CFD and wind tunnel assessment of next generation semi-trailer mounted aerodynamic devices

Abstract

Within the European Project Aeroflex, the goal is to reduce aerodynamic drag by up to 10% over current state-of-the-art vehicles. In order to achieve this, next generation aerodynamic devices are necessary to reduce the aerodynamic drag of trailers. This paper describes CFD and wind tunnel efforts to assess three trailer aerodynamic improvements: extended skirts, elongated side panels for the tail and tails with a variable top panel. Sideskirt and tail modifications showed aerodynamic improvements, where the savings achieved with the variable top panel angle were limited.

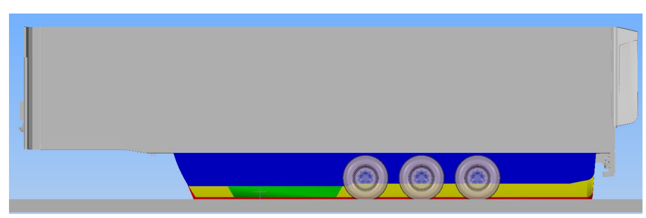
Introduction

Heavy duty vehicles such as lorries, coaches and busses are emit roughly 25% of the CO_2 emission of road transport in the EU. This is equal to 6% of the total EU CO_2 emissions [1].
As such, heavy duty vehicles such are a good candidate for reducing CO_2 emissions. Therefore the EC has set the goal to reduce the emission of lorries by 30% in 2030 [1].
Large gains can be achieved with static aerodynamic modifications to tractors and trailers, but to achieve the ambitious goals next generation aerodynamic devices are necessary.
This is why the EC has set out a call for a project to improve the energy efficiency of logistics [2], which resulted in the AeroFlex project. This project aims to improve logistical efficiency by up to 33%, of which 5-10% should come from improved aerodynamics [3].

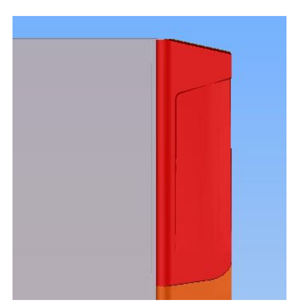
Investigated aerodynamic improvements

Several improvements for the trailer were suggested.

Skirt extension



4 different variations were simulated:
- Baseline (based on commercially available european skirts)
- Realistic extension (mid section -2600mm length- extended to 50 mm ground clearance)
- Full extension (complete skirt extended to 50 mm ground clearance)
- Ground extension (complete skirt extended such that it intersected the ground)



Tail side panel extension

Two different improvements for the tail were investigated. The first was a vertical variation of the side panel lengths.

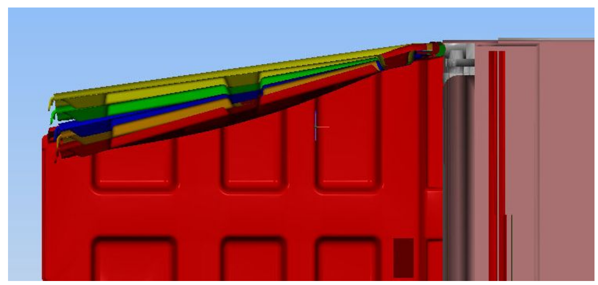
The variations that were tested were

- 1900 mm
- 2300 mm - Baseline (commercially available European Tail)
- 2700 mm
- 2900 mm

Top panel angle variations

Next to this, different top panel angles variations were also investigated:

- 8°
- 10°
- 12.5° - Baseline (commercially available European tail)
- 14°
- 16°



CFD

Simulations were performed using the Simulia Lattice Boltzmann. This transient solver features RNG Turbulence modeling VLES.

Geometry

The tractor geometry was generated by using a blend of OEM tractors. In anticipation of upcoming new european regulation, a 50 cm nose extension was included. Furthermore the underbody was accurately modeled with a realistic inlet and engine compartment. Porous media was modeled such that the pressure drop matched values measured in reality. The complete simulation was set up according to SAE J2966[4] standards, resulting in a total of 120 million voxels. For the flow critical areas (frontal radius, roof deflector, underbody, trailer front) a resolution of 3 mm was employed. To save computational effort and large amounts of simulations, -5° yaw was chosen as a representative case.

Transient Boundary Seeding

To further reduce computational costs, Transient Boundary Seeding was used. In this methodology, a complete simulation was run with a series of measuring planes that record all relevant transient state variables. For subsequent simulations, where only local changes are made (such as a tail at the end of the trailer) and the upstream effects are expected to be limited, it is possible to only run the simulation for a part of the simulation volume and use the data measured in the plane, to seed the simulation. In this work, the two areas of interest were the rear section and the trailer underbody. Therefore, two seeding planes where set up as shown below:

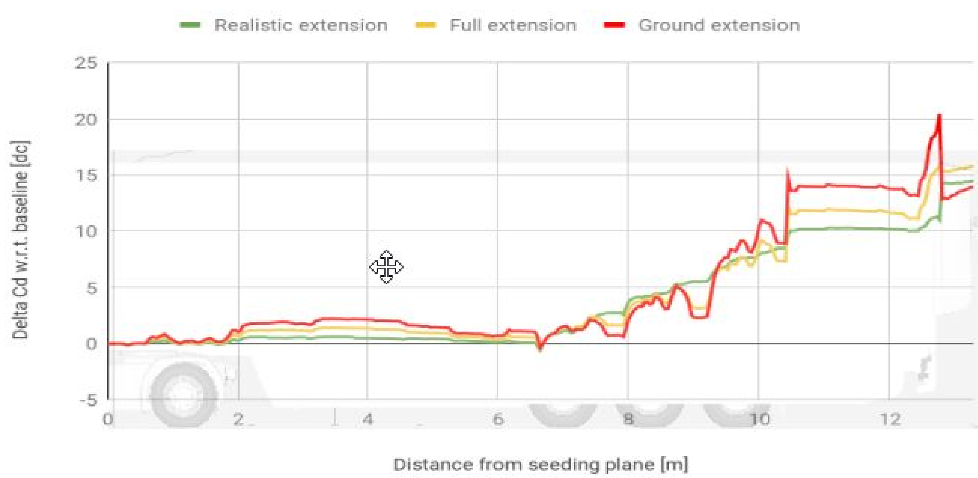
This means that for both areas of interest, the computationally intensive area of the tractor need not be simulated and a lot of simulation effort can be saved.

Results

Skirt extension

For the skirts, the CFD results showed that a realistic extension is able to provide almost the same savings as a complete extension. Both extensions perform better than the realistic extension, until the trailer backface, indicating a strong correlation between the underbody flow and the rear-end drag.

	Delta C_D @ -5° yaw [dc]
Baseline	-
Realistic extension	-15 dc
Full extension	-16 dc
Ground extension	-14 dc



Tail side panel extension

The side panel extension simulations showed no change for the shortest two distances, and an increasing trend with the largest two lengths.

Panel length [mm]	Delta C_D @ -5° yaw [dc]
1900	0
2300 (Baseline)	-
2700	-3
2900	-7

Top panel angle variations

The top panel variations resulted in small differences, and no coherent trends. More specifically, the 10° top panel performed better for 0° and 5° yaw, but worse for the 3° yaw case. Investigation of the forces on the panels and the backface show that there is a trade-off between induced drag of top panel and back pressure reduction.

Delta drag with baseline [dc]		**Yaw angle**		
		0	**-3**	**-5**
Top panel angle	8	-1	-	-1
	10	-2	3	-2
	12.5	0	0	0
	14	4	3	2
	16	4	-	5

Windtunnel

Setup windtunnel

As a part of the project, a windtunnel model of the geometry was tested in the FCA windtunnel in Turin [5]. The model was identical to the CFD setup, but at 33% scale. The windtunnel was operated at 50 m/s, leading to a width based Reynolds number of 3.0 x 10^6. The windtunnel model featured a moving belt, that was used to drive the rotating wheels. Wind tunnel boundary layer suction was applied. Some differences were presented between CFD and wind tunnel, as the wind tunnel model had larger wheels (+5% larger radius) and the tractor had a slightly larger pitch than in the CFD setup.

Results

Skirt extension

The full extension correlated very well with the CFD results, whereas the realistic extension showed large differences between CFD and wind tunnel. The CFD simulations showed very similar results for the realistic and full extension, whereas in the windtunnel the savings of the realistic extension were roughly 50% of that of the full extension. Possible causes for this can be the influence of the rockers as well as boundary layer development of the flow in case of the yawed rolling floor.

	Delta C_D @ -5° yaw [dc]	
	CFD	Windtunnel
Realistic extension	-15 dc	-8 dc
Full extension	-16 dc	-15 dc

Tail side panel extension

The results of the tail extension coincided well between CFD and wind tunnel, as shown below in:

	Delta C_D @ -5° yaw [dc]	
Panel length [mm]	Windtunnel	CFD
2300 (Baseline)	-	-
2700	-4	-3

Top panel angle variations

Due to construction constraints, it was not possible to exactly recreate the geometries simulated in CFD. The table below shows an overview of all the results obtained in CFD and wind tunnel. The trends and results are not coherent among CFD and wind tunnel results. Where the CFD results showed a small improvement for the 10 degree top panel at 0 and -5 degrees, this is not visible in the wind tunnel results.

Delta drag w.r.t baseline [dc]		**CFD**			**Windtunnel**		
		Yaw angle			**Yaw angle**		
		0	**-3**	**-5**	**0**	**-3**	**-5**
Top panel angle	8	-1	-	-1	-	-	-
	10	-2	3	-2	-	-	-
	10.5	-	-	-	1	-1	3
	12.5	0	0	0	0	0	0
	14	4	3	2	-	-	-
	14.5	-	-	-	2	1	1
	16	4	-	5	-	-	-
	16.5	-	-	-	3	-1	3
	18.5	-	-	-	4	-1	4

Conclusion

The realistic side skirt extension showed promising results in CFD which were not confirmed in the windtunnel. The full side skirt extensions showed significant improvements both in CFD and in the wind tunnel.

The tail side panel extension showed coherent results in both CFD and wind tunnel, with longer panels giving higher savings. For the top panel angle adjustments the results did not show clear trends both in CFD and wind tunnel. However, as the magnitude of changes are small using both methods it can conclude that the potential for improvement is limited.

Bibliography

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[5] https://saemobilus.sae.org/content/2018-37-0017/