Vehicle Weights and Dimensions Study

Volume 4

Demonstration Test Program: Five, Six and Seven Axle Tractor Semitrailers

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Volume 4 -- Demonstration Test Program: Five, Six and Seven Axle Tractor Semitrailers

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Abstract

A 5-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated an additional vehicle by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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DISCLAIMER

This publication is produced under the auspices of the Technical Steering Committee of the Vehicle Weights and Dimensions Study. The points of view expressed herein are exclusively those of the authors and do not necessarily reflect the opinions of the Technical Steering Committee, Canroad Transportation Research Corporation or its supporting agencies.

This report has been published for the convenience of individuals or agencies with interests in the subject area. Readers are cautioned that the use and interpretation of the data, material and findings contained herein is done at their own risk. Conclusions drawn from this research, particularly as applied to regulation, should include consideration of the broader context of Vehicle Weights and Dimension issues, some of which have been examined in other elements of the research program and are reported on in other volumes in this series.

The Technical Steering Committee will be considering the findings of these research investigations in preparing its "Final Technical Report" (Volume 1 & 2), scheduled for completion in December 1986.

PREFACE

The report which follows constitutes one volume in a series of sixteen which have been produced by contract researchers involved in the Vehicle Weights and Dimensions Study. The research procedures and findings contained herein address one or more specific technical objectives in the context of the development of a consistent knowledge base necessary to achieve the overall goal of the Study; improved uniformity in interprovincial weight and dimension regulations.

The Ontario Ministry of Transportation and Communications was responsible for carrying out full scale testing of several of the heavy articulated commercial vehicles designated as "special cases" within the vehicle stability and control research program. The cooperation of the following agencies and companies is gratefully acknowledged for their assistance in the conduct of this program:

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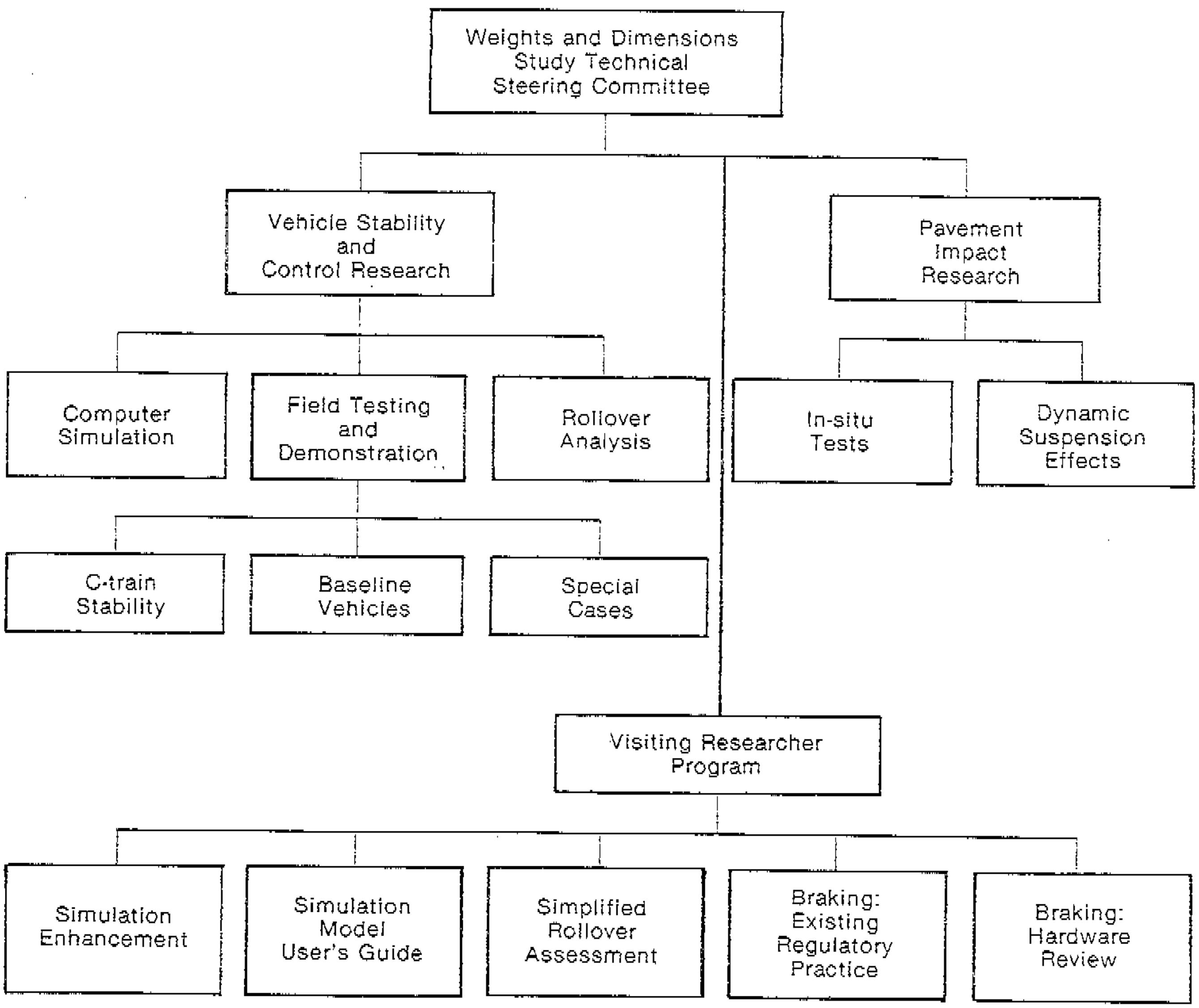

Volume 4

Demonstration Test Program: Five, Six and Seven Axle Tractor Semitrailers

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EXECUTIVE SUMMARY

The effects of weight and dimension parameters on heavy truck stability and control and on pavement response are being examined in the CCMTA/RTAC Vehicle Weights and Dimension Study. The objective of the study is to compile technical information to provide a basis for the provinces to amend their truck weight and dimensions regulations. The goal is to simplify interprovincial trucking through greater uniformity in these regulations.

During the study a number of vehicles of particular interest were identified. Several of these were tractor-trailers, and a single 48 ft (14.63 m) semitrailer with a fixed 2.77 m (109 in) tandem axle and two non-steering airlift axles spaced 2.74 m (108 in) ahead of the tandem was obtained for test. By lowering none, one, or both airlift axles, the trailer could be configured to provide a 5-, 6-, or 7-axle combination. Such combinations are typical of equipment used in Central Canada, where additional gross weight is permitted with a widespread tandem or a belly axle.

The Ontario Ministry of Transportation and Communications subjected each of these vehicles to a standard series of tests for turning; the brake system; lateral/directional and roll stability; trailer sway; and a demonstration of straight-line braking. The same series of tests was also conducted concurrently on a set of six baseline vehicles, which included a 45 ft (13.72 m) 5-axle semi with a 1.37 m (54 in) tandem spread that is generally comparable to the 5-axle 48 ft (14.63 m) semi. The baseline vehicles also included 8-axle A-, B-, and C-train doubles that only have a modest payload advantage over the 7-axle 48 ft (14.63 m) semi, so are reasonably comparable to it.

The primary objective of the test program was to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures. These tests would be used as a background to complement the findings of a comprehensive computer simulation that was used to evaluate variations in weight, dimensions, and equipment for the three configurations.

Turning performance depends upon the effective wheelbase of the trailer. There was essentially no difference between the 5-axle 48 ft (14.63 m) and 45 ft (13.72 m) semitrailers, as the additional trailer length is countered by its greater axle spread. The space required to turn the vehicle was decreased when first one, then the second, airlift axle was lowered, as each step reduced the effective wheelbase of the trailer. The space required by the 7-axle 48 ft (14.63 m) semi to make a right-hand turn approached that required by the three doubles. However, the effort required to turn the 7-axle combination was much greater than that of the 6-axle combination, which exceeded that of the 5-axle combination. This undoubtedly leads to the common practice of raising airlift axles to make turns where an axle control is permitted in the cab.

The air brake system of all three combinations was quite fast and well balanced. Each airlift axle was provided with its own reservoir and relay valve, so brake application and release timing of the fixed tandem axle was essentially unaffected by the airlift axle position.

Dynamic tests of the empty vehicle on a low-friction surface were conducted for all three configurations, even though in normal use the airlift axles would be raised when the vehicle is empty. During a demonstration of straight-line braking, all three vehicles became unstable by tractor jackknife when the tractor drive axles locked. The jackknife became faster as the number of trailer axles increased, because the resistance to turning of the trailer increased. If front axle brakes had been used, it is likely that tractor jackknife would not have occurred.

During an evasive manoeuvre with the empty vehicles on a low-friction surface, the limit of tractor control was reached for the 5-axle vehicle at about 61 km/h, whereas trailer swing was evident with the 7-axle vehicle at about 58 km/h.

The rearward amplification of lateral acceleration of the loaded vehicles was 0.90, 0.92, and 1.05 for the 5-, 6-, and 7-axle combinations, respectively. The 7-axle vehicle is effectively shorter than the other two, which slightly reduces its lateral/directional stability, though all three are very stable vehicles in comparison with any double.

All three vehicles were able to make a lane change in a 30 m (98.4 ft) gate at a speed of 94 km/h, though the articulation response of the trailer increased as the number of trailer axles increased, because of the lower stability of the vehicle.

In a steady circular turn of 50 m (164 ft) radius, the 5- and 6-axle vehicles experienced outrigger touchdown at 0.52 g and 0.53 g, respectively. It is not certain that this would have resulted in rollover, but they were close to the roll threshold. The 7-axle vehicle did not exceed 0.39 g in this turn, as the driver was unable to follow the curve because of the excessive steer demand necessary to turn the trailer with its four widely separated axles. A tilt test conducted on these three vehicles resulted in a lateral acceleration of 0.60 g at rollover for the 5-axle vehicle and 0.56 g for the other two. This test was performed with the airlift axle supply system operating in its normal mode, which may have increased the roll resistance of these axles. The centre of gravity of all three vehicles was relatively low: 1.60 to 1.65 m (63 to 65 in) above the ground. The roll threshold would be substantially reduced if the centre of gravity had been higher, to the extent that rollover could have occurred in the lane-change manoeuvre too.

In summary, there is little practical difference between the 5-axle 48 ft (14.63 m) semi with a widespread tandem and the 5-axle 45 ft (13.72 m) semi tested concurrently as a baseline vehicle. Both are very stable and require much space to manoeuvre. Stability is reduced as axles are added to the trailer, but the 7-axle semi still has much lower rearward amplification of lateral acceleration than any double and, hence, higher lateral/directional stability. However, it requires much greater effort to manoeuvre, and where available friction is limited, tractor jackknife becomes more likely with this vehicle than any other, unless the airlift axles are raised when the remaining axles become overloaded. The 6-axle vehicle is intermediate in performance between the 5- and 7-axle vehicles, but it is suited to a different role than the other vehicles tested in this program and is not reasonably compared with any of them.

The specific results presented here apply to the vehicles tested for the particular test conditions. Results different in some respects might be expected for other vehicles or test conditions.

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Demonstration of Tractor-Trailer Performance: 5-Axle 48 ft Semi

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ABSTRACT

A 5-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated an additional vehicle by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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ACKNOWLEDGEMENTS

This work was conducted on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study, managed by J.R. Pearson. The trailer was provided by the Roads and Transportation Association of Canada (RTAC). Facilities of the Transport Canada Motor Vehicle Test Centre were made available to the Ministry of Transportation and Communications (MTC). Assistance with vehicle preparation, delivery, and refurbishment was arranged by Mr. Pearson in support of this work.

The work was principally undertaken by the staff of the Automotive Technology and Systems Office of the Transportation Technology and Energy Branch of MTC: N.R. Carlton; G.B. Giles; C.P. Lam, P.Eng.; W.R. Stephenson, P.Eng.; and M.E. Wolkowicz; and assigned students G. Goertzen, S. Jazic, and D.R. Sykes. Assistance was provided by staff of various other departments of the ministry and other organizations.

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The efforts of all involved are hereby acknowledged with gratitude.

1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 5-axle 48 ft (14.63 m) semitrailer combination, which is one of the additional vehicles. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and single 48 ft (14.63 m) tandem flatbed-type trailer. The combination is typical of equipment used in Central Canada, where additional weight can be carried on a widespread tandem axle. The same combination was also tested concurrently as a 6- and 7-axle vehicle [8,9].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by Fruehauf and was a 48 ft (14.63 m) flatbed semitrailer with two fixed axles and two non-steering airlift axles that were raised for these tests. The trailer was manufactured in July 1984, bore the serial number 2H8P04843ER033601, and was model PBX4W 48102.

The trailer had a nominal length of 14.63 m (48 ft) and a nominal width of 2.59 m (102 in). The trailer suspension comprised a Reyco four-spring leaf system with long equalizer arms on the fixed axles, which had a spacing of 2.77 m (109 in). The spring centre width was 0.96 m (38 in), and the overall track width was 2.44 m (96 in). The vehicle overall length was 18.69 m (61.32 ft). The trailer was rated at 9620 kg/axle (21 164 lb/axle). The fixed tandem axle was placed to the rear of the trailer, because in that position it can accrue a greater gross weight as a 4-axle trailer. However, current 48 ft (14.63 m) semitrailers often have their axles forward, at the same distance from the trailer kingpin as for a 45 ft (13.72 m) semitrailer, because under current regulations no additional gross weight is gained for rearward placement of the axles, and the turning performance is improved.

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 22 595 kg (49 710 lb). Concrete blocks were used to obtain a loaded weight of 34 409 kg (75 680 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 918	10 820	5 055	11 120
2	5 368	11 810	7 336	16 120
3	4 686	10 310	6 827	15 020
4	4 082	8 980	7 618	16 760
5	3 541	7 790	7 573	16 660
Total	22 595	49 710	34 409	75 680

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment, because of the two lifted axles on the trailer, and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was nearly attained, with the exception of the tractor drive axles. The legal gross weight for the vehicle tested varies between 36 500 and about 44 000 kg (80 300 to 96 800 lb), depending upon the province.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.33 m (13 in) below the top of the floor. The centre of gravity height was estimated as 0.09 m (4 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and trailer was calibrated.
15/ Details of the vehicle and test equipment were recorded on photographs and videotape.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyroscope package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyroscope package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	19.792°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyroscope	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values, shown in the last column of Table 3, is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 2.41 m (7.9 ft), shown in Figure 4, became 2.82 m (9.25 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.52	27.59	0.07	27.55	27.56	+0.04
2	2.37	27.22	27.37	0.15	27.30	27.21	-0.31
3	2.37	27.21	27.37	0.16	27.29	27.21	-0.29
4	2.37	24.74	24.79	0.05	24.77	24.77	0.00
5	2.37	24.68	24.68	0.0	24.68	24.77	+0.36

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was 2.00 m (6.56 ft), over one-half a lane width. It was out of the exit lane for a distance of 26.0 m (85.3 ft), as derived from Figure 5. This test was conducted at a creep speed and represents the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was only 0.73 m (2.39 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle was driven with the left front wheel tracking the curb. In practice, a driver would allow some clearance on his side, if only to stay clear of catch basins. This would mean the rear axle would come close to the inner curb.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi).

The SAE J982a style test was performed, and the results, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test are typical of those obtained from tests conducted on other similar combinations. A typical time history response of application and release is presented in

Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.04	0.18	91.9
Axle 2	0.36	0.56	90.4
Axle 5	0.39	0.84	88.1

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The brake application of about 242 kPa (35 psi) caused all braked wheels to lock, and the tractor jackknifed slightly to the left. No higher brake pressures were used as all axles were already locking at lower pressures. A higher speed would have resulted in a faster jackknife, but use of the tractor front axle brakes would probably have eliminated the jackknife.

A summary of peak vehicle responses is shown in Figure 12, as a function of average treadle valve pressure. The limit of surface adhesion of about 0.15 *g* was reached at a brake pressure of about 159 kPa (23 psi), when most wheels were locking. The vehicle did not become unstable until a considerably higher brake pressure.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. Gates of 22.5 m (73.8 ft) were used for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude for both vehicle units tended to rise up to approximately 54 km/h and then stabilized. Heading angle for the tractor tended to decrease as speed increased, whereas heading angle of the trailer remained relatively uniform. Data indicated that the tractor slid at the higher speeds, while tractor heading angle decreased. The driver commented that the tractor tires clattered and howled, indicating operation at or near their performance limits.

A typical run at 60 km/h is shown in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration of the trailer is presented in Figure 15, as a function of tractor steer input period for the three test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15, that rearward amplification increases only slightly with speed for this vehicle. It is also somewhat sensitive to steer period, reaching the highest value of about 0.90 at around 3.5 s. The results, show that, at highway speed, this is a very stable vehicle, because of its low response to input.

Figure 16 shows the response of a typical run for a steer period of about 2 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

A gate of 30 m (98.4 ft) was used, to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections

The results from all runs are summarized in Figure 17. Throughout the speed range, the peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all remained relatively uniform; the lateral acceleration gain was consistent with rearward amplification; and the vehicle appeared to be quite stable with no major trends. The consistent yaw overshoot appears to be due to tractor steer correcting in the exit lane and moderate tire slippage. It did not appear to increase with speed until modest trailer swing occurred at the limiting speed of 94 km/h.

Figure 18 shows a typical time history of a run at 94 km/h.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was very stable, and if any slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in trailer sway, it was not readily perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 0.92 g/° of RMS steer input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 19. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angles are presented as a function of tractor lateral acceleration. Average steady-state articulation angles decrease modestly with increase in lateral acceleration, and as a consequence, the offtracking decreases. The lateral force experienced by the tractor fifth wheel, presented as a function of tractor lateral acceleration, shows a gradient of 52.5 kN/g (11 800 lb/g).

At the limiting speed of 63 km/h, a lateral acceleration of 0.52 g, the outrigger touched down and the trailer swung out, as shown in Figures 20 and 21. The driver then steered out of the circle. It is possible the vehicle would not have rolled over.

A tilt test was conducted on this vehicle as part of a separate test program [13]. The vehicle is shown on the tilt table, in Figure 22. The high-side wheels of the rear trailer lifted at a tilt angle of 31.0°, after all corrections were made, which corresponds to a lateral accleration of 0.60 g. This is in quite good agreement with the rear trailer's lateral acceleration of 0.52 g at outrigger touchdown . A full discussion of the tilt test is presented elsewhere [13].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly and the two airlift axles were additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, at least in the empty condition.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. It braked well and was easy to manoeuvre. Its length simply meant it required space to manoeuvre. It exhibited high stability in all manoeuvres.

6/ CONCLUSIONS

A 5-axle tractor-semitrailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The trailer was 14.65 m (48 ft) long and had a 2.77 m (109 m) widespread tandem axle. The vehicle was designated as of particular interest by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns.

The air brake system was relatively fast and well balanced.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. The roll stability was high, primarily because of the low trailer centre of gravity height. A higher centre of gravity would have significantly reduced the roll threshold.

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[15] Delisle, G., "Investigating Articulated Vehicle Roll Stability Using a Tilt Table," Vehicle Weights and Dimensions Study Final Technical Report, Volume 7, Roads and Transportation Association of Canada, Ottawa, July 1986.

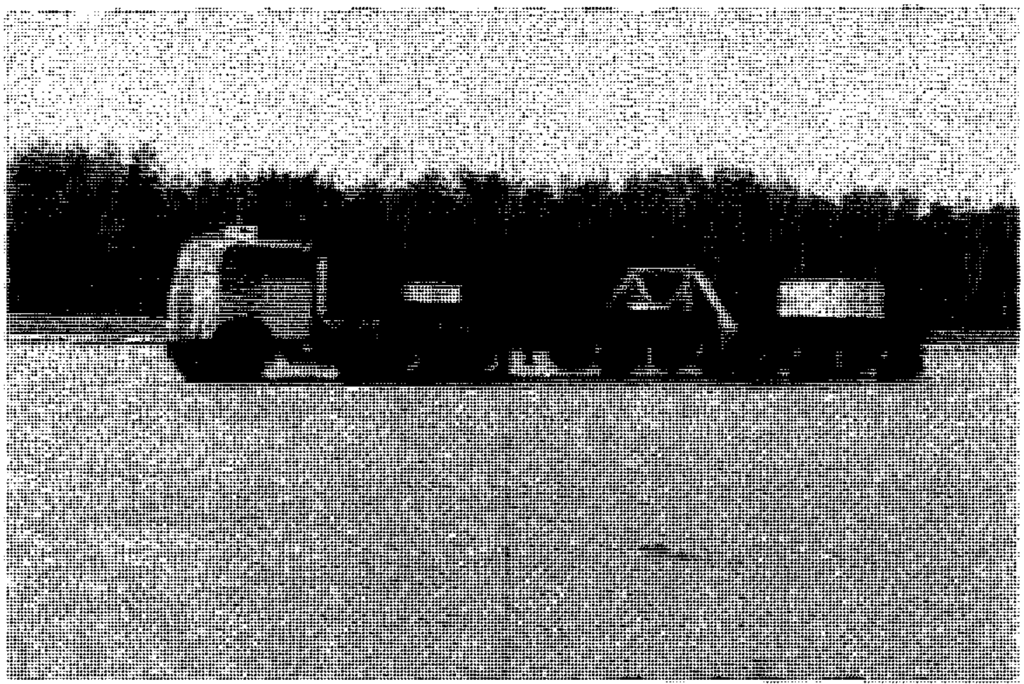


Figure 1/ View of Vehicle

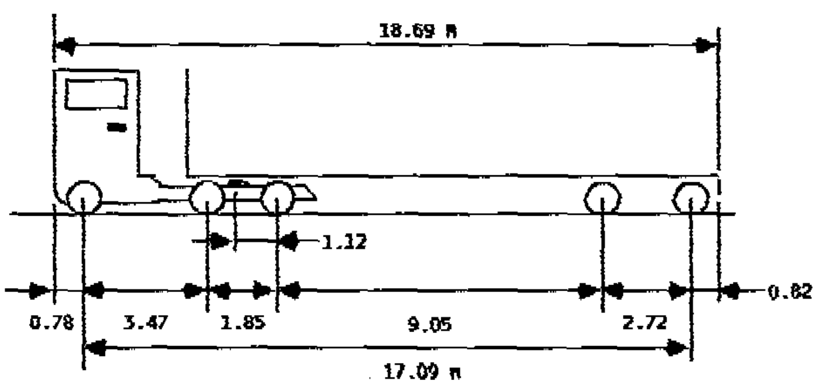


Figure 2/ Vehicle Dimensions

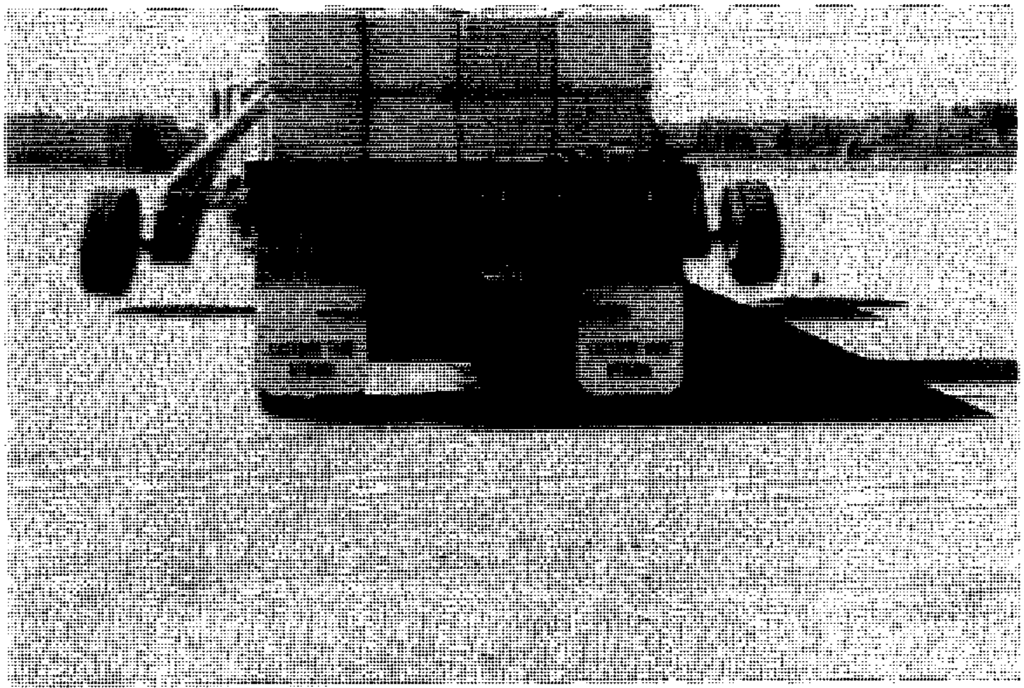


Figure 3/ Offtracking

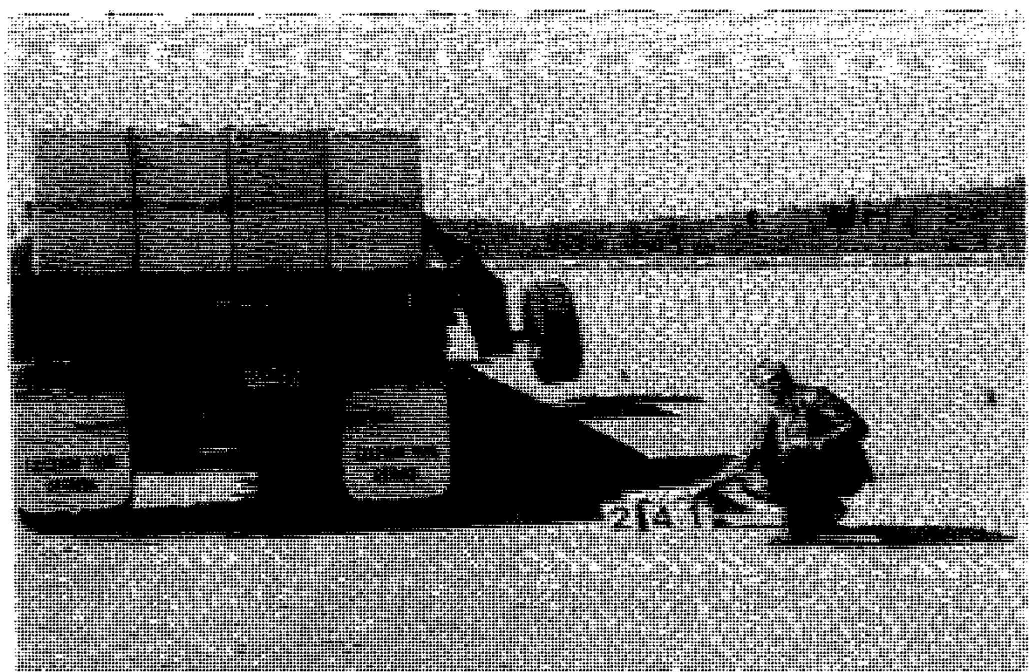
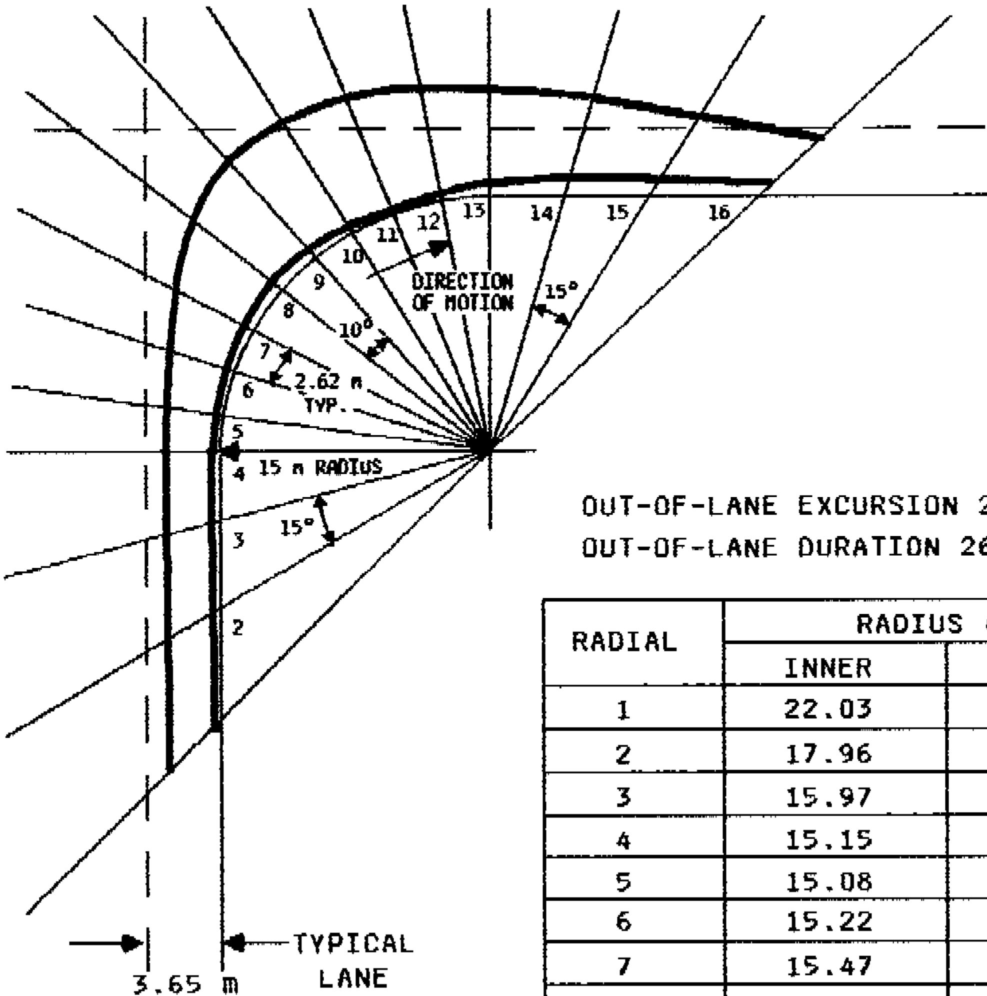


Figure 4/ Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 2.0 m
OUT-OF-LANE DURATION 26 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	22.03	-
2	17.96	-
3	15.97	-
4	15.15	17.79
5	15.08	17.90
6	15.22	18.55
7	15.47	19.66
8	15.39	20.88
9	15.18	21.95
10	15.06	22.16
11	15.02	21.87
12	15.12	21.38
13	15.45	20.83
14	16.39	21.27
15	18.33	22.55
16	22.30	25.92

Figure 5/ Right-Hand Turn Swept Path

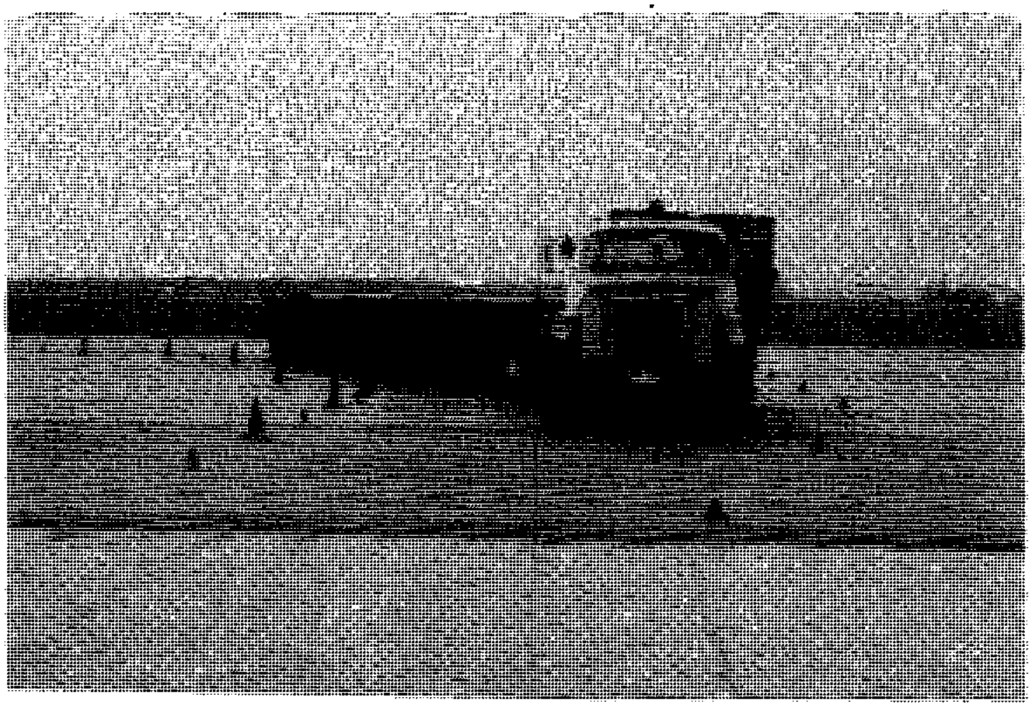


Figure 6/ Right-Hand Turn

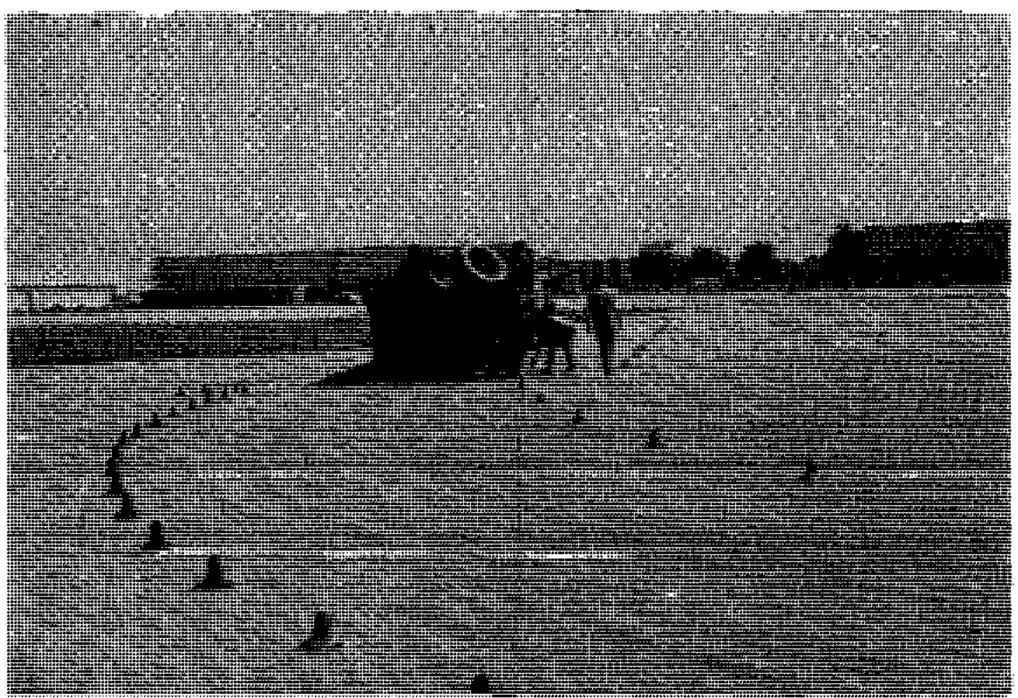
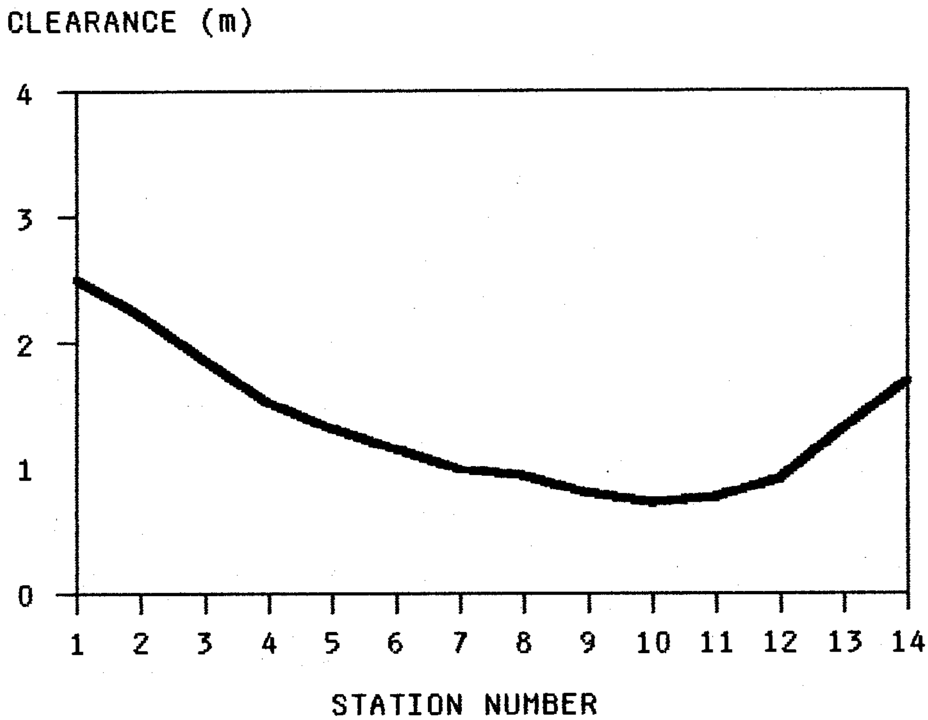


Figure 7/ Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.51
2	2.22
3	1.86
4	1.52
5	1.31
6	1.14
7	0.99
8	0.93
9	0.80
10	0.73 *(LOW)
11	0.76
12	0.92
13	1.31
14	1.70

Figure 8/ Channelized Right Turn Clearance from Inner Curb

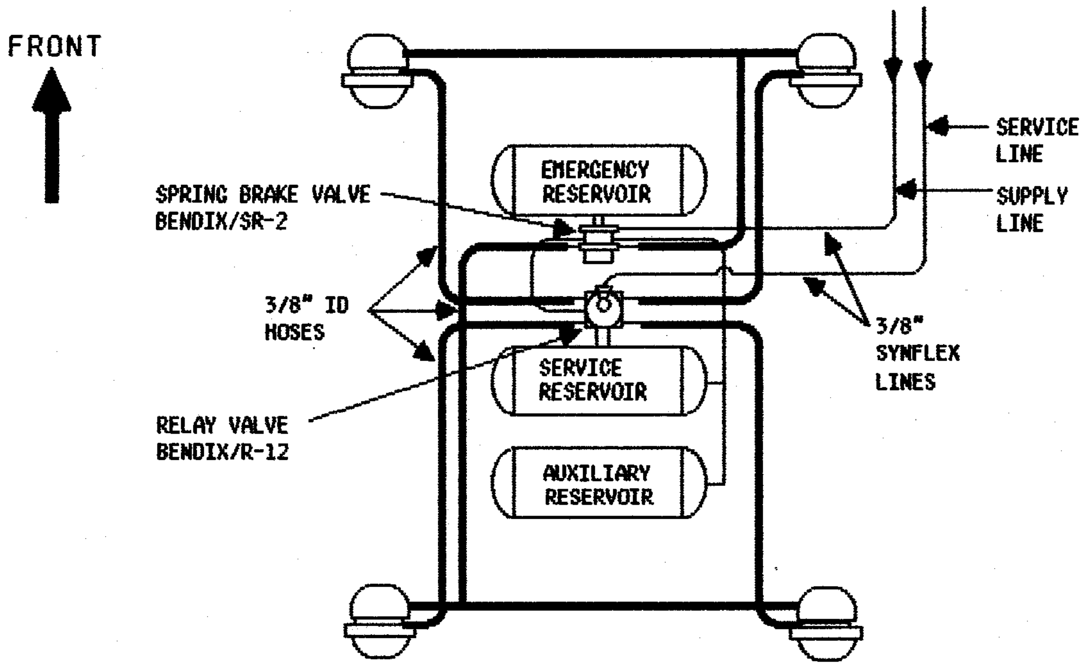


Figure 9/ Air Brake System Schematic

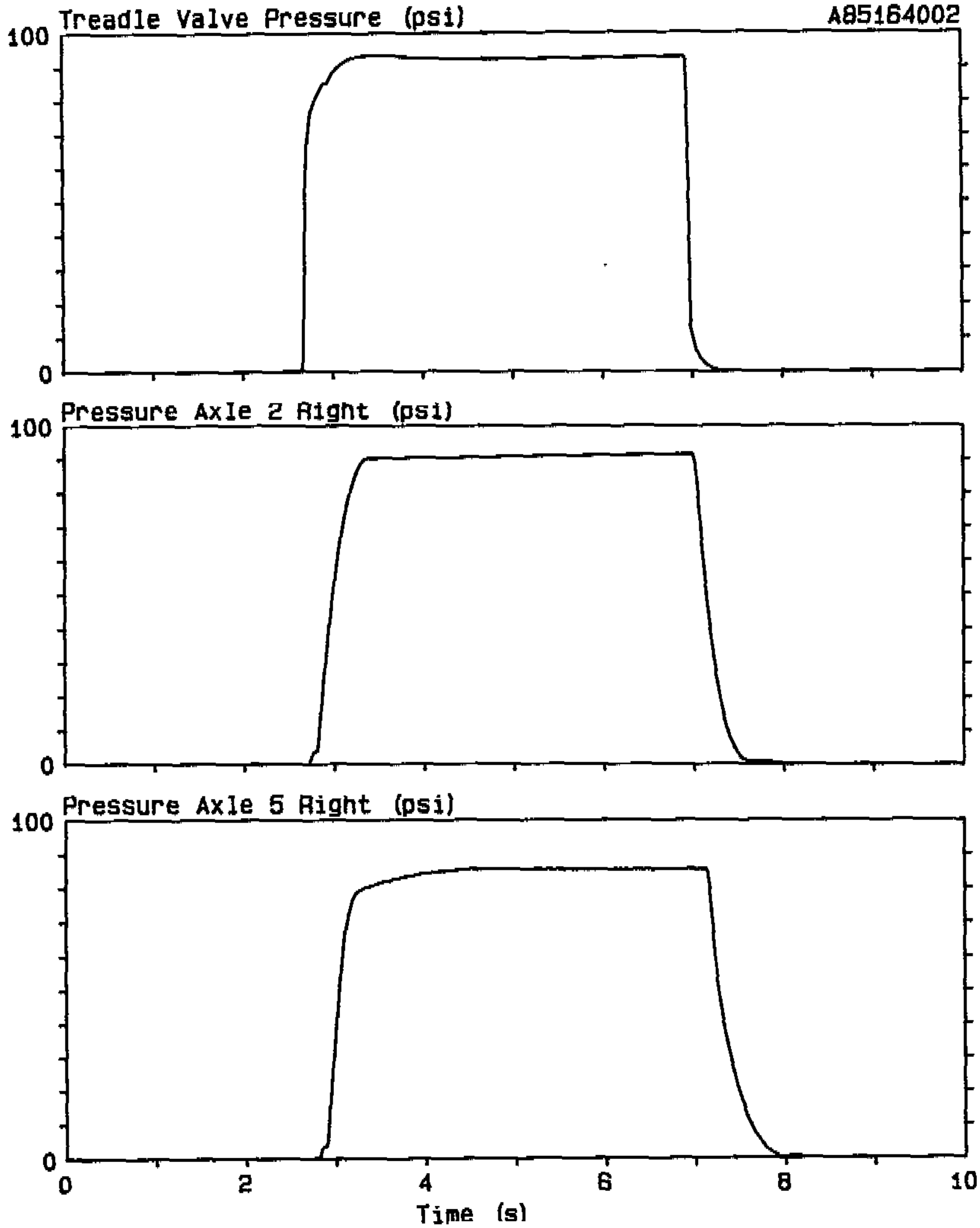


Figure 10/ Air Brake Application and Release

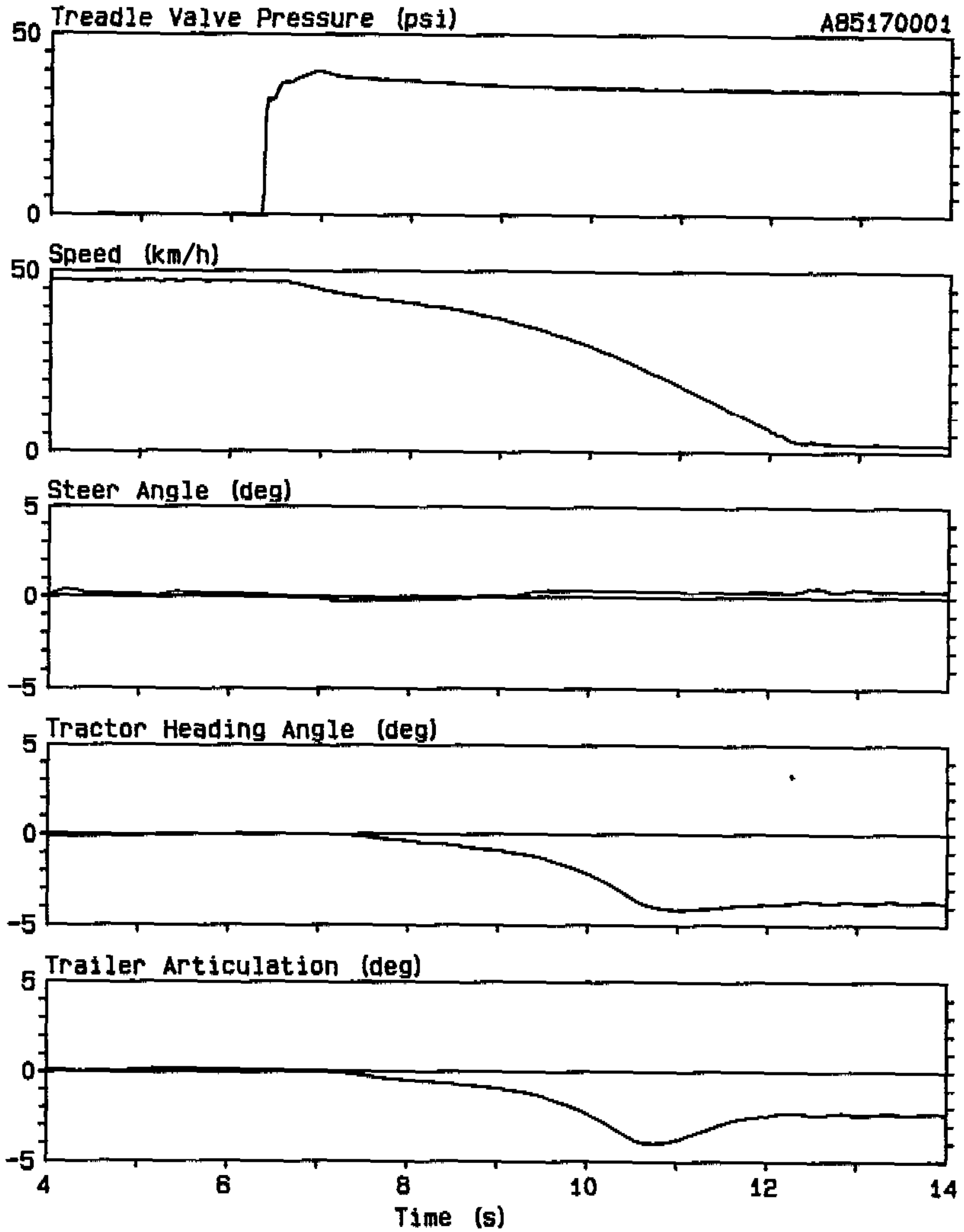


Figure 11/ Vehicle Response to Straight-Line Braking

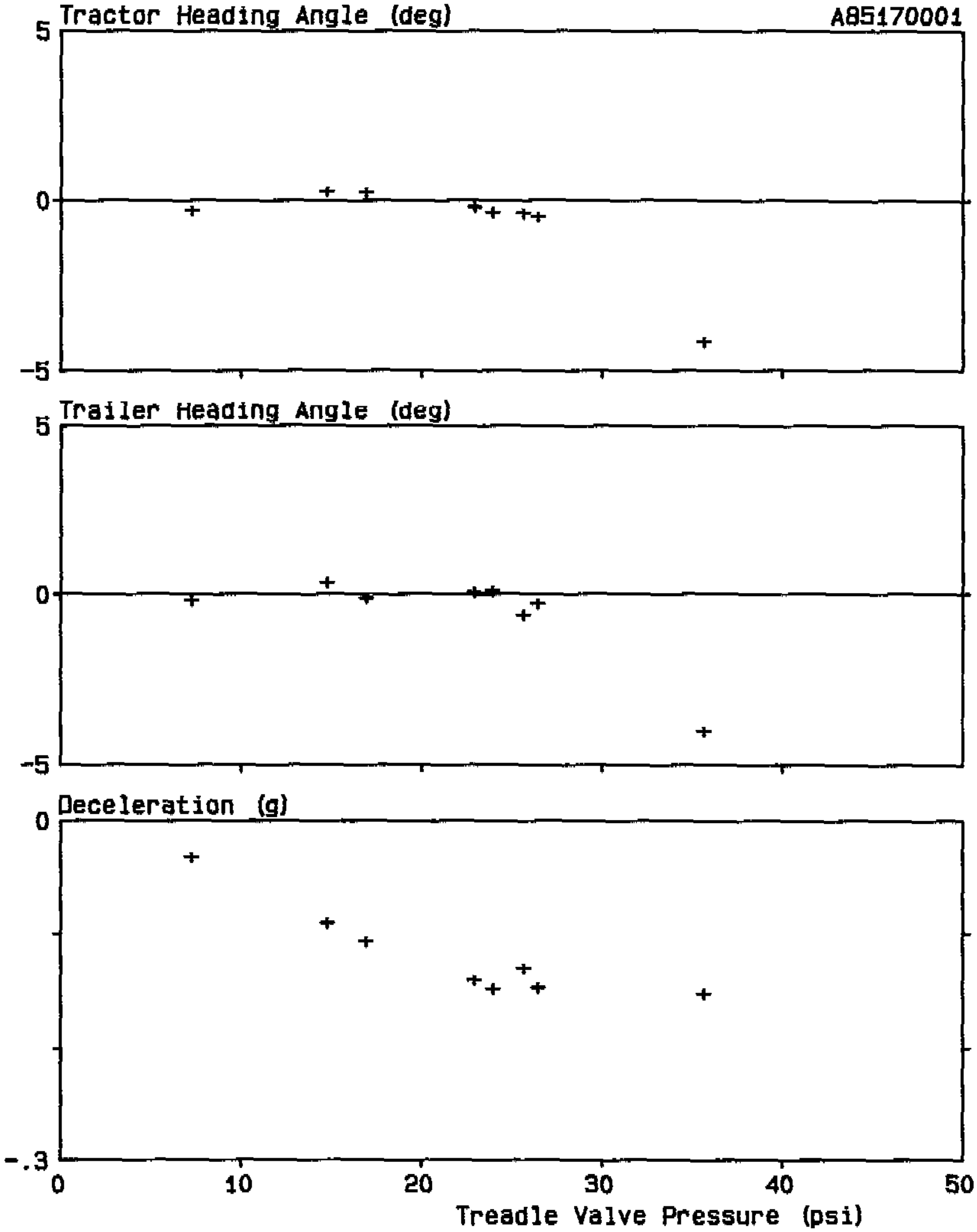


Figure 12/ Straight-Line Braking Responses vs
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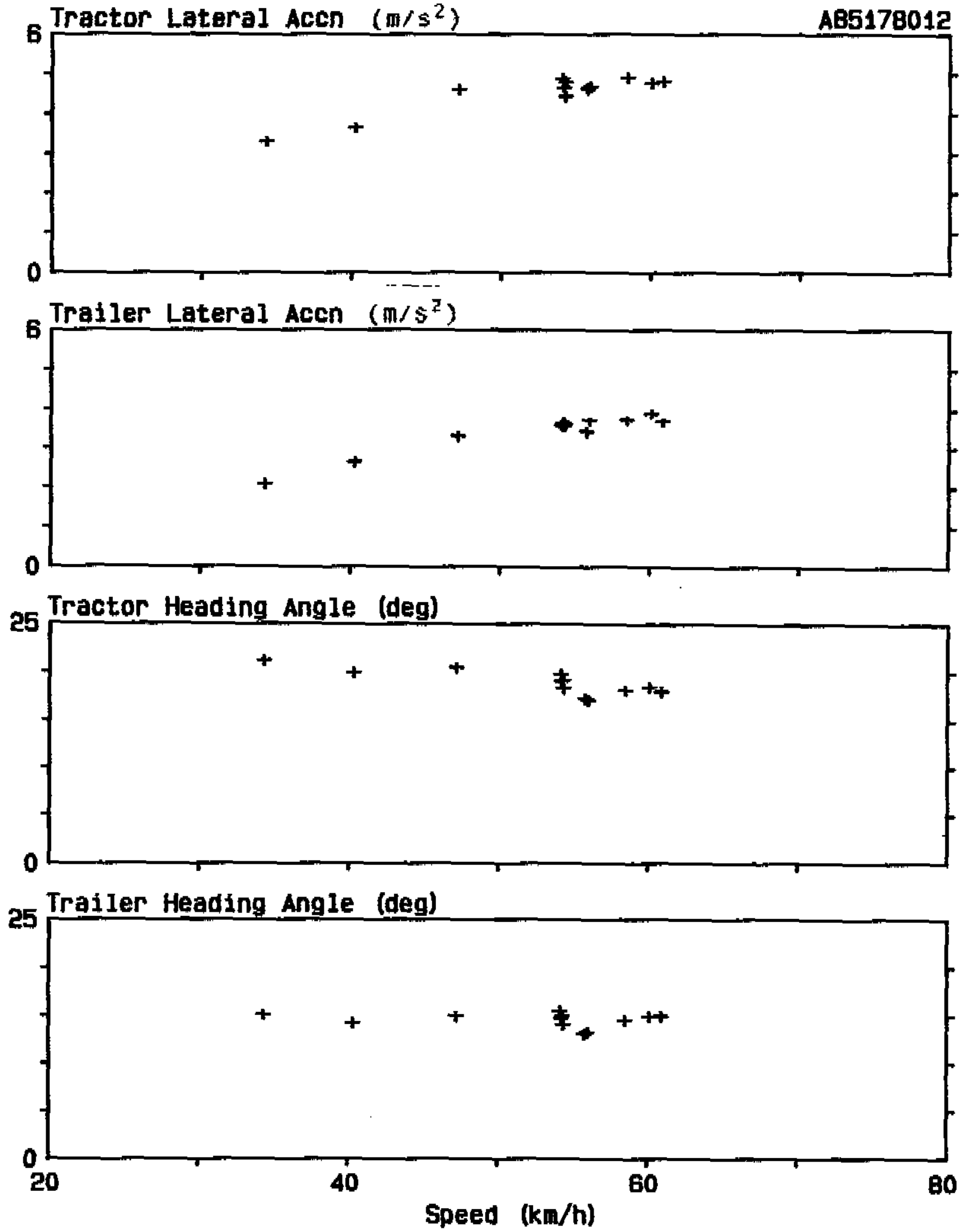

Figure 13/ Evasive Manoeuvre, Peak-to-Peak
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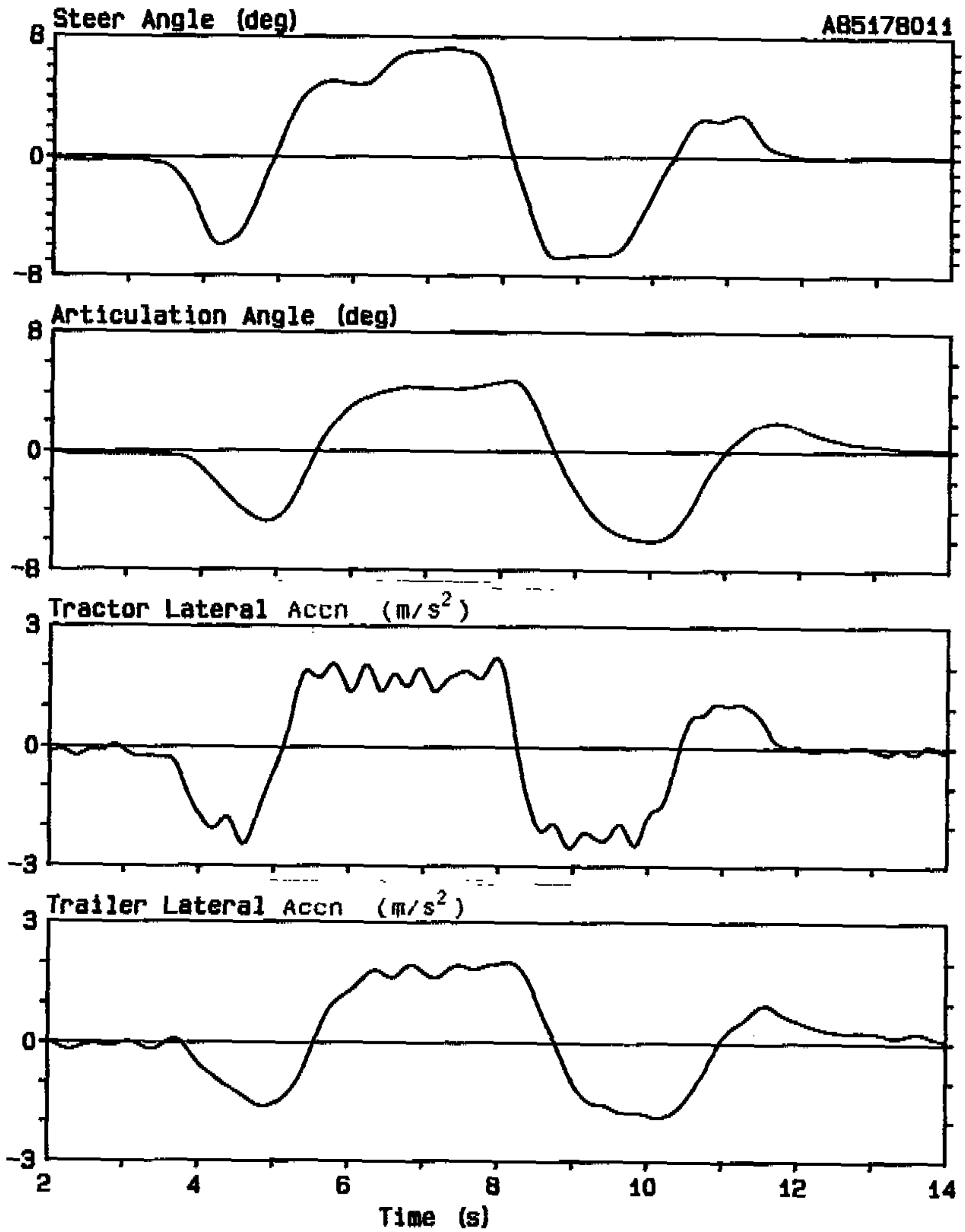

Figure 14/ Vehicle Response in Evasive Manoeuvre

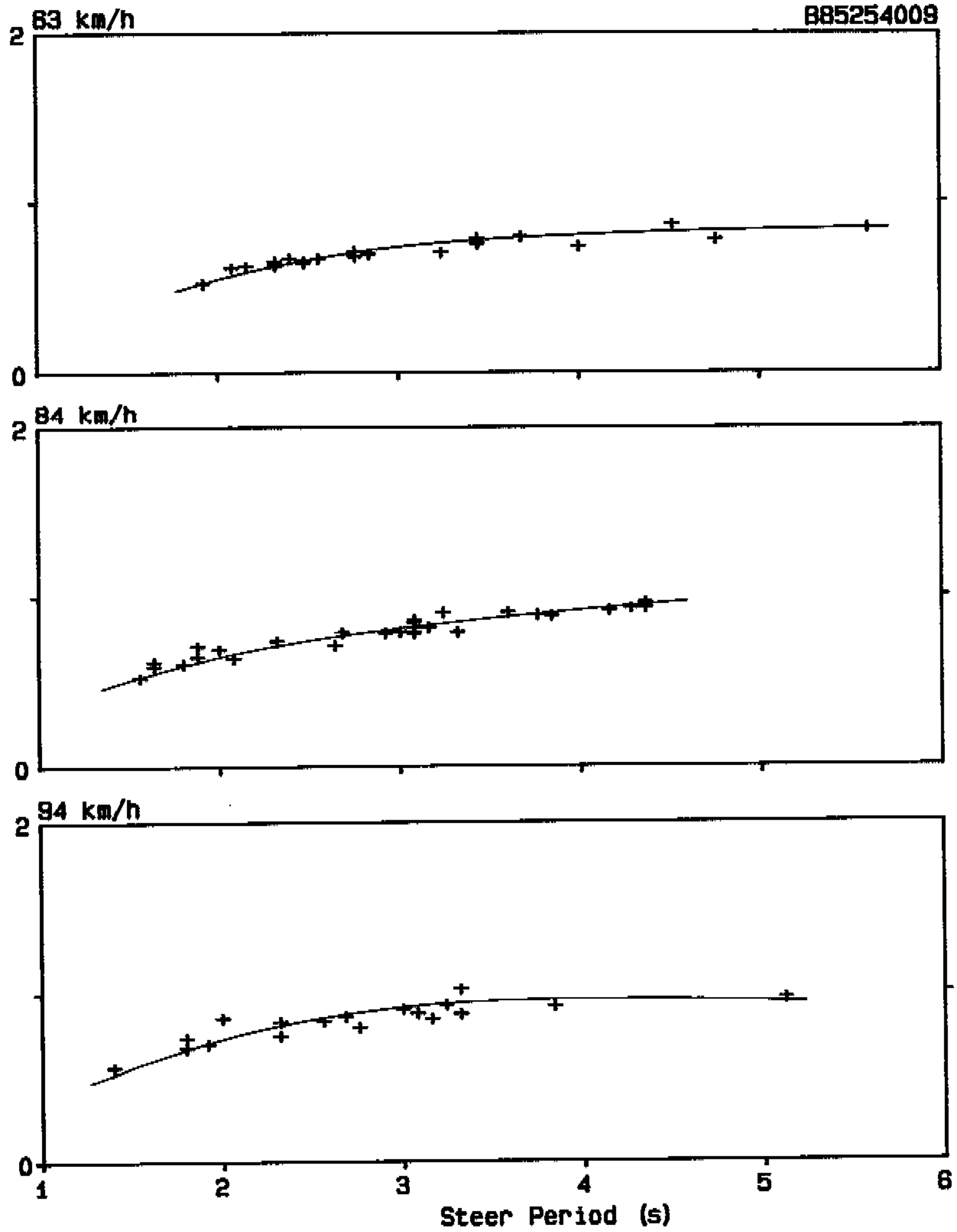

Figure 15/ Rearward Amplification of Lateral Acceleration

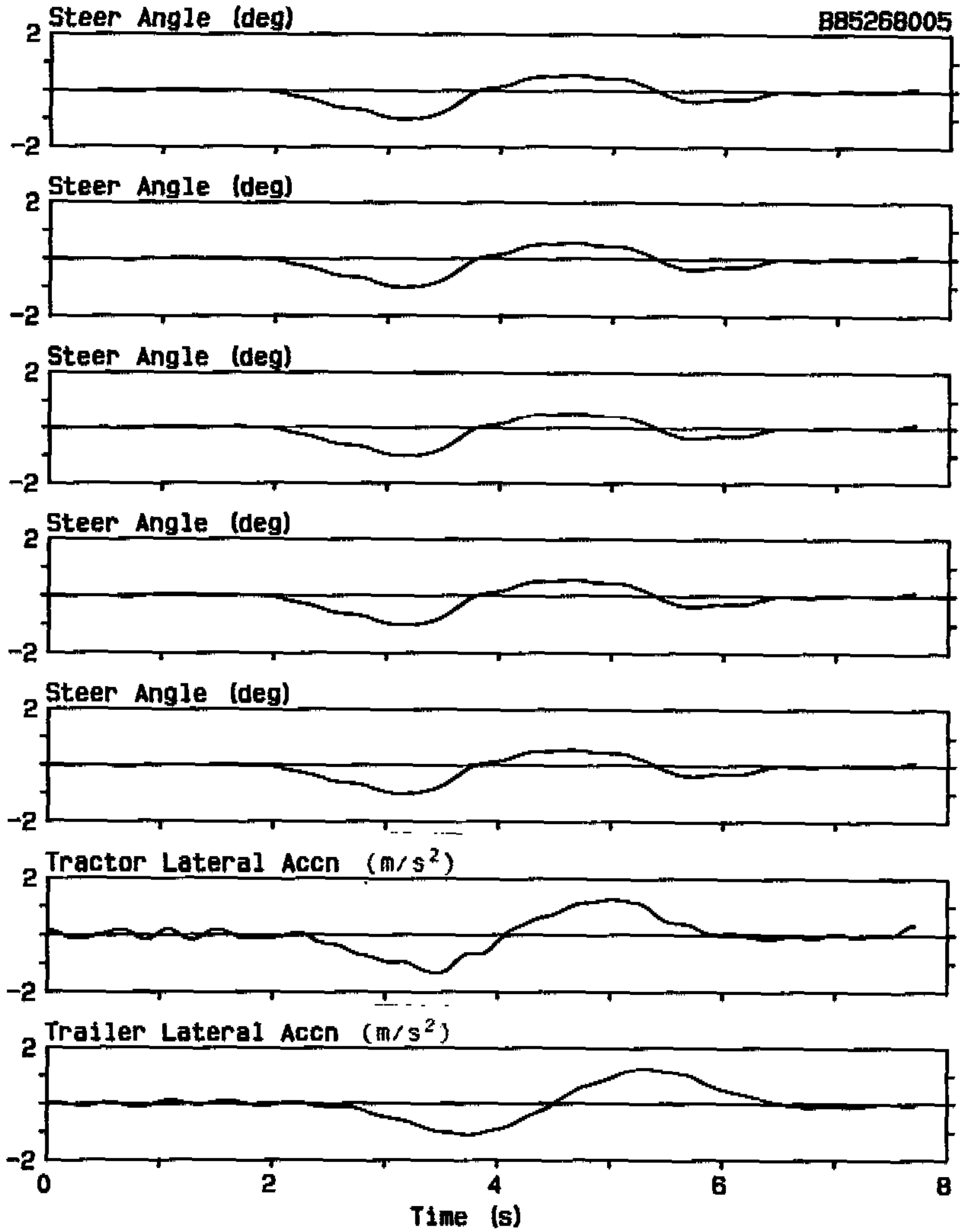

Figure 16/ Vehicle Response to Sinusoidal Steer at 94 km/h

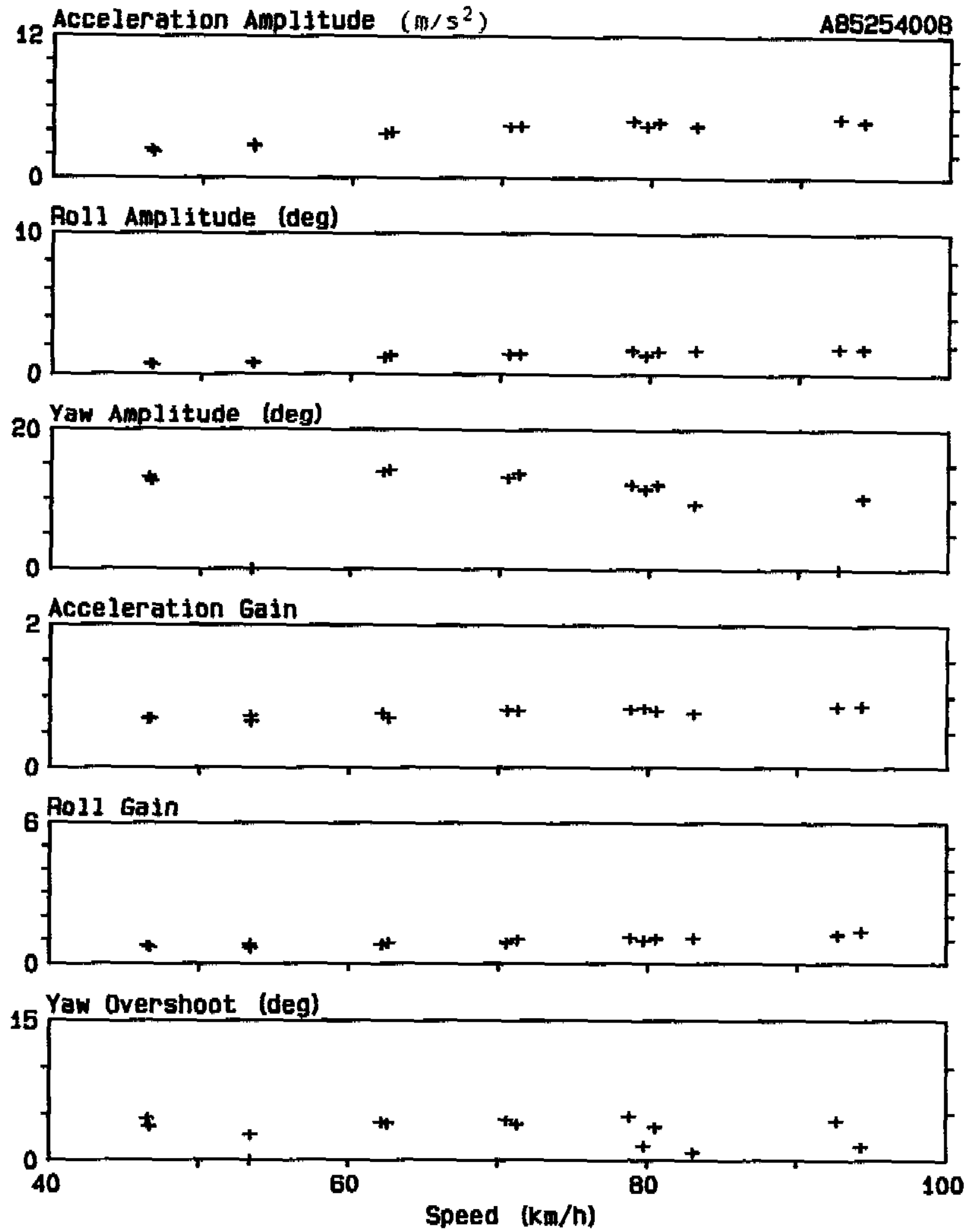

Figure 17/ Lane Change, Vehicle Responses vs Speed

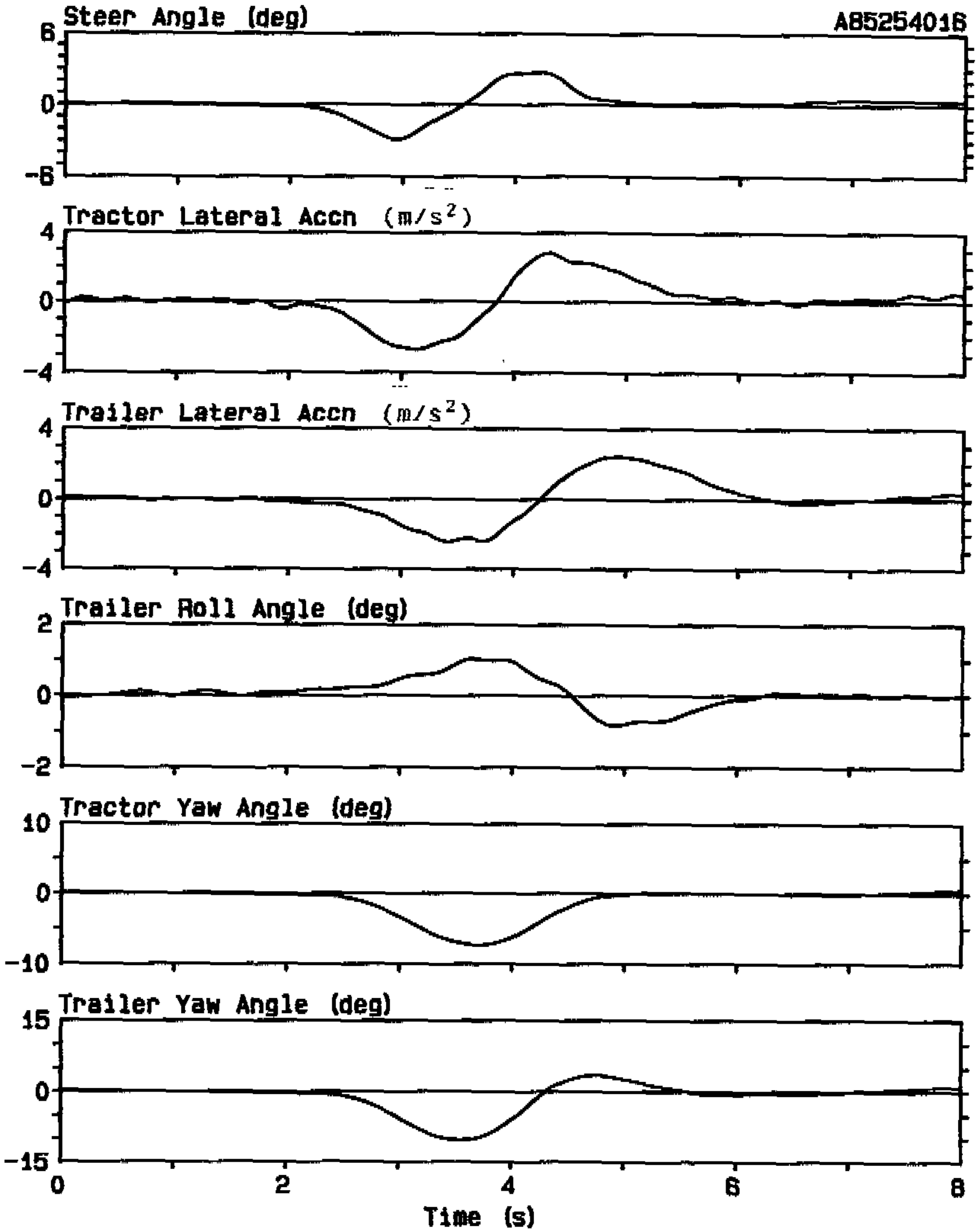

Figure 18/ Lane Change, Vehicle Responses at 94 km/h

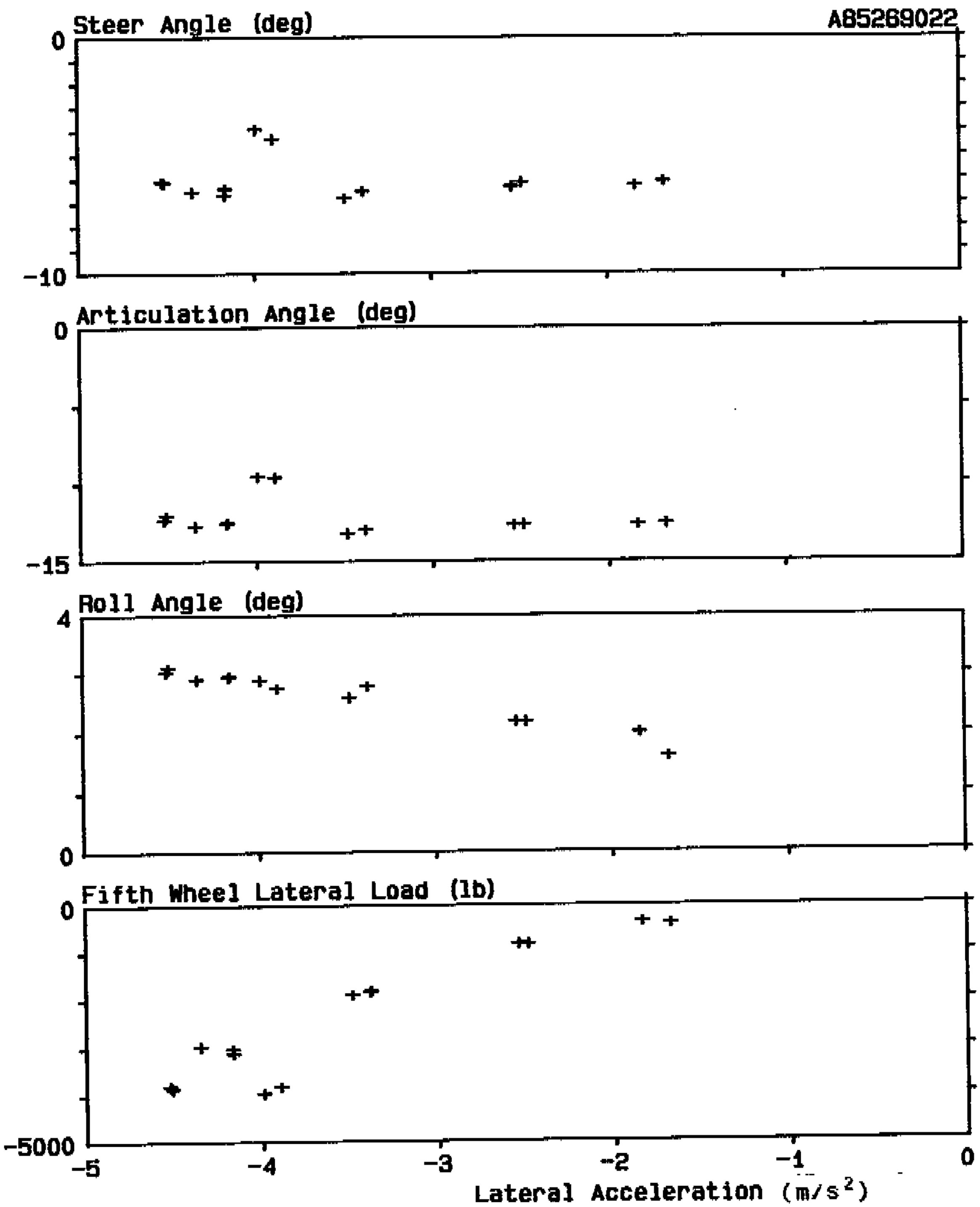

Figure 19/ Steady Circular Turn, Vehicle Responses vs
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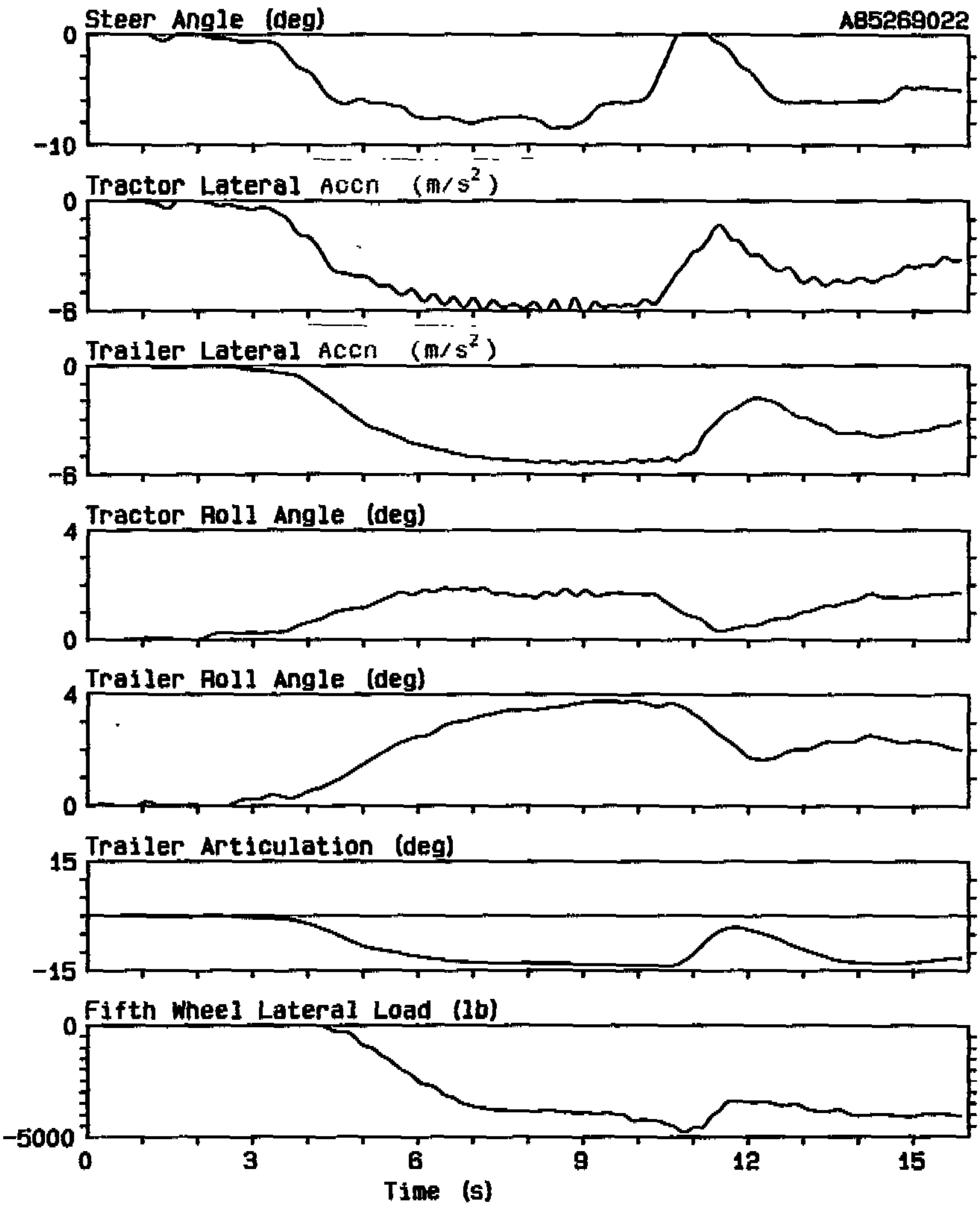

Figure 20/ Steady Circular Turn, Vehicle Responses at 63 km/h

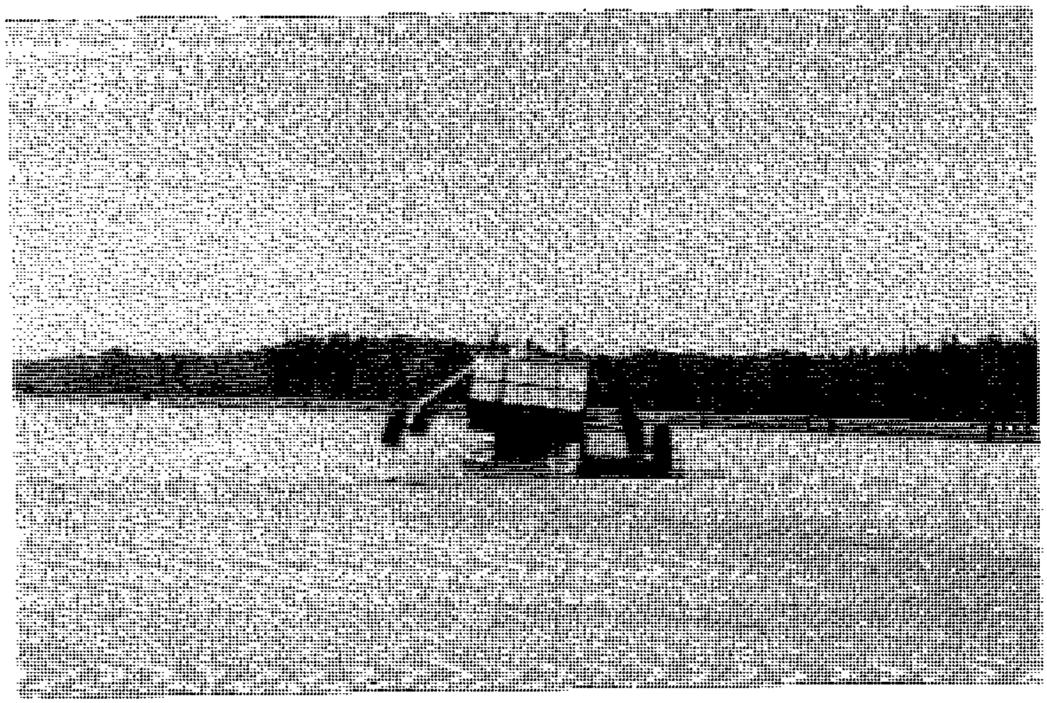

Figure 21/ Vehicle Making Steady Circular Turn

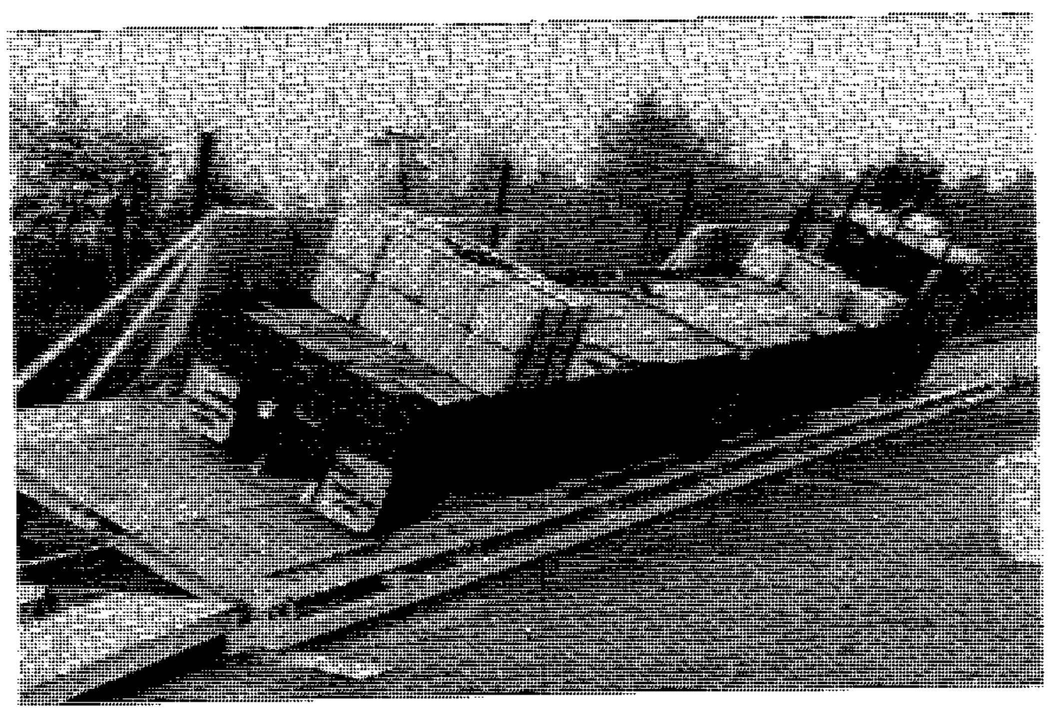

Figure 22/ Vehicle on Tilt Table

CV-86-09

Demonstration of Tractor-Trailer Performance: 6-Axle 48 ft Semi

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Ontario Ministry of Transportation
and Communications

ABSTRACT

A 6-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated an additional vehicle by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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ACKNOWLEDGEMENTS

This work was conducted on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study, managed by J.R. Pearson. The trailer was provided by the Roads and Transportation Association of Canada (RTAC). Facilities of the Transport Canada Motor Vehicle Test Centre were made available to the Ministry of Transportation and Communications (MTC). Assistance with vehicle preparation, delivery, and refurbishment was arranged by Mr. Pearson in support of this work.

The work was principally undertaken by the staff of the Automotive Technology and Systems Office of the Transportation Technology and Energy Branch of MTC: N.R. Carlton; G.B. Giles; C.P. Lam, P.Eng.; W.R. Stephenson, P.Eng.; and M.E. Wolkowicz; and assigned students G. Goertzen, S. Jazic, and D.R. Sykes. Assistance was provided by staff of various other departments of the ministry and other organizations.

The efforts of all involved are hereby acknowledged with gratitude.

1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 6-axle 48 ft (14.63 m) semitrailer combination, which is one of the additional vehicles. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and a single 48 ft (14.63 m) 3-axle flatbed semitrailer. The combination is typical of equipment used in Central Canada, where trailers with a widespread tandem axle and an airlift belly axle are permitted additional weight. The same combination was also tested concurrently as a 5- and 7-axle vehicle [8,9].

The equipment for these tests was obtained from the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by Fruehauf in July 1984 and was a 48 ft (14.63 m) flatbed semitrailer with two fixed and two non-steering airlift axles, one of which was raised for these tests. It was model number PBX4W48102 and bore the serial number 2H8P04843ER033601.

The trailer had a nominal length of 14.63 m (48 ft) and a nominal width of 2.59 m (102 in). The trailer suspension comprised a Reyco four-spring leaf suspension system with long equalizer arms on the fixed axles and a Neway air suspension system for the two airlift axles. The axle spacings were 2.74 and 2.77 m (108 and 109 in). The spring centre width was 0.96 m (38 in) for the fixed axles and 0.76 m (30 in) for the airlift axles. The airlift axles had shock abosorbers in parallel with the air springs, with a spacing of 0.30 m (12 in). The overall track width was 2.44 m (96 in). The vehicle overall length was 18.69 m (61.32 ft). The trailer was rated at 9620 kg/axle (21 164 lb/axle).

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 22 594 kg

(49 710 lb). Concrete blocks were used to obtain a loaded weight of 41 543 kg (91 390 lb). Airlift axle pressure was 159 kPa (23 psi) for the empty vehicle and 345 kPa (50 psi) loaded. Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 918	10 820	5 373	11 820
2	4 554	10 019	7 505	16 510
3	4 554	10 019	6 809	14 980
4	2 856	6 284	7 396	16 270
5	2 856	6 284	7 714	16 970
6	2 856	6 284	6 746	14 840
Total	22 594	49 710	41 543	91 390

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment, because of the lifted axle, and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was nearly attained, with the exception of the tractor drive axles. The legal gross weight of the vehicle tested is about 50 000 kg (110 000 lb) in Ontario and Quebec, and 47 700 kg (105 000 lb) in B.C., where the belly axle is required to be steerable.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.30 m (12 in) below the top of the floor. The centre of gravity height was estimated as 0.23 m (9 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and trailer was calibrated.
15/ Details of the vehicle and test equipment were recorded on photographs and videotape.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyroscope package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyroscope package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	19.792°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyroscope	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values, shown in the last column of Table 3, is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 2.41 m (7.9 ft), shown in Figure 4, became 2.38 m (7.8 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.56	27.45	0.11	27.51	27.56	+0.18
2	2.37	27.31	27.30	0.01	27.31	27.21	-0.37
3	2.37	27.28	27.33	0.05	27.31	27.21	-0.37
4	2.37	25.40	25.49	0.09	25.45	25.45	0.0
5	2.37	25.12	25.15	0.03	25.14	25.30	+0.63
6	2.37	25.11	25.13	0.02	25.12	25.45	+1.30

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was 0.7 m (2.29 ft). It was out of the exit lane for a distance of 21.0 m (68.9 ft), as derived from Figure 5. This test was conducted at a creep speed and represents the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was only 1.12 m (44 in) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle was driven with the left front wheel tracking the curb. In practice, a driver would allow some clearance on his side, if only to stay clear of catch basins. This would mean the rear axle would come close to the inner curb.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi).

The SAE J982a style test was performed, and the results, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test are typical of those obtained from tests conducted on other similar combinations. A typical time history response of application and release is presented in

Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.03	0.18	92.5
Axle 2	0.36	0.56	90.9
Axle 4	0.43	0.91	87.7
Axle 5	0.43	0.95	86.2

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed. Note that the airlift axle was lowered for this test, even though it would be raised in normal operation on the highway when the vehicle was empty.

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The initial average brake application of about 276 kPa (40 psi) caused all braked wheels to lock, the tractor jackknifed to the left, the safety cables were engaged (as seen from the 15° limit on articulation angle), and the vehicle rotated as a unit. The tractor heading reached the limit of the signal conditioning system. If the tractor front axle brakes had been used, the likelihood of a tractor jackknife would have been much reduced.

A summary of peak vehicle responses is shown in Figure 12, as a function of average treadle valve pressure. This shows that the tractor is on the verge of a jackknife at lower brake pressures and the jackknifing was in either direction.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. Gates of 22.5 m (73.8 ft) were used for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. Note that the airlift axle was also lowered for this test. The runs were made in accordance with the standard test procedure [1].

Data from this test were lost due to mechanical failure of the computer disk drive and were found to be unrecoverable from the backup tape. The following comments, therefore, are based upon notes, review of the videotapes, and computer summaries made during the test.

The vehicle's behaviour was predictably between that of the 5- and 7-axle combinations tested concurrently [8,9]. Data captured at the time of the test indicated that the tractor required increasing steer input to negotiate the manoeuvre as speed increased. This, coupled with observations of tractor slide and tire chatter, indicated that the tractor was showing signs of understeer. At the higher speeds, it was noted that key course markers were struck, indicating some loss of tractor directional control. Little sway was noted at the trailer.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s. However, the data from runs at 63 and 84 km/h were lost due to mechanical failure of the computer's disk drive while the data were being archived on tape.

The vehicle combination was evaluated in terms of the lateral acceleration response of the trailer. Rearward amplification of lateral acceleration of the trailer is presented in Figure 13, as a function of tractor steer input period for the one test speed. This gain is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 13 that rearward amplification is somewhat sensitive to steer period reaching the highest value of about 0.92 at around 3 s. The results show that, at highway speed, this is a very stable vehicle, because of its low response to input.

Figure 14 shows the response of a typical run for a steer period of about 2.76 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, which is considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

A gate of 30 m (98.4 ft) was used, to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections.

Unfortunately all data from this test were lost because of the mechanical failure of the computer's disk drive. The data were also not recoverable from the analog tape recorder because of errors on the tape. The following comments, therefore, are based on notes, review of the tapes, and video and computer summaries made during the test.

The vehicle's behaviour was predictably between that of the 5- and 7-axle combinations tested concurrently [8,9]. It remained stable up to the maximum test speed of 94 km/h. Overshoot appeared evident but within lane boundaries, some of which was, no doubt, due to driver steer corrections in the exit lane, as shown in Figure 15. Roll amplitudes appeared somewhat less than for the 7-axle semi [9] but greater than for the 5-axle vehicle [8].

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was very stable and, if any slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in trailer sway, it was not readily perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 0.99 g/° of RMS steer input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 17. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angles, presented as a function of tractor lateral acceleration, increased with speed. Average steady-state articulation angles decreased modestly with an increase in lateral acceleration, and as a consequence, the offtracking decreased. The lateral force experienced by the tractor fifth wheel, expressed as a function of tractor lateral acceleration, shows a gradient of 58.9 kN/g (13 200 lb/g).

At the limiting speed of 63 km/h, a lateral acceleration of 0.53 g, the outrigger touched down, around 8 s in Figure 18, and the trailer swung out around 9 s, relieving the lateral acceleration on the trailer and reducing the articulation angle. This is also shown in Figure 19. It is possible the vehicle would not have rolled over. This manoeuvre at the high lateral acceleration required a very high effort on the part of the driver just to follow the circle.

A tilt test was conducted on this vehicle as part of a separate test program [14]. The high-side wheels of the rear trailer lifted at a tilt angle of 29.3°, after all corrections were made, which corresponds to a lateral acceleration of 0.56 g. This is in quite good agreement with the rear trailer's lateral acceleration of 0.53 g at outrigger touchdown. A full discussion of the tilt test is presented elsewhere [14].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted, particularly those on the right-hand wheel of the rear axle. The tests on this vehicle followed those of the 5-axle 48 ft (14.63 m) semi [8], and the steady circular turn was clearly causing severe wear on the outer edge of this tire. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, at least in the empty condition.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. It tracked well but required more effort to manoeuvre than either the 5-axle 45 ft (13.72 m) semi [2] or the 5-axle 48 ft (14.63 m) semi [8], because of the lowered airlift axle. It did, however, require a little less space to manoeuvre than these vehicles. It exhibited high stability in all dynamic manoeuvres. However, the trailer centre of gravity was quite low -- about 1.73 m (68 in) from the ground. The centre of gravity for some loads can result in a trailer centre of gravity 2.5 m (100 in) or more from the ground, which would reduce the rollover threshold to somewhere around 0.3 g [15]. The lane change would then likely have resulted in rollover at some speed less than 95 km/h.

6/ CONCLUSIONS

A 6-axle tractor-semitrailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated as of particular interest by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns, though it required less space than a comparable 5-axle semi.

The air brake system was relatively fast and well balanced.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. Stability varied little with speed up to 100 km/h. The roll stability was very high, primarily because the trailer centre of gravity was low. A higher centre of gravity would significantly reduce the rollover threshold.

7/ REFERENCES

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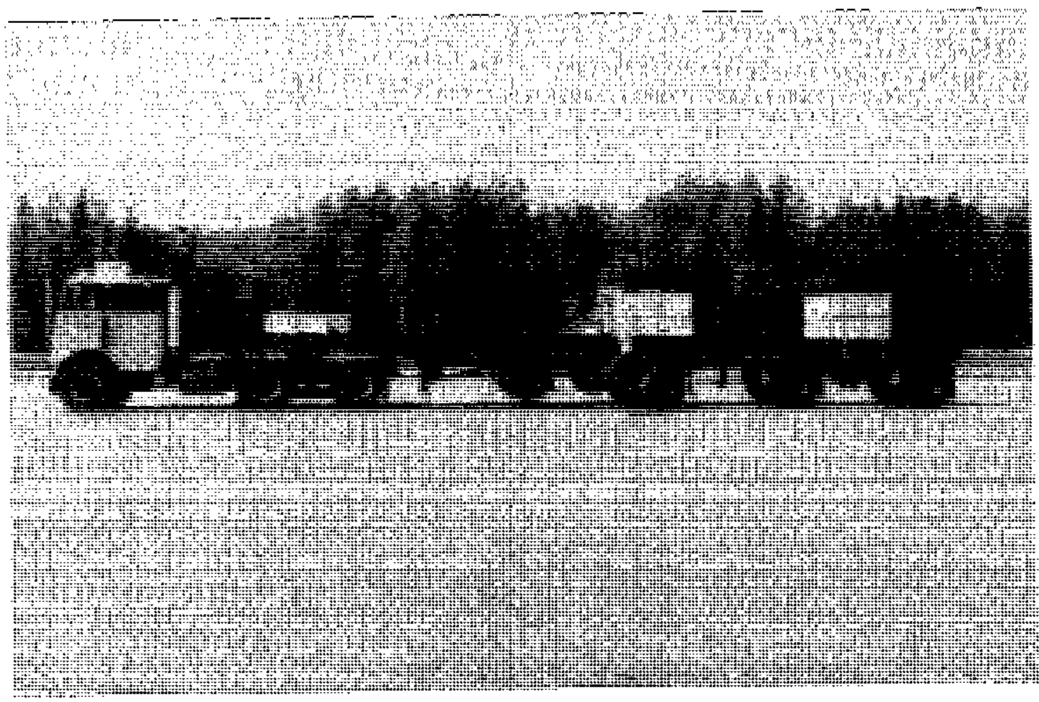


Figure 1/ View of Vehicle

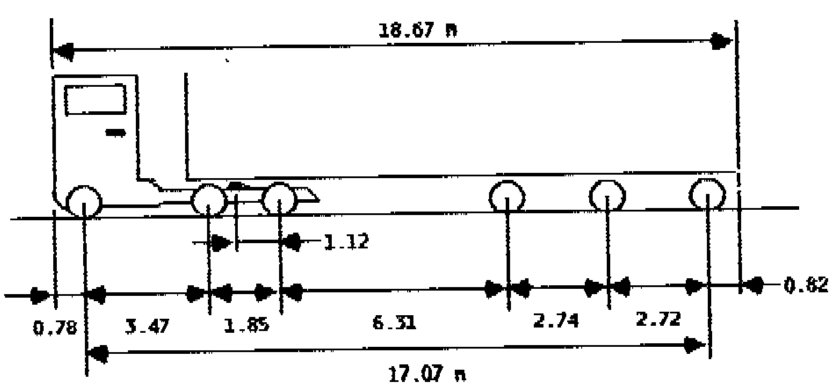


Figure 2/ Vehicle Dimensions

Figure 3/ Offtracking

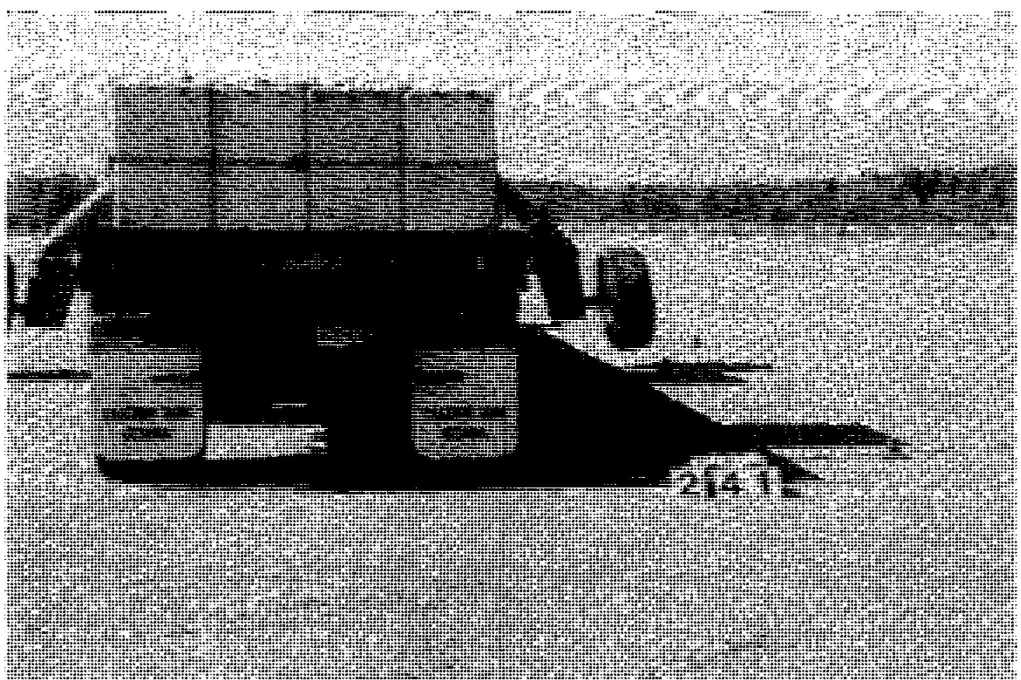
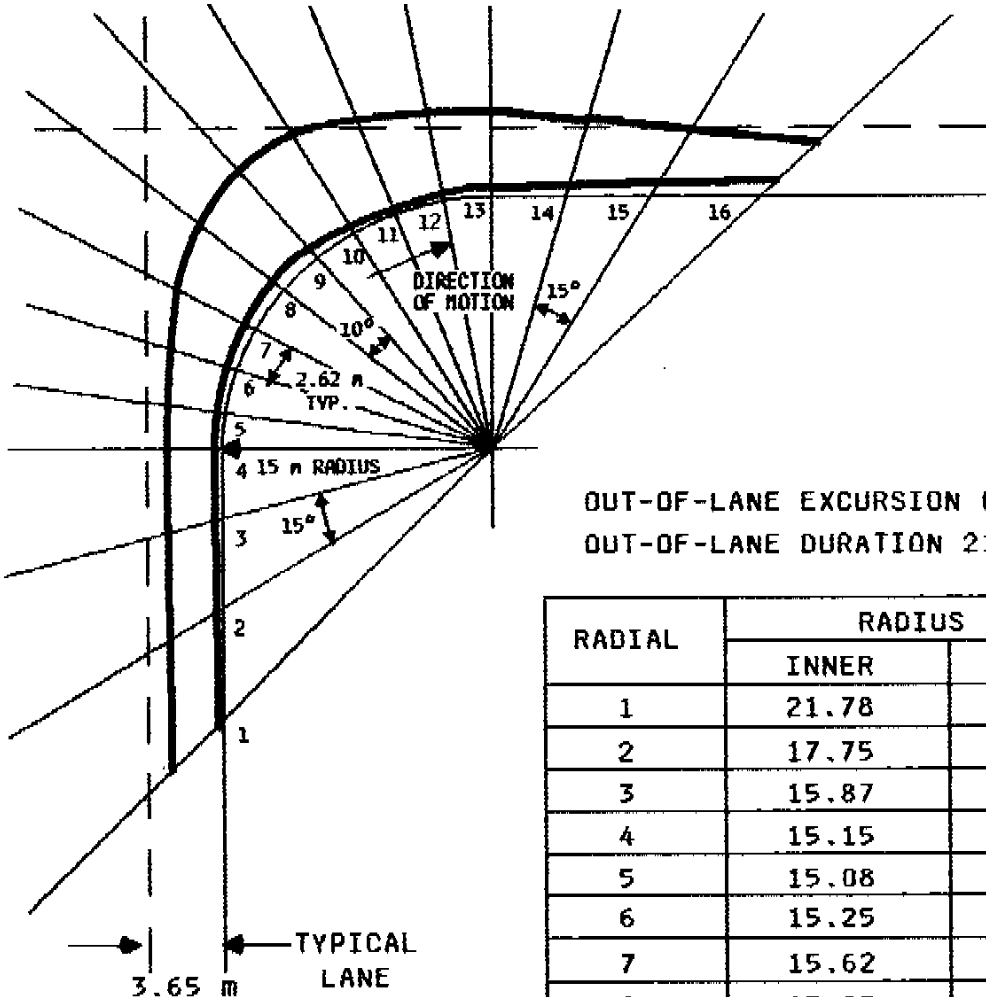


Figure 4/ Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 0.7 m
OUT-OF-LANE DURATION 21 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	21.78	-
2	17.75	-
3	15.87	-
4	15.15	17.75
5	15.08	17.82
6	15.25	18.54
7	15.62	19.62
8	15.87	20.51
9	15.54	21.20
10	15.21	21.56
11	15.07	20.58
12	15.09	19.76
13	15.40	19.54
14	16.47	20.17
15	18.48	-
16	22.40	25.96

Figure 5/ Right-Hand Turn Swept Path

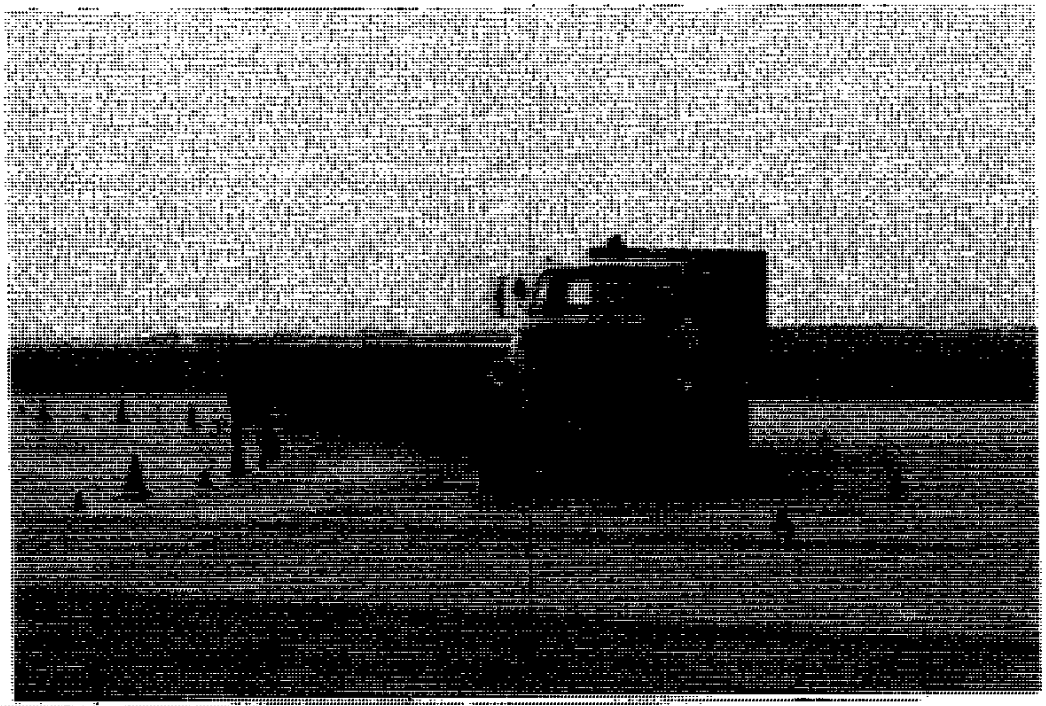


Figure 6/ Right-Hand Turn

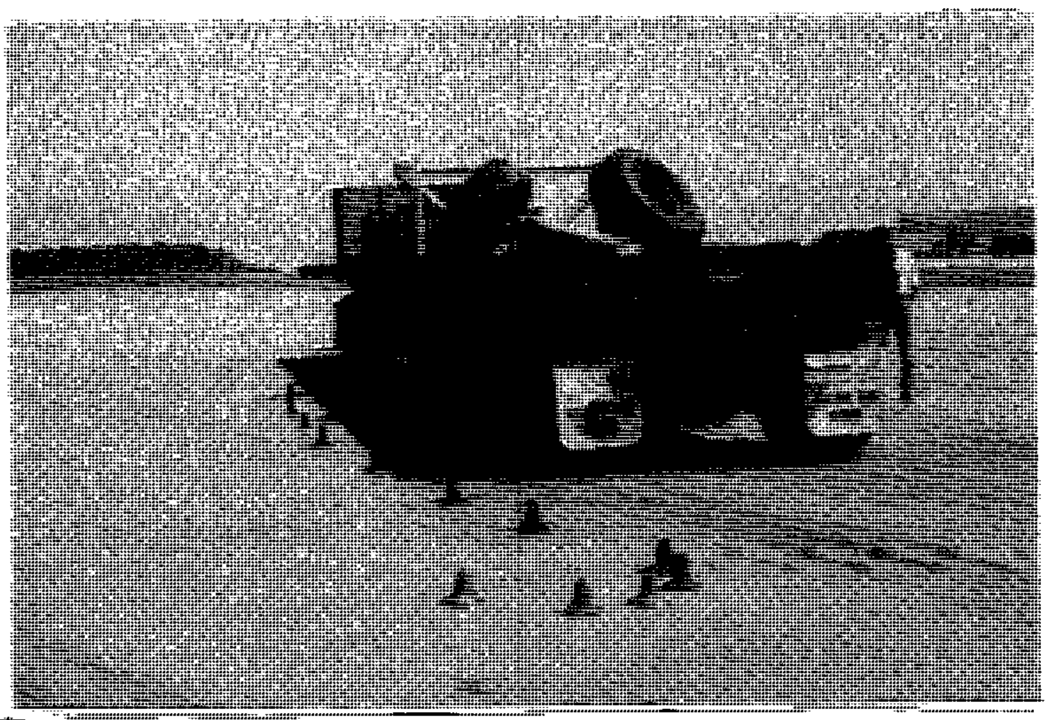
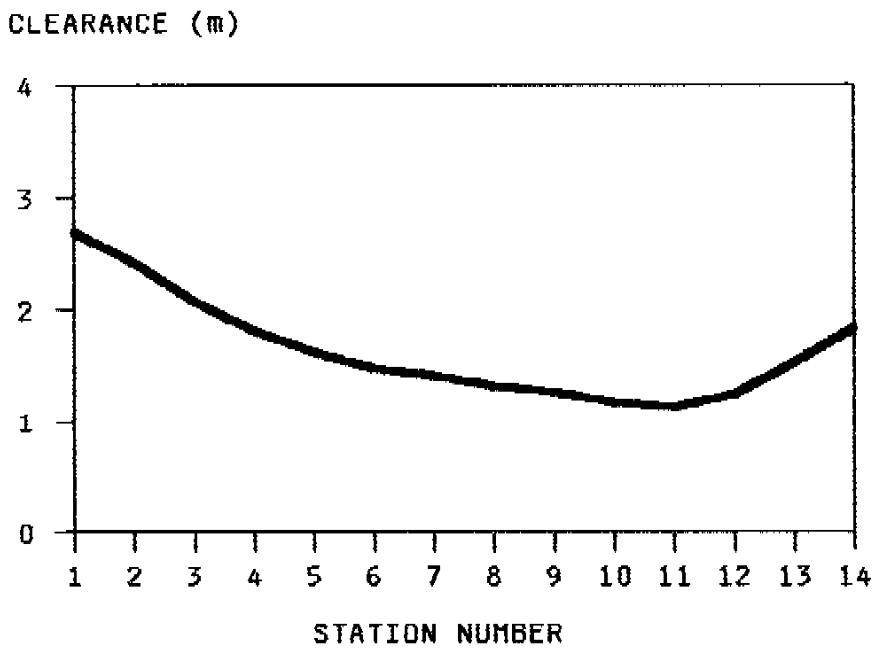


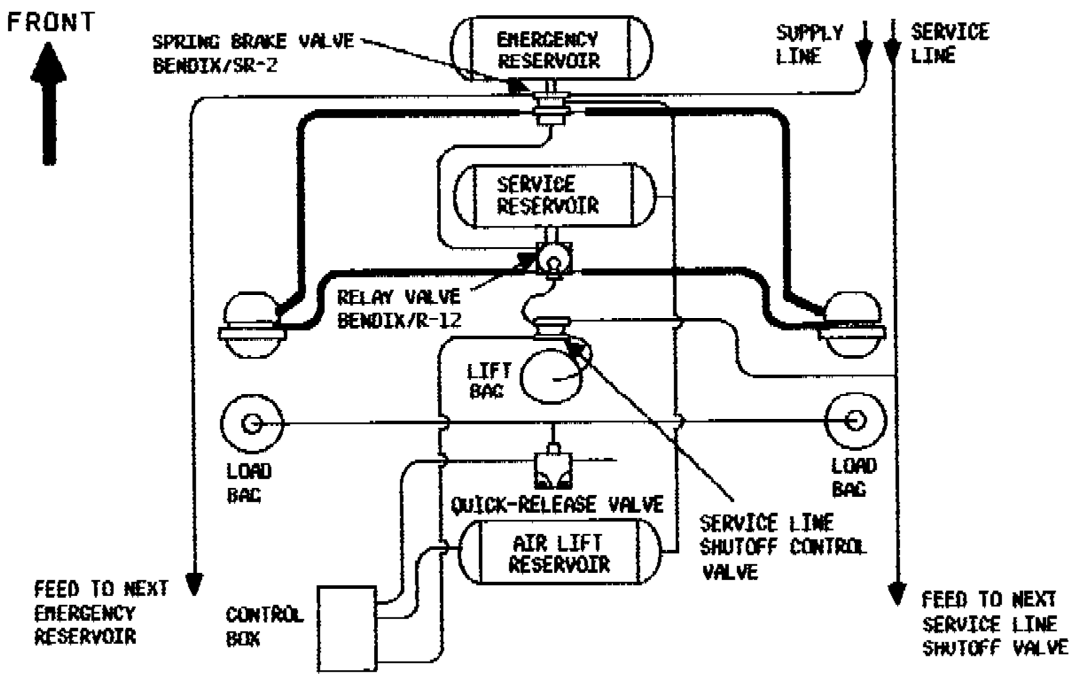
Figure 7/ Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.70
2	2.44
3	2.07
4	1.81
5	1.62
6	1.48
7	1.40
8	1.32
9	1.26
10	1.18
11	1.12 *(LOW)
12	1.25
13	1.53
14	1.85

Figure 8/ Channelized Right Turn Clearance from Inner Curb

Axle 4



Axles 5 and 6

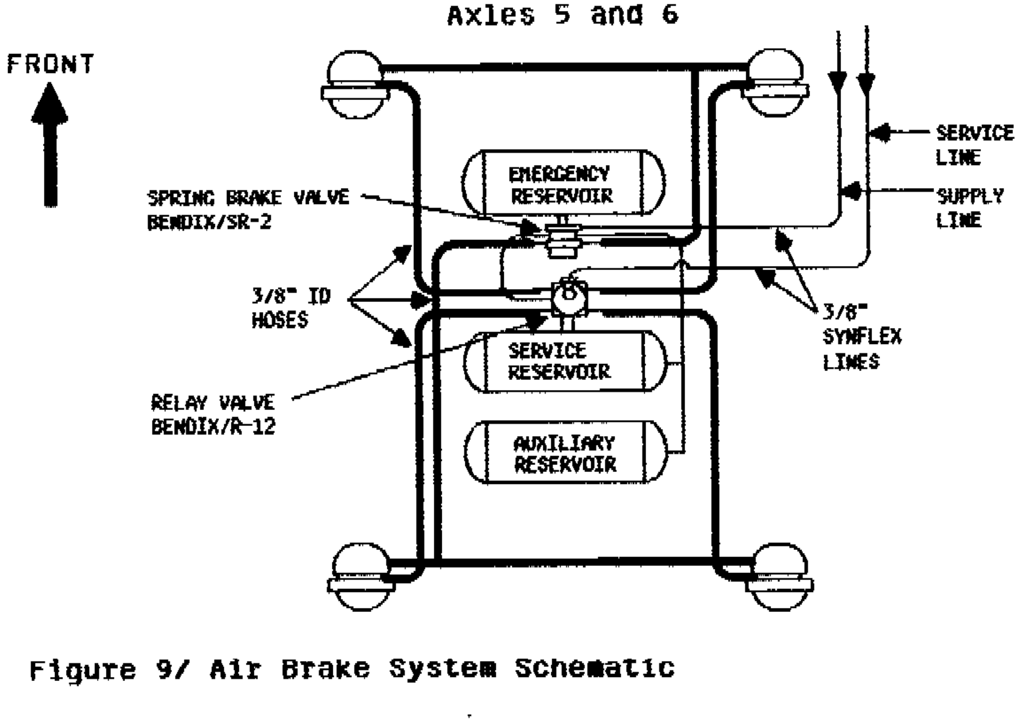


Figure 9/ Air Brake System Schematic

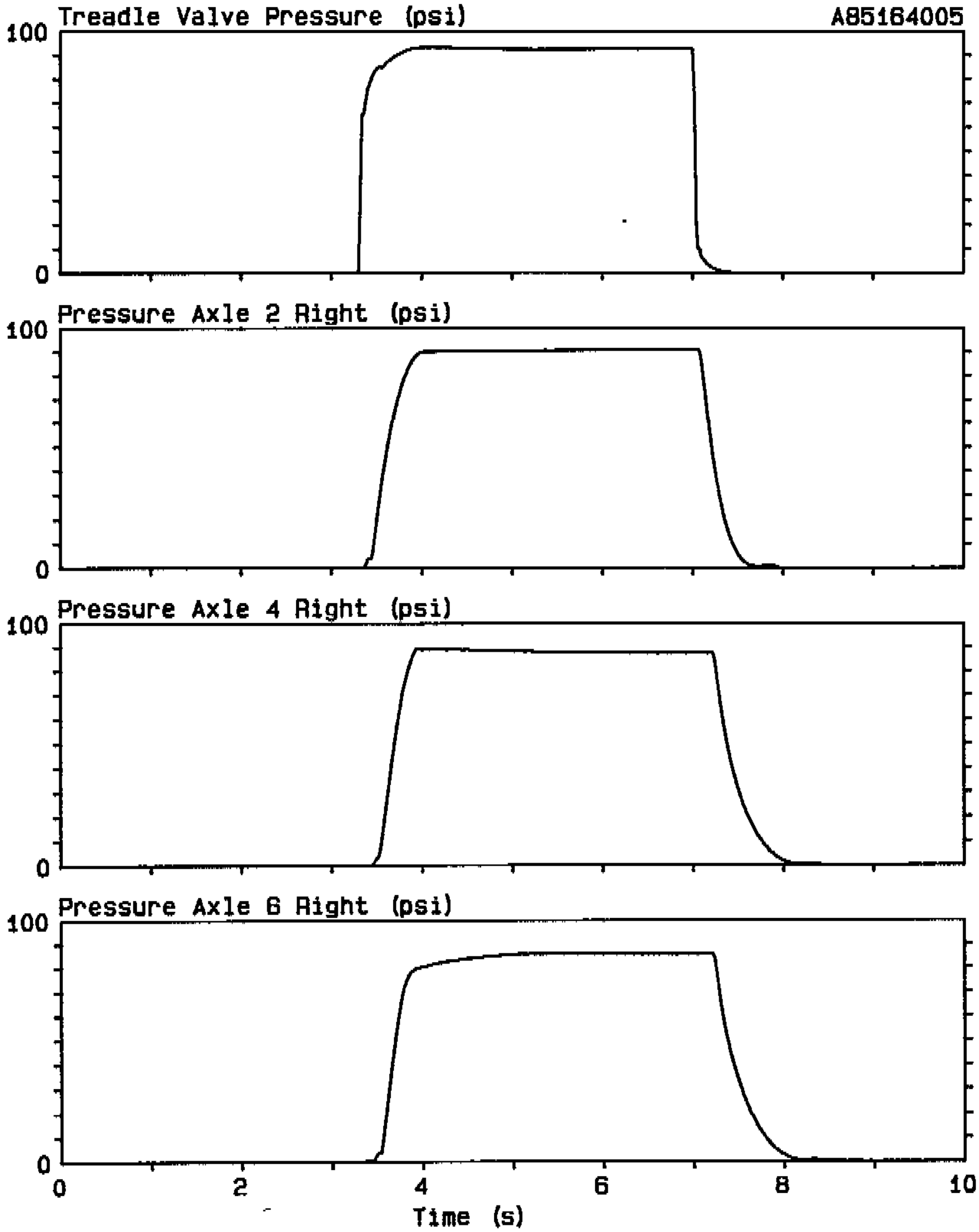


Figure 10/ Air Brake Application and Release

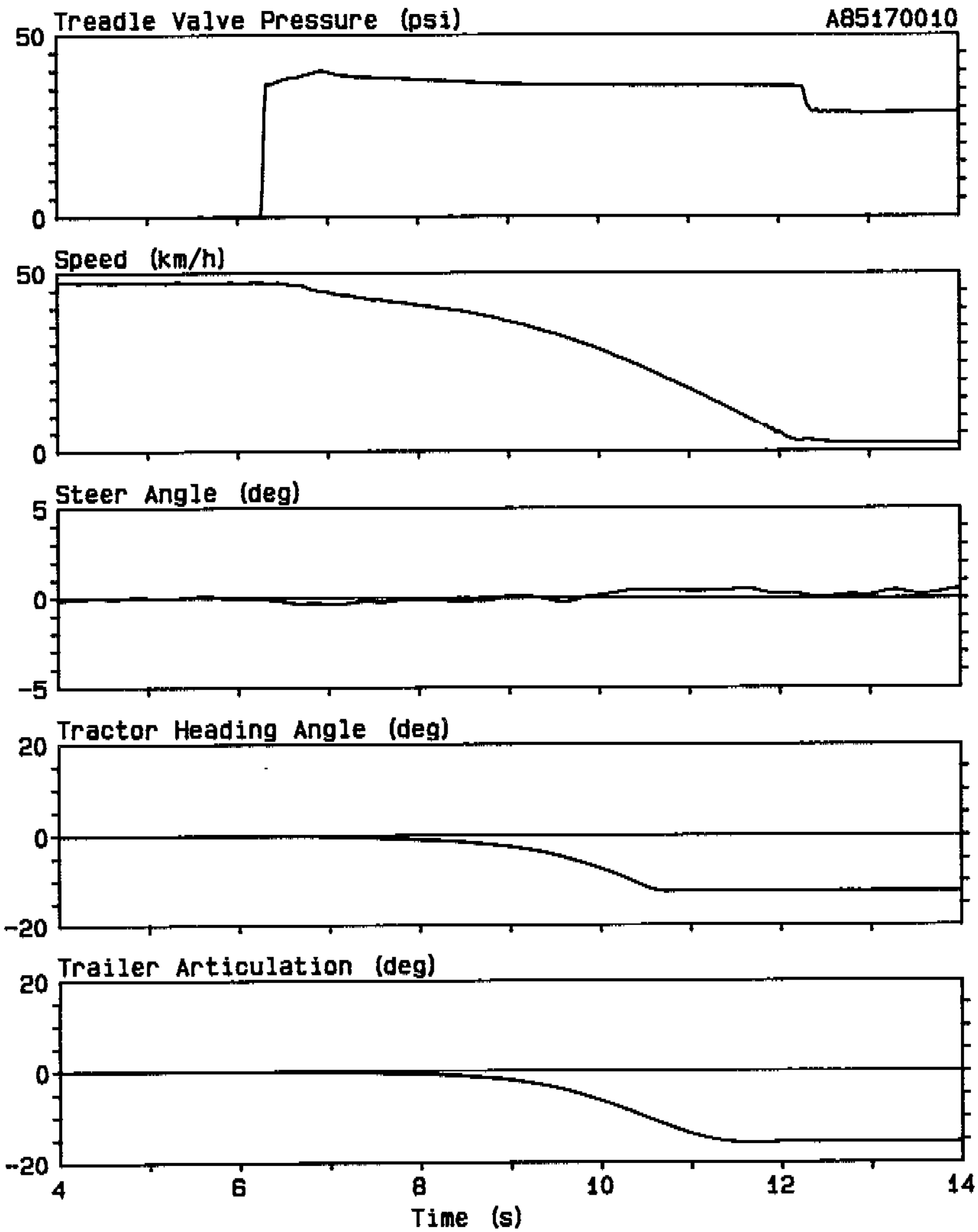


Figure 11/ Vehicle Response to Straight-Line Braking

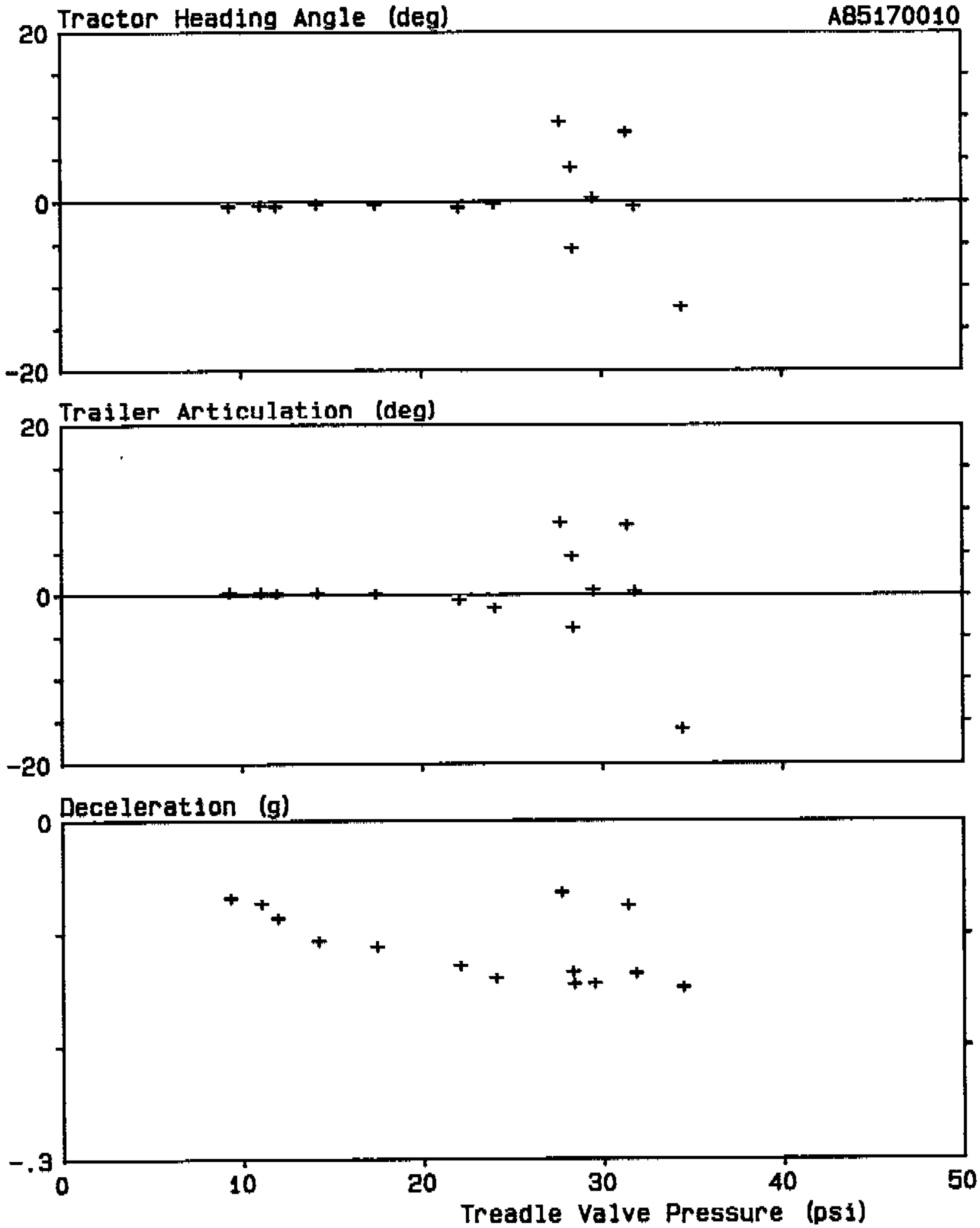


Figure 12/ Straight-Line Braking Responses vs Treadle Valve Pressure

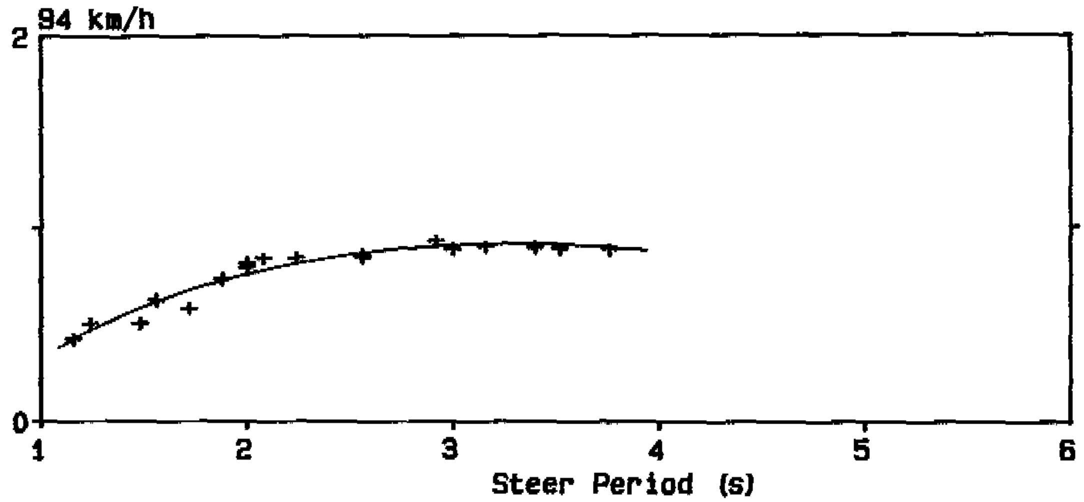


Figure 13/ Rearward Amplification of Lateral Acceleration

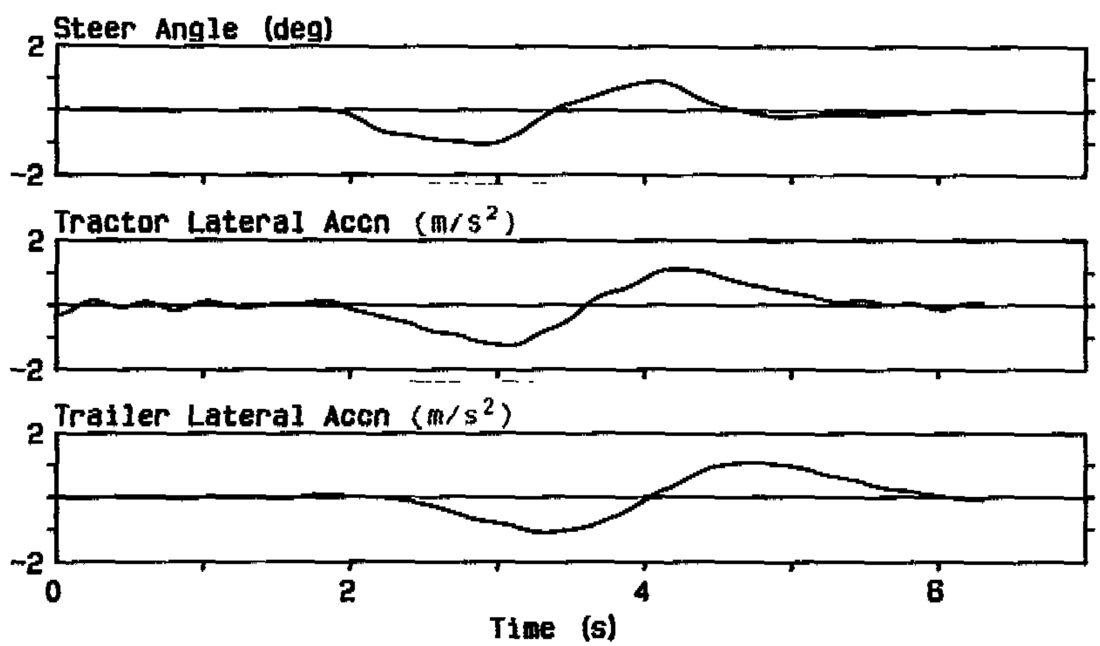


Figure 14/ Vehicle Response to Sinusoidal Steer at 94 km/h

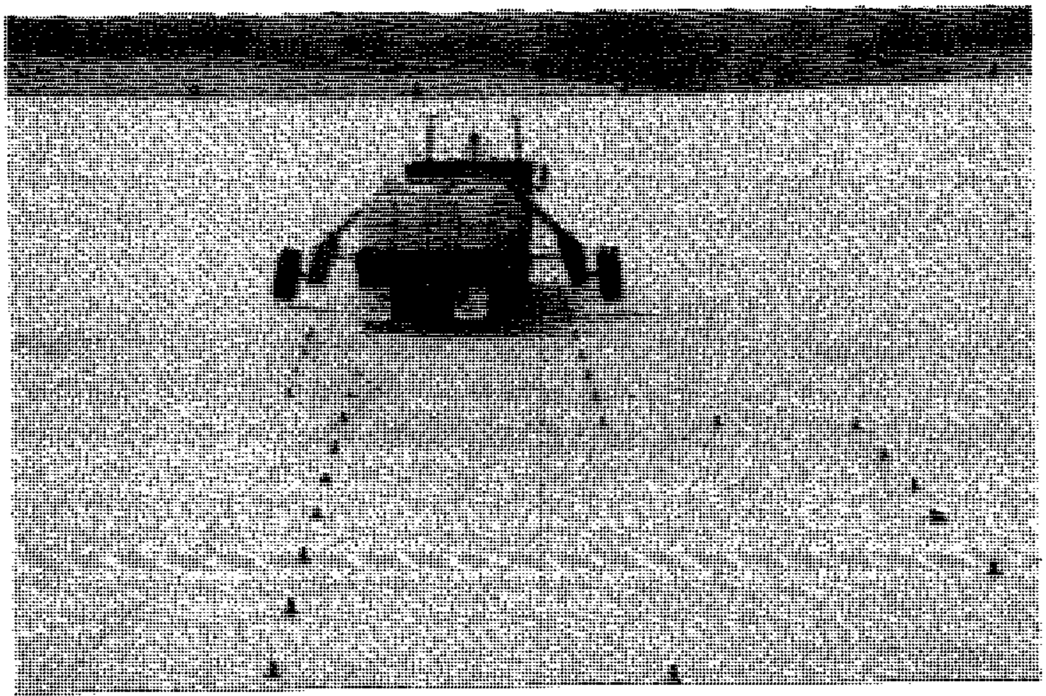


Figure 15/ Vehicle Making Lane Change

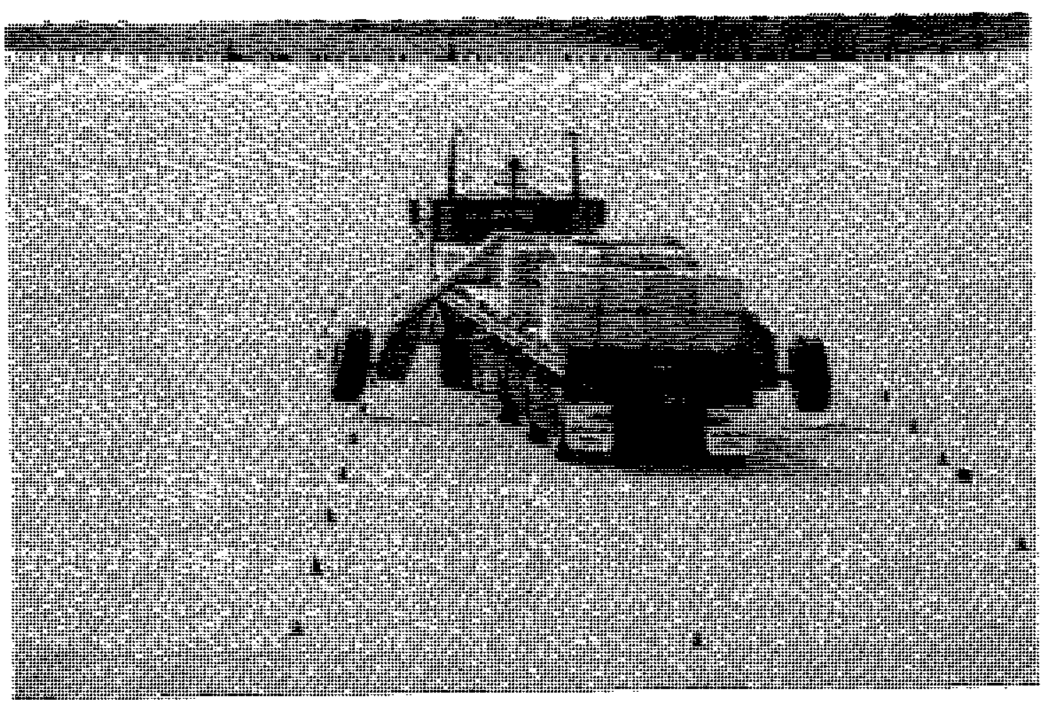


Figure 16/ Vehicle Making Lane Change

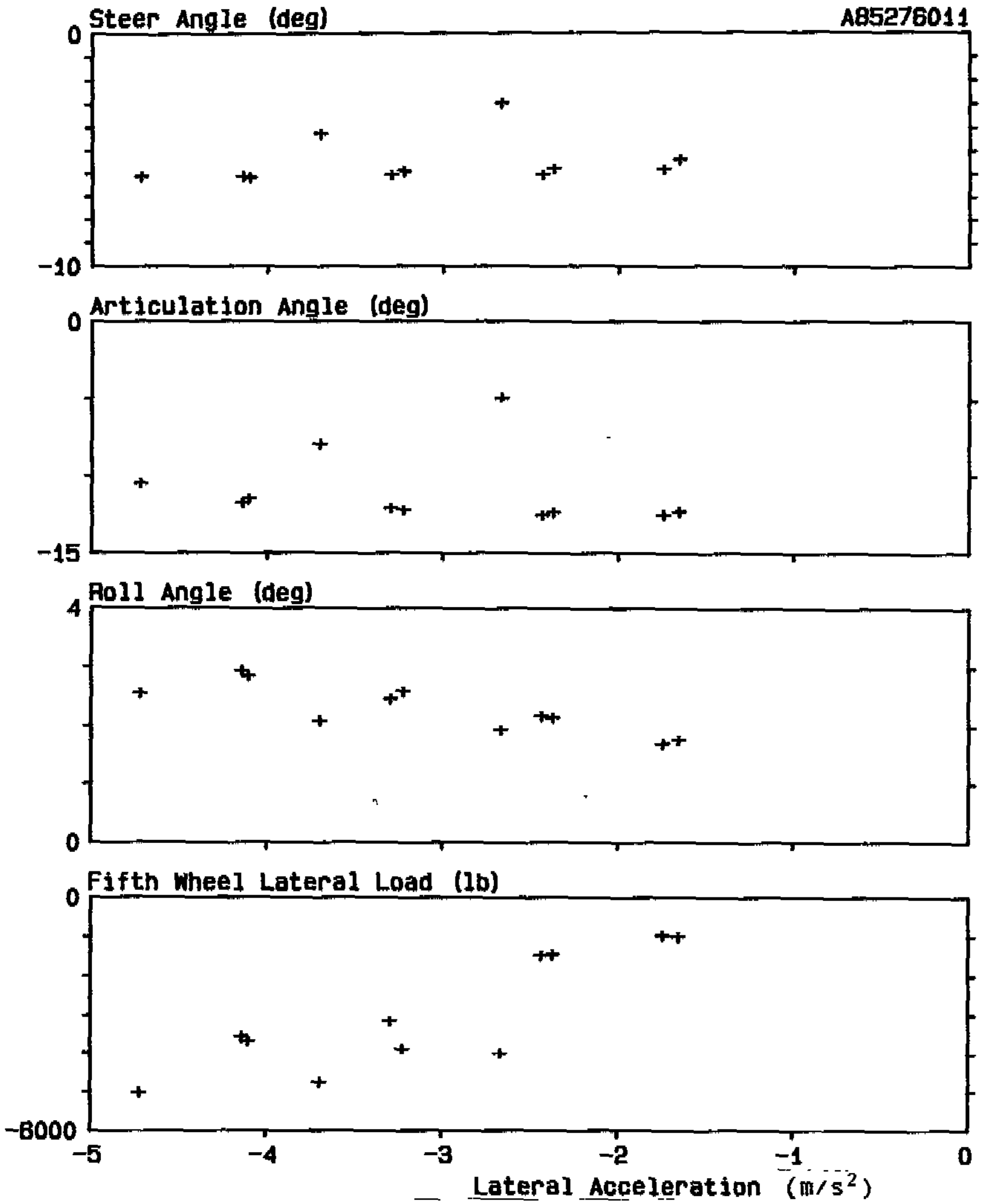


Figure 17/ Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration

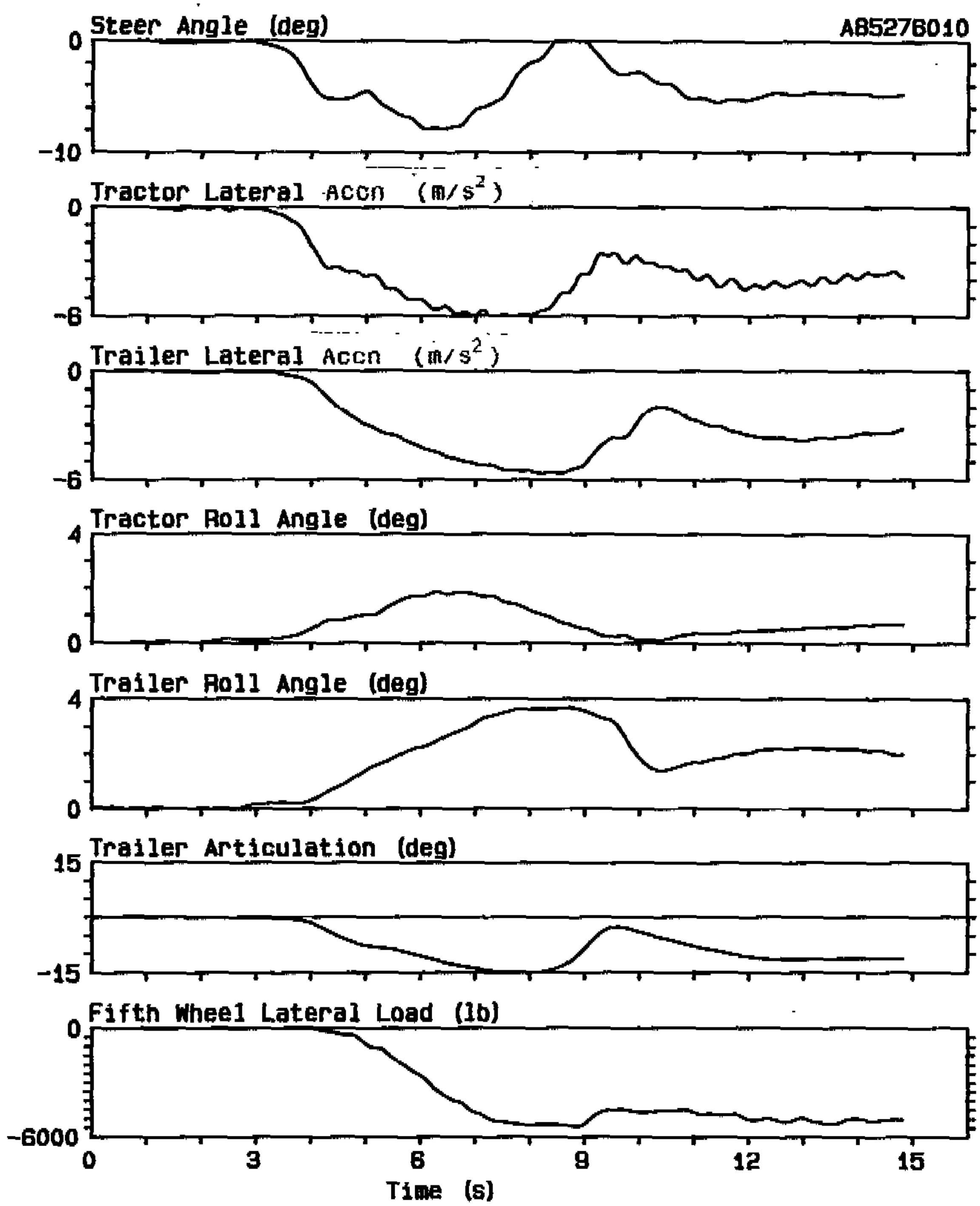


Figure 18/ Steady Circular Turn, Vehicle Responses at 63 km/h

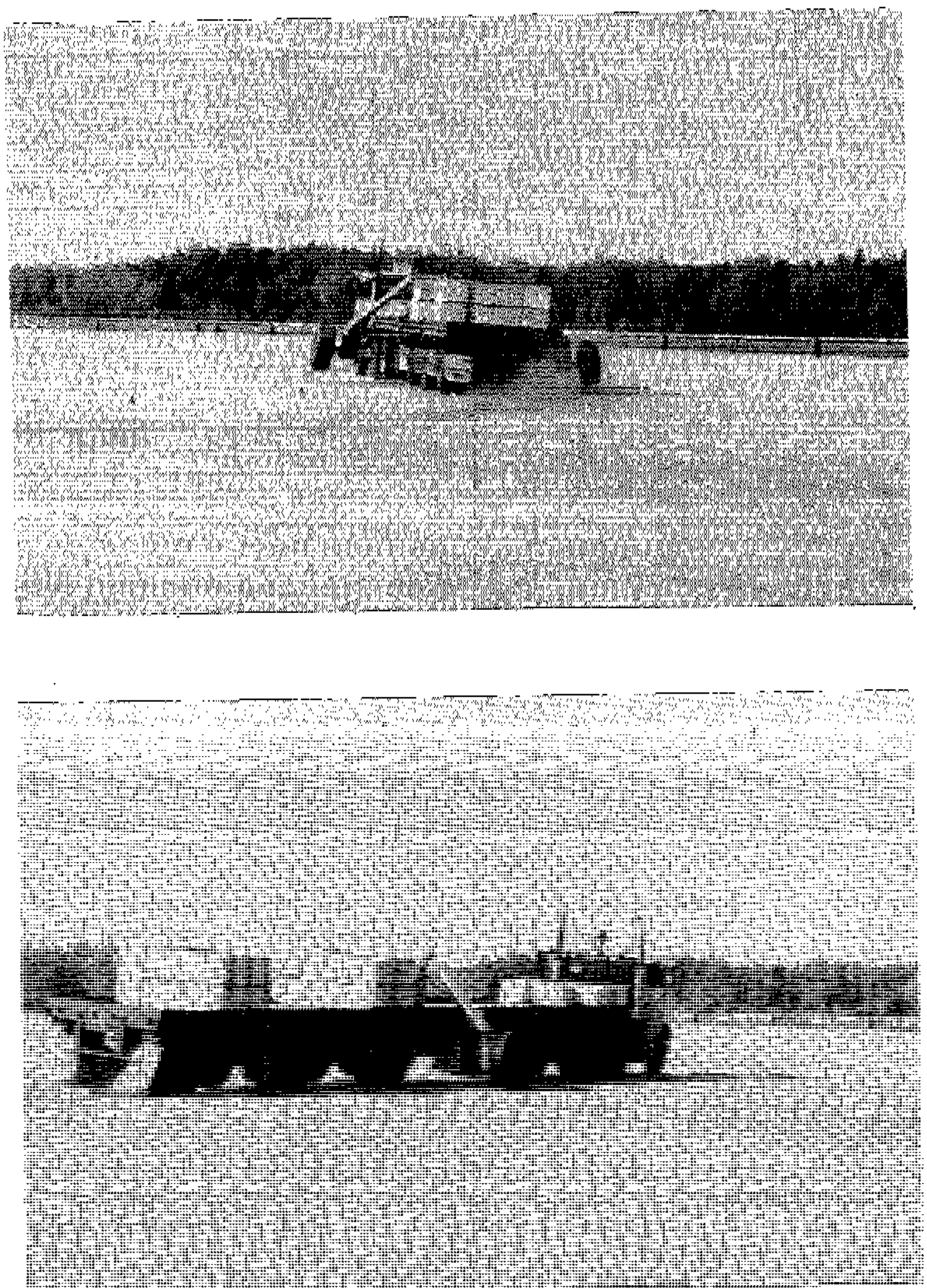


Figure 19/ Vehicle Making Steady Circular Turn

CV-86-10

Demonstration of Tractor-Trailer Performance: 7-Axle 48 ft Semi

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W. Mercer

Commercial Vehicles Section
Ontario Ministry of Transportation
and Communications

ABSTRACT

A 7-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated an additional vehicle by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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ACKNOWLEDGEMENTS

This work was conducted on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study, managed by J.R. Pearson. The trailer was provided by the Roads and Transportation Association of Canada (RTAC). Facilities of the Transport Canada Motor Vehicle Test Centre were made available to the Ministry of Transportation and Communications (MTC). Assistance with vehicle preparation, delivery, and refurbishment was arranged by Mr. Pearson in support of this work.

The work was principally undertaken by the staff of the Automotive Technology and Systems Office of the Transportation Technology and Energy Branch of MTC: N.R. Carlton; G.B. Giles; C.P. Lam, P.Eng.; W.R. Stephenson, P.Eng.; and M.E. Wolkowicz; and assigned students G. Goertzen, S. Jazic, and D.R. Sykes. Assistance was provided by staff of various other departments of the ministry and other organizations.

The efforts of all involved are hereby acknowledged with gratitude.

1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 7-axle 48 ft (14.63 m) semitrailer combination, which is one of the additional vehicles. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and single 48 ft (14.63 m) four-axle flatbed-type semitrailer. The combination is typical of equipment used in Central Canada, where additional gross weight can be carried on a widespread tandem axle and belly axles. The same combination was also tested concurrently as a 5- and 6-axle vehicle [8,9].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by Fruehauf in July 1984 and was a 48 ft (14.63 m) flatbed semitrailer with two fixed and two non-steering airlift axles. It was model PBX4W 48102 and bore the serial number 2H8P04843ER033601.

The trailer had a nominal length of 14.63 m (48 ft) and a nominal width of 2.59 m (102 in). The trailer suspension comprised a Reyco four-spring leaf system with long equalizer arms on the fixed axles and a Neway air suspension system for the two airlift axles. The axle spacings were 2.74, 2.74, and 2.77 m (108, 108, and 109 in). The spring centre width was 0.96 m (38 in) for the fixed axles and 0.76 m (30 in) for the airlift axles. The airlift axles had shock absorbers in parallel with the air springs, with a spacing of 0.30 m (12 in). The overall track width was 2.44 m (96 in). The vehicle overall length was 18.69 m (61.32 ft). The trailer was rated at 9620 kg/axle (21 164 lb/ axle).

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 22 595 kg (49 710 lb). Concrete blocks were used to obtain a loaded weight of

49 898 kg (109 730 lb). Airlift axle pressure was 110 kPa (16 psi) in each axle for the empty vehicle and 345 kPa (50 psi) loaded. Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 918	10 820	5 255	11 560
2	3 885	8 547	7 923	17 430
3	3 885	8 547	7 232	15 910
4	2 477	5 449	7 464	16 420
5	2 477	5 449	8 177	17 990
6	2 477	5 449	6 577	14 470
7	2 477	5 449	7 250	15 950
Total	22 595	49 710	49 878	109 730

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was closely attained. The legal gross weight for the vehicle tested is about 56 000 kg (123 200 lb) in Ontario.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.26 m (10 in) below the top of the floor. The centre of gravity height was estimated as 0.27 m (11 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and trailer was calibrated.
15/ Details of the vehicle and test equipment were recorded on photographs and videotape.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyroscope package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyroscope package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	19.792°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyroscope	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
23	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values, shown in the last column of Table 3, is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4.

Table 3/ Offtracking

Axle No.	Track Width	Radius to Inner Wheel Right Turn (m)	 Left Turn (m)	Difference (m)	Average (m)	Calculated (m)	Difference %
1	2.31	27.59	27.44	0.15	27.51	27.56	+0.20
2	2.37	27.40	27.35	0.05	27.38	27.21	+0.62
3	2.37	27.44	27.42	0.02	27.43	27.21	+0.80
4	2.37	26.13	26.13	0.00	26.13	26.12	+0.03
5	2.37	25.63	25.63	0.00	25.63	25.83	+0.77
6	2.37	25.35	25.39	0.04	25.37	25.83	+1.70
7	2.37	25.38	25.42	0.04	25.40	26.12	+2.75

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was only 0.80 m (2.62 ft). It was out of the exit lane for a distance of 20.4 m (67 ft), as derived from Figure 5. This test was conducted at a creep speed and represents the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was 1.47 m (4.8 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. Such geometrics would not appear to restrict access of this vehicle.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi).

The SAE J982a style test was performed, and the results, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test compare favourably with those obtained from tests on other similar combinations and are considered fast. A typical time history response of application and release is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.02	0.17	92.6
Axle 2	0.36	0.55	91.1
Axle 4	0.40	0.95	87.4
Axle 5	0.45	0.98	88.1
Axle 7	0.44	1.03	86.1

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1]. Note that the airlift axles were lowered for this test, even though they would be raised in normal operation on the highway when the vehicle was empty.

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The initial average brake application of about 242 kPa (35 psi) caused all braked wheels to lock, and the tractor jack-knifed hard to the right. The driver released the brakes, steered hard to the left to full lock, and managed to regain control of the vehicle at a low speed, although the vehicle was grossly distorted and far out of lane. The tractor heading shown in Figure 11 reached the limit of the signal conditioning.

A summary of peak vehicle responses is shown in Figure 12, as a function of average treadle pressure.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. Gates of 22.5 m (73.8 ft) were used for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. Note that the airlift axles were also lowered for this test.

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude of both tractor and trailer rose to 4 to 5 m/s^2 at 57.5 km/h. Vehicle heading angle tended to rise slightly as speed increased, indicating moderate slide within lane. Tractor steer corrections were such that a slight understeer effect was noticeable as speed increased. Indications of tractor slide became evident at the higher speeds. Tractor control appeared to be the limiting factor in this combination.

A typical run at 58 km/h is presented in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration is presented in Figure 15, as a function of tractor steer input period for the three test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15 that rearward amplification increases little with speed. It is somewhat sensitive to steer period reaching the highest value of about 1.05 at around 3.5 s. The results show that, at highway speed, this is a very stable vehicle, because of low response to input.

Figure 16 shows the response of a typical run for a steer period of about 1.5 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

A gate of 30 m (98.4 ft) was used, to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections.

The results from all runs are presented in Figure 17. The peak-to-peak lateral acceleration and roll angles and roll showed a moderate increase up to 95 km/h, and yaw stayed essentially constant. The trailer did not roll aggressively or slide in this manoeuvre. The lateral acceleration gain is consistent with the values from the sinusoidal steer test. The yaw overshoot of the trailer illustrates rear trailer swing at all speeds.

Figure 18 shows a typical run time history at 95 km/h. Although the vehicle appeared to stay in lane, the traces indicate the tractor and trailer manoeuvring or sliding within the confines of the lane.

4.9/ Normal Straight-Line Driving

The objective of this test was to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was very stable, and if any slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in trailer sway, it was not readily perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 1.04 g/° of RMS steer input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 19. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angles increased with speed. Average steady-state articulation angles decreased modestly with increase in lateral acceleration, and as a consequence, the offtracking decreased. The lateral force experienced by the tractor fifth wheel, expressed as a function of tractor lateral acceleration, shows a gradient of 80.3 kN/g (18 000 lb/g).

At the limiting speed of 53 km/h, a lateral acceleration of 0.39 g, the driver was unable to hold the vehicle in circle because of the heavy steer effort required, as shown in Figure 20. The test was terminated at this point.

The slip angle at the rear axle of this vehicle, and the extremely high load on the right side, resulted in very severe wear of the outer shoulder of the outer tire on the right-hand side of the rear axle, as shown in Figure 21. There was lesser wear in a similar pattern on the inner tire at this position and the outer tire on the preceding axle. This wear pattern was initiated in the corresponding test of this trailer in the 5- and 6-axle configurations [8,9].

A tilt test was conducted on this vehicle as part of a separate test program [14]. The vehicle is shown on the tilt table in Figure 22. The high-side wheels of the rear trailer lifted at a tilt angle of 29.1°, after all corrections were made, which corresponds to a lateral acceleration of 0.56 g. The lateral acceleration only reached 0.39 g in the steady circular turn, so it was not possible to compare the rollover threshold with the tilt test.

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted, particularly those on the right-hand wheel of the rear axle, as shown in Figure 21. The tests on this vehicle followed those of the 5- and 6-axle 48 ft (14.63 m) semi-trailers [8,9], and the steady circular turn test had clearly caused the severe wear on the outer edge of this tire. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailer were, therefore, atypical, at least in the empty condition.

It is impossible to make meaningful remarks on the effect these factors might have had on the results. The results pertain only to the particular vehicle tested; some different results might be obtained for another vehicle at another time. Other trailers with four axles having different arrangements from this trailer are also in common use. If this trailer is described as having single-single-tandem axles from front to rear, then the common alternative arrangements are tandem-tandem, single-tandem-single, and single-triple. None of these axles would be typically self-steering. Single axles would be airlift, as would the lead tandem in the tandem-tandem arrangement. These other arrangements would have different results to the ones presented here.

This vehicle was considered an easy vehicle to drive by the test driver. It tracked very well, but required considerably more effort to manoeuvre than either the 45 ft (13.72 m) semi [2] or the 5-axle 48 ft (14.63 m) semi [8], because of the two lowered airlift axles. It did, however, require a little less space to manoeuvre than these vehicles. It was clearly evident to the test driver, with the loaded vehicle on a wet surface, that the resistance to turning of the trailer, which caused the additional effort to manoeuvre, would require greater attention by the driver on the highway as there was less control available. The vehicle exhibited high stability in all dynamic manoeuvres. However, the trailer centre of gravity was quite low -- 1.77 m (70 in) from the ground. The centre of gravity of some loads can result in the trailer centre of gravity rising to 2.5 m (100 in) or more from the ground, which would reduce the rollover threshold to around 0.3 g [15]. The lane change would then likely have resulted in rollover at some speed much less than 95 km/h.

6/ CONCLUSIONS

A 7-axle tractor-semitrailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated as of particular interest by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns, though it required less space than a comparable 5-axle semi.

The air brake system was relatively fast and well balanced.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. Stability varied little with speed up to 100 km/h. The roll stability was high, primarily because the trailer centre of gravity was low. A higher centre of gravity would significantly reduce the rollover threshold.

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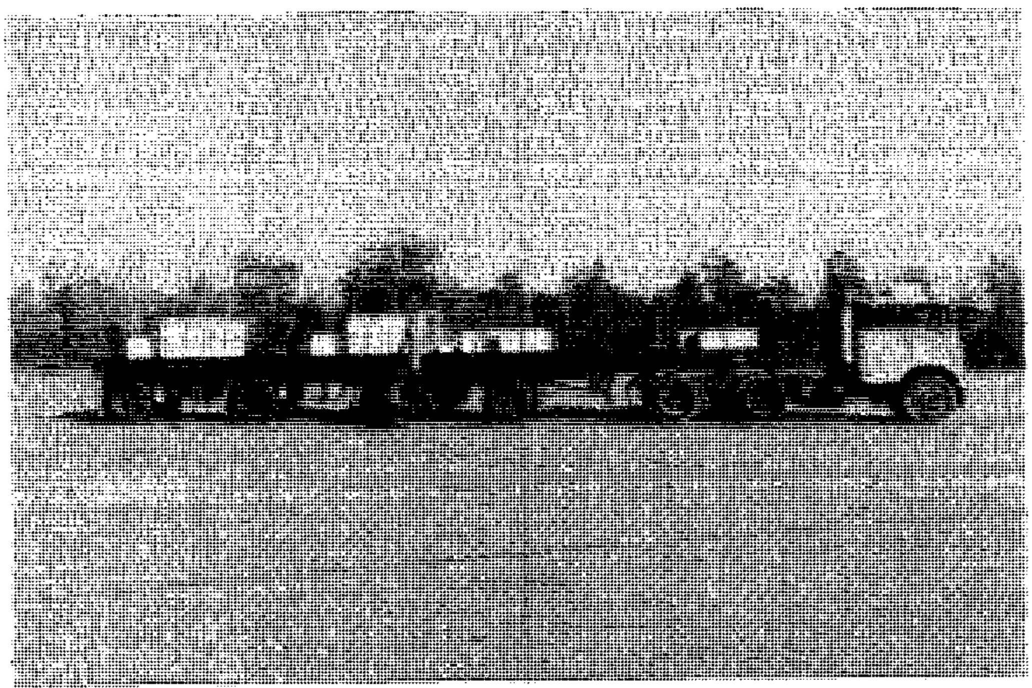


Figure 1/ View of Vehicle

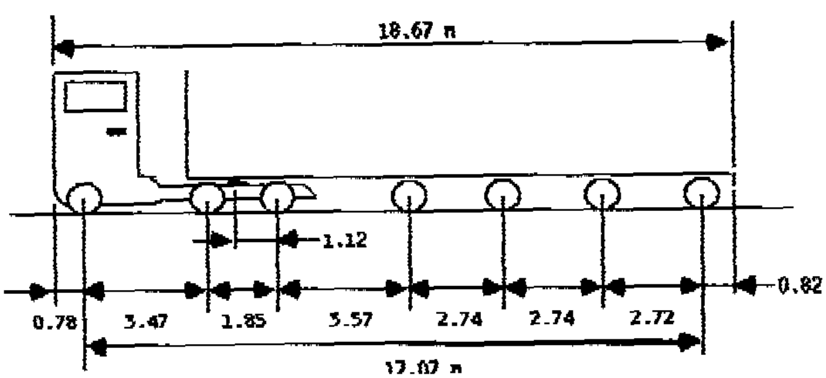


Figure 2/ Vehicle Dimensions

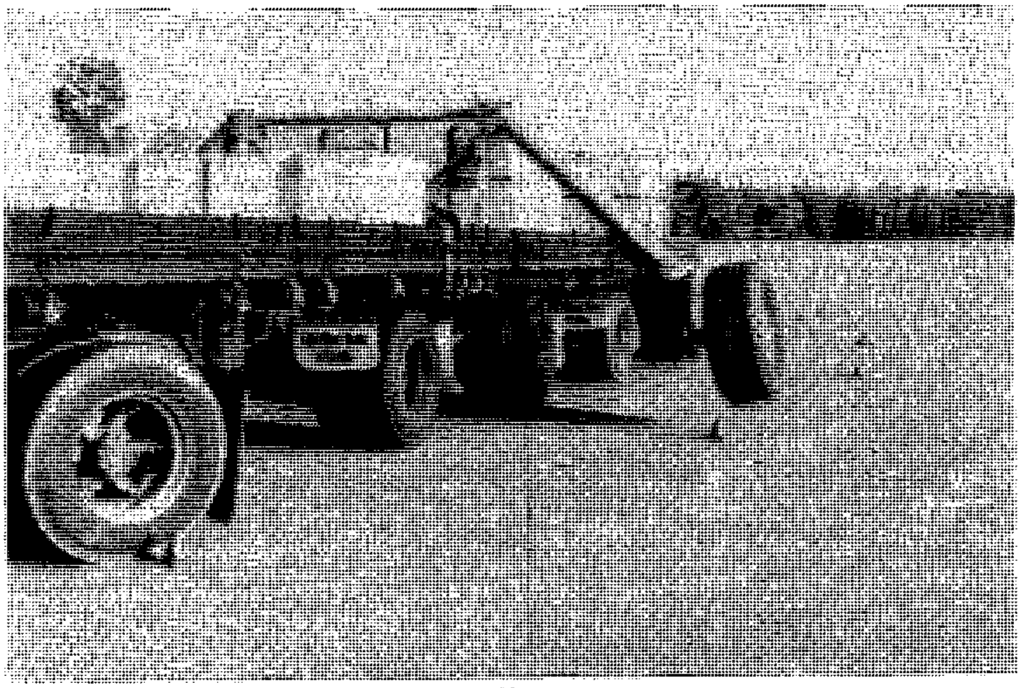


Figure 3/ Offtracking

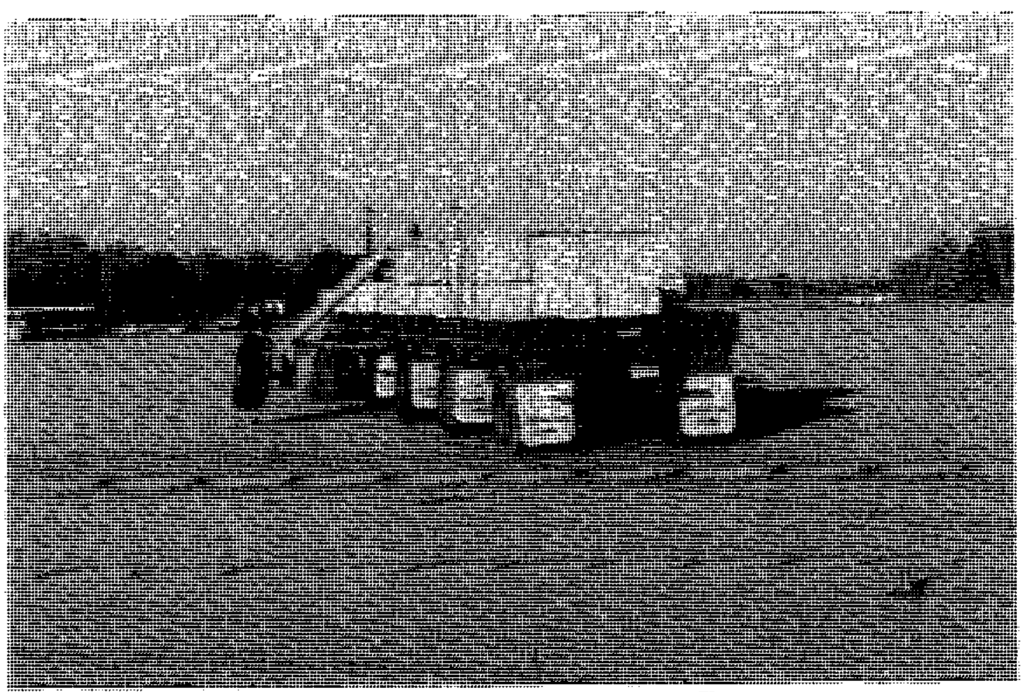
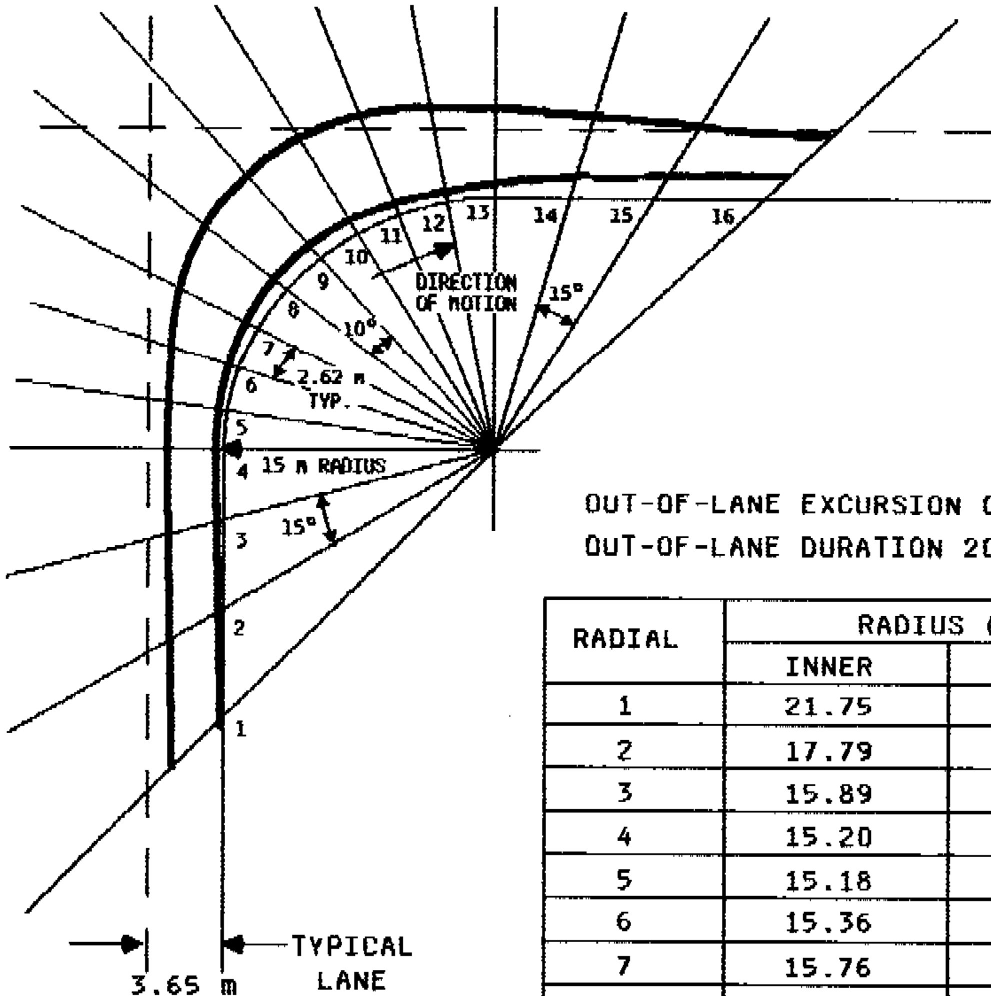


Figure 4/ Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 0.8 m
OUT-OF-LANE DURATION 20.4 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	21.75	-
2	17.79	-
3	15.89	-
4	15.20	17.80
5	15.18	17.90
6	15.36	18.48
7	15.76	19.61
8	15.99	20.44
9	15.76	21.10
10	15.43	21.23
11	15.26	20.95
12	15.30	20.07
13	15.59	19.75
14	16.50	20.10
15	18.68	21.96
16	22.54	26.28

Figure 5/ Right-Hand Turn Swept Path

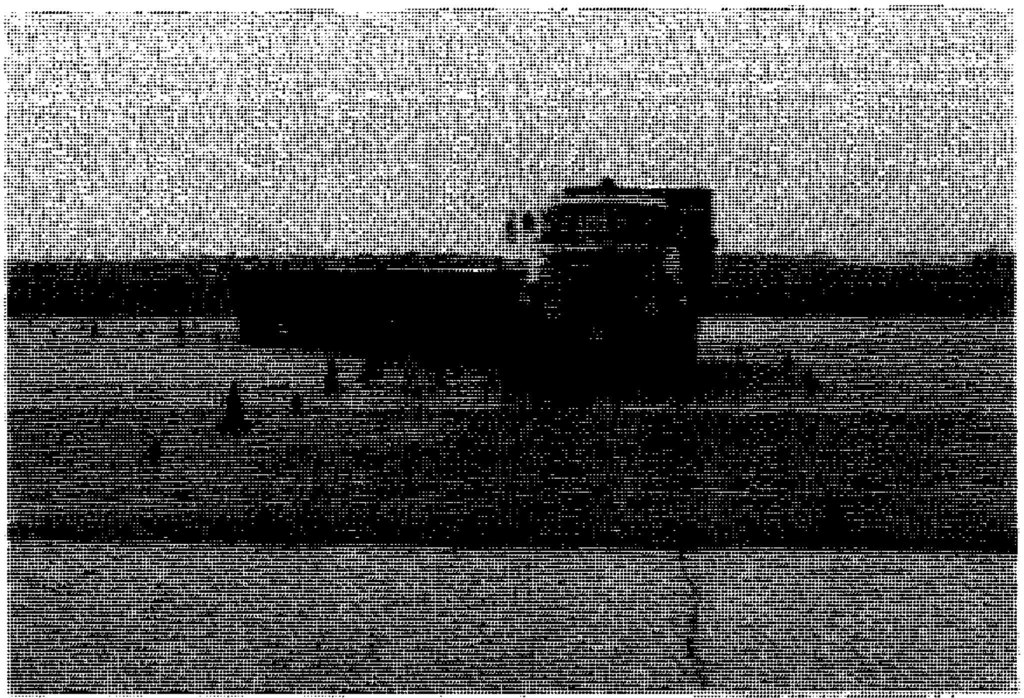


Figure 6/ Right-Hand Turn

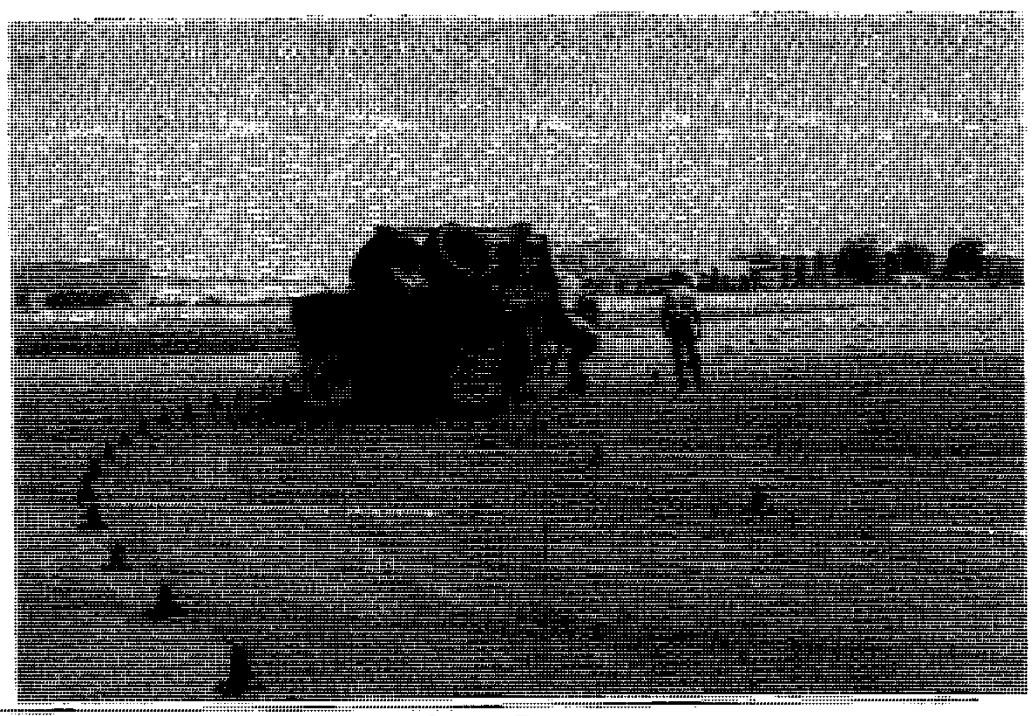
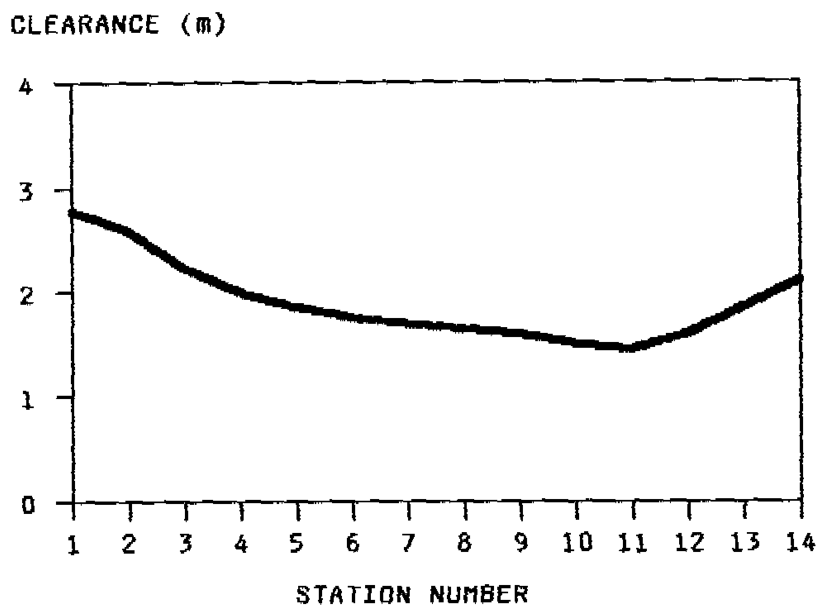


Figure 7/ Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.78
2	2.59
3	2.25
4	2.00
5	1.86
6	1.77
7	1.70
8	1.65
9	1.61
10	1.50
11	1.47 *(LOW)
12	1.60
13	1.86
14	2.13

Figure 8/ Channelized Right Turn
Clearance from Inner Curb

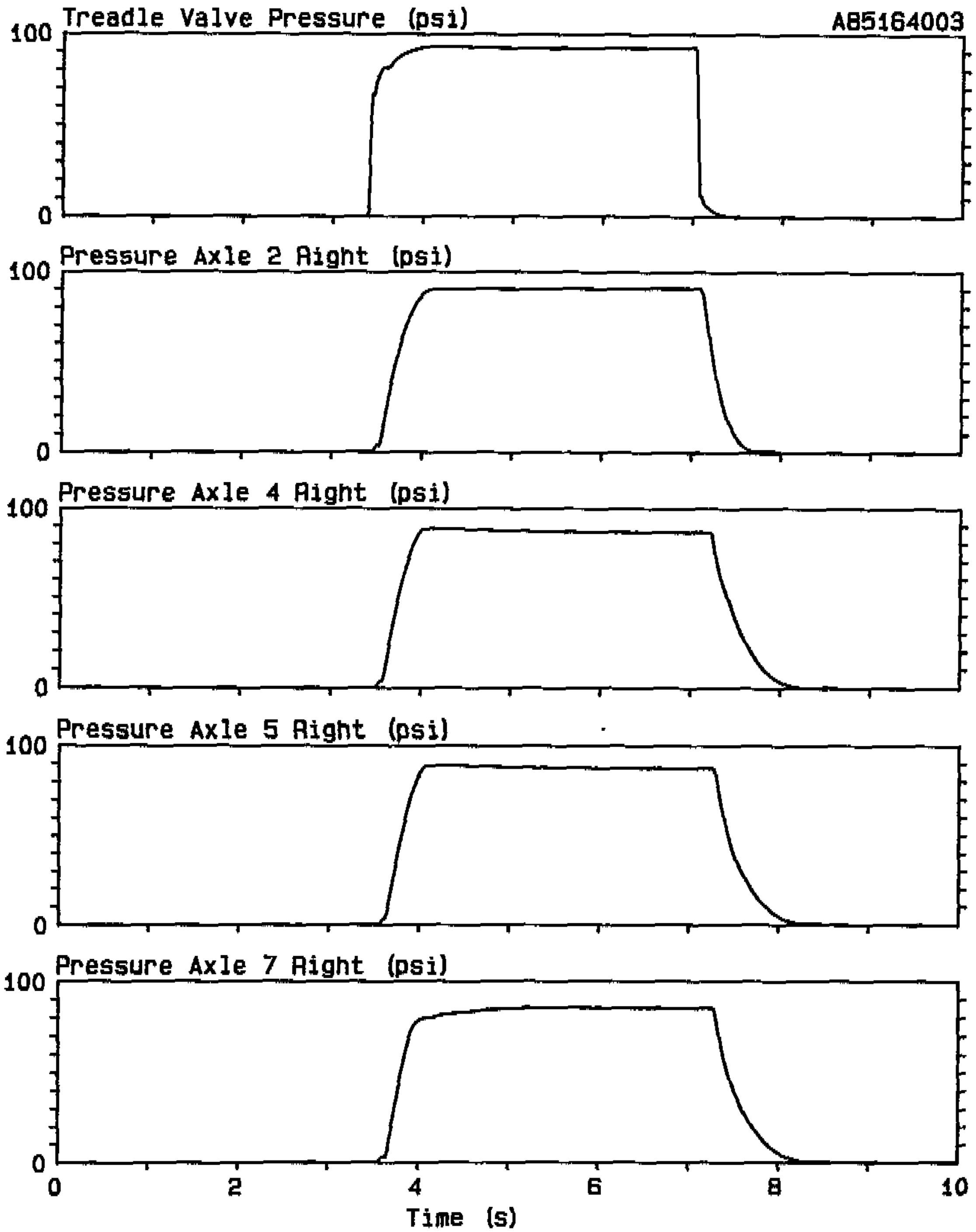


Figure 10/ Air Brake Application and Release

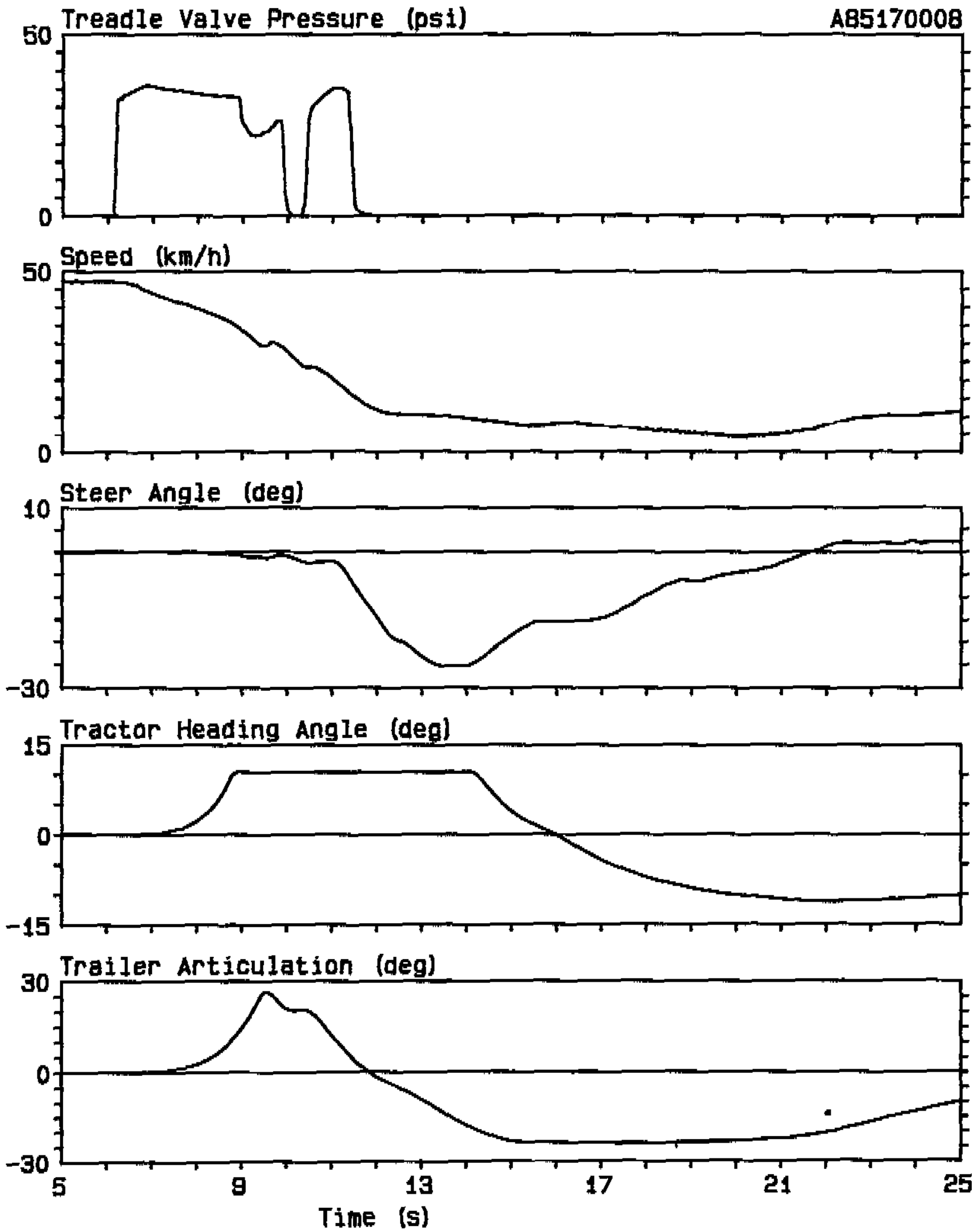


Figure 11/ Vehicle Response to Straight-Line Braking

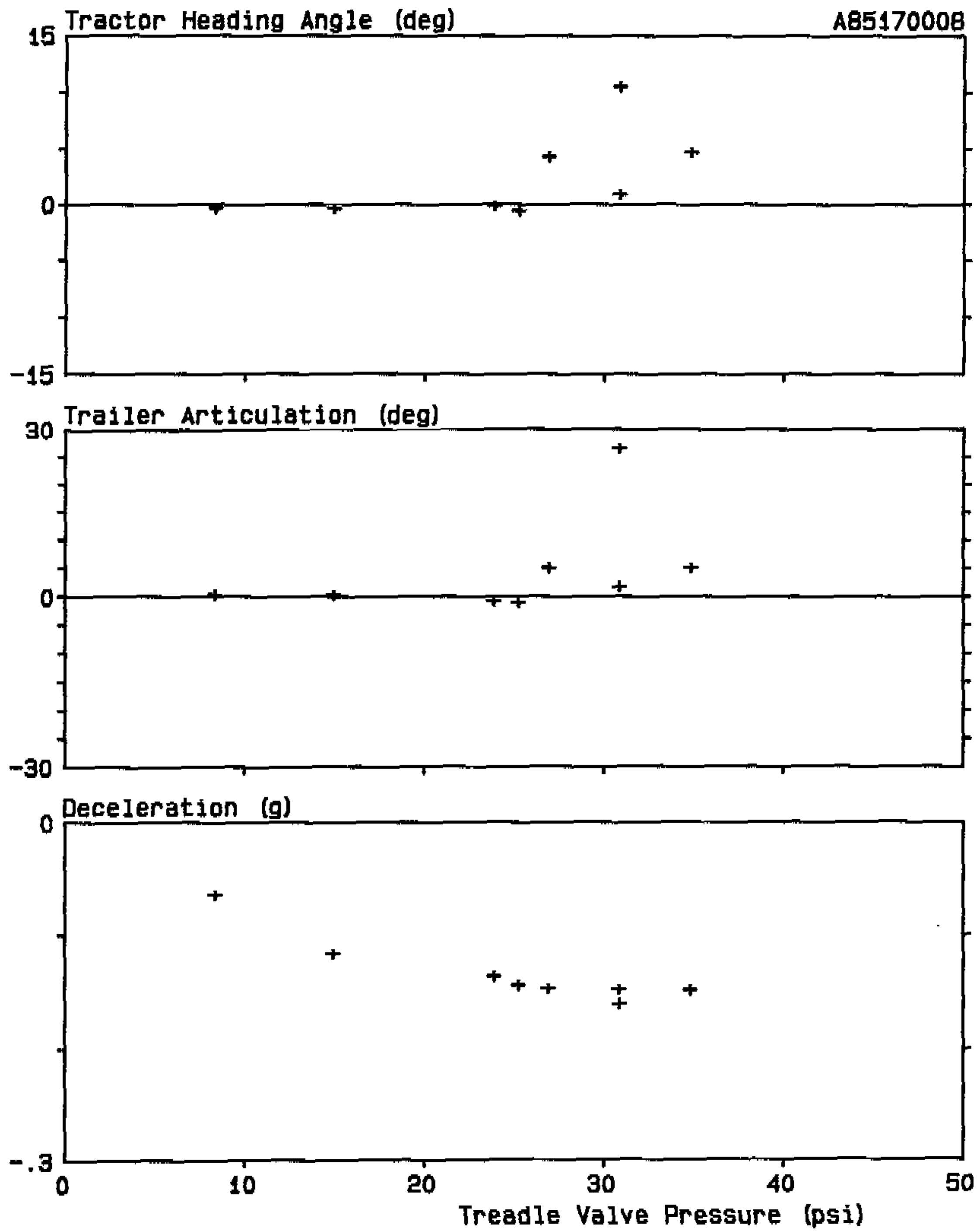


Figure 12/ Straight-Line Braking Responses vs Treadle Valve Pressure

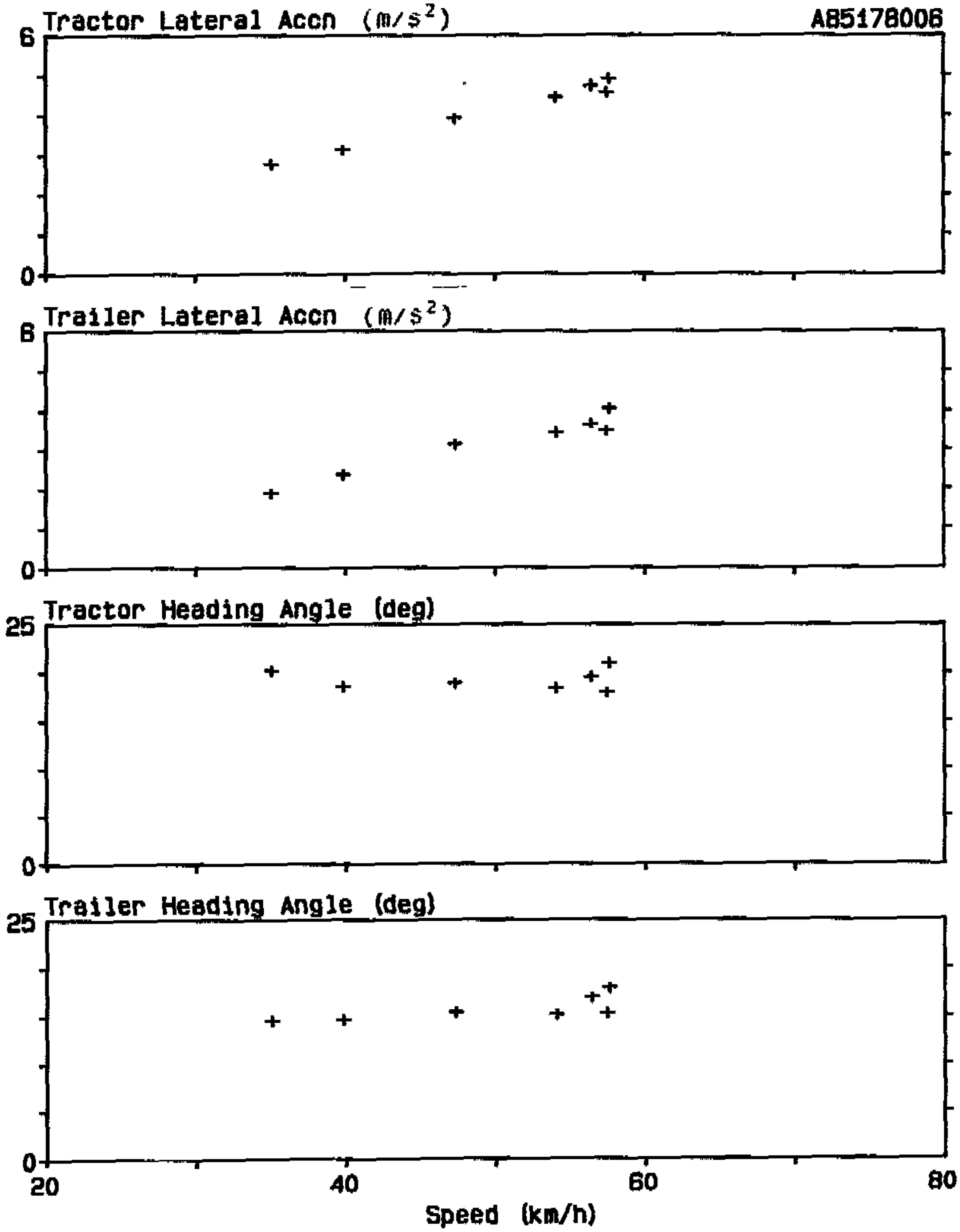


Figure 13/ Evasive Manoeuvre, Peak-to-Peak
Responses vs Speed

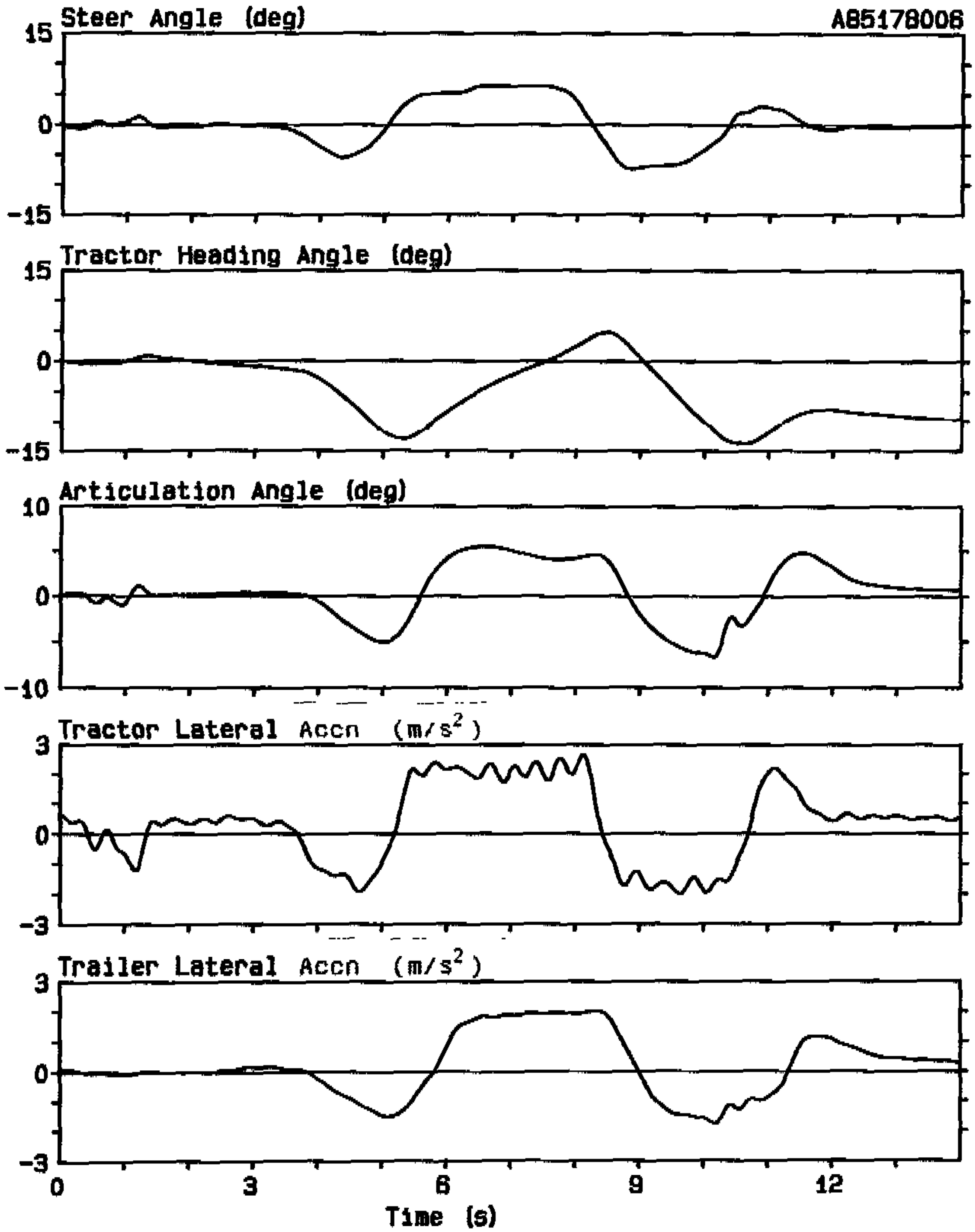


Figure 14/ Vehicle Response in Evasive Manoeuvre

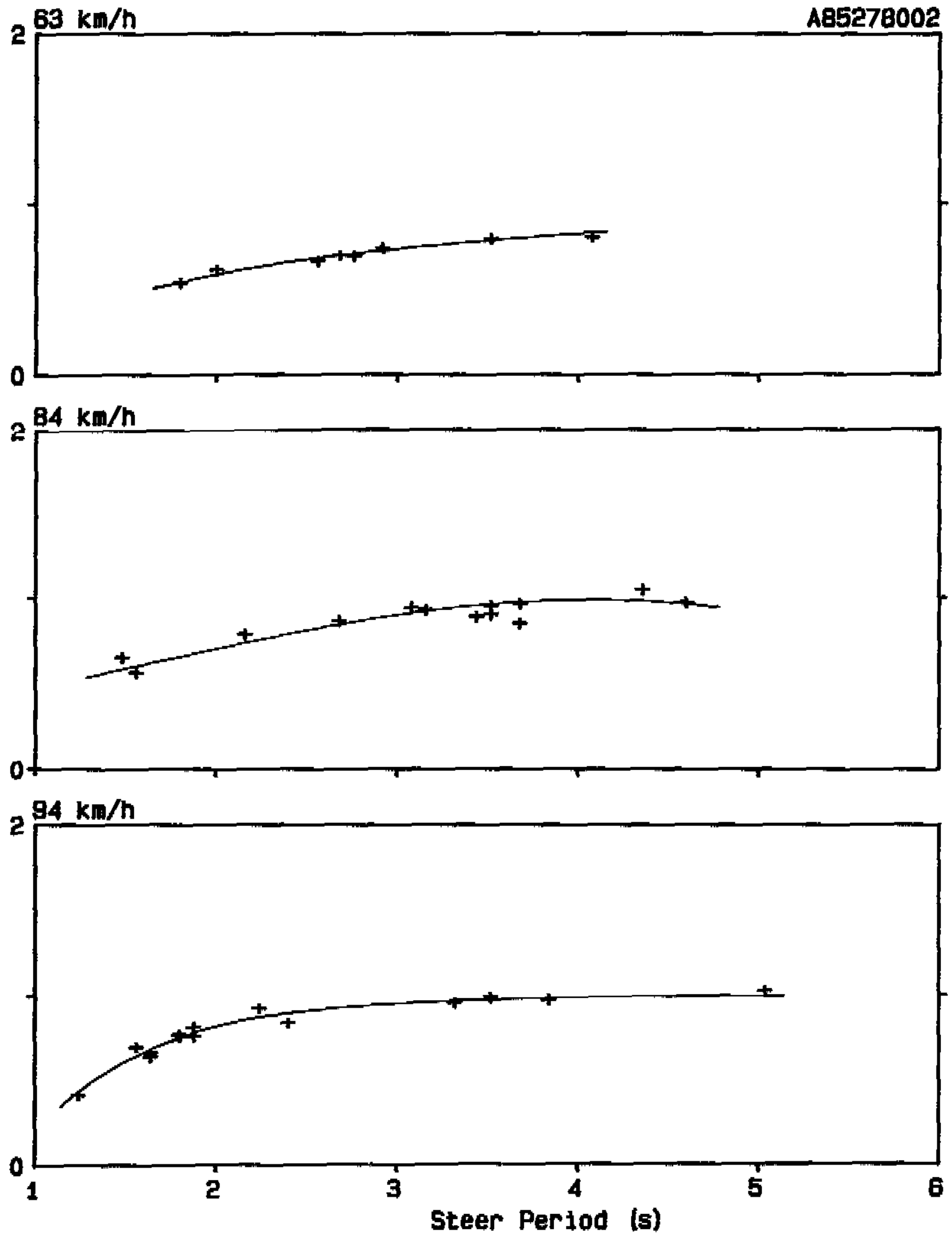


Figure 15/ Rearward Amplification of Lateral Acceleration

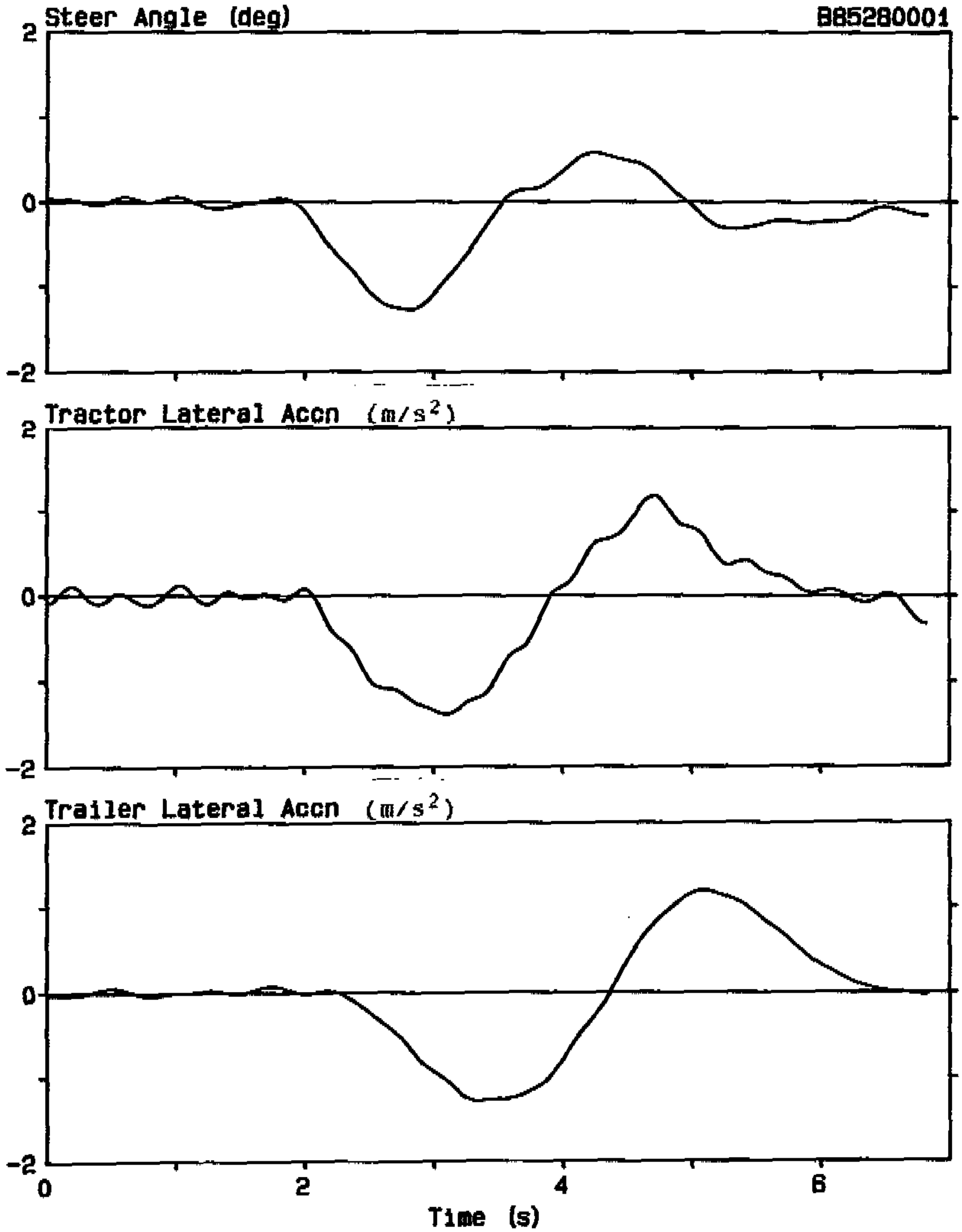


Figure 16/ Vehicle Response to Sinusoidal Steer at 94 km/h

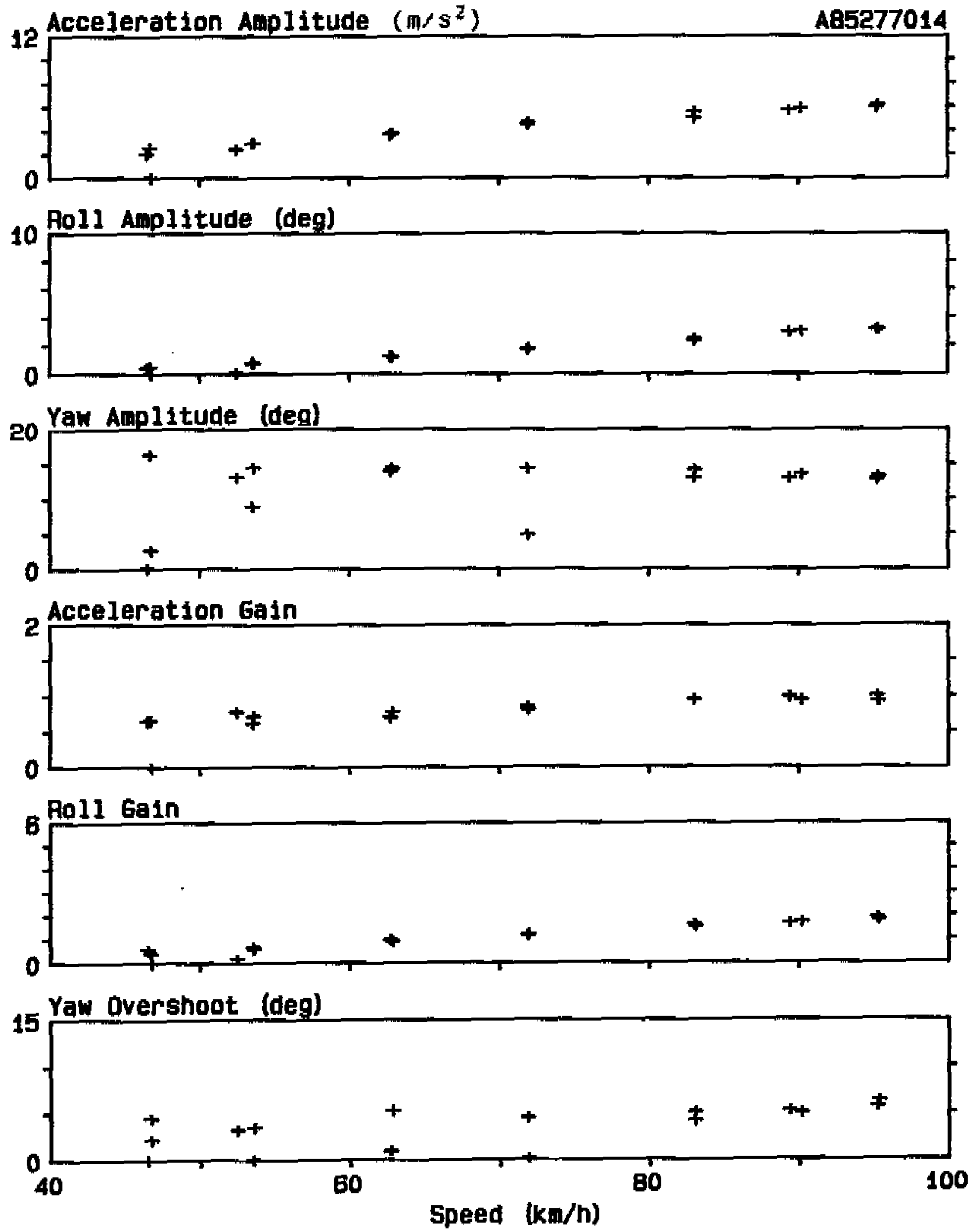


Figure 17/ Lane Change, Vehicle Responses vs Speed

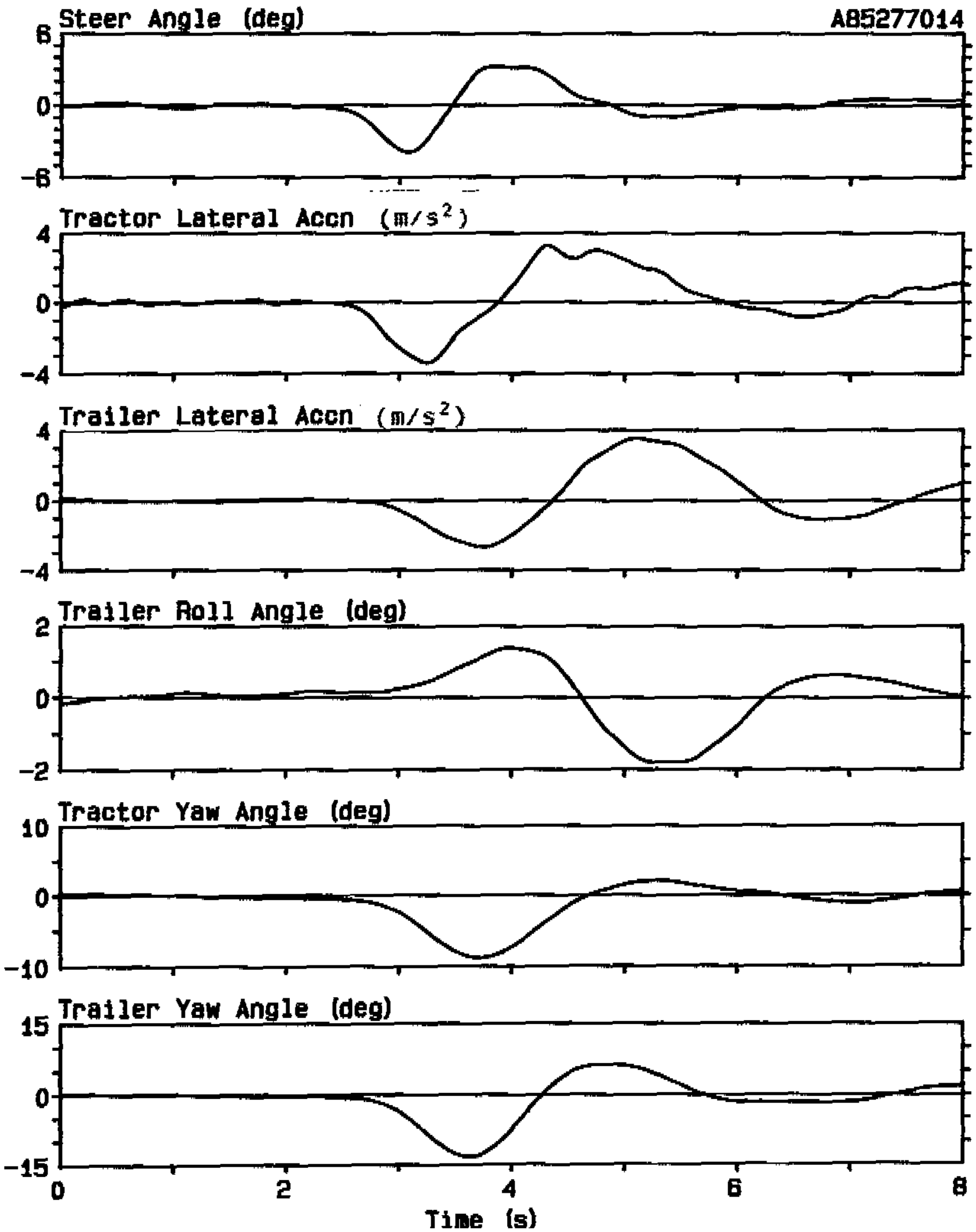


Figure 18/ Lane Change, Vehicle Responses at 94 km/h

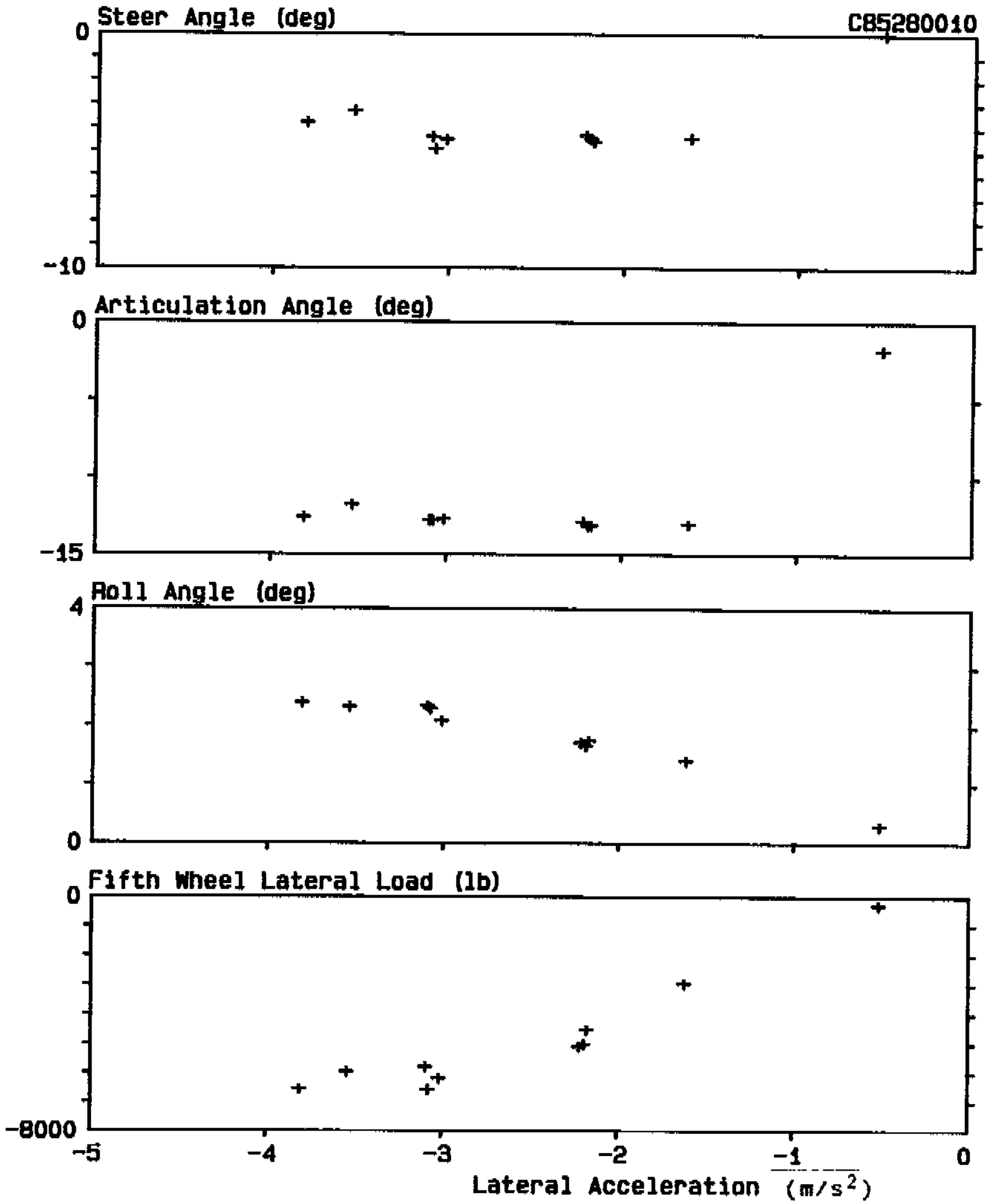


Figure 19/ Steady Circular Turn, Vehicle Responses vs
Tractor Lateral Acceleration

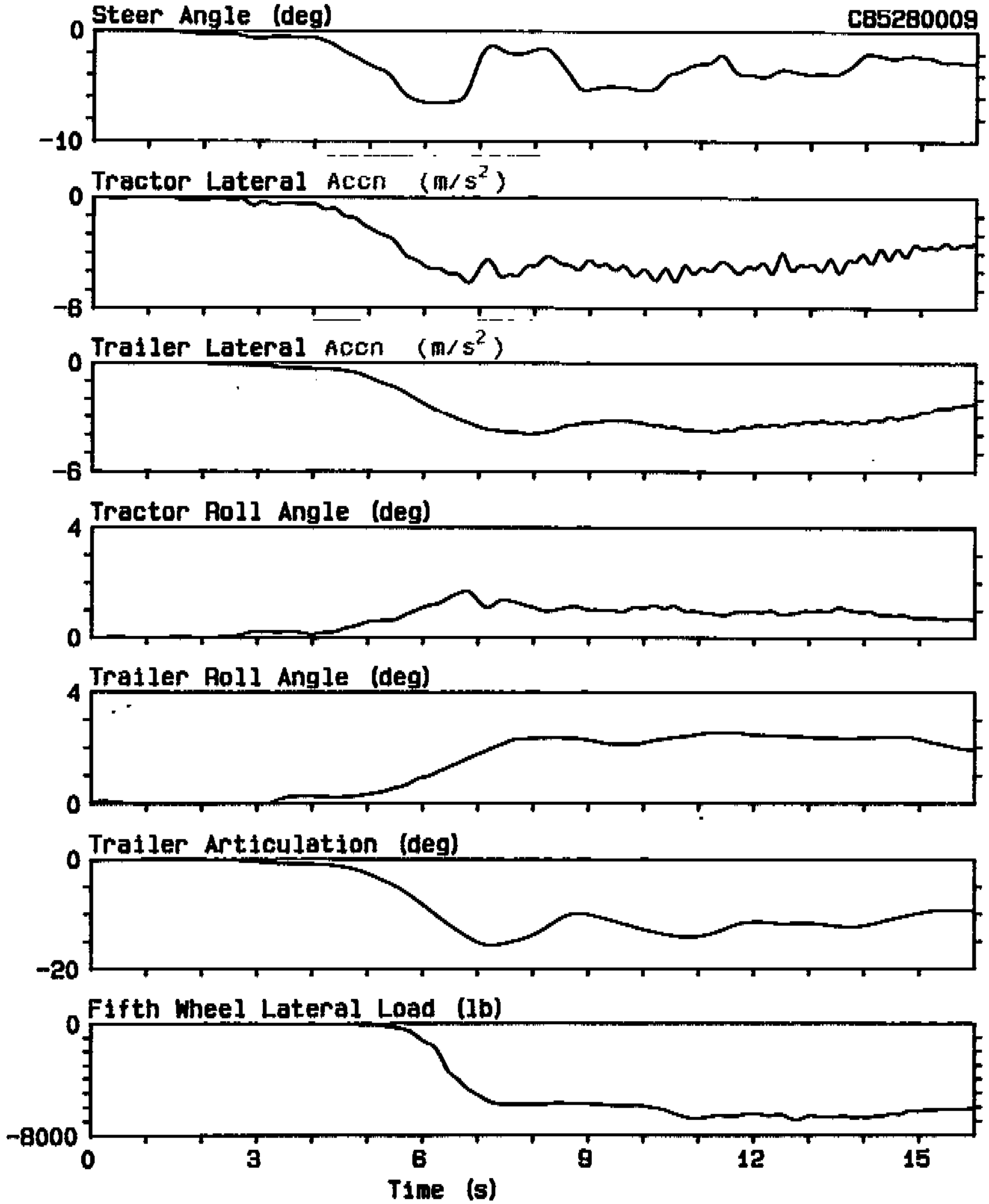


Figure 20/ Steady Circular Turn, Vehicle Responses at 53 km/h

Figure 21/ Wear Pattern on Right Rear Outer Tire After Steady Circular Turn Test

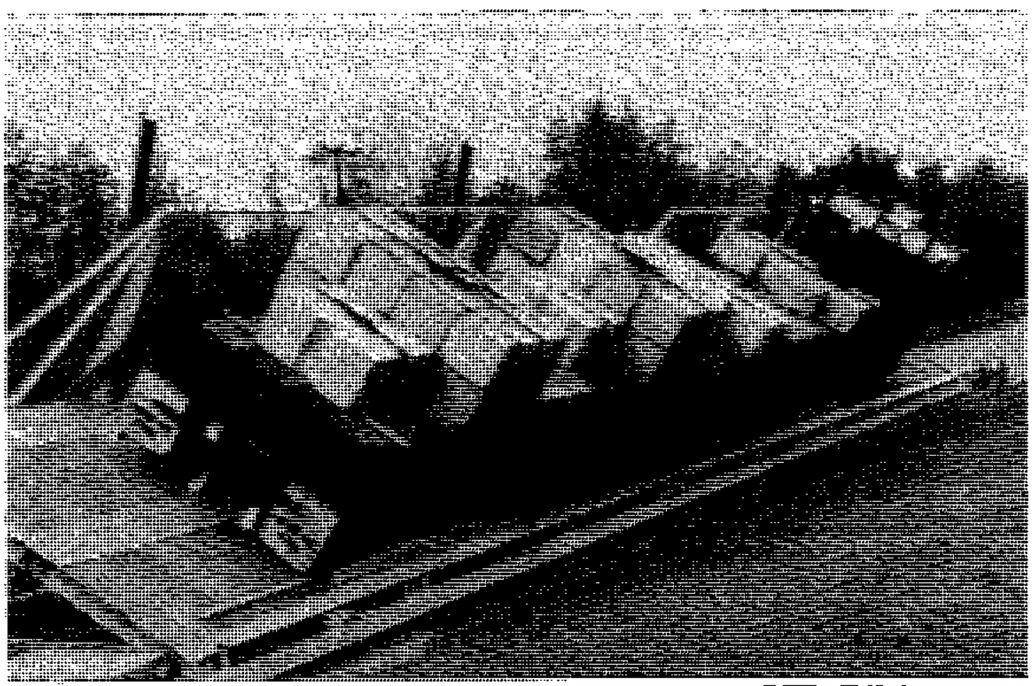


Figure 22/ Vehicle on Tilt Table

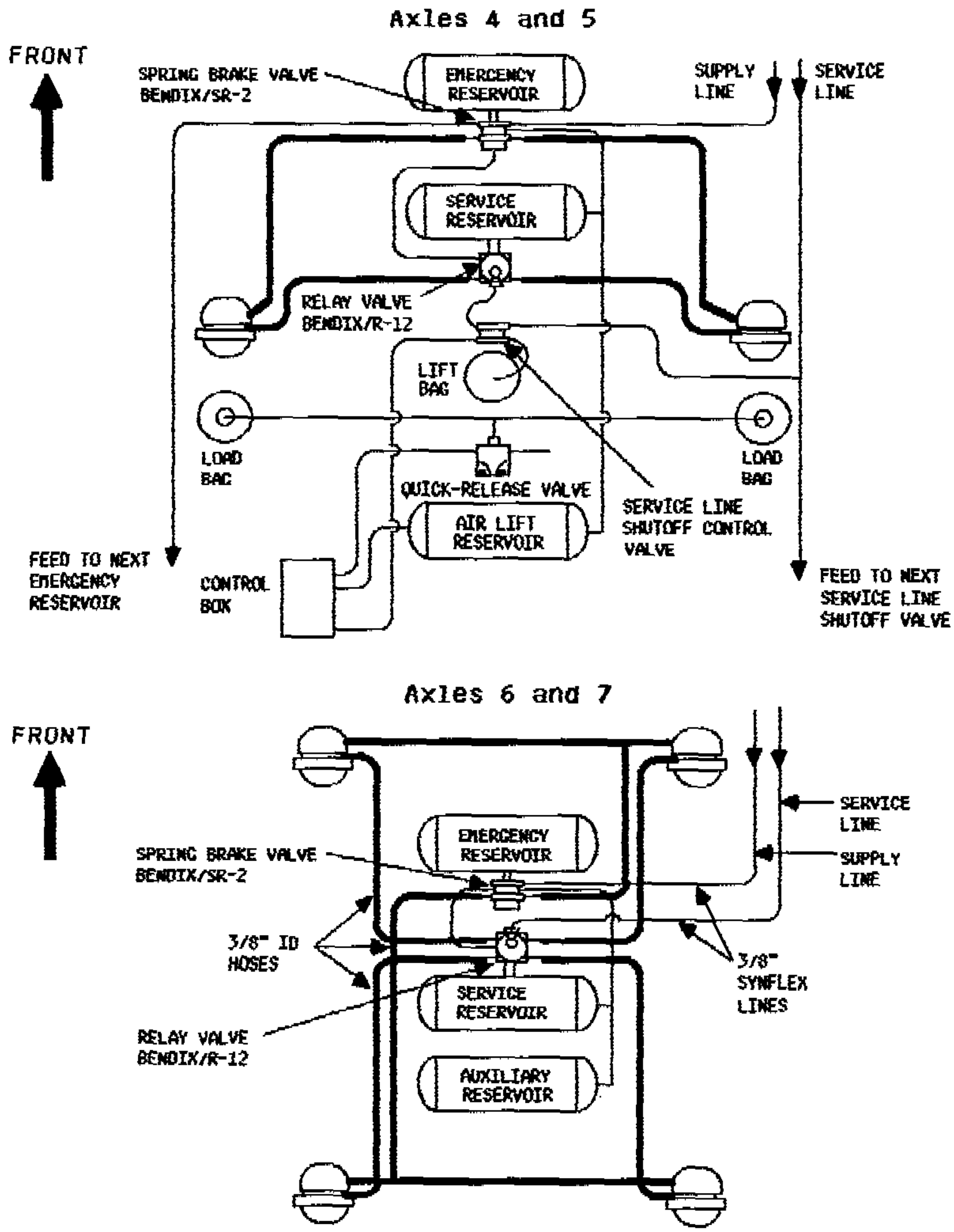


Figure 9/ Air Brake System Schematic