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

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Publishable Executive Summary

As overall objective, AEROFLEX WP6 aims to define a suitable physical test protocol that concludes in energy efficiency and energy consumption results and a wide assessment framework which provides impact results of the developed technologies against the various logistic applications.

To accurately determine the improvement in fuel economy for the aerodynamic and distributed powertrain technological innovations and more effective loading space utilization, a test matrix and a test protocol have been defined to consider all of these innovations in a structured manner for different vehicle configurations and types of test. This test protocol for vehicles fuel consumption measurements is based on the SAE J1526-III protocol with some minor additions and is confirmed by the SAE Charmain, B. McAuliffe as suitable approach for evaluating the performance of the distributed powertrain and aerodynamic innovations. The air drag test protocol is an extension of the Commission Regulation (EU) 2017/2400.

The test program defined, include five different test use-cases being:

1. Fuel consumption tests at steady-state speed on test track
2. Fuel consumption tests on the public road
3. Air drag on test track
4. Vehicle dynamic measurement on test track and
5. Terminal loading tests at a customer's depot.

All these test use cases are included in a test matrix (Figure 1) that includes nine different vehicle configurations including tractor semi-trailers (16,5m) and European Modular System (EMS) configurations (both EMS1 of 25,25m and EMS2 of 32m).

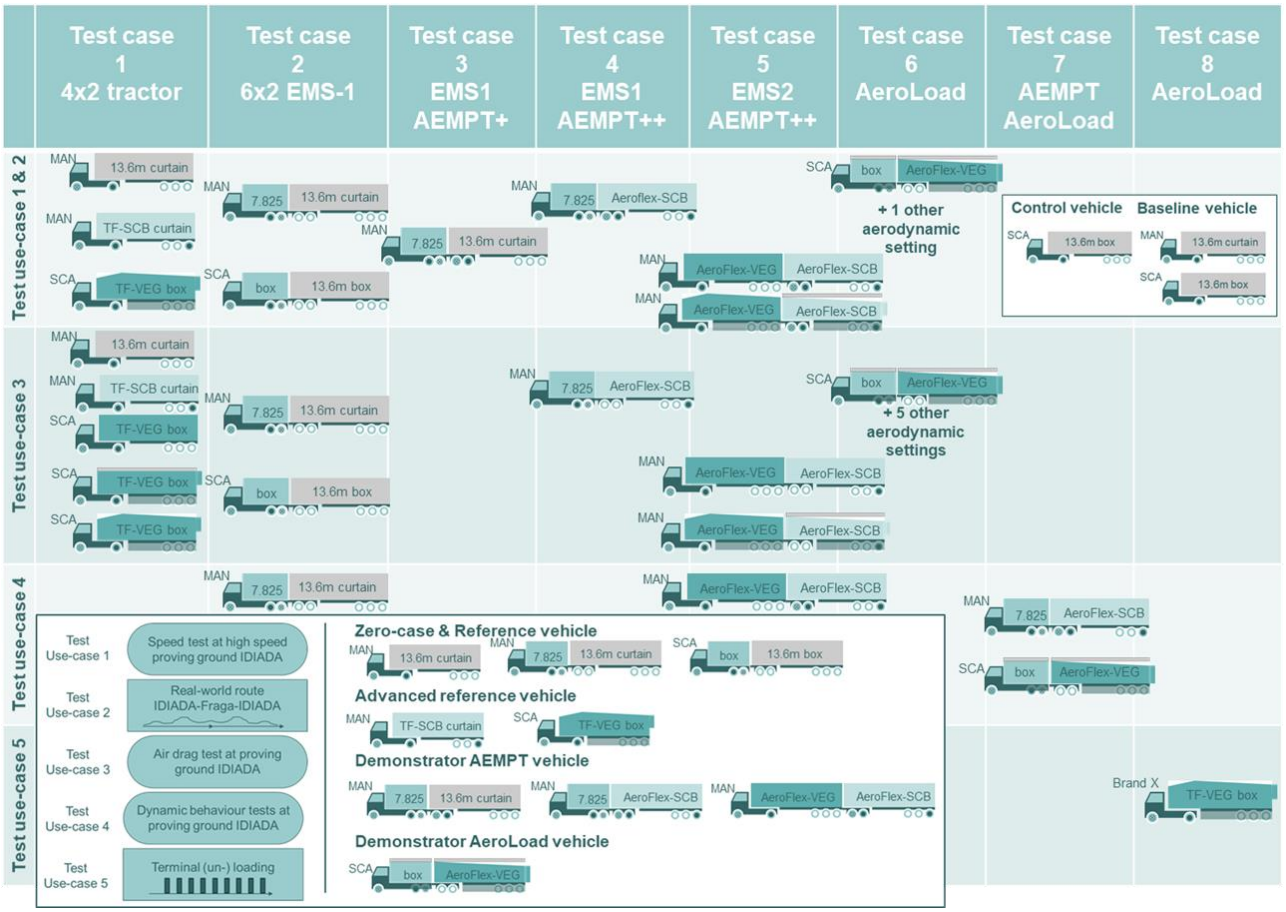

Figure 1. WP6 Test matrix with 8 test cases and 5 test use-cases. Four classes of vehicles are separated: 1) Reference vehicles including zero-case, 2) Advanced reference vehicles, 3) Demonstrator AEMPT vehicles and 4) Demonstrator AeroLoad vehicle

The smart selection of test cases and test use-cases has been made to deal with the trade-off between number of possible vehicle variations and number of repetitions for accurate and significant measurement results versus available test time, budget, equipment and resources. The objective is to evaluate the newly developed

technologies, concepts, and architectures within WP2, WP3 and WP4 and to demonstrate their impact under real conditions followed by a validation and an assessment of the application potential for these concepts in Europe.

Parts of this test protocol are the necessary vehicle preparations, the characteristics of the measurement equipment for each test use case, vehicle loading conditions for the three vehicle configurations, test tracks and specific external location to carry on the tests as real route and loading terminal.

Based on the results of this test program, the aim of WP6 is to execute a technical impact assessments by simulation to quantify the impact of the AEROFLEX innovations for various relevant logistic applications (as part of D6.6).

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List of Abbreviations

AEMPT: Advanced Energy Management Power Train
KPI: Key Performance Indicator
WP: Work Package
EMS: European Modular System
GCW: Gross Combination Weight
NCW: Net Combination Weight
HOD: Hybrid on Demand
CFD: Computational Fluid Dynamics
SOC: State Of Charge
CV: Control Vehicle
TF: Transformers
GETMS: Global Energy and Torque Management
EMG: Electric Motor Generator
GPS: Global Positioning System
DPF: Diesel Particulate Filter
ECU: Engine Control Unit
OBD: On Board Diagnosis
SCR: Selective Catalytic Reduction
PEMS: Portable Emissions Measurement System
VECTO: Vehicle Energy Consumption Calculation Tool
GRC: General Road circuit
HST: High Speed Track
DPA: Dynamic Platform
P&G: Procter & Gamble
WP: Work Package
NET: Net Energy Change

1 Purpose of the document

The overall objective of the 6.3 Test program and protocol deliverable is to evaluate the benefits of the different technologies developed in the WP 2, 3 and 4. To achieve this objective, first a list of assessment and measurement Key Performance Indicators (KPI's) are identified together with the different Work Packages (WP's).
This initial evaluation has allowed to clearly identify the objectives to evaluate each new technology and how to define the test matrix. These KPI's include fuel consumption, aerodynamics, performance based safety standards, and loading efficiency.

Once, the KPI's have been defined, preparations started for defining the final test matrix. The test matrix includes test-cases, which are groups of vehicles that consider the same innovations(s) for a given vehicle type. On the other hand, the test matrix contains test use-cases, which are the different type of tests. The test cases contain nine vehicle configurations which are classified as follows:

- Zero-case;
- Reference vehicles;
- Advanced reference vehicles
- Demonstrator vehicle of the AEMPT type
- Demonstrator vehicles of the AeroLoad type

The test use-cases contain:

- Fuel consumption tests at steady-state speed at proving ground;
- Fuel consumption test at a real-world route;
- Vehicles air drag measurements at proving ground
- Dynamic vehicle behaviour tests at proving ground
- Terminal (un-) loading tests at a customer's depot.

The definition of this test matrix allows us to determine an overview of vehicle comparisons necessary to understand for each vehicle category and KPI. This comparison focusses on the defined KPI's, e.g. fuel consumption, fuel efficiency, air drag reduction, loading and unloading performance as well as performance-based safety standards.

The definition of the test protocol deals with the difficulty to evaluate the different vehicle configurations during a long period of two test years. For this reason, the test protocol includes the necessary tools to control the results obtained and evaluate the benefits of each technology without interferences of external influences, like ambient conditions.
The testing activities will be carried out in IDIADA's test track (fuel consumption test at steady-state speed, air drag and dynamic tests) and surroundings for the fuel consumption on public roadway.
The terminal (un-) loading evaluations will be carried out at P&G facilities.

The data will be provided in a standardized format that can be easily used by each partner to do its own calculations and data post processing.

2 Introduction

A specific test matrix and test programme has been defined to align the interests of each WP and the budget allocated to the testing activities. The WP needs has been identified and explained in the deliverable 6.1 Definition of use cases/test cases and the overall KPIs and the information extracted from that deliverable has been essential for the development of to the test programme and protocol.

The KPI's defined in the deliverable 6.1 used to determine the test matrix and test programme are the following:

Fuel consumption efficiency

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

Aerodynamic efficiency

- Air drag reduction factor [-]

Loading efficiency

- Fill speed [minutes]
- Payload capacity [tonnes]
- Load factor [Volume-%]

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 offtracking (HSTO)
- Yaw damping
- 360º Circle

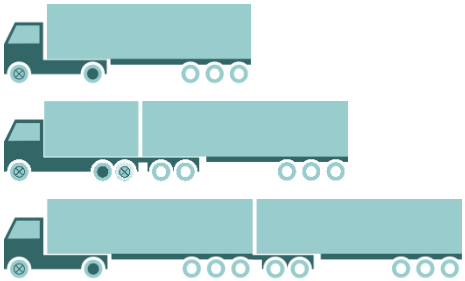
3 Test matrix

Important part of the test program is the test matrix. This chapter describes in detail the combinations of test cases (containing different vehicle configurations) and test use-cases (types of tests), as main dimensions of the test matrix, supplemented with the specifications of these so-called third dimensions, like payload and aerodynamic settings. The Chapter starts with an introduction to the test matrix (Section 3.1) explaining the different dimensions of the test matrix, followed by the test-cases in Section **Error! Reference source not found.** and the test use-cases in Section **Error! Reference source not found.**. Moreover, this Chapter provides an overview of the comparisons to be made, which besides others are applied in the final assessment D6.6 (Section **Error! Reference source not found.**). Finally, deviations from the initial test matrix as part of the Grant Agreement are listed in Section **Error! Reference source not found.**, including its reasoning behind.

3.1 Introduction to the test matrix

It is important to determine accurately the improvement on fuel economy for the different technological innovations towards improved aerodynamics, distributed powertrains and more effective loading space utilization. So, the test matrix considers all of these innovations in a structured manner for different vehicle types and types of tests.

The test matrix contains three vehicle types:



Tractor semi-trailer (16.5m)

EMS1 (25.25m)
(European Modular System)

EMS2 (32m)
(European Modular System)

For each vehicle type, different topologies are possible that demonstrate the innovations. The different vehicles that consider the same innovation(s) for a given vehicle type, are grouped in a so-called test-case. Within a test-case, more than one demonstrator could be tested. That is why the actual number of vehicles tested exceeds the number of test-cases. Additionally each vehicle configuration will need specific type of tests (test use-case).
To limit the number of tests however, usually one vehicle is tested per test use-case. Also to limit the size of the test matrix, not all vehicles are subject to the same number of tests. A smart selection of test-cases and test use-cases is made to deal with the trade-off between number of possible vehicle variations and number of repetitions for accurate and significant measurement results versus available test time, budget, equipment and resources.

The complete test matrix is given in **Error! Reference source not found.** at the end of this Section on page **Error! Bookmark not defined.** and is explained in detail in the successive Sections. It contains of eight test-cases using nine different vehicle configurations and five test use-cases. The test use-cases are listed in Table 1 and each links to a particular KPI category. The test use-cases 1 and 2, which relates to the fuel consumption efficiency KPI category, are executed both on test track and public road. Only test use-case 5 will not be tested at IDIADA premises, but will be executed at the premises of a client of Van Eck Group.

Test use-case	Focus of test	Location	KPI
1.	Fuel consumption and emissions	Proving ground of IDIADA	Fuel consumption efficiency
2.		Public road close to IDIADA	
3.	Air drag	Proving ground of IDIADA	Aerodynamic efficiency
4.	Dynamic vehicle behaviour	Proving ground of IDIADA	Safety standards
5.	Loading and unloading of cargo	Loading dock	Loading efficiency

Table 1. Overview of the test use-cases as part of the test matrix and connected to a particular KPI

The test-cases are listed in Table 2 and are classified as:

- Zero-case vehicle;
- Reference vehicles;
- Advanced reference vehicles;
- Demonstrator vehicles.

For simplicity, this table does not include all different topology and innovation settings. These are covered in the successive sections as well as the complete test matrix (**Error! Reference source not found.**).

	Vehicle classification	Configuration	Name	Part of test-case
0.	Zero-case vehicle		MAN zero-case	1
1.	Reference vehicles		MAN EMS1 reference	2
2.			SCANIA EMS1 reference	2
3.	Advanced reference vehicles		Advanced reference AEMPT	1
4.			Advanced reference AeroLoad	1
5.	AEMPT demonstrator vehicles		AEMPT+ EMS1	3
6.			AEMPT++ EMS1	4 and 7
7.			AEMPT++ EMS2	5
8.	AeroLoad demonstrator vehicle		AeroLoad EMS1	6, 7 and 8

Table 2. Overview of the test-cases as part of the test matrix

The zero-case classification represents the current on-road state-of-the-art with high market sales volume in the EU of the tractor semi-trailer configuration. The reference vehicles are the 25.25m combinations (EMS1) treated as references for the Advanced Energy Management PowerTrain (AEMPT) and AeroLoad demonstrator vehicles. These demonstrators are also of the EMS1 type (except for the additional EMS2 AEMPT demonstrator). The advanced reference vehicles contain of tractor semi-trailer vehicles using the following EU TRANSFORMERS demonstrator trailers:

- Schmitz Cargo Bull (SCB) TRANSFORMERS (TF) Hybrid-on-Demand trailer (HOD)
- Van Eck Group (VEG) TF trailer.

Both semi-trailers have advanced aerodynamics and are visible in Figure 2.
Detailed specifications of the semi-trailers is given in Appendix B.

Figure 2. EU Transformers vehicle on the Swedish public road, left Schmitz Cargo Bull semi-trailer, right Van Eck Group semi-trailer [Source: TRANSFORMERS-D6.4-Final report and Conclusions-PU-FINAL-2017.09.28]

The AEROFLEX demonstrator vehicles are logically grouped in the demonstrator vehicles classification and contain of EMS1 and EMS2 configurations. The AEMPT demonstrator is always configured with a MAN pulling unit, whereas the AeroLoad demonstrator is pulled with a SCANIA unit. This is done, since MAN is involved in the AEMPT developments and SCANIA in the AeroLoad developments. To avoid influences of differences in powertrain controls between brands on the results, the advanced reference pulling units are aligned accordingly. This means that the TF-SCB with HOD is pulled by a MAN tractor unit and the TF-VEG trailer by a SCANIA tractor. Consequence is, that these advanced reference vehicles actually are not the TF demonstrators anymore, because back than DAF and VOLVO pulling units were involved (see Figure 2). Though, for accurate comparisons of the AEROFLEX demonstrators with the advanced references, exclusion of difference between brands is decided to be much more important. Additionally, no concessions are necessary on the tractor semi-trailer interaction, because the AEROFLEX pulling units are equipped with similar aerodynamic devices like in Transformers and the same HOD control functionality is present in the MAN tractor driving with the TF-SCB trailer. Detailed descriptions of both these vehicle configurations are given in Section **Error! Reference source not found.**.

Beside the type of tests and vehicle configurations, other properties (“third dimensions”) have to be specified like payload and aerodynamic settings. Additionally in case of distributed powertrains also State Of Charge (SOC) related settings have to be specified. Since in particular this topic is linked to the fuel consumption measurement protocol it is described in Chapter **Error! Reference source not found.**.Payloads and aerodynamic settings are described in detail in the next Section. Chapter **Error! Reference source not found.** Measurement equipment and protocols, describes in detail the applied methodology to conduct representative and accurate measurements for the individual test use-cases.

The test-case categorization is made to distinguish between tractor semi-trailers at one and the EMS1/EMS2 vehicles at the other end. The latter is splitted further into EMS1 reference vehicles, containing of current on-road rigid trucks, dollies and semi-trailers and the demonstrators, each in its own test-case. Only, test-cases 7 and 8 contain of vehicle configurations originating from test-case 3 (AEMPT) and test-case 6 (AeroLoad). The three AEMPT test-cases (3-5) contain two levels of rated electric propulsion power (test-cases 3 and 4), indicated with the + and ++ signs in Table 2 originating from either the E-dolly (+) supplemented with E-trailer (++) and EMS2 in test-case 5 only with E- dolly and single E-trailer (++).

By conducting the tests according to the test matrix, the following goals are served:

- Quantification of the KPI's for the different test-cases at the corresponding test use-cases, allowing for the comparison with the set KPI targets;
- Providing input for the WP6 final technical assessment to validate the models:
    - Vehicles air drag.
    - Vehicles rolling resistance.
    - Fuel consumption.
- Demonstrate that 4x2 tractors or 6x2 trucks with 13l engines can deal with a broader vehicle portfolio, like EMS1 (European Modular System, configuration 1 containing of 25.25m vehicle with a 6x2 rigid truck – dolly – semi-trailer) and EMS2 (32m vehicle with a 4x2 tractor – semi-trailer – dolly – semi-trailer), if equipped with distributed powertrain and advanced aerodynamics, compared to current situation.