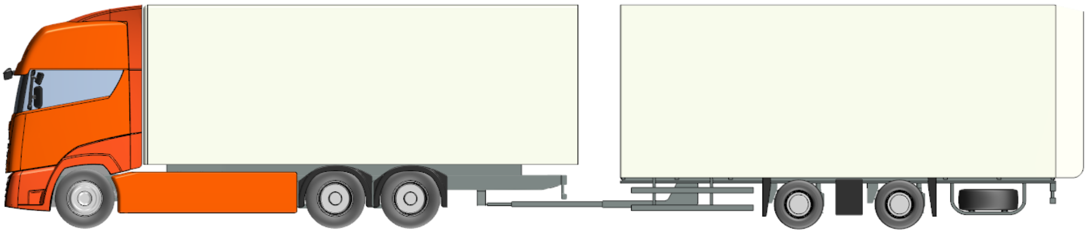


Figure 61. DC-vol Baseline + TRF

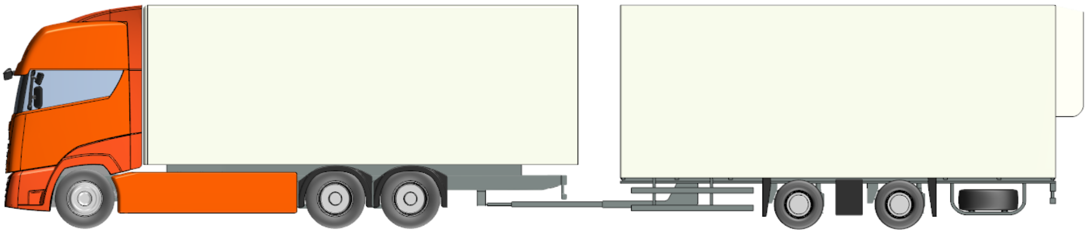


Figure 62. DC-vol Baseline + SRF

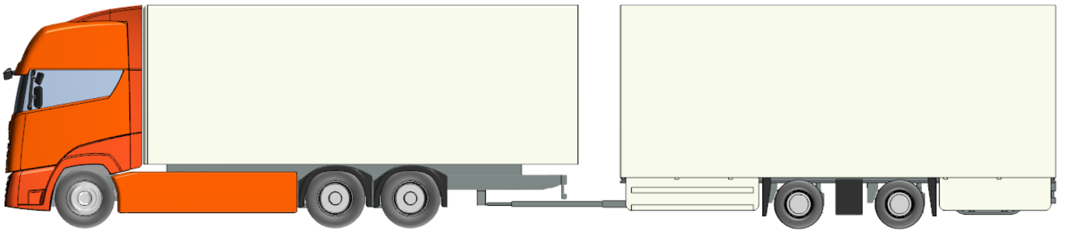


Figure 63. DC-vol Baseline + SSC

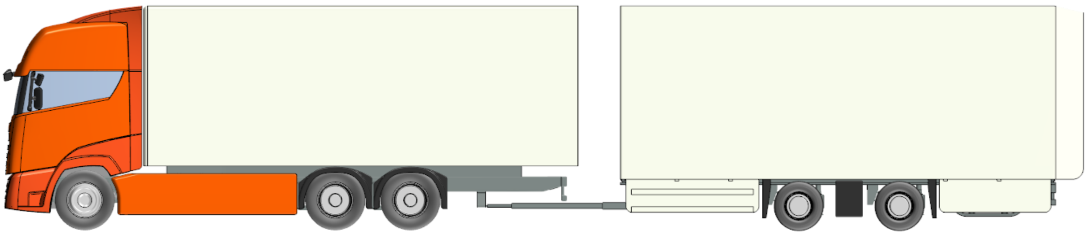


Figure 64. DC-vol Baseline + TRF + SSC

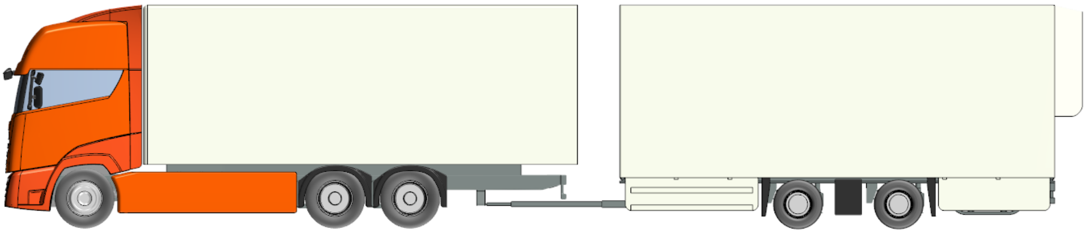


Figure 65. DC-vol Baseline + SRF + SSC

3 Results

All tables within this section are grouped by vehicle type:

- Volume-oriented Semitrailer (DA-vol)
- Drawbar trailer (DB)
- Volume-oriented drawbar trailer (DB-vol)
- Centre-axle trailer (DC)
- Volume-oriented centre-axle trailer (DC-vol)

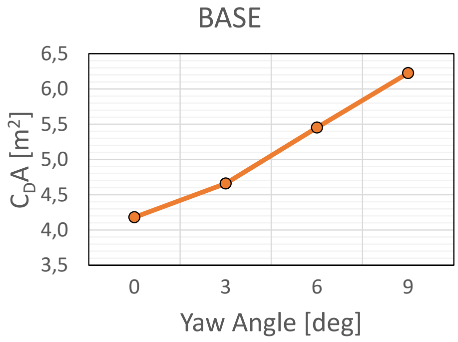
and each vehicle type is equipped with the corresponding aerodynamic devices (and their combination) as presented in all previous figures and each vehicle configuration is reported for all 4 crosswind scenarios (0, 3, 6 and 9 degrees of yaw)

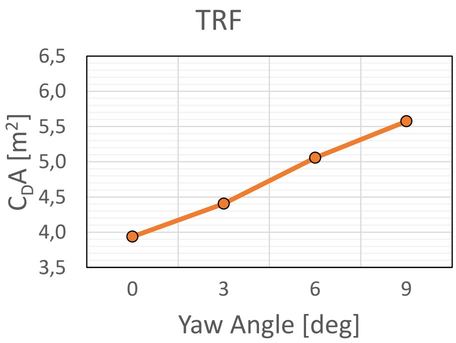
3.1 *Volume-Oriented Semitrailer (DA-vol)*

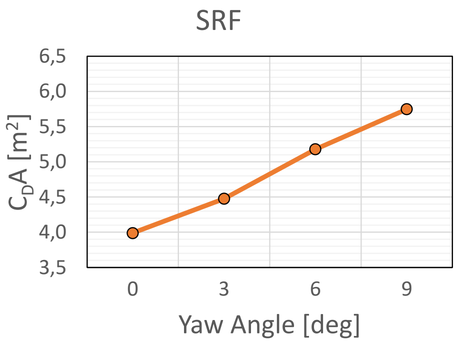
The following table and plots report the C_DxA [m^2] for all DA-vol configurations. As expected, C_DxA increases with the yaw angle, larger aerodynamic panels (TRF and LSC) provide a bigger benefit than smaller ones (SRF and SSC) and adding a second device reduces air drag even further:

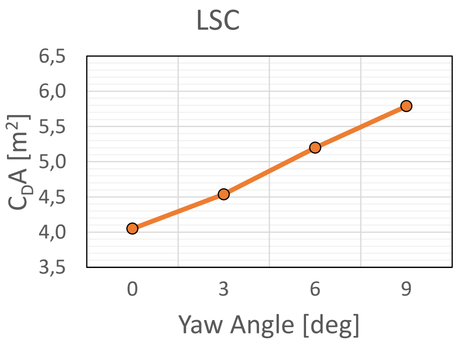
Table 18. DA-vol. Predicted C_DxA [m^2] values

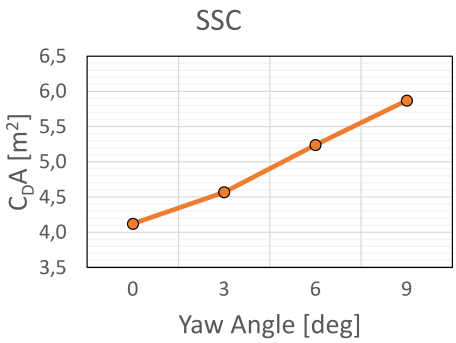
Vehicle Configuration	Yaw Angle [deg]			
	0.0	3.0	6.0	9.0
Baseline	4.18	4.66	5.45	6.23
TRF	3.94	4.40	5.06	5.57
SRF	3.99	4.48	5.18	5.75
LSC	4.05	4.54	5.20	5.79
SSC	4.12	4.57	5.24	5.87
TRF + LSC	3.79	4.20	4.74	5.27
TRF + SSC	3.88	4.31	4.86	5.37
SRF + LSC	3.87	4.31	4.86	5.42
SRF + SSC	3.94	4.37	4.98	5.51

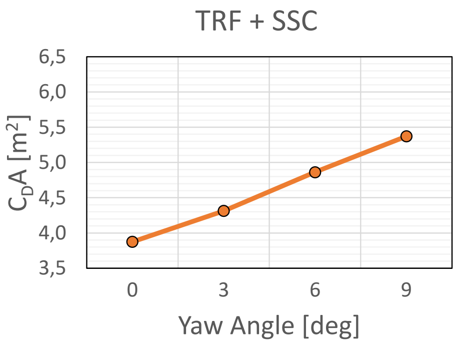

BASE
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]

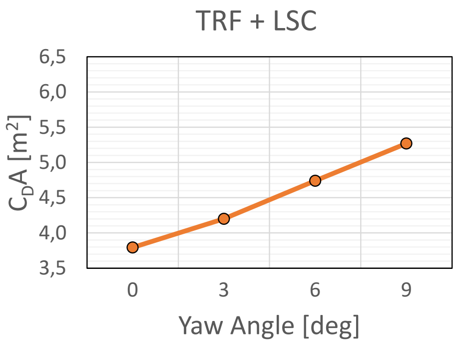

TRF
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]


SRF
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]


LSC
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]


SSC
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]


TRF + SSC
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]


TRF + LSC
6,5
6,0
5,5
5,0
4,5
4,0
3,5
CDA [m2]
0
3
6
9
Yaw Angle [deg]

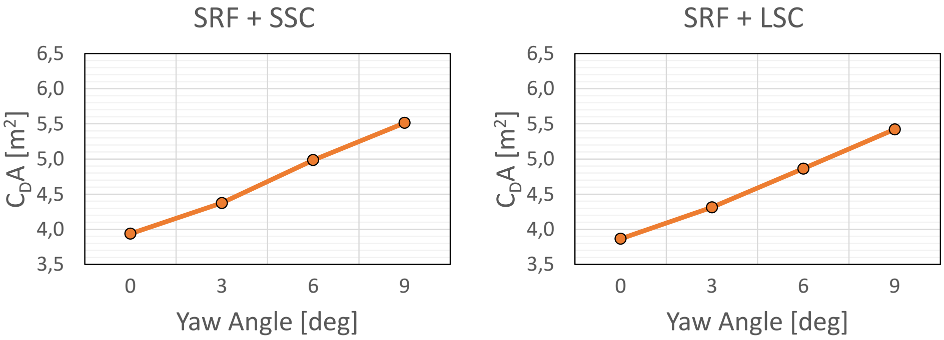


Figure 66. DA-vol. Predicted C_DxA [m^2] values

Table 19. DA-vol. Predicted ΔC_DxA [%] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	**3.0**	**6.0**	**9.0**
TRF	-5.84%	-5.46%	-7.28%	-10.46%
SRF	-4.62%	-3.93%	-5.04%	-7.68%
LSC	-3.16%	-2.62%	-4.66%	-7.03%
SSC	-1.46%	-1.97%	-3.92%	-5.72%
TRF + LSC	-9.25%	-9.83%	-13.06%	-15.36%
TRF + SSC	-7.30%	-7.42%	-10.82%	-13.73%
SRF + LSC	-7.54%	-7.42%	-10.82%	-12.91%
SRF + SSC	-5.84%	-6.11%	-8.58%	-11.44%

3.2 Drawbar Trailer (DB)

The following table and plots report the C_DxA [m^2] for all DB configurations. As expected, C_DxA increases with the yaw angle, larger aerodynamic panels (TRF) provide a bigger benefit than smaller ones (SRF) and adding a second device reduces air drag even further:

Table 20. DB. Predicted $C_D xA$ [m^2] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	**3.0**	**6.0**	**9.0**
Baseline	4.68	5.06	5.62	6.72
TRF	4.43	4.74	5.25	6.37
SRF	4.43	4.83	5.34	6.44
SSC	4.45	4.97	5.46	6.48
TRF + SSC	4.29	4.66	5.13	6.07
SRF + SSC	4.34	4.69	5.19	6.14

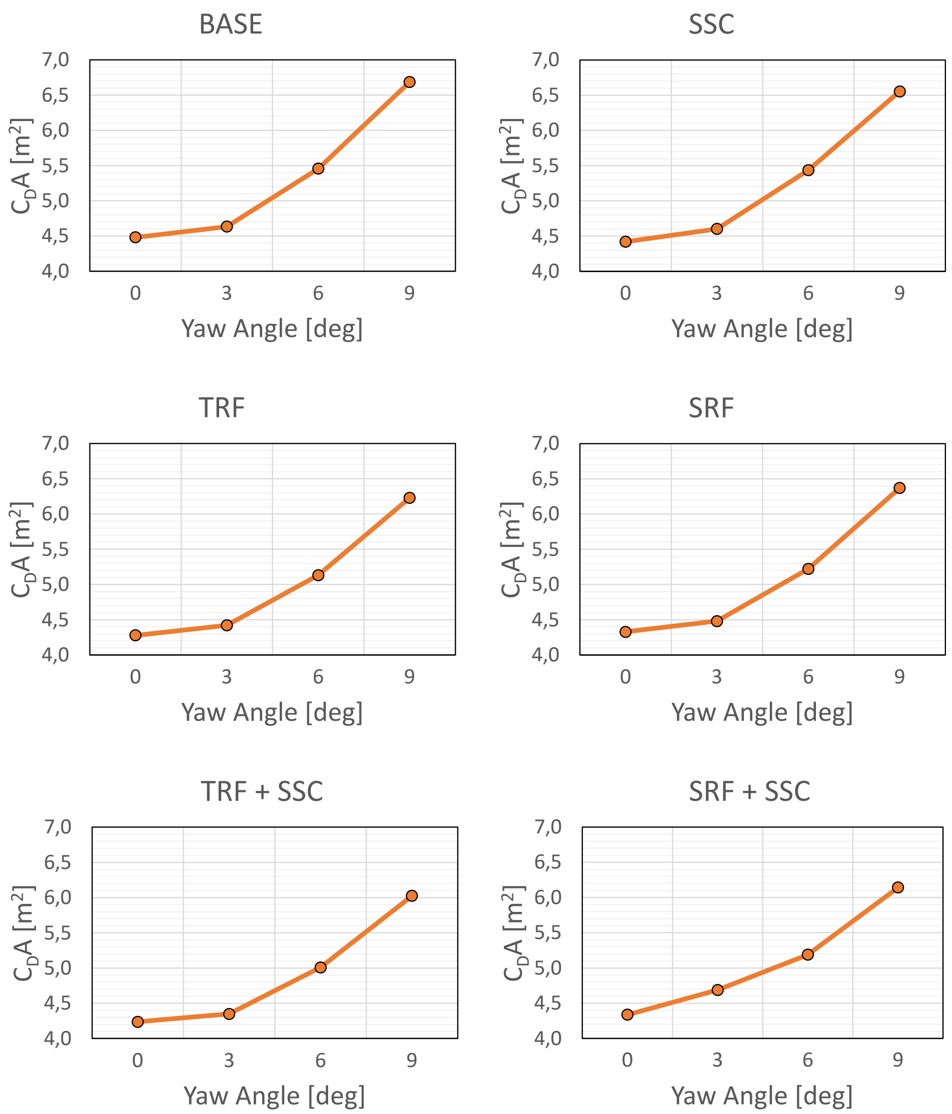


Figure 67. DB. Predicted $C_D xA$ [m^2] values

Table 21. DB. Predicted $\Delta C_D xA$ [%] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	3.0	6.0	9.0
TRF	-5.36%	-6.35%	-6.61%	-5.22%
SRF	-5.36%	-4.56%	-5.00%	-4.18%
SSC	-4.94%	-1.79%	-2.86%	-3.58%
TRF + SSC	-8.37%	-7.94%	-8.75%	-9.70%
SRF + SSC	-7.30%	-7.34%	-7.68%	-8.66%

3.3 *Volume-Oriented Drawbar Trailer (DB-vol)*

The following table and plots report the $C_D xA$ [m^2] for all DB-vol configurations. As expected, $C_D xA$ increases with the yaw angle, larger aerodynamic panels (TRF) provide a bigger benefit than smaller ones (SRF) and adding a second device reduces air drag even further:

Table 22. DB-vol. Predicted $C_D xA$ [m^2] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	3.0	6.0	9.0
Baseline	4.48	4.63	5.46	6.69
TRF	4.28	4.42	5.13	6.23
SRF	4.33	4.48	5.22	6.37
SSC	4.42	4.60	5.44	6.55
TRF + SSC	4.24	4.35	5.01	6.03
SRF + SSC	4.29	4.41	5.12	6.15

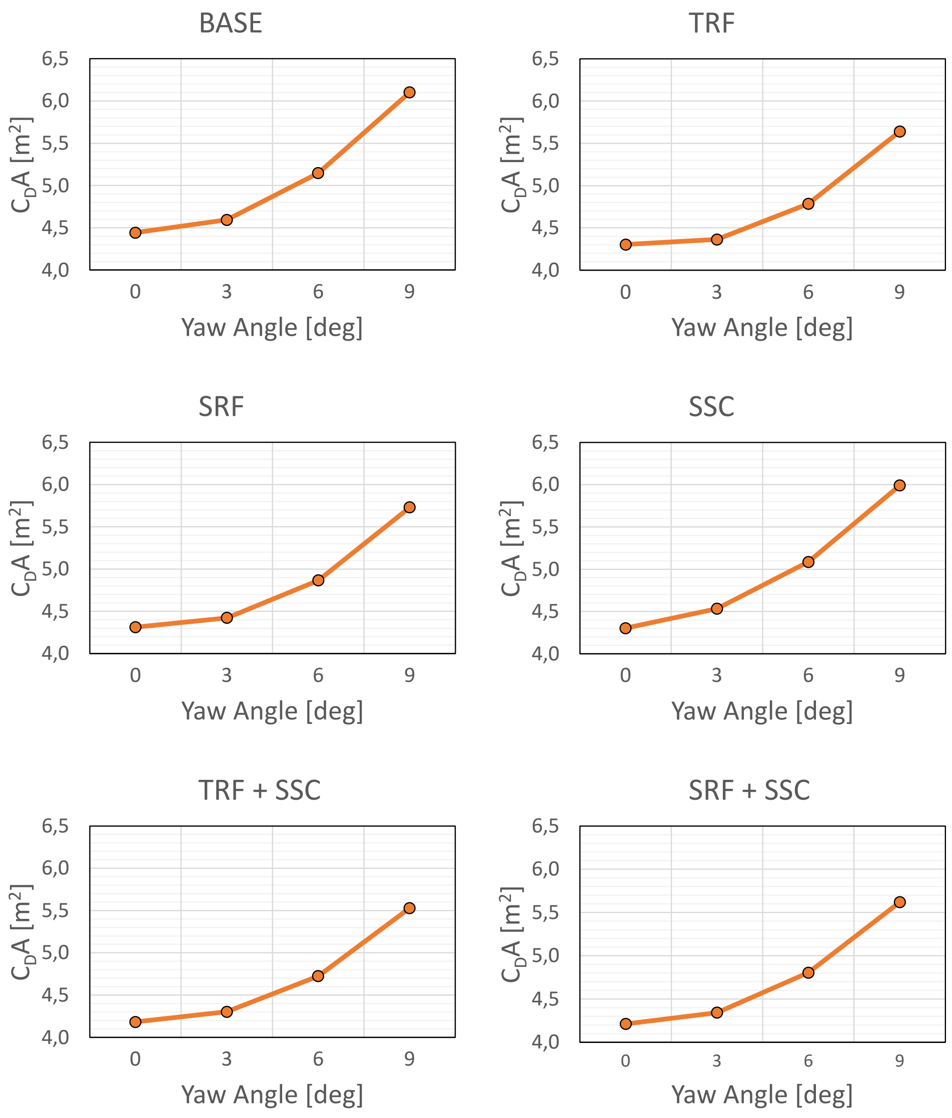


Figure 68. DB-vol. Predicted C_DxA [m²] values

Table 23. DB-vol. Predicted ΔC_DxA [%] values

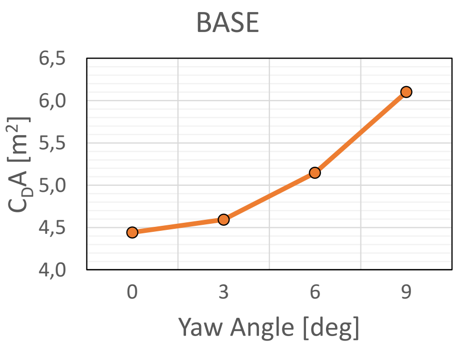
Vehicle Configuration	Yaw Angle [deg]			
	0.0	**3.0**	**6.0**	**9.0**
TRF	-4.54%	-4.61%	-5.96%	-6.84%
SRF	-3.40%	-3.29%	-4.28%	-4.71%
SSC	-1.36%	-0.66%	-0.37%	-1.98%
TRF + SSC	-5.44%	-6.14%	-8.19%	-9.88%
SRF + SSC	-4.31%	-4.82%	-6.15%	-8.05%

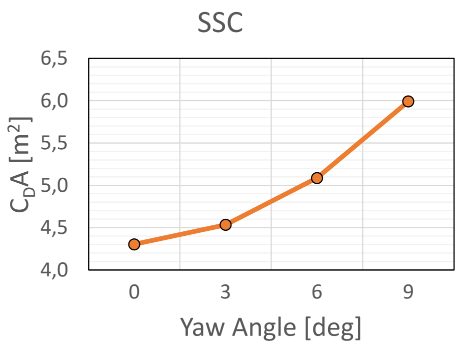
3.4 *Centre-axle Trailer (DC)*

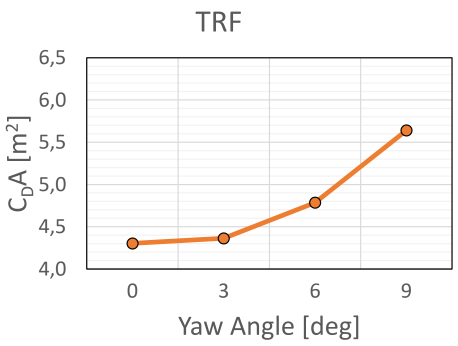
The following table and plots report the C_DxA [m^2] for all DC configurations. As expected, C_DxA increases with the yaw angle, larger aerodynamic panels (TRF) provide a bigger benefit than smaller ones (SRF) and adding a second device reduces air drag even further:

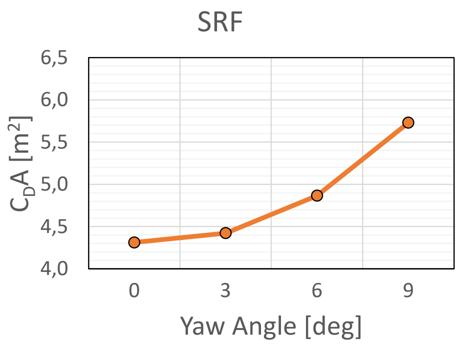
Table 24. DC. Predicted C_DxA [m^2] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	**3.0**	**6.0**	**9.0**
Baseline	4.44	4.59	5.15	6.10
TRF	4.30	4.36	4.78	5.64
SRF	4.31	4.42	4.87	5.73
SSC	4.30	4.53	5.09	5.99
TRF + SSC	4.18	4.30	4.72	5.53
SRF + SSC	4.21	4.34	4.80	5.62









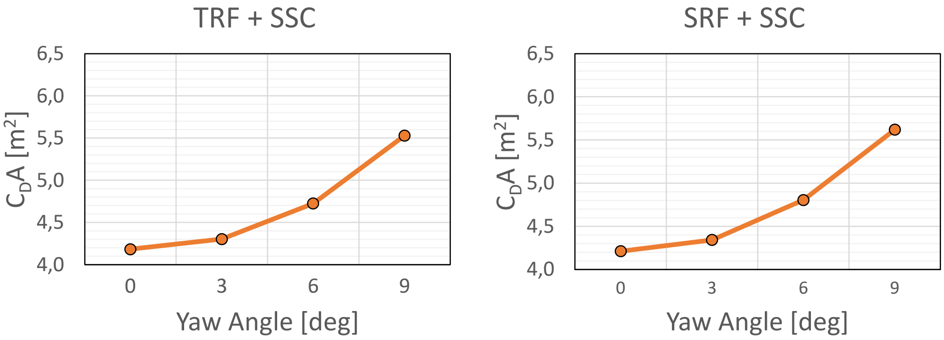


Figure 69. DC. Predicted C_DxA [m^2] values

Table 25. DC. Predicted ΔC_DxA [%] values

Vehicle Configuration	**Yaw Angle [deg]**			
	0.0	**3.0**	**6.0**	**9.0**
TRF	-3.17%	-5.03%	-7.03%	-7.58%
SRF	-2.94%	-3.72%	-5.47%	-6.10%
SSC	-3.17%	-1.31%	-1.17%	-1.81%
TRF + SSC	-5.88%	-6.35%	-8.20%	-9.39%
SRF + SSC	-5.20%	-5.47%	-6.64%	-7.91%

3.5 Volume-Oriented Centre-axle Trailer (DC-vol)

The following table and plots report the C_DxA [m^2] for all DC-vol configurations. As expected, C_DxA increases with the yaw angle, larger aerodynamic panels (TRF) provide a bigger benefit than smaller ones (SRF) and adding a second device reduces air drag even further:

Table 26. DC-vol. Predicted C_DxA [m²] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	**3.0**	**6.0**	**9.0**
Baseline	4.26	4.53	5.19	6.26
TRF	4.05	4.22	4.75	5.66
SRF	4.11	4.31	4.91	5.89
SSC	4.22	4.49	5.13	6.08
TRF + SSC	4.01	4.16	4.69	5.57
SRF + SSC	4.08	4.25	4.83	5.77

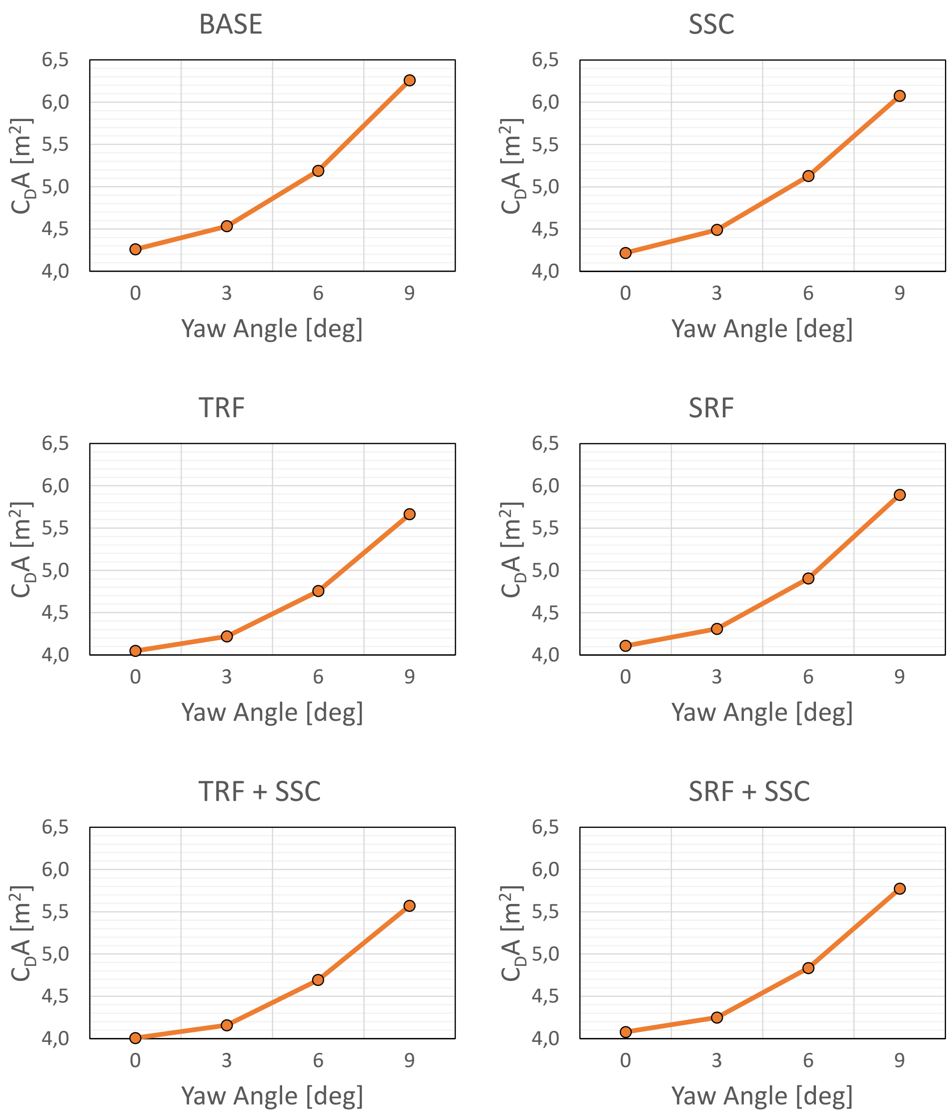


Figure 70. DC-vol. Predicted C_DxA [m²] values

Table 27. DC-vol. Predicted $\Delta C_D xA$ [%] values

Vehicle Configuration	Yaw Angle [deg]			
	0.0	3.0	6.0	9.0
TRF	-4.98%	-6.90%	-8.37%	-9.52%
SRF	-3.55%	-4.90%	-5.45%	-5.81%
SSC	-0.95%	-0.89%	-1.17%	-2.90%
TRF + SSC	-5.92%	-8.24%	-9.53%	-10.97%
SRF + SSC	-4.27%	-6.24%	-6.81%	-7.74%

4 Summary and conclusions

In a first step, the EU generic vehicle consisting of a 4x2 tractor pulling a ST1 semitrailer has been used to validate a CFD methodology by predicting and reporting the aerodynamic benefit, $\Delta C_D xA$ [%], provided by the standard tall rear flaps (TRF) and the standard long side covers (LSC) mounted on the ST1 semitrailer and under different crosswind scenarios.

In a second step, this validated CFD methodology has been applied to the following vehicle configurations:

- 4x2 tractor pulling a volume-oriented semitrailer (DA-vol)
- 6x2 rigid lorry pulling a drawbar trailer (DB)
- 6x2 rigid lorry pulling a volume-oriented drawbar trailer (DB-vol)
- 6x2 rigid lorry pulling a centre-axle trailer (DC)
- 6x2 rigid lorry pulling a volume-oriented centre-axle trailer (DC-vol)

All simulated under different crosswind scenarios, resulting in yaw angles of 0, 3, 6 and 9 degrees of yaw, and each vehicle and scenario also simulated equipping the (semi-)trailer with its corresponding standard aerodynamic devices.

All predicted $C_D xA$ [m^2] values follow the expected trends:

a) Air drag increases with the yaw angle

b) Air drag decreases when adding aerodynamic panels

c) The larger the aero panel, the lower the air drag

d) Two aero panels mounted on the (semi-)trailer provide lower air drag than just having one.

The corresponding aerodynamic benefit, $\Delta C_D xA$ [%], for each device (and combination of devices) has been computed out of all air drag predicted values and reported in the tables in the previous section.

5 Bibliography

[1] "Guidelines for Aerodynamic Assessment of Medium and Heavy Commercial Ground Vehicles Using Computational Fluid Dynamics", SAE International, April 2017.

[2] A. Gascón and M. Soler, "Comparison of CFD methods with air drag test values for commercial vehicles", FISITA 2021.

[3] DG CLIMA, Bodies and trailers – Development of CO2 emissions determination procedure. Procedure Num. CLIMA/C.4/SER/OC/2018/0005

[4] DG CLIMA, Bodies and trailers – Support Preparation of Legislation on Trailers Certification. Procedure Number CLIMA/C.4/SER/2019/0003

Annex I

This annex comprehends the complete validation report with the corresponding stamps and signatures from the Technical Service: