Heavy Truck Brake Designer Validation Testing

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ABSTRACT

In late August 2004, a week-long series of well-documented heavy truck braking tests was conducted at Transportation Research Center (TRC) in East Liberty, OH. Using the same tractor and flatbed semi-trailer, tests were performed with and without ABS, on wet and dry surfaces, loaded and unloaded, and at both 30 and 60 mph. Additional tests were done with the semi-trailer's ABS disabled, with only the tractor's ABS system cross-wired, with some of the tractor and trailer brakes out of adjustment, and with the bobtail tractor alone. Both the tractor and semi-trailer were documented to allow creation of an accurate HVE vehicle model, including all brake components.

For this initial paper, SIMON runs, using the Brake Designer, were made of several actual test runs to validate the software against the actual test data. These were compared to similar simulations using generic vehicles. For this paper, only loaded, non-ABS, 60 mph tests were modeled, with all brakes in adjustment, and some out of adjustment.

INTRODUCTION

Reams of data from almost 100 tests were generated during a series of heavy truck braking tests performed at TRC in late August 2004. Several data acquisition systems recorded speeds and distances, or returned deceleration rates over time. Brake system pressures and dynamic pushrod strokes were monitored, as were brake temperatures. Any tire marks were documented with a total station.

TEST VEHICLE DETAILS

For all tests, the same tractor and semi-trailer were used. Brake adjustments were made before almost every series of runs, and they were checked again afterward. Weights of the tractor steer axle, tractor drive axles, and trailer axles were obtained for each vehicle configuration.

TRACTOR

The tractor was a 2003 Freightliner Columbia with a walk-in sleeper. It has a GVWR of 52,000 pounds, with a front GAWR of 12,000 pounds, and two rear axles with a GAWR of 20,000 pounds each. The front Spicer axle had a two-leaf steel spring suspension. Both rear Meritor axles were suspended by a Freightliner AirLiner with Firestone air bags. A Detroit Diesel Series 60 engine with a DDEC IV was mated to an Eaton Fuller 10-speed transmission.

All tires were 295/75R22.5 radials mounted on white steel hub-piloted wheels. For the tests, a pair of new Dayton Radial Metro All Position tires was used on the steer axle. New Bandag Drive Axle retreaded tires were used on both rear axles.

All wheel positions had S-cam drum brakes with a 4S-4M Wabco ABS system. (For the tests modeled for this paper, the ABS system was disconnected.) On the front axle, it had 15" x 4"drums, Type FF linings, Type 20L (long stroke) MGM air chambers, and 5.5" Rockwell automatic slack adjusters. On both rear axles, it had 16.5" x 8 5/8" drums, Type 30/30L MGM spring brakes, and 5.5" Rockwell automatic slack adjusters. All linings were thicker than 0.5 inches. Figure 1 shows a screen shot of those S-Cam details in the Brake Designer for the rear brakes of the tractor model.

For the tests discussed in this paper, the clevis pins were removed from the automatic slack adjusters to disable the automatic adjustment feature. This allowed them to behave and to be adjusted as manual slack adjusters.

The rolling radius for each front tire was 18.5 inches. At the rear, the rolling radius at each position was 19.5 inches.

SEMI-TRAILER

The semi-trailer was a 2001 Wabash flatbed, with an 80,000 pound GVWR. Although it had three 20,000 pound GAWR axles, the tires and wheels were removed from the forwardmost axle, which was then chained to the frame so it would be out of the way. It had a Wabash air suspension.

All tires were new 295/75R22.5 Bandag retreads with a trailer tread pattern. All were mounted on white steel hub-piloted wheels. At each wheel, the rolling radius was 19.5 inches.

All wheel positions had S-cam drum brakes, with 16.5" x 7" drums, 420FF linings, 5.5" manual slack adjusters, and Type 30/30 spring brakes. All brake linings were more than 0.5 inches thick. There was a 2S-2M Wabco ABS system, but it was disconnected for this series of tests.

TEST FACILITY

All testing was performed on the Vehicle Dynamics Area (VDA) of the Transportation Research Center (TRC) in East Liberty, OH. The TRC scale was used to weigh the tractor and semi-trailer with and without the load. All instrumentation installation, brake adjustments, and loading or unloading were done at Link-Radlinski, also in East Liberty, OH.

For these simulations, a 3-D surface was created from a survey of the VDA. A few car skid tests were performed to establish a baseline, but the data from them hasn't been used.

INSTRUMENTATION

While extensive instrumentation was used, only that significant to this paper will be discussed.

Pressure transducers were installed in the control line and in the brake lines for both the left and right sides of the steer axle, the forward drive axle, and the front trailer axle. Speeds and distances were obtained with the Datron Optical "fifth wheel" sensor.

TESTING OVERVIEW

Overall, the testing was segmented into eleven Series. There were several test configurations in each Series, and two or three tests with each configuration. In each test, after attaining the target speed, the driver fully applied the brakes, and held them firmly until the vehicle came to rest.

In this paper, only a few of the configurations actually tested will be discussed. Common to all the tests under consideration are the following: 60 mph initial speed, dry road, no ABS. The other specifics, listed by test numbers, are as follows (test details are in parentheses):

UD6-1 & UD6-2 (Unloaded, Dry, configuration 6, Runs 1 & 2)

UW6-1 & UW6-2 (Unloaded, Wet, configuration 6, Runs 1 & 2)

LD6-1 & LD6-2 (Loaded, Dry, configuration 6, Runs 1 & 2)

LAD2-1 & LAD2-2 (Loaded, some brakes out-of-Adjustment, Dry, configuration 6, Runs 1 & 2)

The unloaded tests (those beginning with "U") used the tractor and with unloaded semi-trailer. In the tractor, there was the driver, plus two passengers to attend to the data acquisition systems. For the loaded tests (beginning with "L"), concrete blocks, weighing a total of approximately 46,000 pounds, were distributed along the flatbed trailer body.

BRAKE ADJUSTMENTS

The following is the nomenclature that will be used for this paper:

Axle 1 (A1) - Steer Axle
Axle 2 (A2) - Forward Drive Axle
Axle 3 (A3) - Rear Drive Axle
Axle 4 (A4) - Front Trailer Axle
Axle 5 (A5) - Rear Trailer Axle.

For the UD, LD, and UW tests, all the brakes were manually adjusted for optimum braking performance. All adjustments were performed with the engine off, and 100 psi in the reservoir. On Axle 1, both Type 20L front brakes had their pushrod stokes set to 1 3/8". All drive and trailer brakes (Type 30/30L) were adjusted to 1 5/8". All adjustments were made to +/- 1/16".

For the two tests with "A" as the second letter, the brakes on Axles 1, 2, and 4 were backed off to 1/8" beyond the CVSA out-of-service criteria. Brakes on Axles 1 and 4 were adjusted to 2 1/8"; on Axle 2 to 2 5/8" (all +/- 1/16").

SIMULATIONS

SIMON was used for all simulations. Both tractor and trailer vehicle models were modified using the actual dimensions and axle loads from the test vehicles. Finally, the Brake Designer was used, incorporating all the physical component measurements from the vehicles. For nomenclature, these simulations all kept the original test numbers, but added Sim to their names, e.g. UD6-1Sim.

In addition to the brake system, other vehicle model modifications included adjusting connection heights and CG locations to achieve proper axle loads, both with and without the payload. From the EDC database, 11R22.5 Michelin ZXA tires were fitted to all positions on the tractor and semi-trailer.

A total station survey provided the dimensional data to build the environment. Numerous simulations were run to determine the appropriate Friction Factor for both the wet and dry tests. The asphalt surface of the VDA was quite aggressive. These Friction Factors were 0.84 for wet and 0.94 for dry.

The starting point of each simulation was made to correspond to the initial speed from the appropriate test. To ensure that the simulation settled down before the brakes were applied, the truck was run for one second before the brake application. Rather than adding a pre-braking throttle table to the Driver Table, the speed at time zero was adjusted until the speed at one second equaled the speed from the actual test. Then, to make it easier to obtain the braking distance, that distance reached at time one second was reset to zero.

When the target speed was reached, at 1.0 seconds in the simulation, the brakes were applied according to a Driver Table created to mimic the air pressure variations measured during the actual tests. Figure 2 shows the Driver Table for UD6-1.

For comparison, both 60 mph, dry, unloaded tests were repeated with two different setups. The first, referred to as UD6-1Gen & UD6-2Gen, used a generic Class 4 tractor and generic Class 4 semi-trailer. The second used the actual vehicle models, but used generic brakes. These were referred to as UD6-1ActGen (for Actual Generic) and UD6-2ActGen. With generic brakes, the Initial Stroke setting in the Wheels section of the Set-Up menu is disabled.

The Actual Generic (Act Gen) tests were also repeated with the loaded trailer with some brakes out of adjustment. These were called LAD2-1ActGen and LAD2-2ActGen. All Generic and Actual Generic simulations used the Driver Table shown in Figure 3.

DISCUSSION

Many problems were encountered, a lot was learned, and much remains to be done to fully understand both the dynamic behavior of the brake system of a heavy truck, and the most effective way to simulate that behavior with Brake Designer in SIMON. The following summarizes some of the problems encountered, and the solutions tried.

Developing the proper Driver Tables, Brake Rise Times, and Brake Lag Times for the simulations was quite challenging, since they all interacted. During each actual test, the application pressure was measured, as were the pressures at both brake chambers on Axles 1, 2, and 4. But since these chamber pressures never reached the application pressure, using the application pressure in the Driver Table in the Event Editor led to excessive deceleration rates and short braking distances. By studying plots of the brake pressures versus time, a Driver Table was created for each event that mimicked the actual brake pressure variation. Likewise, Brake Rise Times and Brake Lag Times in the Brake Designer were modified to match the rate of air pressure buildup in the actual truck's brake system.

Looking at an overall air pressure versus time graph did not yield enough detail about the initial phase of the air pressure rise. Therefore, a second graph was made for each run that displayed the air pressure rise over the first second only. This allowed for a better understanding of how the brakes reached their full application pressure. Figures 4 and 5 show air pressure versus time graphs for the UD6-1 test, for the full stop and for the first second, respectively.

The tires used during the tests were not in the HVE database, so an 11R22.5 Michelin XZA was chosen. While the differences in tread compound and other specific properties were unknown, it was the closest in size and load capacity. Any effects from the tire model are unknown, but are suspected to be slight.

Both the tractor and semi-trailer had air suspensions, which are not modeled by HVE. Consequently, any interaxle load transfer or overall load transfer effects on the braking performance of the model are not known.

A number of runs were made to determine the Friction Factor on the high-grip VDA surface. In lieu of a specific baseline, a number of simulations were run with various test configurations until one value produced consistent, meaningful results. As expected, the wet surface tests yielded a lower Friction Factor than the dry surface.

When trying to establish the appropriate deceleration rates to use, it was deemed best to split the actual measured values into two segments; from time 0 to 0.5 seconds, and from time 0.5 seconds until the end of the braking. Since neither the test instrumentation nor the simulation respond predictably near zero mph, the tests were considered stopped at 2 mph. The deceleration segment from 0.5 seconds to the end of the test at 2 mph was used to create the Driver Table for each test.

SIMULATION RESULTS

Table 1 shows the simulation results compared to the actual test results.

Using a Driver Table in the models that tracked the air pressure variations in the actual tests, the SIMON simulations using the Brake Designer calculated the braking distances to an error of 4.8%, and the 0.5 seconds-to-2 mph decelerations to within 0.037 g.

In the unloaded, dry, 60 mph tests, using pure Generic vehicles in the simulation produced an error of up to 25.5% in the stopping distance, and up to 0.078g in deceleration error.

Using actual vehicle models, but with generic brakes, greatly reduced the error to approximately 8% of the braking distances, and up to 0.045g in deceleration error. This showed the value of modeling the dimensions and wheel loads accurately.

Finally, with the actual vehicle models and the Brake Designer, the stopping distance errors were less than 1%. The errors in the 0.5 second to 2 mph deceleration rates were negligible at less than 0.01g.

With some of the brakes out of adjustment, (tests LAD2-1 and LAD2-2), the Actual Generic simulations resulted in braking distance errors of 15 to 19.3%, and deceleration errors of approximately 0.10 g. By comparison, both LAD simulation runs where the Brake Designer was used yielded braking distance errors of 4.8%, and deceleration errors of less than 0.037 g.

CONCLUSIONS

For all of the conditions of unloaded dry, unloaded wet, loaded dry, and loaded dry with some brakes out of adjustment, the best correlations between the actual tests and the SIMON simulations were when the actual vehicle models and the Brake Designer were used with the appropriate Driver Tables.

Then, when the actual vehicles were used with generic brakes (ActGen), they generated greater errors in both deceleration rates and braking distances. The errors when the brakes were out of adjustment were approximately twice what they were when all brakes were in adjustment.

Finally, when pure Generic (Gen) vehicles with generic tires and brakes were used to simulate the unloaded dry tests, the errors were up to 25.5% in braking distance and up to 0.078 g in decelerations. Users should be cautioned from blindly using pure Generic vehicles because the accuracy is unknown and the error could possibly be quite large.

But since no vehicle-specific inertial or dimensional data was used, there was no way to either qualify or quantify why the errors might have occurred.

Further validation work will continue using many of the other actual test configurations.

ACKNOWLEDGMENTS

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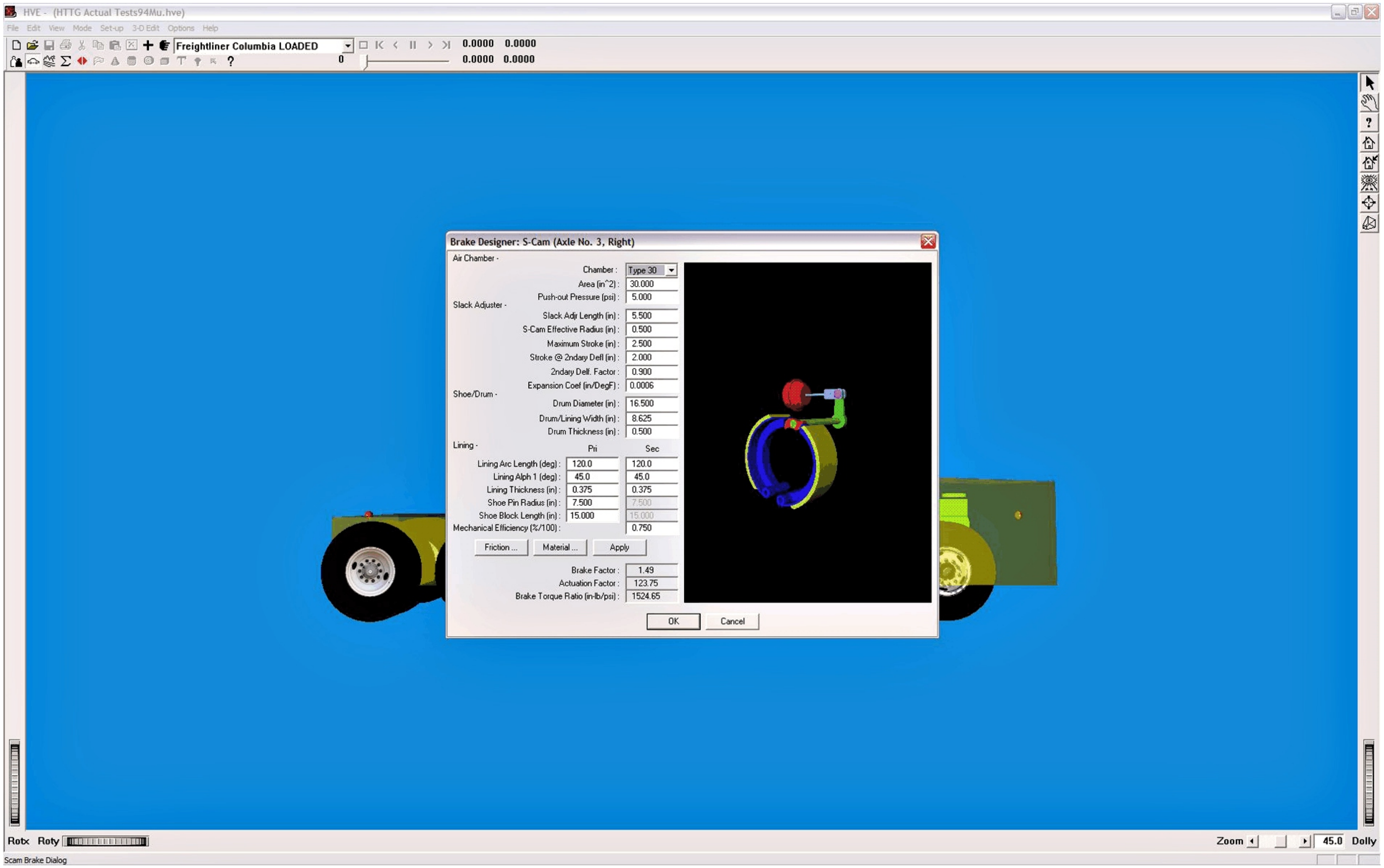

Figure 1 - S-cam data screen in Brake Designer.

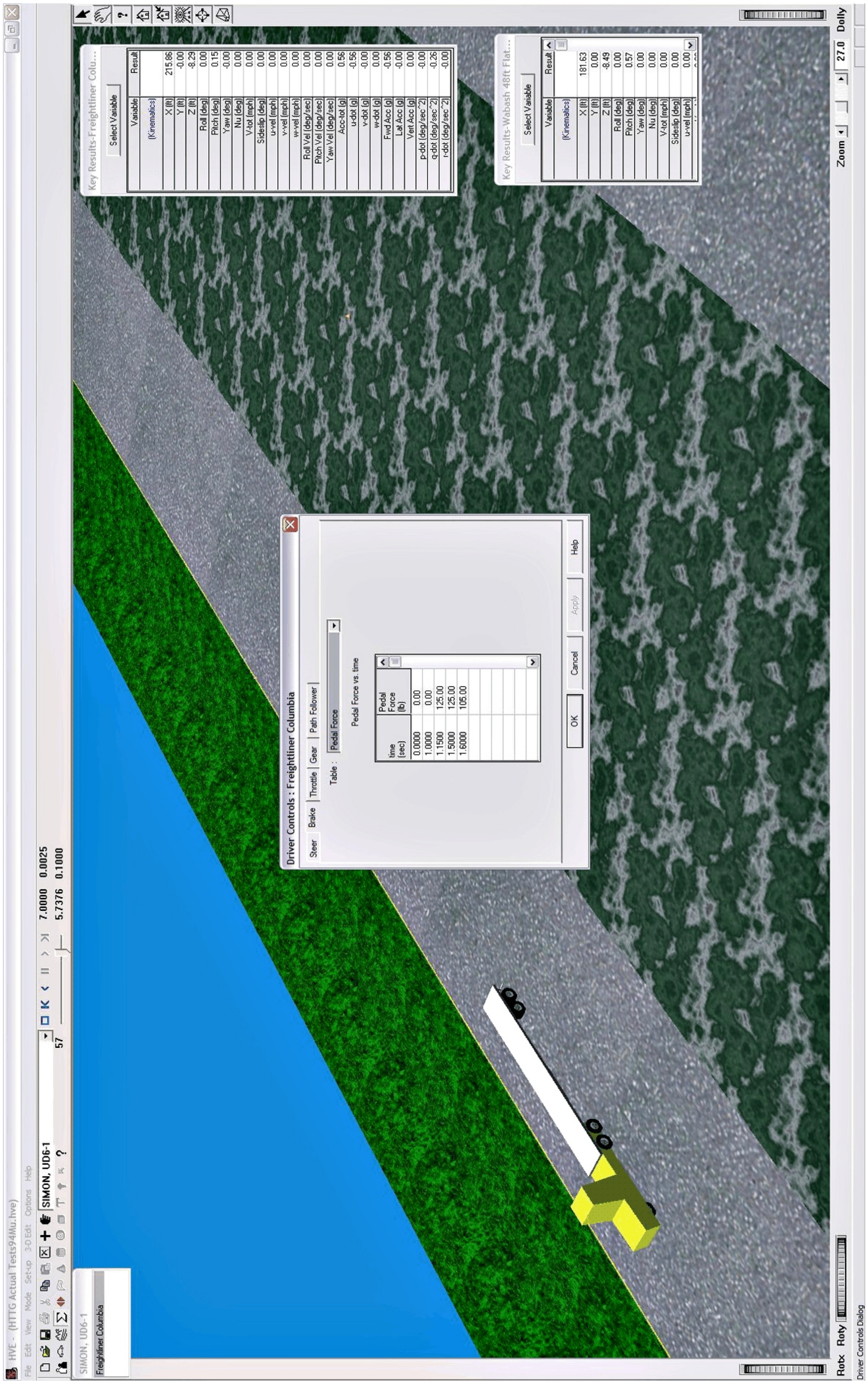

Figure 2 - Driver Table for UD6-1 Sim.

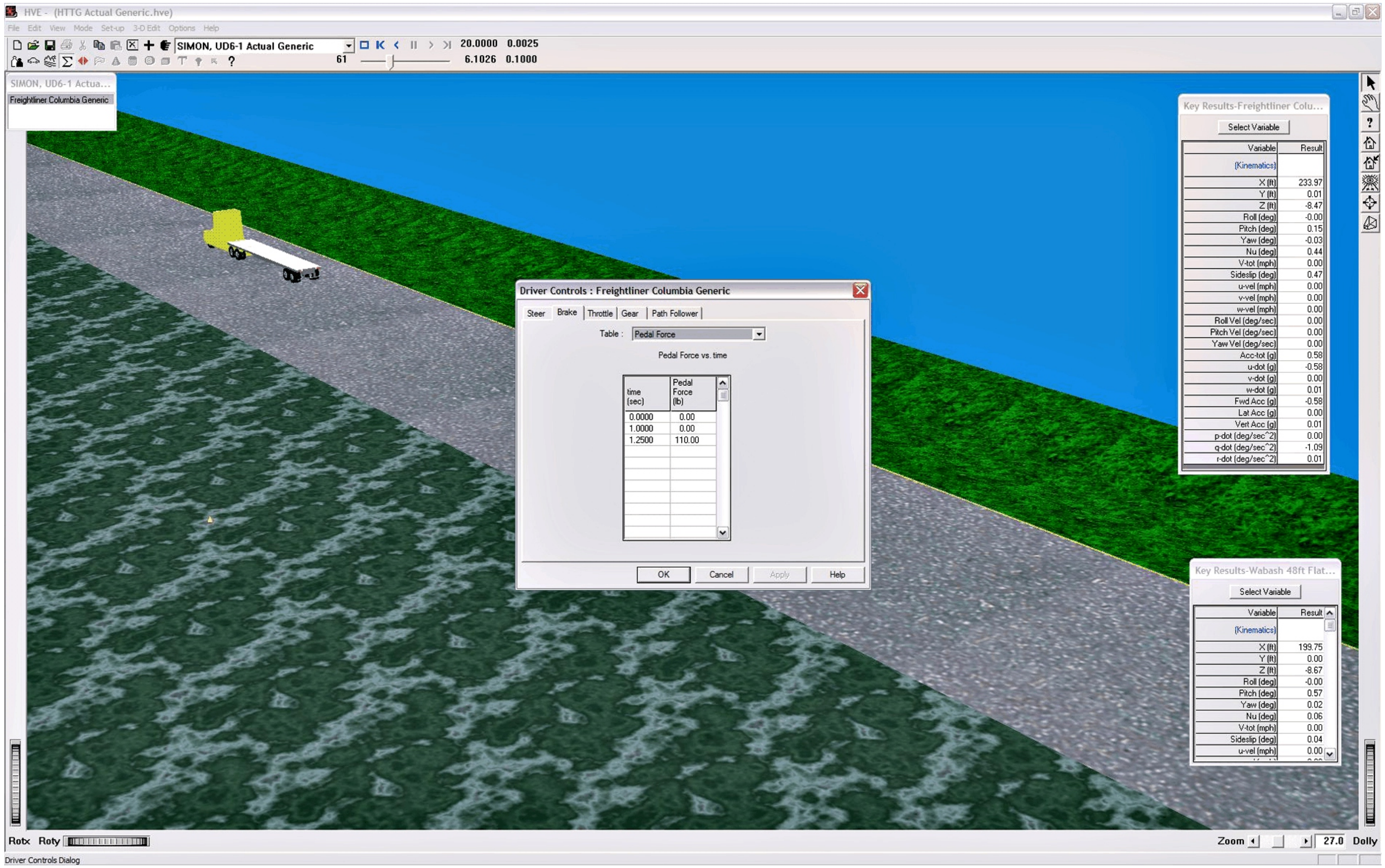

Figure 3 - Driver Table for Generic and Actual Generic simulations.

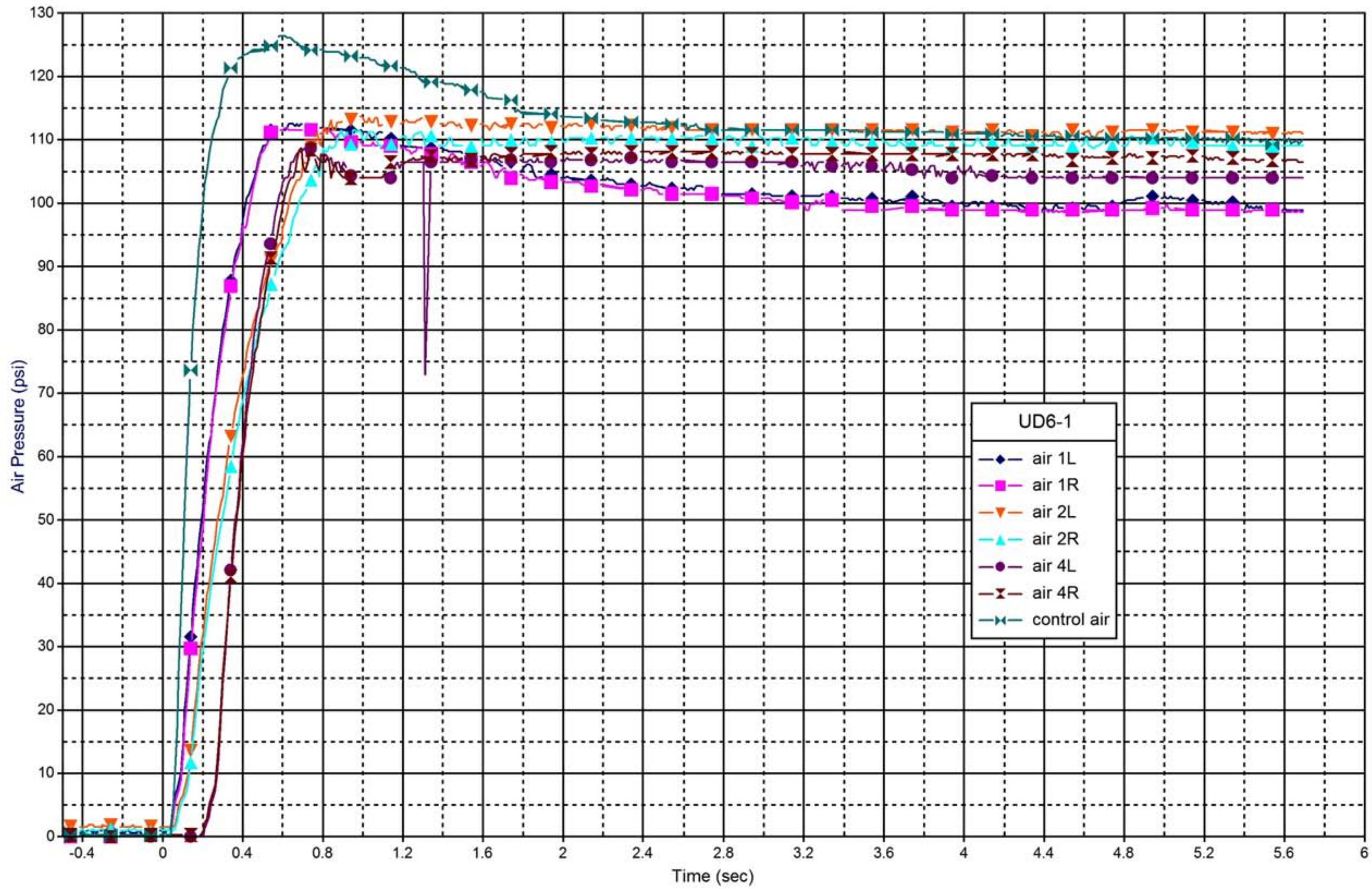

Figure 4 - UD6-1 Air pressure v. Time for entire braking event.

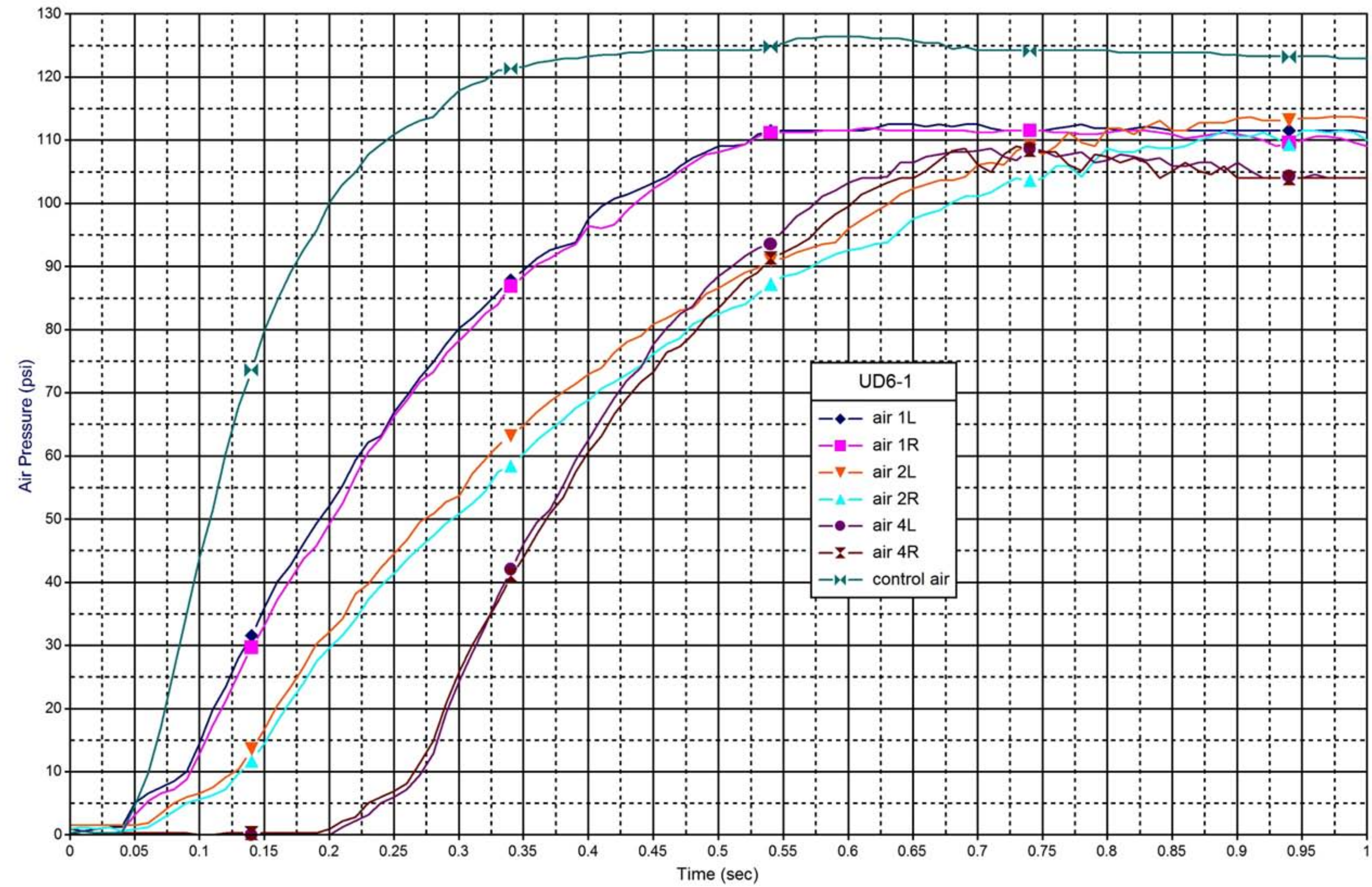

Figure 5 - UD6-1 Air pressure v. Time for first second of brake application.

Table 1 - Actual Brake Tests v. HVE simulations

Run	Initial Speed (mph)	Total Distance Traveled (ft)	1/2 sec Speed (mph)	Distance 1/2 sec to 2 mph (ft)	Avg Decl 1/2 sec to 2 mph (g's)	Avg Decl Initial to 1/2 sec (g's)	First 1/2 sec compared to rest (%)	Distance Error (%)	0 to 1/2 Decel Error (g's)	1/2 to 2 Decel Error (g's)
UD6_1	59.34	216.0	55.01	172.9	0.584	0.395	67.6%			
UD6_1Sim	59.35	215.9	55.18	172.8	0.588	0.380	64.6%	-0.1%	0.015	-0.004
UD6_1ActGen	59.35	234.0	55.98	187.8	0.557	0.307	55.1%	8.3%	0.088	0.027
UD6_1Gen	59.35	271.2	55.49	198.8	0.517	0.352	68.0%	25.5%	0.043	0.067
UD6_2	61.54	234.2	57.96	188.9	0.593	0.326	54.9%			
UD6_2Sim	61.55	232.0	57.38	187.5	0.586	0.380	64.8%	-0.9%	-0.054	0.008
UD6_2ActGen	61.55	251.3	58.18	206.1	0.548	0.307	56.0%	7.3%	0.019	0.045
UD6_2Gen	61.55	289.5	57.66	215.3	0.515	0.354	68.8%	23.6%	-0.029	0.078
UW6_1	60.65	252.0	56.52	206.5	0.516	0.376	72.8%			
UW6_1Sim	60.64	258.3	56.02	191.1	0.548	0.421	76.8%	2.5%	-0.045	-0.032
UW6_2	61.95	259.2	57.83	214.4	0.520	0.376	72.2%			
UW6_2Sim	61.94	266.6	57.32	198.7	0.552	0.421	76.3%	2.9%	-0.045	-0.031
LD6_1	61.82	250.3	59.34	204.8	0.574	0.226	39.3%			
LD6_1Sim	61.83	243.3	59.53	197.0	0.600	0.210	34.9%	-2.8%	0.016	-0.027
LD6_2	61.95	260.4	59.48	214.6	0.550	0.225	41.0%			
LD6_2Sim	61.96	249.4	59.93	204.3	0.587	0.185	31.5%	-4.2%	0.040	-0.036
LAD2_1	60.99	288.5	59.34	243.0	0.48	0.15	31.1%			
LAD2_1Sim	60.98	302.2	58.81	257.4	0.45	0.20	44.1%	4.8%	-0.047	0.035
LAD2_1ActGen	60.99	244.0	58.78	197.4	0.58	0.20	34.5%	-19.3%	-0.051	-0.100
LAD2_2	61.13	288.1	59.55	243.0	0.49	0.14	29.6%			
LAD2_2Sim	61.12	301.8	58.91	257.2	0.45	0.20	44.7%	4.8%	-0.057	0.037
LAD2_2ActGen	61.13	245.0	58.92	197.8	0.59	0.20	34.4%	-15.0%	-0.057	-0.099