Tractor-Trailer ABS Brake Testing on Dry Pavement

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INTRODUCTION

When there is insufficient data to perform brake force calculations, many reconstruction sources recommend applying a 70 to 80 percent correction to the drag factor generated by an automobile to account for the complexities of tractor-trailer braking systems such as higher tire pressure, harder tire material, brake lag time, etc. However, little testing has been done to determine how antilock braking systems (ABS) affect the stopping characteristics of tractor-trailers on dry roads. Recently INTROTECH, Inc. performed several tests with tractor-trailer rigs to gather braking performance data on tractor-trailer rigs both with and without ABS systems.

Furthermore, some commercial vehicle owner-operators have indicated their preference to use trailer or spring brakes only to avoid potential jack-knife situations and to avoid wear on the tractor brakes. Therefore we included in our test program additional braking performance tests using trailer brakes and spring brakes only.

ABS SYSTEM

Antilock braking systems are designed to prevent wheel lockup or skids caused by hard braking, especially on slippery or contaminated road surfaces. In general, ABS systems also allow a vehicle to maintain directional stability while maximizing the braking effectiveness of each braked wheel. When the ABS system computer recognizes that a braked wheel is reaching the skidding threshold it sends a command (pulse) to release the brakes on that wheel. When the skidding wheel begins to roll again the ABS computer allows the brakes to reapply. This cycle will repeat again and again as long as the wheel tends to lock up.

In our testing, each tractor was equipped with a 4-channel ABS system, meaning that there were four separate ABS sensors to detect skidding. Two sensors were on axle number 1, or the steering axle (one sensor for each front wheel). The other two sensors were on the third axle (one for each side, left and right). The second axle had no ABS sensors, but its wheels were “slaved” to the ABS-controlled wheels on the third axle. This configuration limited ABS effectiveness somewhat because the wheels on the second axle would only “pulse” when a corresponding ABS-controlled wheel on the third axle reached skidding threshold. Wheels on the non-ABS-controlled second axle sometimes reached skidding threshold before wheels on the third axle, and when that happened the second-axle wheels completely locked.

TEST SETUP

The test protocol was carefully planned and held in a safe, controlled environment to account for the many complexities of braking systems on tractor-trailers. The tests were performed on November 6, 1999 in the parking lot of a nearby commercial carrier operations facility. The pavement was traveled asphalt, and the test direction was to the

West with a 1.2 degree down-slope. The test equipment was calibrated just prior to each run to compensate for the effects of the down-slope. Weather conditions were excellent with scattered clouds, light winds, temperature varying between 62 and 73 degrees Fahrenheit and 20 percent humidity.

The driver selected to operate the test vehicles was an experienced driver and a CDL instructor who was thoroughly briefed on his role in the performance of the tests. His professional input was considered in refining portions of the test procedures to make them conform as closely as possible to procedures and actions that would actually be performed by professional truck drivers under emergent conditions.

TEST VEHICLES

The test vehicles selected were operational tractors and trailers from the commercial facility's fleet. Two 1995 International cabovers and a 1999 Freightliner conventional, each with Bendix ABS brake systems were selected, along with three 53-foot Wabash van-type trailers (one with and one without ABS). To ensure standardization for testing purposes, a certified mechanic inspected the vehicles and verified that the brakes were adjusted to within proper tolerances as per federal regulations prior to beginning the tests. Vehicle specifics were as follows:

Year	**Make/Model**	**Type**	**ABS**	**Load**
1995	International 9700	Cabover	4-Channel	N/A
1996	Wabash	Van	None	None
1995	International 9700	Cabover	4-Channel	N/A
1995	Wabash	Van	None	15,000 lbs
1999	Freightliner Century Class	Conventional	4-Channel	N/A
1998	Wabash	Van	2-Channel	5,000 lbs

TEST EQUIPMENT

The vehicles were fitted with three VC2000 accelerometers. One accelerometer was fastened to the rear of the trailer and the other two were strapped to the catwalk at the rear of the tractor. One of the accelerometers on the catwalk was set to activate when the brake lights illuminated to capture the brake application point. The other two accelerometers were set to activate upon sensing that the vehicle had begun to decelerate (threshold of – 0.2 G's) during the braking event. This configuration of accelerometers allowed us to determine air brake lag time, which is the time between the instant the brake pedal is depressed until the brakes actually become effective in slowing the vehicle.

A police-style radar unit (K55) was mounted on the tractor's dash to obtain an accurate speed for the test runs. An INTROTECH safety observer in the cab operated the radar unit.

BASELINE DATA

In order to establish a baseline for comparison purposes a 1992 Jeep Cherokee without ABS was instrumented with a VC2000 accelerometer. The Jeep performed two sets of test skids along the path that the tractor-trailers would ultimately use during the truck testing. Both runs yielded an average drag factor of 0.70, thus validating that a good baseline had been established. The run data for the Jeep was as follows:

Parameter	**Run #1**	**Run #2**
Speed	30.4 mph	28.0 mph
Time	1.97 sec	1.87 sec
Distance	41 feet	34 feet
Average G	0.70	0.70
70% G	0.49	0.49

TEST RUNS

The test runs were made at between 31 and 43 miles per hour as measured on the radar display. Test runs were made using the cabover tractors both with and without the ABS system operating. The cabovers were pulling trailers that did not have ABS. Additional test runs were made with the cabover tractor-trailer combinations using spring- and trailer-brakes only as requested by the test driver. One run was made wiith the ABS-equipped Freightliner conventional tractor pulling an ABS-equipped trailer for comparison purposes (run #7). The ABS-equipped Freightliner was also tested in the bobtail configuration for informational purposes only (run #8).
During each run the test driver depressed the clutch and firmly applied the brakes using the "quick, hard, hold" protocol as he passed the designated braking point. The driver maintained hard braking until the vehicle came to a full and complete stop. Accelerometer data and tire skid mark measurements were recorded prior to moving the vehicle from its final rest position. Video and still cameras were used to document the testing and the measurements following each run.

TEST RESULTS

Equipment	Drag Factor	Percent of Baseline
Cabover tractor-trailer without ABS	0.52	74%
Cabover tractor-trailer with ABS on tractor only	0.53	75%
Conventional tractor-trailer with ABS on both units	0.57	81%
Conventional tractor only (bobtail) with ABS	0.60	85%
Cabover tractor-trailer using spring/trailer brakes only without ABS	0.30	43%

SKID MARKS

The most visible evidence produced on the asphalt during these tests was in the form of tire smear skid marks. The casual observer would have seen heavy black marks made when the tire from a locked wheel slid over the asphalt surface. Pavement grinding marks or scratches on the asphalt surface caused by pebbles or foreign matter embedded in the tire treads as the tire slid on the pavement were also present.

The obvious tire smears and pavement grinding marks were not the only physical evidence left on the pavement following the heavy braking in these tests, however. A much lighter mark called a shadow mark (or impending skid mark) was also visible by careful observation. The shadow mark was that portion of a tire mark left by a braked wheel just before complete cessation of rotation.

Because the shadow marks were short-lived evidence that can fade or disappear completely within minutes or hours, depending on weather, wind and other traffic at the scene, they were documented immediately after the vehicles came to final rest. The shadow marks that were produced during these tests were best seen by looking from a prone position along the direction of the braked truck. The shadow marks accounted for between 20 to 60 percent of the total length of the tire mark in our tests.

CONCLUSIONS

- Each crash situation must be individually handled in accordance with its unique circumstances, but it seems obvious from these tests that tractor-only ABS does not appreciably affect the stopping distance of tractor-trailers on a dry, uncontaminated paved surface.
- The primary benefit of ABS for a tractor-trailer when stopping on dry pavement is the enhanced control available while braking. During these tests the tractor-trailers without ABS tended to drift off track, but with ABS they tended to remain fully aligned and straight during the entire heavy braking evolution.
- Great care must be exercised when measuring tire marks because the shadow mark, which makes up a significant percentage of the total tire mark, many times can only be seen from a prone position looking along the direction of the skid. It is important to note that shadow marks are relatively short-lived.
- When calculating minimum **speed** from ***skid mark evidence*** at the scene of a crash, it seems reasonable to use a correction factor of about 74% against a drag factor obtained from passenger car test skid tests performed at the scene.
- When calculating the **braking distance** that would have been required to slow/stop a tractor-trailer in a hypothetical situation it seems reasonable to use a correction factor of 70% against a drag factor obtained from passenger car test skid tests performed at the scene. This is because it is logical that there is some slowing that occurs after the brake application point but prior to the – 2 G accelerometer threshold.
- Brake lag times varied from about 0.33 to 0.50 seconds.
- The practice of some drivers to use only the spring- or trailer-brakes to stop under emergent conditions should be avoided because it significantly lengthens stopping distances.

SUMMARY

Tractor-trailer crashes are amongst the most complex to investigate and reconstruct. It is difficult to document each and every tire mark made by a large commercial vehicle, and many times it is difficult to obtain accurate data about the condition of its brakes. The variation of individual tractor-trailer units, their ABS systems, environmental conditions and the overall condition of their brakes must be considered. Furthermore, weight shift during hard braking of commercial vehicles must also be considered, especially so when carrying heavy loads.

When investigating a commercial vehicle crash, it is recommended that Reconstructionists conduct test skids using the same or an exemplar vehicle under similar vehicle load, road and environmental conditions. If such testing is not feasible, then the results of our tests may be useful. They are published here to supplement existing coefficient of friction data, since much of the existing data was compiled prior to the advent of ABS systems on tractor-trailers. Furthermore, tire compounds and pavement materials are continually improving, a condition that older test data would not necessarily reflect.

Additional testing and research would be beneficial to more fully address drag factor and braking distance issues for ABS-equipped commercial vehicles. Since our tests were conducted on a dry, uncontaminated road surface, additional testing would help to determine the ultimate affect of various ABS systems on wet or snow-covered roads.

ADDITIONAL DATA

A more detailed table listing all of the 8 test runs completed during this testing program is presented at the end of this article. Additionally, a videotape documenting these tests is available. INTROTECH’s web site is www.IntrotechCrash.com.

Parameter	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8
Brakes used	all	all	spring only	trailer only	all	all	all	Bobtail
ABS	None	Tractor	None	None	Tractor	None	Tractor and trailer	Tractor
Speed	37	36	31	31	34	34	39	43
Deceleration time	3.06	2.96	4.01	4.07	2.71	2.57	2.95	3.10
Deceleration distance	71.50	73.00	76.00	79.00	59.50	55.50	75.50	93.00
Average G	0.51	0.54	0.30	0.31	0.53	0.54	0.57	0.60
% of baseline	73%	77%	43%	44%	76%	77%	82%	86%
Longest Skid:								
Shadow mark	18.00	15.25	53.42	42.42	27.17	24.92	42.83	Not measured
Skid mark	65.75	63.50	37.17	45.50	42.42	40.92	48.83	Not measured
Total length	83.75	78.75	90.58	87.92	69.58	65.83	91.67	Not measured
From brake application point:								
Distance to stop	98	102	n/o	n/o	85	84	95	115
Time to stop	3.52	3.49	n/o	n/o	3.20	3.15	3.28	3.46
Brake lag time	0.47	0.53	n/o	n/o	0.49	0.59	0.33	0.36
Average G	0.45	0.46	n/o	n/o	0.45	0.46	0.52	0.54
% of baseline	64%	66%	N/A	N/A	64%	65%	74%	77%