

Brake Timing Measurements for a Tractor-Semitrailer Under Emergency Braking

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ABSTRACT

The timing and associated levels of braking between initial brake pedal application and actual maximum braking at the wheels for a tractor-semitrailer are important parameters in understanding vehicle performance and response. This paper presents detailed brake timing information obtained from full scale instrumented testing of a tractor-semitrailer under various conditions of load and speed. Brake timing at steer, drive and semitrailer brake positions is analyzed for each of the tested conditions. The study further seeks to compare the full scale test data to predicted response from detailed heavy truck computer vehicle dynamics simulation models available in commercial software packages in order to validate the model's brake timing parameters.

The brake timing data was collected during several days of full scale instrumented testing of a tractor-semitrailer performed at the Transportation Research Center, in East Liberty, Ohio. Instrumented braking tests were performed at two speeds of 13.4 m/s (30 mph) and 27 m/s (60 mph) for 4 configurations including a bobtail condition, an unloaded semitrailer configuration, a half loaded semitrailer condition and a full gross vehicle weight condition. These straight-line braking tests were performed on dry concrete surfaces. In addition, brake-in-turn tests and stopping tests were performed on a wet jennite surface to evaluate the vehicle response and handling for ABS and non-ABS configurations

The effects of test conditions on brake timing are analyzed and are presented in this paper. The various braking configurations were simulated using detailed test parameters including brake system parameters at each wheel. Simulated vehicle kinematics were then validated against the full-scale test results and the simulation

process and choices are discussed. Brake lag (delay) times and first-order model time constants are offered and discussed. The findings of this study are also compared to other testing and simulation results published in literature on this topic.

INTRODUCTION

Brake timing for tractor-semitrailer vehicles has been evaluated in a limited fashion in past literature aimed at either accident reconstruction or modeling using computer vehicle dynamics simulation models. In the reconstruction field, brake timing is usually identified as brake lag, or the time required for the air brakes to become fully applied. Although recognizing that wheel location has an impact on the buildup of pressure at a given axle, reconstruction analysis is usually simplified by assigning a single number meant to account for the necessary delay in obtaining full braking at all wheels.

Computer simulation models on the other hand provide the ability to model braking parameters more extensively but present the opposite problem of requiring many parameters. The authors of this research wanted to offer additional and contemporary data of a real world vehicle in addition to the data already available in the public domain. The data are analyzed to provide the basis of both a simplified calculation and a more complex computer simulated analysis of tractor-semitrailer stopping performance.

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 long flatbed semitrailer. The vehicle is shown in Figure 1

during a test at the gross combined vehicle weight (GCW) condition. 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), which were placed on the truck to achieve axle weights that would span those seen in normal use. The three loading conditions chosen include gross combined weight of 80,000 pounds (GCW), half-payload, and zero-payload (LLCW) conditions. As-tested axle weights are listed 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, so burnish state would not be an issue. Brake stroke measurements were taken at the beginning and end of each test day.



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

TEST FACILITY – The test facility for straight-ahead stopping tests was the concrete Skid Pad at the transportation Research Center (TRC), located in East Liberty, Ohio. The concrete skid pad is heavily used in vehicle straight-line braking tests. The section of the Skid Pad that was used in this testing was measured to have nominal ASTM peak and slide traction levels of 0.93 and 0.82, respectively. The braking-in-curve stopping tests were performed on the 500-foot radius curved wet Jennite surface at TRC. TRC's wet jennite is an asphalt test pad coated with a Jennite sealant to achieve lower tire-surface coefficients of friction. The nominal ASTM traction levels were 0.15 and 0.30 to 0.34 for slide and peak, respectively.

TEST PROCEDURE – The truck straight-line brake testing was performed both in general adherence to SAE J1626 and those procedures accepted by the National Highway Traffic Safety Administration (NHTSA) when testing trucks for FMVSS No. 121 compliance. The vehicle was accelerated to near the initial test speed, and then the brake pedal was fully applied while simultaneously de-clutching. Initial braking temperatures were monitored and initial braking

temperature was controlled to remain less than 300 °F (149 °C). Brake applications were full-treadle, and the tractor and semitrailer ABS prevented wheel lock on the controlled brake positions. For each load condition, a set of stops was recorded at the baseline condition (all brakes functioning properly). On the wet Jennite, the stopping tests were performed along a 500-foot radius curve and the ABS was selectively disabled on the brakes of the tractor or the semitrailer.

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:

1. Tractor position (x, y, and z) near the C.G.
2. Longitudinal, lateral, and vertical accelerations (A_x , A_y , and A_z) near the C.G. of tractor and the semitrailer
3. Tractor roll, yaw, and pitch angles and rates
4. Semitrailer roll, yaw, and pitch rates
5. Tractor speed in the longitudinal, lateral, and vertical directions (V_x , V_y , and V_z) near the C.G.
6. Semitrailer lateral speed (V_y) and composite (resultant) speed
7. Individual wheel speeds on the tractor and semitrailer
8. Brake pressures on the tractor steer axle, the left brake position on the tractor drive axles and semitrailer axles (positions 1, 2, 3, 5, and 7)
9. Tractor primary and secondary control pressures
10. Semitrailer control pressure
11. Tractor drive axle brake stroke (1 brake)

Stopping distances were recorded using a Labeco mechanical fifth wheel that recorded initial braking speed and stopping distance. Tractor dynamic parameters (speeds, accelerations, rates of rotation, etc.) were digitally recorded from an OXTS RT-3000 GPS-based inertial measurement unit (IMU) mounted near the tractor's unloaded C.G. Semitrailer dynamic 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 and filtered with a 10 Hz, zero-phase digital low pass filter that emulates a 12-pole Butterworth. Brake pressure signals were similarly low pass filtered at 15 Hz.

TIMING DATA

Selected test data were organized into two groups for the purpose of analysis. Group A (see Table A) tests were performed in a straight line, on a dry surface with ABS functional on both the tractor and the semitrailer. These tests are presented for two loading conditions (GCW and LLCW). Tests were conducted at initial braking speeds of approximately 30 and 60 mph.

Group B (see Table B) includes all tests performed along a curved path on wet Jennite surface at an approximate speed of 30 mph with ABS operational or selectively disabled on the tractor or the semitrailer. All the tests in Group B were performed for a half-payload condition.

Table A: Group A Tests

Run #	Load	Speed (mph)	Brakes Disabled
1	LLVW	30-0	None
2	LLVW	30-0	None
4	LLVW	60-0	None
5	LLVW	60-0	None
6	LLVW	60-0	None
7	LLVW	60-0	None
8	LLVW	30-0	None
9	LLVW	60-0	None
30	GCW	30-0	None
31	GCW	30-0	None
32	GCW	30-0	None
33	GCW	30-0	None
34	GCW	60-0	None
35	GCW	60-0	None
36	GCW	60-0	None
37	GCW	60-0	None
38	GCW	60-0	None
39	GCW	60-0	None

Table B: Group B Tests

Run #	Load	Speed (mph)	Brakes Disabled
91	½ GCW	30-0	None
94	½ GCW	30-0	Tractor ABS off
95	½ GCW	30-0	None
96	½ GCW	30-0	None
98	½ GCW	30-0	Trailer ABS off

In group A (straight line dry tests), pressure rise plots at the wheels for a typical 60 mph LLCW condition are shown in Figures 2 (Steer axle, left and right wheels), Figure 3 (Front drive axle, left and right wheels) and Figure 4 (Front semitrailer axle, right wheel only). Figures 5, 6 and 7 are similarly presented for a 30 mph GCW configuration. For group B (Brake in curve on wet jennite tests), Figures 8, 9 and 10 present the pressure rise at the wheels for a 30 mph stop at the half-load configuration. Note that in Figure 9, the left second axle pressure was not recorded due to instrumentation failure.

Axle 1 Brake Pressure v. Time

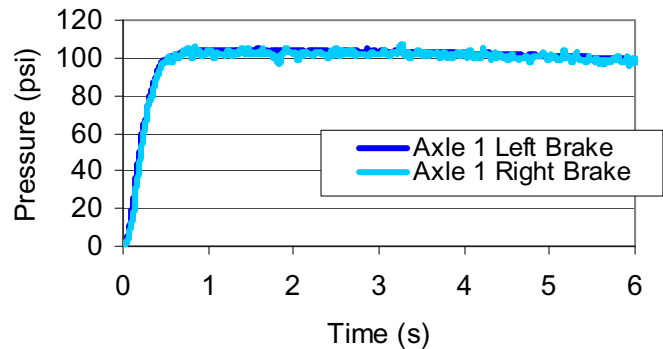


Figure 2: Run 5, 60 mph, LLCW, Dry, Straight Line

Axle 2 Brake Pressure v. Time

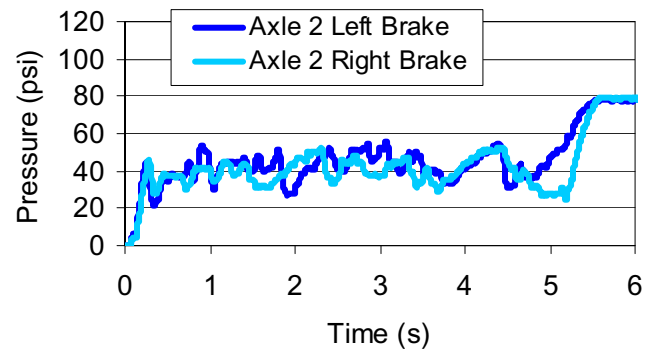


Figure 3: Run 5, 60 mph, LLCW, Dry, Straight Line

Axle 4 Brake Pressure v. Time

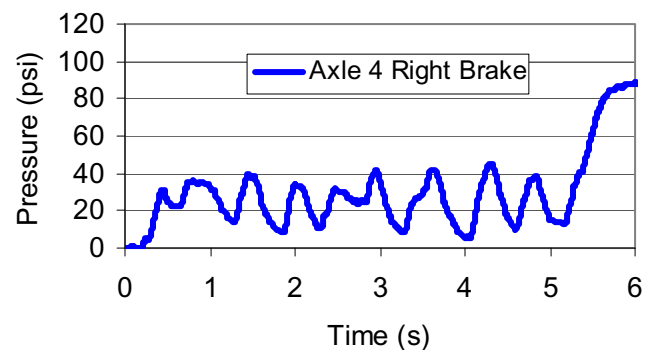


Figure 4: Run 5, 60 mph, LLCW, Dry, Straight Line

Axle 1 Brake Pressure v. Time

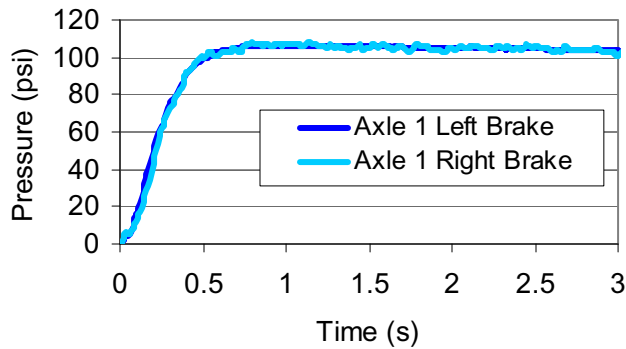


Figure 5: Run 32, 30 mph, GCW, Dry, Straight Line

Axle 1 Brake Pressure v. Time

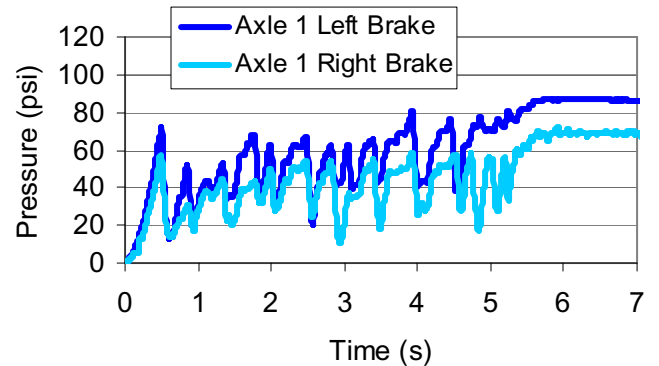


Figure 8: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

Axle 2 Brake Pressure v. Time

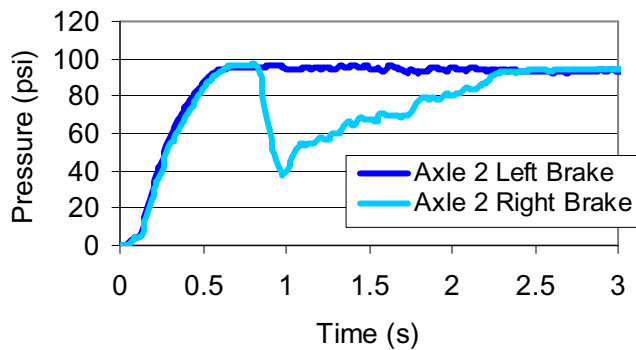


Figure 6: Run 32, 30 mph, GCW, Dry, Straight Line

Axle 2 Brake Pressure v. Time

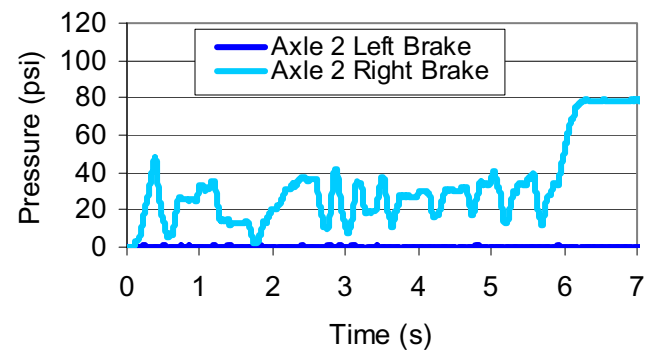


Figure 9: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

Axle 4 Brake Pressure v. Time

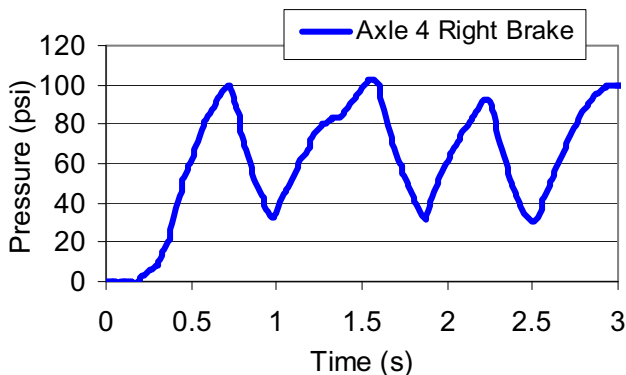


Figure 7: Run 32, 30 mph, GCW, Dry, Straight Line

Axle 4 Brake Pressure v. Time

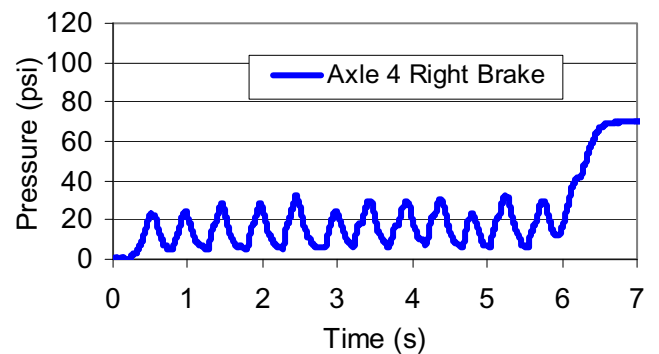


Figure 10: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

Tractor-Semitrailer deceleration data was also recorded and is presented below in Figures 11, 12 and 13 for the 3 cases presented above.