Aerodynamic and Flexible Trucks for Next Generation of Long Distance Road Transport

EUROPEAN COMMISSION
Horizon 2020 | GV-09-2017 | Aerodynamic and Flexible Trucks
GA - 769658

Deliverable No.	AEROFLEX 6.5	
Deliverable Title	Demonstration testing results	
Deliverable Date	30/09/2021	
Deliverable Type	REPORT	
Dissemination level	Confidential – members only (CO)	
Written By	Àlex Freixas (IDIADA) Marc Soler (IDIADA) Abhishek Tomar (HAN) Ton Bertens (VEG)	29/09/2021
Checked by	Julius Engasser (MAN), Per Elofsson (SCANIA), Magnus Olbäck (VOLVO), Gertjan Koornneef (TNO) and Paul Mentink (TNO)	23/09/2021
Approved by	Ben Kraaijenhagen (MAN) – Coordinator	29/09/2021
Status	Final	30/09/2021

Document information

Additional author(s) and contributing partners

Name	Organisation
Karel Kural	HAN
Toni Fargas	IDIADA
Andreu Oltra	IDIADA

Publishable Executive Summary

The general objective of WP6 is to demonstrate, validate and analyse the feasibility of the AEROFLEX innovations. The innovations being part of WP6 are the WP2 distributed powertrain technology called Advanced Energy Management PowerTrain (AEMPT), WP3 advanced vehicle aerodynamics (AeroLoad) and WP4 Smart Loading Units (SLU).

Based on the measurement protocols and test matrix defined in the Deliverable 6.3, WP6 has carried out the indicated testing activities on vehicle demonstrators to obtain and evaluate the final results.

The second phase of the testing activities described in this report is performed on the following demonstrators and new baseline vehicles also called test cases:

Vehicle classification	Configuration	Name	Role
Demonstrators	  	EMS1 demonstrator AEMPT++ (6x2) EMS1 demonstrator Aeroload (6x2) EMS2 demonstrator Aeroload (4x2)	EMS1 and EMS2 demonstrator vehicles configurations developed on WP2 and WP3 of Aeroflex project.
New Baselines	  	EMS1 AEMPT New baseline (6x2) EMS1 Aeroload New Baseline (6x2) EMS2 Baseline (4x2)	Vehicle configurations added on the test matrix to provide more robustness of the results obtained and for comparison with the demonstrators.
Control vehicle		Control vehicle (4x2)	To obtain accurate fuel consumption results and be able to carry out a long testing campaign as defined in SAE protocols, the control vehicle has been included to identify possible deviation of the fuel consumption results caused by external conditions. Test use-cases 1 and 2.

According to the test programme, the following activities called test use-cases are carried out:

- Test use-case 1: Fuel consumption tests at steady-state speed on high-speed test track
- Test use-case 2: Fuel consumption tests on the public road, called Fraga route
- Test use-case 3: Air drag on test track
- Test use-case 4: Vehicle dynamics measurements on test track

The objective of the testing activities described above is to identify the demonstrator results on the following KPI's defined in Deliverable 6.1 to be compared to the first test phase results of reference vehicles:

- Fuel consumption efficiency
  - Fuel consumption [l/km] (Energy consumption)
  - Fuel consumption [l/tonne-km] (Energy efficiency)
  - Average vehicle speed [km/h]

- Aerodynamic efficiency
  - Drag coefficient by cross section area) reduction factor (CdxA)

- Safety standards
  - Startability
  - Gradeability
  - Acceleration capability
  - Low-speed swept path width
  - Tail swing
  - Static rollover threshold
  - Rearward amplification
  - Directional stability under braking
  - High-speed transient off-tracking (HSTO)
  - Yaw damping
  - 360° Circle

This final part of the testing campaign was focused on providing demonstrator and new baseline fuel consumption results. The following table shows the fuel consumption results for test use-cases 1 and 2 and the airdrag results for test use-case 3, taken as reference its specific new baseline vehicle configuration.

	TEST USE-CASE 1		TEST USE-CASE 2		TEST USE-CASE 3	
	Steady-state speed		Real route		Airdrag	
	50% load weight				Empty conditions	
	Result	Confidence interval	Result	Confidence interval	Result	Confidence interval
EMS1 AEMPT Baseline	--	--	Ref.1=0	1.9%	--	--
EMS1 AEMPT++ Demonstrator vs EMS1 AEMPT New baseline	--	--	**-3.5%**	1.2%	--	--
EMS1 AEROLOAD Baseline	Ref.2=0	2.0%	Ref.3=0	2.2%	Ref.4=0	1.3%
EMS1 AEROLOAD Demonstrator vs EMS1 AEROLOAD New baseline	**-8.0%**	1.4%	**-4.1%**	1.5%	**-9.0%**	2.1%
EMS2 AEROLOAD Baseline	Ref.5=0	--	--	--	--	--
EMS2 AEROLOAD Demonstrator vs EMS2 AEROLOAD Baseline	**-2.1%**	--	--	--	--	--

Table 1. Test use-cases 1, 2 and 3. Fuel consumption (l/100km) and airdrag (CdxA) final results

Due to the characteristics of test use-case 1, the electrical devices installed on EMS1 AEMPT++ did not provide any benefit regarding fuel consumption reduction, so it was decided not to evaluate their impact and focus on test use-case 2, obtaining the fuel consumption reduction indicated in the table above.

Due to safety limitations, EMS2 configuration was not tested on test use-case 2, and only one test was performed in each EMS2 vehicle configuration on test track so the results should be considered an estimation of future Aeroload potential on EMS2 vehicles.

The initial part of the test campaign was focused on providing baseline fuel consumption results in reference (advanced) vehicles. After the final test campaign on the demonstrators, it was possible to compare the vehicles defined in the test matrix. The following table shows the fuel consumption results obtained [l/100km], taken as reference the Zero-case vehicle tested in initial part of test campaign.

	TEST USE-CASE 1				TEST USE-CASE 2			
	Steady-state speed				Real route			
	50% Load Weight		GCW Weight		50% Load Weight		GCW Weight	
	Result	Confidence interval	Result	Confidence interval	Result	Confidence interval	Result	Confidence interval
Zero-case	Ref.1=0	0.6%	Ref.2=0	0.4%	Ref.3=0	0.8%	Ref.4=0	0.2%
Advanced Ref. vs Zero-case	**1.8%**	1.1%	**0.5%**	0.3%	**-5.0%**	2.5%	**-6.8%**	1.1%
EMS1 AEMPTT++ Baseline vs Zero-case	--	--	--	--	**44.5%**	2.1%	--	--
EMS1 AEMPT++ vs Zero-case	--	--	--	--	**39.4%**	1.7%	--	--
EMS2 Baseline vs Zero-case	**39.1%**	0.4%	--	--	--	--	--	--
EMS2 AEROLOAD vs Zero-case	**36.2%**	0.5%	--	--	--	--	--	--
Reference vs Zero-case	**-10.2%**	1.0%	**-11.1%**	1.0%	**-7.8%**	1.0%	**-11.8%**	0.3%
Advanced Ref. vs Zero-case	**-14.0%**	0.9%	**-17.6%**	0.4%	**-6.1%**	2.2%	**-13.9%**	1.1%
EMS1 AEROLOAD Baseline vs Zero-case	**20.8%**	1.5%	--	--	**34.5%**	0.8%	--	--
EMS1 AEROLOAD vs Zero-case	**11.1%**	1.1%	--	--	**28.9%**	0.8%	--	--

Table 2. Test use-case 1 and 2. Fuel consumption Zero-case comparative (l/100km)

After analysing the results obtained in each vehicle configuration (three runs for each test use-case 1 and 2 and load configuration), we consider that the repeatability and accuracy of the results fulfils the requirements of the project and provides a good comparative within demonstrators and reference vehicles.

To provide additional information of the influence of the vehicle payload on the fuel consumption results and as defined in the KPI's list, the evaluation and comparison of the results in l/tonne km obtained in each vehicle is detailed in the following table.

	TEST USE-CASE 1				TEST USE-CASE 2			
	Steady-state speed				Real route			
	50% Load Weight		GCW Weight		50% Load Weight		GCW Weight	
	Result	Confidence interval	Result	Confidence interval	Result	Confidence interval	Result	Confidence interval
Zero-case	Ref.1=0	0.6%	Ref.2=0	0.4%	Ref.3=0	0.8%	Ref.4=0	0.2%
Advanced Ref. vs Zero-case	**2,1%**	1.1%	**9,1%**	0.3%	**-4,8%**	2.5%	**1,3%**	1.1%
EMS1 AEMPTT++ Baseline vs Zero-case	--	--	--	--	**-5,6%**	2.1%	--	--
EMS1 AEMPT++ vs Zero-case	--	--	--	--	**-9,0%**	1.7%	--	--
EMS2 Baseline vs Zero-case	**-30,5%**	0.4%	--	--	--	--	--	--
EMS2 AEROLOAD vs Zero-case	**-31,9%**	0.5%	--	--	--	--	--	--
Reference vs Zero-case	**-10,2%**	1.0%	**-4,8%**	1.0%	**-7,7%**	1.0%	**-5,5%**	0.3%
Advanced Ref. vs Zero-case	**-13,6%**	0.9%	**1,0%**	0.4%	**-5,8%**	2.2%	**5,5%**	1.1%
EMS1 AEROLOAD Baseline vs Zero-case	**-23,3%**	1.5%	--	--	**-14,6%**	0.8%	--	--
EMS1 AEROLOAD vs Zero-case	**-29,5%**	1.1%	--	--	**-18,1%**	0.8%	--	--

Table 3. Test use-case 1 and 2. Fuel consumption Zero-case comparative (l/tonne km)

EMS1 and EMS2 vehicles have the greatest benefit when comparing consumption results in l/tonne km.

The aim of test use-case 3 is to measure the aerodynamic resistance of the vehicles by measuring the torque applied to the drive wheels at high and low speed and comparing them. During the test, the air velocity, its yaw angle and the vehicle speed are measured and considered in order to obtain a result of the influence of the wind on the vehicle.

The results of the following table are given as a percentage of variation from the average of the Zero-case and each one of the results of the different tests.

	TEST USE-CASE 3	
	Airdrag	
	Result	Confidence interval
Zero-case	Ref.1=0	0.07%
Adv. Ref. vs Zero-case	**-4.1%**	1.5%
Adv. Aero 1 vs MAN Zero-case	**-11.0%**	1.6%
Adv. Aero 2 vs MAN Zero-case	**-20.6%**	0.8%
Adv. Aero 3 vs MAN Zero-case	**-23.8%**	2.1%
EMS 1 AEROLOAD Baseline vs MAN Zero-case	**9.3%**	2.9%
EMS 1 AEROLOAD vs MAN Zero-case	**-0.5%**	2.3%

Table 4. Test use-case 3. Airdrag comparative (CdxA)

The improvements between the several advanced references and demonstrators are in line with what could be expected. At the same time, due to the EMS1 (6x2) vehicle characteristics, the airdrag results obtained are worse than the standard 4x2 + semitrailer configuration, but the aeroload devices implemented on EMS1 Aeroload vehicle reduced the negative impact of EMS1 vehicle characteristics.

The reference dynamic results are done on a EMS1 reference vehicle according to the Australian Performance Based Standards. The low- and high-speed KPI's are quantified for the respective manoeuvres in the clockwise and anti-clockwise direction. All the KPI's of the test vehicle are summarized below, which is the average of the performance achieved by the test vehicle in clockwise and anti-clockwise directions.

Key Performance Indicators	EMS1 Baseline		EMS1 Demo AEROLOAD		EMS1 Demo AEMPT++	
	Average Performance achieved	PBS level achieved	Average Performance achieved	PBS level achieved	Average Performance achieved	PBS level achieved
1. Startability, [% grade]	15	1	15	1	> 12	2
2. Gradeability-A, [% grade]	18	2	18	2	> 12	3
3. Gradeability-B, [km/h]	> 70	2	> 70	2	> 80	1
4. Acceleration capability, [s]	15.6	1	15.6	1	20.3	2
5. Directional stability under braking: (a) Average deceleration, [g] (b) Maximum lane-width, [m]	 0.47 2.9	 1 1	 0.47 2.9	 1 1	 0.58 2.76	 1 1
6. Frontal swing: (a) Maximum frontal swing (FS_{max}), [m] (b) Maximum of difference (MOD), [m]	 0.47 0.32	 Acceptable Acceptable	 0.47 0.31	 Acceptable Acceptable	 0.57 0.38	 Acceptable Acceptable
7. Tail swing at entry (TS_{entry}), [m]:	0.20	1	0.21	1	0.26	1
8. Low-speed swept path width (SPW): (a) 90 degree, [m] (b) 360 degree, [m]	 6.67 7.78	 1 Acceptable	 6.64 7.85	 1 Acceptable	 6.88 7.91	 1 Acceptable
9. Rearward amplification (RA), [-]	1.54	Acceptable	1.58	Acceptable	1.67	Acceptable
10. High-speed transient off-tracking ($HSTO$): (a) Overshoot, [m] (b) Undershoot, [m]	 0.09 -0.01	 1	 0.08 -0.03	 1	 0.07 -0.01	 1
11. Yaw damping coefficient (YD), [-]	0.37	Acceptable	0.34	Acceptable	0.39	Acceptable
12. Static rollover threshold (SRT), [g]	> 0.48	Acceptable	> 0.47	Acceptable	> 0.39	Acceptable

Table 5: Test use-case 4. Dynamic results

Sections 1 to 5 are directly taken from test data. Sections 6 to 12 are obtained by performing PBS tests (as per the specification) with the validated vehicle model for determining the KPI's final values.
PBS level are listed from 1 to 4, being Level 1 the best and Level 4 the worst. Most of the KPI's evaluated stay inside Level 1 and 2 and pass the criteria as acceptable where only a minimum value to reach is indicated.