

Considerations for the Wind Tunnel Simulation of Tractor-Trailer Combinations: Correlation of Full- and Half-Scale Measurements

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ABSTRACT

The 9-meter wind tunnel of the National Research Council (NRC) of Canada is commonly employed in testing of class 8 tractors at full- and model-scales. In support of this work a series of tests of an identical model at full- and half-scale were performed to investigate some of the effects resulting from simulation compromises.

Minimum Reynolds Number considerations drive the crucial decisions of what scale and speed to employ for testing. The full- and half-scale campaigns included Reynolds Number sweeps allowing conclusions to be reached on the minimum Reynolds number required for testing of fully-detailed commercial truck models. Furthermore the Reynolds sweeps were repeated at a variety of yaw angles to examine whether the minimum Reynolds Number was a function of yaw angle and the resulting flow regime changes.

The test section of the NRC 9-meter wind tunnel is not sufficiently long to accommodate a full-scale tractor and a typical trailer length of 48' or more. Most of full-scale testing is therefore conducted with a more manageable 28' trailer. To quantify the effects of this simplification the half-scale model was tested with representations of 28' and 48' trailers. The changes in the baseline drag curves will be presented along with the effect of trailer devices, such as skirts, on the different lengths of trailer.

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INTRODUCTION

Following the renewal of full-scale tractor-trailer testing at the 9-meter wind tunnel [1] a half-scale to full-scale correlation test was undertaken to evaluate the effects of test section blockage [2] along with the Reynolds Number study presented here. The intent of this work was to determine the ideal scale of model for testing in the 9-meter wind tunnel; with a smaller footprint than the ground simulation system yet large enough to achieve flow similarity.

Test Section Configuration

The test section of the NRC 9-meter wind tunnel has a square 9-meter cross section, with corner fillets, and is 23-meters long. [Figure 1](#) is a plan view showing the boundaries of the test section along with the layout of the 45° corner fillets. The test section is equipped with a rotating floor turntable, containing a ground effect simulation system (GESS), shown in red, over an under-floor balance. The

GESS consists of a center belt, with an exposed area 1-m × 5.7-m, four wheel rollers and four chassis struts for ride height control. Upstream of this are two plenums for a distributed suction system, shown in blue, calibrated to reduce displacement thickness of the floor boundary layer to 4-mm [3] at the leading edge of the model, without inducing flow angularity at the model. Breathers on the floor (shown in yellow) and walls, at the test section exit, are vented to the tunnel surroundings to raise the otherwise negative gauge pressure in the test section closer to atmospheric pressure.

Half-Scale Model Details

The half-scale model was a 2008 VNL630 with a roof deflector, tank skirts, side extenders and sun visor, as shown in [Figure 2](#). Some compromises in model geometry were required in the names of cost and practicality, for instance the rear axles of the trailer utilized off-the-shelf components which are not exact 50% replicas of the full-scale unit. The engine and accessories were simulated with simplified

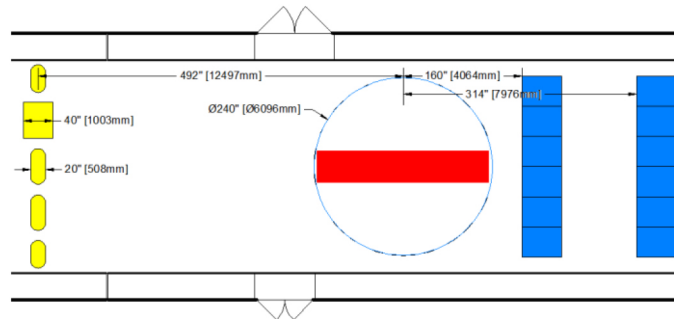


Figure 1. Test section layout for full-scale test; Wind direction from right to left (dimensions in meters).

components. The baseline trailer for this work represented the 28' trailer normally employed in full-scale testing at the 9-meter wind tunnel. Flush, static pressure taps were located along the centerline of the model's upper surface in addition to taps evenly distributed over the side of the cab and rear face of the trailer.



Figure 2. Baseline Configuration of VNL630.

Half-Scale Model Mounting

The half-scale model was completely supported by the under-floor balance and rested almost entirely within the floor turntable. The model mounting points did not match the locations of the struts and wheel rollers, normally employed for automotive testing. The unused rollers and struts that normally support automotive models are part of the main balance structure so plywood covers were fabricated to minimize tare drag loads as shown in [Figure 3](#).

Custom mounts were used which supported the model so the wheels were nominally 10-mm above the floor, while a motor inside the model rotated the tractor wheels at the blockage-corrected freestream velocity. A motor was not installed to rotate the trailer wheels due to weight/structural restrictions of the model and mounts, a necessary compromise it still allowed the study of wheel rotation effects though results with all model wheels rotating may differ.

Unless otherwise noted, all of the model-scale results presented throughout this paper were acquired with the GESS in operation.

The model was mounted so the front bumper was 140-mm downstream of the leading edge of the exposed belt. With a baseline tractor-trailer gap of 0.55-m, equating to approximately 43" in full-scale, the overall model length was 6.8-m. The model was longer than the exposed belt length of 5.7-m so the aft-most 1.3-m of the baseline model overhung the fixed floor. For select runs a trailer extension was added to represent a full-scale 48' trailer; in these cases the overall model length increased by 3.2-m resulting in 4.5-m of the model being over the fixed floor.

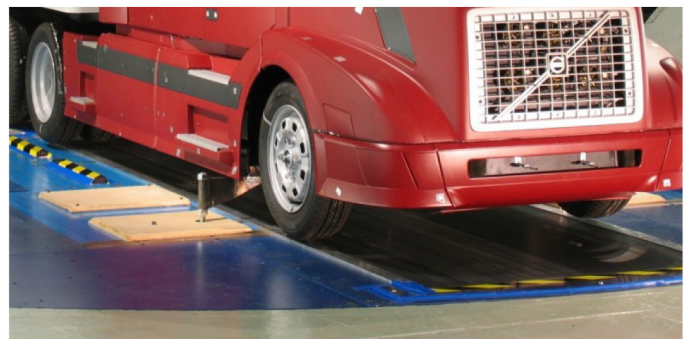


Figure 3. Details of the forward mounts and floor covers.

To prevent distortion of the wake of a bluff body, and consequent errors in drag force, the distance between the base of the model and the end of the test section should ideally exceed two times the square root of the frontal area of the model [4]. This criteria equates to approximately 3.3-m for the half-scale model. In the 9-meter wind tunnel, the end of the test section is defined by the breathers, where the constant static pressure region ends. There was 8.1-m and 4.9-m between the test section breathers and the base of the half-scale 28' and 48' trailers respectively, so the criteria for wake closure was met.

Taking advantage of existing mounting points on the model, the tractor was also supported at the rear bumper and the trailer was secured through the kingpin and a set of struts

near its midpoint. The instrumentation cables were routed along one of the trailer struts as shown in [Figure 4](#).

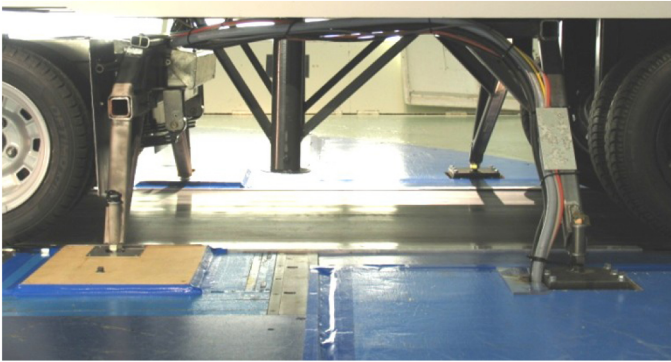


Figure 4. Details of the rear mounts and cabling.

The track width of the half-scale model coincided with the edges of the moving belt. The wide center belt is not attached to the balance therefore it was necessary for the struts to extend outwards as they approached the floor, [Figure 5](#). The struts were attached to the under-floor balance and consequently experienced tare and interference errors that were not quantified. Note that all of the mounting struts passed through clearance holes in the floor and were not attached to the floor itself.

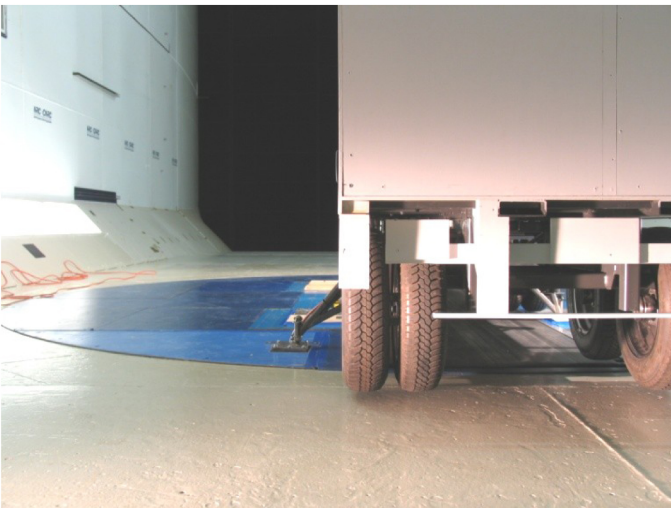


Figure 5. End view of the rear mounts.

Full-Scale Model Mounting

The full-scale test was performed on a production truck and trailer. The structure of the model could not be permanently modified for strut attachment points because it had to return to roadworthiness at the conclusion of the test. Because it utilized road-going engine and drivetrain components, the weight of the model also exceeded the capacity of the under-floor balance. An 8.5-meter (28 ft) trailer is the longest which fits through the test section hatch without modification. Even with this relatively short trailer

the model length exceeded the diameter of the floor turntable. As a result of these issues an unconventional support system was required to mount full-scale truck models in the 9-meter wind tunnel.

The front wheels of the truck were supported by air bearings as shown in [Figure 6](#). The forward trailer axle rested on air bearings while the suspension on the rear trailer axle was locked to maintain ride height, which left it suspended above the floor as shown in [Figure 7](#). The rear wheels of the tractor were supported by cradles, shown in [Figure 8](#), which were attached to the under-floor balance. Through these cradles the model could be rotated in yaw while the balance measured yaw moment, drag and side forces. The air bearings are essentially frictionless in the horizontal plane but transmit model loads to ground in the vertical plane so lift, pitch and roll moments cannot be measured with this setup. Fortunately the vertically-acting aerodynamic loads are generally negligible compared to the vehicle weight so this limitation does not hamper commercial vehicle testing.



Figure 6. Full-scale test of VNL630 in 2008.

To minimize friction at the air bearing / floor interface the air bearings operated on a set of steel plates (painted orange in the photos). The plates provided a smooth surface which was leveled with respect to gravity and set at the same absolute elevation to provide a flat plane for the truck to rest upon. The plates were also necessary to reinforce the test section floor and prevent bending of the floor. As a consequence of the leveling and stiffness requirements, the top surfaces of the plates were several inches above the tunnel floor. This had the undesirable effect of introducing floor discontinuities and distorted the flow compared to the freestream case.

A mitigating factor was that placing the model on the plates and air bearings raised it in relation to the boundary layer of the test section floor. The displacement thickness of the floor boundary layer was measured at 50-mm; the inflated air bearings raise the model 51-mm above the air bearing plates so the underside of the model wheels were essentially the distance of the displacement thickness above the front