

The Influence of Disablement of Various Brakes on the Dry Stopping Performance and Stability of a Tractor-Semitrailer

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ABSTRACT

This research was performed using a designed experiment to evaluate the loss of dry surface braking performance and stability that could be associated with the disablement of specific brake positions on a tractor-semitrailer. The experiment was intended to supplement and update previous research by Heusser, Radlinski, Flick, and others. It also sought to establish reasonable limits for engineering estimates on stopping performance degradation attributable to partial or complete brake failure of individual S-cam air brakes on a class 8 truck. Stopping tests were conducted from 30 mph and 60 mph, with the combination loaded to GCW (80,000 lb.), half-payload, and with the flatbed semitrailer unladen. Both tractor and semitrailer were equipped with antilock brakes. Along with stopping distance, brake pressures, longitudinal acceleration, road wheel speed, and steering wheel position and effort were also recorded. Relative stopping performance levels were comparatively analyzed for the three load conditions and effective deceleration degradation was analyzed for the various combinations of active brakes.

INTRODUCTION

BACKGROUND – Historically, many research projects and associated publications have discussed testing and/or analytical models of the effects of slack adjustment on the stopping performance of S-cam air brakes. These findings have been presented in many forums, including those of Heusser in 1991 [1], Radlinski in 1987 [2], and Flick and Radlinski in 1988 [3].

Radlinski, et al., developed a higher-order polynomial model that was derived from extensive testing on NHTSA's inertia brake dynamometer, once located at the Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. Heusser's models are also based on inertial dynamometer test data, but factors are applied to account for cold brake stroke, etc. Heusser's model uses pressure and stroke force data from typical sized air chambers. Heusser's model also assumes a single drum-lining coefficient of friction of 0.30, which has, at times, been misunderstood and/or misapplied.

MOTIVATION – A goal of this research effort was to update the extensive efforts of Radlinski, Flick, and Heusser by designing an on-vehicle test that would establish upper bounds on the amount of degradation to vehicle braking effectiveness and stability for vehicles with disabled or misadjusted air brakes. A further goal was to establish a series of stopping performance data points that would be representative of contemporary over-the-road combination units being operated in fleet duty in North America. Finally, this test series was designed to develop a better understanding of the effects that disabled or misadjusted brakes might have on vehicle stability or steerability during emergency braking maneuvers.

RESEARCH

TEST VEHICLE – The test vehicle used in this research consisted of a 2006 International 9400i 6x4 conventional tractor, pulling a 2000 Trailmobile 2-axle 48-foot (14.6 m) long flatbed semitrailer. The vehicle is shown during testing at the GCW load condition in Figure 1. Vehicle details are located in tables in the Appendix section of this paper. The vehicle was loaded using calibrated weights at the Transportation Research Center (TRC), in East Liberty, Ohio. The weights were located on the semitrailer to achieve axle weights that would span those seen in normal use. The three loading conditions chosen include GCW (gross combined weight of 80,000 pounds), half-payload, and zero-payload conditions. As-tested axle weights are provided in tables in the Appendix. The service brakes on the truck had been properly maintained and were in proper working order at the time of this test. Care was taken to obtain a tractor and semitrailer whose brakes were suitably worn in, both to be representative of in-use vehicles and to eliminate the need for a burnish procedure. Brake stroke measurements were taken at the beginning and end of each test day.



Figure 1 Photograph of tractor-semitrailer at GCW during a braking maneuver.

TEST FACILITY – The test facility was the concrete Skid Pad at TRC. The concrete skid pad was designed for vehicle straight-line braking tests. The section of the Skid Pad that was used in this testing had nominal peak and slide traction levels of 0.94 and 0.83, respectively, as measured using the ASTM E274 and E1137 procedures.

TEST PROCEDURE – The truck brake testing was performed as per SAE J1626, and those procedures generally accepted by the National Highway Traffic Safety Administration (NHTSA) when testing trucks for FMVSS No. 121 compliance. Stopping distances were recorded using a Labeco 625 mechanical fifth wheel and computer that recorded initial braking speed and stopping distance. Speed signals were digitally recorded from an RT-3000 GPS-based inertial measurement unit mounted near the tractor C.G., and by a Datron optical fifth wheel mounted under the semitrailer, near the midway point between the kingpin and tandem axles. The vehicle was accelerated to a speed slightly above the initial braking speed, and then the brake pedal was quickly and fully applied while simultaneously de-clutching. Initial braking temperatures were monitored on brake positions 1, 3,

and 7 (as defined in Figure 2), and initial braking temperatures were controlled to remain less than 300 °F (150 °C). Initial braking time was that time when a pressure switch, attached to the brake pedal, was closed by pressure from the driver's foot during the stop. Brake applications were full-treadle, and the tractor and semitrailer ABS systems prevented wheel lock on the sensed brake positions. The steer axle and trailing drive axle brakes were sensed on the tractor. The lead axle brakes were sensed on the semitrailer. Un-sensed brakes, although under control of the ABS system, can experience wheel lock under certain condition during braking. For each test condition, four stops were made from 60 mph (96.6 kph). For selected test conditions, four stops were made from 30 mph (48.3 kph). For each load condition, a set of stops was recorded at the baseline condition (all brakes functioning properly), and then brakes were selectively disabled by closing off a ball valve located at the respective air chamber. Up to four brakes were disabled at any one time. Again, brake strokes were checked and recorded at the beginning and end of each test day.

RECORDED DATA – In addition to initial braking speed and integrated stopping distance being registered by the Labeco 625 system, the following data were digitally collected and stored on the computer:

1. tractor x, y, and z position near C.G.
2. tractor and semitrailer A_x , A_y , and A_z accelerations near C.G.
3. tractor roll, yaw, and pitch angles and rates
4. semitrailer roll, yaw, and pitch rates
5. tractor V_x , V_y , and V_z speeds near the C.G.
6. semitrailer V_y and composite (resultant) speeds
7. tractor and semitrailer individual wheel speeds
8. brake pressures at positions 1, 2, 3, 5, and 7 (refer to schematic in Figure 2).
9. tractor primary and secondary control pressures
10. semitrailer control pressure
11. tractor drive axle brake stroke (1 brake).

Tractor C.G. dynamic parameters (velocities, accelerations, rates of rotation, etc.) were measured via an RT-3000 GPS-based system. The inertial measurement unit (IMU) was mounted directly to the frame of the tractor, on the centerline, as close as could be to the estimated position of the tractor's unloaded C.G. The semitrailer inertial parameters (accelerations and rates) were measured via a Crossbow 6-axis IMU that was mounted halfway between the kingpin and rear tandems, on the lateral centerline of the semitrailer. Semitrailer speeds were measured at the same location using a Datron 2-axis optical fifth wheel. Brake pressures were measured using calibrated pressure gauges. Wheel speeds on all ten axle ends were measured via DC tachometers.

TEST ORDER – A schematic describing the brake position nomenclature is shown in Figure 2. The general test design is shown in Figure 3. The configurations depicted in Figure 3 are representative of the testing at the GCW load condition, from 60 mph. Some load-speed-brake configurations were not tested for the sake of test brevity. The as-run test matrix is shown in Table 7, located in the Appendix.

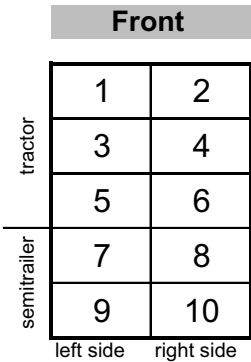


Figure 2 Description of brake position nomenclature

Brake Effectiveness Test Matrix

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Figure 3 Brake disablement test plan

DATA AND FINDINGS

VEHICLE AT GCW – Stopping distance values were corrected for initial braking speed as per SAE J299, then averaged by condition. 95 percent confidence intervals were computed for each mean, as shown in Equation 1. In the data charts that present stopping distance, the comparative stopping distances are shown using horizontal bar charts. The mean value for the four nominal stops for that condition is shown within each bar, and brackets at the end of each bar represent the confidence intervals.

$$CL = \pm z_{\alpha/2} \left(\frac{S}{\sqrt{n}} \right) \quad \text{Equation 1}$$

where:

CL = confidence interval

$z_{\alpha/2}$ = area under the normal curve

($z_{\alpha/2} = 1.96$ corresponds to a 95 percent CL)

S = sample standard deviation

n = number of samples.

If the mean of one sample group does not lie within the limits of the 95 percent confidence interval of another sample, then it can be said that the two sample means are considered statistically different. In other words, the two means are statistically different, with only a 5 percent chance that the sample groups are not different. Figure 4 compares the stopping distances from 30 mph at the GCW load condition. Figure 5 shows the relative drag factors, computed from the stopping distance means using Equation 2:

$$DF = \frac{V^2}{30 \times SD} \quad \text{Equation 2}$$

where:

DF = drag factor

V = initial braking velocity (mph)

SD = stopping distance (feet).

Data charts that present drag factors contain the mean and confidence interval, as do the stopping distance charts. Note that the 30 mph (48.3 kph) test conditions represented only a subset of the 60 mph (96.6 kph) test conditions (whose results are presented in Figure 6 and Figure 7). Where applicable, current NHTSA braking standards are shown for reference as a vertical line on the plot. Note that NHTSA does not publish any stopping distance standard for combination vehicles. The FMVSS No. 121 braking standards – explicitly for

single-unit trucks and truck tractors having a GVWR less than or equal to 50,000 lb (22,680 kg) – are presented here for reference only.

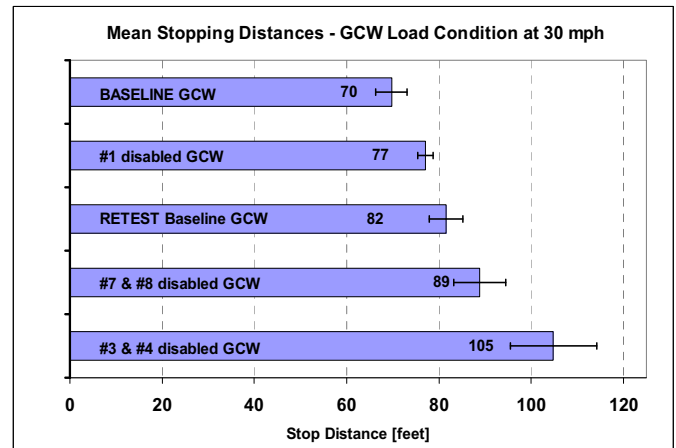


Figure 4 Average stopping distances from 30 mph for the GCW load condition.

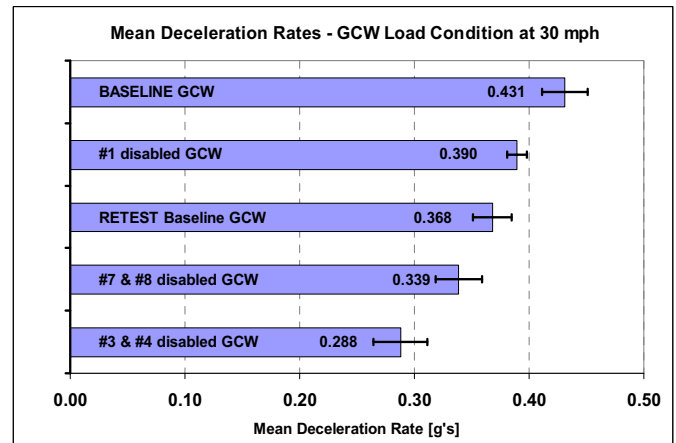


Figure 5 Drag Factors computed for the GCW load condition, stopping from 30 mph.

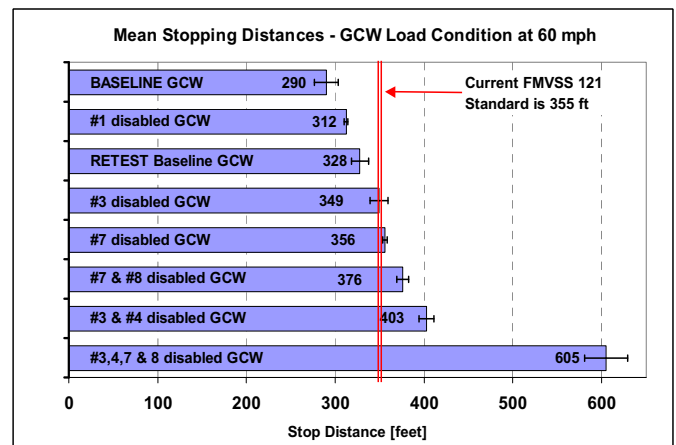


Figure 6 Average Stopping Distances for the 60 mph stops at GCW.