

Fuel Consumption Track Tests for Tractor-Trailer Fuel Saving Technologies

Marius-Dorin Surcel, Yves Provencher and Jan Michaelson

FPIInnovations – Feric Division

Copyright © 2009 SAE International

ABSTRACT

The objective of the project was to conduct controlled test-track studies of solutions for achieving higher fuel efficiency and lower greenhouse gas emissions in the trucking industry. Using vehicles from five Canadian fleets, technologies from 12 suppliers were chosen for testing, including aerodynamic devices and low rolling resistance tires. The participating fleets also decided to conduct tests for evaluating the impact on fuel consumption of vehicle speed, close-following between vehicles, and lifting trailer axles on unloaded B-trains. Other tests targeted comparisons between trans-container road-trains and van semi-trailers road-trains, between curtain-sided semi-trailers, trans-containers and van semi-trailers, and between tractors pulling logging semi-trailers loaded with tree-length wood and short wood. The impact of a heavy-duty bumper on fuel consumption and the influence of B5 biodiesel blend on fuel consumption were also assessed. The test procedure followed the SAE J1321 Joint TMC/SAE Fuel Consumption Test Procedure - Type II.

With payback periods as short as 0 to 9 months, some technologies and approaches represent viable measures for reducing fuel consumption. Conservative estimations show that these technologies could bring annual Greenhouse Gases Emissions reductions of 6.7 tonnes per vehicle.

INTRODUCTION

Class 8 trucks consume approximately 68% of all commercial truck fuel used, from which about 70% is consumed by the trucks operating on-highway. From the energy necessary to sustain vehicle speed at 100 km/h, aerodynamic losses, engine losses, and tire-rolling resistance account for approximately 94% [1].

After gross vehicle weight, air resistance is the largest factor responsible for vehicle energy loss. The magnitude of this resistance is affected by the vehicle's shape, frontal area, and travel speed. Drag significantly increases fuel consumption. It has been estimated that decreasing drag by 2% can improve fuel economy by approximately 1% [2]. Previous FPIInnovations tests confirmed the potential of add-on aerodynamic devices, such as trailer rear deflectors and trailer skirts, which showed fuel improvements up to 5.6%, and respectively 7.2% [3].

Rolling resistance can consume as much as 70% of engine power at low speeds and as much as 40% at high speeds. Each 3% decrease in rolling resistance could improve fuel efficiency by as much as 1% [4]. A way to improve efficiency is to use wide-base tires, which generally cost less, weight less and have lower rolling resistance than conventional duals. The fuel consumption tests performed in October 2007 showed 9.7 % fuel economy for the tractor-trailer combination equipped with wide-base tires [5]. Maintaining the correct tire pressure can be as important as selecting the right tires: the fuel consumption tests conducted with the same occasion resulted in 3.1 % deterioration in fuel efficiency when the tire pressure was decreased with 15 psi (15 %). Another possibility to reduce fuel consumption is to use low rolling resistance tires: all major tire manufacturers now offer fuel-efficient tires with around 20% less rolling resistance than conventional tires.

As conventional diesel fuel becomes more expensive, renewable fuels are becoming more viable. Biodiesel is a non-toxic, alternative fuel made from vegetable oils or animal fats, which can be used as a pure fuel or blended with petroleum-based diesel fuel. FPIInnovations has a continued interest in evaluating bio-fuels. Engine dynamometer tests with several biodiesel blends have

been conducted in February 2008, at the British Columbia Institute of Technology [6].

Fuel additives are now marketed more aggressively as a result of high fuel prices and new emission requirements. Many fuel additives are legitimate, useful and even necessary, but using an additive means changing the properties of the fuel. An improper use of an additive could affect engine startability or the performance of some components such as hoses and gaskets. FPIInnovations – Feric Division has also shown a constant interest in evaluating fuel additives. A previous project evaluated three different diesel fuel additive, using fuel consumption tests, operational observations, and cold start tests, which showed fuel economy improved by 2 to 5%, depending on the additive, and very good cold start performances [7].

The resistance to the flow of exhaust gases through the exhaust system is measured by the exhaust back pressure. Reducing the back pressure can improve fuel efficiency. Thermal coating for exhaust parts is a known technology in the motorsport industry, which proved to be beneficial in increasing engine power and torque. However, the benefits, for heavy-duty tractors are yet to be proved.

Therefore, the objective of the project, which was titled Energotest™, was to provide reliable information on various technological solutions designed for the reduction of fuel consumption and the emissions of greenhouse-effect gases within the road transportation industry. The members of Project Innovation Transport (PIT) selected technologies from 12 suppliers for testing, and also decided to conduct tests that would allow trucking companies to implement some innovative practices in their daily activities:

- Aerodynamic drag reduction measures:
 - Technologies: trailer axles' deflector, trailer rear deflector, trailer side skirts;
 - Approaches: comparing the fuel efficiency of tractors pulling logging semi-trailers loaded with full-length wood and short wood, comparison curtain-sided semi-trailers, tractor-trans-containers and tractor-semi-trailer van, impact of close-following, impact of speed, and impact of a heavy-duty bumper on fuel consumption.
- Rolling resistance reduction measures:
 - Technologies: low rolling resistance tires;
 - Approaches: Impact of lift axles on fuel consumption for unloaded B-trains.
- Technologies for improving engine efficiency:
 - Fuel and additives: impact of B5 biodiesel blend on fuel consumption, and impact of a diesel fuel additive on fuel consumption.
 - Exhaust system technologies: exhaust manifold coating, and low back pressure exhaust mufflers.

METHODOLOGY

TEST SITE - The tests were performed on the high-speed test track of Transport Canada's Motor Vehicle Test Centre in Blainville, Quebec, which is currently operated by PMG Technologies. This track is a high-banked, parabolic oval with a length of 6.4 km. The length of a test run was 15 laps (96 km).

TEST PROCEDURE - The test procedure was based on the SAE J1321 Joint TMC/SAE Fuel Consumption Test Procedure - Type II [8]. The fuel-consumption test compared the fuel consumption of a test vehicle, operating under two conditions, with that of an unmodified control vehicle. Fuel consumption was accurately measured by weighing temporary tanks before and after each trip. The repeatability of the scale measurements was periodically checked during the tests using a set calibration weight.

For each test, control and test vehicles had the same general configuration and were coupled to the same semi-trailers for the base and test trials. The load weights remained the same throughout the entire test period. The vehicles were in good working condition, with all settings adjusted to the manufacturer's specifications.

The test consisted of a baseline stage (using non-modified vehicles) followed by a test stage (using the test vehicle equipped with the technology to be tested). Baseline stage was conducted before installing the technology on the test truck. For this stage, the control and test trucks completed a minimum of three test runs until the results of a group of three runs were within 2% of each other. For the test stage, the test truck was equipped with the technology being tested, while the control truck stayed in its original state. As in the baseline stage, the trucks completed the test runs a minimum of three times until the results of a group of three runs were within 2% of each other. For both the baseline and test stages, the representative results were the ratio between the average fuel consumed by the test truck and the average fuel consumed by the control truck (the T/C ratio). The result of the complete trial consisted of the percentage difference between the test T/C ratio and baseline T/C ratio:

$$P_d = 100 \times \frac{(T/C)_b - (T/C)_t}{(T/C)_b} \quad (1)$$

DRIVING PROCEDURE - Each day, before the testing started, all vehicles were warmed up for the same amount of time at test speeds. The driver's influence on the results was minimized as much as possible by conducting the tests on a closed circuit and strictly controlling the driving cycle as follows:

- Fixed period of idle time;
- Start off with maximum acceleration;
- Cruising speed of 98 km/h;

- Driving on the right side of the track as close as possible to the painted line, without touching it;
- Constant driving speed: the vehicle was free to change lanes on the oval track;
- After the established duration, the driver ceased to use the speed regulator at the designated point;
- During deceleration, the driver used only the service brakes and did not accelerate;
- Once at the meeting point, the trucks stayed idle for equal periods of time before turning off the engines.

During the tests, the driving cycle was controlled with radar and drivers received instructions by 2-way radio. The time interval between two consecutive trucks remained the same in order to avoid the effects of turbulence caused by other trucks and prevent multiple trucks from being at the same place and time on the track. The distance maintained between two consecutive vehicles on the track was 1.3 km. According to [9], for a 55 mph test speed (89 km/h), the trailing vehicle must travel at least 13 seconds behind the lead vehicle, which corresponds to a distance of 320 meters, to be completely out of the lead vehicle's turbulence. Actual test speed was 98 km/h, thus the 13 seconds interval translates to a distance of 354 m, and therefore the distance between the vehicles during the tests (1.3 km) was more than sufficient for avoiding the effects of turbulence.

TEST VEHICLES - The trucks used during the tests were Volvo VNL 630 2003, powered by VED12 engines (five units), Freightliner Columbia 2006, powered by MBE4000 engines (seven units), Kenworth T800 2004 and 2006, powered by Caterpillar C13 engines (two units) and Sterling 2002, powered by Detroit Diesel 60 engines (two units). The tractors pulled Manac 53-ft. Van semi-trailers (eight units). One curtain semi-trailer, two trans-containers, one B-train, and two logging semi-trailers were also used during the tests. Tables 1 to 4 present the type specifications of the tractors and semi-trailers used for the tests.

Table 1: Type specification of the test trucks

Make and model	Freightliner Columbia	Volvo VNL 630
Year	2006	2003
Engine	MBE 4000	VED 12
Rated power (kW)	325	295
Rated torque (Nm)	2100	2100
Transmission	Mo 15G10C-M15 Meritor ZF	Mo 16Z12A Meritor ZF or RTLO 16193L DM3 13
Final ration	3.73	3.55 or 3.70
Tires	275/80 R22.5	275/80 R22.5
Tire pressure (kPa)	690	690
Vehicle test weight (kg)	7403 – 7730	8573 – 8714

Table 2: Type specification of the test trucks (continuation)

Make and model	Kenworth T800	Sterling
Year	2006 and 2004	2002
Engine	Caterpillar C13	Detroit Diesel 60
Rated power (kW)	321	350
Rated torque (Nm)	2100	2237
Transmission	RTLO 16193A	Eaton Fuller 13
Final ration	3.55 or 3.70	3.73
Tires	295/75 R 22.5	11 R 22.5
Tire pressure (kPa)	690	690
Vehicle test weight (kg)	8900 and 8,990	7200 and 7260

Table 3: Type specification of the test semi-trailers

Make and model	Manac 53'	Titan
No. of axles	2	3 + 2
Type	Van 9425301 or 9425302	B-train
Tires	275/80 R22.5 or 11R22.5	11 R 24.5
Tire pressure (kPa)	690	690
Semi-Trailer loaded test weight (kg)	21419 – 21736	-

Table 4: Type specification of the test semi-trailers (continuation)

Make and model	Deloupe	MAX-ARAS CCTBL 53-55	Manac 10448106
No. of axles	4	3	4
Type	Logging trailer	Trans-container	Curtain trailer
Tires	11 R 24.5	11 R 22.5 or 275/80 R 24.5	11 R 22.5
Tire pressure (kPa)	690	690	690
Semi-trailer loaded test weight (kg)	51790 and 51920	25601 and 25310	21092

RESULTS AND DISCUSSION OF THE RESULTS

AERODYNAMIC DRAG REDUCTION MEASURES

Impact of a heavy-duty bumper on fuel consumption - Many transport companies are choosing heavy-duty bumpers because of the combined effect of very high insurance premiums and the fragility of the lightweight materials used for front-end components. Having a heavy-duty bumper makes it possible to avoid claiming minor collisions. The impact on fuel consumption of this approach was thus evaluated. Testing resulted in 2% increase in fuel consumption for the vehicle equipped with the heavy-duty bumper, which can be explained by increased weight compared with the original bumper as well as possible increased turbulence. (Figure 1).



Figure 1. Heavy-duty bumper

REAR AXLES' DEFLECTOR - Results of the test conducted with the device did not show any change in the vehicle's fuel efficiency. Strictly based on the test results and visual observations, we believe that this result can be explained by the poor aerodynamic behavior of the frontal surface of the device, which had an obtuse angle of attack (around 150°). This surface created additional resistance, which eventually outweighed the possible advantages provided by the side panels, which were 3 m long¹. It is believed that a better profiled shape of the frontal area of the device, for example more advanced and with an acute angle of attack, favoring streamlining of air flow, would give better results. These assumptions could be validated in a wind tunnel.



Figure 2. Trailer axles' deflector

Rear deflectors – Rear deflectors (boat tails) have shown a lot of potential for reducing aerodynamic drag and improving the fuel efficiency of tractor-trailer combinations. FPIInnovations-Feric Division tested a few

devices in 2007 and the potential of this approach was confirmed [3]. Rear deflectors were also found to be more efficient when they have larger surfaces. The disadvantage of rear deflectors is that they increase overall vehicle length, which not only poses a problem in terms of compliance with vehicle dimension regulations, but also when docking and loading.

The tested rear deflector (Figure 3) represents an interesting concept, addressing some concerns regarding vehicle length and accessibility. The device, with a width of 2.6 m and height of 2.9 m, is built from lightweight materials and deploys itself when the vehicle reaches a certain speed. The results obtained with the device, 1.5 % fuel improvement, which can be qualified as promising but rather modest, can be mainly explained by the changing shape of the device while the vehicle moves, caused by the device's flexibility and lack of a mechanism to ensure sufficient rigidity. This problem usually occurs when the vehicle's speed decreases, in the presence of crosswinds, and when the vehicle changes direction. Variations in the shape create concave surfaces on the device, which produce additional drag and turbulence. It is advisable to evaluate preliminary designs using simulation software, or a scale model in a wind tunnel, although in the case of this concept it might be difficult to obtain reliable information.



Figure 3. Trailer rear deflector

Trailer Skirts – Seven prototypes from three different manufacturers have been tested.

Three prototypes from the first trailer skirts manufacturer were straight devices (one section), with similar height (0.9 m), ground clearance (0.17 m) and positions relative to the rear of the semi-trailers. They will be referred herein as Prototypes nos. 1, 2, and 3. Prototypes no. 2 and no. 3 had comparable lengths but the length of prototype no. 1 was only half of the length of the other two (roughly 3.5 m). Prototype no. 2 was installed parallel to the longitudinal axis of the semi-trailer, and prototype no. 3 was positioned at an angle to the longitudinal axis (around 5°). Prototype no. 1 was installed at a blunter angle than prototype no. 2. Prototype nos. 2 and 3 performed better than prototype no. 1, which can be explained mainly by their larger surface area, and possibly by the inclination angle of prototype no. 1, which

¹ All dimensions are approximate