Low Carbon HGVs - Technology Testing Study

Final Report

by B Robinson (TRL) & L Kennedy (Millbrook)

FLD401P

CLIENT PROJECT REPORT

Transport Research Laboratory

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	Low Carbon HGVs - Technology Testing Study
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	Name	Date Approved
Project Manager	Mike Ainge	03/09/2010
Technical Referee	Marcus Jones	03/09/2010

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Executive summary

With HGVs accounting for about 20 per cent of the UK's domestic transport emissions, the DfT is eager to support and encourage the decarbonisation of freight and logistics movements. Central to this aim is the assessment of new technologies.

This project (carried out on behalf of the Low Carbon Vehicle Partnership, Commercial Vehicle Steering Group, supported by DfT) is one of an initial group of five inter-related projects aimed at assessing and developing the market for low carbon HGV (LCHGV) technologies. Four organisations (TRL/Millbrook, Ricardo and AEA), between them, led these projects, while working in close collaboration and co-operation with each other under the guidance and assistance of the Low Carbon Vehicle Partnership (LowCVP).

This project was agreed at the outset to involve three major tasks;

Task 1: Profiling and recruitment of participant companies: Use of established industry contacts to engage with interested parties to secure HGV operator involvement in the practical trials;

Task 2: Recommendation and procurement of low carbon technologies: Use of a combination of previous research for DfT and our own expertise/experiences to select a sample of appropriate technologies for evaluation in the practical trials.

Task 3: Practical evaluation of low carbon technologies: Practical testing of low carbon technologies on a range of vehicles using both test track and chassis dynamometer measurements.

This report summarises the work carried out under each of these task headings, with a particular focus on the development of a series of test cycles which could be used in simulated real world conditions and successfully differentiate between various fuel saving technologies on heavy duty vehicles. It also summarises what percentage changes could be confidently measured within given constraints of track, time and vehicle availability and cost.

In total, five vehicles and eight different technologies were assessed. Most of the testing was using the high speed, city and hill circuits of the Millbrook test track, alongside coastdown tests and some chassis dynamometer trials.

The series of track and chassis dynamometer testing described in this report has shown that;

- Track testing can be carried out in a highly controllable and repeatable manner;
- Statistically significant fuel savings can be detected, though not all the technologies tested gave such savings;
- Track testing is considered to be more time- and cost-effective than chassis dynamometer trials (which rely on some track testing anyway), particularly for large vehicles and technologies affecting aerodynamic drag and/or rolling resistance;
- Track testing may be cheaper but may not be as robust for absolute values as dynamometer testing and is very weather dependent. Dynamometer testing can also assess tailpipe emissions much more readily than is feasible with track testing;
- Results from both dynamometer and track testing are highly dependent on the cycles driven/simulated, but a limited programme of chassis dynamometer tests showed reasonable correlation with the equivalent track tests;
- Consideration of both payload mass and volume should be made in defining targets/metrics for carbon saving, but the choice of which may be highly operator dependent;

- Measured fuel savings or consumption increases were generally too small to be statistically significant for the technology combinations assessed (profiled trailer, side skirts and reduced tyre pressures);
- Technologies may be effectively compared using back-back tests or against a robust baseline/comparator. However, whole vehicle absolute targets will require additional testing to determine accurate fuel consumption;
- To be meaningful, carbon emissions have to be assessed over the full supply chain, i.e. well-to-wheel. The carbon content of alternative fuels and energy supply options, e.g. electric vehicles, thus need to be assessed in different ways (especially well-to-tank, or "mine to battery") to conventional (tank-to-wheel) style fuel consumption analyses.

1 Introduction

With the Climate Change Act of 2008 and its setting of progressively tightening carbon budgets to achieve an 80% overall emissions reduction from 1990 levels by 2050, action across Government is being taken forward to identify and implement cost effective carbon reduction measures, as set out in the *UK Low Carbon Transition Plan* published in July 2009 and, more recently, the Coalition's *Programme for Government*. With HGVs accounting for about 20 per cent of the UK's domestic transport emissions, the DfT is eager to support and encourage the decarbonisation of freight and logistics movements. Central to this aim is the assessment of new technologies.

1.1 Project objectives

This study (carried out on behalf of the Low Carbon Vehicle Partnership, Commercial Vehicle Steering Group, supported by DfT) will help inform the Government's carbon reduction strategy for transport in relation to the potential for decarbonisation of road freight and logistics movements. The objective is to provide robust measurement data to refine the Government's evidence base to confirm the cost-benefit of any potential future large capital investment scheme for low carbon technologies for use on HGVs.

This project (carried out on behalf of the Low Carbon Vehicle Partnership, Commercial Vehicle Steering Group, supported by DfT) is one of an initial group of five inter-related projects aimed at assessing and developing the market for low carbon HGV (LCHGV) technologies. Four organisations (TRL/Millbrook, Ricardo and AEA), between them, led these projects, while working in close collaboration and co-operation with each other under the guidance and assistance of the Low Carbon Vehicle Partnership (LowCVP).

1.2 Tasks and Methodology

This project was agreed at the outset to involve three major tasks;

Task 1: Profiling and recruitment of participant companies: Use of established industry contacts to engage with interested parties to secure HGV operator involvement in the practical trials;

Task 2: Recommendation and procurement of low carbon technologies: Use of a combination of previous research for DfT and our own expertise/experiences to select a sample of appropriate technologies for evaluation in the practical trials.

Task 3: Practical evaluation of low carbon technologies: Practical testing of low carbon technologies on a range of vehicles using both test track and chassis dynamometer measurements.

This report summarises the work carried out under each of these task headings, with a particular focus on the development of a series of test cycles which could be used in simulated real world conditions and successfully differentiate between various fuel saving technologies on heavy duty vehicles. It also summarises what percentage changes could be confidently measured within given constraints of track, time and vehicle availability and cost.

2 Vehicle and technology selection

2.1 Vehicles tested

The selection of the vehicles used in the test programme was chosen firstly based upon their use in the real world market. The use of specialised or limited production vehicles would only represent a small corner of the market and may make some of the technologies tested unfit for purpose when looked at with real world applications in mind. Secondly the vehicles selected would have to offer different axle set ups, engines, drivelines, configurations, and maximum loading options, allowing test results to be representative of a larger market share.

The vehicles used (selected from those offered to us by members of the Freight Transport Association, FTA, and rental companies) consisted of two 6x2 tri-axle tractor units, one 4x2 two axle tractor unit and one 4x2 rigid box truck 18,000kg GVW unit. A 10/12 tonne box van plug-in Electric Vehicle (EV) was also assessed.

2.2 Technologies tested

The selection of technologies for testing was based on a combination of factors:

1. The overall population of possible technologies was defined by the Technology Road Map produced by Ricardo as the output of the first of the five inter-related projects.
2. The use of each technology in the current market, those which freight companies were currently spending money on implementing taking priority. Members of the FTA were consulted for their opinion on this; they advised on what they were using and what they would like to see undergo testing.
3. Technologies which claimed to affect different aspects of vehicle dynamics and operation in order to gain a net fuel consumption saving – this served to give a more broad understanding on how robust the test procedures could be, rather than, for example, looking only at aerodynamic aids. Weight savings and claimed reductions in rolling resistance were also investigated.
4. Future technologies where available - testing of a plug in electric truck over various drive cycles was conducted on a chassis dynamometer.
5. Availability of each technology was a limiting factor in the programme. Due to a limited budget and the necessity to loan various equipment there were certain technologies which were unavailable for testing, which could have helped further evaluate the robust nature of the procedure, most notably the lack of hybrid trucks being made available for test. The final technologies were decided upon following discussion and agreement with the Commercial Vehicle Steering Group (CVSG) of the Low Carbon Vehicle Partnership (Low CVP).

2.2.1 Aerodynamic aids

2.2.1.1 Cab deflectors

Cab deflectors are aerodynamic aids fitted to the roof of a heavy duty tractor unit. The purpose of a cab deflector is to angle air flow over the trailer being towed by a vehicle, creating a more streamlined shape, reducing turbulence and consequently aerodynamic drag. A DAF CF85.430 tractor unit towing a standard box semi-trailer was used to investigate the effect of cab deflectors on vehicle fuel consumption.

2.2.1.2 Profiled trailer

A profiled trailer is designed to perform the same function as a standard box trailer but with improved air flow over the whole trailer. The profiled shape, in theory, would reduce turbulent air at the front and in the wake of the trailer consequently reducing overall drag. A Mercedes Actros B2544 tractor was used to tow the profiled semi-trailer, to investigate its effect on vehicle fuel consumption. The peak height from the ground of the profiled trailer was 4.5m, compared to the standard trailer's 4.1m.

2.2.1.3 Trailer side skirts

Trailer side skirts are aerodynamic aids fitted along both sides of a heavy duty trailer. They are intended to streamline the air flow along the sides of vehicle, limiting the flow creating turbulence underneath the trailer and around the wheels. Reducing turbulence in these areas would inevitably reduce the aerodynamic drag experienced by a vehicle. The Mercedes Actros B2544 tractor unit towing the profiled semi-trailer was used to investigate the effect of trailer side skirts on vehicle fuel consumption.

2.2.1.4 Double deck trailer

Although not an aerodynamic aid, double deck trailers are designed to increase the loading capacity of a vehicle (providing the goods being carried are of an acceptable weight). The increased size of the trailer would undoubtedly have an effect on vehicle dynamics, so testing this technology allowed for the extent of this effect to be quantified. The Mercedes Actros B2544 tractor unit was used to tow a double deck semi-trailer, and a single deck trailer for comparison of fuel consumption. When coupled to the same tractor unit, the front edge of the double deck trailer roof was 5.1m from the ground, while the single deck trailer stood 4.1m from the ground.

2.2.2 Tyre Dynamics

2.2.2.1 Low rolling resistance tyres

Low rolling resistance tyres have been developed by various tyre manufacturers for both light and heavy duty applications. The tread pattern, direction, and depth are all designed with the goal of reducing the rolling resistance of the vehicle. A reduction in rolling resistance would reduce the force required to propel the vehicle by a constant offset, regardless of speed. A Scania R420 tractor unit towing a standard box trailer was used to investigate the effect of low rolling resistance tyres on vehicle fuel consumption.

2.2.2.2 Reduced tyre pressures

Many heavy duty vehicles use tyre pressure monitoring equipment, not only as a safety feature but also due to concerns that tyre pressures can affect vehicle fuel consumption. By lowering a vehicle's tyre pressures, the area in contact with the road is increased along with rolling resistance. For the purposes of testing, tyre pressures on all axles of a tractor unit and trailer were reduced by 25% of those recommended by the manufacturer. A Mercedes Actros B2544 tractor unit towing a profiled trailer was used to investigate the effect of reduced tyre pressures on vehicle fuel consumption.

2.2.3 Weight saving

It is well known that the mass of a vehicle has an effect on its fuel consumption. Testing was carried out to investigate the fuel consumption performance of an 18 tonne rigid truck when ballasted to 17,662kg and 16,484kg (the 1,178 kg saving is equivalent to 6.7%). A Scania P230 rigid body truck was used to investigate the effect of weight reduction on vehicle fuel consumption.

2.2.4 *Plug-in electric vehicle*

Plug in, fully electric vehicles eliminate the necessity to consume fossil fuel onboard a vehicle. By using batteries and electric motors to propel the vehicle it is possible to recharge using any 3-phase electricity supply. Although often described as 'zero carbon' vehicles, in reality there is an indirect impact on carbon emissions in the production of the necessary electricity – for the purposes of this trial the CO_2 emission equivalence of the electricity used in charging was taken from the latest official DEFRA figures (greenhouse gas reporting guidelines, 2009), which give a rolling average CO_2-equivalent intensity of electricity consumed of 0.62 $kgCO_2e$/KWh.

For this vehicle, there was no equivalent non-electric vehicle available as a comparator. Its CO_2 emissions are thus compared to published fuel consumption data for similarly sized vehicles (10/12 tonne box vans), to give a broad initial indication of whether or not the electric vehicle assessed has the potential to be categorised as "low carbon". The vehicle as tested weighed 8,144 kg. It should be noted, however, that the latest DEFRA figures[1], used to calculate the carbon intensity of the electricity used to charge the EV's battery, are based on the UK electricity generation grid mix between 2004 and 2008. In time, this intensity is likely to reduce, e.g. as more renewable sources are used.

2.2.5 *Technology combinations*

An important aspect in the assessment of the overall fuel economy and emissions performance of an HGV is the extent to which combinations of different technologies fitted to the same vehicle interact with each other. A full assessment of all the possible combinations of the above technologies was not possible within the constraints of the project, though the tested combinations of profiled trailer and side skirts, and profiled trailer and reduced tyre pressures (both with cab deflector), were intended to provide some initial indication of the propensity for certain technology combinations to interact, favourably or adversely.

2.2.6 *Summary*

Table 2-1 summarises the technologies tested, either individually or in combination.

Table 2-1. Summary of technologies and technology combinations tested

	Test Condition														
	1		2		3		4		5		6		7		8
With technology (a)/without (b)	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a
Vehicle															
2 axle tractor unit	✓	✓													
3 axle tractor unit A			✓	✓	✓	✓	✓	✓			✓	✓			
3 axle tractor unit B									✓	✓					
18t Rigid box													✓	✓	
10/12t Rigid box															✓
Standard box semi-trailer	✓	✓		✓				✓	✓	✓					
Technology															
Cab deflectors (various designs)	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Profiled trailer			✓		✓	✓					✓	✓			
Trailer side-skirts			✓		✓		✓				✓	✓			
Double deck trailer							✓								
Low rolling resistance tyres									✓						
Reduced tyre pressures											✓				
Weight saving													✓		
Plug-in electric vehicle															✓

[1] http://www.defra.gov.uk/environment/business/reporting/pdf/100805-guidelines-ghg-conversion-factors.pdf

3 Test methodologies

3.1 Track testing

Each test cycle on the track was conducted multiple times in each condition resulting in a greater confidence in the data set generated. Outlying cycle results due to driver error, vehicle malfunction, and traffic obstructions were removed whilst still leaving a large enough sample of data to carry out a thorough statistical analysis. A high level of repeatability was observed in all test cycles, whilst the use of a control vehicle throughout the programme allowed for the effects of external variables between two different days (i.e. weather) to be quantified and used in the assessment of the fuel consumption reduction technologies under test. Because all the testing was carried out at a single location (Millbrook), no assessment of the reproducibility of results between different test tracks was possible within the constraints of this project.

3.1.1 High speed steady state route

The steady state test cycle was developed in order to represent long range motorway usage. Many fleets of heavy duty vehicles spend the majority of their operational time on motorways, operating at a constant speed. This cycle would test the high speed performance of a potential fuel consumption improving technology using two speed points (Vmax and 70km/h), staying at each for a prolonged period of time. An example of the procedure followed by test drivers for this cycle is presented in Annex A. Figure 1 shows a satellite image of the banked circular test circuit.

Figure 1. Millbrook high speed steady state route (circle diameter c. 1km)

Figure 2 shows an example of the speed vs time trace for this test, and the high degree of repeatability achieved between laps.

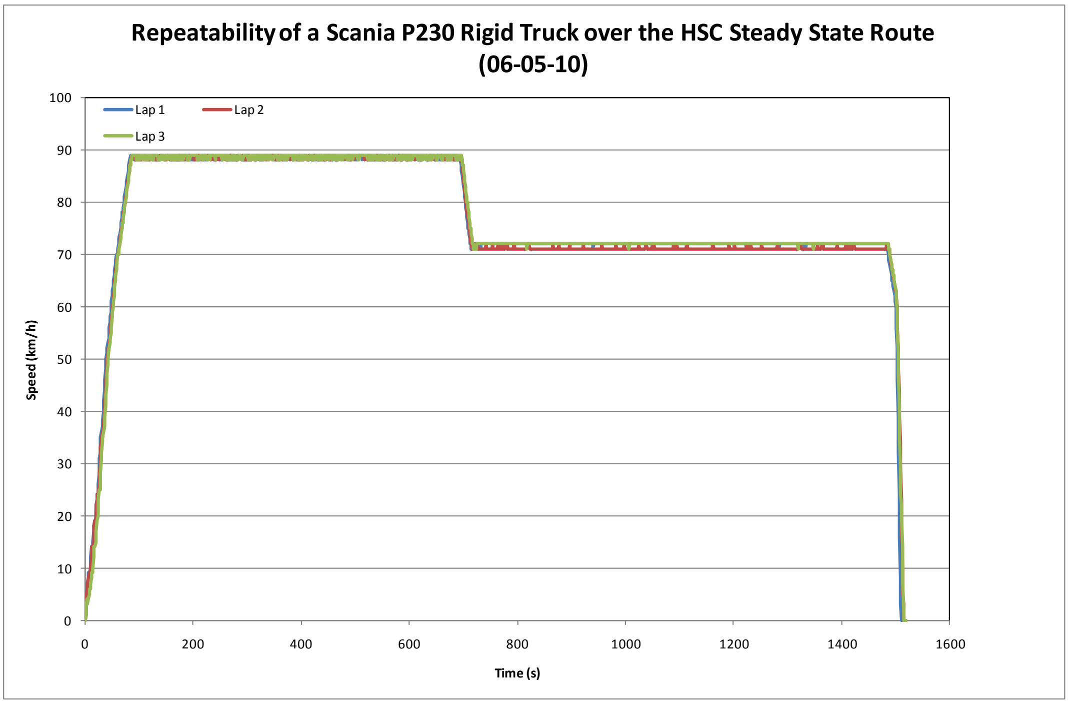

Figure 2. Examples of high speed steady state track testing cycle

3.1.2 High speed transient route

The transient test cycle was developed in order to represent motorway driving during busy periods of traffic and on various stretches of road where the speed is reduced for prolonged distances. This cycle would test a potential fuel consumption improving technology using high speed acceleration and deceleration tasks with steady state periods in between. An example of the procedure followed for this cycle can be seen in Annex A. This route uses the high speed circuit described above.

Figure 3 shows an example of the speed vs time trace for this test, and the high degree of repeatability achieved between laps.

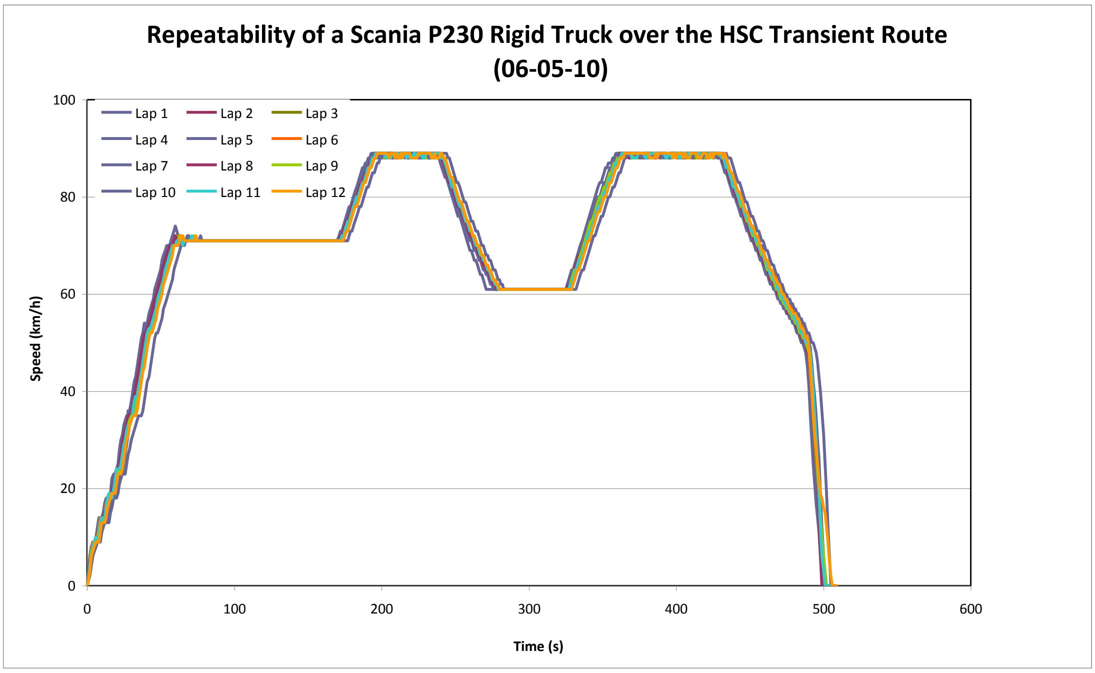

Figure 3. Examples of high speed transient track testing cycle

3.1.3 Hill Route

The hill route cycle was developed in order to represent the suburban A and B road driving of heavy duty vehicles. This cycle would test a potential fuel consumption improving technology using periods of acceleration and deceleration as well as changing gradients (7.6% and 11.6% being the two most extreme used). An example of the procedure followed for this cycle can be seen in Annex A. Figure 4 shows a satellite image of the hill route circuit.

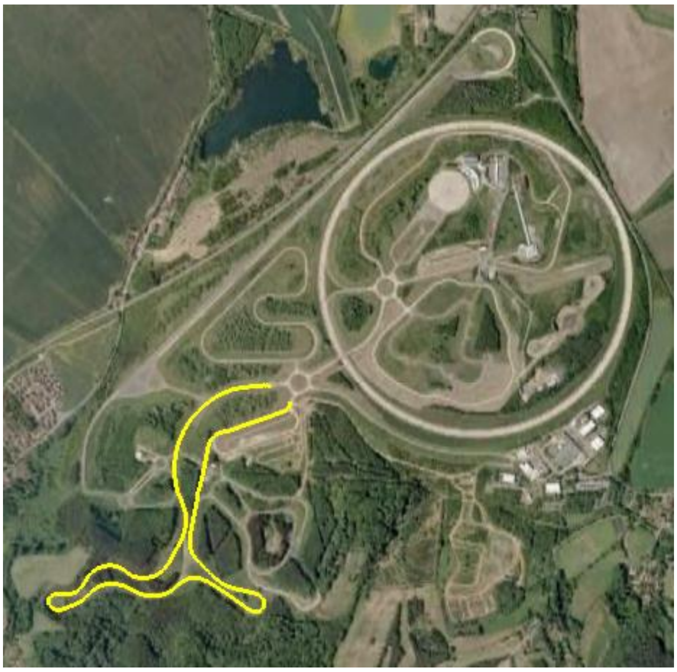

Figure 4. Millbrook hill route circuit

Figure 5 shows an example of the speed vs time trace for this test, and the high degree of repeatability achieved between laps.

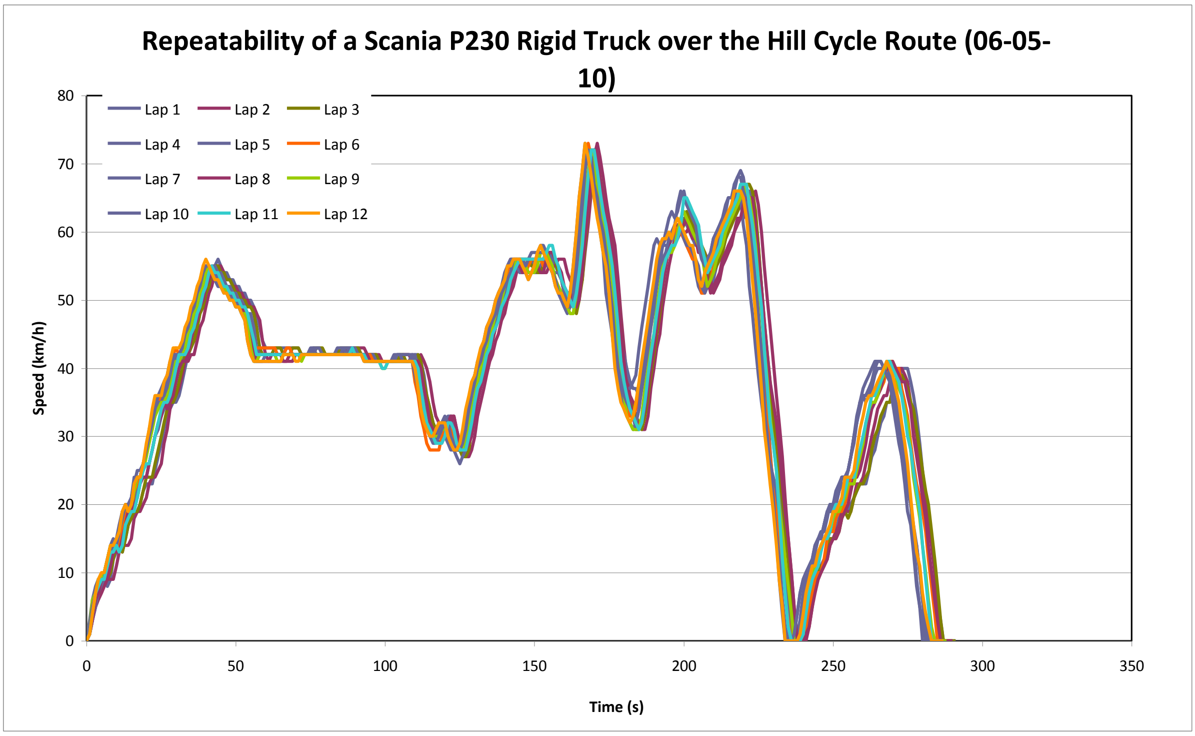

Figure 5. Examples of hill route track testing cycle

3.1.4 City Route

The city route cycle was developed in order to represent the urban operation of heavy duty vehicles. This cycle would test a potential fuel consumption improving technology using start / stop low speed operation which would be seen by vehicles operating in a congested environment and making deliveries in towns and cities. An example of the procedure followed for this cycle can be seen in Annex A. Figure 6 shows a satellite image of the city route circuit.

Figure 6. Millbrook city route circuit

Figure 7 shows an example of the speed vs time trace for this test, and the high degree of repeatability achieved between laps.

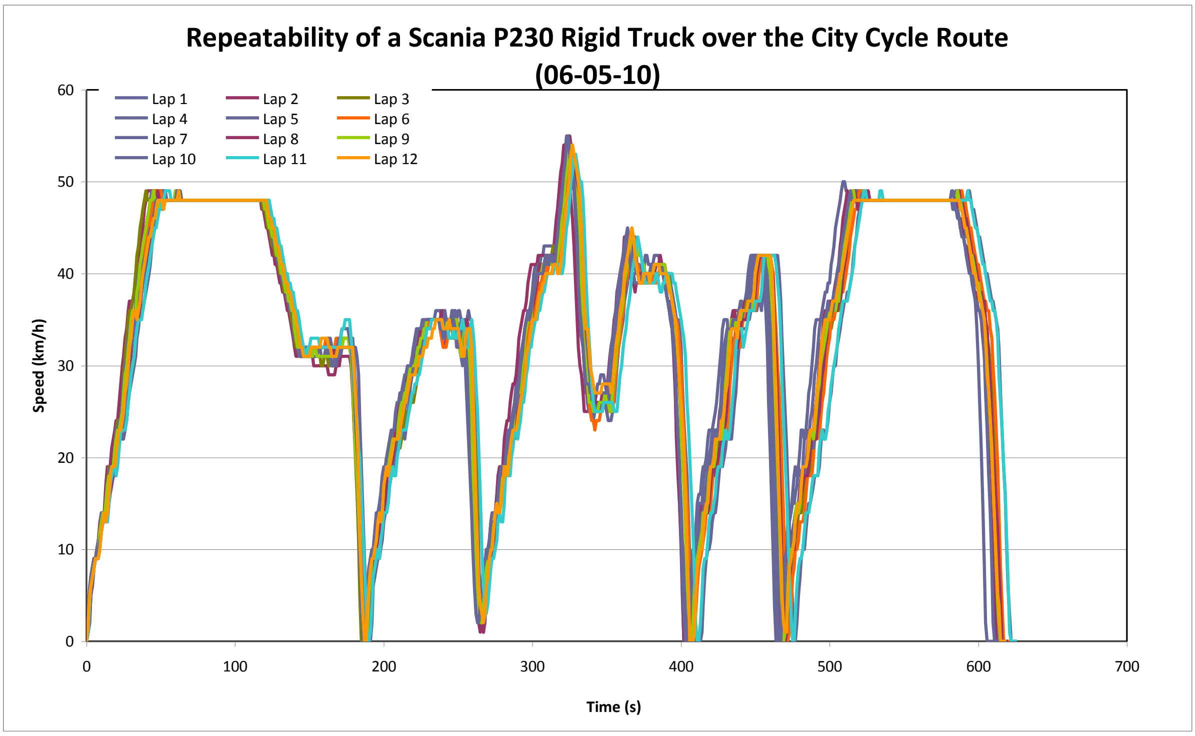

Figure 7. Examples of city route track testing cycle

3.1.5 *Use of reference vehicle*

To allow for any variations in ambient weather and track conditions during the track tests (carried out over a period of about three weeks), a reference vehicle (the 18 tonne 4x2 rigid box truck) was put through each track test cycle each day. The data from each day's reference vehicle test was then used to normalise the data measured from the test vehicles on those days. Figure 8 shows the consistency of the reference vehicle's fuel consumption over the period of the trials in all four track test cycles.

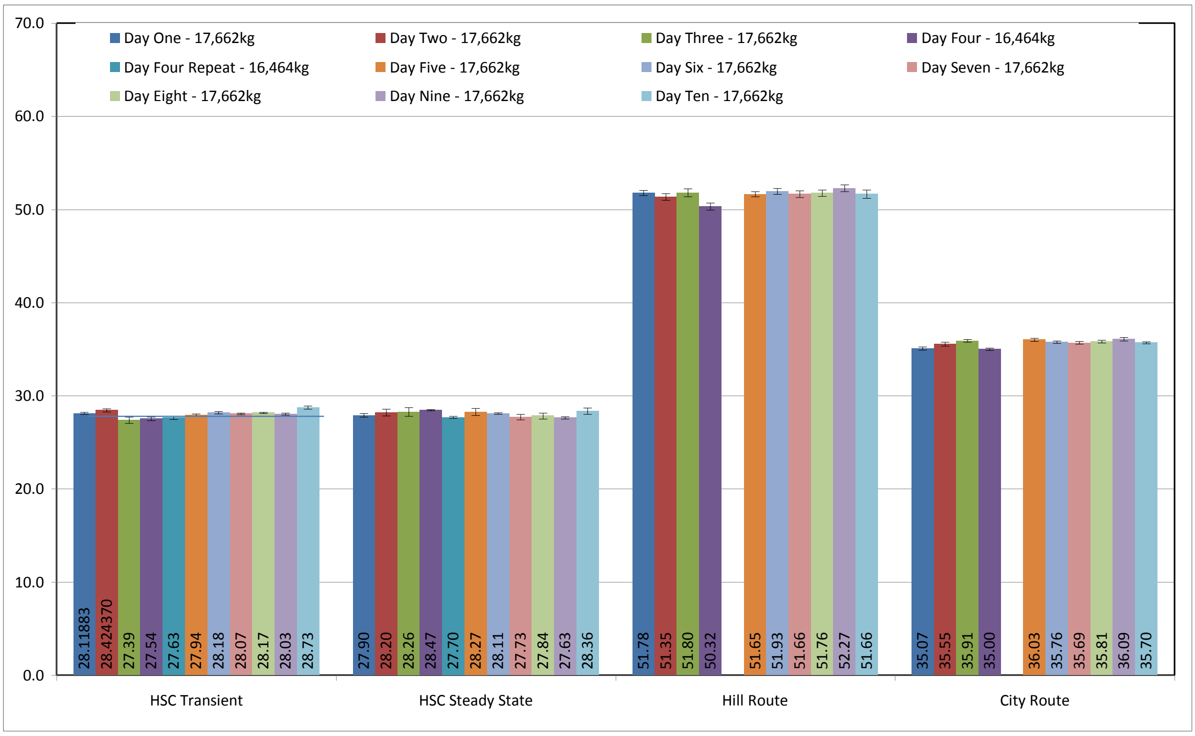

Figure 8. Daily fuel consumption results from reference vehicle (l/100km)

3.2 Coastdown testing

Each vehicle, in each test condition, was put through a coastdown test procedure. A coastdown test involves motoring the vehicle to as high a speed as can be realistically and safely achieved before putting it into a neutral state (disconnecting the vehicle's prime mover from the wheels via the gearbox to prevent engine compression braking) and allowing the vehicle to decelerate due to friction created by the tyres (rolling resistance), the drivetrain friction (mechanical losses), and windage forces (aerodynamic drag). Data logging equipment was used on the vehicle to measure speed against time, this data was then to be used to develop a set of times taken to decelerate between pre-determined speed step points (e.g. 26 seconds to decelerate from 75 to 65 km/h). The times produced could then be used to create a set of coefficients, representing each of the forces acting on the vehicle during the coastdown (rolling resistance, mechanical losses, and aerodynamic drag). These coefficients can be used in a formula to create a curve of force against speed for the vehicle; this could then be used in vehicle behaviour modelling software.

The times generated could also be used on a chassis dynamometer to simulate accurate real world transient running conditions. By changing the dynamometer simulation coefficients and coasting the vehicle down between the same speed step points as were used on the track it is possible to 'match' to the real world times (within a tolerance band). The coefficients used to match these times could then be utilised in lab testing, creating a realistic vehicle model whilst increasing test repeatability by removing many external test variables.

A description of the procedure followed for this test is presented at Annex B.

3.3 Chassis dynamometer testing

Testing of one vehicle was carried out on a heavy duty chassis dynamometer. This was conducted in order to observe whether any significant change in fuel consumption during track based testing could be replicated over test cycles in a laboratory environment, three test cycles were chosen for this:

The NL-ART; a very transient cycle with harsh bursts of acceleration from standing and harsh braking back down – this cycle was developed to represent inner city delivery driving.

The FIGE cycle; a three phase test cycle consisting of urban, suburban, and motorway phases – this cycle was developed alongside the heavy duty engine approval cycle (the ETC test bed cycle).

A steady state cycle; a test cycle developed for this programme which was designed to replicate the steady state cycle carried out on the Millbrook test tracks – this was used in order to try and gain a direct correlation between chassis dynamometer work and the track work. The test vehicle was tested over each of these cycles at two different masses (17,662kg and 16,482kg) following track work under the same conditions.

An example speed vs. time trace (for the FIFE cycle) can be seen in Figure 9.

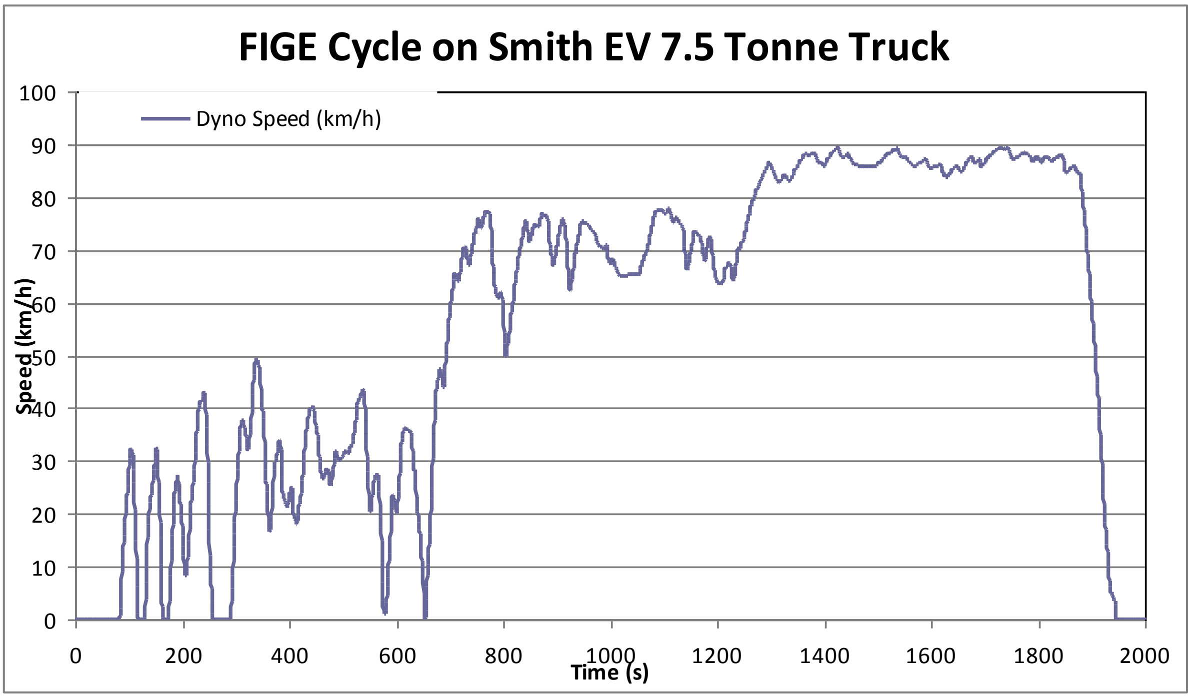

Figure 9. Example of chassis dynamometer duty cycle

4 Results and Discussion

The fundamental purpose of the testing programme described in Section 3 was to determine which test procedure or procedures are likely to be most appropriate for an accreditation/certification scheme for low carbon HGVs, not to define the precise fuel and emissions savings from the specific technologies tested. The generic results from each technology and their implications for the selection of suitable test procedures are discussed in the following sections.

4.1 Track testing results

Track tests were performed on seven separate with/without technology-fitted matched vehicle pairs. These tests were able to detect statistically significant differences in fuel consumption between the vehicles for six of those combinations.

The low rolling resistance tyres and cab deflector tests both showed fuel savings for all test circuits, but more pronounced for the high speed routes. With these technologies, the tested gross vehicle weights were very similar with or without the technology fitted, and there was very little delay between testing each vehicle, so there can be a high degree of confidence that the fuel savings measured were attributable to the technologies, and not to other vehicle or ambient condition effects.

The double deck trailer produced consistently higher fuel consumption figures than the single deck version, when coupled to exactly the same tractor unit, by between 4% and 18%, depending on the test circuit. The double deck trailer was, however, 4 tonnes (11%) heavier than the single deck trailer, and 1m higher (24% greater frontal area). If such a vehicle is used to transport high volume, very low density and delicate goods (i.e. that could not be stacked on top of each other in a single deck trailer), then the doubling of the available loading volume could thus translate into an overall fuel saving (per cubic metre of load carried) of up to 48% (ignoring the additional weight of the goods carried). This emphasises the importance of choosing an appropriately normalised metric for certification purposes; in this case based on cubic-metres of goods carried. If the double deck trailer were assessed against a per tonne metric (or used in operations where overall weight was the constraining factor on loads carried, not volume or where the double deck would not actually permit any more goods to be carried), then it would not be identified as a “low carbon” option.

The (6.7%) weight-saving test (a full loaded vehicle compared to the same vehicle with a lighter load) produced small, but statistically significant, fuel savings on the hill and city routes. The high speed routes produced mixed, though non-significant, results.

Results with the profiled trailer were much less consistent and, generally speaking, not statistically significant, both in comparison to a conventional single deck trailer and when combined with side skirts or reduced tyre pressures. It is possible that these mixed results were due to incompatibilities between the profiled trailer and the tractor unit used to pull it, or the result of counter-balancing interactions between the air flowing over the profiled roof shape and other parts of the trailer, e.g. where the side skirts were or were not fitted, or because of small differences in the gross weights of the vehicles tested (up to 500kg). At the peak of its shaped profile, the profiled trailer was some 0.4m higher than the comparator, standard trailer, which would also have some influence on the results because of the increased frontal area. It is also possible that the test procedure itself contributed to at least some of this variability and inconsistency, because there were delays of up to 8 days between testing the vehicle pairs. Although a reference vehicle was used each day to allow for corrections due to weather variations, it is still possible that some variations due to altered ambient conditions are coming through in the measured results.

4.2 Chassis dynamometer testing results

Only the weight-saving vehicles were tested on the chassis dynamometer. Generally speaking, the chassis dyno tests correlated reasonably well with the track tests; the steady state cycle gave a small increase in fuel consumption, just as was measured in similar track conditions, whereas the more transient, urban and suburban driving cycles gave small fuel savings, again as with the closest equivalent test track routes.

These results, though very limited, do indicate that there is a reasonable degree of correlation between track and chassis dyno testing, which could be exploited by an accreditation/certification scheme (discussed further in the following section).

The chassis dynamometer was also used to test the electric vehicle and was found to be suitable for that purpose. No track testing was carried out with the electric vehicle, so it is not possible to comment on the degree of correlation between the dyno and track testing in this case. No comparator vehicle was available, so it is also not possible to make a direct emissions comparison, though a calculation based on the carbon intensity of grid electricity and an estimate of typical fuel consumption for 10/12 tonne box vans, does indicate that the electric vehicle has the potential to produce carbon savings over its diesel-fuelled equivalents.

4.3 Discussion

Overall, the track testing demonstrates that the procedures were able to identify statistically significant differences in fuel consumption for almost all the technologies tested. They thus seem to represent a potentially suitable set of procedures for accreditation/certification purposes. Further work is need, however, to define:

- How to ensure that the possible effects of changes in vehicle weight and ambient conditions between tests are minimised and/or quantified;
- How reproducible test results are between different test tracks, or between tests performed on the same track but at different times of the year;
- How reproducible test results are between different vehicles, with the same technology fitted;

The tested combinations of technologies (profiled trailer with cab deflector/reduced tyre pressures/side skirts) gave inconsistent results and generally only small variations in fuel consumption were detected, often not large enough to be statistically significant. While the more stringent assessment of the effects of vehicle weight and ambient conditions suggested above may help to explain and quantify some of these results, additional work is needed to fully explore the interactions between technology types. It is suggested that this further work should focus on:

- Isolating the individual effects of the technologies;
- Assessing further combinations of technologies to explore how they interact with one another.

At this stage it is likely that most of this additional work would have to be by physical track and/or chassis dynamometer testing. As knowledge and understanding gained from these tests increases, however, so the potential for modelling to be used as a cheaper and more cost-effective alternative increases, providing this learning can be suitably fed into the modelling software.

In the experience of the project team, track testing is usually more cost effective than a programme of chassis dynamometer tests. This is generally because the chassis dyno tests still rely on data from a coastdown test, which must be carried out on a test track. If the vehicle is already on the test track, it is then usually far easier and quicker to simply drive the vehicle around a controlled test circuit on the track than it is to put it onto a dynamometer, process and programme in the coastdown data and then run the tests. That said, dyno tests are more readily repeatable (track testing is susceptible to driver errors and other track users disrupting the process meaning results from some laps have to be discarded) and obviously less dependent on suitable weather conditions (though the coastdown tests still need good conditions). It is also fair to say that track testing may not be as robust for predicting absolute values of fuel consumption in real world use (as against relative changes) as the more readily variable duty cycles that can be programmed into a dynamometer test.

Another limitation on the suitability of chassis dynamometer testing for HGV certification purposes is that such facilities, generally speaking, are unable to accommodate fully laden, maximum weight vehicles. This would mean that a full assessment of the efficacy of low carbon technologies over the full range of freight and logistics duty cycles and vehicle types to which they may be relevant would be likely to have to resort to track testing in any event, at least for the fully laden or near fully laden case.

Table 4-1 summarises the main points of applicability and issues associated with the three major test types currently considered, in combination, to represent the best approach to the future testing and certification of low carbon HGV products.

Table 4-1. Summary of test type applicability and issues

Test type	Applicability and issues
Track testing	Suitable for any vehicle, of any size/weight. Lower cost, but highly weather dependent, not easily reproducible between different test tracks and unsuitable for absolute fuel/energy consumption measurements. Good for back-to-back and particularly for aerodynamic technologies.
Chassis dyno with coastdown track tests	Not suitable for heaviest vehicles >40t, limiting applicability to technologies whose performance is unlikely to depend on gross weight or fitted only to smaller vehicles. Chassis dyno tests are highly repeatable and reproducible, but coastdown tests still lead to some weather dependence. Overall costs likely to be higher than Track tests. Traceable measurement methods give good absolute figures, appropriate for whole vehicle CO_2 targets.
Coastdown with modelling	Same weather limitations as for coastdown testing. Results highly repeatable and reproducible. Limited accuracy for absolute fuel consumption so not applicable for whole vehicle absolute CO_2. Modelling, though, relies on a well-populated, reliable and validated database, which can only evolve over time on the back of track test (or real world) results. Very cost effective compliment to physical test, to increase applicability of tested technology.

4.4 Conclusions

The series of track and chassis dynamometer testing described in this report has shown that;

- Track testing can be carried out in a highly controllable and repeatable manner;
- Statistically significant fuel savings can be detected, though not all the technologies tested gave such savings;
- Track testing is considered to be more time- and cost-effective than chassis dynamometer trials (which rely on some track testing anyway), particularly for technologies affecting aerodynamic drag and/or rolling resistance;
- Track testing may be cheaper but may not be as robust for absolute values as dynamometer testing and is very weather dependent. Dynamometer testing can also assess tailpipe emissions much more readily than is feasible with track testing;

- Results from both dynamometer and track testing are highly dependent on the cycles driven/simulated, but a limited programme of chassis dynamometer tests showed reasonable correlation with the equivalent track tests;
- Consideration of both payload mass and volume should be made in defining targets/metrics for carbon saving, but the choice of which may be highly operator dependent;
- Measured fuel savings or consumption increases were generally too small to be statistically significant for the technology combinations assessed (profiled trailer, side skirts and reduced tyre pressures);
- Technologies may be effectively compared using back-back tests or against a robust baseline/comparator. However, whole vehicle absolute targets will require additional testing to determine accurate fuel consumption;
- To be meaningful, carbon emissions have to be assessed over the full supply chain, i.e. well-to-wheel. The carbon content of alternative fuels and energy supply options, e.g. electric vehicles, thus need to be assessed in different ways (especially well-to-tank, or "mine to battery") to conventional (tank-to-wheel) style fuel consumption analyses.

4.5 Study limitations and recommendations for further work

The test programme was necessarily restricted in its scope. Within the project constraints, it was only possible to test a small range of vehicles and technologies, and then over only a limited number of trials.

Whilst the results are robust enough to provide an initial degree of confidence that low carbon technologies can be identified through track and/or dyno testing, additional data is required to;

- Assess a wider range of technology types over a wider range of vehicles and test conditions;
- Assess the extent to which performance varies between similar types of products (e.g. does cab deflector A produce better savings than cab deflector B?);
- Assess electric and hybrid vehicles with direct comparator conventional vehicles;
- Define how to ensure that the possible effects of changes in vehicle weight and ambient conditions between tests are minimised and/or quantified;
- Define how reproducible test results are between different test tracks, or between tests performed on the same track but at different times of the year;
- Define how reproducible test results are between different vehicles, with the same technology fitted;
- Assess the full relative advantages and disadvantages of track and dynamometer testing, including, for example, the variations caused by significant weather differences and the relative carbon intensity and costs of each method;
- Isolate the individual effects of the technologies tested to date only in combination;
- Assess further combinations of technologies to explore how they interact with one another.
- Build up a robust data-base of fuel and emissions saving results;
- Develop the protocols needed to ensure good correlation between modelling and track and/or dynamometer results, and with real-world, in use performance.

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Annex A – Fuel economy track test procedures

TRL-LowCVP AERODYNAMIC TRACK TESTS

TEST VEHICLE

TRUCK: KP09 XTA
ODO:
Date

TRAILER: Standard Box Trailer

Time

Weather Conditions

Track	***Dry - Damp***
Ambient Temp	>10, <30
Wind Speed	< 3.2m/s (gust <5m/s)

Before each test day

Refuel
Check and adjust tyre pressures to:

Truck Front Axle 130psi (9 Bar)
Truck Rear Axle 80psi (5.5 Bar)
Trailer All Axles 125psi (8.5 Bar)

Pre-Conditioning

After refuelling and checking tyre pressures leave both trucks connected to trailers in trailer park for overnight soak.

Truck Conditioning Cycle

Prior to starting the vehicle, start both the ECO Logger & Vbox logging. The truck will need to be driven through a warm up procedure consisting of the following as soon as the vehicle air system has built up;

- 6 laps High Speed Circuit – top gear, maximum speed
- 2 laps Hill Route - normal driving
- 4 lap High Speed Circuit – Full throttle, top gear
- At end of 4^{th} lap stop at end of brake pad 1

FUEL ECCONOMY TEST 1

Start Time:
Start Odo:

Finish Time:
Finish Odo:

HSC TRANSIENT DRIVE CYCLE

WHERE POSSIBLE LANE 2 OF HSC SHOULD BE USED AT ALL TIMES

1. **Start from end of BP1.**
2. **Mod accel to 70km/h & hold, changing gear @ 1500rpm.**
3. **@ zero mile marker WOT to max speed & hold.**
4. **Overrun @ 1 mile marker to 60km/h & hold.**
5. **@ zero mile marker WOT to max speed & hold.**
6. **@ 1½ mile marker overrun until start of BP1.**
7. **@ start of BP1 light braking to a stop @ end of BP1.**
8. **Repeat items 1 - 7, 10 times.**

FUEL ECCONOMY TEST 2

Start Time: Finish Time:
Start Odo: Finish Odo:

HSC STEADY STATE CYCLE NOTES

WHERE POSSIBLE LANE 2 OF HSC SHOULD BE USED AT ALL TIMES

1. **Start from end of BP1.**
2. **Mod accel to max speed & hold, changing gear @ 1500rpm.**
3. **Hold max speed until zero mile marker @ end of 5th lap.**
4. **Overrun to 70km/h & hold until zero mile marker @ end of 10th lap.**
5. **@ zero mile marker overrun until start of BP1.**
6. **@ start of BP1 light braking to a stop @ end of BP1.**
7. **Repeat items 1 - 6, three times.**

FUEL ECCONOMY TEST 3

Start Time: Finish Time:
Start Odo: Finish Odo:

HILL ROUTE CYCLE DRIVER NOTES

1. **Start from 1st lay-by on Hill Route.**
2. **Mod accel to 40km/h & hold, changing gear @ 1500rpm.**
3. **Overrun @ Special Surface's sign.**
4. **WOT from dip @ start of 7.6% incline.**
5. **Overrun @ 7.6% end sign.**
6. **Hold 30km/h around hairpin.**
7. **Overrun until 50km/h & hold down 7.6% (≥ 8th gear).**
8. **WOT @ 11.6% loop junction.**
9. **Overrun @ 11.6% down sign until 50km/h & hold (≥ 9th gear).**
10. **WOT @ bottom of 11.6% & hold until Valley Road sign.**
11. **Overrun until 55km/h & hold.**
12. **@ No Entry sign brake, stopping @ junction with Rough Track.**
13. **Mod accel to 40km/h & hold until end of Rough Track.**
14. **Stop in lay-by before Island A.**
15. **Repeat items 1 - 14 , 10 times.**

FUEL ECCONOMY TEST 4

Start Time: Finish Time:
Start Odo: Finish Odo:

CITY CYCLE DRIVER NOTES

WHERE POSSIBLE LANE 2 OF HSC SHOULD BE USED AT ALL TIMES

1. **Start from end of BP2, mod accel to 48km/h gear change @ 1500rpm.**
2. **Hold 48km/h until exit ¼ mile sign.**
3. **Overrun to 30 km/h & hold whilst leaving HSC.**
4. **@ start of Armco on HSC exit road overrun & stop @ Island B.**
5. **Proceed around Island B @ 25km/h.**
6. **Take 4th exit over bridge & hold 30km/h.**
7. **Overrun @ end of bridge stopping @ Island A**
8. **Proceed around Island A @ 25km/h.**
9. **Take 3rd exit onto Hill Route.**
10. **Mod accel to 40km/h & hold until Special Surface's sign.**
11. **Overrun taking R/H turn to Truck Slopes.**
12. **Proceed around Truck Slope round about @ 20km/h.**
13. **Head back to Island A holding 40 km/h.**
14. **@ 1st lay-by on R/H/S overrun stopping @ Island A.**
15. **Take 2nd exit over bridge & 30km/h.**
16. **Overrun @ end of bridge stopping @ Island B.**
17. **Take 1st exit onto HSC, mod accel to 48km/h & hold.**
18. **@ start of BP2 overrun stopping @ end of BP2.**
19. **Repeat items 1 - 18, 10 times**

Annex B – Coastdown track test procedure

TRL-LowCVP AERODYNAMIC TRACK TESTS

TEST VEHICLE

TRUCK: KP09 XTA
ODO:
Date

TRAILER: Standard Box Trailer

Time

Weather Conditions

Track	***Dry - Damp***
Ambient Temp	>10, <30
Wind Speed	< 3.2m/s (gust <5m/s)

Before each test day

Refuel
Check and adjust tyre pressures to:

Truck Front Axle 130psi (9 Bar)
Truck Rear Axle 80psi (5.5 Bar)
Trailer All Axles 125psi (8.5 Bar)

Pre-Conditioning

After refuelling and checking tyre pressures leave both trucks connected to trailers in trailer park for overnight soak.

Truck Conditioning Cycle

Prior to starting the vehicle set both the JPS/Vbox and truck fuel measuring device logging. The truck will need to be driven through a warm up procedure consisting of the following as soon as the vehicle air system has built up;

- 6 laps High Speed Circuit – top gear, maximum speed
- 2 laps Hill Route - normal driving
- 4 lap High Speed Circuit – Full throttle, top gear
- At end of 4th lap stop at end of brake pad 4

<u>HSC COASTDOWN</u>

- Inform track control & request caution for lanes 1& 2
- Drive vehicle up to max speed & hold until start of brake pad 1
- At start of brake pad 1 neutral steer & neutral selected
- Allow vehicle to coastdown until Vbox display reads below 5km/h
- Repeat this operation twice for each of the 4 brake pad

Annex C – Detailed Results

The normalised results for all the technologies assessed (except the electric vehicle which is discussed later) are presented in Table C-1. Each test condition is compared to the same vehicle without the low carbon technology fitted, and the results are presented as percentage changes in fuel consumption. The shaded percentages represent statistically significant differences.

Table C-1. Results summary

Test Specifics	Vehicle Used	MX08 DWJ	KP09 XTA	KP09 XTA	KP09 XTA	KP09 XTA	BU06 FXP	RX59 AHF
	Test Condition	Reduced loading	Double deck trailer	Profiled trailer	Profiled trailer - no side skirts	Profiled trailer - reduced tyre pressures by 25%	Cab deflector fitted	Low rolling resistance tyres fitted
	Test Date	14/05/2010	06/05/2010	13/05/2010	17/05/2010	21/05/2010	20/05/2010	24/05/2010
	Test vehicle Mass (kg)	16482	38304	34964	34798	34964	32540	33716
	Comparison Condition	Vehicle fully loaded	Single deck trailer	Single Deck trailer	Profiled trailer	Profiled trailer	Cab deflector removed	Standard tread tyres fitted
	Comparison Date	16/05/2010	05/05/2010	05/05/2010	13/05/2010	13/05/2010	18/05/2010	25/05/2010
	Comparison Vehicle Mass (kg)	17662	34489	34489	34964	34964	32502	33709
Track Work	HSC Transient Route (L/100km)	-1.8%	13.3%	-2.2%	0.6%	-2.2%	-6.6%	-9.1%
	HSC Steady State Route (L/100km)	1.6%	17.6%	2.0%	0.1%	-0.8%	-8.8%	-11.2%
	Hill Route (L/100km)	-2.5%	4.0%	0.0%	0.0%	-0.5%	-3.2%	-0.8%
	City Route (L/100km)	-1.9%	10.2%	6.3%	-0.4%	-1.0%	-3.6%	-3.9%
Chassis Dyno Work	NL-ART (L/100km)	-0.3%						
	FIGE (L/100km)	-0.7%						
	Dyno Steady State Route (L/100km)	2.4%						
Coastdown Work	Coastdown Rolling Resistance (L/100km)	-9.3%	-5.9%	-3.5%	-3.4%	-9.6%	-3.2%	19.9%
	Coastdown Aerodynamic Drag	-3.2%	32.7%	-6.5%	20.5%	14.7%	-11.6%	10.3%

C.1 Aerodynamic aids

Cab deflectors

With the cab deflector fitted to the test vehicle (registration BU06 FXP, tractor unit), statistically significant fuel savings were achieved in all four track test cycles. As expected, the highest savings (6.6% and 8.8%) were achieved on the high speed routes. Perhaps more surprisingly, though, savings (of 3.2% and 3.6%) were also measured on the hill and city routes.

Figure C1. Test vehicle with cab deflector

Profiled trailer

Results for the profiled trailer were mixed; fuel consumption reduced by a statistically significant 2.2% on the high speed transient route, but increased by 6.3% on the city route, though this may in part at least be due to the profiled trailer vehicle combination weighing almost 500kg more than the single deck comparator. Non significant differences were measured on the steady state and hill routes. Although the results have been normalised from the reference vehicle data, the 8 day gap between testing these two vehicle types may also be playing some part in the results.

Figure C2. Test vehicle with profiled trailer

Trailer side skirts

Statistically significant differences in fuel consumption were not detected on any of the track test circuits, although small savings (0.6%) were achieved on the high speed transient route, and a small increase (0.4%) in fuel consumption was detected on the city route. The vehicle without side-skirts weighed about 170kg less than when side-skirts were fitted.

Figure C3. Test vehicle without side-skirts

Double deck trailer

The double deck trailer weighed almost 4 tonnes more than the single deck trailer used as comparator. Perhaps not surprisingly, therefore, its fuel consumption was statistically significantly higher than its comparator on all four track test routes; by between 4.0% and 17.6%.

These results highlight the importance of choosing the right carbon intensity metric; if, for example, a double deck trailer can carry twice the load of a single deck equivalent, then a 100% increase in load carried might only produce a, say 10-20% increase in fuel consumption. A measure based on grammes CO_2 per cubic-metre kilometre of load carried would be a more useful metric in this condition than per tonne-kilometre.

Figure C4. Test vehicle with single and double deck trailers

C.2 Tyres

Low rolling resistance tyres

With low rolling resistance tyres fitted, the test vehicle achieved statistically significant fuel savings (of 9.1% and 11.2%) on the high speed routes, and 3.9% on the city route. A small, non significant saving of 0.8% was also measured on the hill route.

Figure C5. Test vehicle for low rolling resistance tyre tests

Reduced tyre pressures

Contrary to expectations, reducing tyre pressures by 25% (on the profiled trailer and tractor unit shown in Figure C2) produced a statistically significant fuel saving of 2.2% on the high speed transient route. Small, though non significant savings (of between 0.5% and 1.0%) were also measured on the hill, city and high speed steady state routes. Although the results have been normalised from the reference vehicle data, the 8 day gap between testing these two vehicle types may be playing some part in the results. It is also conceivable that with the vehicle at well below full load and with only a 25% reduction in pressure, there may have been a reduced tyre contact patch area leading to reduced rolling resistance and/or the extra heat build-up may have increased the pressure back up to near the standard value.

C.3 Weight saving

The 6.7% reduction in weight (from 17,662kg down to 16,482kg) produced statistically significant fuel savings on the hill and city routes, of 2.5% and 1.9% respectively. The high speed routes produced mixed, though non significant, results, with a 1.8% saving on the transient route and a 1.6% increase in fuel consumption on the steady state route.

For further comparison purposes, these vehicles were also tested on the chassis dynamometer. Generally speaking, the chassis dyno tests correlated reasonably well with the track tests; the steady state cycle gave a small increase in fuel consumption, just as was measured in similar track conditions, whereas the more transient/urban and suburban driving NL-ART and FIGE cycles gave small fuel savings, again as was the case on the closest equivalent test track routes.

Figure C5. Test vehicle for weight saving tests

C.4 Plug-in electric vehicle

The 10/12 tonne electric vehicle was tested with the FIGE cycle on the chassis dynamometer, which is broadly representative of a mixture of city, suburban and motorway driving. After 30.7km total driving distance, starting with a fully charged battery, the vehicle needed 24.8 KWh of electrical energy to fully recharge. With an assumed grid average carbon intensity of 0.62 $kgCO_2e$/KWh (official DEFRA figure, 2008 rolling average), this is equivalent to about 500 gCO_2e/km.

No direct comparison is possible because no comparator vehicle was available. However, information available to the project team suggests that 10/12 tonne box vans can typically be expected to deliver average fuel consumption figures of about 10-12 miles per gallon. This is equivalent to about 750-900 gCO_2e/km, so the electric vehicle does show some indication that its overall carbon intensity is considerably less than an equivalent conventional vehicle (by around 30-45%).

As well as the ongoing reduction in carbon intensity of grid-based electricity, which will further decarbonise electric vehicles in the future, it is also noteworthy that, on the basis of these data, the EV would have energy-related running costs of about 8 pence per kilometre (at 10p per KWh), and the diesel-fuelled equivalent would be about 23p (at £1.22 per litre).

Figure C5. Plug-in Electric Vehicle