

Understanding Practical Limits to Heavy Truck Drag Reduction

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ABSTRACT

A heavy truck wind tunnel test program is currently underway at the Langley Full Scale Tunnel (LFST). Seven passive drag reducing device configurations have been evaluated on a heavy truck model with the objective of understanding the practical limits to drag reduction achievable on a modern tractor trailer through add-on devices. The configurations tested include side skirts of varying length, a full gap seal, and tapered rear panels. All configurations were evaluated over a nominal 15 degree yaw sweep to establish wind averaged drag coefficients over a broad speed range using SAE J1252. The tests were conducted by first quantifying the benefit of each individual treatment and finally looking at the combined benefit of an ideal fully treated vehicle. Results show a maximum achievable gain in wind averaged drag coefficient (65 mph) of about 31 percent for the modern conventional-cab tractor-trailer.

INTRODUCTION

Fuel costs and environmental pressures continue to promote interest in improving fuel economy in the commercial vehicle transportation sector.¹ Heavy trucks have evolved with most truck manufacturers now

offering streamlined models. Conversely, most trailer manufacturers have strived to maintain operational objectives such as a rectangular cross section for the maximum cargo space and a bluff rear end for easy loading access.² This has led to the development of commercially available trailer-mounted add-on devices for the purpose of drag reduction.

Some performance claims made by inventors and commercial vendors lack the backing of rigorous testing. In addition, experimental studies fall short by not reporting results with a true uncertainty analysis.

A research program is underway at the Langley Full Scale Tunnel to understand the ideal limits to drag reduction due to add-on technologies used with standard trailer designs and a modern streamlined conventional cab. This work is aimed at contributing to the art by providing a data set with the following attributes:

- Ideal limits to popular device performance
- Modern streamlined tractor design
- Sufficient model detail
- Drag reduction devices representative of many current market offerings
- Virtually no boundary effects over yaw sweep

- Sufficient Reynolds Number
- Minimum interference from support structure
- Overall uncertainty analysis, (not back to back point repeatability)

EVOLUTION OF HEAVY TRUCK DRAG REDUCTION TECHNOLOGIES

The pursuit of low-drag heavy truck designs started in the 1930's. Early efforts at reducing truck drag focused on integrated streamlined cab and trailer designs, a concept now being revisited by major manufacturers. Conversely, the majority of heavy trucks in the current fleet make use of trailers and tractors from independent manufacturers. Over the past 30 years, tractor manufacturers have made great strides in streamlining their product. Initially, add on roof-top flow deflectors were introduced and gradually an overall design philosophy has evolved which integrates the rooftop flow deflector concept, streamlines the side transitions with skirts and cab extensions, may include a front bumper treatment, and provides detail optimization in areas like mirrors and blending fillets.³ On the other hand until very recently, trailer designs have focused more on optimizing utility and cargo capacity, not aerodynamic drag. One noted exception is the work of Trailmobile where a wind tunnel program led to detail optimization of trailer corner radii and side panels.⁴ The technology to provide significant drag savings with add-on devices has been available since at least the 1970's. Recent work has focused on creating devices that are operationally friendly – those that do not restrict access to the cargo doors or gap area or reduce ground clearance drastically. The heavy truck wind tunnel model chosen for this study was originally developed in 2005 to evaluate several new minimally invasive drag reduction devices under the sponsorship of the US Department of Energy.² For a fairly recent, concise historical review of commercial vehicle drag reduction, see reference 4.

EXPERIMENT DETAILS

FACILITY - The LFST (formerly the NASA LaRC Full-Scale or NASA 30 by 60) features a large $\frac{3}{4}$ open-jet test section and large ground board.⁵ Full-scale vehicles ranging from conventional cars to Class-8 tractors with shortened trailers can be accommodated. The test section is semi-elliptical in cross section with a width of 18.3 m (60 ft) and a height of 9.1 m (30 ft). The ground board is 13 m wide by 16.0 m long and features a turntable with a diameter of 8.7 m. The overall aerodynamic layout of the facility, showing the double return design, is given in Figure 1. Power is supplied by two 3 MW (4000 HP) electric motors driving two 10.6 m diameter four-bladed fans. For this test the 6-DOF automotive balance was used to measure body-axis vehicle drag, side force, and yawing moment. Ground board boundary layer control was provided through a raised ground board with a suction slot located just

upstream of the vehicle.⁶ The large $\frac{3}{4}$ open jet test section of the LFST is ideal for testing the $\frac{1}{4}$ scale truck model at high yaw angles with negligible boundary

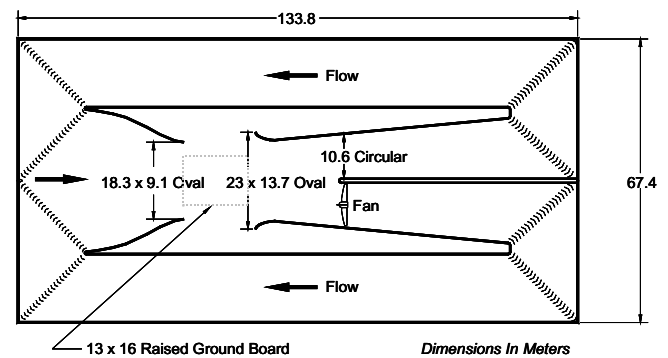


Figure 1 The Langley Full Scale Tunnel Plan View

effects.

MODEL – The SOLUS and ODU Representative Heavy Truck (SORHT) model is a $\frac{1}{4}$ scale, class 8, heavy truck model with overall proportions derived from the DOE Generalized Conventional Model (GCM), but with the addition of tires and axles, trailer structural underbody elements, landing gear, mud flaps, and other details. The cab contours were chosen as representative of current streamlined commercial models. A picture of the model in the test section is shown in figure 2 and a



Figure 2 SORHT Wind Tunnel Model

dimensioned drawing is included in the appendix. It should be noted that the model was tested without mirrors. The model was positioned on the balance such that the ground board boundary layer control slot was located approximately 0.23 m upstream of the cab bumper as shown in figure 3. Roughness elements were positioned on the trailer sides to force transition in order to match the full-size turbulent boundary layer character at the trailer base.

DRAG REDUCTION DEVICES – all the devices chosen for this test have been shown in the literature to be practical add-on devices with many variants available commercially. The configurations were chosen to characterize, as well as bracket the practical through

ideal potential of the devices, both individually and working in concert as a full treatment. Figure 4 summarizes the tested configurations where the baseline model is the unmodified SORHT model and the shaded areas illustrate the devices.

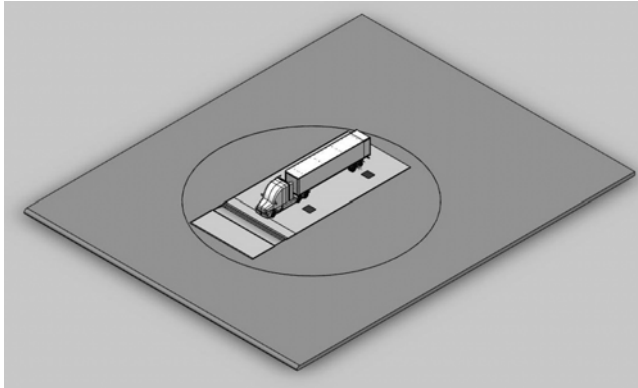


Figure 3 Model Location on Ground Board Showing Turntable and Boundary Layer Control Slot

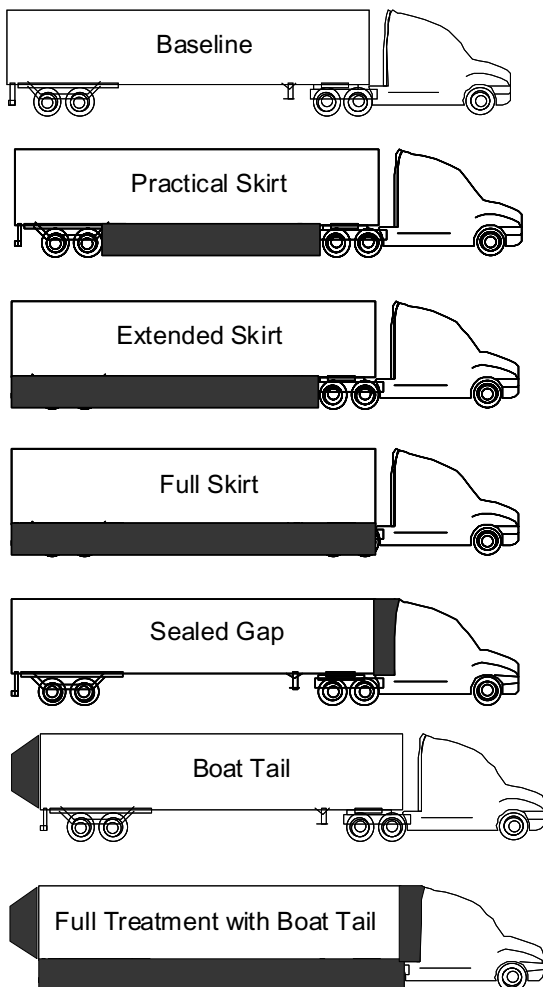


Figure 4 Test Configurations

Practical Skirt - The practical skirt represents many of the commercially available trailer skirts in that it fits between the cab rear wheels and the trailer wheels. The ground clearance was adjusted to approximately 8 mm (on the model), an impractical height, but one that would indicate the ideal limit to potential performance gains.

Extended Skirt - The extended skirt explores the potential of covering the trailer wheels. Again, the ground clearance was adjusted to approximately 8 mm.

Full Skirt - The full skirt explores the potential of covering both the trailer and rear tractor wheels. Again, the ground clearance was approximately 8 mm. This skirt is the least operationally practical but provides the upper bound in performance particularly when used with other devices in the fully treated case.

Sealed Gap - The detrimental effects of gap flows are well known. Many current gap treatments strive to prevent as much cross flow as possible. In order to seek the ideal, the gap was completely blocked and formed to smoothly transition the cab to trailer gap. All seams were taped to ensure a seal. A picture of the sealed gap filler is included in the appendix.

Boat Tail - The open boat tail treatment (or base flaps) was constructed of thin sheet metal which formed a 15 degree tapered rear with an open cavity, extending 0.15 m aft of the baseline trailer model.

TEST PROCEDURE AND DATA REDUCTION

Test Conditions and Drag Measurement - All configurations were tested at a nominal dynamic pressure of 10 psf over a yaw sweep of +/- 15 degrees. The nominal Reynolds number based on trailer width (Re_w) was 1.26×10^6 , felt to be adequate to avoid scaling issues.^{8,9} The zero yaw case was repeated for each configuration, and two of the configurations were chosen at random to be run as complete replicates for uncertainty estimates. A PC based data acquisition system with a 16-bit A/D samples both automotive balance load cell forces, as well as a differential pressure transducer dedicated to dynamic pressure measurement. The drag force measurement and wind tunnel dynamic pressure calibration was conducted as specified in the SAE J1252 recommended practice. Detailed data for each configuration yaw sweep is presented in the summary plot of the appendix.

Response Model - A cubic spline was fit to each configuration yaw sweep to allow interpolation between the recorded yaw values and those required for calculation of wind averaged drag coefficients at various highway speeds.¹⁰ Wind averaged drag coefficients calculated using SAE J1252 with a chosen highway speed of 55 and 65 mph are presented (in rank order) in figure 5. Individual device drag increments are