

Fuel-Savings from Aerodynamic Efficiency Improvements for Combination Tractor-Trailers Relative to Vehicle Speed

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ABSTRACT

Commercial, class-8 tractor-trailers were tested to develop a relationship between vehicle speed and fuel savings associated with trailer aerodynamic technologies representative of typical long-haul freight applications. This research seeks to address a concern that many long-distance U.S. freight companies hold that, as vehicle speed is reduced, the fuel savings benefits of aerodynamic technologies are not realized. In this paper, the reductions in fuel consumption were measured using the SAE J1231 test method and thru-engine fueling rates recorded from the vehicle's electronic data stream. Constant speed testing was conducted on road at different speeds and corresponding testing was conducted on track to confirm results. Data was collected at four (4) vehicle speeds: 35, 45, 55, and 62 miles per hour. Two different trailer aerodynamic configurations were evaluated relative to a baseline tractor trailer.

Reductions in fuel consumption displayed a strong relationship to vehicle speed, with aerodynamic improvements demonstrating a maximum reduction of fuel consumption of nine (9) percent relative to the baseline at 62 miles per hour. Results at high vehicle speeds are consistent with earlier wind tunnel studies published for trailer aerodynamic technologies. Reductions in fuel consumption demonstrated at 35, 45 and 55 miles per hour are consistent with anticipated performance based on changes in the coefficient of drag for the aerodynamic technology packages tested. At speeds as slow as 35mph, a trailer side skirt and full trailer aerodynamic package demonstrated fuel savings of over 2 and 3 percent, respectively. Fuel savings results at high speeds were relatively insensitive to baseline selection when compared to five (5) different baselines.

The relationships derived from the tests provide a good fit (i.e., high R^2 values) to mathematical regression models and suggest these curves can be used to estimate reductions in fuel consumption savings for aerodynamic technologies for modern class-8 tractor-trailers operating at different vehicle speeds. When applying the SAE J1321 approach (i.e., use of a control vehicle and calculating fuel savings relative to a baseline), ECU-derived fuel savings generally agree with the gravimetric measurement.

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INTRODUCTION

The trucking industry currently transports around 70% of all freight in the United States. In considering U.S. fuel consumption in the transportation sector, class 8 tractor-trailer combinations account for the second highest amount, approximately 20% of fuel used, and projections are for heavy-duty trucks to be the fastest growing fuel consumption transportation sector. (ref 1) In an effort to reduce fuel consumption and associated greenhouse gas emissions from the heavy-duty vehicle sector, the Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) finalized the first fuel economy and GHG regulations in 2011. (ref 2) While these first regulations did not include requirements for trailers used in combination with tractors, on July 13, 2015, EPA and NHTSA proposed regulations (Phase 2) which included requirements for trailers. (ref 3) The Department of Energy's SuperTruck Program is also supporting research and prototype designs for potential aerodynamic improvements in future tractor and trailer designs. Since 2004, EPA's voluntary SmartWay program has been working with

fleets to improve freight efficiency and demonstrate fuel saving technologies. These efforts are advancing the understanding and deployment of fuel- and emission-saving technologies. Not only have fleets' use of aerodynamic devices become more common but, more recently, some fleets are using combinations of devices to achieve even greater reductions in aerodynamic drag and reduce fuel consumption.

Long-distance trucking fleets typically run at high-speed cruise conditions ranging from 60 to 65 miles per hour. As a result, most class-8 trailer aerodynamic technologies are demonstrated at these highway speeds. However, many fleets question the benefits of using these aerodynamic devices because their average vehicle speeds are lower due to traffic, state speed limits, or other operating constraints.

Some of the skepticism over using aerodynamics at lower speeds arises from an examination of the sources of drag on the tractor-trailer.

Aerodynamic losses account for 21 percent of the power requirements for a heavy duty vehicle operating on highway speeds. (ref 4) At lower

vehicle speeds, aerodynamic-drag induced losses remain significant but other sources of energy losses (e.g. vehicle rolling resistance and drivetrain friction) gradually become the majority share of power consumption. Many assume that the mechanical and rolling resistance losses becoming a greater portion of the total losses as speed decreases means that aerodynamic losses are now “insignificant.” As a result, the potential benefits of using aerodynamic improvements for class-8 applications is not typically demonstrated at lower vehicle speeds.

EPA’s SmartWay Technology Program has used SAE 1321 testing, coastdown testing and wind tunnel testing to evaluate fuel savings benefits and aerodynamic drag benefits of aerodynamic devices for use on trailers. Companion research programs using coastdown and wind tunnel testing were designed to provide companion data sets that use the same equipment or close representations. (ref 5). This study demonstrates certain aspects of aerodynamic technology performance on a class-8 tractor trailer with the following primary objectives:

- Investigate the impact of aerodynamic devices on fuel use at varying speeds;
- Identify a relationship between vehicle speed and fuel savings; and,
- Evaluate the potential for using ECU data in assessing fuel savings.

TESTING APPROACH

Reductions in fuel consumption at different vehicle speeds were evaluated using the SAE J1321 (2013 revision) method with tests conducted on a public highway and a controlled track environment.¹ A three (3) truck approach (i.e., one control and two test trucks) was used in the track testing in order to allow for simultaneous testing of two trailer aerodynamic configurations - one with a front-side-rear fairing combination and the second with just a side fairing.

Test Track, Test Road, and Equipment

Track testing for this study was conducted by Southwest Research Institute (SwRI) at the ARA test track near Pecos, Texas. This high-speed, circular test track is eight (8) miles in circumference with one overpass. The three (3) lane track is surrounded by low brush (typically less than eight feet in height) and characteristic of west Texas.

Road testing for this study was conducted by SwRI on a 50 mile route consisting of a stretch of Interstate Highway 37 in the vicinity of Pleasanton, Texas, about 35 miles south of San Antonio. This was considered representative of long-haul interstate highways in grade and surface (i.e., asphalt). It has relatively flat road grade and runs consisted of portions in both directions to improve the comparability to the track, which was designed to minimize the impacts of grade changes. The surrounding terrain is generally flat with some gentle rolling hills. This stretch of road had relatively low traffic density. Lower speed runs (i.e., 35 and 45 mph) were conducted on a parallel service road due to legal speed restrictions and safety concerns. Gravimetric measurement of the portable fuel tank was done at a roadside rest area with level ground sufficient for the trucks.



Figure 1. Test tractor-trailer on track in skirt-only configuration.

Track weather data was provided by a portable weather station positioned approximately 50m inside the track in an open, paved area. The weather station sampled wind speed and direction (Met One Instruments, model 034B) at 10 feet above the ground and temperature (Met One Instruments, model 083E) at approximately five (5) feet. The weather station was calibrated in accordance with manufacturer specifications at the SwRI San Antonio, Texas, facility. Ambient temperature and wind speed data (both average and gust wind speeds) were used to determine if the runs were valid relative to weather constraints of the J1321 standard.

Fuel weights were taken using a portable scale (Ohaus Scale, model T51P-Defender 5000) affixed to a rolling lift. This combination scale-lift was rolled under the portable fuel tank which could then be elevated to lift the portable fuel tank out of its cradle (See figure 2). The scale was calibrated at the beginning of each test day with a 25 lb weight.



Figure 2. Example of weigh tank apparatus retrofitted to each tractor.

Three (3) combination tractor-trailers were selected that had identical manufacturer specifications and similar wear.² The trucks used for this test were USEPA SmartWay-designated, 2012 Freightliner Cascadia model 125 trucks with Detroit DD15 engines. The engines were rated at 488 hp at 1800 RPM. They had Fuller model FRO-15210C 10-speed transmissions with a Rockwell model MT-40-14X rear axle that has a 3.36 gear ratio. Each tractor was retrofitted with a cradle for a portable fuel tank that extended rearward from the frame rails. (See figure 1.) The tank location was selected to minimize the length of the connecting

² The control tractor was retrofitted with manufacturer-produced, aerodynamic chassis fairings to match the two test tractors. All three trucks used ten (10) new, verified low rolling resistance tires that were conditioned, from new, by SwRI in accordance with the SAE J1321 requirements.

¹ The SAE J1321 protocol uses a two or more trucks to determine if a change made to test truck(s) changes the amount of fuel used to run the same distance and speed. One truck, and control truck, remains unchanged to account for environmental and testing variables.

fuel hoses and potential for interfering with natural airflow around the tractor. Straps secured the tank while moving and incorporated quick release buckles so they could quickly be loosened and allow the tank to float freely. This enabled the scale-lift to be rolled under a portable tank and suspend the tank to expeditiously obtain the tank weight. Additionally, each tractor was retrofitted with external electronic fuel valves that to allow the driver to switch between the truck saddle tanks and the portable weigh tanks. A toggle switch and LCD timer (counter) were mounted on the dash of each truck so the driver had easy access to switch between fuel sources while driving. The in-cab switch allowed the driver to accelerate to the test speed, switch to the weigh tank at a predetermined location, then switch back to the saddle tanks at a predetermined location once the desired distance had been traveled. This eliminated fuel draw from the weigh tanks during the acceleration and deceleration portion of the runs.

Prior to each test, each tractor's cruise control was calibrated at the track. This was done using the retrofitted, in-cab timers. A target distance was selected and each of the three tractor-trailers was timed while using the cruise control set to 62mph. Any differences in the time it took the trucks to complete the distance was addressed by normalizing the cruise controls to match one of the truck times. This was done onsite by accessing the tractor's electronic control unit (ECU). Once the cruise controls were calibrated, they were checked each day of testing during the warm-up (practice) laps and adjusted as necessary once the tractor-trailers were at test conditions.

ECU data was recorded during each run. The ECU was connected to a Campbell Scientific, Inc. CR3000 Micrologger, and vehicle performance data was recorded at a rate of 1 Hz. The vehicle performance data used to calculate the reduction in fuel consumption was the fuel rate.

The trailers were 2009 Wabash 53 foot box, van type trailers, with bi-fold rear doors and air ride suspension. The trailers were ballasted so that each tractor-trailer totaled 65,720 lbs $\pm$ 500 lbs.

The trailer aerodynamics package tested include front, side, and rear fairings, commonly referred to as nose, side skirts, and boat tails, respectively. The front (1% bin), side (5% bin), and rear (5% bin) fairings were USEPA SmartWay verified as individual components so they had undergone some level of testing and review prior to selection for this research. They had not undergone USEPA SmartWay verification testing as a single, collective package. The same side skirts were used in both aerodynamic configurations, i.e., the full package and side skirt only installations.

Gravimetric Test Method

Reduction of fuel consumption was evaluated using the Society of Automotive Engineers (SAE) J1321 test method, also known as the SAE J1321 - SAE Fuel Consumption Test Procedure Type II (2012 revision). This method provides a standardized test procedure for comparing the fuel consumption of two conditions of a test vehicle.

An unchanging control vehicle was run in tandem with the test vehicle to provide reference fuel consumption data. This procedure is especially suitable for testing components that require substantial time for removal and replacement or modification, (e.g. tires and aerodynamic fairings.) During the track testing, a three (3) truck approach was taken using one (1) control truck and two (2) test trucks. On-road testing was done with the conventional, two (2) truck scheme.

The SAE J1321 procedure requires the use of "T/C ratios" to calculate a reduction in fuel consumption. The T/C ratio for a run is found using³

$$\frac{T}{C} = \frac{\text{Test Truck Fuel Consumption}}{\text{Control Truck Fuel Consumption}}$$

In accordance with the current version of the SAE J1321, all data for which there was no mechanical or procedural disqualification was considered valid. However, the "2% test" from the previous (1986 reaffirmed) version was applied as a diagnostic. Specifically, after three runs have been completed, the T/C ratios are tested for repeatability by multiplying the highest T/C ratio by 0.98 to establish the lowest acceptable T/C ratio, ensuring that the highest and lowest T/C values for a run vary by no more than 2%. If the three T/C ratios are outside of the acceptable range, it trigger additional review of the equipment and procedures for that segment. At least three (3) valid runs are needed to make a segment.⁴

To determine the percentage of fuel saved, an average T/C ratio is calculated for each segment. The average T/C ratios from each baseline segment (B) and each test segment (T) are used to calculate percent fuel saved as follows:

$$\text{Percent fuel saved} = \left(\frac{(B - T)}{B} \right) \times 100$$

Engine Control Unit Data Collection and Analysis

In addition to the gravimetric fuel usage measurement, ECU fuel-rate data was collected and used to explore how the fuel-savings estimates would compare. ECU generated fuel-rate data was logged for each segment (i.e., baseline and test). Start and end times for each run were manually recorded by the drivers, and the time associated with each fuel-rate data point was recorded by the data logger. Time stamps for each data point were compared to the start and end times provided by drivers in order to organize the ECU generated fuel-rate data by test, truck, and run (e.g. test 7, test truck, run 1). The arithmetic average fuel rate was then calculated for each individual run.

Further analysis of the fuel rate data was designed to closely mirror the methods prescribed by the SAE J1321 method.⁵ The average fuel rates were used to calculate a T/C ratio for each run.

³ A "run" is a fixed distance. It can be multiple laps around a track or simply driving out and back on a highway. Fuel usage is weighed after each run.

⁴ A "segment" is a set of at least three (3) valid runs under the same configuration. For example, the "baseline" segment is the set of valid runs with all trucks in the baseline configuration. The "test" segment is the set of runs with the modification (e.g., adding a trailer skirt) on the test truck and the control truck remaining in the baseline.

⁵ No confidence interval was calculated for the three (3) ECU data points for each segment since each ECU "run" was an averaged value.