

EPA Smartway Verification of Trailer Undercarriage Advanced Aerodynamic Drag Reduction Technology

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ABSTRACT

The results of a technology verification study are presented. The study focused on undercarriage aerodynamic drag reduction devices that improve the operational fuel economy of tractor-trailer vehicles and increase undercarriage access for maintenance and inspection. The Split Skirt (SS) and Wheel Cavity Cover (WCC) concepts were tested to obtain Environmental Protection Agency (EPA) SmartWay (SW) verification, California Air Resources Board (CARB) acceptance and to address the needs of the industry. Fuel consumption tests were performed in accordance with the Society of Automotive Engineers (SAE) J1321 Test Procedure as modified by the EPA SW Interim Test Method. To further minimize sources of error the test employed identical tractor-trailer combination vehicles and constrained the test to wind velocity less than 10mph. Test results were obtained on nine (9) SS variations and two (2) WCC based concepts. Three SS concepts were EPA verified to provide fuel savings greater than 5% and four SS concepts had EPA verified fuel savings between 4 and 5%. To develop an understanding of the in-service fuel savings of the Split Skirt concept various skirt gap settings were evaluated. For the 18-foot SS the data show a 2-foot gap reduces the fuel savings from 4.5% to 4.3% and a 4-foot gap reduces fuel savings from 4.5 to 4.2%. In a worst-case scenario, slider in the full aft position, fuel savings is reduced from 4.5% to 3.8%. EPA verified WCC test data were obtained for the WCC installed with and without the SS aft panel. WCC test results show a fuel savings of 1.3% and 2.4% for the WCC based concepts.

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INTRODUCTION

The rising cost of fuel is placing a heavy burden on the freight industry. Numerous studies have shown that the application of aerodynamic technology to the heavy truck-trailer vehicle can provide up to twenty percent improvement in fuel economy [1, 2]. In addition the freight industry requires aerodynamic solutions be operationally practical, aerodynamically robust, and satisfy all safety requirements. It is within this context that the subject study has been conducted.

The primary resistance forces for heavy trucks are drive-train losses, rolling friction, and aerodynamic drag, [3, 4, 5]. However, the rate of increase in aerodynamic drag with increasing vehicle speed is much greater than that for rolling friction such that at approximately 50 mph the force to overcome aerodynamic drag exceeds that required to overcome rolling resistance. Aerodynamic design efforts must take into account operational and environmental factors, such as wind disturbances from traffic and weather. Compared to the ideal case these factors can dominate the aerodynamic drag of tractor-trailer trucks [1, 2, 6, 7, 8] and

increase the aerodynamic loading on a vehicle. The review showed that under ideal conditions a tractor-trailer have a drag coefficient between 0.6 and 0.7 whereas a tractor-trailer truck that does not have aerodynamic shaping and fairings will have a drag coefficient of 0.7 to 0.9.

A review of heavy truck aerodynamic design trends [3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18] show that the industry has focused on reducing the aerodynamic drag of the forward facing surfaces of both the tractor and trailer. Test data have produced reductions in the aerodynamic drag of 30% with corresponding improvements in fuel economy approaching 15%. However these improvements have not been consistently realized under operational conditions for the reasons mentioned previously [5, 6, 7, 12, 14, 19, 20]. In an operational environment the unsteady and erratic flow that the vehicle experiences degrades the effectiveness of these aerodynamic devices. An assessment of the aerodynamic drag in an operational environment indicates that the reduction in aerodynamic drag at 60 mph would be closer to 20%, which corresponds to a 10% improvement in fuel economy.

The objective of the present activity is to design, develop, and demonstrate undercarriage aerodynamic drag reduction devices that would improve the operational fuel economy of tractor-trailer vehicles. A further objective was to develop novel technologies and concepts that would improve undercarriage access for maintenance and inspections. The design activity initiated with an extensive literature review to identify the numerous devices and technologies that have been previously developed [21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38]. To ensure relevance of the design activity vehicle operations, maintenance, safety, weight, and cost would be primary constraints in the design. Additional vehicle performance factors addressed in the design activity are aerodynamic loads, stability and handling, braking, and splash and spray.

DISCUSSION

Trailer undercarriage drag reduction is currently an area that has seen a rapid growth interest as indicated by the large number of products seeking verification from the Environmental Protection Agency (EPA) SmartWay (SW) program [38] and acceptance by the California Air Resources Board (CARB) [39]. Obtaining EPA verification and CARB approval requires that a proposed technology be tested, by a third party provider, in accordance with the EPA fuel consumption test protocol [40] based on the Society of Automotive Engineers (SAE) J1321 Recommended Practice [41]. The remainder of this paper will present the results of the EPA SW verification testing of the Split Skirt (SS) and Wheel Cavity Cover (WCC) undercarriage aerodynamic drag reduction technologies.

Background

Trailer undercarriage aerodynamic drag results from air interacting with; A) structural elements, B) landing gear, C) reefer tanks, D) tool boxes, E) spare tires, F) slider assembly, G) brake and axle systems, and H) wheels and tires. Under operational conditions trailer skirts have shown to be effective at minimizing the drag associated with items A through G but are ineffective for item H. In addition, single panel skirts may interfere with trailer maintenance and restrict access to the reefer tanks, toolboxes and spare tire. Constrained access is partly attributed to the length of continuous skirts that vary from 22 to 26 feet [35, 36, 37, 38, 39], see upper sketch of [figure 1](#). To provide access manufacturers of continuous skirts may request waivers from EPA SW [38] and CARB [39] to modify their products by reducing skirt length and cutting holes, slots and doors into the skirt panel. These modifications can result in a reduction in the fuel savings benefit. The most significant limitation of continuous skirts may be the loss in fuel savings, compared to EPA test data, when a gap opens between the rear edge of the skirt and the forward tire of the tandem, see lower sketches in [figure 1](#). A few manufacturers [38] have addressed the skirt-

to-wheel gap problem with a telescoping system that increases the length of the continuous panel concept.

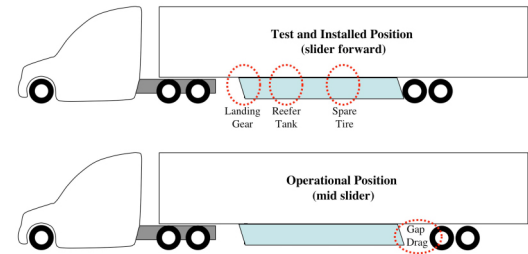


Figure 1. Sketch highlighting potential limitations for single panel skirts.

Aerodynamic Technologies

The Split Skirt (SS) and Wheel Cavity Cover (WCC) concepts were developed as companion technologies to address the operational and maintenance concerns noted for continuous panel skirts and reduce undercarriage drag of all components including wheels and tires.

Split skirt

Shown in [figure 2](#) are sketches of a two panel SS. The SS is a patent pending multi-panel skirt (with two or more panels) in which the aft most panel is installed so that it moves with the slider, see [figure 2](#). Allowing the aft panel to move with the tandem eliminates the skirt-to-wheel gap (wheel-gap) and replaces it with a skirt-gap that has a significantly lower gap drag penalty resulting in greater fuel savings compared to continuous panel designs. When a gap is created the shear layer separating from the trailing edge of a skirt panel, located immediately upstream of the gap, will turn inward towards the trailer centerline. For a skirt with a wheel-gap the inward turning flow will impinge on the blunt face of the tire resulting in an increase in surface pressures and a significant increase in drag. In contrast the SS concept replaces the wheel-gap with a skirt-gap where the inward turning flow impinges on a forward edge of the aft panel resulting in a minimal increase in surface pressure and drag on the aft panel. The aft panel of the SS concept redirects the airflow past the high drag blunt forward facing surface of the tire.

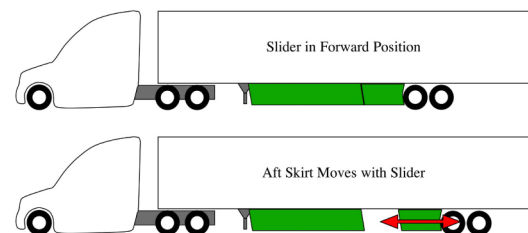


Figure 2. Schematic showing the Split Skirt concept.

Wheel cavity cover

Shown in [figure 3](#) is a sketch of the patent pending WCC. The WCC is a rigid circular panel with a large centrally located hole that restricts the drag producing air from entering the wheel cavity while providing visual and physical access to the wheel and hub for maintenance and safety checks. The design blends performance and functionality to maximize performance and wheel access. The dimensions of the centrally access hole are based on aerodynamic flow control technology which directs the high speed drag producing air to pass over the opening and at the same time allows for low volume and low velocity cavity inflow and outflow air exchange for brake cooling.

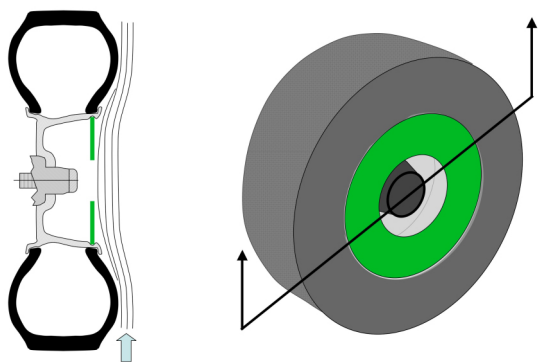


Figure 3. Schematic showing the Wheel Cavity Cover concept.

Test Process

The SS and WCC concepts were tested to obtain EPA SW verification [38], CARB acceptance [39] and to address the needs of the industry [34]. Fuel consumption tests were performed by the Transportation Research Center [42] in accordance with the SAE J1321 "Joint TMC/SAE Fuel Consumption Test Procedure - Type II" [41] with the added requirements of the EPA SW "Interim Test Method for Verifying Fuel Saving Components" described in the February, 2010 release [40].

Below is a listing of the additional EPA SW test method requirements.

- a. Test track length > 1.5 miles (5 miles recommended).
- b. Grade change not greater than 2 degrees.
- c. Altitude less than 4,000 feet.
- d. Air temperatures 41° to 95° F, change in test temperature 30° F.
- e. Wind speed ≤ 12 mph. Wind gusts ≤ 15 mph.
- f. Top speed ≤ 65 mph.
- g. Test trailer; similar dry box semi-trailer, 53' long, 102" wide, and 13' 6" high.
- h. Weight of the trailer and payload of 46,000 pounds, +/- 500 pounds.

i. Tires must be inflated to manufacturer-recommended maximum cold inflation pressure.

j. Tires must be similar in size and condition with at least 500 miles wear-in prior to start of test.

k. Tractor-trailer gap; similar on all trucks.

l. Test tractors; similar with features typical of line haul combination trucks.

These additional EPA SW test requirements improve the test process but do not adequately address wind speed and vehicle differences that significantly impact the test results, see items e, g, k, and l above. The combination of these four factors can produce results that are not representative of the subject technology under investigation. Vehicle mismatch coupled with variations in wind conditions during the test can produce test results that reflect differences in test vehicles and not the technology under investigation. To minimize these sources of error the current test employed identical tractor-trailer combinations and constrained the test to wind conditions below 10mph.

Description of test vehicles

2006 Freightliner Century tractors towing 53-foot van trailers were used for the test. Details of the test vehicles are listed in [Table 1](#). Photographs of the test vehicle with the SS installed are shown in [Figures 4](#) and [5](#). Photographs of the test vehicle with the both the SS aft panel and WCC installed is shown in [Figure 6](#) and a photograph of the WCC installed is shown in [Figure 7](#).

Table 1. EPA Smartway verification test vehicle descriptions.

	CONTROL VEHICLE	TEST VEHICLE 1 / 2
TRACTOR MAKE	Freightliner	Freightliner
TRACTOR MODEL	Century	Century
TRACTOR YEAR	2006	2006
ENGINE	Detroit	Detroit
RATED POWER	515 HP @ 2,100 RPM	515 HP @ 2,100 RPM
ODOMETER	505,085 miles	507,439 miles
TRANSMISSION	Eaton Fuller FRO-16210C 10-Speed	Eaton Fuller FRO-16210C 10-Speed
DRIVE AXLES (FR)	Arvin Meritor R020/45NFN1053	Arvin Meritor R020/45NFN1053
DRIVE AXELS (RR)	Arvin Meritor R020/45NFN1073	Arvin Meritor R020/45NFN1073
AXLE RATIO	3.58:1	3.58:1
TRAILER MAKE	Vanguard	Vanguard
TRAILER MODEL	VIP4000	VIP4000
5 th WHEEL SETTING	30"	30"
TRAILER TEST WEIGHT	46,050 lbs.	45,930 lbs. / 46,390 lbs.