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SAE Technical Paper Series

870493

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International Congress and Exposition
Detroit, Michigan
February 23-27, 1987

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SAE GLOBAL MOBILITY DATABASE

ISSN 0148-7191

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ABSTRACT

This paper addresses the issue of front wheel braking on heavy trucks and reviews testing that has been performed over the years dating back to 1948 to evaluate the effect of front brakes on braking performance. It also describes in detail a test and demonstration program on front wheel brakes that was conducted in September 1986. The paper indicates that front wheel brakes have a strong effect on braking performance and that vehicles without front wheel brakes take longer distances to stop and are more likely to lose control in emergency situations. The paper also indicates that the use of front brake pressure limiting valves with typical, current design front brakes degrades vehicle braking performance.

IN JULY 1986, THE SECRETARY of Transportation announced that the Federal Highway Administration (FHWA) would begin a rulemaking that would require truck operators to keep front wheel brakes on all large trucks and truck-tractors in service fully operational. This rulemaking would eliminate an exemption in the Federal Motor Carrier Safety Regulations (FMCSR), originally issued by the Interstate Commerce Commission in 1952, which allows truck operators to remove braking systems on the front (steering) axle wheels of trucks and truck tractors with three or more axles (the FMCSR have always required that two-axle vehicles have front brakes). This change would result in the FMCSR being consistent with the requirement of the National Highway Traffic Safety Administration (NHTSA) specified in Federal Motor Vehicle Safety Standard (FMVSS) No. 121, Air Brake Systems, which states that newly manufactured air braked vehicles must be equipped with brakes acting on all wheels.

In October 1986, Congress passed (and the President signed into law) the Commercial Motor Vehicle Safety Act of 1986. This act has provisions which require that FHWA revise Section 393.42(c) of the FMCSR within 90 days to eliminate the front brake exemption. In effect, this law established a specific timetable for FHWA's rulemaking.

The move to require front brakes on all commercial vehicles is based on the results of research conducted by the NHTSA and others which indicate that the braking performance of commercial vehicles is degraded when the front axle is not equipped with operational brakes.

The advisability of having front wheel brakes on heavy trucks has been debated within the trucking industry for years and many drivers, owner-operators, and fleet operators have been opposed to requirements for front wheel brakes. Recent studies (1,2,3)* indicate that a significant number of truck operators remove, disconnect, disable or fail to maintain front wheel brakes. Many apparently believe that vehicles are safer when the front brakes are not operational. Available data does not support this belief.

In order to demonstrate the potential benefits of its proposed rulemaking and to educate truck operators as to the benefits of front wheel brakes, the FHWA conducted tests and a public demonstration at the Transportation Research Center (TRC) of Ohio in September 1986. FHWA asked NHTSA's Vehicle Research and Test Center (VRTC), located at TRC, to assist in designing and executing the test and demonstration program.

The purpose of this paper is to highlight the results of past research that has been done on the issue of front wheel brakes and to describe in detail the results of the September 1986 test and demonstration program.

REVIEW OF RESEARCH PRIOR TO SEPTEMBER 1986

NATIONAL SAFETY COUNCIL WINTER TESTS (1948, 1952, 1958 and 1968) -- Since 1939, the National Safety Council's Committee on Winter Driving

*Numbers in parenthesis indicate references listed at the end of the report.

0148-7191/87/0223-0493$02.50

Hazards has been involved in testing commercial vehicles on ice and snow covered roadways. Tests were conducted during the winter months (usually each year) to address various issues related to winter driving. A review of the reports published by the National Safety Council indicates that the effect of front brakes on braking performance on ice surfaces was addressed in the tests conducted in 1948, 1952, 1958 and 1968. The results of the 1948, 1952, and 1958 tests can be found in Reference 4 which is a summary of the 1939-66 tests; Reference 5 covers the 1968 testing.

The 1948 tests evaluated the stopping performance of two and three-axle trucks and several combinations (all with two-axle tractors) on dry concrete and ice with and without front brakes operational. Some of the vehicles were empty and others were loaded. Most of the tests were performed at 10 or 20 mph. The data presented indicates that in straight line stops on ice and concrete where panic full treadle brake applications were made, vehicles with front brakes always stopped in shorter distances than those without. For tests that were run on a 200 ft radius ice curve, however, the results were mixed. In this maneuver, where the brakes were "fanned" (brakes pumped to lock and unlock wheels), the loaded three-axle truck and all of the combinations that were tested could stop shorter under better control on an ice curve when the front brakes were turned <u>off</u>. The 1948 tests also included a series of runs with and without front brakes to determine the highest speed at which the test vehicles could be driven through an ice covered 200 ft radius curve while "power" braking. Power braking is an action where the driver applies the brakes and throttle simultaneously. The results of these tests indicate that the driver (a single proving ground test driver was used in all runs) could achieve a higher speed on several of the vehicles when the front brakes were off.

It is interesting to note that Reference 4 mentions that the front brake issue was controversial in 1948 (and apparently had been for many years) and that the 1948 tests did not resolve differences in opinion on the subject. The report recommended that more studies be run in future years.

The 1948 test results are the only published findings (that the authors are aware of) that indicate a performance improvement when front brakes were turned off. In fact, this finding is contradicted by results of later National Safety Council tests.

In 1952 a series of tests were run to evaluate braking techniques on ice using two and three-axle trucks and combinations (with two and three-axle tractors). All of the vehicles were empty. In these tests, various drivers were asked to make evasive maneuvers from 20 mph on ice to avoid hitting an object in the roadway. The maneuver required braking and steering simultaneously and drivers were told to stop in the shortest possible distance while keeping the vehicle under full control. This series of tests was run with and without operational front brakes. The conclusions of the 1952 tests indicated that steering control with all brakes operational was "as good as" performance with the front brakes turned off. In all cases stopping distance with front brakes on was shorter, however.

In 1958, both straight line and brake in a curve tests were run on ice using three unloaded combinations (one with a three-axle tractor, one with a three-axle truck and one with a two-axle tractor). All tests were run with and without front brakes and the front brakes were evaluated with manual front brake pressure limiting valves in both the limiting ("slippery road") and non-limiting ("dry road") positions. The conclusions of the 1958 tests indicated that vehicles stopped in shorter distances in the straight line stops (where panic full treadle applications were made) when the vehicles' front brakes were operational. In the ice curve tests, where the drivers were told to stop under full control by modulating the brakes, vehicles stopped shorter in all but two of 13 cases when the front brakes were on as opposed to off. In addition, in all but two of the 17 cases where the two positions of the front brake limiting valve were evaluated, the vehicles stopped shorter under control when the valve was in the "dry road" or non-limiting position as opposed to the "slippery road" or limiting position.

In the 1968 tests (5), only loaded combinations (singles, doubles and triples) with two-axle tractors were evaluated and only tests with front brakes on were run, although both positions of the manual front brake pressure limiting valve were evaluated. Both straight lane and brake in a curve maneuvers were included and all stops were made with driver "best effort" or modulated brake applications. The 1968 test results indicate in all cases that the drivers were able to stop the combinations in shorter distances under full control when the front brake pressure limiting valves were in the "dry road" position (i.e., full front brakes).

NHTSA TESTS (1975 TO PRESENT) -- Since 1975 the NHTSA has conducted many tests to evaluate the effect of front wheel braking level on overall vehicle braking performance. Published findings are included in References 6, 7, 8 and 9. Reference 6 describes tests that were run in 1975 on two three-axle tractors and one two-axle tractor both in bobtail configurations and with semitrailers. In 60 mph tests that were run on a dry road, stopping distances for all combinations evaluated increased significantly when the front brakes were turned off. One of the three-axle bobtails took 78 percent longer to stop without front brakes and a loaded combination with a three-axle tractor took 28 percent longer to stop.

When the tractors were tested with empty semitrailers in various braking and steering maneuvers on wet slippery surfaces with and without front brakes, the stopping distance increase without front brakes was also significant, ranging from 18 to 41 percent for the three-axle tractor configurations.

Reference 7 describes tests that were run in 1977 utilizing a three-axle tractor semitrailer and a three-axle truck full-trailer combination. Vehicles were tested empty and loaded in various straight line braking and braking and turning maneuvers on wet slippery surfaces. Vehicles without front brakes exhibited the greatest amount of instability and the longest stopping distances.

Reference 8 describes tests run between 1979 and 1982 on a large number of vehicles with many different front brake configurations under a broad range of conditions. Test surfaces included dry roads, wet slippery roads and ice and both straight lane braking as well as braking and turning maneuvers were included. Both test drivers and actual over-the-road drivers performed the tests (previous NHTSA tests utilized only test drivers). In all cases, under all conditions, vehicles stopped shorter and were more stable when full front brakes were utilized on the vehicles. The results indicated that limiting pressure to the front brakes, either with manually operated or automatic pressure limiting valves, degraded braking performance. Poorest performance occurred when the front brakes were turned off.

Reference 9 includes an analysis of tests run in 1985 and 1986 to address tractor and trailer brake system compatibility and indicates that removal or limiting of front brakes degrades compatibility by reducing combination vehicle braking efficiency (i.e., the maximum possible deceleration a vehicle can achieve on a given surface before it becomes unstable). In addition, results of tests that were run to simulate mountain descents are also given. In these tests, brake temperatures were measured on a three-axle tractor/two-axle semitrailer both with full front brakes and limited (by an automatic limiting valve) front brakes. The test data indicates that when front brakes are limited, tractor drive and trailer brakes run measurably hotter. Presumably, if front brakes had been removed, even greater demand would have been placed on the drive and trailer brakes causing them to run even hotter. (This has been confirmed by more recent tests yet to be published.) This is an aspect that has not been considered by other researchers but is significant because it indicates a greater likelihood of brake fade and excessive brake wear (both of which are related to brake temperature) on the drive and trailer brakes if front brakes are limited or removed entirely.

INSURANCE INSTITUTE FOR HIGHWAY SAFETY TESTS (1985) -- National Technical Systems under the sponsorship of the Insurance Institute for Highway Safety (IIHS) conducted straight line, dry road braking tests from 55 mph (using full treadle panic applications) on a three-axle tractor when bobtail and in combination with empty and loaded semitrailers. The results (10) show that the stopping distance increase without front brakes was 75 percent for the bobtail, 38 percent for the empty tractor semitrailer and 24 percent for the loaded tractor semitrailer.

TRANSPORT CANADA TESTS (1986) -- Transport Canada conducted tests on a three-axle tractor/two-axle semitrailer combination both loaded to GVWR and empty on ice and snow covered roadways with and without front brakes. All stops were made from 50 km/ (31 mph) in a straight lane. Both modulated and full treadle panic brake applications were made. Results (11) indicate shorter stopping distances and better control with front brakes. In many cases the combination spun a full 180 degrees when the front brakes were off.

INSURANCE CORPORATION OF BRITISH COLUMBIA TESTS (1986) -- Tests were run by Transtech Engineering Limited for the Insurance Corporation of British Columbia using two bobtail three-axle tractors. Four different levels of front axle braking were evaluated by limiting pressure to the front brake chambers to 0, 50, 75 and 100 percent of the full pressure available in the reservoirs. Wet and dry roads were utilized and initial speeds were 50 and 80 km/h (31 and 50 mph). All brake applications were panic full treadle level and all stops were done in a straight lane. In these tests, the driver was instructed to hold the steering wheel straight and vehicle stability was assessed by measuring vehicle yaw and lane deviation during the stops. Results of the tests (12) indicate that vehicle deceleration essentially doubled when front brake pressure was increased from zero to the maximum (100 percent) level and the authors concluded that there was little evidence to support the contention that the use of 100 percent steering axle brakes in wet conditions decreases the stability of bobtail tractors. The authors recommend that steering axle brakes should be required for all heavy trucks and that the manual limiting valves should be set to the 100 percent, or no limiting, position on all bobtail tractors. (Canada permits vehicles with manual limiting valves which have a driver control on the dash board. Such valves have not been permitted since 1975 in the U.S.)

SUMMARY OF PAST RESEARCH

With the exception of the 1948 tests conducted by the National Safety Council, all tests (including those run more recently by the National Safety Council) to evaluate the performance of vehicles with and without front brakes indicate improved braking performance when front brakes are operational. These more recent tests universally indicate significantly shorter stopping distance when front brakes were operational and show equal or improved steering control and stability on all surfaces including ice. In those tests that have addressed front brake pressure limiting, results show that full pressure to the front brakes provides better overall braking performance than limited pressure. Finally, tests by the NHTSA also show that vehicles with full front brakes are less likely to experience high temperatures, fade and excessive wear in mountain descent situations.

SEPTEMBER 1986 TEST AND DEMONSTRATION

Major events in this program were scheduled as follows:

- <u>September 2-16</u> -- Vehicle Preparation and Preliminary Tests.
- <u>September 17</u> -- Driver Practice and Familiarization.
- <u>September 18</u> -- Testing.
- <u>September 19</u> -- Testing and Public Demonstration.

The following sections describe the program and present and analyze the test results. More detail is available in Reference 13. All testing was performed by the NHTSA's Vehicle Research and Test Center.

TEST VEHICLES -- Five three-axle truck tractors were utilized in the program. A description of these vehicles is included in Table 1. Although all five tractors (numbered 1-5 for identification purposes) were utilized in some of the testing in a bobtail mode, three of the tractors, Vehicles 1-3, were tested with semitrailers during the majority of the tests. Vehicles 4 and 5 remained in the bobtail configuration during all testing.

The semitrailers used with Vehicles 1-3 were 40 or 42 ft tandem axle flat beds. All three of these semitrailers utilized 16.5 x 7 inch brakes with type 30 brake chambers and 6 inch manual slack adjusters. Trailer brake linings were asbestos-based materials with SAE "EE" friction ratings. For tractors 1 and 2, semitrailers were run empty; for tractor 3, the semitrailer was loaded with concrete blocks so that the gross combination weight was a nominal 80,000 lb.

All of the tractors were late model vehicles in a "like-new" condition. Prior to starting the tests, all brakes were adjusted (where necessary) in accordance with the manufacturers recommendations to achieve the minimum possible chamber pushrod stroke without brake drag. One of the vehicles (Vehicle 5) was delivered to VRTC with essentially zero miles on the odometer. Brakes on this vehicle were burnished by running approximately 150 snubs from 40 to 20 mph at 10 ft/sec^2 on a 1.5 mile interval with a loaded semitrailer attached. The remaining four vehicles were either burnished by the manufacturers before delivery to VRTC or had accumulated a significant number of miles eliminating the need to burnish.

In order to be able to evaluate different levels of front axle braking in the testing, each of the tractors were modified by installing special plumbing on the front axle. Four different levels of front braking could be selected:

a) Full Front Brakes
b) Limited Front Brakes
c) No Front Brakes
d) Left Front Brake Only

In the full front brake mode, full air pressure from the treadle valve reached the front brake chambers. In the limited front brake mode, air from the treadle valve passed through a device called an automatic front axle limiting valve (ALV). This valve, an available option on most vehicles (and specified by many truck users), automatically proportions pressure to the front brakes to 50 percent of the treadle valve pressure level when the pressure at the treadle valve is below 40 psi. At a treadle valve pressure of approximately 40 psi, the ALV enters a blend back region (i.e., reduction starts to decrease from 50 percent). When the treadle valve reaches 60 psi, the ALV no longer proportions and passes full air pressure to the front brakes. Since the driver has no direct control over this valve, it is called an "automatic" front axle limiting valve. In the no front brake mode, no air pressure was allowed to reach the front brake chambers. In the fourth and final mode (left front brake only) the pressure from

TABLE 1 -- Test Vehicle Description

					Brake Configuration					
				Wheel-	Front			Rear (Drive)		
Tractor Number	MFGR	Cab Style	Steering	Base (in)	Size (in)	AxL*	Lin**	Size (in)	AxL*	Lin*
1	Volvo White	Long Conventional	Power	212	15x4	12x5.5	551D(A)	16.5x7	30x5.5	931-162(NA)
2	Navistar	Long Conventional	Power	248	15x4	20x5.5	551C(A)	16.5x7	30x5.5	MMD39A(A)
3	Ford	Short Conventional	Manual	150	15x4	16x5.5	8C5(A)	16.5x7	24x6	931-162(NA)
4	Freightliner	Short Conventional	Power	150	15x4	20x5.5	D39A(A)	16.5x7	30x5.5	D39A(A)
5	GMC	Long Conventional	Power	238	15x4	16x5.5	551C(A)	16.5x7	30x6	551C(A)

*A = Brake Chamber Area (in^2), L = Slack Adjuster Length (in)
**Letters in parenthesis after lining formulation code denote asbestos (A) or non-asbestos (NA).

the treadle valve was prevented from reaching the right front brake while full air pressure is supplied to the left front brake. This mode was included in the program because it simulated an extreme case of front brake unbalance left to right.

The three tractor-semitrailer combinations were equipped with special safety cables to prevent the tractor from rotating or jackknifing into the trailer (or to prevent the trailer from spinning or swinging into the tractor). These safety cables were installed so as to allow approximately 20 to 25 degrees of free rotation of the tractor with respect to each side of the trailer before becoming taut. Fifteen degrees is generally considered the articulation angle beyond which a driver cannot recover control of the combination. The articulation angle was allowed to go beyond this so that the potential jackknife situation would be more obvious to outside observers. The safety cables consisted of two one-inch diameter wire rope slings that were crossed in an "X" pattern in front of the trailer. One end of each cable was attached to a plate welded to the front corner of the trailer and at the other end to a sturdy steel bracket bolted just behind the cab to the tractor frame.

INSTRUMENTATION -- Two basic types of on-board instrumentation were used for these tests: the first measured the speed and stopping distance of the vehicles and the second measured the pressures in the control line and the left front brake chamber. The speed and stopping distance measurements were made using a commercially available fifth wheel system.

The pressure measurements were made by putting tees in the air lines and then installing strain gauge pressure transducers in the tees. The pressure transducers provided a signal suitable for recording and each of the vehicles was equipped with a two-channel strip-chart recorder to record the pressure signals.

The control line pressure was measured in order to have information about how the drivers were applying and modulating the brakes as they went through the maneuvers. The front brake chamber pressure was monitored to confirm that the front brakes were set up in the desired mode.

The three tractor-trailer combinations were also equipped with a red strobe light (visible to outside observers) and a passenger car type electric horn. The light and the horn were powered through a pushbutton switch controlled by the VRTC observer riding in the tractor cab. If the safety cables became tight during a run, the observer would operate the switch activating the strobe light and horn to indicate to outside observers that a jackknife had occurred.

Test runs were recorded on videotape with three cameras. One of the cameras was located in a tower approximately 15 ft above ground level and provided an elevated 3/4 view of the right side of the vehicle. The other two cameras were located on tripods at ground level on both sides of the maneuver lane.

DRIVERS -- Twelve volunteer professional over-the-road truck drivers participated in the demonstration. In addition, several test runs were made by two VRTC test drivers who regularly perform brake tests. Six of the volunteer drivers were employed by trucking companies and six owned/operated their own trucks. One group of drivers was selected by the International Brotherhood of Teamster Chauffeurs, Warehousemen and Helpers of America; the other group was selected by the Owner-Operators Independent Drivers Association of America.

Since time did not permit all twelve drivers to drive all five vehicles it was necessary to assign drivers to specific vehicles. This was done by drawing numbers. Each driver drove at least two but not more than three vehicles, each in a different type of maneuver.

TEST SITE -- All testing was performed on the Vehicle Dynamics Area (VDA) at the TRC. The VDA is a large asphalt pad measuring 1200 x 1800 ft and covers 50 acres. There are loops at each and of the VDA to allow for high speed entry to the pad. The bulk of the testing was performed at the south end of the VDA on a large (300 x 600 ft) area covered with driveway sealer (Jennite). This surface has an American Society for Testing and Materials (ASTM) skid number of approximately 20 at 40 mph when wet and is representative of a wet secondary roadway in "poor" condition. Test maneuvers that were set up on this area ran from west to east so that the 1 percent north to south slope existing on the VDA provided a cross slope to the maneuver lane not dissimilar to that which can exist on actual roads. The VDA has essentially a zero slope east to west.

A limited number of tests were also performed on the uncoated VDA asphalt both wet and dry. This surface has an ASTM skid number (at 40 mph) of approximately 65 when wet and 80 when dry

TEST MANEUVERS -- Three different types of braking maneuvers were utilized:

- Straight Line Stops (wet and dry asphalt, wet Jennite)
- Stops in a Curve (wet Jennite only)
- Stops in a Lane Change (wet Jennite only)

Twelve-foot wide traffic lanes, delineated with traffic cones spaced at 20 ft intervals, were used in each braking maneuver.

The maneuvers are shown in Figure 1. In the curve maneuver, the driver attempted to stop the vehicle while negotiating a 500 ft radius curve to the left. In the lane change maneuver, the driver applied the brakes, traveled straight for 30 ft and then attempted to change lanes to the left through a 100 ft long opening or "gate".

BRAKE APPLICATIONS -- Two different types of brake applications were utilized in the stopping maneuvers: driver "best effort" and "full treadle panic". In the driver "best effort" stops, the type of application specified in the majority of the tests, the driver was told to start applying the brakes at a designated location and bring the vehicle to a stop under full control as quickly as possible without deviating from the marked lane boundaries. He was given full freedom to modulate the brakes and steer the

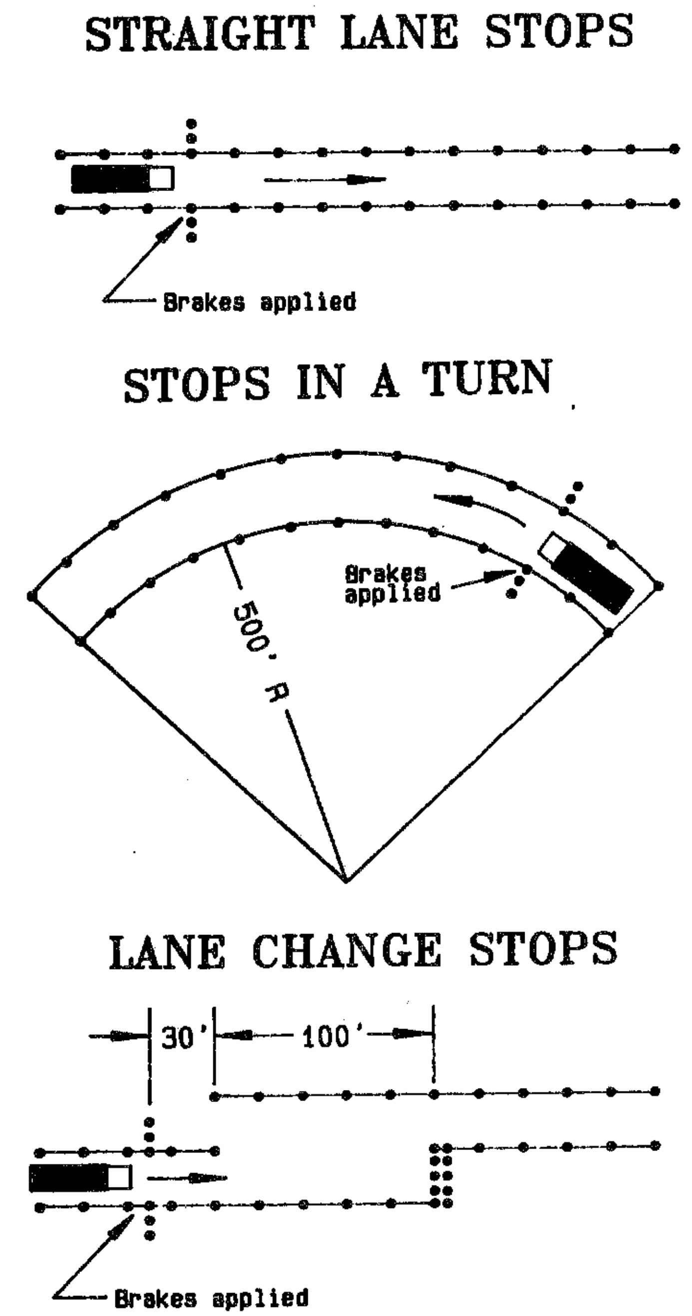

Fig. 1 - Test maneuvers utilized (all lanes 12 ft wide)

vehicle in whatever manner he felt appropriate; however, he was repeatedly encouraged to obtain the best possible braking performance from the vehicle. In these best effort type of stops, the drivers were always given three attempts (or repeats) for a given situation; the shortest distance achieved (when the vehicle also stayed within the lane) was utilized when analyzing the data.

In the "full treadle panic" applications, the driver was simply told to fully apply the brake control as rapidly as possible. Because this application method can result in wheel lockup and uncontrolled skidding, it was only used in a few low speed (20 mph) stops with the volunteer drivers. VRTC test drivers also utilized full treadle panic applications in the preliminary tests to evaluate the 20 mph stopping capability of the tractors with and without full front brakes and to demonstrate the dynamics of skidding vehicles in 40 mph stops with and without front brakes during the public demonstration.

TEST PLAN -- Four different types of tests were included in the test plan as follows:

Preliminary Tests -- Prior to conducting tests with the twelve volunteer drivers, a VRTC driver tested the five tractors (in a bobtail configuration only) to evaluate their stopping capability from 20 mph on dry pavement with and without front brakes. These tests were run in order to compare the braking performance of the vehicles to that specified in the Federal Motor Carrier Safety Regulations (FMCSR) Section 393.52. This section of the FMCSR specifies that bobtail tractors must be able to stop from 20 mph in 40 ft or less. During these tests, each vehicle was subjected to two full treadle stops with front brakes and two without. With front brakes, only the full front brake level was evaluated (i.e., no tests were run with the limiting valve operational.

Preliminary tests were also run by two VRTC Drivers on the five vehicles to determine test speeds for the various maneuvers. During these runs, the vehicles were configured as they would be in the regular tests (i.e., Vehicles 1-3 were attached to trailers; Vehicles 4 and 5 were bobtail). The VRTC drivers, experienced in these types of tests, established the highest possible speed at which the maneuver could be successfully completed and be safe in the event the driver lost control. It was important that vehicles not be traveling so fast as to be able to leave the wetted test area in the event the drivers locked the wheels and skidded out of control. These preliminary runs also established the basic dimensions of the area to be wet by the water trucks before each test run.

Driver Practice Day -- All twelve volunteer drivers were given time to practice each of the maneuvers that they would be running with each of the test vehicles they would be driving. In these practice runs, they gained experience with the different front brake configurations on their vehicles. Each driver was given up to three runs for each front brake configuration.

The primary purpose of the practice day was to have each driver become familiar with the vehicles and the overall test procedures so that he would be proficient in the actual tests. Past experience indicates that if drivers are not given such practice, they make basic mistakes during testing such as letting vehicle speed fall well below the desired test speed, stopping at the wrong location, missing the entrance to the test lane, hitting cones before applying the brakes, etc.

Test Day 1 -- On Test Day 1, each driver drove one vehicle in one maneuver (either the curve or the lane change) with three different front brake levels: full front brakes, limited front brakes and no front brakes. The order of changing the front brake configurations was varied among the drivers to minimize the effect of the driver learning curve in the data. The previous day of practice also helped to minimize this effect (i.e., the learning curve should have been in a "flat" region due to the first day's practice). As discussed earlier, each driver made three runs with each front brake configuration. Vehicles were tested in pairs alternating their runs. One of two VRTC observers always rode in the vehicles with the drivers participating in the demonstration.

<u>Test Day 2 and Public Demonstration</u> -- The difference from Day 1 was the omission of limited front brake tests and the addition of the one front brake tests. Also, at the beginning of Day 2, two of the test drivers ran the two bobtails (Vehicles 4 and 5) in 20 mph full treadle stops to demonstrate stops run in the preliminary tests by the VRTC drivers. Unfortunately, because it was raining, the tests could not be run on a dry surface as was done in the preliminary tests.

After the 20 mph tests were completed, two VRTC test drivers demonstrated the dynamics of vehicles in full treadle or panic stops in a straight lane from 40 mph on wet Jennite with and without full front brakes. One driver drove the short-wheelbase bobtail (Vehicle 4) and the other driver drove a long-wheelbase tractor with an empty trailer (Vehicle 1). The rest of the day's testing, all of which was done with the twelve volunteer drivers, included stops in a curve and lane change on the wet Jennite as were done on Day 1, straight lane stops on wet Jennite with only one front brake (and no front brakes), and high speed (55 mph) straight lane stops on wet and dry (uncoated) asphalt with and without full front brakes.

TEST RESULTS -- It is important to remember that the primary purpose of these tests was to compare the performance of vehicles with different levels of front braking -- not to compare one vehicle make to another or one driver to another. Comparison of vehicle makes should not even be attempted because the vehicles were driven by different drivers and were not comparable configurations (i.e., different wheelbases, axle loads, tires, brake conditioning (prior to testing), etc.). Drivers should not be compared because their performance in a particular vehicle may be influenced by their past driving experiences. For example, a driver who drives bobtail tractors frequently in his job would be expected to perform better in a bobtail than a driver who rarely drives such vehicles.

All stopping distances presented in the following sections have been corrected to the "target" or desired test speeds using the standard stopping distance correction formula as specified in SAE Recommended Practice J299. This makes the comparison of the various front brake configurations more precise by eliminating the effect of variability in actual test speeds from the data. SAE J299 specifies that this correction should only be utilized if the actual test speed deviation from the target or desired speed is less than ± 2 mph. Drivers stayed within this tolerance during the formal test days.

<u>20 mph Preliminary Tests by VRTC Driver</u> -- Figure 2 gives the results of the 20 mph straight lane full treadle stopping tests run with the five bobtail tractors on a dry asphalt surface. These tests were run by a VRTC test driver prior to the tests with the volunteer drivers. Figure 2 shows the best of two stops for the full front brake and no front brake configurations on each tractor. All stops were made within the 12 ft wide lane and the variation between the two runs was small (1 ft or less). It can be seen that all of the vehicles stopped in less than the 40 ft requirement in FMCSR 393.52 with full front brakes. Distances ranged from 22 ft to 24 ft.

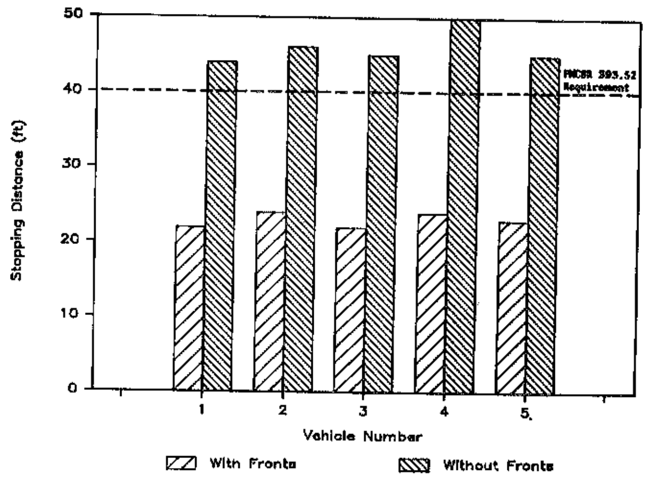

Fig. 2 - Full treadle stopping distance with and without front brakes for five bobtail tractors -- 20 mph on dry asphalt (VRTC driver)

Without front brakes, however, all of the vehicles exceeded the FMCSR requirement. Distances ranged from 44 to 50 ft. Without front brakes, the stopping distance was from 92 to 108 percent longer.

<u>40 mph Full Treadle Stops to Demonstrate Skidding Vehicle Dynamics by VRTC Drivers</u> -- The previous section on the test schedule indicated that 40 mph straight lane full treadle (panic) stops were made during the public demonstration on the wet Jennite surface with a bobtail (Vehicle 4) and an empty tractor trailer (Vehicle 1). VRTC drivers performed these stops to demonstrate the dynamics of these two different types of vehicles with and without front brakes (1 run each condition). Stopping distance was not recorded during these tests due to the fact that without front brakes the vehicles spun-out making the data from the trailing fifth wheel instrument meaningless. With the bobtail, the fifth wheel actually automatically lifted off the ground via a system designed to protect it. By reviewing the videotapes of these runs it was possible, however, to reconstruct, on an approximate basis, the path of the vehicles and the final position of the vehicle with respect to the

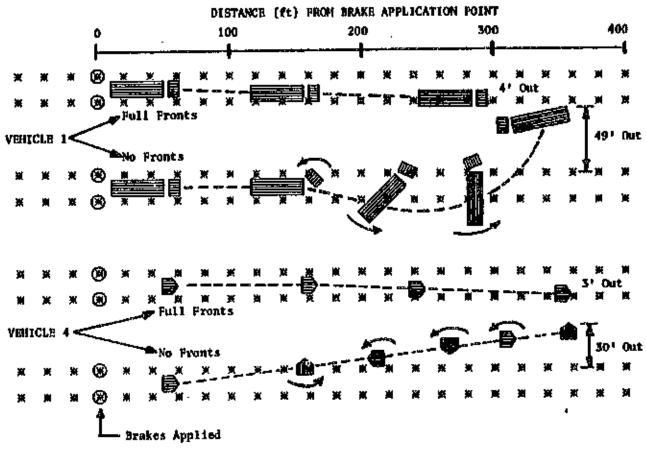

Fig. 3 - Approximate vehicle trajectories for 40 mph full treadle straight lane stops on wet Jennite (lane has 1 percent cross slope - down to right of vehicle)

brake application point and the straight lane boundaries. Figure 3 provides a graphical depiction of this reconstruction.

With both the bobtail tractor and the empty combination in the full front brake mode, the vehicles plowed straight ahead (i.e., they did not yaw or rotate), but, they did drift out of the lane to their right. This was due to the 1 percent cross slope (down to the right) on the lane. The bobtail hit 5 cones and left the lane by 3 ft; the combination hit 6 cones and left the lane by 4 feet.

With the front brakes turned off, the bobtail spun approximately 450° (1-1/4 rotations), hit 8 cones and left the lane to the left by 30 ft. With the empty combination, the tractor rotated into the safety cables (i.e., jackknifed) and then the entire combination spun approximately 190° hitting 16 cones and leaving the lane to the left by 49 ft.

With the bobtail, the downrange distance (i.e., distance from the brake application point along the lane to the final resting point) was about the same in both front brake configurations. With the empty combination, the downrange distance was approximately 50 ft further without front brakes (as measured from the starting point to the point on the vehicle furthest from the starting point).

<u>Tests With Volunteer Drivers</u> -- Performance comparisons were made using the "best" stop of the three runs made by each driver with each front brake configuration. The best stop is the shortest stop within the lane boundaries. If none of the three stops in a given configuration were within the lane, the one that had the least deviation from the lane was selected as the best. Note, however, that in the 20 mph full treadle stops (first pair of tests on Day 2) only one stop was made for each front brake configuration. These were the only stops made by the volunteer drivers that were not best effort type stops.

Figure 4 shows the percent increase in stopping distance when the front brakes were off on bobtail tractors 4 and 5 for the 20 mph full treadle stops on wet asphalt. Without front brakes, Vehicle 5 took 68 percent longer to stop and Vehicle 4 took 130 percent longer to stop for an average of 99 percent which is comparable to the increase experienced by test drivers in the earlier demonstration (Figure 2).

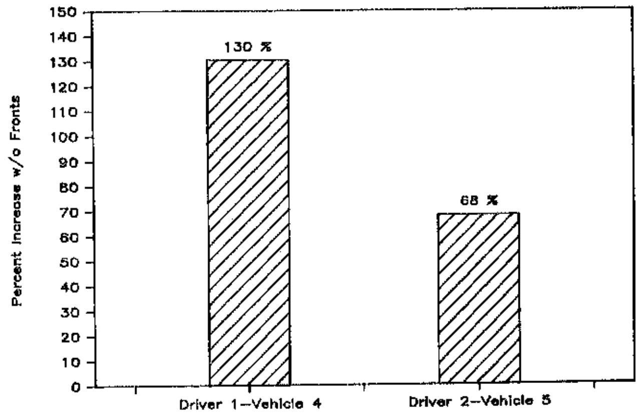

Fig. 4 - Percent increase in full treadle stopping distance when front brakes were off for 20 mph stops on wet asphalt -- two bobtails

Figures 5 and 6 show the percent increase in best effort stopping distance on wet Jennite when the front brakes were off for the curve and lane change maneuvers, respectively. Vehicle target speeds for these tests varied from 30-35 mph depending upon the vehicle.

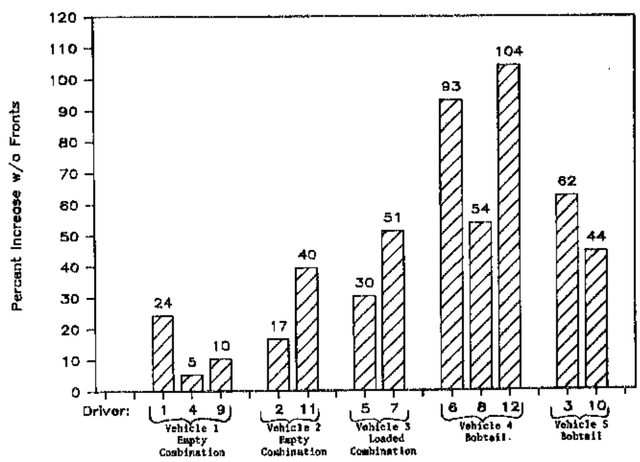

Fig. 5 - Percent increase in best effort stopping distance when the front brakes were off for 30-35 mph stops in a curve on wet Jennite

In all cases, stopping distances increased when the front brakes were off. On the curve, the increase ranged from 5 percent for Vehicle 1/Driver 4 to 104 percent for Vehicle 4/Driver 12. In the lane change, the increase varied from 16 percent for Vehicle 3/Driver 8 to 85 percent for Vehicle 4/Driver 10.

Figure 7 shows the percent increase in best effort stopping distance when the front brakes were off during the 55 mph straight lane stops on wet and dry asphalt. In both cases, the increase was significant -- 15 percent on Vehicle 1/Driver 10 (wet asphalt) and 27 percent on Vehicle 2/Driver 9 (dry asphalt).

Figures 8 and 9 show the percent increase in best effort stopping distance when the front brakes were limited (as compared to full front brakes) for the curve and lane change maneuvers, respectively.

The effect of the limiting valve was such that stopping distance always increased over that with full front brakes when the valve was operational. The increase on the curve ranged from 7 percent for Vehicle 1/Driver 4 to 38 percent for Vehicle 5/Driver 3. In the lane change, the increase varied from 8 percent for Vehicle 2/Driver 12 to 35 percent for Vehicle 1/Driver 11 and Vehicle 4/Driver 10.

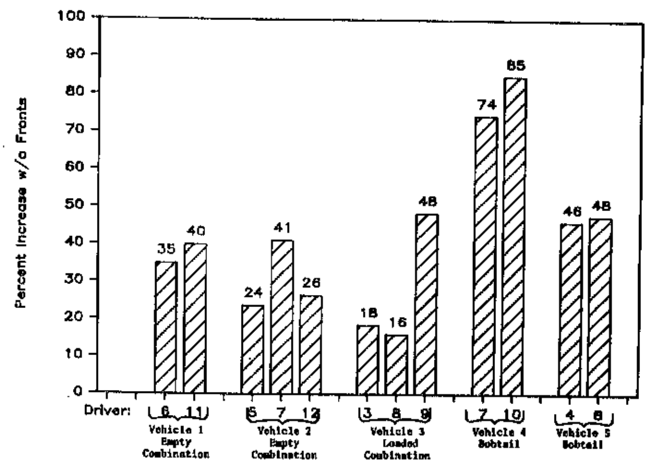

Fig. 6 - Percent increase in best effort stopping distance when the front brakes were off for 30-35 mph stops in a lane change on wet Jennite

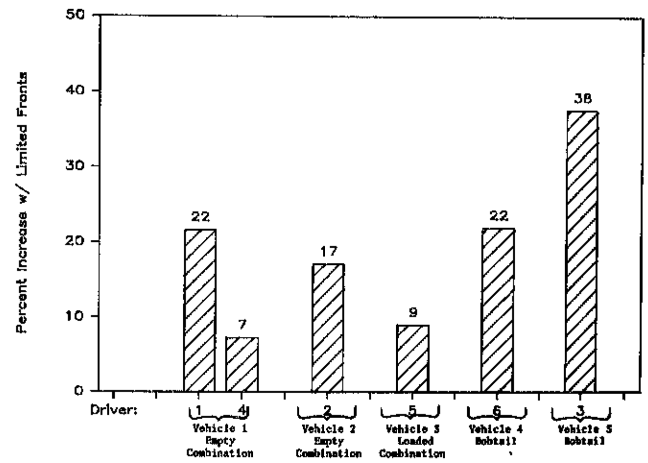

Fig. 8 - Percent increase in best effort stopping distance with limited front brakes (compared to full fronts) for 30-35 mph stops in a curve on wet Jennite

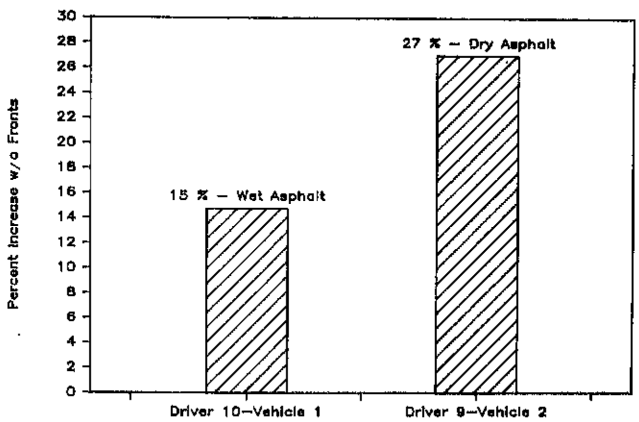

Fig. 7 - Percent increase in best effort stopping distance when the front brakes were off for 55 mph straight lane stops on wet and dry asphalt for two empty combinations

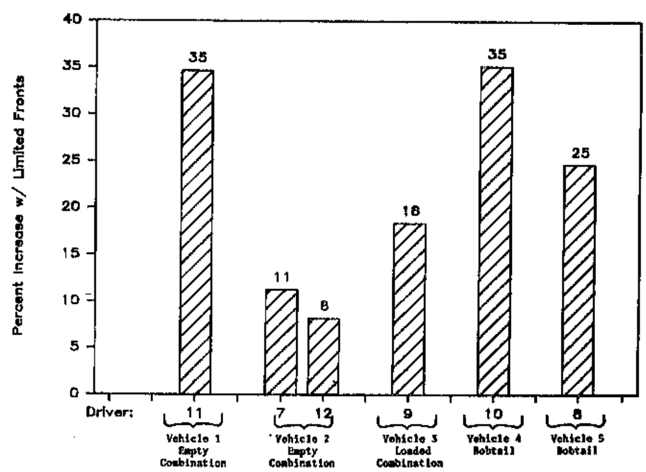

Fig. 9 - Percent increase in best effort stopping distance with limited front brakes (compared to full front brakes for 30-35 mph stops in a lane change on wet Jennite

Figure 10 shows the percentage increase in best effort stopping distance when the front brakes were off compared to that achieved with only the left front brake operational. In all cases, the best effortstopping distance was longer with no front brakes than it was with only one front brake. The increase with no front brakes varied from 4 percent for Vehicle 3/Driver 2 to 24 percent for Vehicle 5/Driver 1. It should be pointed out that Vehicle 3, the fully loaded combination, had manual steering. With the heavy load and manual steering, pull should have been the most pronounced on this vehicle. This pull did not deter the two drivers from keeping their vehicle in the 12 ft lane and achieving a shorter stop than they achieved with no front brakes. Driver 4 with vehicle 3 stopped 13 percent shorter with the one front brake.

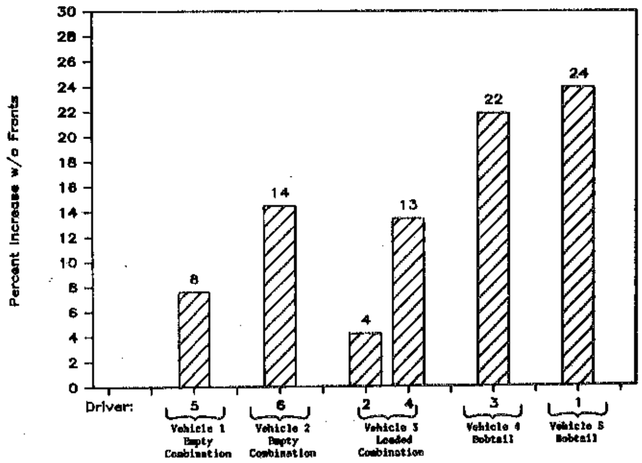

Fig. 10 - Percent increase in best effort stopping distance when front brakes were off (as compared to having only one front brake) for 30-35 mph straight lane stops on wet Jennite

After completing tests on each vehicle, the voluntary drivers were asked to write down any comments that they had relative to their experience with that vehicle.

Reviewing these comments, all contained verbatim in Reference 13, indicates that 8 of the 12 drivers appeared to be in favor of front wheel brakes after the tests. Several of these eight indicated a change in their position on front brakes as a result of the test. Of the remaining four drivers, two had no comments, one stated in one test he could see no difference and had no comments on the other two tests that he ran and one driver had mixed comments. This driver stated on Day 1 after driving the empty combination (Vehicle 1) in the lane change that, "It seems I did better with control with no front brakes than I did with full front brakes. Perhaps the thought of having full front brakes stuck in the back of my mind." On Day 2 after driving Vehicle 4 in the curve he indicated that he had the same comments as on Day 2 but added, "Control conditions do show front wheel brakes work better." This driver's comments reflected his performance; in one case he appeared to have slightly better control without front brakes but his stopping distance was longer. In the other case, he clearly did much better with front brakes. In the first case, he may have done better with front brakes if he had not applied the brakes so hard. The data indicates a lighter application would have lengthened his stopping distance somewhat but allowed him to keep the vehicle in the lane. Two other drivers who drove the same vehicle in the same maneuver had no problems and did much better with full front brakes.

CONCLUSIONS - SEPTEMBER 1986 TEST AND DEMONSTRATION -- Based on an analysis of the results of the September 1986 testing and demonstration, the following conclusions can be stated:

- None of the five bobtail tractors could meet the 40 ft stopping distance requirement (from 20 mph) specified in FMCSR 393.52 when their front brakes were turned off; distances without front brakes were 44-50 ft. With full front brakes distances ranged from 22-24 ft.
- With the exception of one driver in one series of tests, drivers were clearly able to achieve better performance with full front brakes than without in all cases. They stopped in shorter distances under full control with full front brakes. Without front brakes, best stopping distances were 5 to 130 percent longer and drivers were more likely to lose control. For the one exception, the results indicate slightly better control without front brakes than with full front brakes; however, it took the driver 81 ft longer to bring the vehicle to a stop.
- When automatic limiting valves were operational on front axles, the drivers always took longer to stop under full control than when the vehicles had full front brakes. Increase in the best effort stopping distance with the limiting valves ranged from 7-38 percent.
- Even with only one front brake, drivers were able to stop shorter under full control than with no front brakes (i.e., the pull resulting from having only one brake did not cause as much problem as having no front brakes). This was true even with a fully loaded combination (80,000 lb) with manual steering (Vehicle 3). With no front brakes, the vehicles took 4-24 percent longer to stop within the lane than with only one front brake.

- In 40 mph full treadle panic stops by VRTC drivers in a straight lane on wet Jennite with a 1 percent cross slope, a bobtail (Vehicle 4) spun 450° and left the lane by 30 ft without front brakes. With front brakes, the vehicle did not spin or yaw and left the lane by only 3 ft. An empty tractor trailer (Vehicle 1) operating without front brakes in this maneuver jackknifed into the safety cables, spun as an entire unit 190° and left the lane by 49 ft without front brakes. With front brakes, the vehicle skidded without the tractor or trailer yawing and left the lane by only 4 ft.

- Eight of the twelve drivers had very positive comments about front brakes after their runs. Many changed their minds as a result of the tests. Two had no comments, one could see no difference and one had mixed comments.

OVERALL SUMMARY AND CONCLUSIONS

In July 1986 the FHWA began rulemaking to eliminate an exemption in the FMCSR which permits truck operators to remove front brakes on trucks and truck tractors with three or more axles. The advisability of having front wheel brakes on heavy vehicles has been a controversial topic for many years and many truck operators remove, disable, or fail to maintain front brakes. With the exception of tests that were run almost 40 years ago (on vehicles that are not representative of today's vehicles), all work that has been done to evaluate the performance of heavy vehicles with and without front wheel brakes indicates that performance of vehicles is degraded when front brakes are removed. Not only is stopping distance increased significantly but vehicle stability and control is compromised. Drive and/or trailer brakes are more likely to lock up when the front axle does not have brakes. Removal of front brakes also places greater thermal energy demands on drive axle and trailer axle brakes in mountain descent situations making the brake system more prone to fade or loss of braking effectiveness due to high temperature. Testing indicates that limiting of typical, current design front brakes by the use of pressure reduction valves degrades vehicle braking performance as well. When given the opportunity to operate vehicles in simulated emergency situations with and without front wheel brakes most drivers are able to stop vehicles shorter and are less likely to lose control if they have full front brakes; and many drivers opposed to front wheel brakes experience a change of opinion.

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