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Brake Timing Measurements for a Tractor-Semitrailer Under Emergency Braking

Fawzi P. Bayan, Anthony D. Cornetto III, Ashley (Al) Dunn, Eric Sauer
SEA Limited

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 (Ax, Ay, and Az) 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 (Vx, Vy, and Vz) near the C.G.
6. Semitrailer lateral speed (Vy) 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	1/2 GCW	30-0	None
94	1/2 GCW	30-0	Tractor ABS off
95	1/2 GCW	30-0	None
96	1/2 GCW	30-0	None
98	1/2 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.

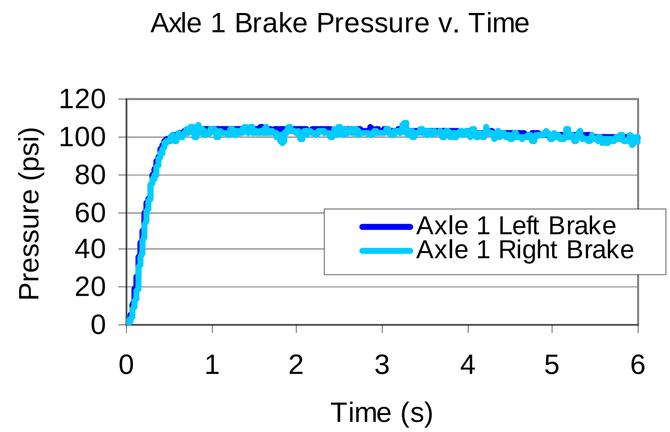

Figure 2: Run 5, 60 mph, LLCW, Dry, Straight Line

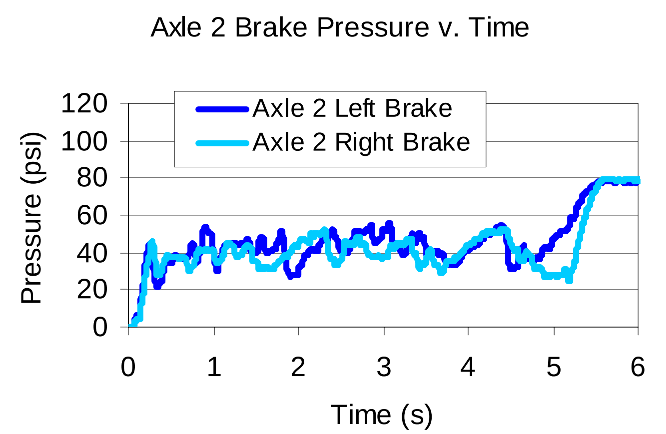

Figure 3: Run 5, 60 mph, LLCW, Dry, Straight Line

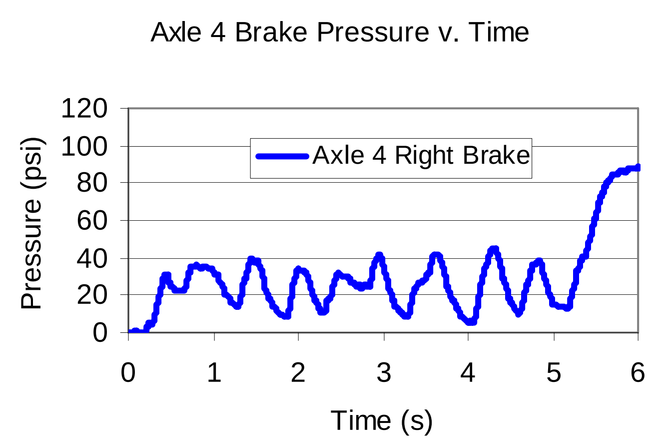

Figure 4: Run 5, 60 mph, LLCW, Dry, Straight Line

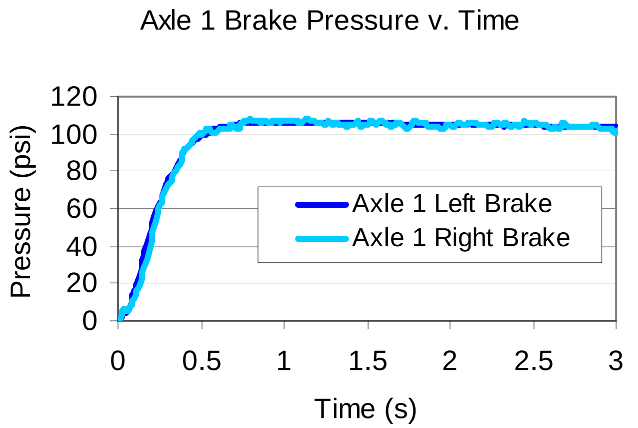

Figure 5: Run 32, 30 mph, GCW, Dry, Straight Line

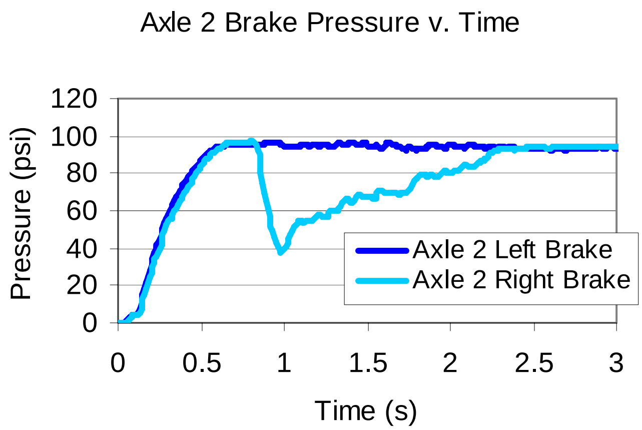

Figure 6: Run 32, 30 mph, GCW, Dry, Straight Line

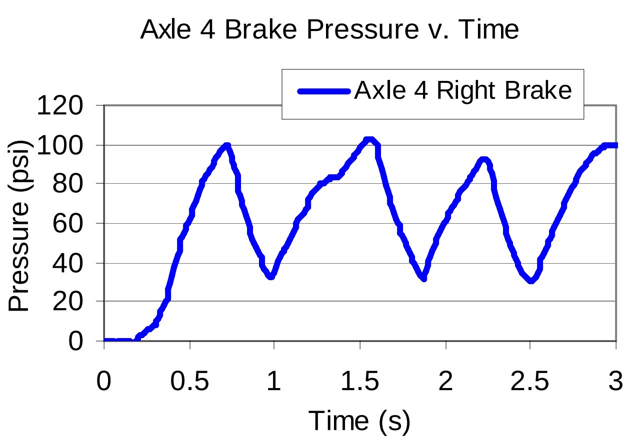

Figure 7: Run 32, 30 mph, GCW, Dry, Straight Line

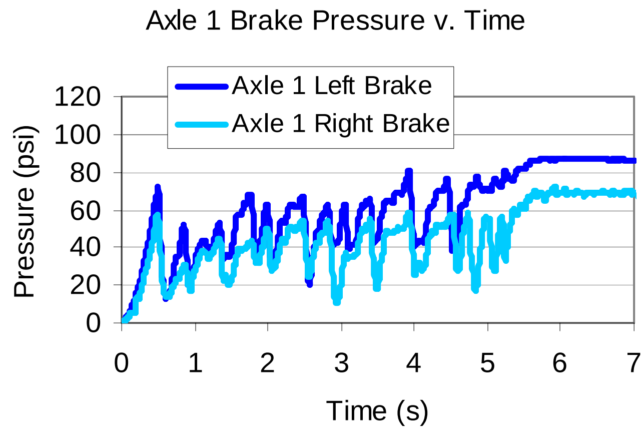

Figure 8: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

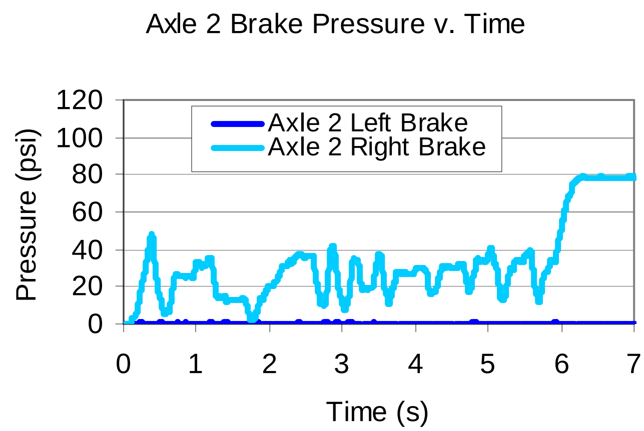

Figure 9: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

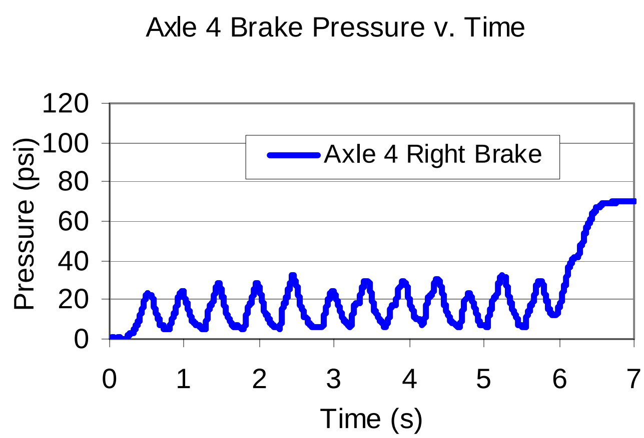

Figure 10: Run 95, 30 mph, ½ GCW, Wet, Brake in Curve

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

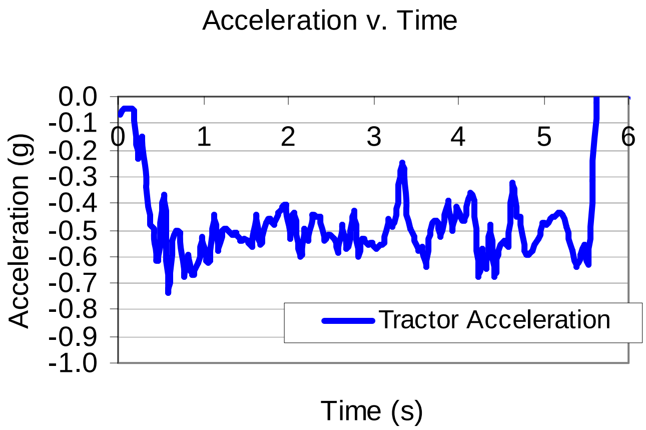

Figure 11: Run 5, 60 mph, LLCW, Dry, Straight Line

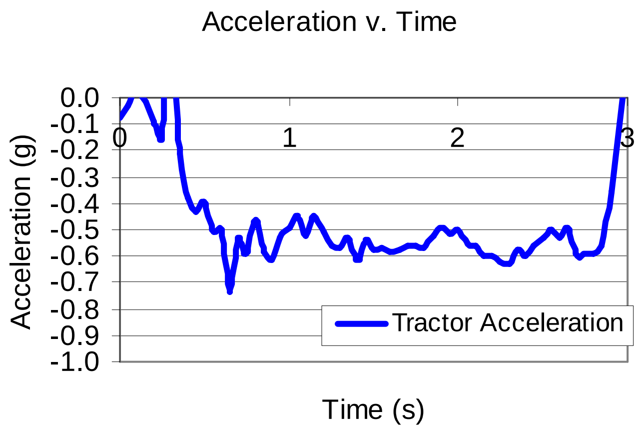

Figure 12: Run 32, 30 mph, GCW, Dry, Straight Line

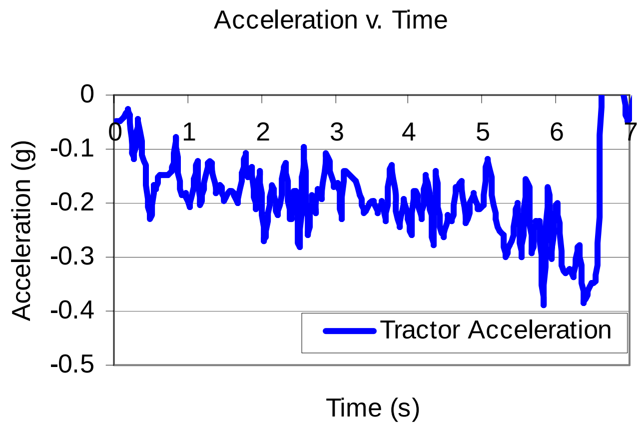

Figure 13: Run 95, 30 mph, 1/2GCW, Wet, Brake in Curve

ANALYSIS AND DISCUSSION

Analysis of the data was performed to obtain brake timing data. The extracted data includes the lag time, or the time for deceleration to begin, and the rise time, or the time for steady-state deceleration to be established.

Total delay time, representing the time at which deceleration has reached steady-state, was calculated as the sum of the lag time and the rise time. The reference time (time zero) is the time step immediately prior to the initial pressure buildup in the primary control pressure due to application of the brake pedal.

In addition, it is of interest to note the line pressures at various axles when maximum levels of vehicle braking are established. Although steady-state pressure may not have been reached at each axle, sufficient pressure exists for the vehicle to reach steady-state deceleration.

DRY STRAIGHT LINE BRAKING

Table C lists the deceleration lag time, rise time, total delay time (or the time to reach steady-state deceleration) and steady-state deceleration level.

Table D lists the line axle pressures at steady-state deceleration onset.

Table C: Group A, Times and deceleration levels

Run	Lag (sec)	Rise (sec)	Total Delay (sec)	Steady-state Decel. (g)
1	0.12	0.37	0.49	0.61
2	0.14	0.31	0.45	0.54
4	0.16	0.33	0.49	0.37
5	0.15	0.28	0.43	0.51
6	0.14	0.32	0.46	0.51
7	0.09	0.31	0.40	0.51
8	0.14	0.31	0.45	0.64
9	0.16	0.28	0.44	0.55
30	0.23	0.49	0.72	0.51
31	0.13	0.44	0.57	0.53
32	0.14	0.44	0.58	0.56
33	0.14	0.42	0.56	0.54
34	0.13	0.37	0.50	0.44
35	0.13	0.49	0.62	0.41
36	0.17	0.34	0.51	0.45
37	0.14	0.44	0.58	0.46

Table D: Group A, Pressures at steady-state deceleration levels

Run	Press_L 1 (psi)	Press_L 2 (psi)	Press_R 1 (psi)	Press_R 2 (psi)	Press_R 4 (psi)
1	102	39	101	32	34
2	95	36	96	32	30
4	97	N/A	96	N/A	40
5	95	33	93	35	30
6	97	29	95	35	30
7	94	25	92	33	27
8	103	39	101	37	30
9	95	42	93	30	33
30	88	88	89	86	59
31	100	91	96	89	76
32	102	93	101	91	81
33	98	87	96	86	73
34	92	82	92	78	54
35	95	53	96	92	42
36	94	85	93	81	47
37	102	93	101	92	65

It should be noted that in the table above the left and right pressure for axle 2 in run 4 failed to record due to an instrumentation problem.

Review of the data for group A shows that the average lag time, rise time and steady-state delay times are 0.14 seconds, 0.37 seconds, and 0.52 seconds, respectively.

WET STOPPING IN CURVE

Tables E and F offer the corresponding values for the wet tests in a curve.

Table E: Group B, Times and deceleration levels

Run	Lag (sec)	Rise (sec)	Total Delay (sec)	Steady-state Decel. (g)
91	0.15	0.32	0.47	0.20
94	0.13	0.23	0.36	0.13
95	0.21	0.25	0.46	0.18
96	0.20	0.22	0.42	0.17
98	0.15	0.32	0.47	0.15

Table F: Group B, Pressures at steady-state deceleration levels

Run	Press_L 1 (psi)	Press_L 2 (psi)	Press_R 1 (psi)	Press_R 2 (psi)	Press_R 4 (psi)
91	69	N/A	65	30	24
94	78	N/A	76	70	24
95	63	N/A	50	23	18
96	44	N/A	40	24	19
98	47	N/A	50	20	21

It should be noted that in the table above the left pressure for axle 2 in all runs failed to record due to an instrumentation problem.

Review of the data for group B shows that the average lag time, rise time and steady-state delay times are 0.17 seconds, 0.27 seconds, and 0.44 seconds, respectively.

COMBINED GROUP DATA

Review of the data for both groups A and B shows that the average lag time, rise time and steady-state delay times are 0.15 seconds, 0.33 seconds and 0.49 seconds, respectively.

It was also noted, based on the results of the dry testing, that the increase in loading from the unloaded condition (LLVW) to the fully loaded condition (GCW) resulted in an increase in the rise time of approximately 0.1 second. This result is consistent with an increased time required to slow down the wheel and reach steady-state when the load increases.

With respect to the wet testing, the rise time was found to be shorter than the corresponding value for any of the dry testing. The rise time was found to be approximately 0.08 seconds shorter. This result is consistent with the wheels reaching available friction sooner (at lower pressures) due to the wet conditions.

EQUIVALENT BRAKE DELAY TIME

Brake timing can be modeled, in a first approximation, as a step function. During an “equivalent” time delay deceleration is assumed to be zero followed by a step steady-state deceleration. The steady-state component of the step function is assumed to equal the actual deceleration steady-state. It is of interest to accident reconstruction specialists to have such an approximation to quickly assess the stopping distance of a vehicle for example. Figure 14 depicts the proposed model as applied to run number 5.

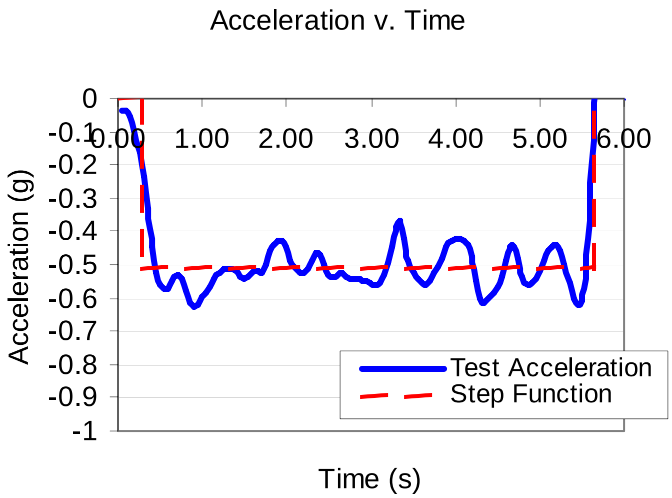

Figure 14: Proposed equivalent step function for Run 5

The analysis consists of insuring that integration of each function (the step function and the actual deceleration curve) yields the same result thus resulting in an equivalent deceleration effort. A reasonable estimate of the equivalent time delay is the lag time plus one half of the rise time. For Run 5 (LLVW, dry, 60 mph), the actual lag and rise times were found to be 0.15 and 0.28 seconds, respectively and the steady-state deceleration was approximately 0.51 g. The equivalent delay time for the step function model using the above methodology was calculated to be 0.29 seconds. The actual stopping distance for Run 5 was 249 feet in a time of 5.52 seconds. The predicted stopping distance using the step function and equivalent delay time is 257 feet in 5.61 seconds, which is an error of 3% in distance and 2% in time. (Note that an equivalent delay time of 0.20 seconds would minimize the error for Run 5).

Using the above methodology for all runs shows that the equivalent delay time, or time at which the steady-state deceleration begins using a step function model, ranges from 0.25 to 0.48 seconds.

SIMULATION

Simulation was performed using the SIMON vehicle dynamics simulation package within HVE. SIMON is a vehicle dynamic simulation model capable of simulating vehicle motion in 3-dimensional environments. The dynamics model allows a sprung mass with six degrees of freedom and multiple axles with up to five degrees of freedom per axle. A generic Class 4 truck and a generic Class 4 trailer were selected from the HVE vehicle database for the simulations. (HVE does not have generic Class 8 vehicles available in the vehicle database.) The vehicle geometries and masses were adjusted to match the values measured from the test vehicles. A vehicle payload was added to the trailer and suspension properties were adjusted match the measured axle loads from the full-scale test setup.

SIMON also has a brake model, referred to as the Brake Designer, which allows for customization of the brake parameters at each wheel. For the comparison simulations, each brake type was changed to an S-cam and the known parameters, including chamber size, slack adjuster length, and drum diameter, were set to the documented values from the brake test. A brake pedal force was applied one second after the simulation began. This allowed the vehicle to reach a steady-state before braking. The brake pedal force was ramped from zero to maximum over one tenth of a second. A brake pedal force was input to match the brake pressures from the full scale testing. The time lag, time rise, push-out pressure, ABS tire slip minimum and maximum, ABS apply delay, apply rate, release delay, and release rate were adjusted at each brake to match the pressures documented in the full-scale testing. Axle 1 of the simulated vehicle was adjusted to match the measured pressures at axle 1 of the test vehicle. Both axles 2 and 3 of the simulated vehicle were adjusted to match the measured pressures at axle 2 of the test vehicle. Both axles 4 and 5 of the simulated vehicle were adjusted to match the measured pressures at axle 4 of the test vehicle. The roadway surface friction was selected to be consistent with the full scale testing. Upon making these inputs, good correlation was found to exist. For example, the overall vehicle deceleration levels and pressure rise at the wheels from the comparison simulation of Run 5 are shown in Figures 15 through 18. Figure 19 shows the deviation between the simulated distance traveled and the test distance traveled as a function of time. The deviation is at all times less than 0.9 feet. The total travel distance from initial brake pedal application to when the vehicle stopped was approximately 250 feet. As illustrated, with the appropriate information about the brake system, the simulated vehicle responded in a manner consistent with the test vehicle and given this accuracy, SIMON could be used to study the effects of numerous braking parameters, including lag time, rise time, and ABS functionality.

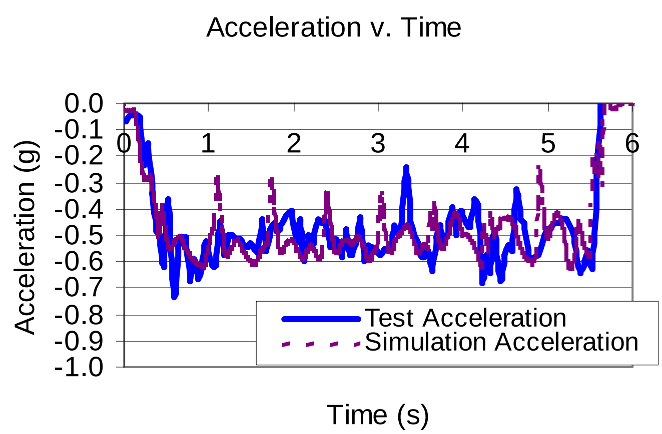

Figure 15: Run 5, 60 mph, LLCW, Dry, Straight Line

Given the validation of the simulation package, brake pressure lag times and rise times from the testing described in this paper can thus be used to provide appropriate input data to users of HVE in order to properly simulate a tractor semitrailer braking event.

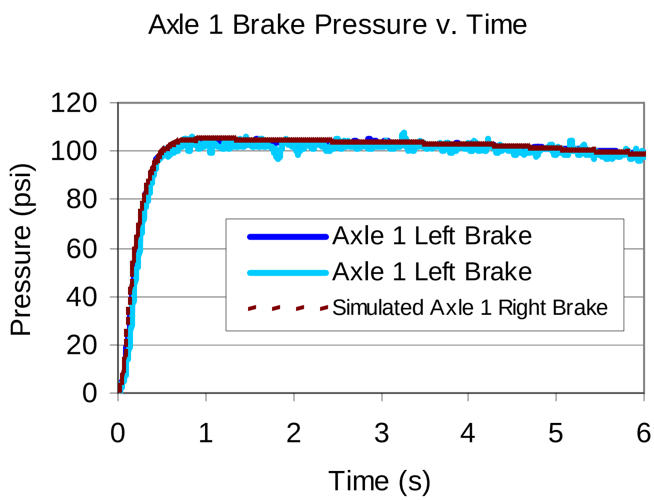

Figure 16: Run 5, 60 mph, LLCW, Dry, Straight Line

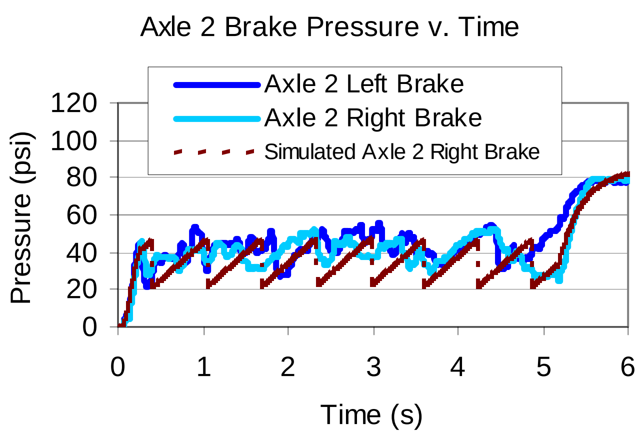

Figure 17: Run 5, 60 mph, LLCW, Dry, Straight Line

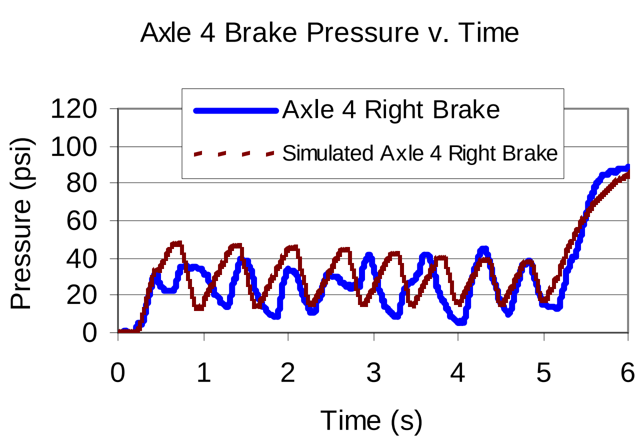

Figure 18: Run 5, 60 mph, GCW, Dry, Straight Line

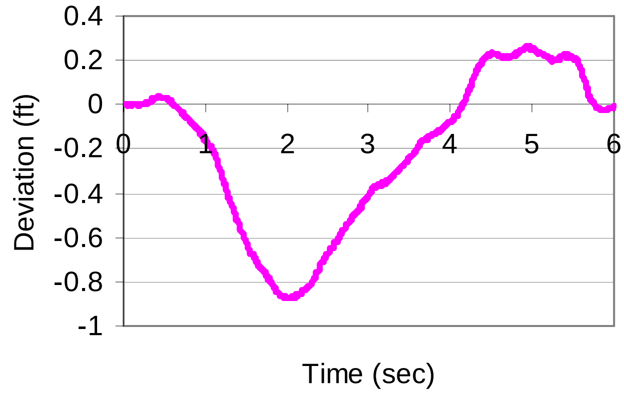

Figure 19: Run 5, 60 mph, LLCW, Dry, Straight Line

PREVIOUSLY PUBLISHED DATA

The authors researched and reviewed the available published technical research on brake timing.

An early published paper by Lewis et al (1) addresses the importance of time delays in braking calculations. The paper discusses time equivalent delays of 0.1 to 1 second. David Stopper (2) reports a time of 0.26 seconds for drive axles to begin locking from 50 mph on a 1995 Kenworth towing an empty Fruehauf tanker semi trailer.

Limpert et al (3) reports a brake pedal application time, the time between the beginning of brake pedal movement and the beginning of deceleration, of 0.1 second. He also reported a deceleration build-up time of 0.5 seconds, which he notes to correspond to the time for brake line pressure to reach 80 psi at the brake chamber. He further adds that this build-up time can only be used in the case of brakes in good adjustment and in the case of the driver applying the brake pedal rapidly. A slow pedal application is reported to increase the build-up time. The basis for the above data could not be found in the paper and the authors state that the findings in the paper are based on “more than 250 commercial vehicle” investigations.

Bartlett (4) proposes theoretical analyses based on work done by Heusser. He also reported UMTRI data suggesting the lag time between first treadle valve movement and change in brake chamber pressure was 0.15 to 0.24 seconds. Trailer axles are reported to require 0.25 to 0.3 seconds more to reach 60 psi and an additional 0.1second to reach 80 psi. Using this and other data, Bartlett predicts a lag time of approximately 0.1 second for the steer axle, 0.15 sec for the drive axle and 0.4 seconds for the trailer axles. The total delay in reaching steady-state is calculated as 0.6 seconds for the drive axle and approximately 0.8 seconds for the full vehicle.

Radlinski (5) reports that the time delay for tractor brake application is of the order of 0.3 seconds. For the trailer the corresponding number is reported as 0.6 seconds.

CONCLUSIONS

Analysis of braking test data from a real world tractor semitrailer tested on dry and wet pavement, at 30 and 60 mph and under varying levels of loading was used to evaluate various brake timing parameters.

Deceleration test results show that a brake lag of approximately 0.15 seconds exists followed by a rise time of approximately 0.33 seconds to reach a steady-state deceleration in approximately 0.48 seconds.

Although lag time was found to be essentially constant for various conditions, rise time was found to increase for dry and loaded conditions and to decrease for wet and unloaded conditions.

Modeling the deceleration of the vehicle as a step function, an equivalent delay time can be obtained and was found to range from 0.25 to 0.48.

This paper also demonstrates that, the 3-dimensional SIMON simulation package within HVE can be utilized to properly predict the braking performance of commercial trucks. The simulated vehicle responded in a manner very consistent with the test vehicle thus validating the use of this program to properly predict the braking performance of a tractor semitrailer. The simulation program can accordingly be used to study the effects of numerous braking parameters, including lag time, rise time, and ABS functionality. In addition, the test data parameters presented here, such as pressure lag and rise time, can be used to simulate real world performance.

ACKNOWLEDGMENTS

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CONTACTS

For inquiries, please contact:

Mr. Fawzi P. Bayan, SEA Ltd., Maryland office, Telephone: 410-987-1077. E-mail: fbayan@sealimited.com, and

Mr. Anthony D. Cornetto III, SEA Ltd., Maryland office, Telephone: 410-987-1077. E-mail: fbayan@sealimited.com, and

Mr. Ashley (Al) Dunn, SEA, Ltd., Ohio office, Telephone: 614.888.4160. E-mail: adunn@sealimited.com, and

Mr. Eric Sauer, SEA, Ltd., Ft Lauderdale office, Telephone: 954.777.4793. E-mail: esauer@sealimited.com.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

IMU: Inertial Measurement Unit – used to measure vehicle inertial rates and accelerations at one point on the vehicle.

ABS: Anti-lock Braking System – separate autonomous systems are used on the tractor and semitrailer to limit wheel slip, prevent wheel lock, and assist the driver in maintaining control and stability of the vehicle.

TRC: Transportation Research Center – independent vehicle research and test facility located in East Liberty, Ohio.

GCW: Gross Combined Vehicle Weight – for tractors and semitrailers, all axles are loaded to GAWR.

GAWR: Gross Axle Weight Rating

LLCW: Lightly Loaded Combination Weight – i.e., having zero-payload (other than weight of instrumentation, driver, and test engineers)

NHTSA: National Highway Traffic Safety Administration

VRTC: NHTSA's Vehicle Research and Test Center, located on TRC's proving grounds in East Liberty, Ohio.

IBT: Initial braking temperature – the brake lining temperatures just before the braking run is commenced.

CG: Center of Gravity

APPENDIX

Table 1 Vehicle Information for the 2006 International 9400i 6x4 tractor

Parameter	Value
Gross Vehicle Weight Rating (GCW, lb)	52,000
Unloaded Curb Weight (lb)	17,523 (includes fuel)
Wheelbase (in)	236
Front suspension	12k# 2 Leaf spring
Rear suspension	40k# Pneumatic
ABS system	Bendix 4s/4m w/ trailing axle side control
Steer axle tires	275/80R22.5 Michelin Pilot XZA2 rib
Drive axle tires	295/75R22.5 Goodyear G372 LHD lug
Engine	Cummins ISX series 435hp
Mileage at beginning of test (mi)	281,337

Table 2 Vehicle Information for the 2000 Trailmobile flatbed semitrailer

Parameter	Value
Gross Vehicle Weight Rating (GCW, lb)	80,000
Approximate Unloaded Curb Weight (lb)	12,000
Wheelbase (in)	variable
Track width f/r (in)	77.5
Lead axle suspension	20k# 2-Leaf spring trailing arm
Trailing axle suspension	20k# 2-Leaf spring trailing arm
ABS system	Eaton 2S1M
Lead axle tires	11R22.5 Goodyear / Bridgestone mix
Trailing axle tires	11R22.5 Goodyear / Bridgestone mix
Mileage at beginning of test (mi)	222,701

Table 3 Table of As-Tested Axle Weights (in lbs.) for 6x4 Truck Tractors at GCW

Axle		**GCW Weights (lb)**	**Half- payload (lb)**	**LLCW Weights (lb)**
1	Steer	12,000	11,570	11,600
2	Lead Drive	16,260	11,790	7,030
3	Trailing Drive	16,730	12,300	6,970
4	Leading Semitrailer	34,920	22,260	10,040
5	Trailing Semitrailer			
All	Totals	79,910	57,920	35,640

Table 4 Brake Specifications

Component	**2006 International 9400i**			**2000 Trailmobile Flatbed**	
	Steer axle	**Lead Drive axles**	**Trailing Drive axles**	**Lead axle**	**Trailing axle**
Air chamber	T 20	T-30/30	T-30	T-30/30	T-30/30
Slack adjuster	5.5” auto	5.5” auto	5.5” auto	5.5” auto	5.5” auto
Brake shoe/lining	Rockwell Q-plus			Carlisle	Carlisle
Brake drum	Meritor	Meritor	Meritor	Webb	Webb
ABS	Bendix 4s/4m rear axle control			Wabco 2s/1m	