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Publishable Executive Summary

This document represents Deliverable D3.6 of the AEROFLEX project. It summarizes the performed activities within Work Package 3 (WP3), to fulfil the requirements and Key Performance Indicators (KPIs) prescribed in the project for drag reduction on heavy trucks.

As an initial phase, different concepts were identified to reduce the aerodynamic drag for heavy trucks, with preliminary estimates of the potential drag reduction for each concept, as a basis for selection of those most promising for further investigation. The concepts included a variety of measures, to actively or passively influence the flow field at different locations or parts of the vehicle in aerodynamically favourable direction. More detailed information about the concepts is available in Deliverable D3.1 (ref [**Fout! Verwijzingsbron niet gevonden.**]). A summary of the initial performance estimates and a comparison with the targets for WP3 are shown in Table 0-1.

Table 0-1 Estimated and targeted drag reduction for the considered vehicle combinations in WP3 (ref [Fout! Verwijzingsbron niet gevonden.**])**

Case	Estimated ΔCD x A [m2]	Estimated ΔCD x A [%]	Targeted ΔCD x A [%]
Tractor semi-trailer (16.5m)	1.38-2.39	22-39	25
EMS truck trailer (25.25m)	1.38-2.43	17-30	17
Demonstrator (EMS 25.25m)	1.34-2.25	16-27	15

In the next phase, D3.2, detailed simulation geometries were prepared to represent the generic Reference and Baseline models for the Tractor – semi-trailer and EMS1 25.25m vehicles, which then were used for the concept investigations and drag change predictions. These models were simulated by all the designated partners participating in the CFD work, each using their own respective best-practice CFD method. Despite the different methods applied, the results showed generally good agreement in terms of the overall flow structure and most of the key features in the flow field. A comparison of change in drag when the boat-tail was removed, showed reasonable spread between the results from different partners (Table 0-2).

Table 0-2 ΔC_D predictions by different partners, with different methods, for the CFD Baseline model with and without Boat-Tail at yaw -5˚ (crosswind right to left from drivers viewpoint) (ref [Fout! Verwijzingsbron niet gevonden.**])**

Partner	CFD SoftWare	Method	ΔC_D (cts)
Scania	PowerFLOW	Lattice Boltzmann (transient)	40
CRF	Helyx OpenFOAM 3.0.0	Finite Volume (transient)	40
NLR	OpenFOAM	Finite Volume (steady state)	29
WABCO[1]	PowerFLOW	Lattice Boltzmann (transient)	36
CREO	OpenFOAM v1606	Finite Volume (steady state)	34

Each partner was assigned a number of concepts to prepare and simulate as individual measures on the applicable vehicle type, and evaluate the change in drag compared to the corresponding Baseline, as presented in Deliverable D3.2 (ref [**Fout! Verwijzingsbron niet gevonden.**]).

In summary, the simulated results for the geometry-related measures, showed gains which were generally less than predicted in ref [**Fout! Verwijzingsbron niet gevonden.**]. The reason can to some extent be explained by the concepts not being optimised for best performance. Still, according to the simulations, the investigated concepts provided considerable potential for drag reduction on both vehicle configurations.

Simulations of the active flow control-related concepts, however, didn't show any encouraging results. This is partly due to the difficulties related to simulating such devices, and partly because of the extensive iteration schemes required for each concept to arrive at an optimal solution, which was unfeasible to perform within the time frame of the work package.

During this phase, a few additional number of new concepts, not listed in ref [**Fout! Verwijzingsbron niet gevonden.**], were also developed and investigated, which added to the potential for improvement.

In accordance with the agreed evaluation method, the most promising candidates simulated by different partners, were simulated again, now using a single predefined CFD method, to confirm and establish an uniform result database to be used in the coming stages of the project. These confirmation simulations showed the same trends and generally good agreement in levels of improvement, as the initial CFD simulations by the partners

[1] *WABCO* Holdings Inc. became part of *ZF* in May 2020. WABCO is used as company name throughout this report to be consistent with previously issued deliverables

indicated. Many of the concepts were also optimised further during this process, adding to the potential gain by those concepts.
To demonstrate validity of the CFD results, extensive analyses were conducted, comparing CFD simulation results with wind tunnel measurements performed in the FCA wind tunnel, as described in D3.4 (ref[**Fout! Verwijzingsbron niet gevonden.**]). This was done, quantitatively, in terms of drag prediction and more importantly, change in drag due to geometrical modifications, and also by qualitative assessments of how well the flow field captured in the simulations matched corresponding measured data.
In addition to simulations of the full scale model in Open road condition, the validation analyses included new simulations with the 1:3 scale model in the FCA wind tunnel domain, and modelling minor geometrical discrepancies, to as far as possible replicate the measurement setup.
The results of the simulations with different scales were then compared to each other, as well as to the equivalent wind tunnel measurements. The analyses showed in general satisfactory agreement between CFD simulation results of the 1:3 scale model in wind tunnel and the experimental data, especially in terms of ΔC_D trends and predictions, with very few exceptions. The discrepancies observed when comparing with the full scale simulations (Figure 0-1), could mainly be traced to geometrical differences between the models and not having identical similarity parameters (Reynolds number) due to the speed limitation in the wind tunnel.

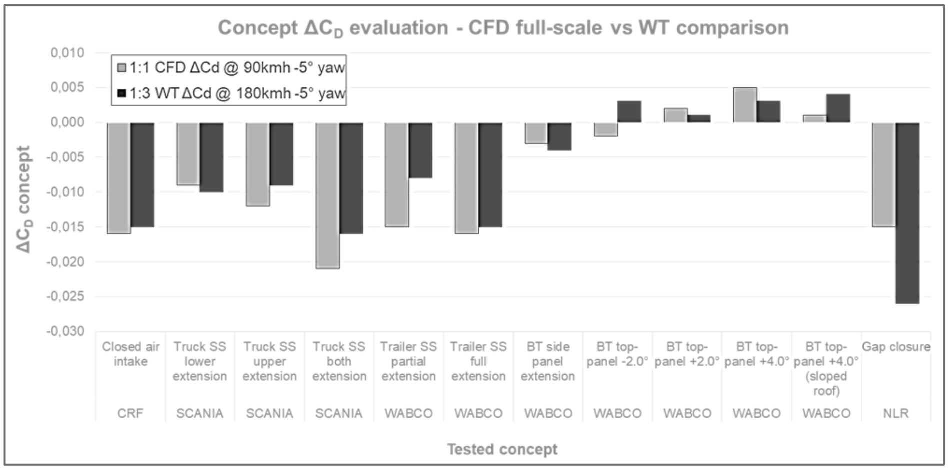


Figure 0-1 Comparison of ΔC_D due to concepts predicted by CFD full scale and measured data in wind tunnel (ref [Fout! Verwijzingsbron niet gevonden.**])**

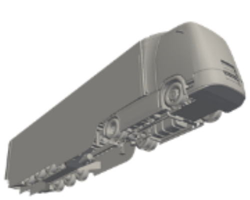
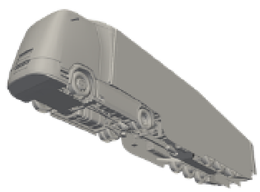
Additional simulations with the CFD scale model setup to verify the effect of the tested concepts, individually and when combined, also showed good correlations between numerical and experimental data.
Furthermore, acceptable correlations in the general flow field were observed between the CFD simulation results and experimental data, for various conditions and configurations.
Based on these observations, it was concluded that the CFD simulation method as practiced in this work package, provided reliable results for drag reduction predictions.

The robustness of the CFD results were tested through a series of sensitivity simulations, consisting of both variations in simulation strategies and various geometrical discrepancies. The analyses showed variations of ΔC_D due to the applied changes, which were generally small in comparison to the predicted gain for the investigated concept, and more importantly, did not show a different trend. The comparison between transient and steady-state simulations with the wind tunnel model showed the largest differences in this part of the study. However, as mentioned, there were good agreement in drag change results for most of the concepts investigated by both transient and steady-state runs, indicating that this difference could be more specific to the wind tunnel simulations. The sensitivity analyses were therefore considered to point to satisfactory robustness and validity of the results, both in terms of the applied methodology and the choice of the concepts.

In order to demonstrate fulfilment of the KPIs for the baseline models specified in Table 0-1, two sets of concept combinations were defined and simulated for each vehicle type. The configurations were simulated for four different yaw angles, to more correctly estimate wind averaged C_D x A values. The resulting drag reductions for the different vehicle types, compared to corresponding Reference models, are presented in The combinations used and presented in Table 0-3 are regarded as the basis for recommendations for concepts to be implemented on the two truck configurations considered in the project.

Table 0-3, showing improvements which by far exceed the stipulated target values. The margin to the target is noticeably higher for the EMS vehicle, due to the additional concepts which were not accounted for in ref [**Fout! Verwijzingsbron niet gevonden.**].
The combinations used and presented in Table 0-3 are regarded as the basis for recommendations for concepts to be implemented on the two truck configurations considered in the project.

Table 0-3 Calculated wind averaged ΔC_D x A, compared to the Reference models, for the considered vehicle combinations (ref [Fout! Verwijzingsbron niet gevonden.**])**

	Realistic Combination	Maximum Performance	Realistic Combination	Maximum Performance
				
	Concepts	**Concepts**	**Concepts**	**Concepts**
	Truck active side skirt extension	Truck active side skirt extension	Truck active side skirt	Truck active side skirt
	Trailer active side skirt extension	Trailer active side skirt extension	Retractable trailer (min gap)	Retractable trailer (min gap)
	Inflatable gap sealing	Inflatable gap sealing	Trailer active side skirt extension	Trailer active side skirt extension
	Extended boat tail	Adaptable trailer shape	Extended boat tail	Adaptable trailer shape
	Adjustable underbody fairing (-80mm)	Adjustable underbody fairing (-80mm)	Adjustable underbody fairing (-80mm)	Adjustable underbody fairing (-80mm)
	Trailer chassis covering diffuser	Trailer chassis covering diffuser	Trailer chassis covering diffuser	Trailer chassis covering diffuser
	Air shutter and curtains	Air shutter and curtains	Dolly side skirt	Dolly side skirt
			Air shutter and curtains	Air shutter and curtains
			Truck rear side skirt	Truck rear side skirt
Calculated $\Delta C_{DWA} A$ [m^2]	**2.09**	**2.37**	**2.35**	**2.62**
Calculated $\Delta C_{DWA} A$ [%]	**42**	**48**	**40**	**44**
Targeted $\Delta C_{DWA} A$ [%]	**25**	**25**	**17**	**17**

In D3.3, suitable combination of concepts studied for the CFD Baseline EMS1 25.25 model[2] in D3.2, were applied to the model for the SCANIA Demonstrator EMS1[3], in order to validate the aerodynamic gains due to the developed concepts when applied to a realistic truck geometry and to select components and technologies for implementation on the Demonstrator EMS1 vehicle for fulfilment of the KPI specified for the vehicle in Table 0-1. Three different setups, with different number of concepts and level of complexity, were therefore simulated, as described in Deliverable D3.3 (ref [**Fout! Verwijzingsbron niet gevonden.**]). The results, were also used to find a suitable setup for implementation on the real demonstrator (AeroLoad) to fulfil the target KPI.

The simulated combinations were compared with the Reference EMS1 model, for KPI assessment. Additionally, the realistic truck geometry equipped with a Boat-tail, (denoted as Demonstrator EMS1 in the table below) was also used for comparison purposes to better illustrate and quantify the actual benefit of the selected concepts. The resulting ΔC_D x A values, for yaw -5˚ are presented in the Table 0-4.

[2] The CFD Baseline model is a generic truck model, with extended front, representing the 2022 standard and equipped with what is considered as state-of-the-art today (ref [**Fout! Verwijzingsbron niet gevonden.**])

[3] The Demonstrator EMS1 model is the base model with the realistic SCANIA truck, on which the different improvement concepts are applied and simulated

Table 0-4 ΔC$_D$ x A for the Demonstrator EMS1 equipped with different concept combinations, compared to reference models (ref [Fout! Verwijzingsbron niet gevonden.**])**

	ΔC$_D$ x A @ yaw -5˚					
	High potential		*Moderate combination*		*Feasible combination*	
	[m2]	*[%]*	*[m2]*	*[%]*	*[m2]*	*[%]*
Vs. Reference EMS1	**-2.07**	**35.4**	**-1.58**	**27.0**	**-1.87**	**32.0**
Vs. Demonstrator EMS1	**-1.48**	**28.1**	**-0.98**	**18.7**	**-1.28**	**24.4**

The result summary in Table 0-4 shows that all the different combinations presented fulfil the required KPI for the Demonstrator EMS1 with broad margin. Based on the results and the complexity of the concepts involved, the *Feasible combination* (**Fout! Verwijzingsbron niet gevonden.**) was therefore recommended as suitable modification package to be applied on the test vehicle.

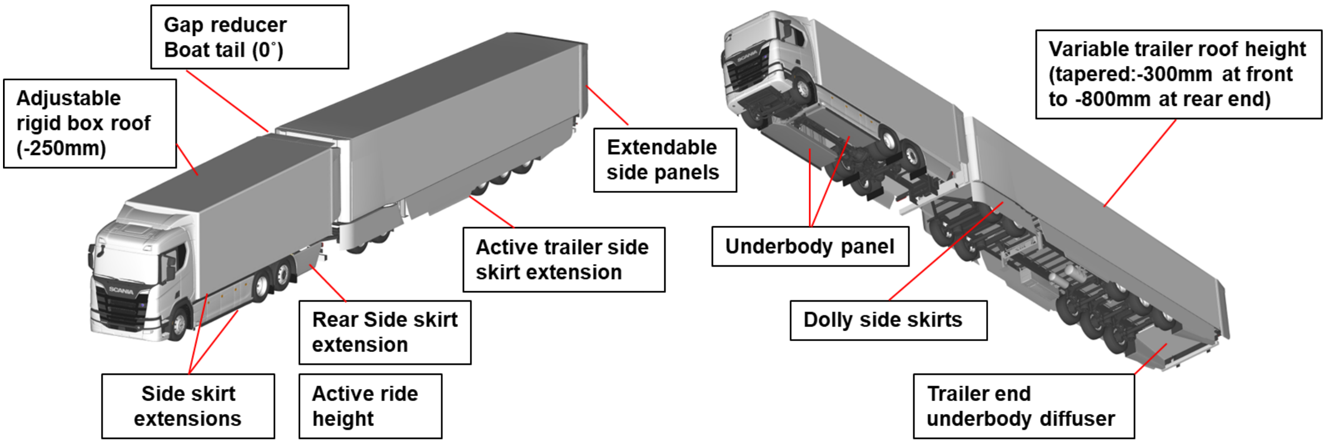


Figure 0-2 Recommended concepts for implementation on the Demonstrator EMS1 vehicle (ref [Fout! Verwijzingsbron niet gevonden.**])**

In D3.5 of WP3 a full-scale AeroLoad Demonstrator was planned and prepared, as described in Deliverable 3.5 (ref [**Fout! Verwijzingsbron niet gevonden.**]). This demonstrator consisted of:

- A newly specified Scania three axle rigid truck
- An existing Schmitz dolly
- The existing Van Eck trailer as used in the TRANSFOMERS project (ref [**Fout! Verwijzingsbron niet gevonden.**])

The vehicle was specified to provide a good baseline state-of-the-art reference vehicle, meeting the currently valid regulations, to serve as a platform for the later aerodynamical improvements.
The aerodynamic package for drag improvement consisted of 14 most promising innovations according to the recommendations in D3.2, adding modification to all three main parts of the vehicle, to constitute the Scania AeroLoad Demonstrator. This task required design, manufacturing and testing of new parts to be retrofitted to the vehicle, considering suitable positioning and robust attachments, a control system to operate the active devices on the vehicle.
Initial cost and weight estimates were provided for all the aerodynamic features, which can be used as input to the cost and benefit analysis that will be performed within Work Package 6 of the AEROFLEX project.

Since the manufactured parts were in many ways different to the more idealized geometries developed and proposed in D3.2 and D3.3, additional simulations were performed for the Demonstrator EMS1 vehicle, using the CAD geometry data of the actual parts as mounted on the vehicle. The simulation results showed a minor (3%) reduction of the predicted gains in D3.3, most of which could be attributed to geometry deviations other than those associated the more realistic concepts, such as a higher swap body and increased gap between the truck and the trailer.

In conclusion, the methodology and concept development approach applied in WP3 showed to be a successful way to improve the aerodynamics on heavy trucks, when different independent partners are involved.

Furthermore, it is demonstrated that the outcome, scrutinized through different simulation methods and wind tunnel tests, is completely realizable and surpasses the expected drag reductions prescribed as aerodynamic goal in the AEROFLEX project, by 17 to 27% as stated in Table 0-3 and Table 0-4.