

Contract No. DOT-FH-11-8562

August 1975

**CONTROL OF LARGE COMMERCIAL
VEHICLE ACCIDENTS CAUSED BY
FRONT TIRE FAILURES**

FINAL REPORT



Prepared for:

**DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Bureau of Motor Carrier Safety
Washington, D.C. 20590**

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13

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle CONTROL OF LARGE COMMERCIAL VEHICLE ACCIDENTS CAUSED BY FRONT TIRE FAILURE		5. Report Date	
		6. Performing Orgn Code	
7. Author(s) R. L. Anderson, R. A. Nidey, G. McCormick, F. Russoniello		8. Performing Orgn Rpt No. 2320-75-130	
9. Performing Organization Name and Address Ultrasystems, Inc. The Dynamic Science Division 1850 West Pinnacle Peak Road Phoenix, Arizona 85027		10. Work Unit No.	
		11. Contract or Grant No. DOT-FH-11-8562	
		13. Type of Report and Period Covered FINAL REPORT Sep 74 - Aug 75	
12. Sponsoring Agency Name and Address Bureau of Motor Carrier Safety Federal Highway Administration Department of Transportation Washington, D.C. 20590		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract The Federal Highway Administration of the U.S. Department of Transportation is concerned with the loss of life, injury, and property damage that result from front tire failure on heavy-duty trucks. The Bureau of Motor Carrier Safety contracted with Ultrasystems, Inc., the Dynamic Science Division (Contract No. DOT-FH-11-8562), to conduct an investigation of front tire failure on heavy trucks. This effort included an investigation of the magnitude of the front tire problem, baseline tire failure tests, and tests with devices commercially available which are designed to minimize the front tire failure problem. Instrumentation on the truck was designed to aid in the definition of the magnitude of the problem. Baseline testing finalized the testing procedure and provided a comparative evaluation of variations in tire loading, tire construction, and misalignments. The device evaluation phase involved testing of twelve devices and concepts. A ranking of the devices tested and a cost-effective analysis summarize the findings of the program.			
17. Key Words Tire Failure, Device Evaluation, Accident Reduction, Combination Truck		18. Distribution Statement Unlimited - Document is available to the public through the National Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. Pages 256	22. Price

EXECUTIVE SUMMARY

The Federal Highway Administration of the U.S. Department of Transportation is concerned with the loss of life, injury, and property damage that result from front tire failure on heavy-duty trucks. As part of the effort to investigate the front tire failure problem, the Bureau of Motor Carrier Safety contracted with Ultrasystems, Inc., the Dynamic Science Division (Contract No. DOT-FH-11-8562), to conduct an investigation of front tire failure on heavy trucks. This effort included an investigation of the magnitude of the front tire problem, baseline tire failure tests, and tests with devices commercially available which are designed to minimize the front tire failure problem. Instrumentation on the truck was designed to aid in the definition of the magnitude of the problem as well as providing the basis for a relative ranking of the various devices and concepts which were tested.

Baseline testing finalized the testing procedure and provided a comparative evaluation of variations in tire loading, tire construction, and misalignments.

The device evaluation phase involved testing of twelve devices and concepts.

It was discovered that for a flat, dry surface with the vehicle driving straight, the driver could control the combination vehicle which was loaded up to the gross combination weight of 73,280 pounds.

While a benefit could not be assigned to each device, a relative ranking was obtained by measuring how effectively each device decreased the most important parameters which were the average steering wheel torque, average tie rod force, and peak lateral path deviation of the truck.

The rank analysis showed that among the most effective devices were a Safety Roller insert inside the tire mounted on the rim, axles with reduced kingpin offset, a Cantilever Tire, and power steering.

Monetary benefits could not be established for the devices on an individual basis, but the maximum total benefit (annual accident cost) of \$28 per truck compares reasonably well with the computed annual cost per truck of the factory-installed Centerline and Centerpoint Axles (\$28 - \$37) and is not substantially less than the cost of the Cantilever Tire (\$36 - \$54). The estimated annual cost of the Safety Roller is about twice the additional cost of the factory-installed Centerline and Centerpoint Axles. However, since the Safety Roller is still under development, its ultimate large-scale production costs are somewhat uncertain.

The maximum benefit, or accident cost, to the operator would be \$12 per year per truck which is less than the computed costs for any of the devices. Furthermore, the maximum operator benefits of \$12 per year per truck would be realized only for a perfect device that reduces the accident probability almost to zero, so the benefits realized for actual devices would be somewhat less. This implies that additional incentives would be required to make regulations for these devices more acceptable to the operators.

TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY.	iii
LIST OF ILLUSTRATIONS.	ix
LIST OF TABLES	xiv
1.0 INTRODUCTION.	1-1
1.1 PROGRAM OBJECTIVES	1-1
2.0 FRONT TIRE FAILURE ACCIDENT CAUSES AND STATISTICS.	2-1
2.1 GENERAL TRUCKING INDUSTRY STATISTICS	2-1
2.2 TRUCK ACCIDENT STATISTICS.	2-2
2.3 CHARACTERISTICS OF TRUCK TIRE FAILURE ACCIDENTS.	2-7
2.4 CAUSES OF FRONT TIRE FAILURE	2-12
2.5 RECAPITULATION OF STATISTICS	2-18
3.0 STEERING AND ALIGNMENT AS RELATED TO FRONT TIRE FAILURE	3-1
3.1 RELEVANT DATA.	3-5
3.2 FLAT TIRE ON A STRAIGHTAWAY.	3-8
3.3 OVERRUNNING AN OBSTRUCTION	3-10
3.4 BLOWOUT ON A CURVE	3-11
3.5 RECAPITULATION OF SIMPLIFIED ANALYSES.	3-12
4.0 CANDIDATE DEVICES TO REDUCE THE EFFECTS OF FRONT TIRE FAILURE.	4-1
4.1 SPRING-TYPE SAFETY DEVICES	4-2
4.1.1 Two Parallel Noncollinear Spring - Steer Safe.	4-2
4.1.2 Four-Spring System Shure-Guide, Steering Stabilizer	4-2
4.1.3 Collinear Two-Spring System - Positrol.	4-5

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
4.2 AXLE CONCEPTS - CENTERLINE AND CENTERPOINT STEERING	4-6
4.3 SAFETY ROLLER.	4-9
4.4 HYDRAULIC SAFETY DEVICES	4-10
4.4.1 HECO System	4-11
4.4.2 Steerline	4-11
4.4.3 Cure Ride	4-12
4.5 POWER STEERING	4-13
4.5.1 Hydraulic Power Steering.	4-13
4.5.2 Air-Power Assist - Air-O-Matic.	4-14
4.6 CANTILEVER TIRE.	4-15
4.7 DEVICES SELECTED FOR TESTING	4-15
5.0 TEST METHODOLOGY.	5-1
5.1 TEST VEHICLE	5-1
5.2 TEST CONDITIONS.	5-3
5.3 TIRE FAILURE METHOD.	5-4
5.4 TEST MATRIX.	5-11
5.4.1 Phase 1 - Baseline Testing.	5-11
5.4.2 Phase 2 - Alignment Sensitivity Testing	5-12
5.4.3 Phase 3 - Device and Concept Evaluation.	5-12
5.5 INSTRUMENTATION.	5-12
5.6 PHOTOGRAPHY.	5-14
5.7 FACILITIES	5-18
5.8 TEST PROCEDURE	5-20

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
6.0 SUMMARY OF TESTING.	6-1
6.1 BASELINE TESTING	6-2
6.1.1 Device Evaluation Basis (Tests 19, 22, and 48)	6-2
6.1.2 Empty and Slow Deflation Baseline Tests (Tests 20 and 21)	6-13
6.1.3 Preliminary Baselines (Tests 1 through 5).	6-19
6.1.4 Tire Construction Tests	6-19
6.2 ALIGNMENT TESTS (TESTS 10 THROUGH 15).	6-26
6.3 DEVICE TESTS	6-37
6.3.1 Spring-Type Devices	6-37
6.3.2 Axle Concepts	6-59
6.3.3 Safety Roller (Tests 45 and 49)	6-84
6.3.4 Hydraulic Devices	6-85
6.3.5 Power-Assisted Steering	6-105
6.3.6 Cantilever Tire (Tests 42 and 43)	6-116
7.0 TEST EVALUATION AND SUMMARY	7-1
7.1 BASELINE TESTS	7-2
7.2 ALIGNMENT TESTING.	7-10
7.3 DEVICE EVALUATION.	7-11
8.0 COST-EFFECTIVENESS ANALYSIS	8-1
8.1 COST ANALYSIS.	8-4
8.1.1 Safety Roller	8-6
8.1.2 Centerline and Centerpoint Axles.	8-9
8.1.3 Cantilever Tire	8-10

TABLE OF CONTENTS (CONTD)

	<u>Page</u>
8.1.4 Power-Assisted Steering (Air-O-Matic)	8-10
8.1.5 Spring Devices.	8-11
8.1.6 Hydraulic Devices	8-11
8.2 COST/BENEFIT AND COST-EFFECTIVENESS ANALYSES	8-11
8.2.1 Determination of Expected Accident Costs	8-13
8.2.2 Determination of Accident Probability From Test Data.	8-14
8.2.3 Measures of Internal Behavior	8-17
9.0 CONCLUSIONS	9-1
10.0 RECOMMENDATIONS	10-1
11.0 REFERENCES AND BIBLIOGRAPHY	11-1
11.1 REFERENCES	11-1
11.2 BIBLIOGRAPHY	11-2

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
3-1	Ackermann Steering	3-2
3-2	Configuration of Right-Hand Kingpin.	3-2
3-3	Tire Axis System	3-6
3-4	Rolling Resistance	3-7
3-5	Vehicle Forces in a Left Turn.	3-11
4-1	Steer Safe System.	4-3
4-2	Shure-Guide System	4-3
4-3	Steering Stabilizer.	4-4
4-4	Positrol Spring System	4-5
4-5	Centerline Steering.	4-6
4-6	Centerpoint Steering	4-8
4-7	Safety Roller.	4-9
4-8	HECO System.	4-11
4-9	Steerline System	4-12
4-10	Airshox System	4-12
4-11	Linkage-type Power Steering.	4-13
4-12	Typical Tie Rod Mount.	4-14
5-1	Test Vehicle Front View.	5-2
5-2	Tire Deflation Device.	5-5
5-3	Tire Deflation Device, Solenoid Firing Cable, and Recoil Spring	5-6
5-4	Tire Deflation Control Switch Panel.	5-7
5-5	Typical Post-test Point of Entry Holes for Deflation Projectiles.	5-8
5-6	Typical Post-test Exit Holes for Deflation Projectiles.	5-9

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
5-7	Bullet Trap to Catch Projectile After Passing Through Tire	5-10
5-8	Instrument Locations	5-15
5-9	View of String Pot Used to Measure Tractor to Trailer Angle	5-15
5-10	View of Tie Rod Strain Gauges Used to Measure Tie Rod Loads.	5-16
5-11	View of Devices Used to Measure Steering Wheel Angle and Torque	5-16
5-12	Rate Gyro and Signal Conditioning Electronics.	5-17
5-13	Fifth Wheel.	5-17
5-14	Signal Conditioner, Battery Pack, and Telemetry Equipment.	5-18
5-15	Dynamic Science Test Facility.	5-19
5-16	Skid Pad Test Area	5-20
6-1	Test No. 19 - Baseline	6-4
6-2	Test No. 22 - Baseline	6-5
6-3	Test No. 48 - Baseline	6-6
6-4	Test No. 19 Post-test View	6-7
6-5	Test No. 22 Post-test View	6-8
6-6	Test No. 48 Post-test View	6-9
6-7	Test No. 20 - Empty Baseline	6-15
6-8	Test No. 21 - Slow Deflation Baseline.	6-16
6-9	Test No. 5 - Preliminary Baseline.	6-25
6-10	Test No. 6 - Retread Tire Test	6-27
6-11	Test No. 8 - Retread Tire Test	6-28
6-12	Test No. 6 Post-test View of Retread Tire. . .	6-31

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
6-13	Test No. 7 - Radial Tire Test.	6-32
6-14	Test No. 9 - Radial Tire Test.	6-33
6-15	Test No. 7 Post-test View of Radial Tire Test	6-36
6-16	Test No. 10 - Positive 2 Caster Alignment Test	6-38
6-17	Test No. 11 - Positive 2 Caster Alignment Test	6-39
6-18	Test No. 12 - One Inch Tow-in and Positive 2 Caster Alignment Test	6-40
6-19	Test No. 13 - One Inch Tow-in and Positive 2 Caster Alignment Test	6-41
6-20	Test No. 14 - One Inch Tow-in Alignment Test	6-42
6-21	Test No. 15 - One Inch Tow-in Alignment Test	6-43
6-22	Steer Safe Device as Seen Mounted on Front Axle	6-50
6-23	Test No. 33 - Steer Safe	6-51
6-24	Test No. 34 - Steer Safe	6-52
6-25	Test No. 29 - Steer Safe	6-53
6-26	Test No. 30 - Steer Safe	6-54
6-27	Shure-Guide System as Seen Mounted on Truck. .	6-60
6-28	Test No. 39 - Shure-Guide.	6-61
6-29	Test No. 40 - Shure-Guide.	6-62
6-30	Test No. 41 - Shure-Guide.	6-63
6-31	Steering Stabilizer Mounted on Lower Portion of Truck	6-67
6-32	Test No. 31 - Steering Stabilizer Test	6-68

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
6-33	Test No. 32 - Steering Stabilizer Test	6-69
6-34	Centerline Axle.	6-73
6-35	Test No. 36 Post-test.	6-74
6-36	Test No. 35 - Centerline	6-75
6-37	Test No. 36 - Centerline	6-76
6-38	Centerpoint Axle as Seen Mounted on Truck Before Test.	6-79
6-39	Test No. 37 - Centerpoint.	6-80
6-40	Test No. 38 - Centerpoint.	6-81
6-41	Safety Roller.	6-84
6-42	Test No. 45 - Safety Roller.	6-86
6-43	Test No. 49 - Safety Roller.	6-87
6-44	Pre-test View of HECO Device as Seen From Center of Tie Rod.	6-90
6-45	Test No. 25 - HECO	6-91
6-46	Test No. 26 - HECO	6-92
6-47	Test No. 16 - Preliminary HECO Test.	6-95
6-48	Test No. 17 - Preliminary HECO Test.	6-96
6-49	Test No. 18 - Preliminary HECO Test.	6-97
6-50	Test No. 46 - Steer Line	6-101
6-51	Test No. 47 - Steer Line	6-102
6-52	Cure Ride Device Mounted on Truck as Seen From Underside	6-106
6-53	Test No. 23 - Cure Ride.	6-107
6-54	Test No. 24 - Cure Ride.	6-108
6-55	Positrol Device as Seen Mounted on Truck Axle	6-111

LIST OF ILLUSTRATIONS (CONTD)

<u>Figure</u>		<u>Page</u>
6-56	Test No. 27 - Positrol	6-112
6-57	Test No. 28 - Positrol	6-113
6-58	Air-O-Matic Air Sensing Valve.	6-117
6-59	Air-O-Matic Power Cylinder Installed on Test Truck	6-118
6-60	Test No. 52 - Power Steering	6-119
6-61	Test No. 53 - Power Steering	6-120
6-62	Test No. 42 Post-test View of Cantilever Tire	6-123
6-63	Test No. 42 - Firestone Cantilever	6-124
6-64	Test No. 43 - Firestone Cantilever	6-125
7-1	Correlation Between Peak and Average Steering Wheel Torque.	7-13
7-2	Correlation Between Peak and Average Tie Rod Force.	7-13
7-3	Relationship of Tie Rod Force and Steering Wheel Torque.	7-15
7-4	Relationship of Displacement and Steering Wheel Torque	7-16
7-5	Relationship of Displacement and Tie Rod Force.	7-17
8-1	Factors Affecting Probability of Leaving the Lane	8-16
8-2	Functional Relationships for Control of Front Tire Failure Effects	8-18

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2-I	Trucking Industry Use Statistics	2-2
2-II	Truck Usage.	2-3
2-III	Bureau of Motor Carrier Safety Selected Accident Statistics of Large Interstate Motor Carriers of Property for Years 1960-1972.	2-5
2-IV	Summary of Truck Front Tire Failure Accidents Reported to BMCS	2-6
2-Va	HSRI Tire Failure Accident Data Summary. . . .	2-8
2-Vb	HSRI BMCS Tire Failure Accident Summary. . . .	2-9
2-Vc	HSRI Ohio Turnpike Tire Failure Accident Summary, January 1, 1966 to June 30, 1970. . .	2-10
2-Vd	HSRI Indiana Turnpike Tire Failure Accident Summary, January 1, 1966 to December 31, 1970.	2-10
2-Ve	HSRI Pennsylvania Turnpike Tire Failure Accident Summary	2-11
2-Vf	HSRI State of Texas Tire Failure Accident Summary.	2-11
2-VI	Associated Truck Line, Inc. Mileage and Accident Data Summary.	2-12
2-VII	Associated Truck Lines, Inc. Summary of Tire Failure Accidents	2-13
2-VIII	Summary of Associated Truck Lines, Inc. Study of Cause of Tire Failure	2-14
3-I	Increase in Total System Efficiency Associated with an Increase in Individual Component Efficiency.	3-5
3-II	Load Limits of Single Tires.	3-6
3-III	Lateral Force (Pounds) as a Function of Slip Angle	3-7
3-IV	Self-Aligning Torque (lb-ft) as a Function of Slip Angle	3-8

LIST OF TABLES (CONTD)

<u>Table</u>		<u>Page</u>
4-I	Safety Device Summary.	4-1
5-I	Truck Inventory Summary.	5-1
5-II	Safety Device Summary.	5-13
5-III	Instrumentation List	5-14
6-I	Test No. 19 Data Summary	6-10
6-II	Test No. 22 Data Summary	6-11
6-III	Test No. 48 Data Summary	6-12
6-IV	Average Baseline Test (Basic for Device Tests 19, 22, and 48).	6-14
6-V	Test No. 20 Data Summary	6-17
6-VI	Test No. 21 Data Summary	6-18
6-VII	Test No. 1 Data Summary.	6-20
6-VIII	Test No. 2 Data Summary.	6-21
6-IX	Test No. 3 Data Summary.	6-22
6-X	Test No. 4 Data Summary.	6-23
6-XI	Test No. 5 Data Summary.	6-24
6-XII	Test No. 6 Data Summary.	6-29
6-XIII	Test No. 8 Data Summary.	6-30
6-XIV	Test No. 7 Data Summary.	6-34
6-XV	Test No. 9 Data Summary.	6-35
6-XVI	Test No. 10 Data Summary	6-44
6-XVII	Test No. 11 Data Summary	6-45
6-XVIII	Test No. 12 Data Summary	6-46
6-XIX	Test No. 13 Data Summary	6-47
6-XX	Test No. 14 Data Summary	6-48

LIST OF TABLES (CONTD)

<u>Table</u>		<u>Page</u>
6-XXI	Test No. 15 Data Summary	6-49
6-XXII	Test No. 33 Data Summary	6-55
6-XXIII	Test No. 34 Data Summary	6-56
6-XXIV	Test No. 29 Data Summary	6-57
6-XXV	Test No. 30 Data Summary	6-58
6-XXVI	Test No. 39 Data Summary	6-64
6-XXVII	Test No. 40 Data Summary	6-65
6-XXVIII	Test No. 41 Data Summary	6-66
6-XXIX	Test No. 31 Data Summary	6-70
6-XXX	Test No. 32 Data Summary	6-71
6-XXXI	Test No. 35 Data Summary	6-77
6-XXXII	Test No. 36 Data Summary	6-78
6-XXXIII	Test No. 37 Data Summary	6-82
6-XXXIV	Test No. 38 Data Summary	6-83
6-XXXV	Test No. 45 Data Summary	6-88
6-XXXVI	Test No. 49 Data Summary	6-89
6-XXXVII	Test No. 25 Data Summary	6-93
6-XXXVIII	Test No. 26 Data Summary	6-94
6-XXXIX	Test No. 16 Data Summary	6-98
6-XL	Test No. 17 Data Summary	6-99
6-XLI	Test No. 18 Data Summary	6-100
6-XLII	Test No. 46 Data Summary	6-103
6-XLIII	Test No. 47 Data Summary	6-104
6-XLIV	Test No. 23 Data Summary	6-109

LIST OF TABLES (CONTD)

<u>Table</u>		<u>Page</u>
6-XLV	Test No. 24 Data Summary	6-110
6-XLVI	Test No. 27 Data Summary	6-114
6-XLVII	Test No. 28 Data Summary	6-115
6-XLVIII	Test No. 52 Data Summary	6-121
6-XLIX	Test No. 53 Data Summary	6-122
6-L	Test No. 42 Data Summary	6-126
6-LI	Test No. 43 Data Summary	6-127
7-I	Data Summary Table	7-3
7-II	Parameters for Assumed Normal Distribution of Baseline Data	7-9
7-III	Data Summary Table	7-12
7-IV	Rank Analysis.	7-20
8-I	Device Cost Summary.	8-3
8-II	Safety Device Investment Cost Components . . .	8-7
8-III	Annual Maintenance/Replacement Costs	8-8
8-IV	Safety Device Cost Summary	8-9

1.0 INTRODUCTION

The Federal Highway Administration of the U.S. Department of Transportation is concerned with the loss of life, injury, and property damage that result from front tire failure on heavy-duty trucks. As part of the effort to investigate the front tire failure problem, the Bureau of Motor Carrier Safety contracted with Ultrasystems, Inc., the Dynamic Science Division (Contract No. DOT-FH-11-8562), to conduct an investigation of front tire failure on heavy trucks. This effort included an investigation of the magnitude of the front tire problem, baseline tire failure tests, and tests with devices commercially available which are designed to minimize the front tire failure problem. Instrumentation on the truck was designed to aid in the definition of the magnitude of the problem as well as providing the basis for a relative ranking of the various devices and concepts which were tested.

Baseline testing finalized the testing procedure and provided a comparative evaluation of variations in tire loading, tire construction, and misalignments.

The device evaluation phase involved testing of twelve devices and concepts.

A ranking of the devices tested and a cost-effective analysis summarize the findings of the program.

1.1 PROGRAM OBJECTIVES

As specified in the Statement of Work, the objective of the program is to investigate the magnitude of the front tire failure problem and to evaluate the relative merits of a representative sample of front tire failure attenuator devices and concepts on vehicles that are representative of the majority in interstate movement. This evaluation will include consideration of the following:

- Effects of vehicle loading and weight distribution
- Power steering
- Safety stabilizer or equivalent devices
- Front-end alignment changes (i.e., increased caster, kingpin inclination changes)
- Tire type and quality
- Tube-type versus tubeless tires
- "Safety" tire or wheels
- Wheels designed to retain failed tires at high speeds
- Radial versus bias-type construction
- Improved driver and/or carrier preventive maintenance.

During "high-speed" tire failure tests, the evaluation included driver evaluation, observer information, and objective recorded data (e.g., steering wheel torque, heading angle, vehicle velocity, lateral and longitudinal accelerations, yaw rates, steering wheel and front wheel angle).

Finally, the cost effectiveness of the various devices and concepts are to be investigated.

2.0 FRONT TIRE FAILURE ACCIDENT CAUSES AND STATISTICS

Causes of front tire failure must be understood in order to design a program to test and evaluate safety devices which may mitigate the effects of front tire failures. Statistically describing the frequency of such accidents in the context of total transportation activities and economics is necessary for performing cost-effectiveness and cost/benefit analyses of the safety devices. To provide such information, a survey of available literature was made, and an analysis of 180 front tire failure accident reports submitted to BMCS in 1973 was performed.

General information describing the number of trucks operating in the United States, annual vehicle-miles driven, and accident rates is given below. Specific information describing accidents involving front tire failures is provided, and the results of several studies describing tire failure accidents in greater detail are discussed. The analysis of 1973 BMCS Tire Accident Reports provides some information regarding the causes and attendant conditions of truck tire failure accidents. A brief telephone survey was conducted, inquiring of members of the trucking industry as to what they believed to be the major causes of tire failure; the results are briefly discussed. Factors that will be used in analysis of tire failure accidents and test results are summarized at the end of this section.

2.1 GENERAL TRUCKING INDUSTRY STATISTICS

In 1972, there were approximately 21 million trucks registered in the United States, of which 990,000 were combination vehicles. The large trucks each traveled an average of 47,000 miles during the year for a total of over 46 billion vehicle-miles. These data were taken from Table 2-I (reproduced from MVMA, 1974 - see Section 11.0, References). The distribution of annual mileage is given in Table 2-II (reproduced from the same source). Note that the median annual mileage from Table 2-II lies between 20,000 and 30,000 miles.

TABLE 2-I. TRUCKING INDUSTRY USE STATISTICS											
Vehicle-Miles of Travel (Million Vehicle-Miles)											
Year	Passenger Vehicles						All Passenger Vehicles	Cargo Vehicles			All Motor Vehicles
	Personal Passenger Vehicles			Buses				Single- Unit Trucks	Combina- tions	All Trucks	
	Passenger Cars	Motor- cycles	All Personal Passenger Vehicles	Commer- cial	School	All Buses					
1972	986,407	17,091	1,003,498	2,750	2,359	5,109	1,008,607	213,122	46,613	259,735	1,268,342
1971	939,102	15,053	954,155	2,885	2,212	5,097	959,252	184,396	42,641	227,037	1,186,289
1970	890,844	10,148	900,992	2,943	2,100	5,043	906,035	174,443	40,227	214,670	1,120,705
1969	849,663	9,225	858,858	3,007	2,030	5,037	863,895	167,241	39,439	206,680	1,070,575
1968	805,693	8,337	814,030	3,031	1,937	4,968	818,998	158,938	37,713	196,651	1,015,649
1967	766,466	7,737	774,203	3,024	1,870	4,894	779,097	147,450	35,006	182,456	961,553
1966	744,844	6,896	751,740	3,008	1,844	4,852	756,592	140,893	33,012	173,905	930,479
1965	706,386	5,208	711,594	3,019	1,763	4,782	716,376	140,117	31,319	171,436	887,812
1960	588,083	(1)	588,083	2,872	1,481	4,353	592,436	N/A	N/A	126,409	718,845
1955	492,635	(1)	492,635	2,922	1,272	4,194	496,829	N/A	N/A	108,817	605,646
1950	363,613	(1)	363,613	3,271	810	4,081	367,694	N/A	N/A	90,552	458,246
Motor Vehicle Travel in the United States (1972)											
Motor Vehicle Travel (Million Vehicle-miles)	Passenger Vehicles						All Passenger Vehicles	Cargo Vehicles			All Motor Vehicles
	Personal Passenger Vehicles			Buses				Single- Unit Trucks	Combina- tions	All Trucks	
	Passenger Cars (2)	Motor- cycles (2)	All Personal Passenger Vehicles	Commer- cial	School	All Buses					
Main Rural Roads			330,605	913	880	1,793	332,398	84,674	31,958	116,632	449,030
Local Rural Roads			105,352	190	1,004	1,194	106,546	33,481	1,170	34,651	141,197
All Rural Roads			435,957	1,103	1,884	2,987	438,944	118,155	33,128	151,283	590,227
Urban Streets			567,541	1,647	475	2,122	569,663	94,967	13,485	108,452	678,115
Total Travel	986,407	17,091	1,003,498	2,750	2,359	5,109	1,008,607	213,122	46,613	259,735	1,268,342
Vehicles Registered (Thousands)	96,860	3,798	100,658	88.8	318.2	407	101,065	20,249	990	21,239	122,304
Average Miles Traveled per Vehicle	10,184	4,500	9,969	30,968	7,414	12,553	9,980	10,525	47,084	12,229	10,370
Fuel Consumed (Million Gallons)	73,121	342	73,463	561	320	881	74,334	22,118	8,600	30,718	105,062
Average Fuel Con- sumption per Vehicle (Gallons)	755	90	730	6,318	1,006	2,165	736	1,092	8,687	1,446	859
Average Miles Traveled per Gallon	13.49	50.00	13.67	4.39	7.37	5.80	13.57	9.63	5.42	8.46	12.07
(1) Included with passenger cars. (2) Separate estimates of passenger car and motorcycle travel are not available by highway category.											
Traveled way of mileage which is adequate for present traffic but will need further construction and improvement to bring it to full interstate standards. In some instances, these are divided highways with full control of access and in others they are two-, three-, or four-lane undivided highways with no access control.											

2.2 TRUCK ACCIDENT STATISTICS

Table 2-III summarizes accidents reported to BMCS by Class I and Class II carriers for the years 1960-1972. As can be seen from the table, approximately 3,000 carriers experienced approximately 37,000 intercity accidents (2.3 accidents per million vehicle-miles), resulting in approximately 16,000 injuries, 1,300 fatalities (0.08 fatalities per million vehicle-miles), and causing over \$84,000,000 in property damage, an average of \$2,295 per accident.

TABLE 2-II. TRUCK USAGE

Characteristics of Trucks Owned						
Characteristic	Total Trucks		Truck Size Class			
	Number (Thousands)	Percent	10,000 Or Less Lb GVW (Percent)	10,001- 20,000 Lb GVW (Percent)	20,001- 26,000 Lb GVW (Percent)	26,001- Or More Lb GVW (Percent)
Major Use						
Agriculture	4,258	21.6	20.1	32.1	33.2	10.3
Forestry and Lumbering	187	1.0	.5	1.4	2.8	3.6
Mining	77	.4	.2	.6	.7	1.9
Construction	1,693	8.6	6.9	10.2	14.0	19.1
Manufacturing	443	2.3	1.3	3.3	4.4	8.5
Wholesale and Retail Trade	1,875	9.5	6.1	18.9	23.0	18.3
For Hire	770	3.9	.6	6.0	7.2	30.6
Personal Transportation	8,122	41.2	53.4	11.0	2.1	1.0
Utilities	505	2.6	2.5	3.1	3.8	1.9
Services	1,490	7.6	7.7	10.5	6.0	2.5
All Other	327	1.7	1.2	3.5	3.4	2.8
Body Type						
Pickup, Panel, Multi-Stop, or Walk-in	14,464	73.3	92.6	31.3	4.4	2.1
Platform	1,645	8.4	2.2	27.4	28.9	21.0
Platform With Added Device	336	1.8	.4	5.6	7.0	4.4
Cattlerack	479	2.5	1.4	6.7	6.7	2.4
Insulated Nonrefrigerated Van	96	.5	.1	1.2	1.2	3.1
Insulated Refrigerated Van	178	1.0	.1	2.4	2.3	5.3
Furniture Van	192	1.0	.2	3.7	2.8	3.2
Open-Top Van	58	.3	.1	.6	.4	1.9
All Other Vans	610	3.1	.7	6.3	7.2	18.6
Beverage Truck	87	.5	.1	1.4	3.0	1.6
Utility Truck	370	1.9	1.7	3.4	2.0	.9
Garbage and Refuse Collector	69	.4	.1	1.3	1.4	1.2
Winch or Crane	83	.5	.1	.8	3.5	1.8
Wrecker	115	.6	.3	2.3	.6	.2
Pole and Logging	53	.3	.1	.3	1.4	2.4
Auto Transport	30	.2	.1	.2	.1	1.4
Dump Truck	468	2.4	.3	3.1	17.3	14.0
Tank Truck for Liquids	287	1.5	.1	2.3	9.7	9.1
Tank Truck for Dry Bulk	29	.2	- *	.1	.6	1.5
Concrete Mixer	66	.4	.1	.2	.1	4.1
All Other	33	.2	.1	.6	.5	.6

TABLE 2-II. TRUCK USAGE (CONTD)

Characteristics of Trucks Owned

Characteristic	Total Trucks		Truck Size Class			
			10,000 Or Less Lb GVW (Percent)	10,001- 20,000 Lb GVW (Percent)	20,001- 26,000 Lb GVW (Percent)	26,001- Or More Lb GVW (Percent)
	Number (Thousands)	Percent				
Annual Miles						
Less Than 5,000 Miles	4,621	23.5	22.0	33.2	35.8	12.7
5,000 to 9,999 Miles	5,540	28.1	30.2	25.6	25.2	13.8
10,000 to 19,999 Miles	6,598	33.5	36.2	27.8	24.0	22.4
20,000 to 29,999 Miles	1,647	8.4	8.1	8.1	8.3	11.5
30,000 to 49,999 Miles	772	4.0	2.9	4.1	4.9	13.4
50,000 to 74,999 Miles	270	1.4	.5	.9	1.5	11.5
75,000 Miles or More	300	1.6	.4	.6	.6	15.1
Acquisition						
Purchased New	9,954	50.5	48.6	52.8	51.6	63.4
Purchased Used	9,430	47.8	50.0	44.7	46.6	33.0
Leased and Not Reported	364	1.9	1.6	2.6	2.0	3.8
Year Model						
1971 and 1972	2,915	14.8	15.3	12.7	10.0	16.4
1969 and 1970	3,722	18.9	19.4	16.3	14.5	21.9
1967 and 1968	2,989	15.2	15.3	14.2	13.3	17.3
1965 and 1966	2,792	14.2	14.4	12.4	14.5	15.1
1963 and 1964	1,986	10.1	10.2	9.1	11.7	10.0
Pre-1963	5,343	27.1	25.7	35.6	36.3	19.6
Cab Type						
Tilt Cab	587	3.0	.1	3.5	8.4	27.2
Not Tilt Cab	17,459	88.5	90.0	90.3	88.2	69.9
Not Reported	1,700	8.7	10.0	6.3	3.5	3.0
Total Percent		100.0	100.0	100.0	100.0	100.0
Total Trucks (000)	19,745		14,598	2,822	828	1,500

* - = Less than .05 percent

Source: U.S. Bureau of the Census, Census of Transportation, 1972 Truck Inventory and Use Survey

TABLE 2-III. BUREAU OF MOTOR CARRIER SAFETY SELECTED ACCIDENT STATISTICS OF LARGE INTERSTATE MOTOR CARRIERS⁽¹⁾ OF PROPERTY FOR YEARS 1960-1972

Calendar Year	Carriers ⁽²⁾ Reporting	Total ⁽³⁾ Intercity Vehicle-Miles (000's omitted)	Total ⁽⁴⁾ Intercity Accidents	Accident ⁽⁵⁾ Rate	Injuries	Fatalities	Fatality ⁽⁵⁾ Rate	Property Damage (000's omitted)
1960	3,006	9,086,862	22,616	2.49	14,336	1,353	0.15	42,643
1961	3,096	8,838,678	19,922	2.25	13,024	1,130	0.13	38,289
1962	3,171	9,544,860	22,566	2.36	15,296	1,437	0.15	44,402
1963	3,214	9,883,710	28,628	2.90	18,517	1,451	0.15	52,513
1964	3,343	9,535,579	30,267	3.17	19,297	1,492	0.16	55,218
1965	3,309	10,862,252	24,794	2.28	15,158	1,471	0.14	52,058
1966	2,975	10,956,258	26,606	2.42	15,478	1,361	0.12	52,853
1967	2,811	10,704,605	25,981	2.43	14,882	1,291	0.12	55,990
1968	2,734	11,704,240	29,209	2.50	16,124	1,421	0.12	66,872
1969	2,753	12,460,796	30,672	2.46	16,232	1,361	0.11	72,191
1970	2,995	12,389,873	33,203	2.68	15,793	1,375	0.11	76,242
1971	2,928	13,951,297	30,581	2.19	13,988	1,163	0.08	72,607
1972	3,050	15,883,104	36,682	2.31	15,822	1,294	0.08	84,183

(1) Prior to 1968, large motor carriers of property included interstate motor carriers of property having annual operating revenues of \$200,000 or more. From 1968 to the present, data relates to interstate motor carriers of property having annual operating revenue of \$300,000 or more. Source of data are reports of accidents filed by these carriers which also report vehicle-miles to the Interstate Commerce Commission.

(2) The carriers reporting in any given year represent approximately 20 percent of the total ICC authorized carriers and account for some 95 percent of the total mileage for all authorized carriers.

(3) ICC Quarterly Reports of Revenues, Expenses, and Statistics for Class I and II Motor Carriers of Property.

(4) Accidents involving vehicles in motion.

(5) Per million vehicle-miles.

Other costs of accidents include loss of wages, medical expenses, and insurance administrative costs. The National Safety Council (1974 - see Section 11.0) estimates that these expenses for all motor vehicle accidents in 1973 totaled \$13.9 billion in 1,348,100 fatal/injury accidents, an average of \$10,300 per serious accident. From the employer's point of view, he must ultimately pay for at least medical expenses (\$1.7 billion) and insurance administrative costs (\$5.6 billion) which together average \$5,415 per accident.

The data in Table 2-III show that in 1972, the average property damage per motor carrier accident was \$2,295. Other data indicate that front tire failure accidents result in greater than average property damage. Table 2-IV summarizes front tire failure accidents from BMCS reports. While all mechanical defect accidents average \$3,370 property damage, front tire failure accidents average \$7,008 property damage.

TABLE 2-IV. SUMMARY OF TRUCK FRONT TIRE FAILURE ACCIDENTS REPORTED TO BMCS								
Year	Total Mechanical Defects Accidents	Fatalities	Injuries	Property Damage	Front Tire Failure Accidents	Fatalities	Injuries	Property Damage
1973					180	6	145	\$ 1,983,000
1972	1,901	56	709	\$ 6,969,000	361	29	195	\$ 2,467,900
1971	2,082	33	753	\$ 8,032,931	317	10	155	\$ 2,173,847
1970	2,287	48	862	\$ 7,604,739	264	8	136	\$ 1,808,773
1969	2,640	63	1,059	\$ 8,053,364	264	11	150	\$ 1,780,211
1968	2,209	44	1,007	\$ 6,809,450	247	6	123	\$ 1,231,256
Total (excluding 1973)	11,119	244	4,390	\$37,469,484	1,633	70	904	\$11,444,987
Average Property Damage per Accident				\$ 3,370				\$ 7,008
Note: Data for 1973 include all front tire failure accidents reported to BMCS.								

From these data then, front tire failure accidents will be assumed to cost the truck operator \$5,400 in medical and insurance administrative costs and \$7,000 in property damage for a total average per accident cost of \$12,400. The societal cost of front tire failure accidents, including loss of wages, will be taken as \$17,300.

The data in Tables 2-III and 2-IV also help to place tire failure accidents in context with regard to other trucking accidents. For example, during the period 1968-1972, BMCS reported 160,400 trucking accidents (Class I and II carriers equaling 95 percent of intercity traffic), resulting in a total property damage of \$3.72 million (\$2,319 average). During the same period, 11,119 mechanical defect accidents were reported with \$37.5 million in property damage (\$3,370 average); 1,633 front tire failure accidents were reported with \$9.9 million property damage (\$6,834 average). During this five-year period the following comparisons can be made:

	<u>Number</u>	<u>Vehicle-Miles (Million)</u>	<u>Accident Rate per Million Vehicle-Miles</u>
All Truck Accidents	160,400		2.42
Mechanical Defect Accidents	11,119	66,389	0.17
Front Tire Failure Accidents	1,633		0.02

2.3 CHARACTERISTICS OF TRUCK TIRE FAILURE ACCIDENTS

The Highway Safety Research Institute of the University of Michigan recently published a report of an analysis of tire failure accidents (1974). Data from this report are reproduced in Tables 2-Va through 2-Vf. These data verify data previously discussed. Note, however, that incidents of tire failure accidents reported in the three turnpike studies are greater than that reported in the studies previously discussed. No explanation for this is offered in the report.

TABLE 2-Va. HSRI TIRE FAILURE ACCIDENT DATA SUMMARY

Data Source	Total Accidents of All Types	Total Truck Accidents (Percent)*	Total (Percent)	Truck Accidents Involving Tire Failure							
				Fatalities** (Rate)	Injuries** (Rate)	Type Vehicle			Number of Vehicles		
						Straight Truck** (Percent)	Tractor-Semi** (Percent)	Other (Percent)	1** (Percent)	2** (Percent)	>2** (Percent)
BMCS 1968-71	-	195,801	1,598 (0.82%)*	56 (0.035)	705 (0.44)	-	-	-	85	-	-
Associated Truck Line 1970-73	-	1,853	14 (0.75%)*	0 (0.00)	-	-	-	-	-	-	-
Grow Chemical Corporation 1963-73	-	79	0 (0.0%)*	0 (0.00)	0 (0.00)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Ohio Turnpike 1966-70	8,663	2,093 (24.2%)	87 (4.16%)*	1 (0.011)	36 (0.41)	5 (6%)	78 (89%)	4 (5%)	86 (99%)	1 (1%)	0 (0%)
Indiana Turnpike 1966-70	5,744	1,422 (24.8%)	60 (4.21%)*	1 (0.017)	12 (0.20)	7 (11%)	52 (86%)	2 (3%)	59 (93%)	1 (2%)	0 (0%)
Pennsylvania Turnpike 1969-72	11,492	1,914 (16.7%)	90 (4.70%)*	1 (0.011)	35 (0.39)	19 (21%)	68 (76%)	3 (3%)	84 (93%)	5 (6%)	1 (1%)
State of Texas 1969-72	1,567,000	41,277 (27.4%)	354 (0.86%)*	12 (0.037)	144 (0.41)	212 (60%)	127 (36%)	15 (4%)	319 (90%)	35 (10%)	0 (0%)

*Based on total accidents.

**Based on total truck accidents involving tire failure.

***Based on total truck accidents.

TABLE 2-Vb. HSRI BMCS TIRE FAILURE ACCIDENT SUMMARY

Bureau of Motor Carrier Safety Accident Data Summary

Year	Total Accidents ¹			Vehicle Defect Accidents ²		
	Number	Fatalities ₃ (Percent)	Injuries ₃ (Percent)	Number (Percent) ₃	Fatalities ₄ (Percent)	Injuries ₄ (Percent)
1968	43,116	1,588 (3.7)	15,012 (35)	2,209 (5.1)	44 (2.0)	1,007 (46)
1969	47,630	1,631 (3.4)	15,844 (33)	2,640 (5.3)	63 (2.4)	1,059 (40)
1970	50,000 ⁵	1,600 ⁵ (3.2)	15,500 ⁵ (31)	2,287 (4.6)	48 (2.1)	862 (38)
1971	55,055	1,592 (2.9)	16,200 (29)	2,082 (3.8)	33 (1.58)	753 (36)
1972	61,918	1,748 (2.8)	17,345 (28)	2,310 ¹ (3.7)	57 ¹ (2.5)	831 ¹ (36)
Totals ⁶	195,801	6,411 (3.3)	62,556 (32)	9,218 (4.7)	188 (2.0)	3,481 (38)

Tire Failure Accidents Only²

Year	Front	Other	Total (Percent) ³	Fatalities			Injuries			Fire			Single Vehicle 7 (Percent) ⁷
				Front	Other	Total (Percent) ⁷	Front	Other	Total (Percent) ⁷	Front	Other	Total (Percent) ⁷	
1968	247	147	394 (0.91)	6	4	10 (2.5)	123	41	164 (42)	-	-	95 (24)	-
1969	264	146	410 (0.86)	11	9	20 (4.9)	150	45	195 (48)	-	-	94 (23)	335 (82)
1970	264	118	382 (0.76)	8	5	13 (3.4)	136	37	173 (45)	-	-	60 (15.7)	319 (84)
1971	317	95	412 (0.75)	10	3	13 (3.2)	155	18	173 (42)	19	43	62 (15.0)	365 (89)
1972	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals ⁶	1,092	506	1,598 (0.82)	35	21	56 (3.5)	564	141	705 (44)			311 (19.5)	

- (1) Data from BMCS Accident Data Tapes at HSRI.
- (2) Data from BMCS Mechanical Defect Report Series (6).
- (3) Based on total accidents.
- (4) Based on total mechanical defect accidents.
- (5) Estimate - This tape has been damaged.
- (6) 1968, 1969, 1970, 1971 only.
- (7) Based on total tire failure accidents.

TABLE 2-Vc. HSRI OHIO TURNPIKE TIRE FAILURE ACCIDENT SUMMARY, JANUARY 1, 1966 TO JUNE 30, 1970

Year	Truck Accidents Involving Tire Failure		Fatalities	Injuries	Blowouts		Tire Fires	Type Vehicle		
	Confirmed	Questionable			Right Front	Left Front		Straight Truck	Tractor- Semi	Tractor- Semi and Trailer
1966	33	0	1	9	14	6	13	3	29	1
1967	18	3	0	7	4	4	10	0	17	1
1968	11	1	0	6	4	4	3	1	9	1
1969	12	0	0	8	10	1	1	1	11	0
1970*	13	0	0	6	5	3	5	0	12	1
Totals	87	4	1	36	37	18	32	5	78	4

*First 6 months only.

TABLE 2-Vd. HSRI INDIANA TURNPIKE TIRE FAILURE ACCIDENT SUMMARY, JANUARY 1, 1966 TO DECEMBER 31, 1970

Year	Total Truck Accidents	Truck Accidents Involving Tire Failure		Fatalities	Injuries	Blowouts			Tire Fire	Type Vehicle		
		Confirmed	Questionable			Right Front	Left Front	Other		Straight Truck	Tractor- Semi	Tractor- Semi and Trailer
1966	193	19	0	1	1	8	3	0	8	1	17	1
1967	192	5	0	0	1	1	2	0	2	0	5	0
1968	249	14	0	0	4	6	4	2*	2	4	10	0
1969	251	15	0	1	4	8	4	2**	1	1	14	0
1970	255	7	1	0	2	2	3	1**	1	1	5	1
Totals	1,140	60	1	2	12	25	16	5	14	7	52	2

*These two blowouts each occurred on the right rear of a straight truck.

**These cases involved blowouts on trailers of semi-rigs which led to loss of control.

TABLE 2-Ve. HSRI PENNSYLVANIA TURNPIKE TIRE FAILURE ACCIDENT SUMMARY

Year	Total Accidents of All Types	Total Truck Accidents	Truck Accidents Involving Tire Failure	Fatalities	Injuries	Type Vehicle			Number of Vehicles		
						Straight Truck	Tractor- Semi	Other	1	2	3
1967	4,461	692	27	1	8	10	15	2	25	2	0
1968	4,992	826	36	0	16	4	31	1	34	1	1
1969*	2,039	396	27	0	11	5	22	0	25	2	0
Totals	11,492	1,914	90	1	35	19	68	3	84	5	1

*First 6 months only.

TABLE 2-Vf. HSRI STATE OF TEXAS TIRE FAILURE ACCIDENT SUMMARY

Year	Total Accidents of All Types*	Total Truck Accidents	Truck Accidents Involving Tire Failure								
			Total	Fatalities	Injuries	Type Vehicle		Other	Number of Vehicles		
						Straight Truck	Tractor- Semi		1	2	>2
1969	377,000	11,590	95	0	34	51	41	3	88	7	0
1970	388,000	10,680	86	5	43	45	36	5	78	8	0
1971	382,000	8,172	71	3	22	53	16	2	65	6	0
1972	420,000	10,835	102	4	44	63	34	5	88	14	0
Totals	1,567,000	41,277	354	12	144	212	127	15	319	35	0

*Estimate based on 5-percent sample.

This study also indicates (Table 2-Va) that most truck tire failure accidents occur on tractor-semi vehicles and that over 90 percent of these are one-vehicle accidents. This result is significant to the present study for two reasons: (1) it verifies the decision to confine the evaluation of safety devices to large vehicles which do account for the majority (55 percent from these data) of such accidents and (2) the models used for estimating cost effectiveness and cost benefits of safety devices can, as a first good approximation, reasonably assume a one-vehicle accident.

2.4 CAUSES OF FRONT TIRE FAILURE

Data on causes of front tire failure accidents are sparse. In the HSRI report just described, a study of tire failure accidents at Associated Truck Lines, Inc., a major motor carrier, was presented. The data are shown in Tables 2-VI and 2-VII.

TABLE 2-VI. ASSOCIATED TRUCK LINE, INC. MILEAGE AND ACCIDENT DATA SUMMARY									
Year	Mileage		Total Accidents				Accidents Caused by Tire Failure		
	Road Haul	Steel and Special Products	Road Haul	Steel and Special Products	City	Total	Number	Percent*	Accidents per 10 Vehicle-Miles
1970	21,341,992	6,196,494	102	66	263	431	4	0.93	1.45
1971	25,880,830	6,725,164	106	60	268	434	3** (0)	0.69 (0.00)	0.92 (0.00)
1972	26,356,391	8,040,900	136	63	253	452	5*** (4)	1.10 (0.88)	1.45 (1.16)
1973	29,506,892	9,954,212	122	112	302	536	2**** (0)	0.37 (0.00)	0.51 (0.00)
Totals	103,086,105	30,916,770	466	301	1,086	1,853	14 (8)	0.75 (0.43)	1.04 (0.60)
*Based on total accidents. **Two tires were made of a defective rubber compound and one blew out after hitting an abandoned wheel hub lying in the road. ***Tire failure may not have occurred in one of these accidents. ****One tire blew out after running over scrap metal on the road; the other lost a recap which hit another vehicle and broke the windshield. The second tire did not blow out.									

Table 2-VII presents details of 15 selected tire failure accidents. All but one occurred during intercity transportation; all were front tire failures. In many cases, the tread depth of the failed tire was not reported; in one case, a bald tire is indicated.

TABLE 2-VII. ASSOCIATED TRUCK LINES, INC. SUMMARY OF TIRE FAILURE ACCIDENTS

Date	Time	Weather	Light	Road	Speed (mph)	C = City I = Intercity	Tire	Tread Depth (in.)	Comment
3/3/70	3:17 p.m.	Clear	Daylight	No Def.	55	I	LF-1*	?	Hit guardrail
4/3/70	4:50 a.m.	Clear	?	No Def.	50	I	RF-1	20/32	Went into ditch
6/11/70 Private Owner- Operator	10:00 p.m.	Cloudy(?)	Dark	No Def.	?	I	RF-1,2	6/32	Tire about to be replaced
7/31/70	4:00 p.m.	Clear	Daylight	No Def.	55	I	RF-1	?	
8/13/70 Private Owner- Operator, Running empty	12:15 a.m.	Clear	Dark	Dry	50- 55**	I	RF-1,2	0/32	
1/20/71	5:15 a.m.	Cloudy	Dark	Blowing Snow	58	I	RF-1,5	?	Hit wheel hub lying in road
6/17/71	1:00 a.m.	Clear	Dark	Dry	60	I	RF-1,4,5,6	7/32	Tread separated from side- wall, 71,000 miles on tire
6/24/71	5:30 a.m.	Clear	Daylight	Dry	60	I	LF-1,4,8	6/32	RF blew out after accident
4/12/72	4:30 p.m.	Clear	Daylight	Dry, No Def.	55	I	RF-1	?	New tire on new tractor
4/14/72	3:30 p.m.		Daylight	Dry, No Def.	15	C	?	?	
5/16/72	12:05 p.m.	Clear	Daylight	Dry, No Def.	55	I	RF-1	13/32-19/32	35,000 miles on tire
6/28/72	3:30 a.m.	Clear	Dark	Dry	55	I	LF-1,2	14/32	Tire 3 months old
8/17/72	6:00 a.m.	Clear	Daylight	Dry, No Def.	50	I	LF-1,7(?)	?	May have been recap
6/4/73	11:15 p.m.	Cloudy	Dark	No Def.	60	I	RF-7	?	Recap hit windshield of other vehicle, no collision or blowout
9/10/73	2:00 p.m.	Clear	Daylight	Dry	55	I	RF-1,3,5	?	

*1 - Blowout - lost control; 2 - Clear evidence of blowout on pavement; 3 - Blowout claimed by driver, but uncertain; 4 - Experimental tire compound; 5 - Ran over metal or object; 6 - No cuts found in tire; 7 - Recap broke loose; 8 - Overloaded or underinflated.
 **Speed stated to be above legal limit.

Table 2-VIII summarizes other attendant conditions as reported by Associated. These data are representative of all data examined with regard to causes and conditions attendant to tire failure. A preponderance of right tire failures appears to exist, little evidence of use of tires with inadequate tread depth has been reported, a dominant reported cause of tire failure is road obstructions, and finally, it appears that most tire failures are reported under the broad generic term "blowout." Little careful examination to determine cause is undertaken. These data and all data found to date describing cause of tire failure are very sparse, are not statistically significant, and conclusions should be drawn only very carefully.

TABLE 2-VIII. SUMMARY OF ASSOCIATED TRUCK LINES, INC. STUDY OF CAUSE OF TIRE FAILURE										
Accident Number	Failed Tire		Blowout	Evidence of Blowout	Uncertain Blowout	Experimental Tire	Raw Over Object	No Cuts on Tire	Recap Loosened	Over-loaded or Under-inflated
	LF	RF								
1	1		1							
2		1	1							
3		1	1	1						
4		1	1							
5		1	1	1						
6		1	1				1			
7		1	1			1	1	1		
8	1		1			1				1
9		1	1							
10										
11		1	1							
12	1		1	1						
13	1		1						2	
14		1							1	
15		1	1		1		1			
Total	4	10	13	3	1	2	3	1	3	1

Other data published by BMCS (see Section 11.0) indicate some evidence of overloading, right tire failures are in the majority, usually there is adequate tread depth on the failed tire, and an approximately uniform distribution of accumulated mileage on the failed tire varying from 5,000 to over 70,000 miles exists

with a significant peak in the range of 10,000 to 20,000 cumulative miles. Also reported in the BMCS study pamphlet was a random sample of 44 trucks in which 31 trucks had a total of 55 tires underinflated and 6 trucks had a total of 12 tires overloaded. The American Trucking Association, Inc. has replied to the study and they disagree with the method of determining underinflated tires. Therefore, while there is some evidence that overloading and underinflation may be significant causes of tire failure, there is not general agreement on this fact.

Dynamic Science conducted a brief opinion survey within the industry, inquiring as to causes of tire failure. A total of 29 individuals were polled in the sample, although inquiry into the problem itself encompassed a considerable number of other tire and truck representatives. Due to multiple responses, the total number of responses was 35. The data represent personal opinion and are not based upon data or studies with which the respondent was familiar. The initial question was succeeded by inquiring whether the answer was based upon known data. In no case did the respondent reply that the answer was derived through data or pertinent studies.

<u>Cause of Front Tire Failure</u>	<u>Number of Responses</u>
Road Obstructions	14
Underinflation	10 — 29%
Overinflation	2
Overloading	2 — 6%
Front Tire Failure is Not a Problem	2
Miscellaneous	2
Panic Stops	1
No Opinion	1
Tire Quality (manufacturing defects)	1
Total Responses	35

Say 44 trucks @ 14 tires per truck = 616 tires
 Underinflated 55 tires or 9% normal tires / 29% of accident opinions
 Overloaded 12 tires or 2% " " / 6% " " " "

Results of this poll should be considered very preliminary because of the small sample size. Load obstructions and underinflation were most often mentioned as causes of tire failure. Note the apparent disagreement between ATA's objection to methods of determining tire underinflation as reported in the BMCS pamphlet and the apparent agreement among members of the industry that underinflation may be one of the primary causes of tire failure.

Dynamic Science also analyzed 180 front tire failure accident reports of 395 such reports submitted to BMCS in 1973 (215 of the reports were submitted too late to be included). Analysis of those studied shows the following:

- Left front tire failures - 91, right front tire failures - 89.
- For left front failure, 70 respondees indicated there were no tire defects present, 2 indicated defects were present, 6 gave no answer. Responses were inconsistent, however: 19 of the respondees who indicated no tire defects present in one part of the form, indicated elsewhere on the form that a tire defect did exist; 14 were classified as cord separation, 1 as heat failure, 3 as "defective tire," and 1 as improperly cured tube.
- For right front tire failure, 60 respondees indicated no tire defects, 2 indicated tire defects, 8 gave no answer. Some respondees indicating no tire defects on one part of the form did indicate elsewhere on the form that tire defects were present. Thus, total defects reported include 9 classified as cord separation and 1 as defective tube.
- Mileage reported on failed tires is as follows: No significant difference was reported between right tire failures and left tire failures.

<u>Mileage</u>	<u>Number of Responses</u>	<u>Percent of Responses</u>
0-10,000	50	28
10,000-15,000	15	8
15,000-20,000	15	8
20,000-30,000	25	14
30,000-50,000	32	18
Over 50,000	16	9
No Answer	27	15
	<u>180</u>	<u>100%</u>

- Respondees reported the following distribution of distance traveled after the tire failure. No significant difference was reported between left and right tire failures.

<u>Distance (ft)</u>	<u>Number of Responses</u>	<u>Percent of Responses</u>
0-100	29	16
100-200	24	13
200-400	24	13
400-650	19	11
Over 650	10	6
None	22	12
No Answer	52	29
	<u>180</u>	<u>100%</u>

- Respondees indicated the following tread depths on failed tires. No significant difference was reported between left and right tire failures.

<u>Category</u>	<u>Number of Responses</u>	<u>Percent of Responses</u>
Good-Excellent	51	28
New	22	12
0-6/32 In.	11	6
6/32-11/32 In.	19	11
11/32-17/32 In.	36	20
Greater Than 17/32 In.	14	8
Other	27	15
	<u>180</u>	<u>100%</u>

2.5 RECAPITULATION OF STATISTICS

Data collected as reported above which will be used in the study program include:

- General trucking statistics
 - 21 million trucks operating, 990,000 large cargo vehicles
 - Average truck annual mileage: 47,000 miles
 - 37,000 intercity accidents annually, 2.3 accidents per million vehicle-miles
 - 16,000 injuries, 1,300 fatalities (0.08 fatalities per million vehicle-miles)
 - \$2,395 property damage per accident
- Cost of accidents
 - Medical and insurance overhead: \$5,400 per accident
 - Property damage (all trucks): \$2,295 per accident
 - Property damage for those analyzed (tire failure): \$7,000 per accident
 - Operator's cost of accident: \$12,400 per accident
 - Societal cost of accident (includes lost wages): \$17,300

- Average annual mileage: 47,000 miles
- Front tire failure accident rate: 0.02 accidents per million vehicle-miles

Data indicate that most truck tire failure accidents occur on large vehicles and are one-vehicle accidents. These data thus validate the initial direction from BMCS to test safety devices for large commercial vehicles. They also indicate that cost-effectiveness and cost/benefit evaluations of the safety devices can be conducted assuming tire failure causes one-vehicle accidents in a great majority of cases.

Data defining causes of tire failure accidents are sparse. Opinion indicates obstructions and underinflation are major causes. The incidence of underinflation is supported by a BMCS random sample of 44 trucks. This survey also indicated that overloading may be a frequent cause of tire inflation.

The data indicate a preponderance of right tire failures. A tally of all 395 front tire accidents reported to BMCS in 1973 show 228 right failures versus 167 left failures.

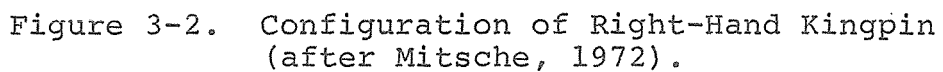
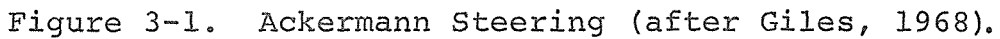
3.0 STEERING AND ALIGNMENT AS RELATED TO FRONT TIRE FAILURE

A brief simplified study was made of the steering geometry and mechanics for a truck and is presented in this section. This analytical study combines some of the fundamentals of the front suspension and steering mechanics with some typical data describing truck steering systems to form the basis for some simple calculations of the magnitudes for forces and displacements which can be expected during a front tire failure.

"Steering is always by the Ackermann System, which provides a kingpin for each front wheel" (Easton, 1969; Patent issued in 1818 in England). In this system, the axes of all four wheels are caused to intersect at a common point (Creson, 1960) as shown in Figure 3-1 adapted from Giles (1969). The configuration of a front axle, with the definitions of the factors of front axle configuration are given in SAE Standard SAEJ695a, Turning Ability and Offtracking from the SAE Handbook.

The 6 factors associated with the kingpins that must be considered in treating the effect of a front tire failure are tagged in Figure 3-2, adapted from Mitsche (1972). These are as follows:

- Kingpin inclination angle, typically of the order of 5 degrees although 0 degree is not uncommon.
- Camber angle, typically 1 degree although 0 degree is not uncommon.
- Caster angle, typically 2 degrees although 0 degree is not uncommon.
- Kingpin offset at the ground, typically 2 inches even with 0 degree kingpin inclination angle.
- Caster offset, typically 0 inch although 2 inches is used.
- Toe-in, typically 1/16 inch although 0 inch is not uncommon.



The first three are angles and the last three are lengths. The kingpin inclination is the angle in front elevation between the steering axis and the vertical; the camber angle is the inclination of the wheel plane to the vertical; the caster angle is the angle in side elevation between the steering axis and the vertical; the kingpin offset at the ground is the horizontal distance in front elevation between the point at which the steering axis intersects the ground and the center of tire contact; the caster offset is the distance in side elevation between the point at which the steering axis intersects the ground and the center of tire contact; and static toe-in is the difference in the transverse distances between the wheel planes taken, respectively, at the rear and front points of the tire treads. These definitions are those adopted by the Vehicle Dynamic Committee of the Society of Automotive Engineers and are given in Vehicle Dynamics Terminology - SAE J670b.

All but the offset dimensions are tabulated in the Truck and Bus Alignment Settings, published by L. C. Hunter Engineering Company (1974).

Ackermann originally adopted the kingpin inclination with compensating camber to accommodate the solid spokes of a carriage wheel. The practice has continued in cars and trucks principally to provide space for the wheel brakes and to provide a spring restraint. The spring restraint tends to return the steering to the neutral position after a turn and is an aid in the recovery from the turn.

The camber angle has been used to reduce the kingpin offset at the ground to limit the magnitude of the road shock felt at the steering wheel. Generally, however, the camber is chosen to assure that the effective camber is negligible at the design static load on the vehicle.

The kingpin offset at the ground is used to provide some rolling action of the tire as the front wheels are turned during parking, thereby reducing the otherwise very large steering forces required.

The caster angle is sometimes used with, or in place of, kingpin inclination to promote recovery after a turn. Common practice is to provide only enough caster to assure negligible caster during forward motion of the vehicle at the design speed and load. Durstine (1973) states that industry practice is zero caster.

The toe-in is similarly chosen; i.e., to assure negligible toe-in during forward motion of the vehicle at the design speed and load.

Note that the effect of caster can be obtained with caster offset even with zero caster angle by introduction of the offset AE in Part c of Figure 3-2. Although such an offset has been used on the 1969 BMW 2500 automobile, it is rarely, if ever, used on a truck.

Road disturbances introduce ~~steering~~ shocks to the steering assembly and to the driver as a result of the moment arms provided by kingpin offset and caster offset. These moment arms should be kept as small as practical, but not so small as to adversely constrain other design considerations.

In theory, a small amount of negative kingpin offset at the ground would have a stabilizing influence during a front tire failure. Specifically, the steering moment produced by the increased rolling resistance of the failed tire would automatically modify the slip angle of the other front tire to produce a corrective yaw moment of the proper sense. In practice, the use of a negative kingpin offset reduces the space available for the kingpin, brake, spindle, etc. Furthermore, as we shall see, the magnitude of the steering moment is dependent upon whether the failure occurs on a straightaway or on a curve.

We will compute the steering hand force required in these two cases as well as that due to an explosive blowout and to over-running an obstruction.

Although Mitsche (1972) has, in part, corrected the lack of a mathematically correct description of steering effort cited by Durstine (Op. Cit.), it will be sufficient to adopt a much simpler model.

3.1 RELEVANT DATA

Durstine (Op. Cit.) gives the range of modern truck steering ratios as 24:1 to 32:1. Let's assume 25:1. Durstine (Op. Cit.) also sums all the component efficiencies to arrive at the overall efficiencies in three hypothetical cases (see Table 3-I). The reverse efficiency is usually intended to be lower than the forward efficiency, so as to isolate the driver from road shock without impairing his steering ability. Let's adopt 0.32 for both values.

TABLE 3-I. INCREASE IN TOTAL SYSTEM EFFICIENCY ASSOCIATED WITH AN INCREASE IN INDIVIDUAL COMPONENT EFFICIENCY (AFTER DURSTINE, 1973)

Hypothetical Individual Component Efficiencies									
Steering Column Bearings	Steering Shaft U-Joints	Steering Gear	Drag Link Ball Joints		King Pin Bushings		Tie Rod Ball Joints		Total System Efficiency
			Pitman Arm	Steering Arm	Left	Right	Left	Right	
.85	.85	.70	.85	.85	.85	.85	.85	.85	.19
.90	.90	.75	.90	.90	.90	.90	.90	.90	.32
.95	.95	.80	.95	.95	.95	.95	.95	.95	.53

The forces and moments in the tire axis system are depicted in Figure 3-3, adapted from Davisson (1969). We will be concerned about the normal force and the aligning torque, in addition to the rolling resistance and the slip angle. Davisson (Op. Cit.) also tabulates the load ratings of commercial tires used as singles on the front of a truck tractor. Table 3-II is

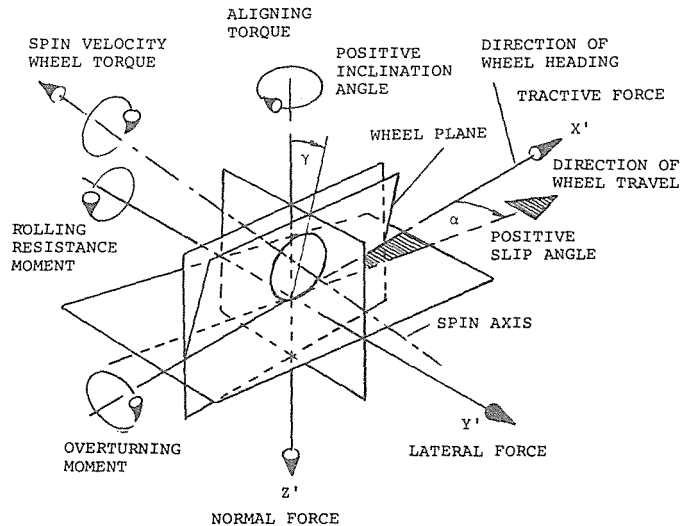


Figure 3-3. Tire Axis System (After Davisson, 1969).

TABLE 3-II. LOAD LIMITS OF SINGLE TIRES (AFTER DAVISSON, 1969)													
Tire Identification					Inflation Pressure (psi)								
Size	Load Range	45	50	55	Tire Load Limits (lb)								
					60	65	70	75	80	85	90	95	100
10.00-20	F				4290	4530	4770	4990	5220	5430			
10.00-20	G				4290	4530	4770	4990	5220	5430	5640	5840	6040
18-19.5	H	6700	7130	7540	7930	8310	8680	9040					

adapted from his Table 5. Let's adopt Size 10.00-20, load range G, inflated to 75 psi and a normal force of 5,000 pounds. The rolling resistance of the tire is given in Figure 3-4. Curtis (1975) gives 80-90 pounds per thousand-pound load as the rolling resistance of a flat 10.00-20 truck tire.

The lateral force required to turn the vehicle is developed by a complex interaction between the roadway and the tire (Set-right, 1972). By virtue of the rolling distortion of the tire, a lateral force, as well as a self-aligning torque, is developed;

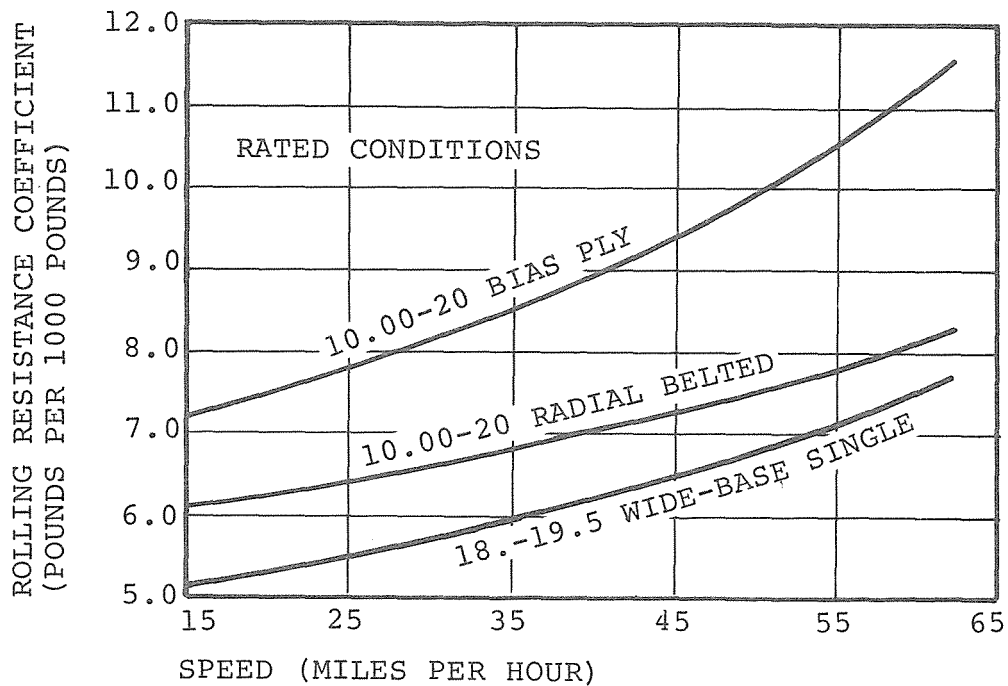


Figure 3-4. Rolling Resistance (After Davisson, 1969).

these are tabulated in Tables 3-III and 3-IV for a new highway tread 10.00-20/G mounted on a 20 x 7.50 rim, respectively (Bernard, et. al, 1973).

TABLE 3-III. LATERAL FORCE (POUNDS) AS A FUNCTION OF SLIP ANGLE (AFTER BERNARD, ET. AL, 1973)						
Normal Force (lb)	Slip Angle (Degrees)					
	1	2	4	8	73	16
3,300	461	833	1427	2195	2574	2971
5,000	535	1012	1799	2893	3521	5127
6,700	554	1074	1975	3337	4193	4983

TABLE 3-IV. SELF-ALIGNING TORQUE (LB-FT) AS A FUNCTION OF SLIP ANGLE (AFTER BERNARD, ET. AL, 1973)

Normal Force (lb)	Slip Angle (Degrees)					
	1	2	4	8	12	16
3,300	69	115	147	123	74	44
5,000	110	189	268	257	177	122
6,700	152	262	390	423	315	237

3.2 FLAT TIRE ON A STRAIGHTAWAY

At 55 mph, the 10.00-20 bias-ply tire exhibits a rolling resistance coefficient of 10.5, implying a rolling resistance of 52.5 pounds with the normal force of 5,000 pounds as opposed to a rolling resistance coefficient of 80 to 90 for the flat 10.00-20 truck tire, implying a larger rolling resistance of as much as 450 pounds. With a kingpin offset at the ground of 2 inches, and on a level straightaway, the resulting net aligning torque would be $(450 - 52.5) * 2/12 = 66$ lb-ft.

With a 25:1 steering ratio and 0.32 system efficiency, the driver would feel only $66 * .32/25 = .84$ lb-ft or with an 18-inch diameter steering wheel, $.84 * 12/9 = 1.2$ pounds hand force. Taborek (1957) cites 80-pound steering hand force limit for trucks and commercial vehicles; the hand force required to resist the disturbance due to the flat tire is small by comparison. A hand force requirement of this magnitude would cause difficulties only if the driver were very careless.

To counter the differential rolling resistance and maintain the pre-blowout course, the driver would have to steer against the flat to develop additional lateral force (and self-aligning torque) in the other front tire.

Let's adopt a wheel track of 87 inches and a wheelbase of 142 inches. The differential rolling resistance then produces a turning moment on the vehicle of $(450 - 52.5) * (87/(2*12)) = 1442$ lb-ft. To counter this moment, the other front tire would have to develop an outward lateral force of $1442/(142/(12*2)) = 244$ pounds.

By interpolation of the lateral force data in Table 3-III, the required slip angle is $244/535 = 0.46$ degrees. Furthermore, by interpolation of the aligning moment data in Table 3-IV, the corresponding aligning torque is $0.46 * 110 = 51$ lb-ft. To develop the lateral force, the steering wheel would have to be turned a total of $0.46 * 25 = 11.5$ degrees and the maximum hand force required would be $[(51 + 66) / (0.32 * 25)] * (12/9) = 19.5$ pounds.

Again, this is not asking too much of the driver.

If, however, the blowout occurs explosively in the sidewall of the tire at a point fore or aft of the spindle, the moment of the jet impulse could sorely tax the driver. There is about 2.2 pounds of air in a 10.00-20 truck tire inflated to 75 psig; of which 1.25 pounds would be adiabatically expelled at an average velocity of 1,252 ft/sec (assuming sonic flow) before the pressure has dropped to 13 psig (Hedberg, 1975). In this computation, the initial temperature of the air in the tire has been assumed to be 300°F in accordance with White's (1967) statement that the blowout danger zone is 250°F to 300°F. At 55 mph, the tire will make a 1/4 revolution in 6 milliseconds. Assuming a discharge coefficient of 0.8, 1.25 pounds of air would be expelled through a 10-inch-diameter hole in 6 milliseconds, producing a total impulse of 49 lb-sec (Hedberg, Op. Cit.). Assuming the centroid of the blowout is 15 inches from the kingpin, the average hand force at the steering wheel due to the impulse would be $(49/.066) * (15/9) * (0.32/25) * .70711 = 123$ pounds.

Although this hand force could be countered if the driver were prepared for the impulse, it would sprain the fingers, if not the wrist, of an unwary driver.

The probability of such a severe impulse is extremely small. First, a 10-inch-diameter hole implies the loss of the entire sidewall; second, the odds are equally good that the rupture would occur below or above the spindle causing no steering disturbance; third, a significantly smaller hole would provide an averaging of the moment since during part of the time the moment would be of the opposite sense; and fourth, because of the jagged edges of the hole, the discharge coefficient would probably be much less than 0.8.

Furthermore, we have intentionally neglected the mass-spring-sink properties of the tire and wheel, front axle and suspension, and the steering assembly. These will tend to lengthen, average, and attenuate the pulse, reducing the severity of the event.

3.3 OVERRUNNING AN OBSTRUCTION

Inasmuch as running over an obstruction may contribute to a front tire failure, we will consider the steering impulse resulting from driving one front wheel up a 6-inch-high ramp with a 45-degree incline. Because of the incline, the maximum value of the horizontal force exerted on the tire will be equal to the normal force (i.e., 5,000 pounds). Furthermore, this force can be applied no longer than it takes for the tire to climb the incline, i.e., less than $(1.4 * 6/12) / (55 * 5280/3600) = 6.5$ milliseconds. Hence, this impulse looks very much like that due to an explosive blowout of a tire. However, the moment arm in this case is essentially the kingpin offset at the ground; thus the hand force seen by the driver is less than $(5000 * 2/9) * (0.32/25) = 14$ pounds.

Again, we have neglected the reduction of the pulse by the mass-spring-sink properties of the system.

We should also note that overrunning folds in the collapsed tire after a blowout should be much less severe than the example we have just computed.

3.4 BLOWOUT ON A CURVE

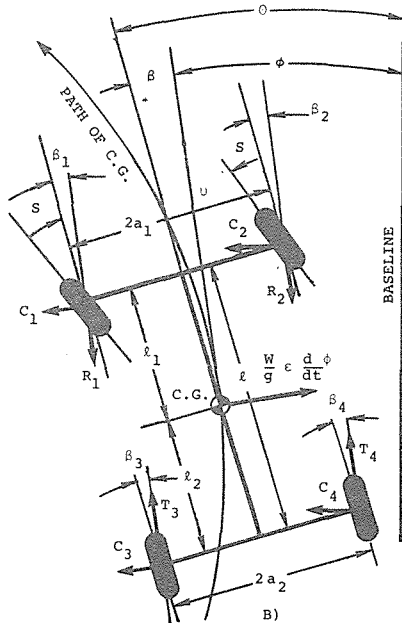


Figure 3-5. Vehicle Forces in a Left Turn (After Kondo, et. al, 1968).

Kondo, et. al. (1968), have found that deflation of the outside tire on a curve is more serious because the yawing moment due to the flat tire tends to increase the radius of the turn. Thus we will assume this condition. Figure 3-5 shows the forces on the vehicle: R_1 will then be 52.5 pounds; R_2 , 450 pounds. Let's assume a curve and load distribution for which the normal force on the outside front tire is 6,700 pounds (leaving 3,300 pounds on the inside front tire) and for which the total lateral force on both front tires is 2,500 pounds. Because of the Ackermann geometry, the slip angle on the inside tire is greater than that on the outside; however, for steering angles less than 10 degrees, as for high speed, the difference is small.

Thus, we shall assume $\beta_1 = \beta_2$. By interpolating the data of Table 3-III, the slip angles must both be 2.8 degrees before the blowout. For this angle, the net steering hand force is $((313-138) / (0.32 * 25)) * (12/9) = 31$ pounds where we have used interpolated data from Table 3-III.

At the blowout, the lateral force developed by the outside front tire drops dramatically, perhaps even becoming negative (Kondo, Op. Cit.); we shall assume the lateral force drops to zero. To maintain equilibrium, the driver must turn away from the flat tire to transfer the entire front lateral force to the

inside front tire. This requires a stepwise increase of the slip angle of this front tire to 11.2 degrees as we have interpolated from Table 3-III.

Assuming the self-aligning torque of the flat tire to be the same as that of the inflated tire (Kondo, Op. Cit., says that it increases), the hand force due to the net self-aligning torque must be increased to $((337-83.8) / (0.32 * 25)) * (12/9) + 19 = 61$ pounds. We have added the 19 pounds computed in Section 3.2 to account for the rolling resistance. Furthermore, the steering wheel must be turned an additional $(11.2-2.8) * 25 = 210$ degrees. Both the hand force and the angle are very large. Thus it is clear, in spite of our gross assumptions, that it would be quite difficult to maintain the turn without deviating from the curve.

3.5 RECAPITULATION OF SIMPLIFIED ANALYSES

The rolling resistance of a flat truck tire under load is of the order of 450 pounds as opposed to the normal value of about 60 pounds. The added resistance results in a yawing moment on the vehicle of the order of 1,400 lb-ft and because of kingpin offset, a steering moment of the order of 50 lb-ft.

On a curve, the difficulties are compounded by a shift of the normal force to the outer tire. If the outer tire fails, the requisite cornering force must be transferred, essentially en toto, to the inside tire, requiring a large steering hand force (of the order of 60 pounds) and a large steering wheel rotation (of the order of 200 degrees). Inasmuch as the cornering force that can be developed by the inside tire is quite limited, it may be impossible to avoid a skid-out.

If the failure of a front truck tire occurs explosively in the sidewall of the tire, a steering impulse will be produced not unlike that of overrunning an obstruction. In an extremely rare case, the impulse could sprain the wrist of the driver or wrest the steering wheel from his hands.

4.0 CANDIDATE DEVICES TO REDUCE THE EFFECTS OF FRONT TIRE FAILURE

Several types of devices are available which could reduce the effects of front tire failure. These devices are briefly discussed in this section. Table 4-I summarizes the types available and if available, the manufacturer's estimate of the number now in service.

TABLE 4-I. SAFETY DEVICE SUMMARY			
Name	Manufacturer	Type	Number in Service*
Steer Safe	Steer Safe, Inc.	Spring	8,000
Shure-Guide	Steering Stabilizer Corporation	Spring	16,000
Steering Stabilizer	Safety Products, Inc.	Spring	Unknown
Positrol	Fleet Industries	Spring	Unknown
Centerline Steering	Centerline Corporation	Axle Design	Unknown
Centerpoint Steering	North American Rockwell	Axle Design	Unknown
Safety Roller	Patecell Corporation	Roller Within Tire	Newly Developed
Cure Ride	Airshox, Inc.	Hydraulic	5,500
HECO	Heckethon Products	Hydraulic	7,500
Steerline	Triple S	Hydraulic	Unknown
Power Steering	(Numerous)	Power Steering	Unknown
Air-O-Matic	Sycon Corporation	Air-actuated Power Assist	Unknown
Firestone Cantilever	Firestone	Tire	Newly Developed
*Estimate from manufacturers.			

4.1 SPRING-TYPE SAFETY DEVICES

The spring-type devices utilize a system of springs designed to absorb energy caused by front tire failure and control the vehicle by maintaining the wheels in a straight-ahead position. Three different types available from different manufacturers have been identified.

4.1.1 Two Parallel Noncollinear Spring - Steer Safe

The Steer Safe device consists of two identical springs which are attached to a fixed bracket bolted to the spindle assembly on one end and to a pivoting fulcrum bar, pivoting on the axle, on the other end (see Figure 4-1). Since the fulcrum lever arms are of equal length, the springs exert an equal pressure on the wheel. The pivot point of the fulcrum bar is designed such that the hole in the fulcrum bar is larger than the shaft around which it is moving. As the fulcrum bar turns, its pivoting point is changed, thereby varying the length of the moment arms to the springs. Thus, there is equal continuous pressure on the springs as the wheels are steered. It is claimed that loads on the wheels are automatically absorbed by the spring regardless of wheel position. The "feel" of the steering wheel is not affected.

The installation of this device is simple and maintenance is minimal since there is only one moving part. The manufacturer guarantees the device for the life of the vehicle to which it is attached.

4.1.2 Four-Spring System Shure-Guide, Steering Stabilizer

4.1.2.1 Shure-Guide

The Shure-Guide system (Figure 4-2) is a four-spring unit. As in the Steer Safe device, the springs are designed to absorb the energy from any movement of the wheels due to road shocks or tire failure. The manufacturer states that the unit has improved control since there are four springs to maintain straight wheel steering in the event of a front tire failure. However, one disadvantage of this design is the increased load on the steering

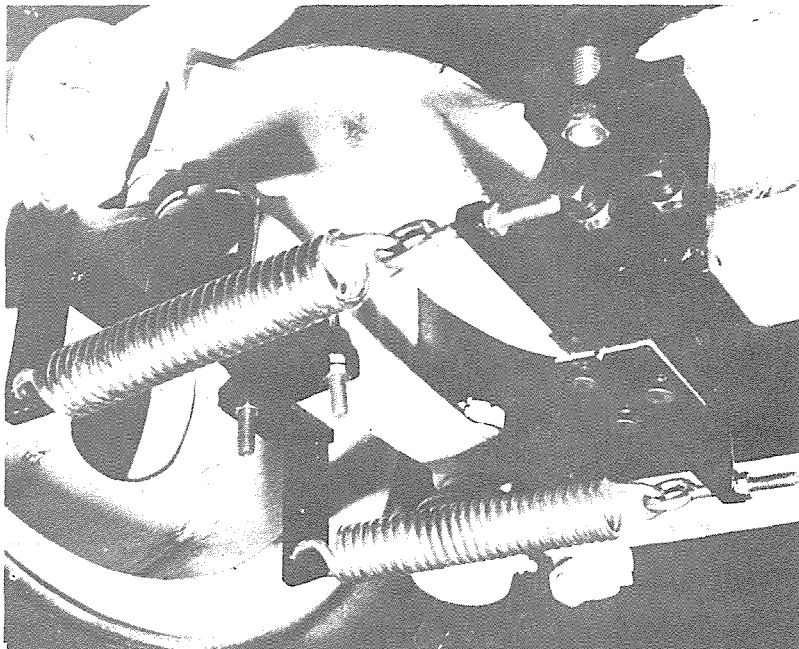


Figure 4-1. Steer Safe System.

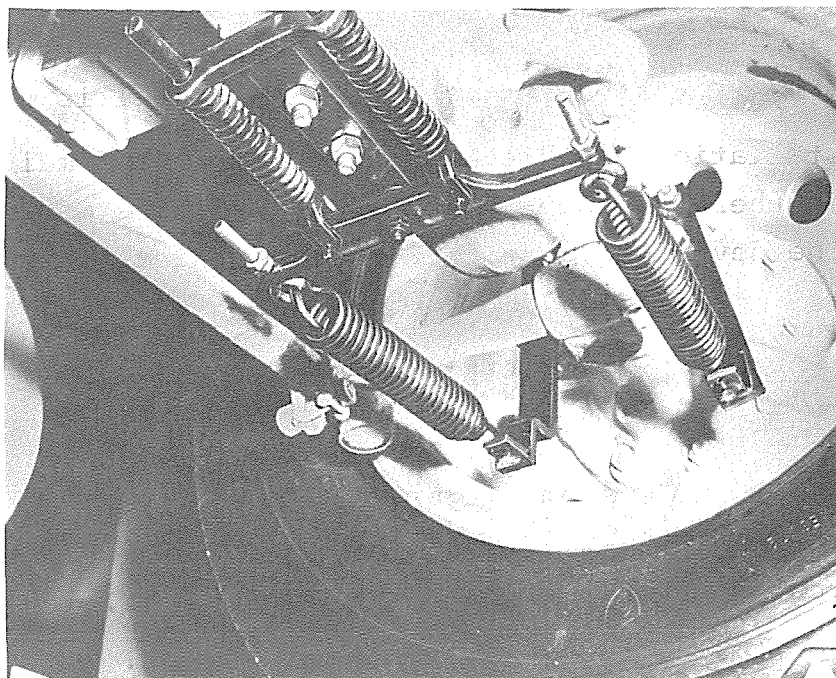


Figure 4-2. Shure-Guide System.

system as the wheels approach full turn - one set of springs is compressed while the other is expanded.

The installation procedure is simple and mounting hardware is available to assure installation on all makes of trucks. The maintenance is minimal as there is only one moving part.

4.1.2.2 Steering Stabilizer

The Steering Stabilizer system is similar to the Shure-Guide unit. It consists of two spring assemblies which mount from the front axle to the wheel. Each assembly consists of four springs, two attached to the wheel and two attached to the axle by way of a special mounting bracket. All four springs are attached to a rotary bar which also bolts to the axle (see Figure 4-3). The theory of operation is to absorb, by means of mechanical spring action, any shock which may be experienced in driving situations, like a tire blowout.

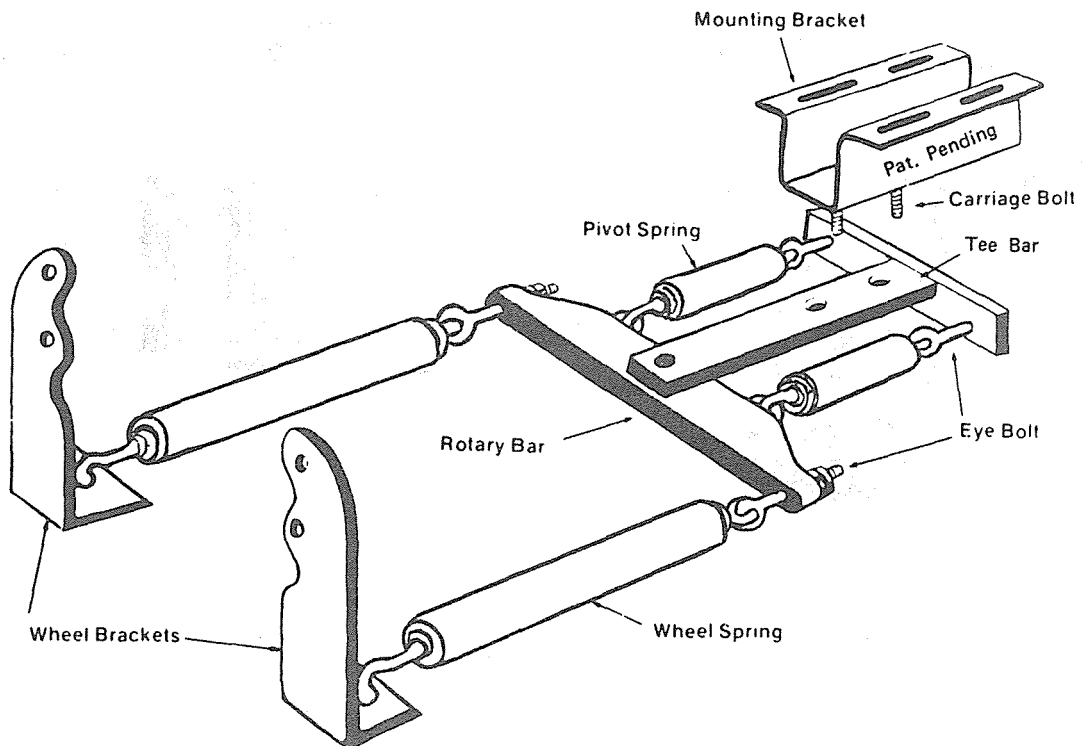


Figure 4-3. Steering Stabilizer.

4.1.3 Collinear Two-spring System - Positrol

The Positrol system consists of two coil springs mounted on a common shaft (see Figure 4-4). The shaft is fixed at one end to a bracket mounted on the axle spindle. The shaft is supported in the middle by a bracket mounted to the axle. The shaft slides through the bracket as the tie rod is moved. The springs are mounted on either side of the axle bracket and are alternately compressed or expanded

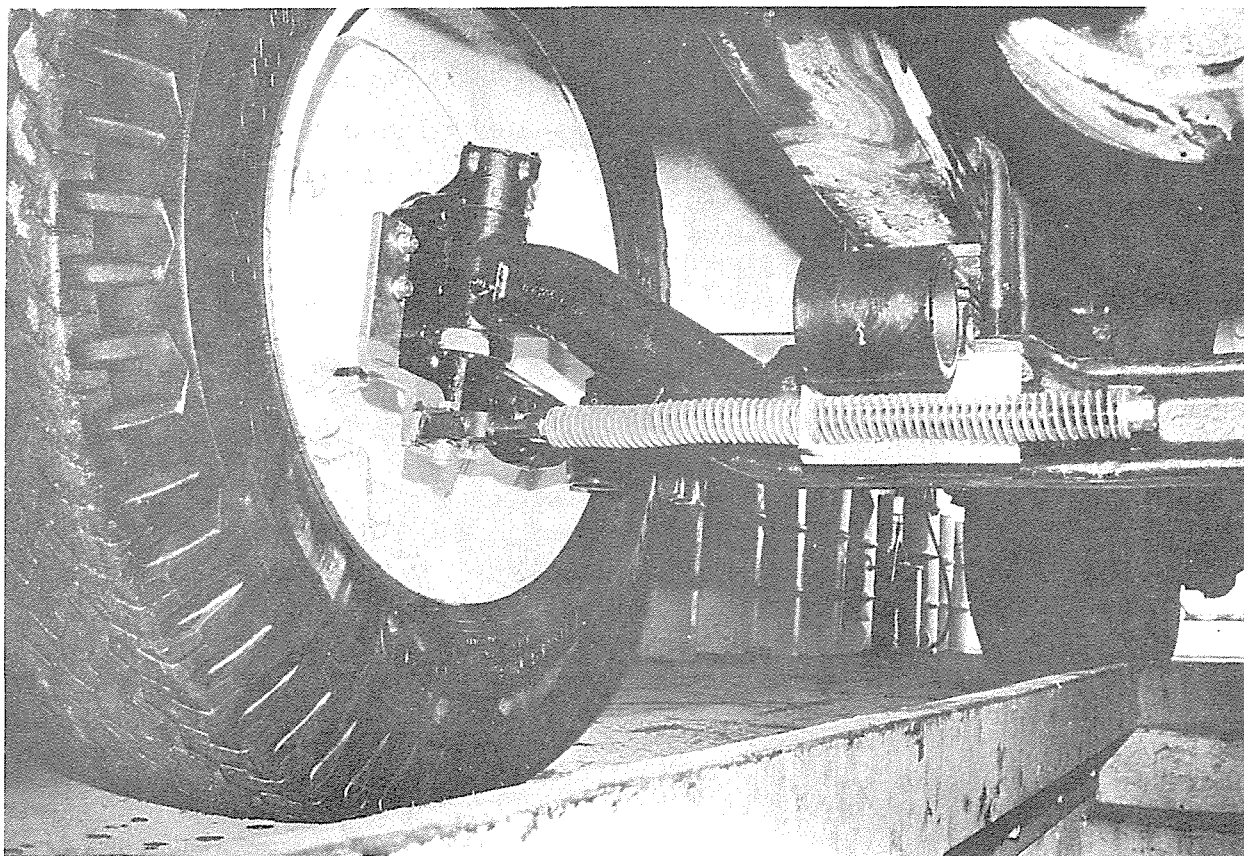


Figure 4-4. Positrol Spring System.

This design has two disadvantages: (1) the moment arm of the bracket mounted on the spindle is short and a large amount of movement of the wheel is necessary to initiate action of the

springs and (2) the steering effort of the driver is increased as the turning angle is increased.

As with the previous devices, the installation is simple and the device requires little maintenance.

4.2 AXLE CONCEPTS - CENTERLINE AND CENTERPOINT STEERING

Centerline Steering consists of a complete axle assembly (see Figure 4-5). This assembly includes axles with spring pads, spindles, bearings, trunion pins, and brake assemblies.

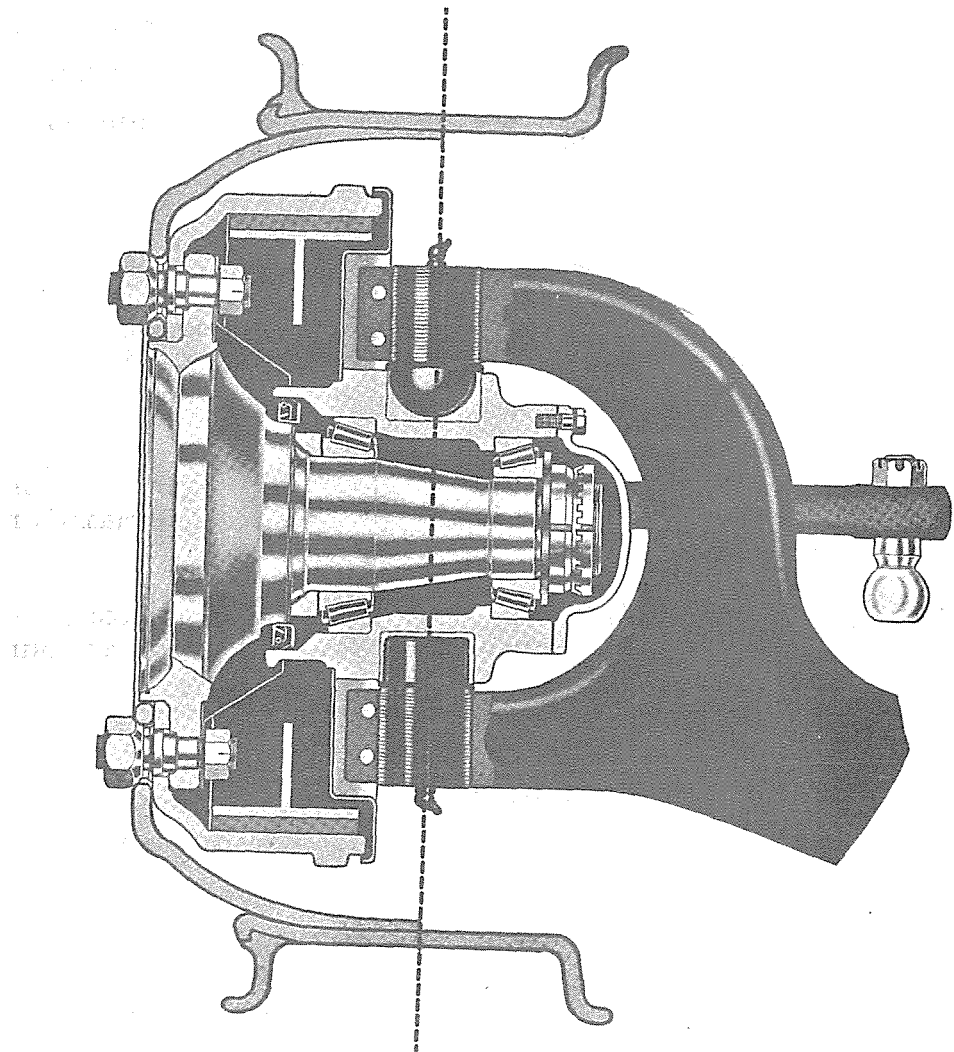


Figure 4-5. Centerline Steering.

In a conventional front suspension system, the wheel pivots around the spindles which are hinged inboard from the vertical centerline of the wheels. The inboard attachment of the spindles through kingpins, creates a cantilevered support which multiplies any loads applied to the wheels, affecting steering control and causing wear on front wheel bearings, steering linkage, and suspension parts.

The advantage of Centerline Steering lies in the fact that the pivotal action of the wheel is in line with the vertical centerline of the wheel and tire. There is no cantilevered arm between the kingpin and vertical centerline of the wheel as in a conventional steering system. Any forces which act on the axle assembly as a result of front tire failure, act through the center of the tire, wheel, and spindle assembly, hence, produce no steering moments.

The advantages claimed for this design are as follows:

1. Road shock to the steering linkage is reduced since a large percentage of the load acting on the trunions is cancelled out and less load is transmitted to the steering system.
2. The toe-in and camber settings are set at zero degrees. Since the trunions are adjustable and the assembly is of heavy construction, the alignment maintenance is reduced and tire life is improved.
3. Maintenance is reduced since the trunions, which replace the kingpins, are adjustable to account for normal wear in the system.

The cost and installation time for this device is greater than that of the spring-type systems. The complete front axle assembly must be removed and replaced by the Centerline Axle assembly. However, this cost is reduced if the axle is installed during vehicle manufacture.

Centerpoint Steering consists of a complete axle assembly similar in design to the centerline concept (Figure 4-6). This assembly includes the axle, spring pads, spindles, bearings, and kingpins. Centerpoint Steering, unlike the centerline system,

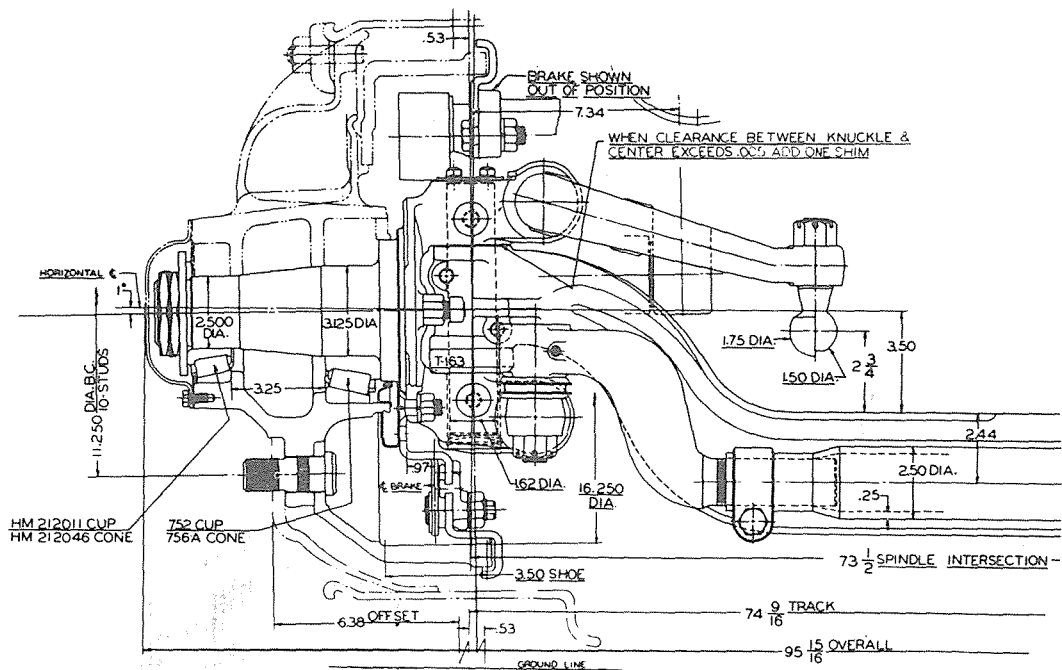


Figure 4-6. Centerpoint Steering.

has a small kingpin inclination angle. This angle causes a slight scrub radius (0.53 inch) which assists in decreasing the steering effort required when the vehicle is stationary.

As with the centerline design, having the kingpin inclination angle at approximately zero degrees eliminates the cantilevered design which multiplies loads applied through the wheels, affecting steering control and wear. The elimination of this angle directs any forces acting on the wheel through the wheel and spindle assembly, keeping the wheel in a straight-ahead direction.

The cost and installation time for this device is greater than the spring or hydraulic-type system; the complete axle assembly must be replaced. However, if the assembly is installed during vehicle manufacture, the cost is reduced.

4.3 SAFETY ROLLER

The Safety Roller allows a deflated tire to be run for a limited number of miles at reduced speeds without any damage to the tire (see Figure 4-7).

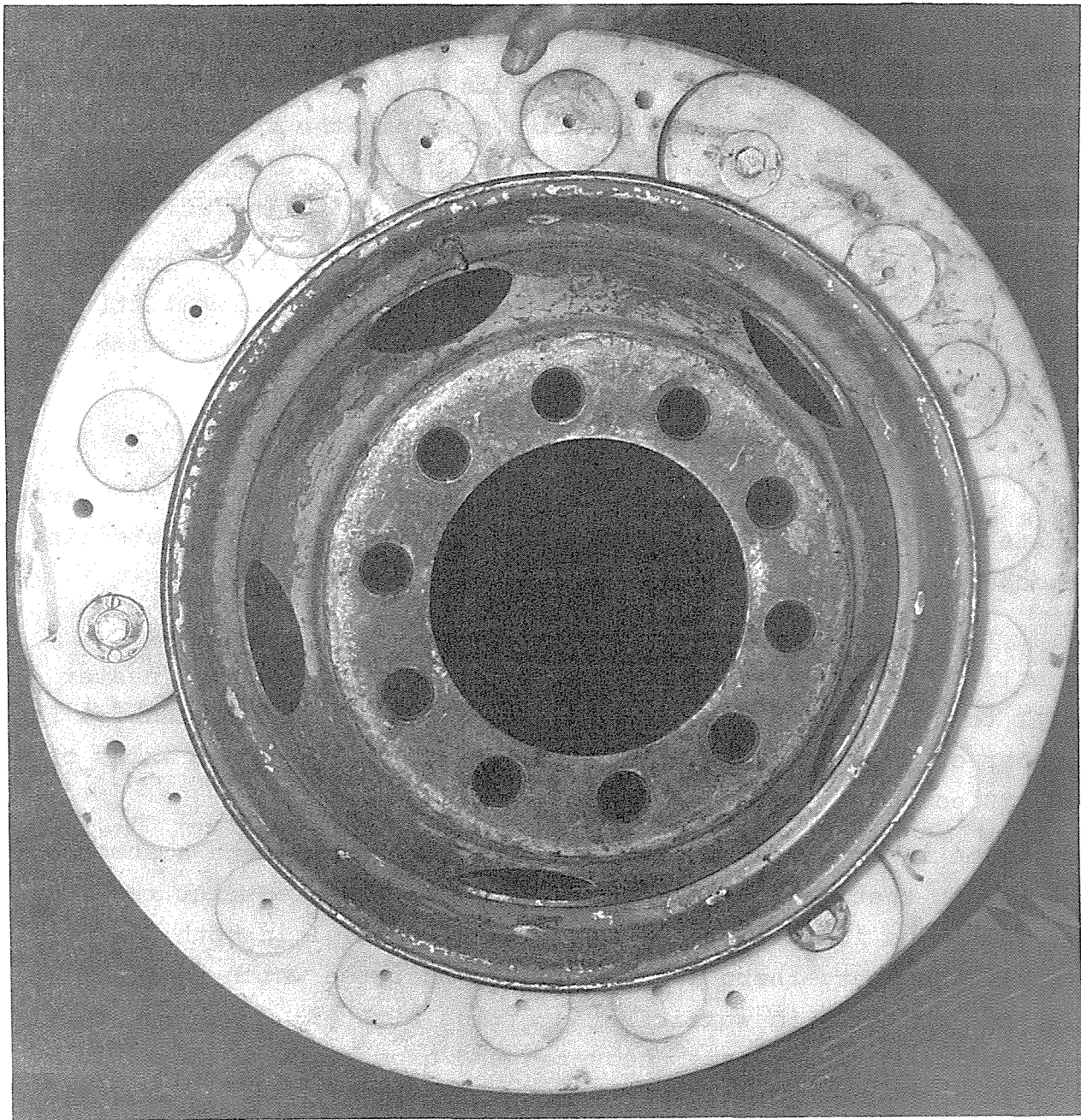


Figure 4-7. Safety Roller.

This device is an annular ring which is clamped around the wheel rim inside the tire. The diameter of the Safety Roller allows approximately 1.5 inches between the roller and the tire.

In the event that a tire failure does occur, the tire collapses and rests on the Safety Roller. The roller supports the wheel without damaging the tire structure. Since the circumference of the tire is greater than that of the roller, a rubbing occurs between them which would result in a heat buildup and damage to the tire. To alleviate this problem, the roller is constructed from a plastic material with lubricative properties and additional lubricants can be added prior to tire inflation.

Although the initial cost of this device is high, its life is unlimited. Installation cost is minimal, requiring little more than a tire-changing effort but the cost is reoccurring at each tire change.

4.4 HYDRAULIC SAFETY DEVICES

Hydraulic devices are similar to shock absorbers. They are installed horizontally between wheel and axle to absorb steering shocks and to help maintain straight-ahead steering.

These devices are often used on smaller trucks (1/2 to 2 tons) with front wheel drive and vehicles with positive caster of 2 to 5 degrees to eliminate wheel shimmy. Table 4-I shows the number of units installed in truck tractors with front axles of 10,000 pounds or more.

The internal design of this device is similar to a shock absorber in that there are internal valves which restrict the flow of oil, thus limiting the piston rate of travel in both directions. However, there are two design features which are added: (1) the cylinder is sufficiently filled with oil (ensuring that the valves do not become uncovered and exposed to air), since the device is mounted in a horizontal position, and (2) a charge of freon can also be introduced to ensure a somewhat constant rate over a wide range of temperatures.

4.4.1 HECO System

The HECO system is a piston-type device which mounts between the front axle and tie rod (see Figure 4-8). The device is fixed at both ends. The diameters of the body and mountings are much larger than in a conventional shock absorber, thus increasing the loads which the device can absorb. This device is normally installed as a single unit and is used as a device to absorb normal road shock to prevent shimmy in the front wheels of the truck. No claims are made as to its performance in regard to controlling a front tire failure.

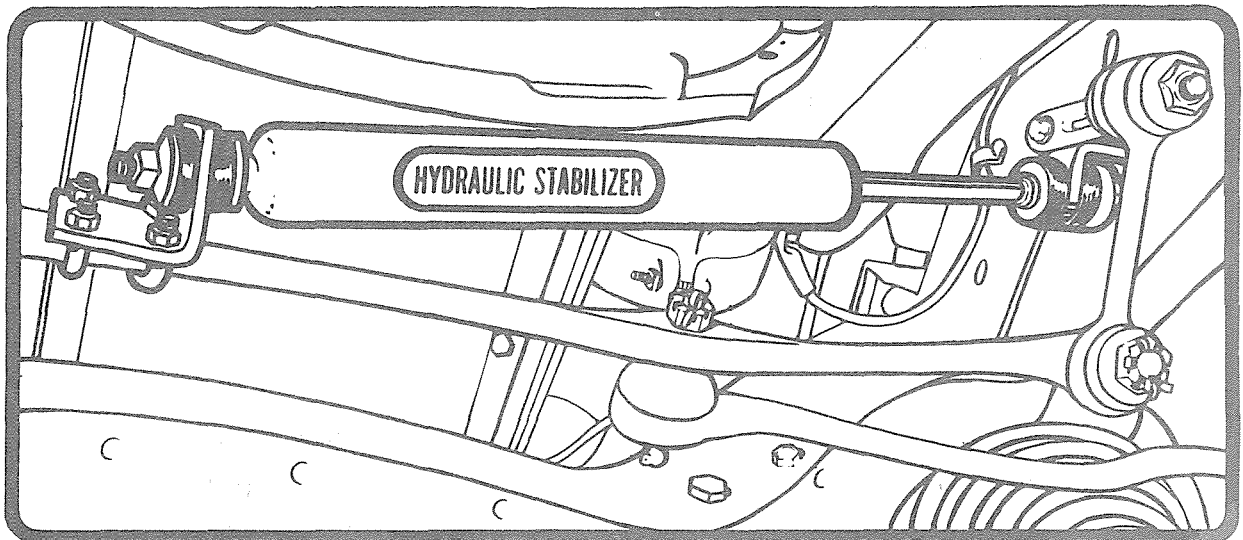


Figure 4-8. HECO System.

This device is simple to install and the average life of the unit is 5 years.

4.4.2 Steerline

The Steerline system is similar to the HECO hydraulic system. It is a heavy-duty hydraulic cylinder mounted between the frame and tie rod as seen in Figure 4-9. The design is aimed at reducing vibration and sudden movement of the front wheels from impacts by hydraulic dampening.

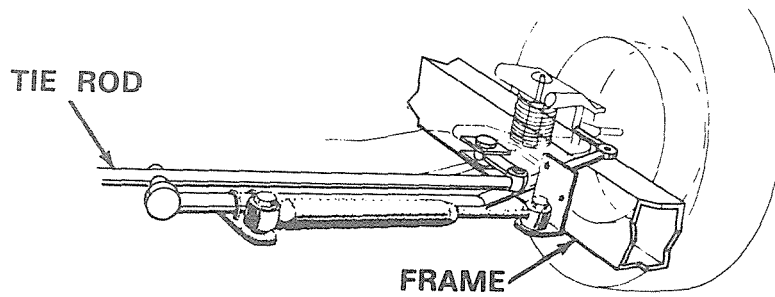


Figure 4-9. Steerline System.

4.4.3 Cure Ride

This device is similar to the HECO and Steerline systems discussed in Section 4.4.1 and Section 4.4.2. However, the Cure Ride system consists of two cylinders which are mounted in pairs with the body of the device fixed on a bracket at the center of the axle and the piston arm bolted to the outer tie rod ends. This system is shown installed in Figure 4-10.

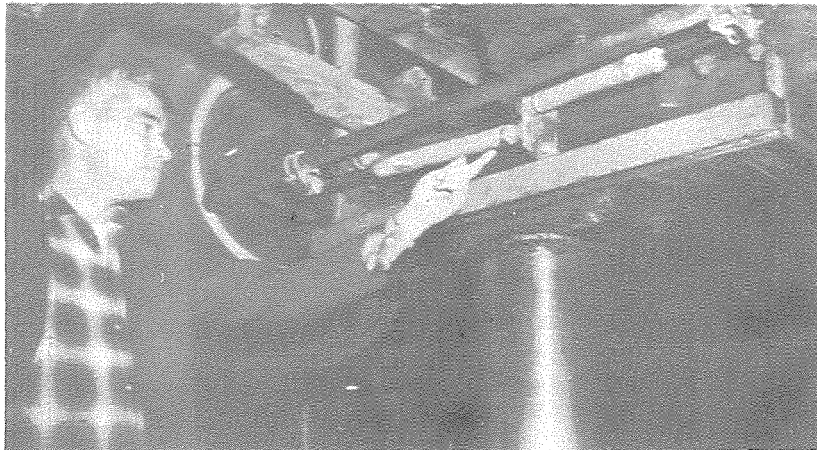


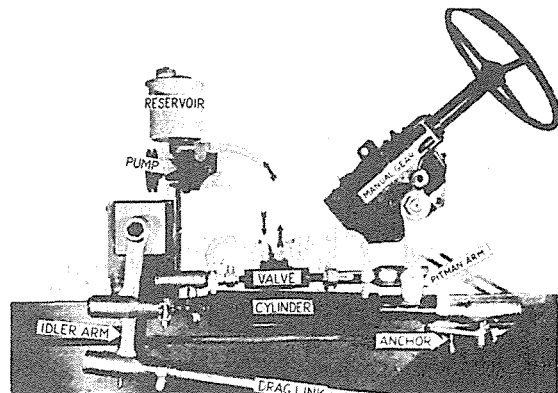
Figure 4-10. Airshox System.

This device is designed to absorb normal road shocks, prevent shimmy, and minimize steering wheel movement due to uneven road surfaces.

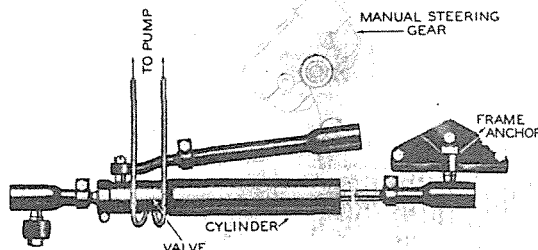
4.5 POWER STEERING

4.5.1 Hydraulic Power Steering

Hydraulic power steering systems on large trucks consist of a high-pressure pump, hydraulic piston, and actuator (see Figure 4-11). The pump is driven off the engine and normal operating pressure is in the range of 900 to 1,200 psi. The hydraulic piston can be either an integral type within the gear box or an external hydraulic piston which is fixed to the axle at one end and fixed to the tie rod on the other. Movement of the piston moves the tie rod in the desired direction. With the external piston type, an actuator valve is mounted with the steering gear shaft to sense movement and direct fluid pressure to actuate the piston in the desired direction.



Valve and Cylinder
Mounted Separately



Valve and Cylinder in
Single Inline Unit

Figure 4-11. Linkage-Type Power Steering.

The advantage of a complete power steering system is two-fold. The system is working at all times, assisting the driver in all steering maneuvers. In the event of a front tire failure, it will reduce the associated steering torque loads, and control of the vehicle should be improved. The systems designed for trucks have internal springs which require the steering wheel effort to exceed a threshold before the power system is actuated. This gives a "road feel" to the driver.

Power steering systems can be installed as a factory option, or installation can be accomplished after delivery. The cost is much greater than the spring or hydraulic devices. As an item installed after vehicle delivery, the installation cost will be approximately 20 percent of the total system cost. As a factory-installed item, the installation cost is greatly reduced. The unit requires periodic maintenance.

4.5.2 Air-Power Assist - Air-O-Matic

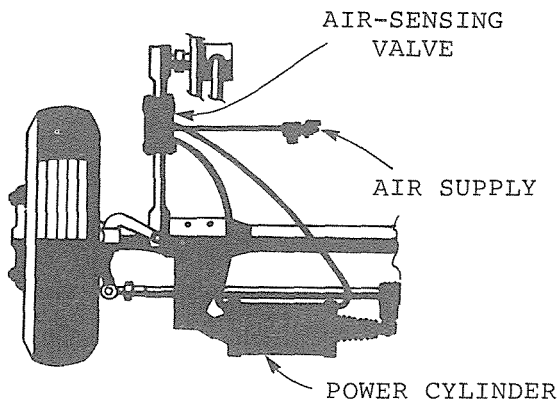


Figure 4-12. Typical Tie Rod Mount.

Air-O-Matic is another device which is available as an option after manufacture. It is basically a power-assist steering system that utilizes air as a medium of activation (Figure 4-12). This type of system is used to supplement the manual steering efforts of the driver. It provides steering assist in the event of front tire failure or any other adverse actions.

This system utilizes the existing air supply of the vehicle and does not require a separate pump. The other main parts are an air sensing valve on the drag link and an air-power cylinder which is mounted from a fixed point on the vehicle to the tie

rod or pitman arm. The air-sensing valve senses any movement of the manual steering and directs air to the air cylinder to assist in the steering motion. It is a passive system in that it requires a minimum steering effort to activate the air-sensing valve, and the design is such that the air system ceases working if supply pressure drops below a minimum value. This protects the air supply for normal functions of the vehicle.

The initial cost of this device is similar to that of power steering and requires similar periodic maintenance.

4.6 CANTILEVER TIRE

The Firestone Cantilever Tire is a low-profile, low-aspect ratio tire. The bowed sidewalls of the tire bulge further out upon deflation and do not have the same tendency to periodically fold and buckle under the rim as the rim rolls on the wide tread. The tire size designation is E60C-25.6LXXX.

4.7 DEVICES SELECTED FOR TESTING

As discussed later in Section 5.0, all of the above described devices were tested except for the power steering unit. The power steering unit is custom installed and a long lead item. The performance of a hydraulic power steering unit is expected to be comparable to the air-power assist unit tested.

5.0 TEST METHODOLOGY

5.1 TEST VEHICLE

Trucks are classified in four primary groups comprised of light (10,000 pounds or less), medium (10,000-20,000 pounds), light-heavy (20,000-26,000 pounds), and heavy-heavy (over 26,000 pounds), where weight values represent Gross Vehicle Weight (GVW). Our tests will employ a heavy-heavy class vehicle. Table 5-I shows that although this class of motor carrier vehicle represents only 8 percent of all trucks in the United States (i.e., ignoring panel, pickup, and walk-in vehicles), some 21 percent of all commercial truck-miles driven utilize the heavy-heavy vehicle. On a vehicle-to-vehicle basis, the heavy-heavy class is driven 230 percent more miles annually than any other truck/vehicle combination.

TABLE 5-I. TRUCK INVENTORY SUMMARY*			
Class Type	Number of Trucks (000)	Estimated Annual Miles Driven (000,000)	Average Miles Per Truck (000)
Heavy-Heavy	1,500	52,019	34.7
Light-Heavy	828	8,755	10.6
Medium	2,822	29,316	10.4
Light	14,598	154,451	10.6
*U.S. Department of Commerce, Truck Inventory, and Use Survey, TC72-T52, Census of Transportation, 1973.			

One truck tractor was instrumented and used for all tests. The tractor was a three-axle cab-over engine with the following specifications:

International Harvester 1973 Transtar COF 4070A

Front Axle FA139, 12,000 pounds

Tandem Axle

Front Tire Sizes

10:00 x 22 Tube Type

11:00 x 22.5 Tubeless

Figure 5-1 is a photograph of the truck used for these tests.

International has the largest segment of the large-weight-class truck market (Automotive News 1974, eight months registration showed 21,215 trucks out of a total of 93,459 trucks registered in the 33,000 GVW and greater weight class).



Figure 5-1. Test Vehicle Front View.

Two identical 40-foot van-type trailers were utilized during the course of the testing. Each trailer had a different load. In order to change from one loading condition to another, the trailers were simply exchanged.

One trailer was empty and made the gross combination weight 28,380 pounds while the other trailer was loaded with approximately 45,000 pounds of gravel to make the gross combination weight at the typical legal limit of 73,280 pounds. The empty front axle weight was 7,930 pounds and the loaded front axle weight was 10,400 pounds.

Safety cables were attached between the cab of the tractor and the semi-trailer to help limit the yaw angle between the tractor and trailer to between 10 and 15 degrees, which helped minimize the possibility of jackknifing.

5.2 TEST CONDITIONS

Common conditions in all tests include the following:

- Test speed of 50 miles per hour (± 2 mph)
- Left-front tire failed
- Tire manufacturer's recommended pressure of 90 psi
- Transmission in high gear with clutch engaged
- Truck coasting with throttle control released
- Brakes not applied until several seconds after tire deflation
- Steering manually controlled with tire deflation triggered by driver.

A test speed of 50 mph was chosen to be reasonably close to the maximum expected speed for highway travel. This was also close to the top speed for the loaded combination. The front tire failure problem was expected to be more severe at the higher speeds.

Although the right-front tire appears to fail more frequently, a left tire failure has the potential of being more severe and causing a greater loss of life and injury, since other vehicles are likely to be involved.

To achieve the proper test speed and eliminate the influence of the throttle, the truck was driven to a speed in excess of 50 mph, the throttle released, and the failure triggered as the truck passed through the test speed of 50 mph.

The brakes were not applied until seconds after the tire deflation to minimize the effect of the braking on the test.

The driver controlled the truck after tire deflation was initiated. For some of the earlier baseline tests, the driver delayed his steering input for either two or five seconds to get significant deviations upon tire deflation. For the device evaluation tests, the driver controlled the test from the beginning.

5.3 TIRE FAILURE METHOD

The method selected for failing the tire involved attaching a modified double barrel shotgun to the front axle of the truck as shown in Figure 5-2. The gun was triggered via a solenoid connected by cables to the trigger as shown in Figure 5-3. The solenoid was activated by the driver via a switch inside the cab of the truck as shown in Figure 5-4.

The projectiles used in the gun were solid deer slugs which produced repeatable holes in both sidewalls of the tire. Figures 5-5 and 5-6 show typical holes in the tire on the entry and exit sides, respectively. A bullet trap was attached on the outboard side of the tire, shown in Figure 5-7, to catch the projectiles after they passed through the tire to eliminate safety hazards due to partially spent bullets.

This method caused the tire to deflate repeatably in approximately one second.

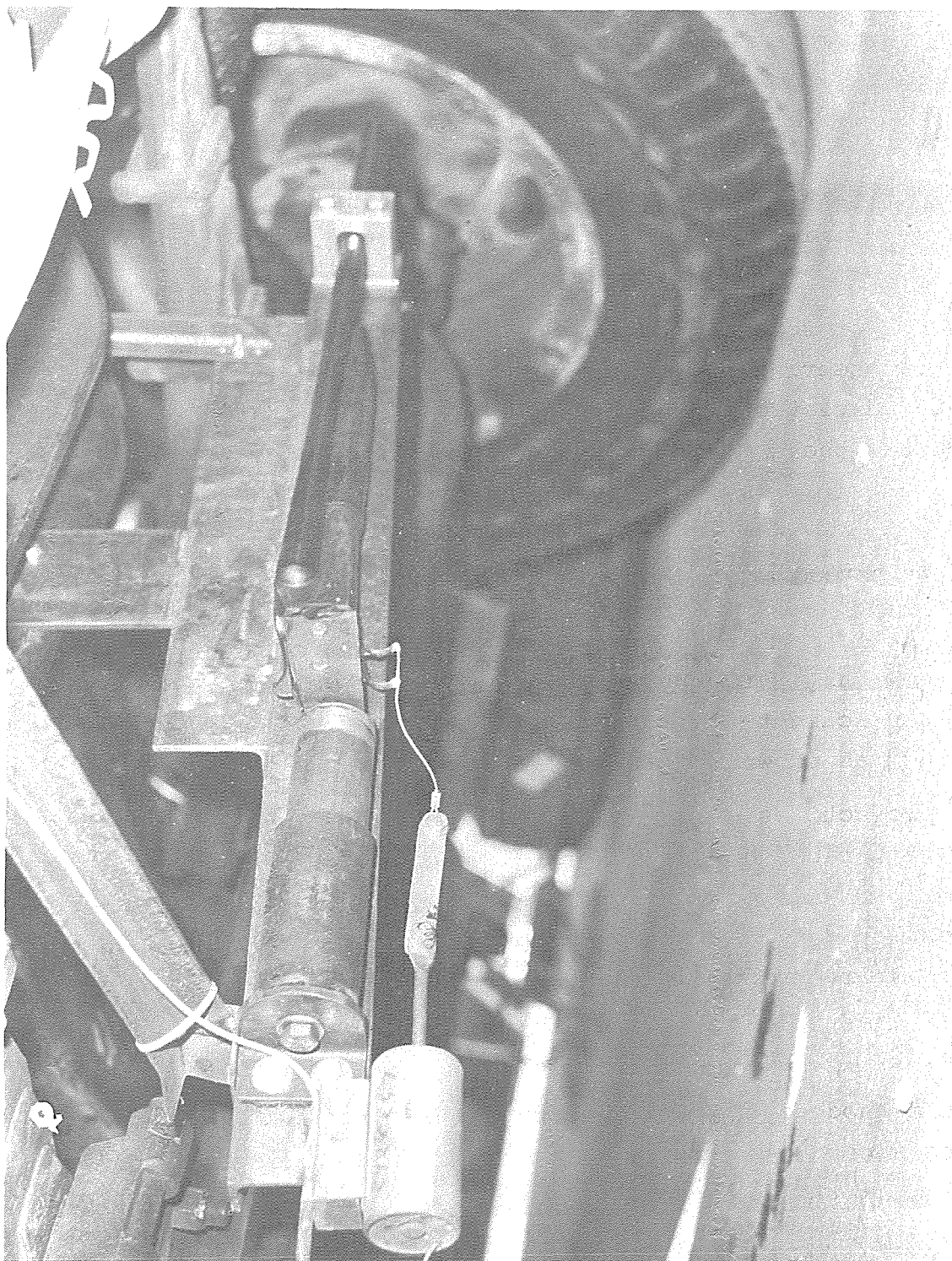


Figure 5-2. Tire Deflation Device.

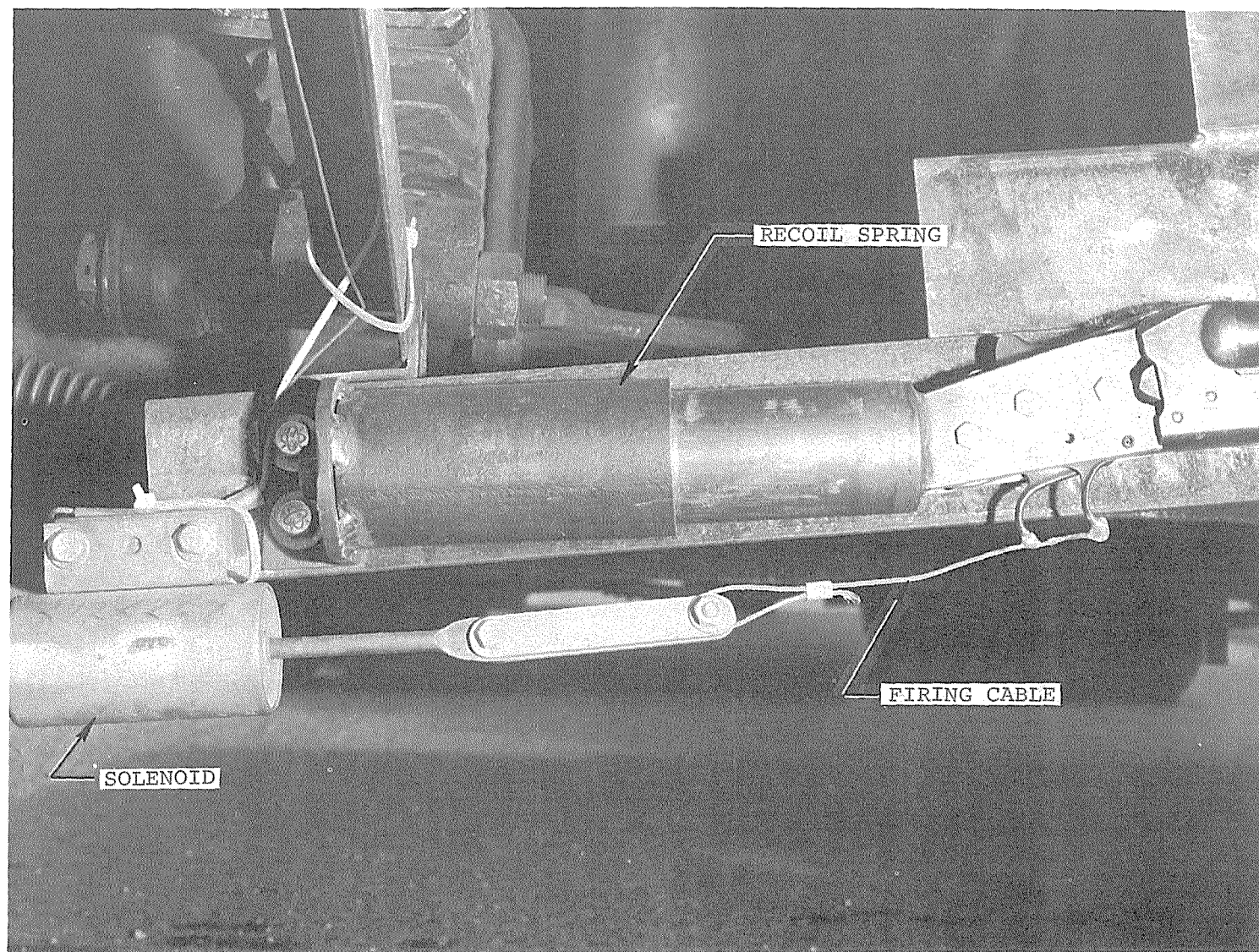


Figure 5-3. Tire Deflation Device, Solenoid Firing Cable, and Recoil Spring.

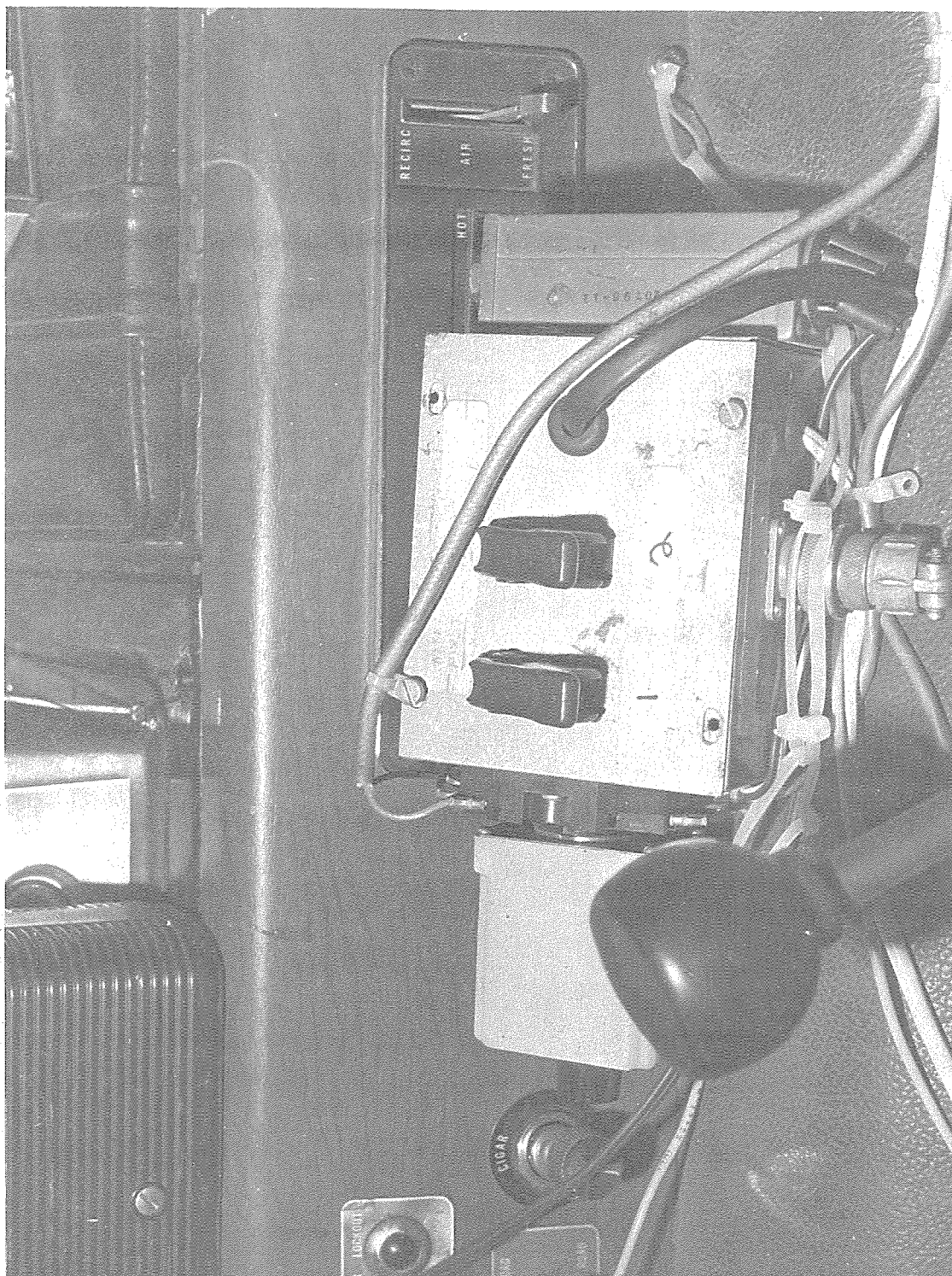


Figure 5-4. Tire Deflation Control Switch Panel.



Figure 5-5. Typical Post-test Point of Entry Holes for Deflation Projectiles.

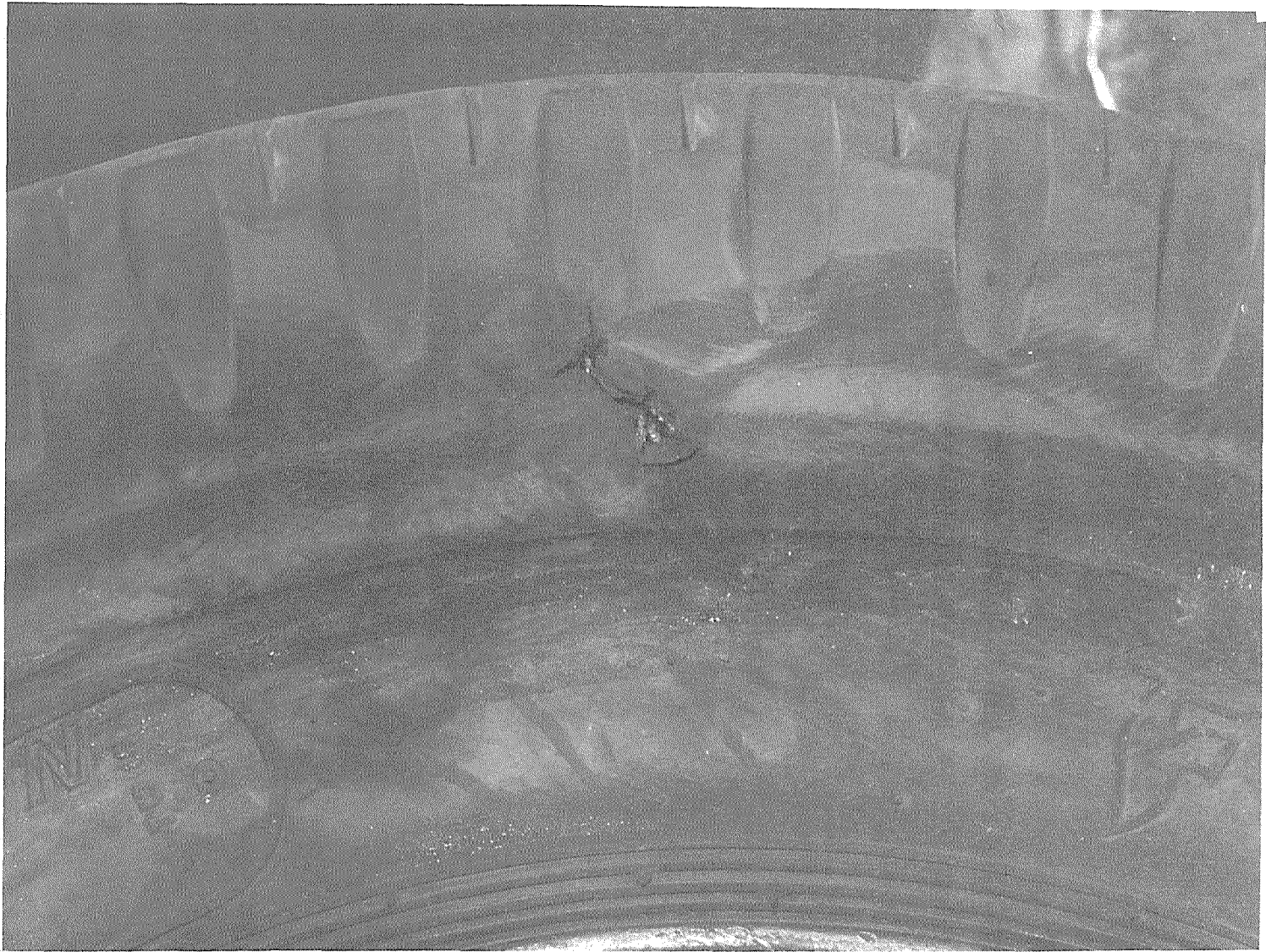


Figure 5-6. Typical Post-test Exit Holes for Deflation Projectiles.



Figure 5-7. Bullet Trap to Catch Projectile After Passing Through Tire.

5.4 TEST MATRIX

The tests were conducted in three phases as follows:

Phase 1 - Baseline Testing

Phase 2 - Alignment Sensitivity Testing

Phase 3 - Device and Concept Evaluation

5.4.1 Phase 1 - Baseline Testing

The primary objective of this phase of the testing was to establish a baseline vehicle response for comparison with tests where devices were installed.

The basic tire tested was a bias-ply tubeless-type tire. Tests were also performed on a tubeless radial tire and on a tube-type recap tire.

Tests number 7 and 9 were the loaded and empty weight tests of the radial tire while Tests 6 and 8 were the corresponding tests for the recap tire. All other baseline tests were performed with bias-ply tires.

A Cantilever Tire was tested during Phase 3 as one of the concept evaluation tests.

Baseline Tests 1, 4, and 20 were performed with the empty trailer. Tests 2, 3, 5, 19, 21, 22, and 48 were baseline, loaded truck tests.

The test procedure varied during the baseline tests as the driver input requirements varied. During the first seven tests, the driver was instructed to keep his hands off of the steering wheel for two seconds after initiation of tire deflation. During the next eight tests, the delay time was 5 seconds except for Test 12 where no steering input was applied. The remaining tests required the driver to attempt to control the truck from initiation of tire deflation.

For Baseline Test 21, only one shotgun shell fired, causing a slower deflation time than the other tests.

Since the devices were tested with the driver controlling the vehicle from the start of the test and with the loaded trailer, Tests 19, 22, and 48 are the tests that form the basis of comparison for the subsequent device testing.

5.4.2 Phase 2 - Alignment Sensitivity Testing

Changes in vehicle response due to gross alignment changes of the vehicle front-end were evaluated during Phase 2 testing.

Camber changes are not a normal adjustment for a truck with a solid axle since changes in camber angle would require bending of the axle. No camber modifications were made during Phase 2.

Tests 10 and 11 involve empty and loaded tests with an additional positive 2 degrees of caster above normal.

Tests 12 and 13 involve a one-inch tow-in in addition to the 2-degree positive caster.

Tests 14 and 15 involve a one-inch tow-in with the standard caster.

5.4.3 Phase 3 - Device and Concept Evaluation

A total of twelve devices and concepts were evaluated. Table 5-II identifies the devices, the manufacturer, type of device, and the device test numbers.

Each test was run with a loaded truck with a gross combination weight of 73,280 pounds. The driver triggered the tire deflation device himself and attempted to control the truck from the initiation of the tire deflation.

5.5 INSTRUMENTATION

The combination was instrumented to obtain the following measurements:

- Vehicle velocity
- Steering wheel angle
- Steering wheel torque

5060501

TABLE 5-II. SAFETY DEVICE SUMMARY

Name	Test Number	Manufacturer	Type
Cure Ride	23 & 24	Air Shox Inc.	Hydraulic
HECO	25 & 26	Heckethon Products	Hydraulic
Positrol	27 & 28	Fleet Industries	Spring
Steer Safe	33 & 34	Steer Safe Inc.	Spring
Str. Stab.	31 & 32	Safety Products Inc.	Spring
Centerline	35 & 36	Centerline Corp.	Axle Design
Centerpoint	37 & 38	North American Rockwell	Axle Design
Shure Guide	39 & 40	Steering Stabilizer Corp.	Spring
Firestone Ctlr.	42 & 43	Firestone	Tire
Safety Roller	45	PateCell Corp.	Roller within tire
Steer Line	46 & 47	Triple S	Hydraulic
Baseline	19, 20, & 21	-	-
Air-O-Matic	50 & 51	Sycon Corp.	Air Actuate Steering Boost

- Lateral and longitudinal acceleration
- Yaw rate
- Tie rod strain
- Angular displacement between truck tractor and trailer.

These measurements were performed with the devices described in Table 5-III. Figure 5-8 is a schematic of the truck which shows the approximate location of the instruments on the truck.

Figure 5-9 shows the string pot used to measure the relative yaw angle between the truck cab and trailer.

Figure 5-10 shows the strain gauge location on the tie rod.

Figure 5-11 shows the strain gauge locations for measuring steering wheel torque and the string pot installation for measuring steering wheel angle.

TABLE 5-III. INSTRUMENTATION LIST

Measurand	Type of Transducer	Instrument Manufacturer	Model Number	Full-Scale Range	Full-Scale Transducer Accuracy
Vehicle Velocity	Fifth Wheel	Labeco	TT481	150 ft/sec	± 0.15 ft/sec
Steering Wheel Angle	Linear Potentiometer	Houston Scientific	1800-15-B	± 800 deg	± 4 deg
Lateral and Longitudinal Acceleration (earth reference)	Force Balance Accelerometer	Kistler	3036	$\pm 1.0G$	$\pm 0.01G$
Yaw Rate	Rate Gyro	Sperry	-	± 40 deg/sec	± 0.5 deg/sec
Steering Wheel Torque	Strain Gauge	Micro Measurements	-	-	-
Tie Rod Strain	Strain Gauge	Micro Measurements	-	-	-
Angular Displacement	Linear Potentiometer	Houston Scientific	1800-15-B	-	-

Figure 5-12 shows the rate gyro installation along with some of the signal conditioning electronics. Figure 5-13 shows the fifth wheel used for velocity measurement. Figure 5-14 shows the signal conditioner, battery pack, and telemetry equipment.

The signals were recorded, amplified, and converted to FM form; transmitted to a stationary data acquisition station; and recorded on a magnetic tape and strip chart.

5.6 PHOTOGRAPHY

Each test run was covered by 16mm color movies. The post-test condition of the rig, tire, and rim was also recorded on movie film.

A camera was mounted on the truck pointing downward, photographing a series of parallel lines on the roadway. From an analysis of the film (which had timing marks), the lateral displacements, yaw angle, and time out of the lane were documented. The camera was turned on just prior to tire failure. The camera can be seen in Figure 5-1 on the front of the truck.

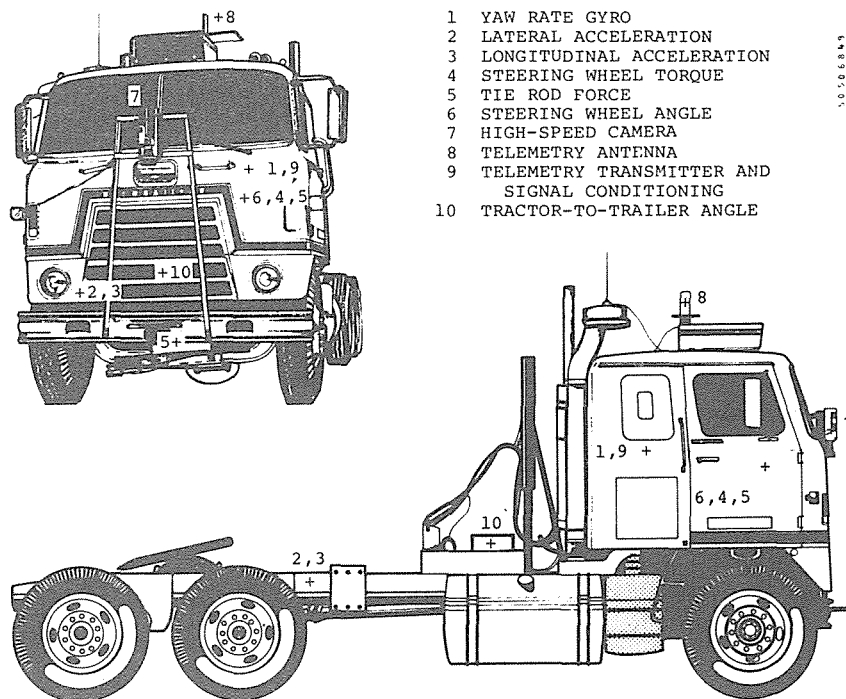


Figure 5-8. Instrument Locations.

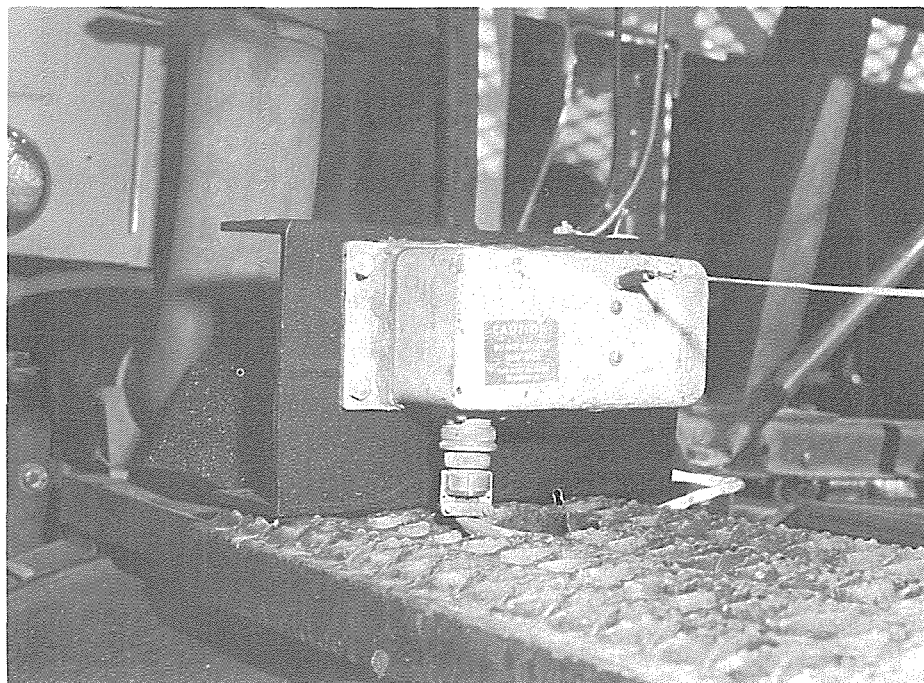


Figure 5-9. View of String Pot Used to Measure Tractor to Trailer Angle.

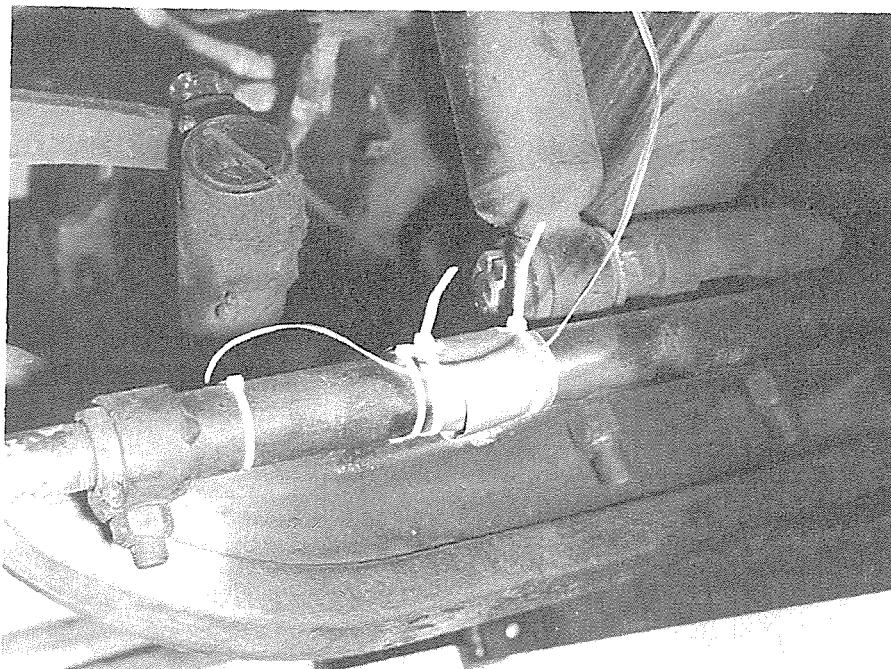


Figure 5-10. View of Tie Rod Strain Gauges
Used to Measure Tie Rod Loads.

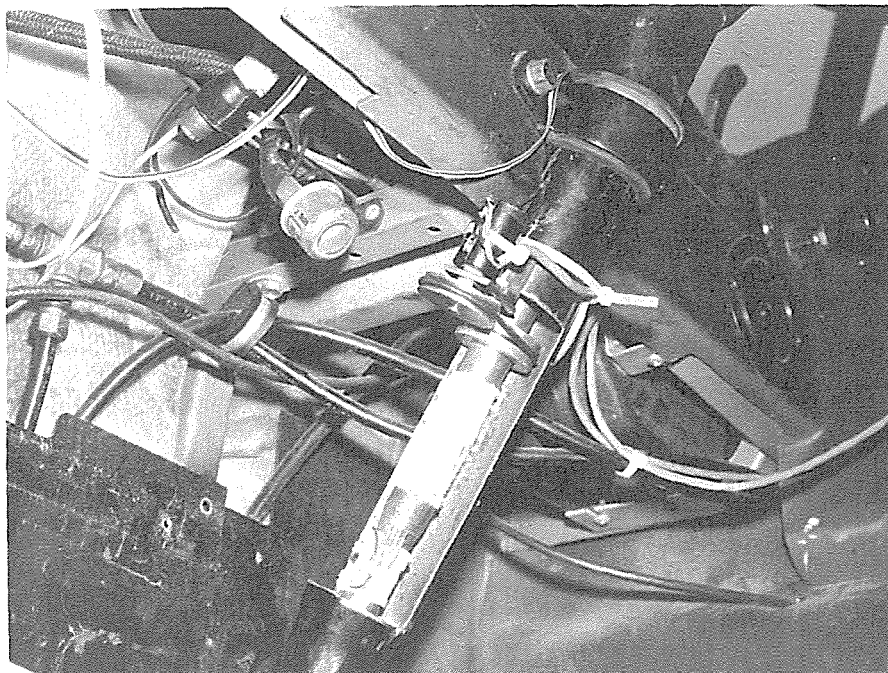


Figure 5-11. View of Devices Used to Measure Steering
Wheel Angle and Torque.

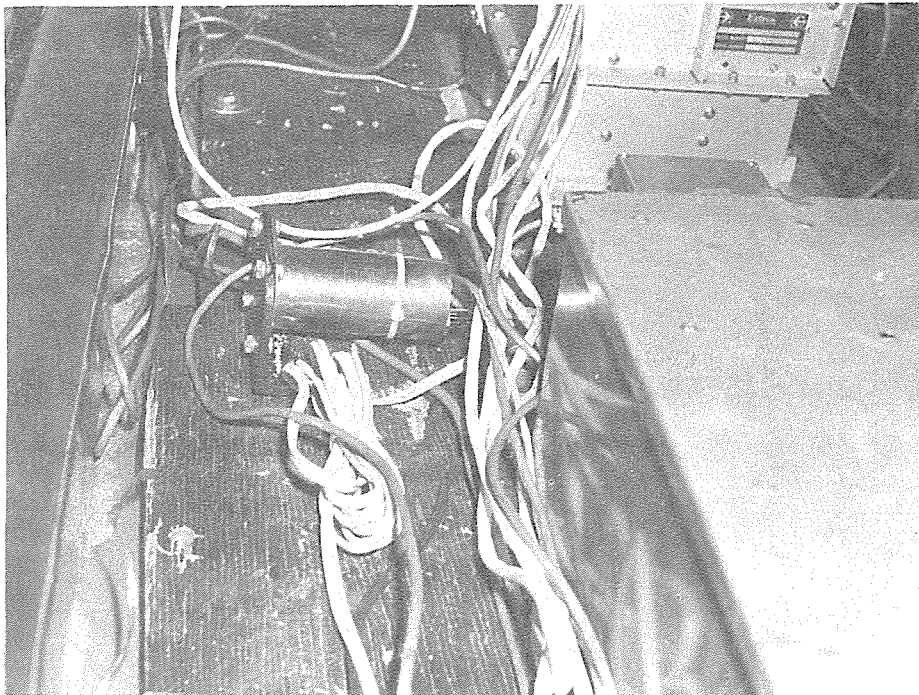


Figure 5-12. Rate Gyro and Signal Conditioning Electronics.

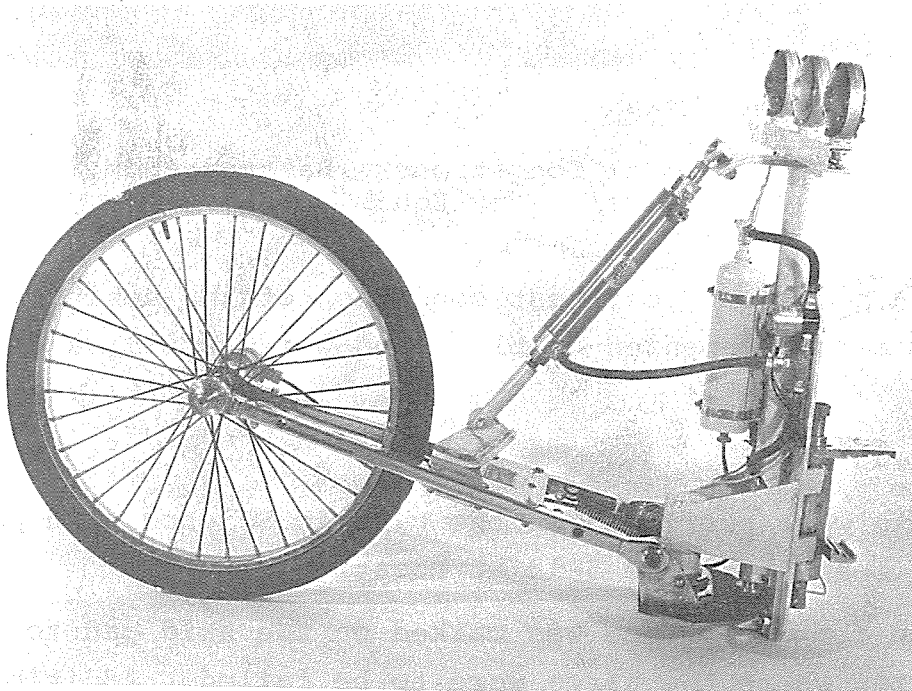


Figure 5-13. Fifth Wheel.

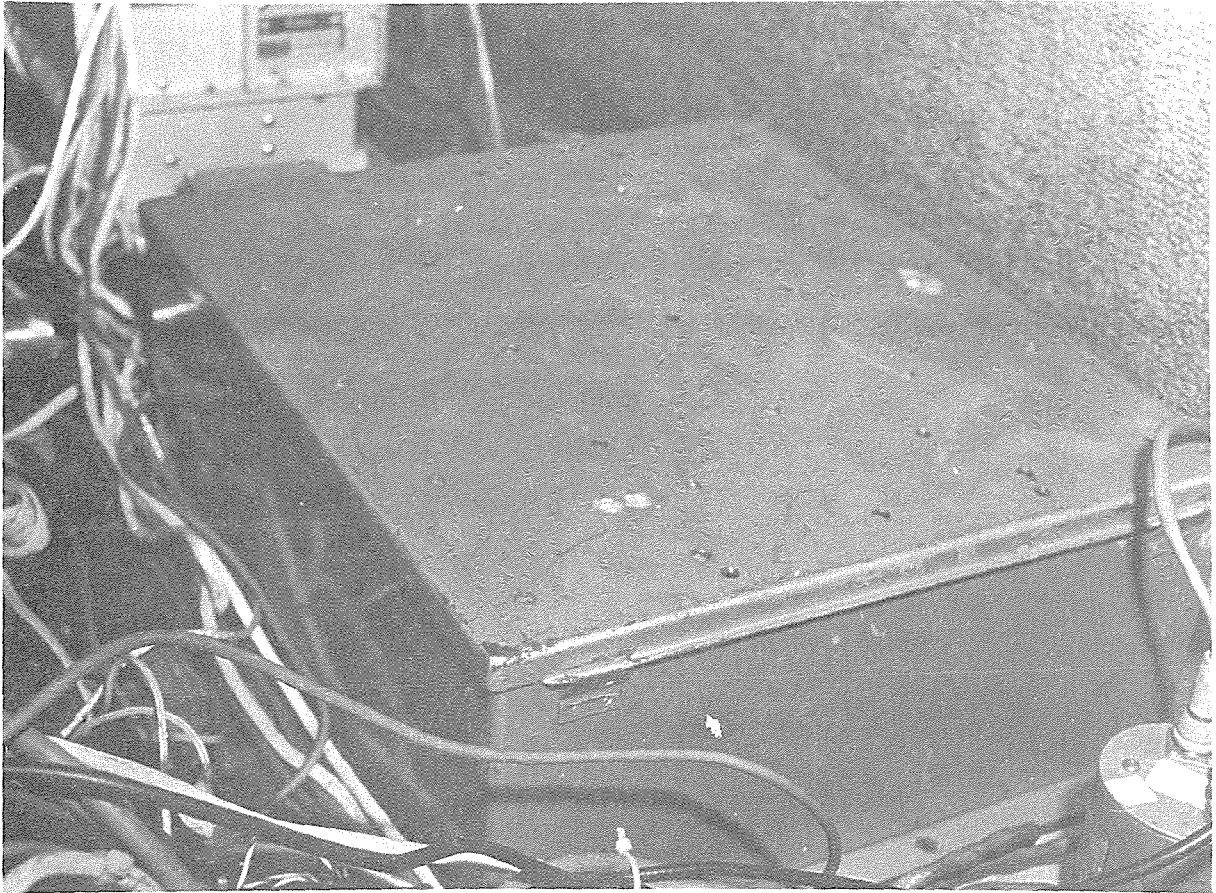


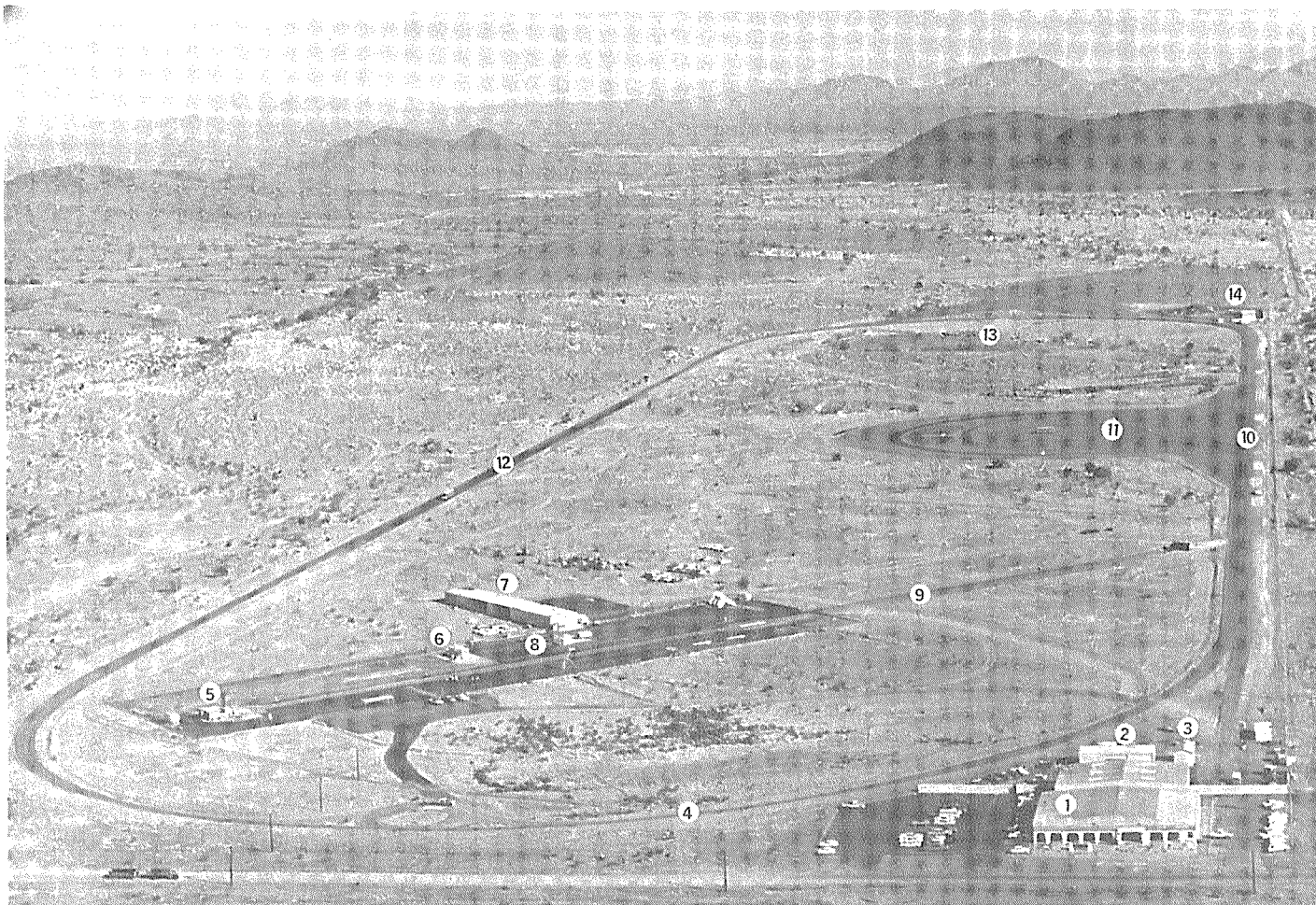
Figure 5-14. Signal Conditioner, Battery Pack, and Telemetry Equipment.

The test setup and post-test condition of the vehicle, tire, and rim were also documented by black-and-white stills and color slides.

5.7 FACILITIES

The tests were performed on the Dynamic Science skid pad, which can be seen in Figure 5-15 at Location 11.

A twelve-foot-wide lane was marked on the skid pad to indicate the region where the tires were to be failed. Additional parallel lines were added in the lane for photographic measurement of lateral displacement and yaw angles as mentioned previously. Figure 5-16 shows a schematic of the test area.



1. ENGINEERING/ADMINISTRATION CENTER
2. GARAGE/MAINTENANCE OPERATIONS
3. ENVIRONMENTAL CHAMBER
4. TWO-MILE OVAL
5. IMPACT FACILITY

6. DATA ACQUISITION AND CONTROL STATION
7. NONMETALLICS LABORATORY AND TEST SERVICE BUILDING
8. PENDULUM FACILITY
9. 1200-FOOT MONORAIL CRASH FACILITY

10. RIDE QUALITY COURSE
11. SKID PAD
12. HIGH AND LOW SKID NUMBER BRAKING LANES
13. PARKING BRAKE TEST RAMP
14. BALLISTICS RANGE

Figure 5-15. Dynamic Science Test Facility.

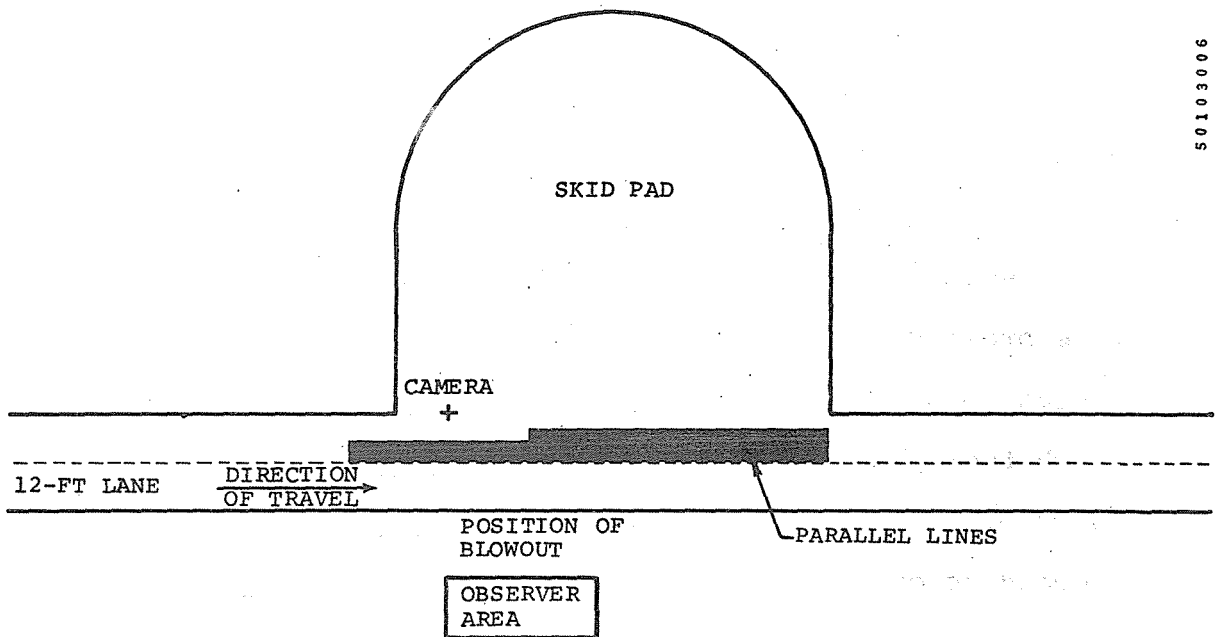


Figure 5-16. Skid Pad Test Area.

5.8 TEST PROCEDURE

Prior to the test run, the vehicle and instrumentation were checked to ensure readiness for testing. All personnel connected with the test were briefed on the purpose and plan for each specific test.

The checklist shown on the following page was followed.

Task	Checked By	Time
Record test conditions	_____	_____
Perform calibration of instruments	_____	_____
Check operation of deflation device	_____	_____
Check speed setting	_____	_____
Check tire pressure	_____	_____
Take pre-test photo	_____	_____
Position photographer	_____	_____
Alert observers	_____	_____
Verify recorders operational	_____	_____
Perform test	_____	_____
Take post-test photos	_____	_____
Take post-test comments and measurements	_____	_____
Repair damage and prepare for next test	_____	_____

The test conditions recorded included:

- Vehicle
- Weight
- Alignment
- Device
- Date
- Time
- Temperature
- Wind velocity
- Tire pressure
- Tire type
- Device
- Test speed
- Driver comments
- Observer comments

6.0 SUMMARY OF TESTING

This section provides a summary of each test which includes a description of the test condition and device, if any. Photographs of the devices and data records of the discriminating data channels are also presented.

Since for the majority of the tests the driver was instructed to control the truck, the lateral deviation, acceleration, and relative yaw angle between cab and trailer are minimized.

The primary measure of how the device or concept aids in a front tire failure situation is how easily the driver can maintain control of the truck. The best measure of the ease of control for the driver is the steering wheel torque required to control the truck. The truck steering wheel had an inside diameter of 1.63 feet and an outside diameter of 1.83 feet or a moment arm of 0.87 feet for a driver gripping the wheel which is close to the 1.5 feet assumed in the analytical analysis of Section 4.0. The measured steering wheel torque, in foot-pounds, must then be multiplied by 1.1 in order to convert the torque to pounds of tangential force.

The steering wheel angle is a related parameter and indicates if a change in hand holds on the steering wheel is necessary.

The lateral deviation of the truck and the cab yaw rate are measures of how successfully the driver can meet the objectives of holding the truck on course.

For those tests where steering input was delayed, the deviation at a particular time is a measure of the severity of the tire deflation.

While a high tie rod force is not necessarily a detrimental condition, lower forces seem desirable since forces higher than normal could conceivably cause additional failures or complications.

The steering wheel torque, yaw rate, and tie rod strain have been filtered with a 1-Hz low-pass filter to make the data evaluation easier.

Time averages of steering wheel torque and tie rod forces were averaged over 15 seconds.

The tests will be summarized and compared in Section 6.0.

6.1 BASELINE TESTING

This section summarizes Tests 1 through 9, Tests 19 through 22, and Test 48. As discussed in Section 5.4.1, Tests 19, 22, and 48 form the basis of evaluation for the device testing and constitute the first group of tests summarized in this section.

Tests 20 and 21 represent an empty baseline test and a test where only one shell fired, respectively. These two tests are presented together and provide an indication of the baseline performance change with loading and rate of deflation.

Tests 1 through 5 were preliminary baseline tests for procedural checkout and also to provide a baseline for evaluation of the radial and recap tires.

Finally, Tests 6 through 9 involve radial and recap tires and provide the basis for investigating influences of tire construction on the truck response.

6.1.1 Device Evaluation Basis (Tests 19, 22, and 48)

Each of Tests 19, 22, and 48 were performed with a loaded truck (GVW 73,280 pounds) with a weight of 10,400 pounds on the front axle.

The driver initiated tire failure and attempted to keep the truck on a straight course.

The front axle was equipped with a bias-ply tire and the left front tire was failed at a nominal test speed of 50 mph by shooting two solid 12 gauge slugs through both side walls.

Figures 6-1 through 6-3 are data records from Tests 19, 22, and 48. Figures 6-4 through 6-6 are post-test photographs of the tire after each baseline test.

The test data seem to be broken into three major time segments. The first segment lasts approximately 8 seconds and represents the driver providing steering input to correct for the perturbation caused by the tire losing air. The second segment bridges the gap between the other two areas of the data record and is characterized by more stable steering input with fewer high peaks. The third segment comes at the end of the event at low speed and is characterized by an oscillating steering input and tie rod force caused by the rim periodically running over the deflated tire folds.

Tables 6-I through 6-III are summaries of the data from the Baseline Tests 19, 22, and 48. The average steering wheel torque seems to be the parameter that provides the least scatter between tests and is an indication of the ability of the driver to control the vehicle. While peak steering wheel torque is also important from an impulsive loading point of view, if the load is of short duration, the vehicle does not have time to respond significantly as far as a path deviation is concerned. If the peak torque required to hold the steering wheel is greater than the strength of the driver but the duration of that high torque is short, the steering wheel will probably see a higher angle at a torque near the capability of the driver, and the driver will then overcorrect to neutralize the instantaneous inability to control the steering wheel. On the other hand, because of the impulsive nature of a steering wheel torque spike, the driver probably cannot handle as high a load as if the load were at a constant level. As will be seen in Section 7.0, there is a high degree of correlation between average and peak steering wheel torque, which means either one is an equally good measure of the ability to control the truck.

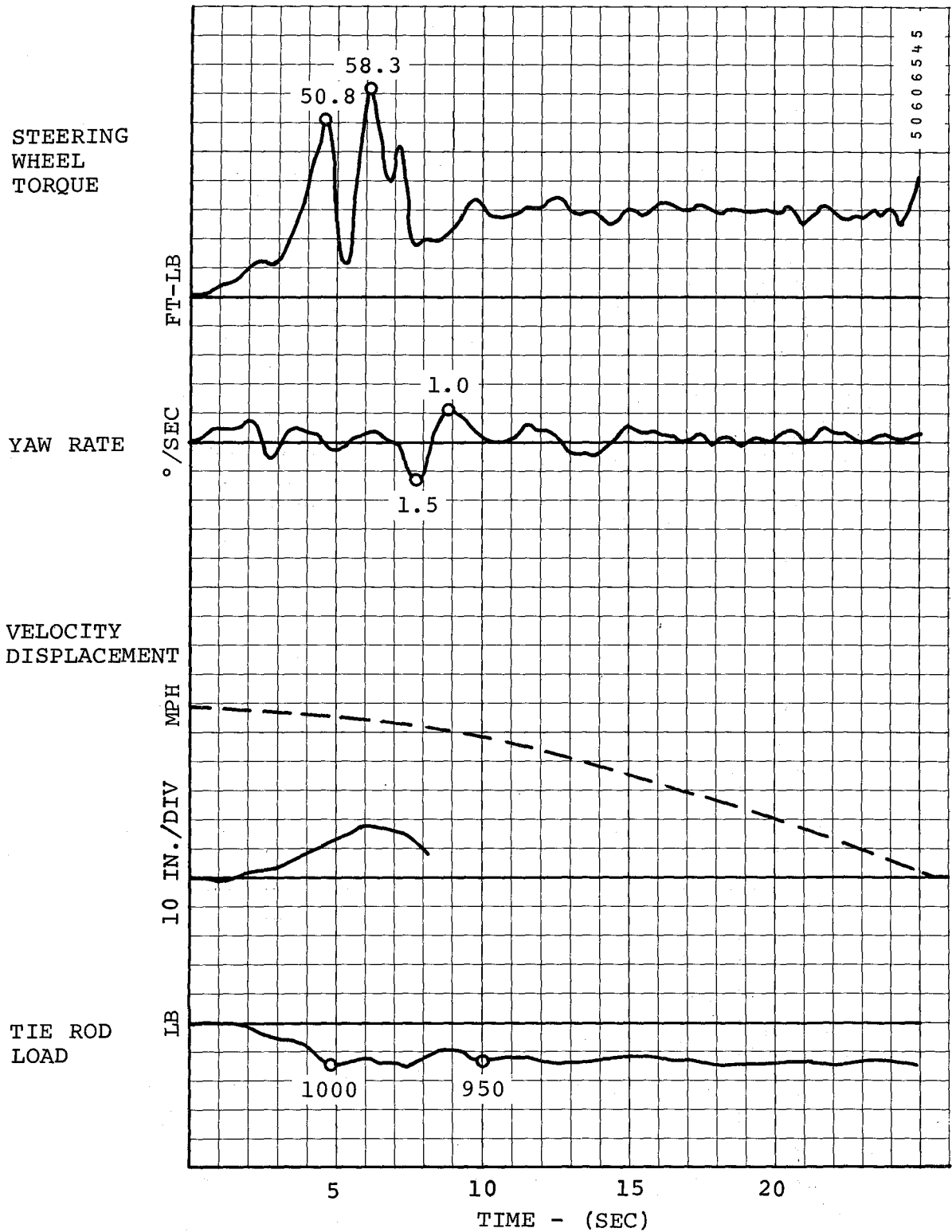


Figure 6-1. Test No. 19 - Baseline.

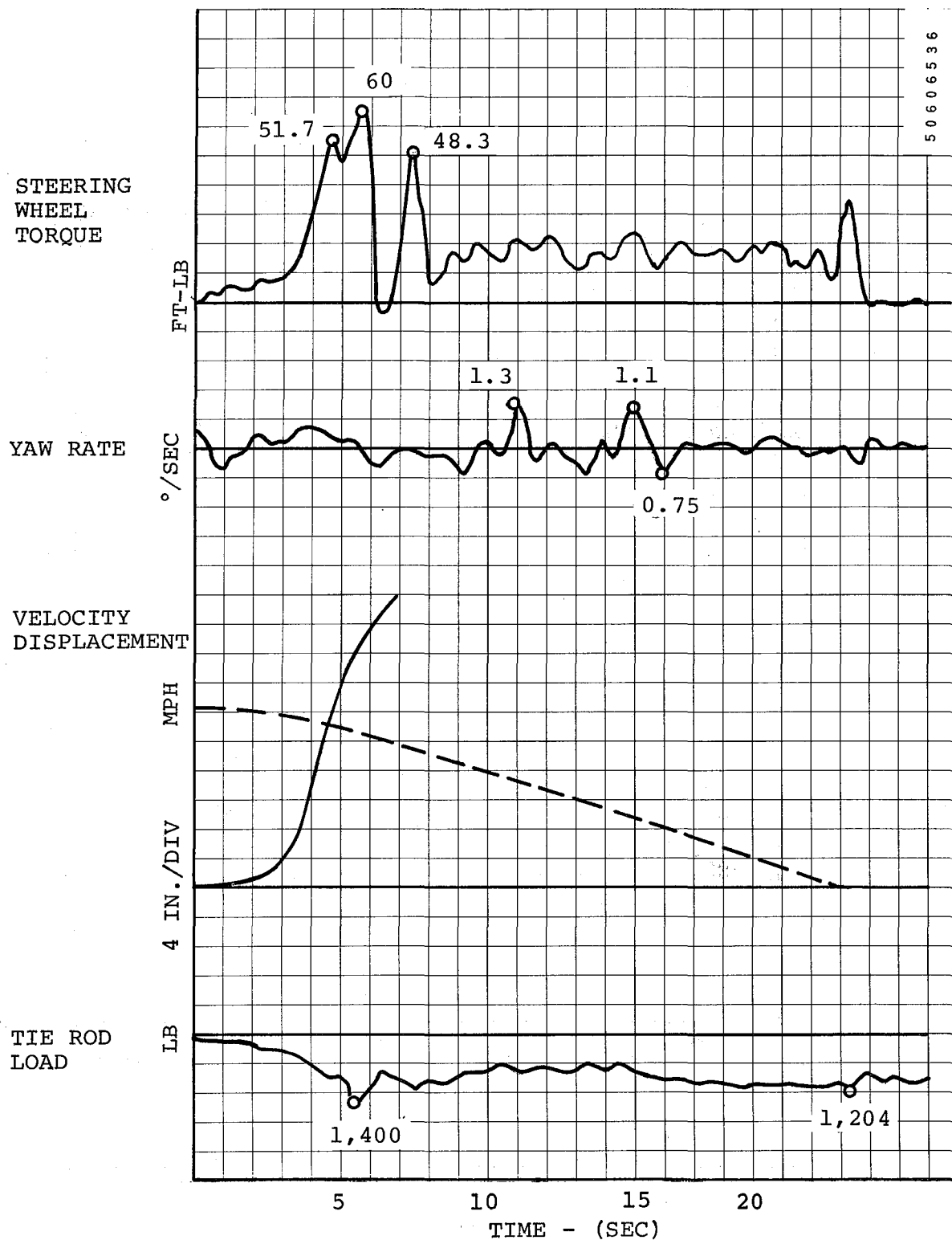


Figure 6-2. Test No. 22 - Baseline.

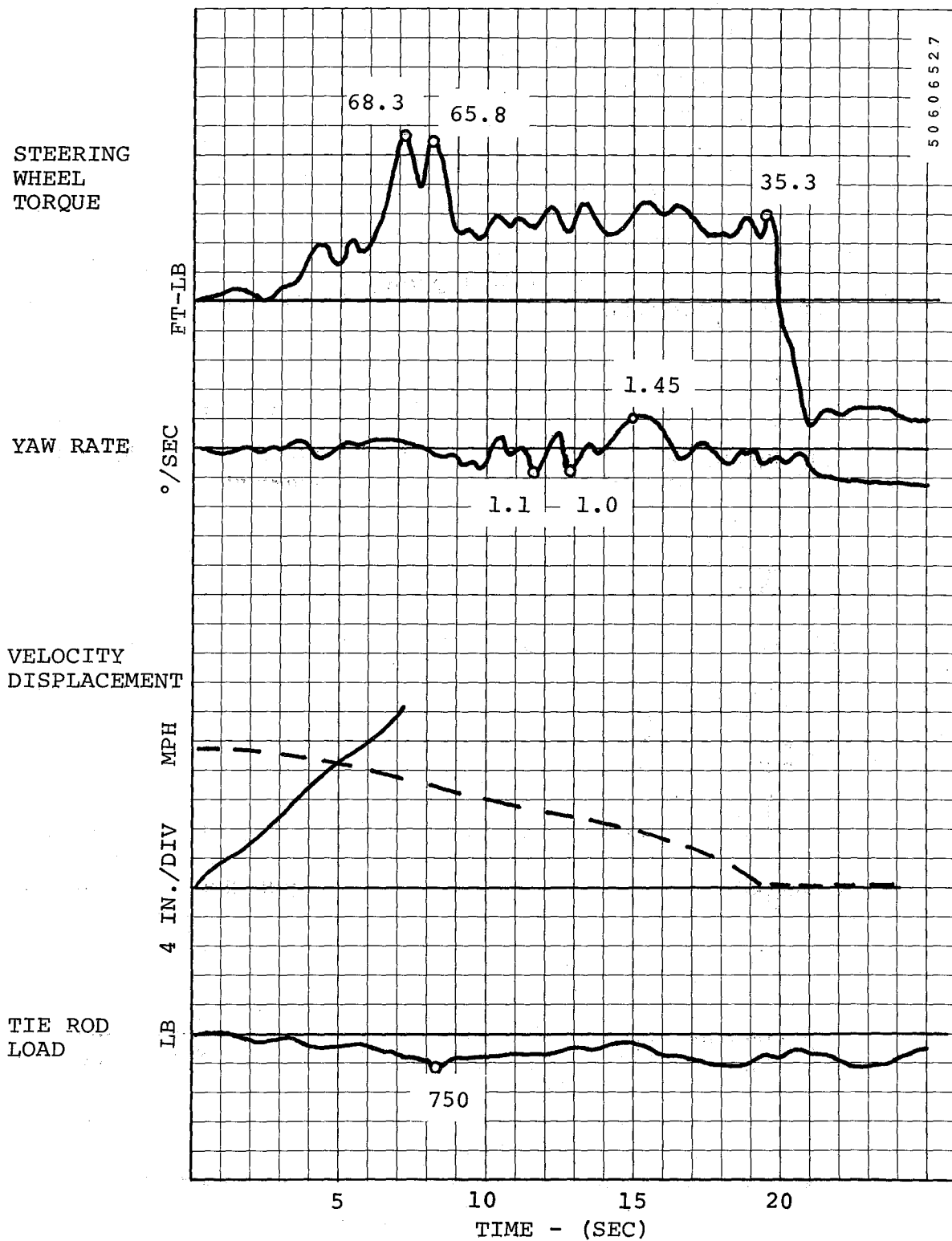


Figure 6-3. Test No. 48 - Baseline.



Figure 6-4. Test No. 19 Post-test View.



Figure 6-5. Test No. 22 Post-test View.



Figure 6-6. Test No. 48 Post-test View.

TABLE 6-I. TEST NO. 19 DATA SUMMARY

Test Date: March 26, 1975 Test Number: 19

Vehicle: International Truck Combination

Test Conditions:

Safety Device None - Baseline

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21 ft-lb

Peak Steering Wheel Torque 58.3 ft-lb at 8 sec

Maximum Steering Wheel Angle 205 deg at 8 sec

Time Averaged Tie Rod Force 581 lb

Peak Tie Rod Force 1000 lb at 6 sec

Lateral Truck Deviation After 6 Sec 1.3 ft

Maximum Lateral Deviation Within 6 Sec 1.3 ft

Rate of Lateral Deviation at 6 Sec -.03 ft/sec

Maximum Rate of Lateral Deviation Within 6 Sec .61 ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate 1.5 deg/sec at 8 sec

Maximum Tractor/Trailer Angle .49 in. 7.5 sec

Maximum Longitudinal Acceleration .15 G at 17.5 sec

Maximum Lateral Acceleration .23 G at 14.75 sec

Driver and Observer Comments: Attempted to keep truck in
straight line from beginning of test.

TABLE 6-II. TEST NO. 22 DATA SUMMARY

Test Date: March 31, 1975 Test Number: 22Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21 ft-lbPeak Steering Wheel Torque 60 ft-lb at 6 secMaximum Steering Wheel Angle No DataTime Averaged Tie Rod Force 747 lbPeak Tie Rod Force 1400 lb at 5 secLateral Truck Deviation After 6 Sec 3.7 ftMaximum Lateral Deviation Within 6 Sec 3.1 ftRate of Lateral Deviation at 6 Sec .56 ft/secMaximum Rate of Lateral Deviation Within 6 Sec 1.09 ft/secInitial Vehicle Velocity 48 mphMaximum Tractor Yaw Rate 1.3 deg/sec at 11 secMaximum Tractor/Trailer Angle .5 in. 13.5 secMaximum Longitudinal Acceleration .3 GMaximum Lateral Acceleration .2 G

Driver and Observer Comments: Driver controlled truck from
initiation of tire deflation and attempted to hold truck on
initial course.

TABLE 6-III. TEST NO. 48 DATA SUMMARY

Test Date: May 7, 1975 Test Number: 48

Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Baseline)

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 27 ft-lb

Peak Steering Wheel Torque 68.3 ft-lb at 7 sec

Maximum Steering Wheel Angle 155 deg at 11 sec

Time Averaged Tie Rod Force 371 lb

Peak Tie Rod Force 750 lb at 8.5 sec

Lateral Truck Deviation After 6 Sec 1.67 ft

Maximum Lateral Deviation Within 6 Sec 1.67 ft

Rate of Lateral Deviation at 6 Sec .23 ft/sec

Maximum Rate of Lateral Deviation Within 6 Sec .39 ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate 1.45 deg/sec at 15 sec

Maximum Tractor/Trailer Angle 1.4 in. at 16 sec

Maximum Longitudinal Acceleration .32 G at 12.3 sec

Maximum Lateral Acceleration .11 G at 15.2 sec

Driver and Observer Comments: _____

The data from the three baseline tests were averaged to form the average baseline test as summarized in Table 6-IV. Note that the average steering wheel torque is 23 ft-lb, the peak steering wheel angle is 180 degrees, and the average tie rod force is 717 pounds.

6.1.2 Empty and Slow Deflation Baseline Tests (Tests 20 and 21)

Tests 20 and 21 were run identical to the Baseline Tests 19, 22, and 48 except that the truck was lightly loaded for Test 20 and only one shell fired in the tire deflation device for Test 21.

The lightly loaded GVW is 28,380 pounds with a front axle weight of 7,930 pounds.

Figures 6-7 and 6-8 are data records from Tests 20 and 21, respectively. Tables 6-V and 6-VI summarize the data from the two tests.

For the lightly loaded truck, the average steering wheel torque was not significantly lower than the loaded baseline, although the peak seems to be less severe than for the loaded truck. The tie rod forces are also somewhat lower.

It appears that the front tire failure with an empty truck is less severe than that for a loaded truck.

It should be noted that while the GVW of the truck combination changes significantly from the lightly loaded truck to the heavily loaded truck (28,380 pounds to 73,280 pounds, 158-percent increase), the front axle load, which drastically affects steering, does not change as severely (7,930 pounds to 10,300 pounds, 30-percent increase).

For the slowly deflating tire, the average steering wheel torque was higher while the peak torque was not significantly higher.

Based on this test, it appears that for a slow deflation, the forces are slightly higher on the average but do not necessarily have peaks as high as for a more rapid tire deflation.

TABLE 6-IV. AVERAGE BASELINE TEST (BASIC FOR DEVICE TESTS,
19, 22, AND 48)

Test Date: _____ Test Number: _____

Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Baseline)
Vehicle Weight (lb) 73280
Tire Type Bias Ply
Tire Pressure (psi) 90
Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 23 ft-lb
Peak Steering Wheel Torque 62.2 ft-lb at 7 sec
Maximum Steering Wheel Angle 180 deg at 9.5 sec
Time Averaged Tie Rod Force 717 lb
Peak Tie Rod Force 1,050 lb at 6.5 sec
Lateral Truck Deviation After 6 Sec 2 ft
Maximum Lateral Deviation Within 4 Sec 2.2 ft
Rate of Lateral Deviation at 4 Sec .25 ft/sec
Maximum Rate of Lateral Deviation Within 4 Sec .70 ft/sec
Initial Vehicle Velocity 49 mph
Maximum Tractor Yaw Rate 1.42 deg/sec at 11 sec
Maximum Tractor/Trailer Angle .8 in 13 sec
Maximum Longitudinal Acceleration .26 G at 15 sec
Maximum Lateral Acceleration .18 G at 11 sec

Driver and Observer Comments: _____

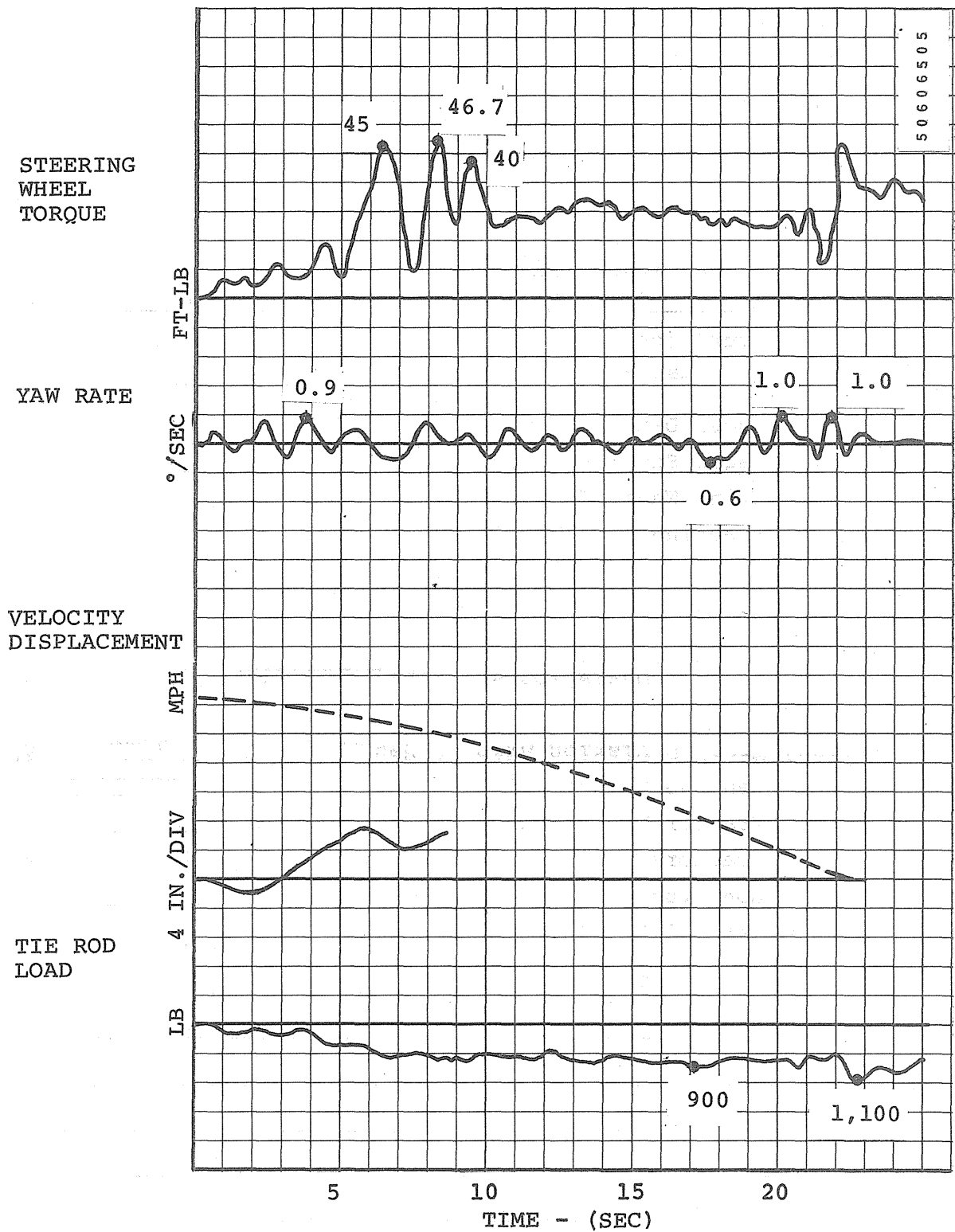


Figure 6-7. Test No. 20 - Empty Baseline.

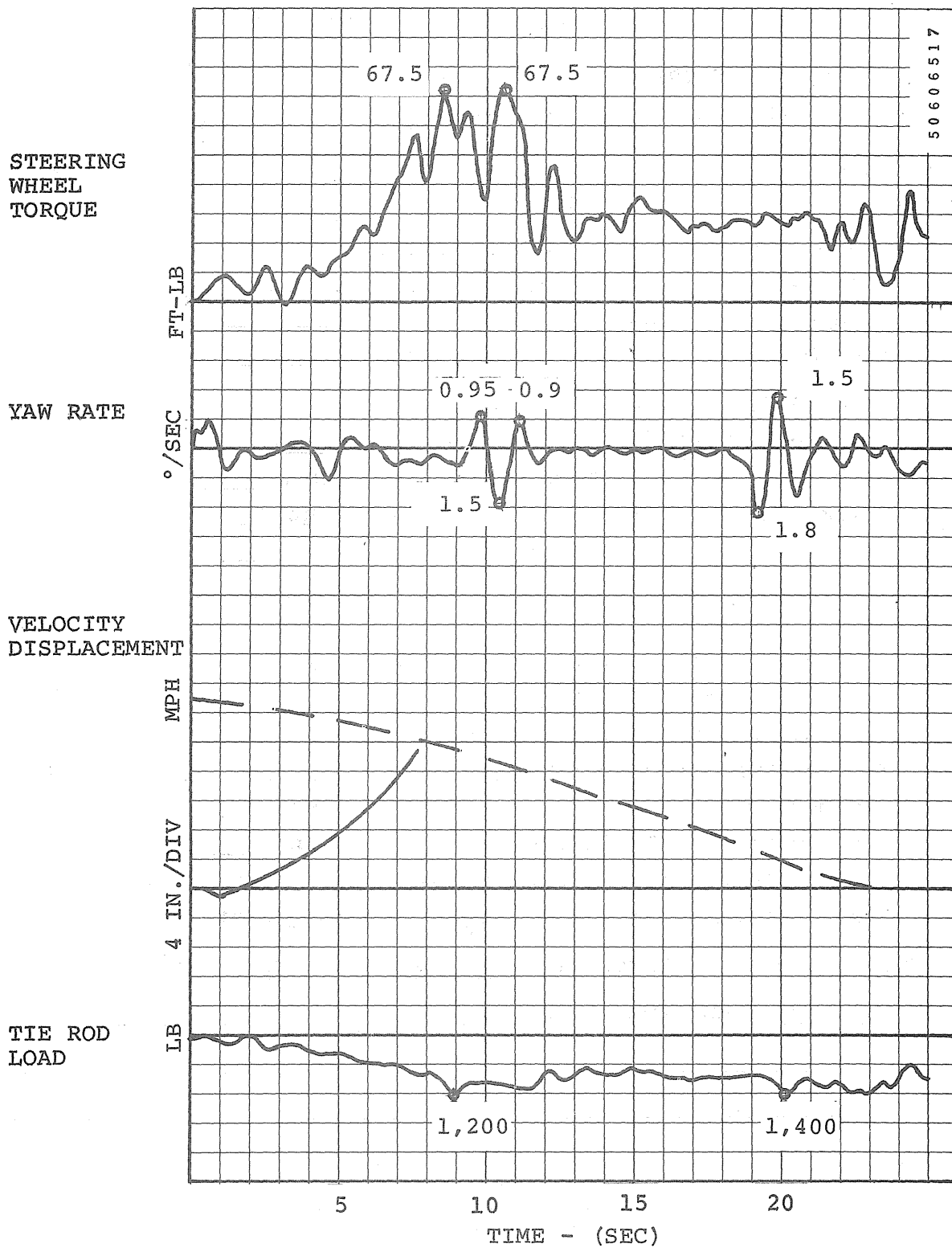


Figure 6-8. Test No. 21 - Slow Deflation Baseline.

TABLE 6-V. TEST NO. 20 DATA SUMMARY

Test Date: March 26, 1975 Test Number: 20Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 28380Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21 ft-lbPeak Steering Wheel Torque 46.7 ft-lb at 8 secMaximum Steering Wheel Angle 150 deg at 8 secTime Averaged Tie Rod Force 433 lbPeak Tie Rod Force 1100 lb at 24 secLateral Truck Deviation After 6 Sec .6 ftMaximum Lateral Deviation Within 6 Sec .7 ftRate of Lateral Deviation at 6 Sec .25 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .4 ft/secInitial Vehicle Velocity 52 mphMaximum Tractor Yaw Rate 1.0 deg/sec at 20 secMaximum Tractor/Trailer Angle .68 in 18 secMaximum Longitudinal Acceleration .5 G at 10.5 secMaximum Lateral Acceleration .35 G at 16.5 secDriver and Observer Comments: Continuous steering control,
attempting to keep truck straight.

TABLE 6-VI. TEST NO. 21 DATA SUMMARY

Test Date: March 31, 1975 Test Number: 21

Vehicle: International Truck Combination

Test Conditions:

Safety Device None - Baseline
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 32 ft-lb
 Peak Steering Wheel Torque 67.5 ft-lb at 9 sec
 Maximum Steering Wheel Angle 200 deg at 11 sec
 Time Averaged Tie Rod Force 587 lb
 Peak Tie Rod Force 1400 lb at 9 sec
 Lateral Truck Deviation After 6 Sec 1 ft
 Maximum Lateral Deviation Within 6 Sec 1 ft
 Rate of Lateral Deviation at 6 Sec .32 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec .53 ft/sec
 Initial Vehicle Velocity 51 mph
 Maximum Tractor Yaw Rate 1.8 deg/sec at 11.5 sec
 Maximum Tractor/Trailer Angle .5 in. 11.75 sec
 Maximum Longitudinal Acceleration .27 G at 12 sec
 Maximum Lateral Acceleration .30 G at 11.75 sec

Driver and Observer Comments: Steering control input from
initiation of tire deflation. One shell fired from gun which
caused slower deflation.

6.1.3 Preliminary Baselines (Tests 1 through 5)

All tests for this series involved deflating a bias-ply tire. Tests 2, 3, and 5 were heavily loaded at a GVW of 73,280 pounds, and Tests 1 and 4 were at the light load of 28,380 pounds.

The steering control input was delayed for approximately two seconds after the initiation of the tire deflation. At the end of the two seconds, the driver brought the vehicle under control but did not attempt to bring the truck back to its original course.

Since these tests were preliminary, some of the data are missing; however, test data summary sheets are presented for the available data as shown in Tables 6-VII through 6-XI. The acceleration data from these tests do not directly compare with most of the subsequent tests. The accelerometers were initially mounted in the cab which had a lot of local vibration.

The steering wheel torque and tie rod forces from Tests 1 through 4 are unfiltered and cannot be directly compared with later tests filtered at 1 Hz.

The maximum trailer yaw rate seems to be a fairly good basis for comparison between these preliminary baseline tests with a mean peak yaw rate of 12.8 deg/sec for the available loaded baseline data and 11.0 deg/sec for the unloaded baseline.

From Test 5 on, the steering wheel torque, tie rod force, and yaw rate were filtered at 1 Hz to smooth the data. Figure 6-9 is data records from Test 5 with these parameters filtered at 1 Hz.

6.1.4 Tire Construction Tests

Tests 5 through 9 involve tests with radial-ply and recap tires. A Cantilever-type tire is tested as Tests 42 and 43 as a concept to diminish the effect of the tire deflation on truck control.

TABLE 6-VII. TEST NO. 1 DATA SUMMARY

Test Date: March 6, 1975 Test Number: 1

Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Preliminary Test)

Vehicle Weight (lb) 28380

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque No Data ft-lb

Peak Steering Wheel Torque* 35 ft-lb

Maximum Steering Wheel Angle 40 deg

Time Averaged Tie Rod Force No Data lb

Peak Tie Rod Force* 2800 lb

Lateral Truck Deviation After 4 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec No Data ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec No Data ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate No Data at sec

Maximum Tractor/Trailer Angle 2 in. at 13 sec

Maximum Longitudinal Acceleration** .4 G at 11 sec

Maximum Lateral Acceleration** .8 G at 9 sec

Driver and Observer Comments: Delayed steering input for 2
seconds after initiation of tire deflation.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-VIII. TEST NO. 2 DATA SUMMARY

Test Date: February 21, 1975 Test Number: 2Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Preliminary Test)Vehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque No Data ft-lbPeak Steering Wheel Torque* 70 ft-lbMaximum Steering Wheel Angle 120 degTime Averaged Tie Rod Force No Data lbPeak Tie Rod Force No Data lbLateral Truck Deviation After 4 Sec No Data ftMaximum Lateral Deviation Within 4 Sec No Data ftRate of Lateral Deviation at 4 Sec No Data ft/secMaximum Rate of Lateral Deviation Within 4 Sec No Data ft/secInitial Vehicle Velocity 51 mphMaximum Tractor Yaw Rate No Data in./secMaximum Tractor/Trailer Angle .8 in.Maximum Longitudinal Acceleration** .32 GMaximum Lateral Acceleration** .72 GDriver and Observer Comments: Preliminary Test.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-IX. TEST NO. 3 DATA SUMMARY

Test Date: March 6, 1975 Test Number: 3

Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Preliminary Test)

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque No Data ft-lb

Peak Steering Wheel Torque* 55 ft-lb

Maximum Steering Wheel Angle 40 deg

Time Averaged Tie Rod Force* No Data lb

Peak Tie Rod Force 2800 lb

Lateral Truck Deviation After 4 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec 5 ft

Rate of Lateral Deviation at 4 Sec 4.8 ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec 7.4 ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate* No Data deg/sec at No Data sec

Maximum Tractor/Trailer Angle 3 in. at 15.7 sec

Maximum Longitudinal Acceleration** .48 G at 9 sec

Maximum Lateral Acceleration** .90 G at 5.2 sec

Driver and Observer Comments: Delayed steering input for 2
seconds after initiation of tire deflation.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-X. TEST NO. 4 DATA SUMMARY

Test Date: February 21, 1975 Test Number: 4

Vehicle: International Truck Combination

Test Conditions:

Safety Device None (Preliminary Test)

Vehicle Weight (lb) 28280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque No Data ft-lb

Peak Steering Wheel Torque* 50 ft-lb

Maximum Steering Wheel Angle 110 deg

Time Averaged Tie Rod Force No Data lb

Peak Tie Rod Force No Data lb

Lateral Truck Deviation After 4 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec No Data ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 6 Sec No Data ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate No Data deg/sec

Maximum Tractor/Trailer Angle No Data deg

Maximum Longitudinal Acceleration** .17 G at 3.2 sec

Maximum Lateral Acceleration** .5 G at 16.2 sec

Driver and Observer Comments: Preliminary Test

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab location later changed.

TABLE 6-XI. TEST NO. 5 DATA SUMMARY

Test Date: March 10, 1975 Test Number: 5Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 5.3 ft-lbPeak Steering Wheel Torque 16 ft-lbMaximum Steering Wheel Angle 35 degTime Averaged Tie Rod Force 217 lbPeak Tie Rod Force 554 lbLateral Truck Deviation After 4 Sec 2.1 ftMaximum Lateral Deviation Within 4 Sec 2.1 ftRate of Lateral Deviation at 4 Sec 2.7 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 4.9 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate* 12.3 deg/sec at 10.7 secMaximum Tractor/Trailer Angle 3 in. at 15.5 secMaximum Longitudinal Acceleration** .47 G at 5.5 secMaximum Lateral Acceleration** .50 G at 10 secDriver and Observer Comments: Delayed steering input for 2
seconds after initiation of tire deflation.

*Unfiltered peak which cannot necessarily be directly compared
with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mount-
ing point in cab - location later changed.

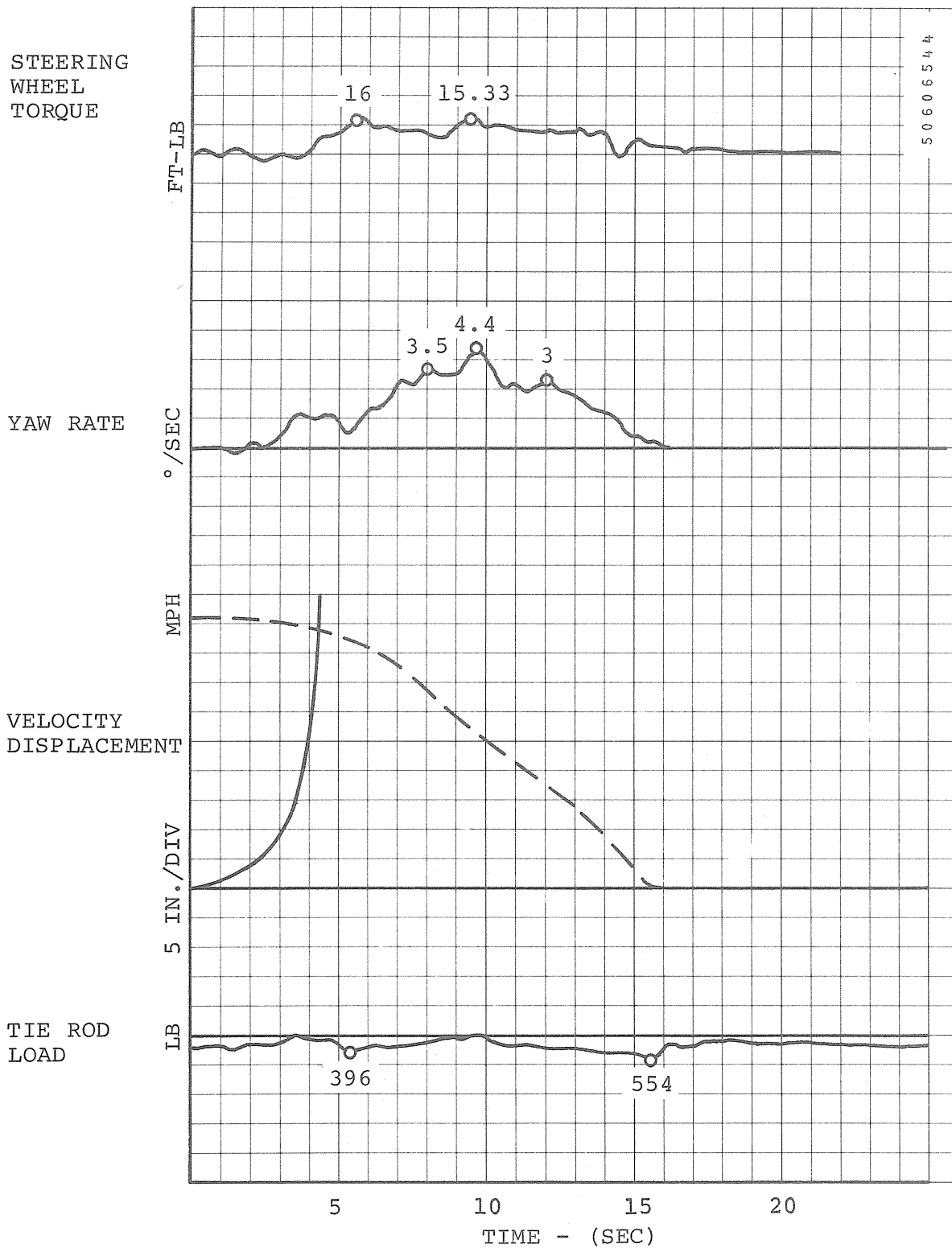


Figure 6-9. Test No. 5 - Preliminary Baseline.

6.1.4.1 Retread Tires (Tests 6 and 8)

Both Tests 6 and 8 were run like Test 5 except that Test 8 involved a lightly loaded truck. Figures 6-10 and 6-11 are data records from Tests 6 and 8.

Tables 6-XII and 6-XIII summarize the data from Tests 6 and 8.

Figure 6-12 shows a typical post-test view of the retread tire.

The peak yaw rate for these tires is significantly less than for the preliminary baseline tests which indicates that perhaps the stiffer tread of a recap is beneficial in the event of a front tire failure.

6.1.4.2 Radial Ply Tires (Tests 7 and 9)

Both Tests 7 and 9 were run like preliminary Baseline Test 5 except that Test 9 involved a lightly loaded truck.

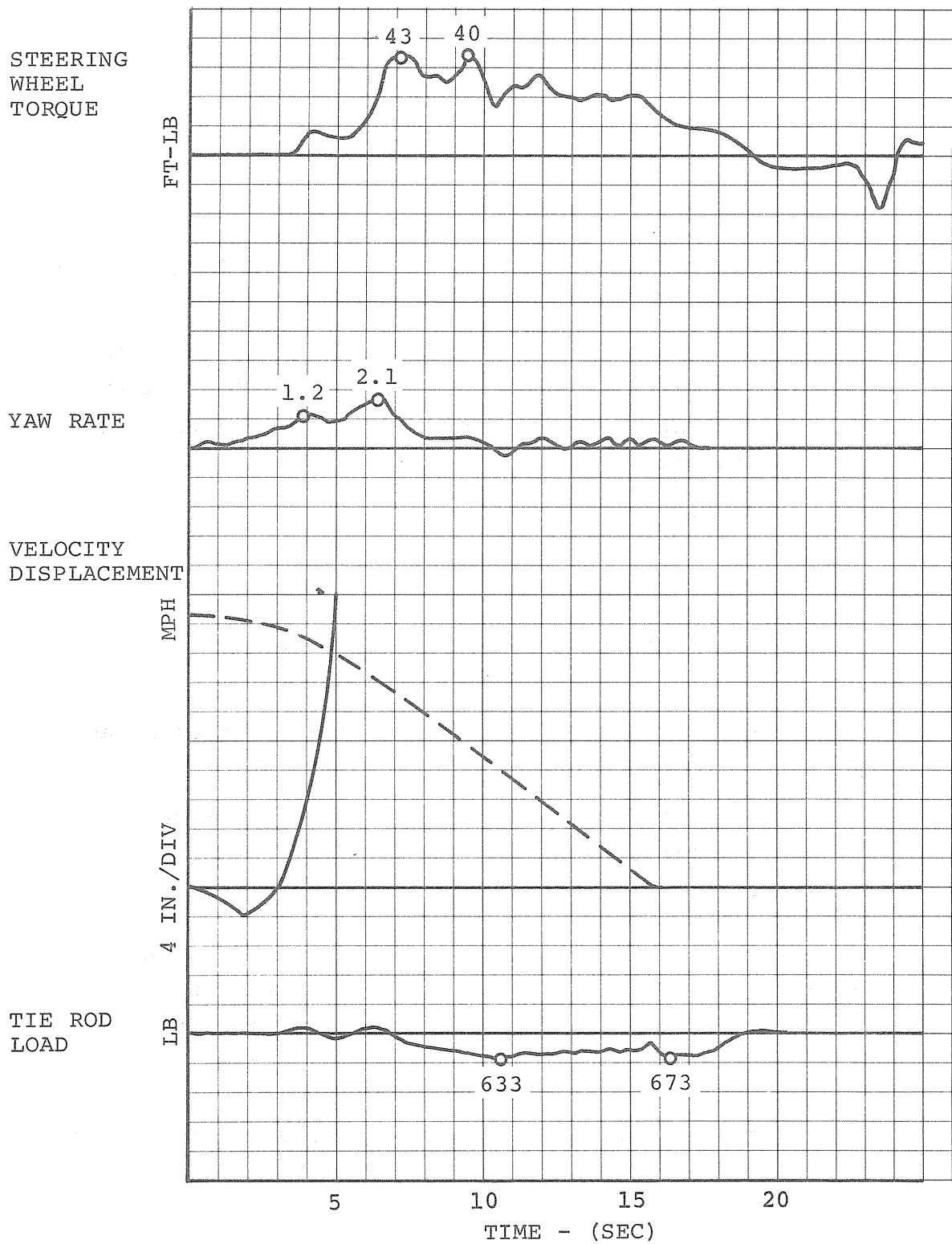
Figures 6-13 and 6-14 are data records from Tests 7 and 9.

Tables 6-XIV and 6-XV summarize the data from these two tests. Figure 6-15 shows a typical post-test view of a radial tire.

The peak yaw rate appears to be reduced as a result of using radial-ply tires.

6.2 ALIGNMENT TESTS (TESTS 10 THROUGH 15)

Since camber is not a standard adjustable alignment for a solid axle truck and involves bending the front axle, camber was not changed. The caster was changed to +2 degrees for Tests 10 and 11. In addition to the +2 degree caster, one inch of tow-in was added for Tests 12 and 13. Tests 14 and 15 involved only the one-inch tow-in. Tests 10, 12, and 15 used a heavily loaded truck.



50606542

Figure 6-10. Test No. 6 - Retread Tire Test.

STEERING
WHEEL
TORQUE

FT-LB

33

31

34

38

50606534

YAW RATE

°/SEC

1.2

1.05

0.07

0.07

VELOCITY
DISPLACEMENT

MPH

5 IN./DIV

TIE ROD
LOAD

LB

475

554

5

10

15

20

TIME - (SEC)

Figure 6-11. Test No. 8 - Retread Tire Test.

TABLE 6-XII. TEST NO. 6 DATA SUMMARY

Test Date: March 10, 1975 Test Number: 6Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 73280Tire Type RetreadTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 17 ft-lbPeak Steering Wheel Torque 43 ft-lbMaximum Steering Wheel Angle 80 degTime Averaged Tie Rod Force 271 lbPeak Tie Rod Force 673 lbLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 1.0 ftRate of Lateral Deviation at 4 Sec 2.3 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 5.4 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate* 7.5 deg/sec at 3.5 secMaximum Tractor/Trailer Angle 1 in. at 6.5 secMaximum Longitudinal Acceleration** .37 G at 3.5 secMaximum Lateral Acceleration** .35 G at 6.5 secDriver and Observer Comments: Delayed steering input for 2seconds after initiation at tire deflation. Tire did not un-seat from rim.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration at mounting point in cab - location later changed.

TABLE 6-XIII. TEST NO. 8 DATA SUMMARY

Test Date: March 11, 1975 Test Number: 8Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 28380Tire Type RetreadTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 14.3 ft-lbPeak Steering Wheel Torque 38 ft-lb at 15 secMaximum Steering Wheel Angle No Data degTime Averaged Tie Rod Force 313 lbPeak Tie Rod Force 554 lb at 11.5 secLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 1.6 ftRate of Lateral Deviation at 4 Sec 1.31 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 3.71 ft/secInitial Vehicle Velocity 48 mphMaximum Tractor Yaw Rate* 10 deg/sec at 9 secMaximum Tractor/Trailer Angle .3 in. 17 secMaximum Longitudinal Acceleration** .34 G at 11 secMaximum Lateral Acceleration** .4 G at 12.7 secDriver and Observer Comments: Delayed steering input for 2
seconds after initiation of tire deflation.*Unfiltered peak which cannot necessarily be directly compared
with later tests or summary table of filtered data.**Acceleration peaks are high due to local acceleration of mount-
ing point in cab - location later changed.

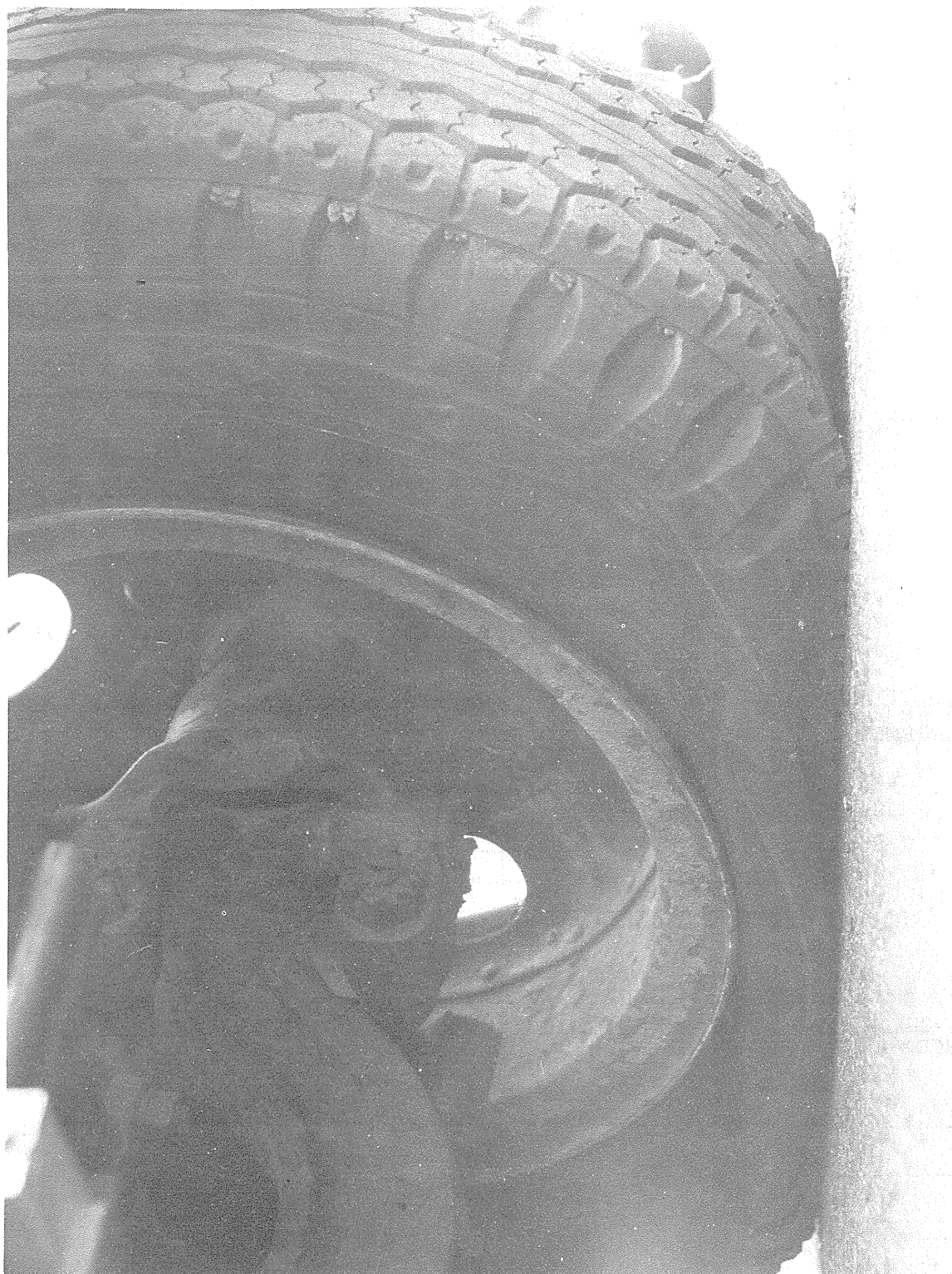


Figure 6-12. Test No. 6 Post-test View of Retread Tire.

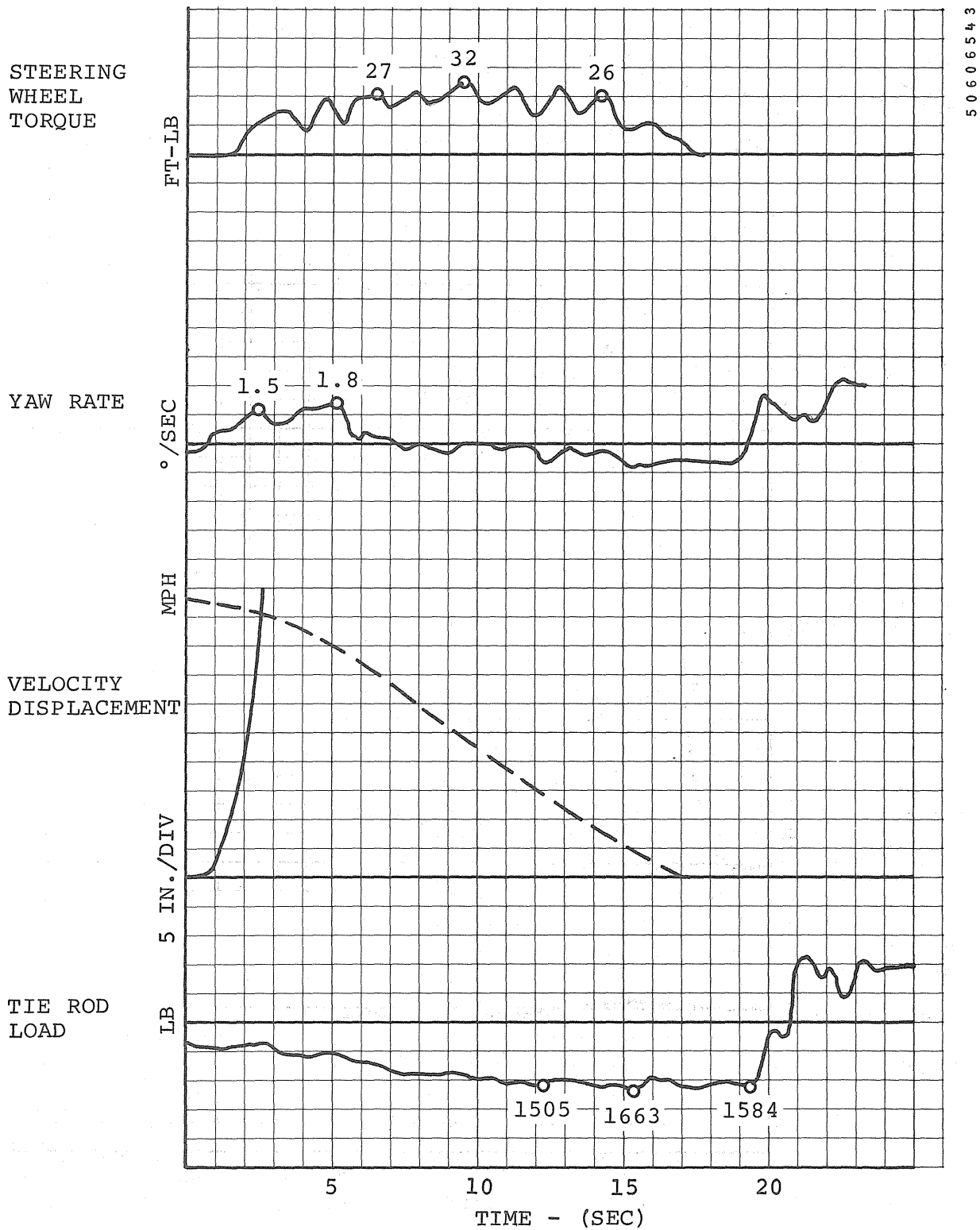


Figure 6-13. Test No. 7 - Radial Tire Test.

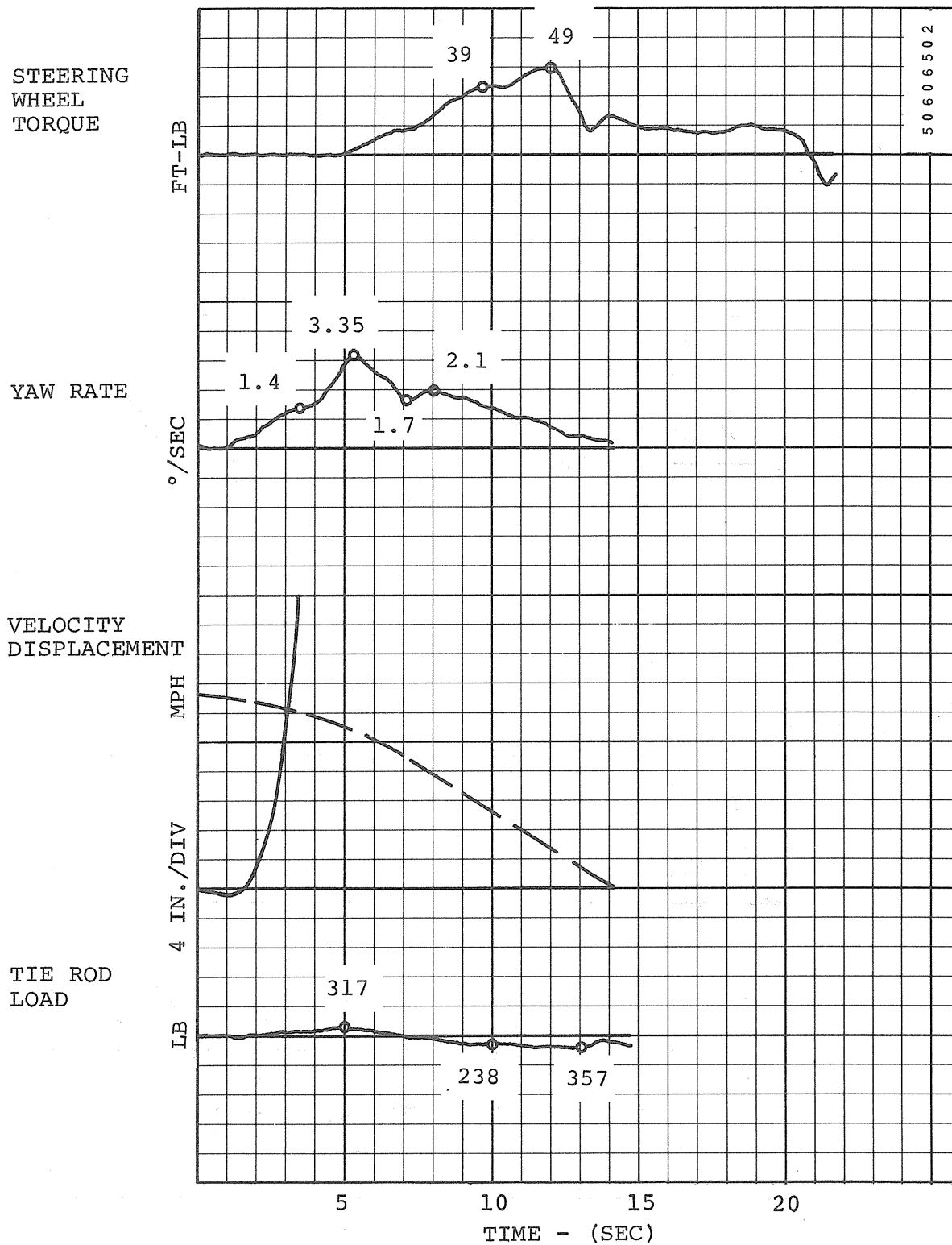


Figure 6-14. Test No. 9 - Radial Tire Test.

TABLE 6-XIV. TEST NO. 7 DATA SUMMARY

Test Date: March 10, 1975 Test Number: 7Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 73280Tire Type RadialTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 16 ft-lbPeak Steering Wheel Torque 32 ft-lbMaximum Steering Wheel Angle 50 degTime Averaged Tie Rod Force 433 lbPeak Tie Rod Force 1663 lbLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 9.3 ftRate of Lateral Deviation at 4 Sec No Data ft/secMaximum Rate of Lateral Deviation Within 4 Sec 6.6 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate* 6 deg/sec at 6 secMaximum Tractor/Trailer Angle 1.5 deg at 5.5 secMaximum Longitudinal Acceleration** .37 G at 1.0 secMaximum Lateral Acceleration** .45 G at 4 sec

Driver and Observer Comments: Delayed steering input for 2
seconds after initiation of tire deflation. Larger hole in tire.

*Unfiltered peak which cannot necessarily be directly compared
 with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration at mounting point in cab - location later changed.

TABLE 6-XV. TEST NO. 9 DATA SUMMARY

Test Date: March 11, 1975 Test Number: 9Vehicle: International Truck Combination

Test Conditions:

Safety Device None
 Vehicle Weight (lb) 28380
 Tire Type Radial
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 18.8 ft-lb
 Peak Steering Wheel Torque 49 ft-lb at 12 sec
 Maximum Steering Wheel Angle 50 deg
 Time Averaged Tie Rod Force 157 lb
 Peak Tie Rod Force 357 lb at 13 sec
 Lateral Truck Deviation After 6 Sec No Data ft
 Maximum Lateral Deviation Within 4 Sec 6.8 ft
 Rate of Lateral Deviation at 4 Sec 7.1 ft/sec
 Maximum Rate of Lateral Deviation Within 4 Sec 7.1 ft/sec
 Initial Vehicle Velocity 48 mph
 Maximum Tractor Yaw Rate* 5 deg/sec at 4.5 sec
 Maximum Tractor/Trailer Angle 3.35 deg at 5.2 sec
 Maximum Longitudinal Acceleration** .35 G at 8.5 sec
 Maximum Lateral Acceleration** .5 G at 12 sec

Driver and Observer Comments: Delayed steering control for 2
seconds after initiation of tire deflation.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.
 **Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

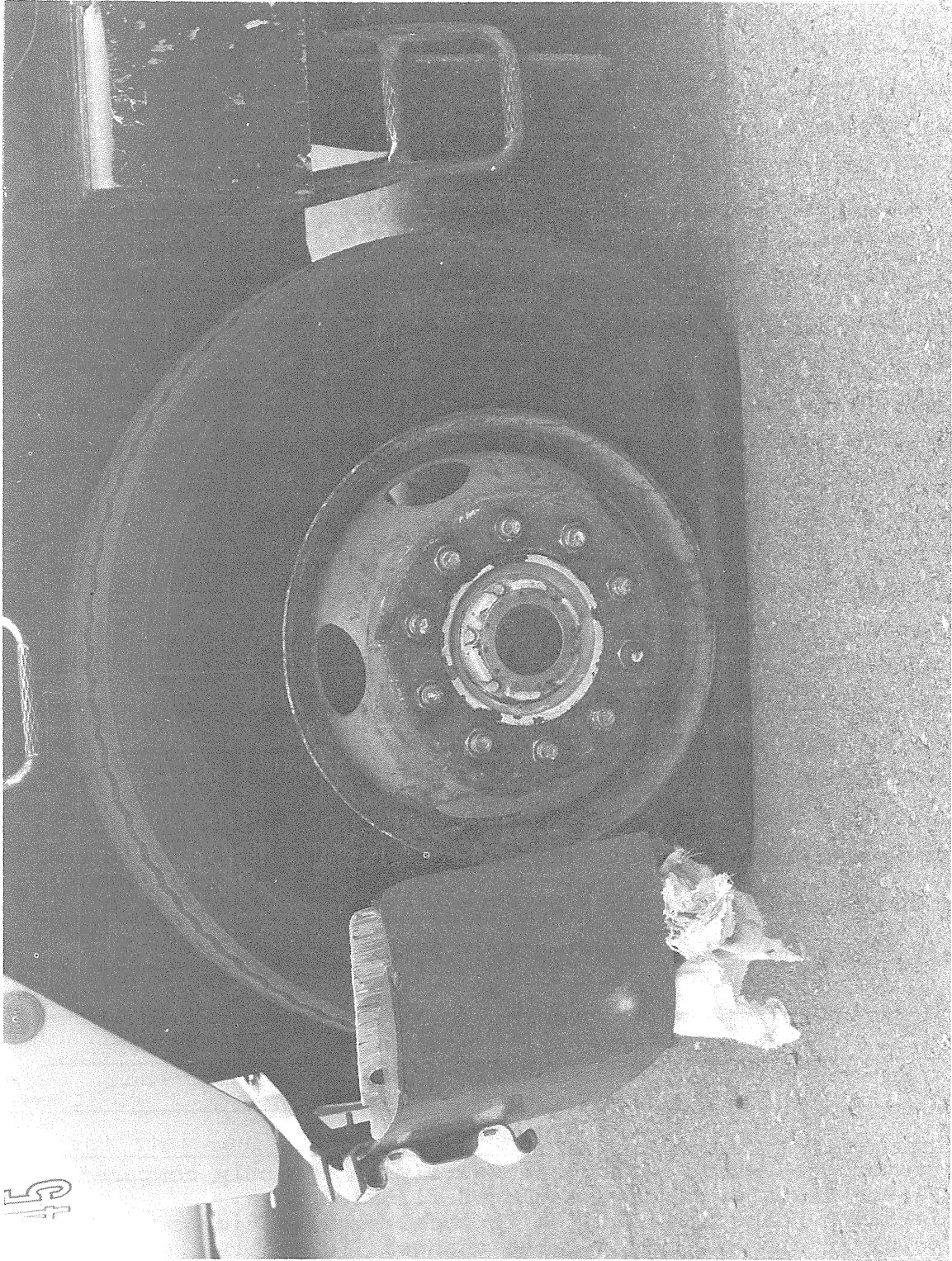


Figure 6-15. Test No. 7 Post-test View of Radial Tire Test.

The steering wheel was released for approximately two seconds for Tests 10 and 11, completely released for the duration of the test for Test 12, and released for approximately 5 seconds for Tests 14 and 15.

Figures 6-16 through 6-21 are data records from Tests 10 through 15.

Tables 6-XVI through 6-XXI summarize the data from Tests 10 through 15.

No significant improvement in truck performance during a tire deflation was observed from the data as a result of these equipment changes.

6.3 DEVICE TESTS

This section presents the results from the devices and concepts tested during this program. These results are to be compared with the baseline tests presented in Section 6.1.1.

6.3.1 Spring-Type Devices

6.3.1.1 Two Parallel Noncollinear Springs

Steer Safe (Tests 33, 34, 29, and 30)

The Steer Safe device consists of two parallel springs as described in Section 4.1.1. Figure 6-22 is a photograph of the Steer Safe device installed on the test truck.

The device was tested for Tests 29 and 30 where only one shell fired in the tire deflation device. The tests were repeated as Tests 33 and 34 where both shells fired. Figures 6-23 through 6-26 are data records from Tests 33, 34, 29, and 30, and Tables 6-XXII through 6-XXV summarize the data from these tests.

There was no evidence of improvement in performance of the truck during a front tire deflation over the baseline tests for Tests 33 and 34. Tests 29 and 30, however, indicate a lower average steering wheel torque and tie rod force for the slow deflation tests. This represents an improvement after Test 21 which was the baseline test with only one shell firing.

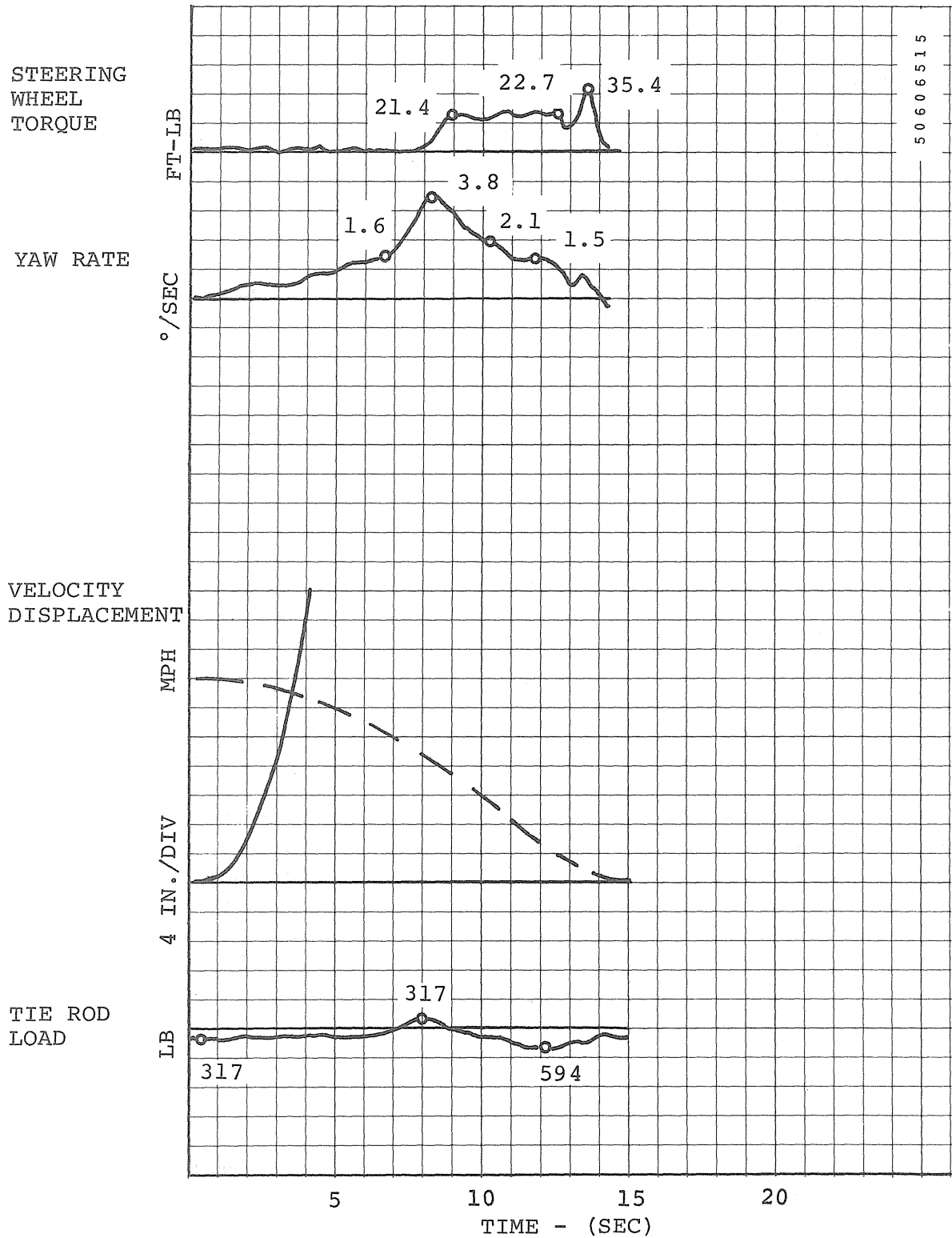


Figure 6-16. Test No. 10 - Positive 2 Caster Alignment Test.

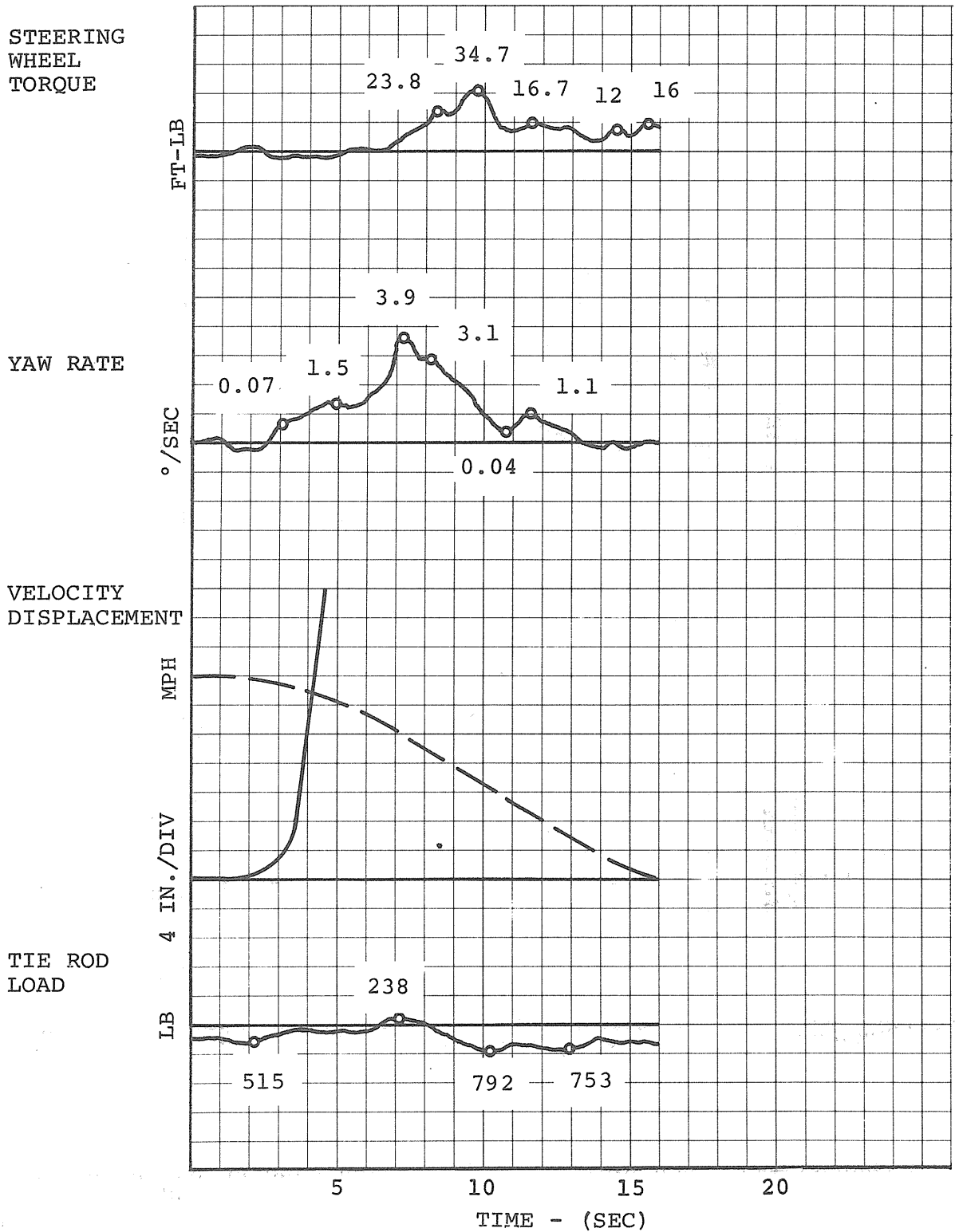


Figure 6-17. Test No. 11 - Positive 2 Caster Alignment Test.

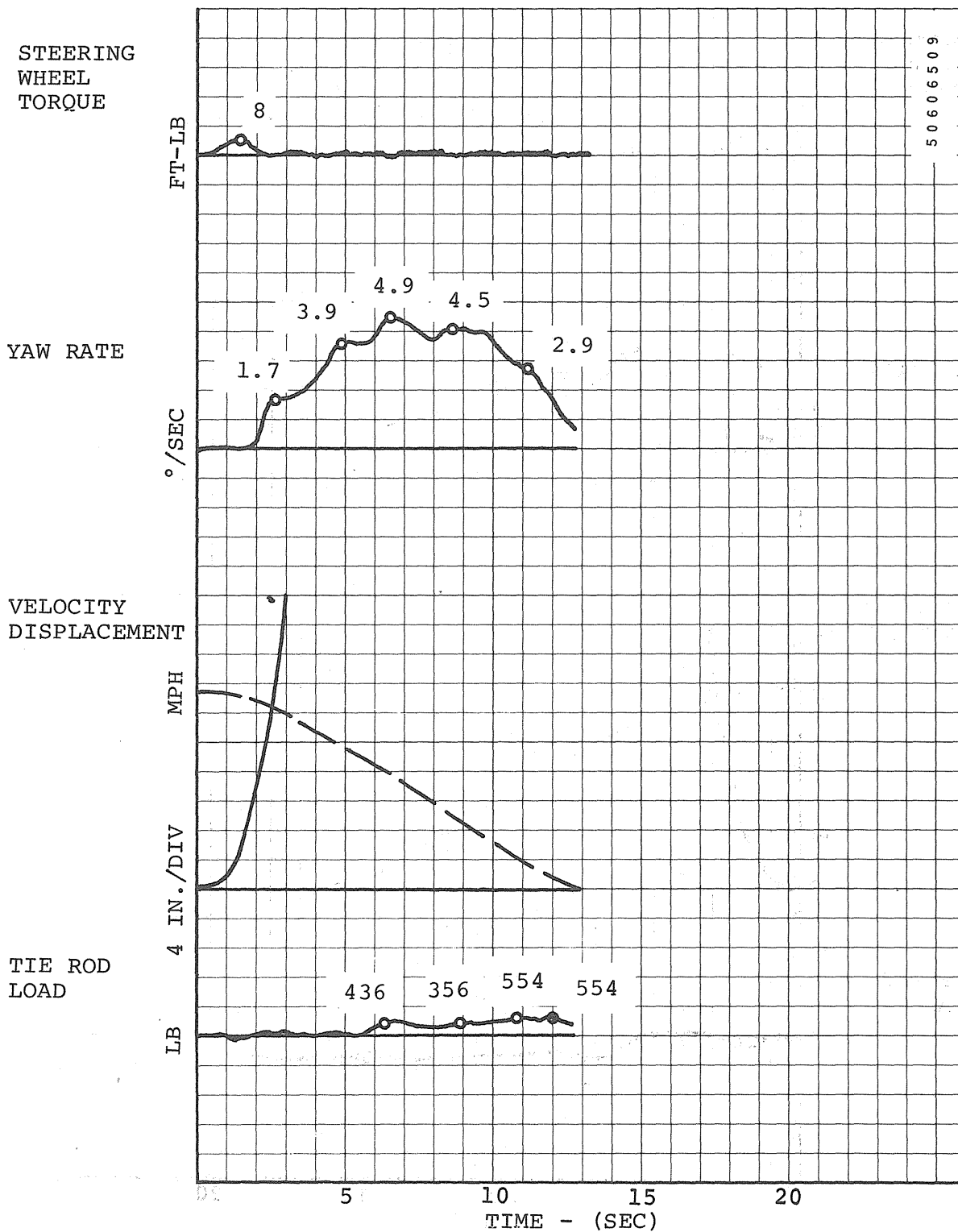


Figure 6-18. Test No. 12 - One Inch Tow-in and Positive 2 Caster Alignment Test.

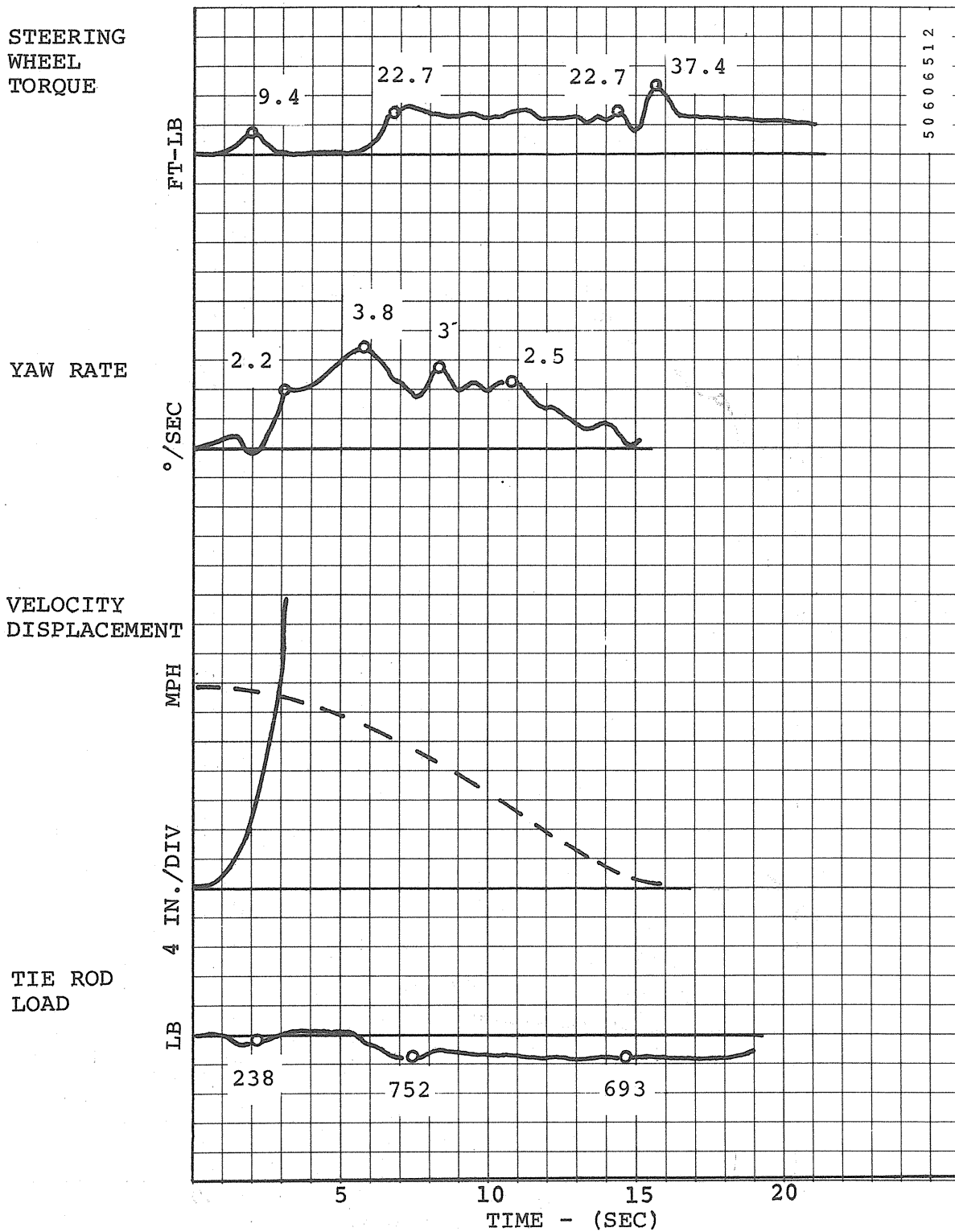


Figure 6-19. Test No. 13 - One Inch Tow-in and Positive 2 Caster Alignment Test.

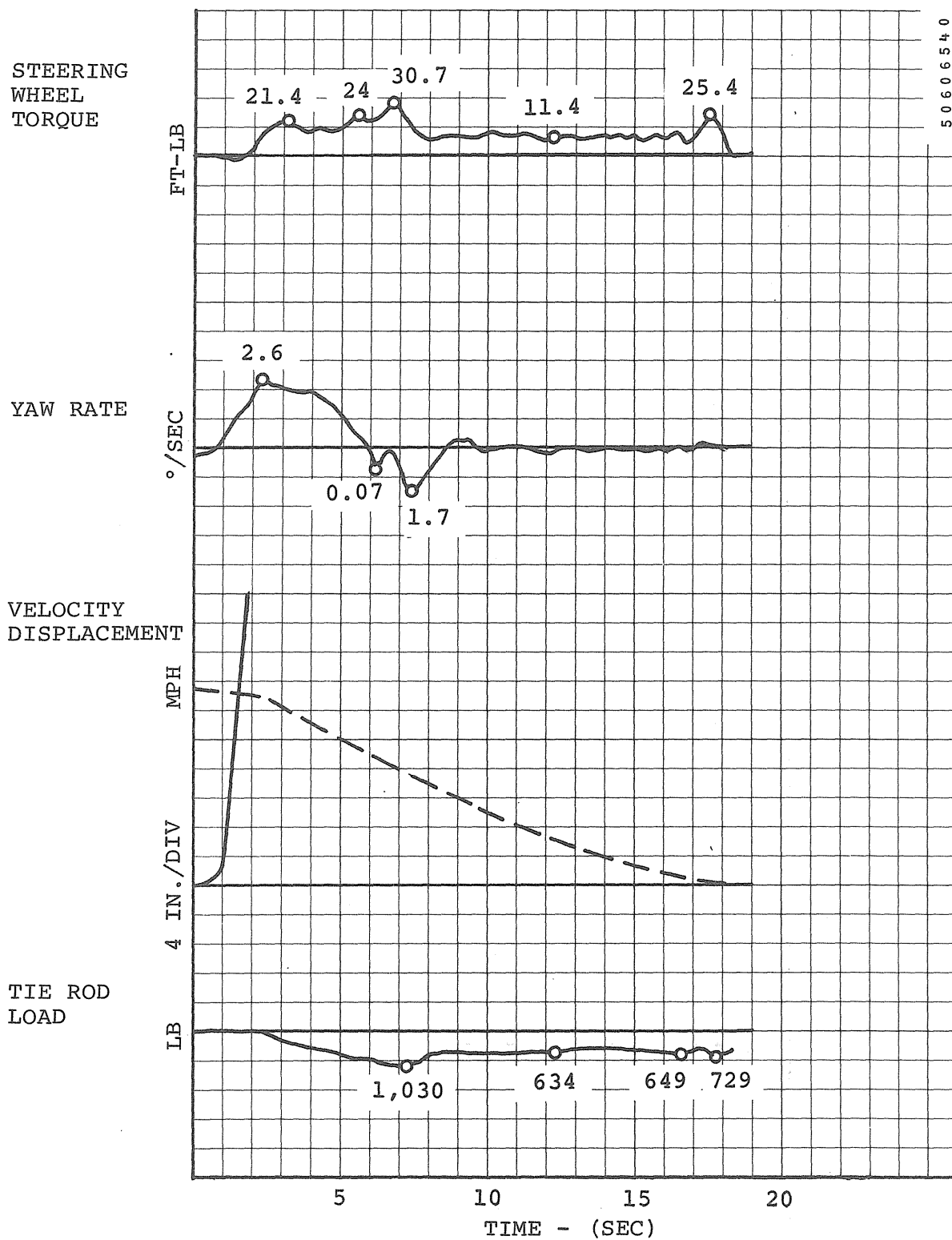


Figure 6-20. Test No. 14 - One Inch Tow-in Alignment Test.

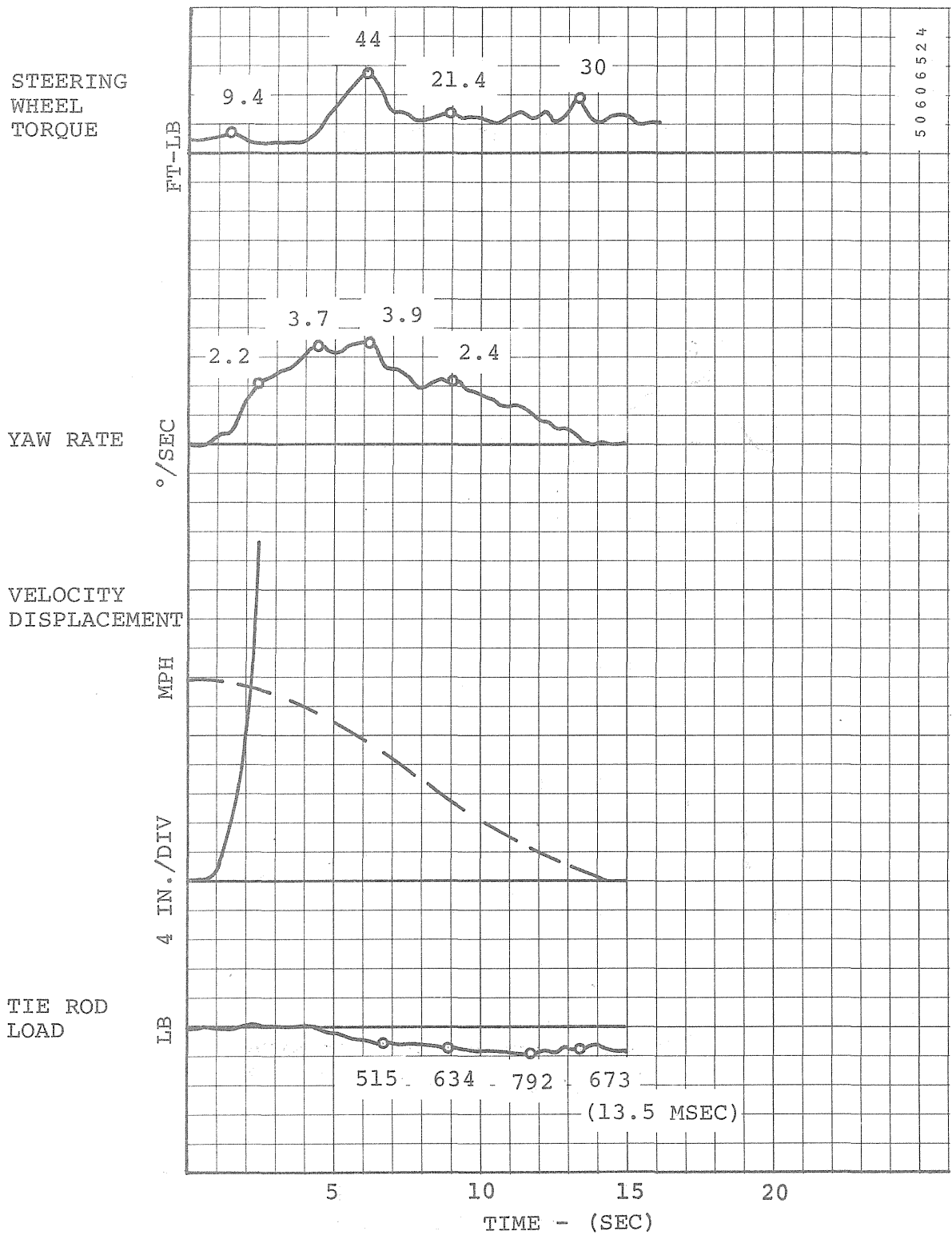


Figure 6-21. Test No. 15 - One Inch Tow-in Alignment Test.

TABLE 6-XVI. TEST NO. 10 DATA SUMMARY

Test Date: March 17, 1975 Test Number: 10Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 28380Tire Type Bias PlyTire Pressure (psi) 90Alignment Additional 2° positive caster.

Summary of Reduced Data

Time Averaged Steering Wheel Torque 8.7 ft-lbPeak Steering Wheel Torque 35.4 ft-lb at 13.6 secMaximum Steering Wheel Angle No Data degTime Averaged Tie Rod Force 388 lbPeak Tie Rod Force 594 lb at 12.2 secLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 3.1 ftRate of Lateral Deviation at 4 Sec 2.1 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 3.8 ft/secInitial Vehicle Velocity 50.3 mphMaximum Tractor Yaw Rate* 13.5 deg/sec at 9.5 secMaximum Tractor/Trailer Angle 2.4 in. at 8.5 secMaximum Longitudinal Acceleration** .5 G at 9.2 secMaximum Lateral Acceleration** .6 G at 7.7 secDriver and Observer Comments: Delayed steering control for 2
seconds after initiation of tire deflation.*Unfiltered peak which cannot necessarily be directly compared
with later tests or summary table of filtered data.**Acceleration peaks are high due to local acceleration of mount-
ing point in cab - location later changed.

TABLE 6-XVII. TEST NO. 11 DATA SUMMARY

Test Date: March 17, 1975 Test Number: 11Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Additional 2° positive caster

Summary of Reduced Data

Time Averaged Steering Wheel Torque 8.7 ft-lbPeak Steering Wheel Torque 34.7 ft-lb at 9.7 secMaximum Steering Wheel Angle No Data degTime Averaged Tie Rod Force 465 lbPeak Tie Rod Force 792 lb at 11.3 secLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 1.5 ftRate of Lateral Deviation at 4 Sec 2.75 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 2.37 ft/secInitial Vehicle Velocity 50.3 mphMaximum Tractor Yaw Rate* 12.5 deg/sec at 5.5 secMaximum Tractor/Trailer Angle 2.3 in. at 8 secMaximum Longitudinal Acceleration** .2 G at 6 secMaximum Lateral Acceleration** .75 G at 7.5 secDriver and Observer Comments: Delayed steering input for 2seconds after initiation of tire deflation.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-XVIII. TEST NO. 12 DATA SUMMARY

Test Date: March 18, 1975 Test Number: 12Vehicle: International Truck Combination

Test Conditions:

Safety Device NoneVehicle Weight (lb) 28380Tire Type Bias PlyTire Pressure (psi) 90Alignment Additional 2° Positive caster and 1" tow-in

Summary of Reduced Data

Time Averaged Steering Wheel Torque .72 ft-lbPeak Steering Wheel Torque 8 ft-lb at 1.4 secMaximum Steering Wheel Angle No Data degTime Averaged Tie Rod Force 155 lbPeak Tie Rod Force 554 lb at 12 secLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 7.8 ftRate of Lateral Deviation at 4 Sec No Data ft/secMaximum Rate of Lateral Deviation Within 4 Sec 6.6 ft/secInitial Vehicle Velocity 49.7 mphMaximum Tractor Yaw Rate* 7.8 deg/sec at 6 secMaximum Tractor/Trailer Angle 4.9 in. at 12 secMaximum Longitudinal Acceleration** .4 G at 6 secMaximum Lateral Acceleration** .7 G at 6.5 secDriver and Observer Comments: No steering control applied
throughout test.*Unfiltered peak which cannot necessarily be directly compared
with later tests or summary table of filtered data.**Acceleration peaks are high due to local acceleration of mount-
ing point in cab - location later changed.

TABLE 6-XIX. TEST NO. 13 DATA SUMMARY

Test Date: March 18, 1975 Test Number: 13

Vehicle: International Truck Combination

Test Conditions:

Safety Device None

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment One inch tow-in

Summary of Reduced Data

Time Averaged Steering Wheel Torque 14.4 ft-lb

Peak Steering Wheel Torque 22.7 ft-lb at 6.8 sec

Maximum Steering Wheel Angle No data deg

Time Averaged Tie Rod Force 310 lb

Peak Tie Rod Force 752 lb at 7.5 sec

Lateral Truck Deviation After 6 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec 8.2 ft

Rate of Lateral Deviation at 4 Sec 6.8 ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec 6.8 ft/sec

Initial Vehicle Velocity 49.2 mph

Maximum Tractor Yaw Rate* 8.9 deg/sec at 9.5 sec

Maximum Tractor/Trailer Angle 2.6 in. at 12.5 sec

Maximum Longitudinal Acceleration** .55 G at sec

Maximum Lateral Acceleration** .8 G at sec

Driver and Observer Comments: Steering input delayed for about
5 seconds.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-XX. TEST NO. 14 DATA SUMMARY

Test Date: March 19, 1975 Test Number: 14

Vehicle: International Truck Combination

Test Conditions:

Safety Device None

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment One inch tow-in

Summary of Reduced Data

Time Averaged Steering Wheel Torque 14.4 ft-lb

Peak Steering Wheel Torque 30.7 ft-lb at 6.7 sec

Maximum Steering Wheel Angle No Data deg

Time Averaged Tie Rod Force 654 lb

Peak Tie Rod Force 1030 lb at 7.2 sec

Lateral Truck Deviation After 6 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec 7.6 ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec 6.5 ft/sec

Initial Vehicle Velocity 50.3 mph

Maximum Tractor Yaw Rate* 12.3 deg/sec at 3.5 sec

Maximum Tractor/Trailer Angle 1.3 in. at 2.7 sec

Maximum Longitudinal Acceleration** .73 G at 3.2 sec

Maximum Lateral Acceleration** .8 G at 4 sec

Driver and Observer Comments: Steering input delayed for about
5 seconds. Truck had tendency to pull to left prior to tire
deflection.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.

**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

TABLE 6-XXI. TEST NO. 15 DATA SUMMARY

Test Date: 19 March 1975 Test Number: 15

Vehicle: International Truck Combination

Test Conditions:

Safety Device None

Vehicle Weight (lb) 28380

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment One inch tow-in

Summary of Reduced Data

Time Averaged Steering Wheel Torque 17.3 ft-lb

Peak Steering Wheel Torque 44 ft-lb at 6 sec

Maximum Steering Wheel Angle No Data deg

Time Averaged Tie Rod Force 545 lb

Peak Tie Rod Force 792 lb at 12.6 sec

Lateral Truck Deviation After 6 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec 9.2 ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec 7.4 ft/sec

Initial Vehicle Velocity 51.3 mph

Maximum Tractor Yaw Rate* 13.7 deg/sec at 8.5 sec

Maximum Tractor/Trailer Angle 2.7 in. at 6 sec

Maximum Longitudinal Acceleration** .67 G at 7 sec

Maximum Lateral Acceleration** .78 G at 7 sec

Driver and Observer Comments: Steering input delayed for about
5 seconds.

*Unfiltered peak which cannot necessarily be directly compared with later tests or summary table of filtered data.
**Acceleration peaks are high due to local acceleration of mounting point in cab - location later changed.

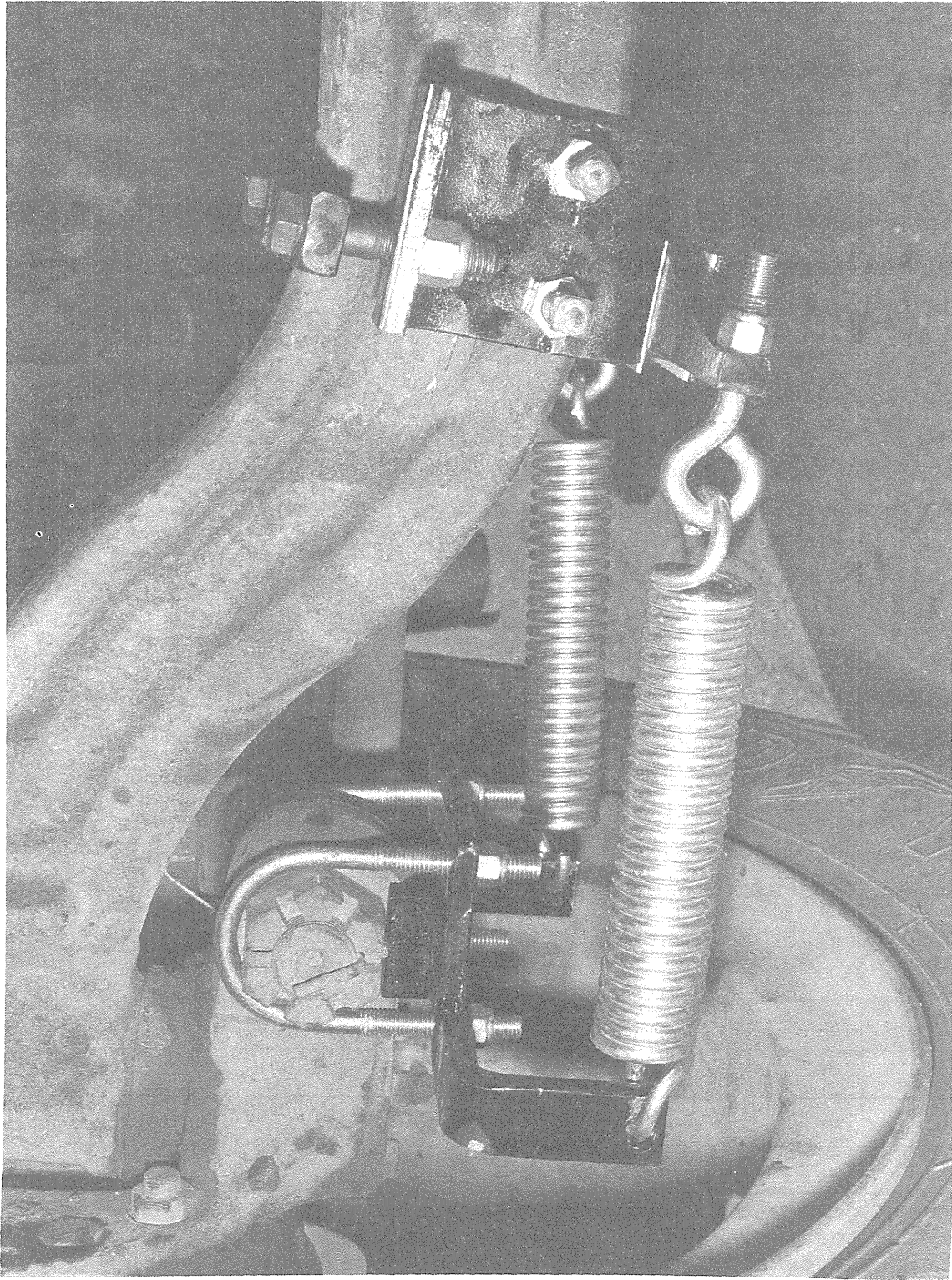


Figure 6-22. Steer Safe Device as Seen Mounted on Front Axle.

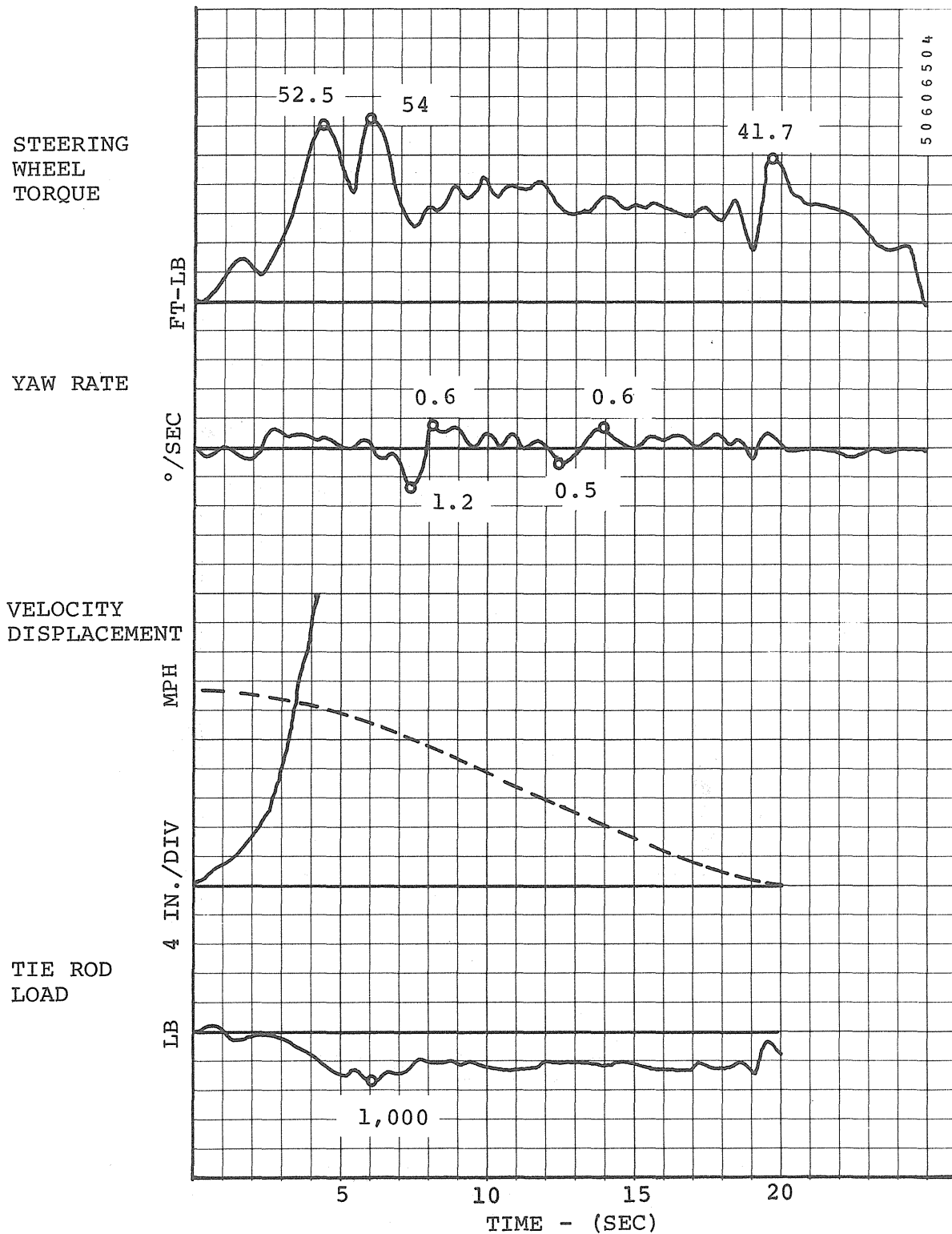


Figure 6-23. Test No. 33 - Steer Safe.

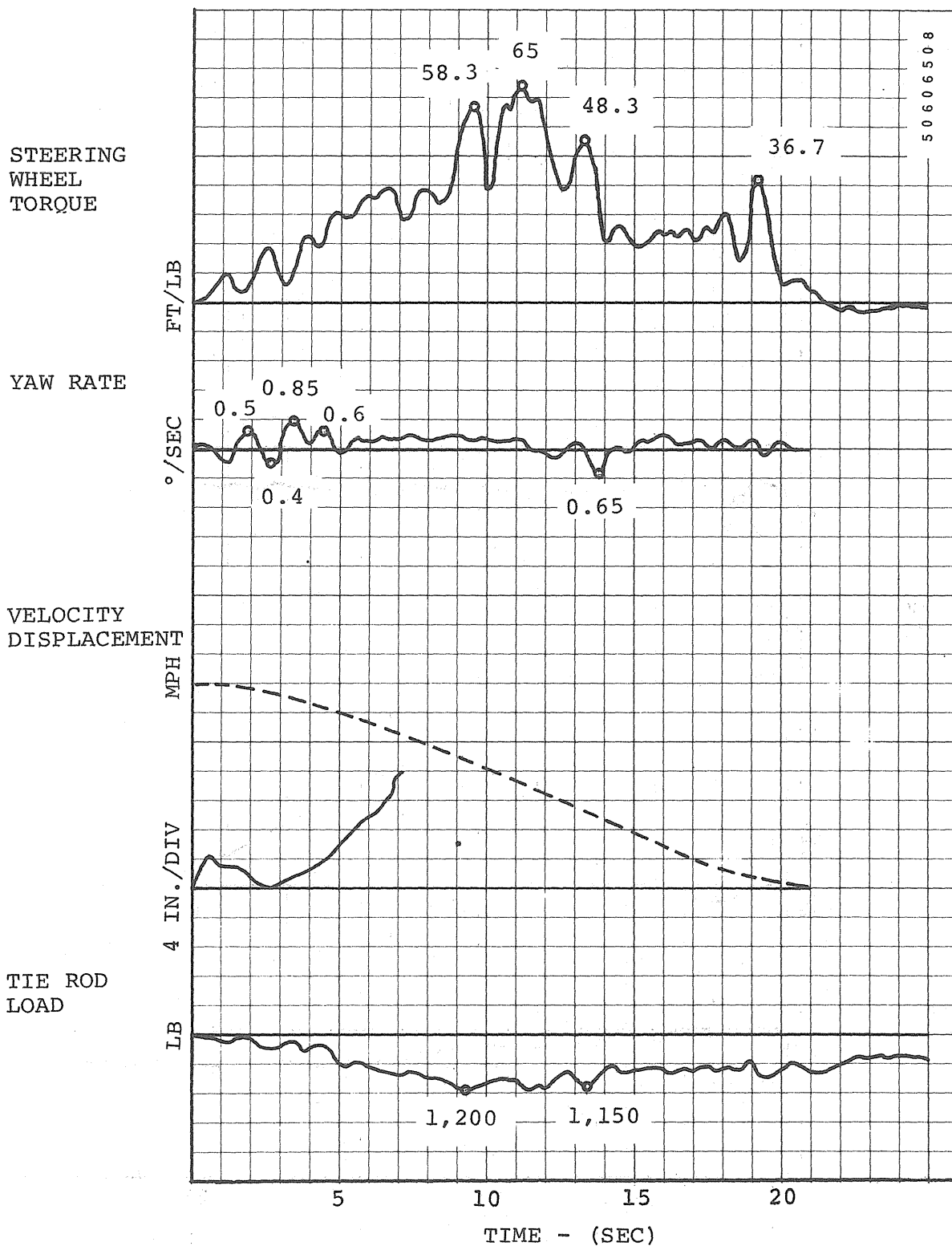


Figure 6-24. Test No. 34 - Steer Safe.

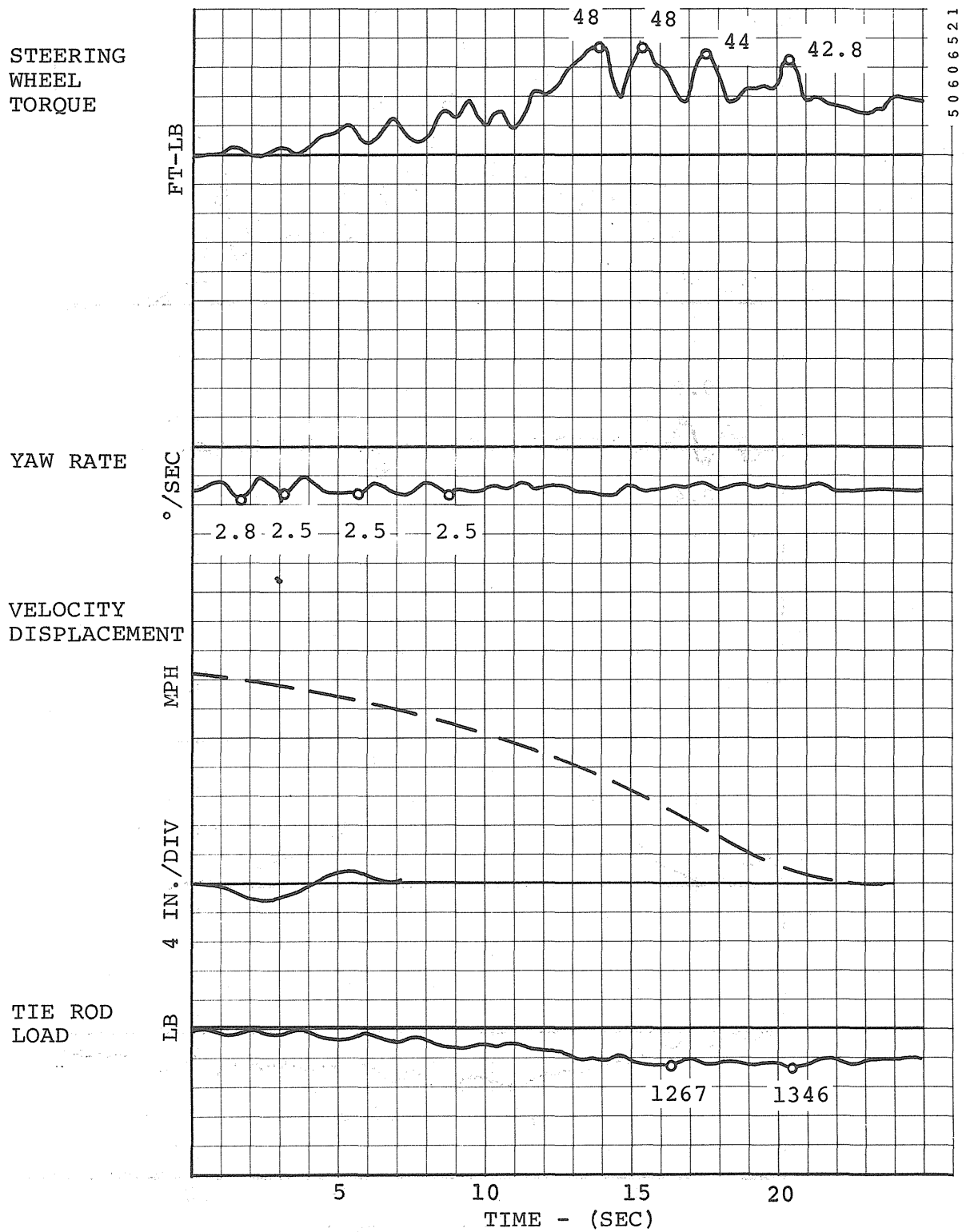


Figure 6-25. Test No. 29 - Steer Safe.

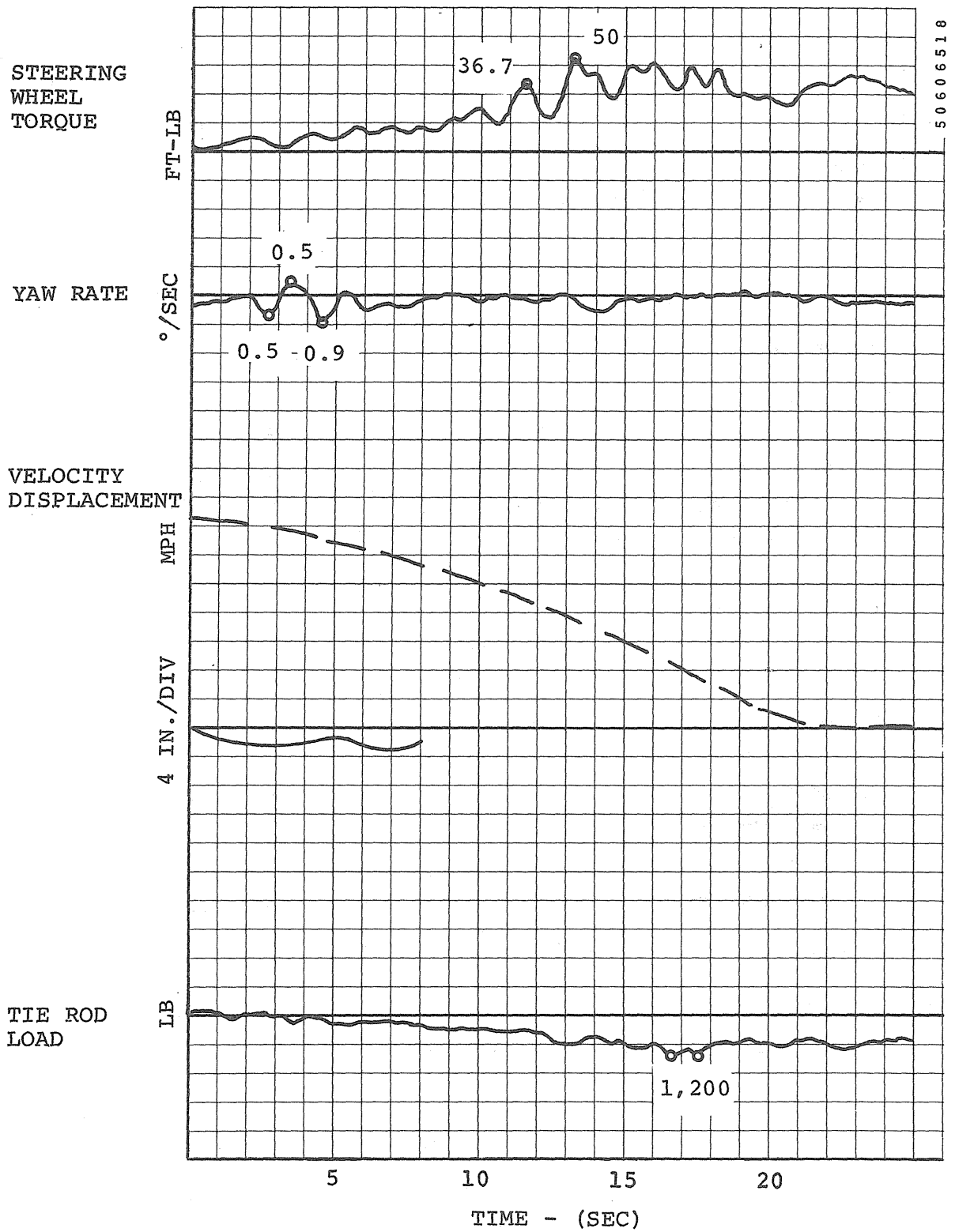


Figure 6-26. Test No. 30 - Steer Safe.

TABLE 6-XXII. TEST NO. 33 DATA SUMMARY

Test Date: 15 April 1975 Test Number: 33

Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer Safe
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 24 ft-lb
 Peak Steering Wheel Torque 54 ft-lb at 7 sec
 Maximum Steering Wheel Angle 250 deg at 6 sec
 Time Averaged Tie Rod Force 475 lb
 Peak Tie Rod Force 1000 lb at 6 sec
 Lateral Truck Deviation After 6 Sec 6.2 ft
 Maximum Lateral Deviation Within 6 Sec 6.2 ft
 Rate of Lateral Deviation at 6 Sec 1.7 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 2.2 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate 1.2 deg/sec at 7 sec
 Maximum Tractor/Trailer Angle .42 in. at 7 sec
 Maximum Longitudinal Acceleration .86 G at 9 sec
 Maximum Lateral Acceleration .60 G at 8.5 sec

Driver and Observer Comments: Truck controlled throughout test.

TABLE 6-XXIII. TEST NO. 34 DATA SUMMARY

Test Date: 15 April 1975 Test Number: 34Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer SafeVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 28 ft-lbPeak Steering Wheel Torque 65 ft-lb at 12.5 secMaximum Steering Wheel Angle 250 deg at 11 secTime Averaged Tie Rod Force 735 lbPeak Tie Rod Force 1,150 lb at 13.5 secLateral Truck Deviation After 6 Sec .83 ftMaximum Lateral Deviation Within 6 Sec .83 ftRate of Lateral Deviation at 6 Sec .26 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .86 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate .85 deg/sec at 3.5 secMaximum Tractor/Trailer Angle .61 in. at 14 secMaximum Longitudinal Acceleration .30 G at 12 secMaximum Lateral Acceleration .30 G at 13.5 secDriver and Observer Comments: Truck controlled throughout test.

TABLE 6-XXIV. TEST NO. 29 DATA SUMMARY

Test Date: 10 April 1975 Test Number: 29Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer SafeVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 15 ft-lbPeak Steering Wheel Torque 48 ft-lb at 13 secMaximum Steering Wheel Angle 170 degTime Averaged Tie Rod Force 342 lbPeak Tie Rod Force 1346 lb at 20.7 secLateral Truck Deviation After 6 Sec .1 ftMaximum Lateral Deviation Within 6 Sec .2 ftRate of Lateral Deviation at 6 Sec .03 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .05 ft/secInitial Vehicle Velocity 51 mphMaximum Tractor Yaw Rate 2.8 deg/sec at 1.7 secMaximum Tractor/Trailer Angle .53 in. at 3.75 secMaximum Longitudinal Acceleration .30 G at 12 secMaximum Lateral Acceleration .20 G at 2.8 secDriver and Observer Comments: One shell fired from gun -
therefore a slower deflation.

TABLE 6-XXV. TEST NO. 30 DATA SUMMARY

Test Date: 10 April 1975 Test Number: 30Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer SafeVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 15 ft-lbPeak Steering Wheel Torque 50 ft-lb at 13 secMaximum Steering Wheel Angle 160 degTime Averaged Tie Rod Force 293 lbPeak Tie Rod Force 1200 lb at 18 secLateral Truck Deviation After 6 Sec .4 ftMaximum Lateral Deviation Within 6 Sec .25 ftRate of Lateral Deviation at 6 Sec .13 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .13 ft/secInitial Vehicle Velocity 51 mphMaximum Tractor Yaw Rate .9 deg/sec at 4 secMaximum Tractor/Trailer Angle .61 in. at 15 secMaximum Longitudinal Acceleration .30 G at 15 secMaximum Lateral Acceleration .25 G at 3.2 secDriver and Observer Comments: Only one shell fired again -
tests 29 and 30 repeated as number 33 and 34.

The performance of this device appears to be dependent upon the rate of deflation of the tire.

6.3.1.2 Four-Spring System

Shure-Guide (Tests 39, 40, and 41)

The Shure-Guide is a four-spring unit as described in Section 4.1.2.1. Figure 6-27 is a photograph of the device installed on the test truck.

Figures 6-28, 6-29, and 6-30 are data records from Tests 39, 40, and 41 and Tables 6-XXVI, 6-XXVII, and 6-XXVIII are data summaries from the front tire failure tests with the Shure-Guide device installed.

Based on the test data, even though the truck was allowed to deviate more than for the baseline tests, there was no significant improvement of the truck response with the Shure-Guide device installed.

6.3.1.3 Four-Spring System

Steering Stabilizer (Tests 31 and 32)

The Steering Stabilizer device consists of four springs as described in Section 4.1.2.2. Figure 6-31 is a photograph of the steering stabilizer installed on the test truck. Figures 6-32 and 6-33 are data records from Tests 31 and 32 and Tables 6-XXIX and 6-XXX are summaries of the test data.

Based upon the test data, there was no evidence of change in performance of the truck during a front tire deflation test over the baseline tests.

6.3.2 Axle Concepts

6.3.2.1 Centerline Axle (Tests 35 and 36)

The Centerline Axle involves an unconventional axle and steering system concept where the kingpin axis coincides with the centerline of the tire contact patch instead of the more conventional configurations with the kingpin axes inboard from the

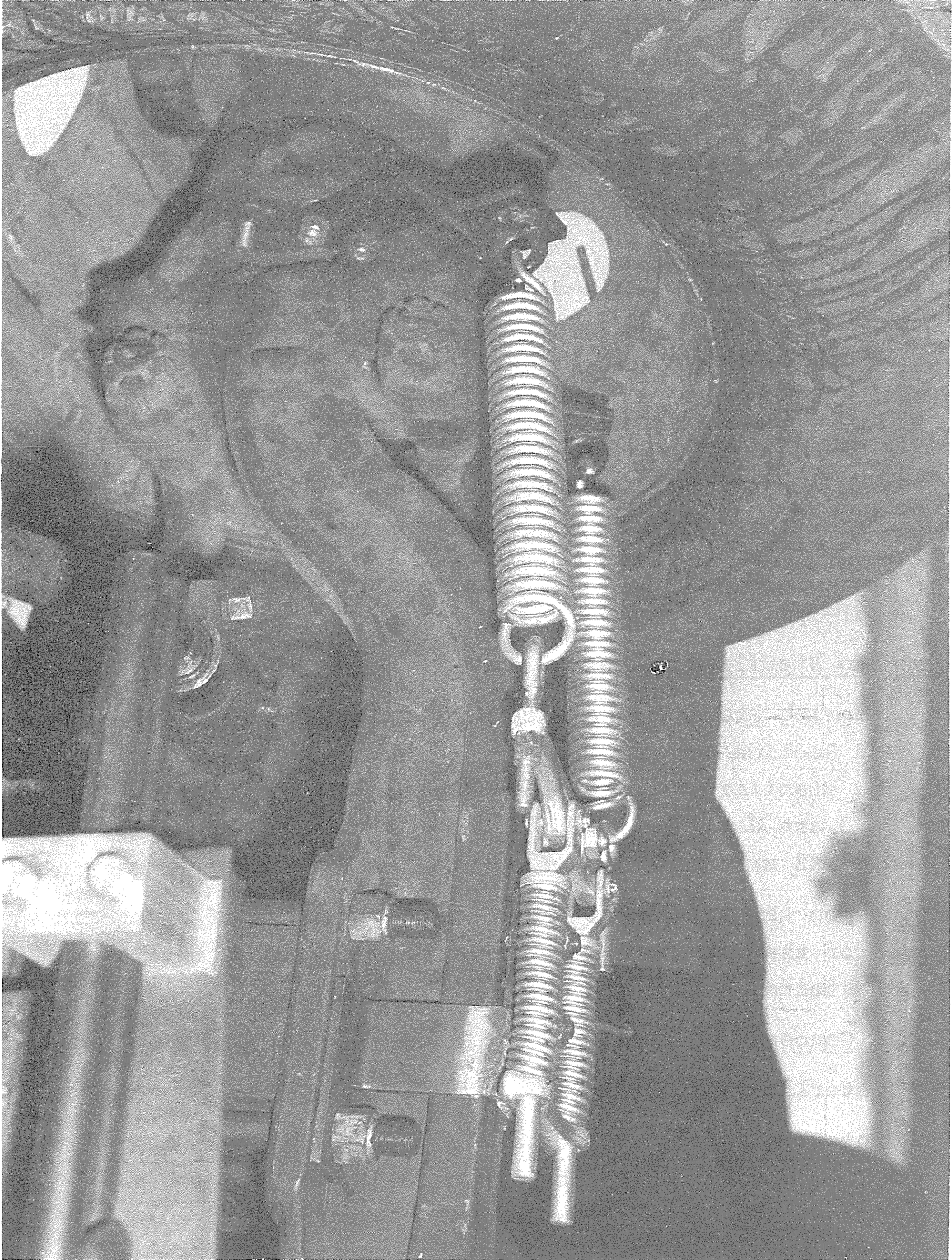


Figure 6-27. Shure-Guide System as Seen Mounted on Truck.

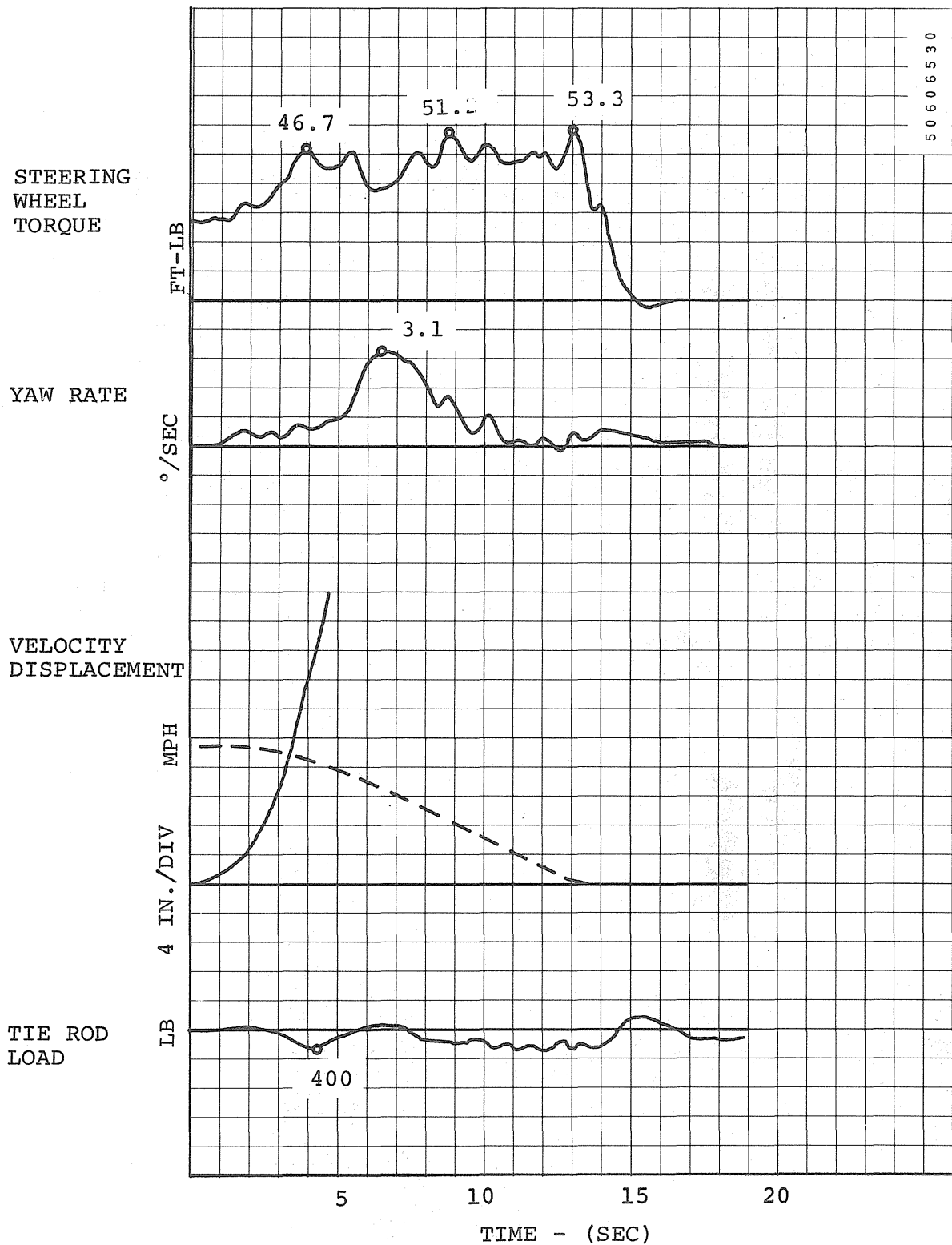


Figure 6-28. Test No. 39 - Shure-Guide.

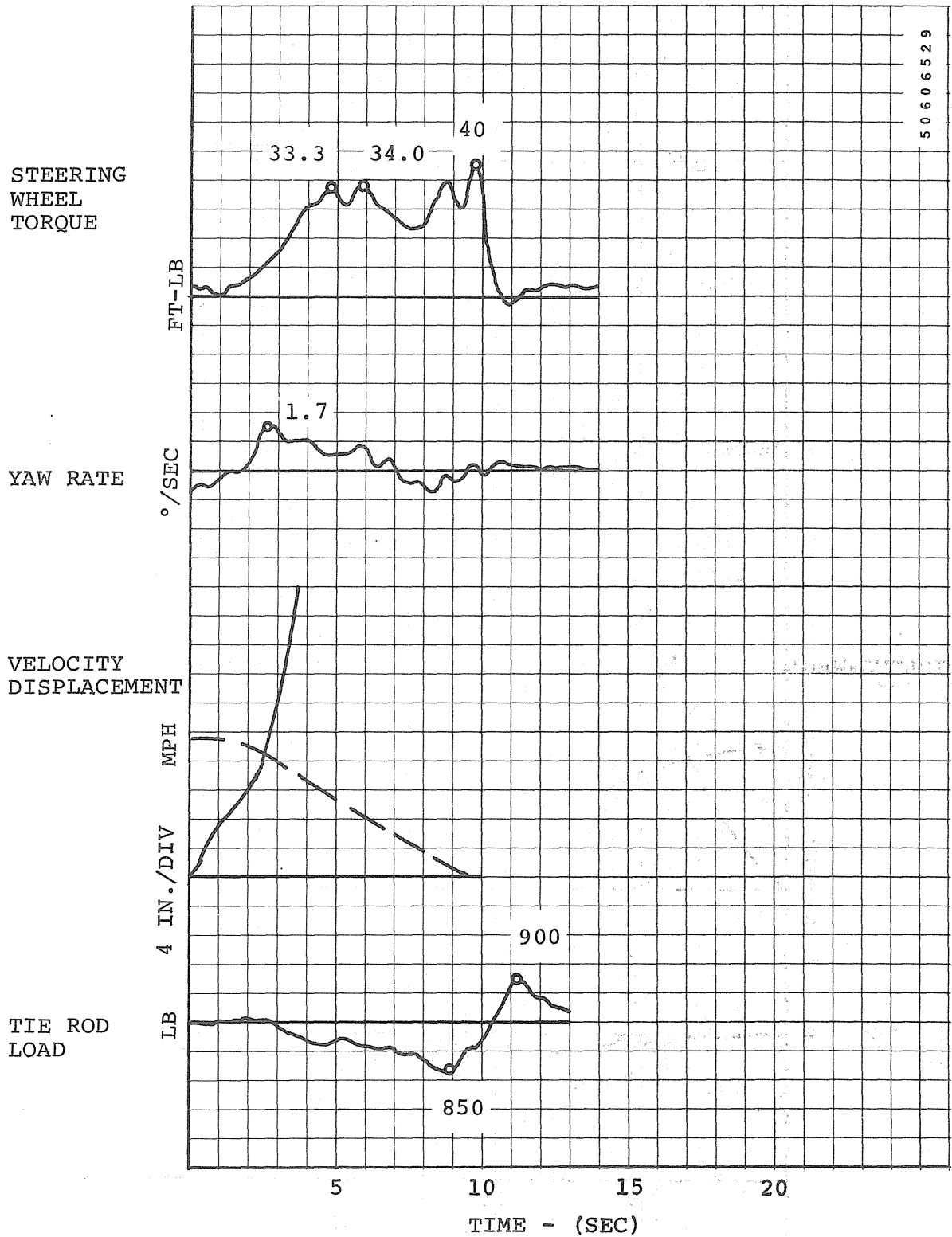


Figure 6-29. Test No. 40 - Shure-Guide.

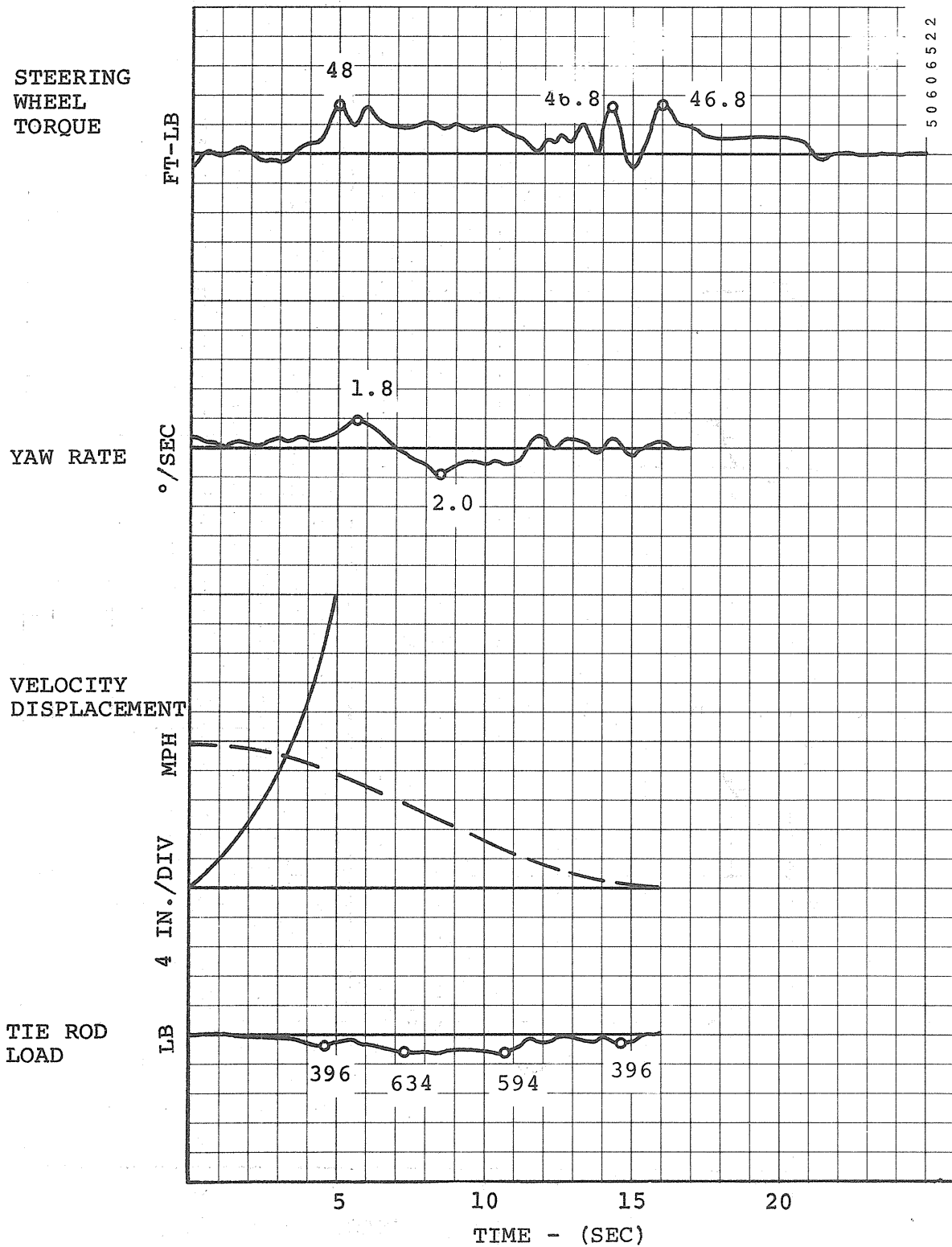


Figure 6-30. Test No. 41 - Shure-Guide.

TABLE 6-XXVI. TEST NO. 39 DATA SUMMARY

Test Date: 1 May 1975 Test Number: 39

Vehicle: International Truck Combination

Test Conditions:

Safety Device Shure Guide
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 35 ft-lb
 Peak Steering Wheel Torque 53 ft-lb at 8.5 sec
 Maximum Steering Wheel Angle 190 deg at 8.5 sec
 Time Averaged Tie Rod Force 304 lb
 Peak Tie Rod Force 400 lb at 5 sec
 Lateral Truck Deviation After 6 Sec 6.9 ft
 Maximum Lateral Deviation Within 6 Sec 6.9 ft
 Rate of Lateral Deviation at 6 Sec 4.1 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 5.8 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate 3.1 deg/sec at 8 sec
 Maximum Tractor/Trailer Angle 2.2 in. at 7.5 sec
 Maximum Longitudinal Acceleration .37 G at 6.5 sec
 Maximum Lateral Acceleration .64 G at 6 sec

Driver and Observer Comments: Continuous control of truck, new driver allowed more lateral deviation.

TABLE 6-XXVII. TEST NO. 40 DATA SUMMARY

Test Date: 1 May 1975 Test Number: 40

Vehicle: International Truck Combination

Test Conditions:

Safety Device Shure Guide
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 14 ft-lb
 Peak Steering Wheel Torque 40 ft-lb at 9 sec
 Maximum Steering Wheel Angle 280 deg at 9 sec
 Time Averaged Tie Rod Force 130 lb
 Peak Tie Rod Force 900 lb at 14 sec
 Lateral Truck Deviation After 6 Sec 9.25 ft
 Maximum Lateral Deviation Within 6 Sec 9.25 ft
 Rate of Lateral Deviation at 6 Sec 1.9 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 2.8 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate 1.7 deg/sec at 3 sec
 Maximum Tractor/Trailer Angle .91 in. at 2.5 sec
 Maximum Longitudinal Acceleration .50 G at 6 sec
 Maximum Lateral Acceleration .11 G at 5.75 sec

Driver and Observer Comments: Continuous control of truck, new driver allowed more lateral deviation.

TABLE 6-XXVIII. TEST NO. 41 DATA SUMMARY

Test Date: 5 May 1975 Test Number: 41

Vehicle: International Truck Combination

Test Conditions:

Safety Device Shure Guide

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21 ft-lb

Peak Steering Wheel Torque 48 ft-lb at 5.1 sec

Maximum Steering Wheel Angle 190 deg at 10 sec

Time Averaged Tie Rod Force 392 lb

Peak Tie Rod Force 634 lb at 7.4 sec

Lateral Truck Deviation After 6 Sec 5 ft

Maximum Lateral Deviation Within 6 Sec 5 ft

Rate of Lateral Deviation at 6 Sec 1.9 ft/sec

Maximum Rate of Lateral Deviation Within 6 Sec 2.8 ft/sec

Initial Vehicle Velocity 47 mph

Maximum Tractor Yaw Rate 2 deg/sec at 8.5 sec

Maximum Tractor/Trailer Angle 1.7 in. at 11 sec

Maximum Longitudinal Acceleration .20 G at 6 sec

Maximum Lateral Acceleration .25 G at 6 sec

Driver and Observer Comments: Continuous control of truck,
additional test run to give new driver another attempt to con-
trol truck in straight line.

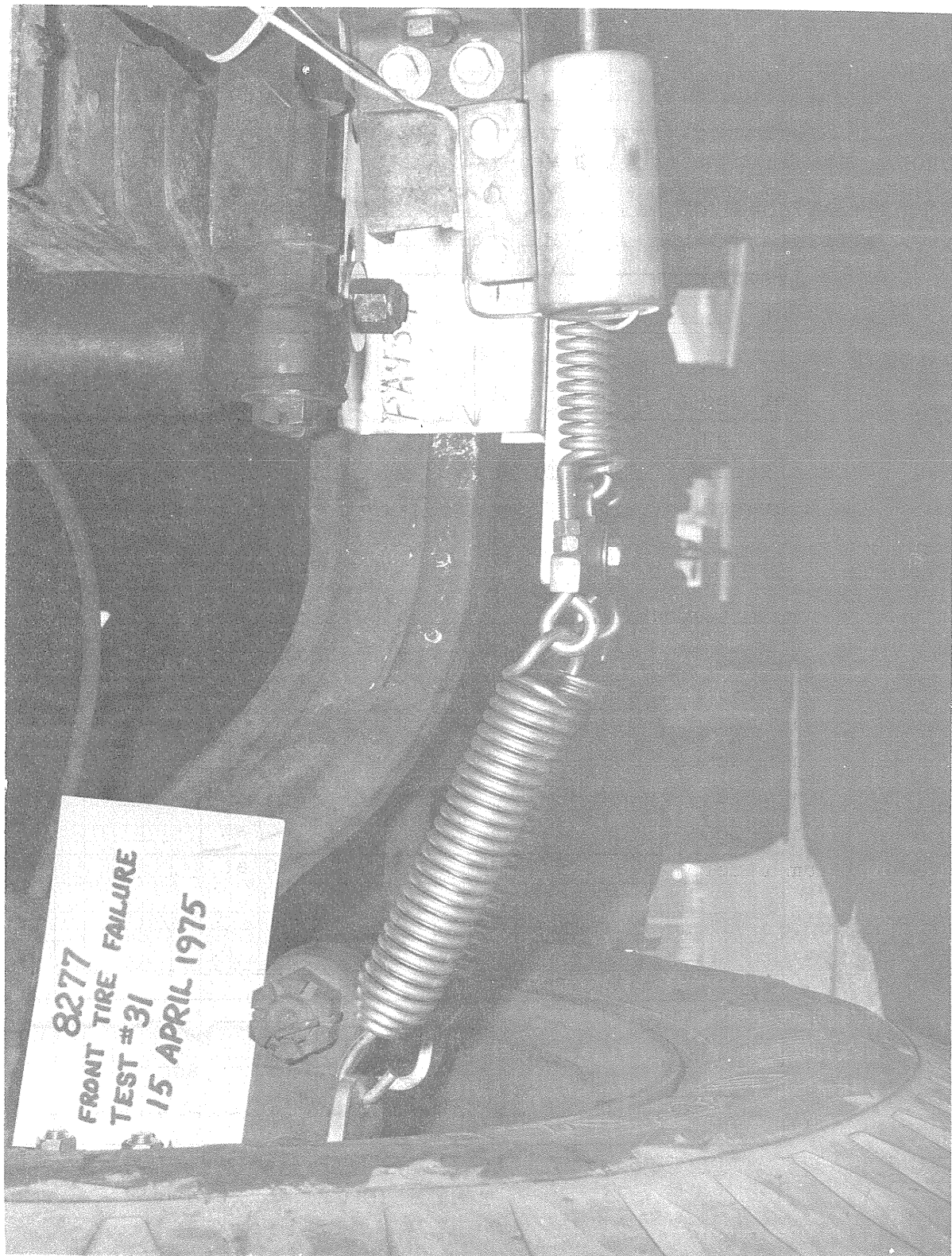


Figure 6-31. Steering Stabilizer Mounted on Lower Portion of Truck.

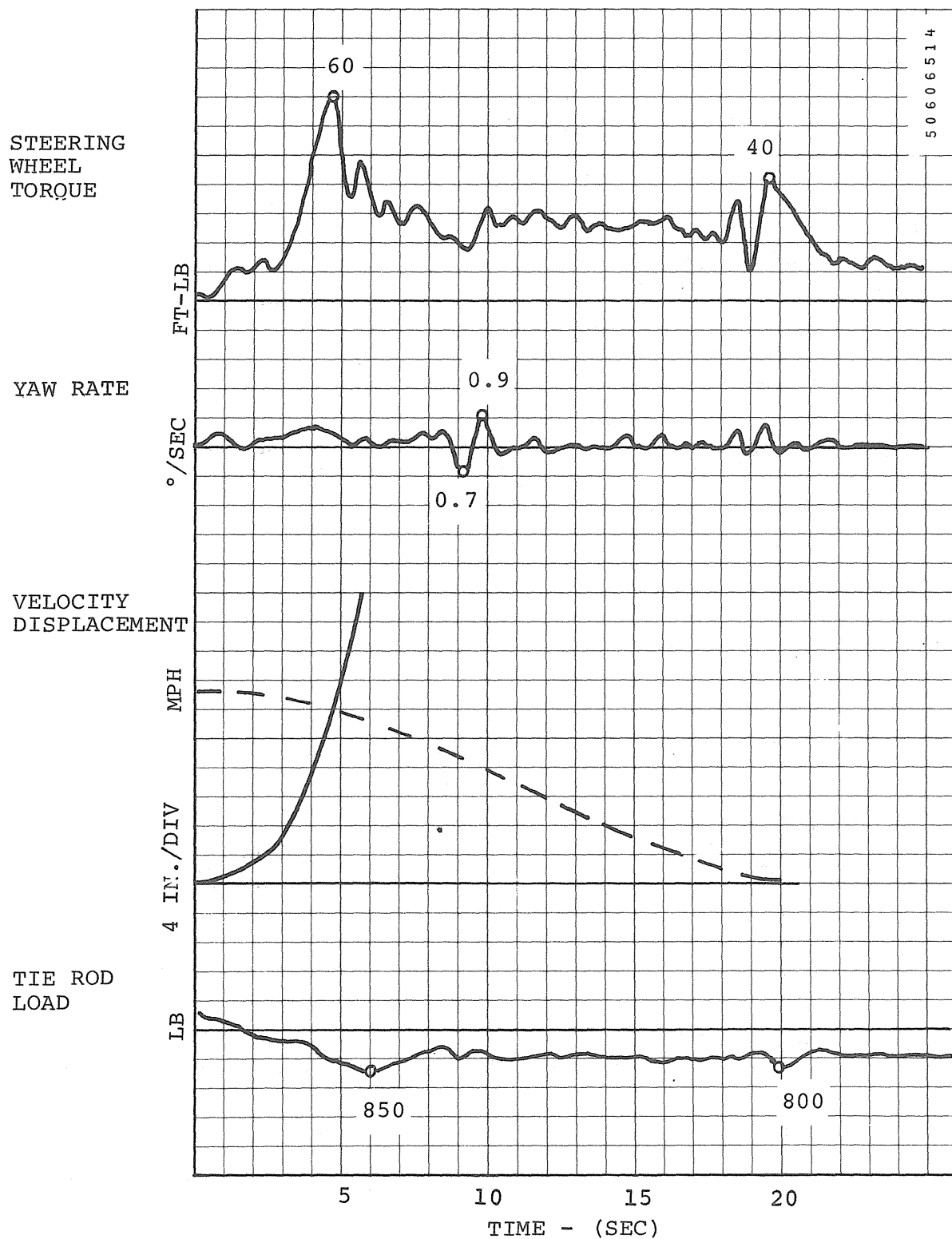


Figure 6-32. Test No. 31 - Steering Stabilizer Test.

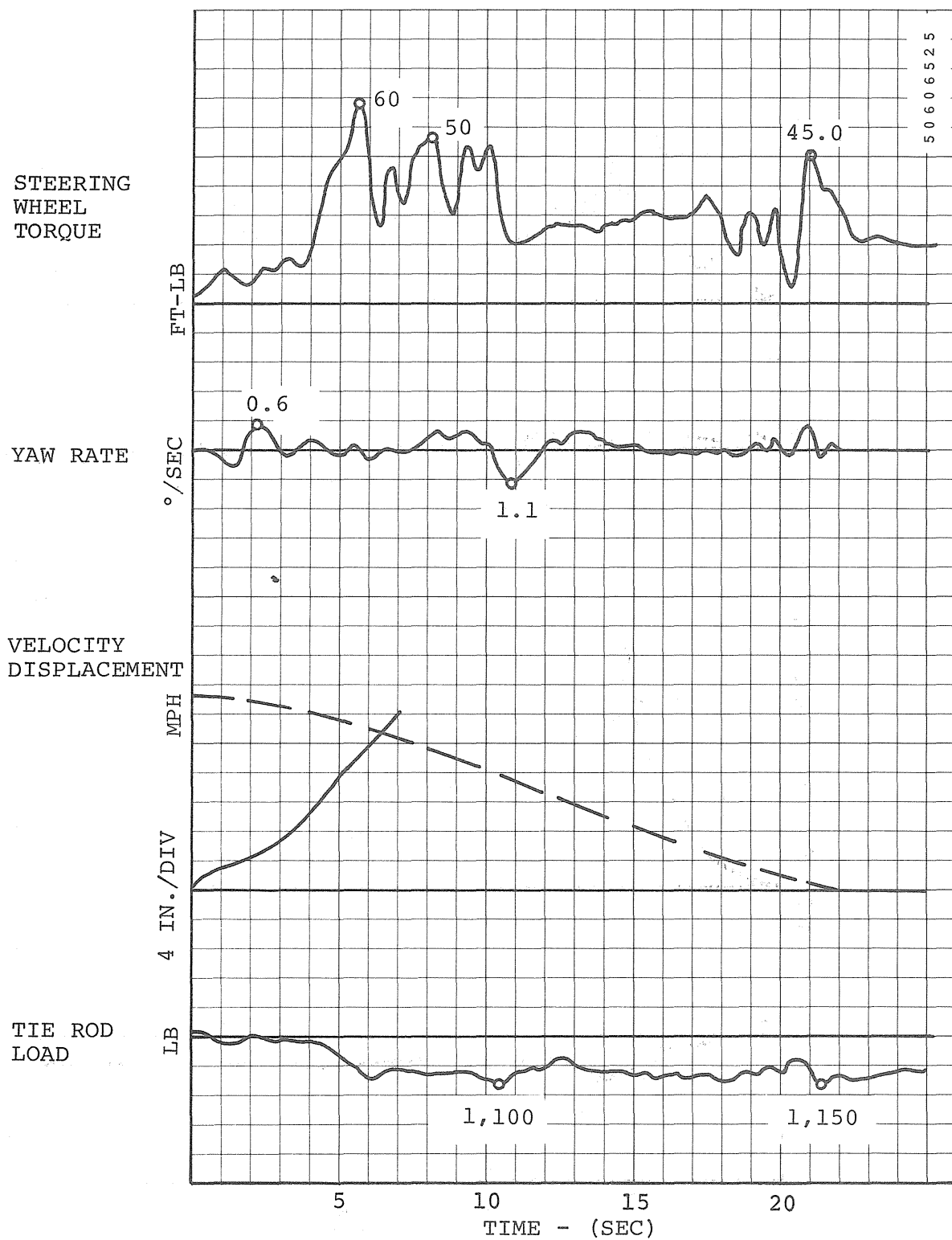


Figure 6-33. Test No. 32 - Steering Stabilizer Test.

TABLE 6-XXIX. TEST NO. 31 DATA SUMMARY

Test Date: 15 April 1975 Test Number: 31

Vehicle: International Truck Combination

Test Conditions:

Safety Device Steering Stabilizer
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 23 ft-lb
 Peak Steering Wheel Torque 60 ft-lb at 5 sec
 Maximum Steering Wheel Angle 190 deg at 6 sec
 Time Averaged Tie Rod Force 391 lb
 Peak Tie Rod Force 850 lb at 7 sec
 Lateral Truck Deviation After 6 Sec 3.8 ft
 Maximum Lateral Deviation Within 6 Sec 3.8 ft
 Rate of Lateral Deviation at 6 Sec 1.39 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 2.01 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate .9 deg/sec at 10 sec
 Maximum Tractor/Trailer Angle .19 in. at 8 sec
 Maximum Longitudinal Acceleration .32 G at 7.7 sec
 Maximum Lateral Acceleration .40 G at 3 sec

Driver and Observer Comments: Truck controlled throughout test.

Driver commented he felt less severe oscillations as tire
flopped on rim.

TABLE 6-XXX. TEST NO. 32 DATA SUMMARY

Test Date: 15 April 1975 Test Number: 32Vehicle: International Truck Combination

Test Conditions:

Safety Device Steering StabilizerVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 26 ft-lbPeak Steering Wheel Torque 60 ft-lb at 6 secMaximum Steering Wheel Angle 220 deg at 9 secTime Averaged Tie Rod Force 558 lbPeak Tie Rod Force 1,150 lb at 24 secLateral Truck Deviation After 6 Sec 1.6 ftMaximum Lateral Deviation Within 6 Sec 1.6 ftRate of Lateral Deviation at 6 Sec .42 ft/secMaximum Rate of Lateral Deviation Within 6 Sec 1.5 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 1.1 deg/sec at 11 secMaximum Tractor/Trailer Angle .53 in. at 11 secMaximum Longitudinal Acceleration .62 G at 14 secMaximum Lateral Acceleration .27 G at 13.5 secDriver and Observer Comments: Driver did not notice difference
from test 31.

centerline of the tire patch. Section 4.2 is a brief description of the axle along with a schematic of the wheel assembly. Figure 6-34 is a photograph of the axle prior to being installed on the test truck. Figure 6-35 is a close-up of the wheel assembly after a tire deflation test with the Centerline Axle installed. Figures 6-36 and 6-37 are data records from Tests 35 and 36 and Tables 6-XXXI and 6-XXXII are data summaries of those tests.

The driver reported a much reduced steering feedback due to road roughness. The steering wheel torque required to hold the truck in a straight line while going on and off of the edge of the pavement was also significantly reduced.

The data indicates that there was a significant reduction in the steering wheel torque required to control the truck during the tire deflation tests.

Since no tow-in is required for this axle, significant tire life improvement is reported by the manufacturer.

6.3.2.2 Centerpoint Axle (Tests 37 and 38)

The Centerpoint Axle is similar to the Centerline Axle discussed in Section 6.3.2.1 except that the kingpin axis is about 1/2 inch inboard of the centerline of the tire patch as discussed in Section 4.2 which includes a diagram of the wheel assembly.

Figure 6-38 is a photograph of the Centerpoint Axle installed on the test truck. Figures 6-39 and 6-40 are data records from Tests 37 and 38 and Tables 6-XXXIII and 6-XXXIV are summaries of the tire deflation tests with the Centerpoint Axle installed.

The performance of the truck with a Centerpoint Axle is similar to that of a Centerline Axle during a tire deflation test.

The steering wheel torque and tie rod loads were significantly reduced during the test as the driver controlled the truck on course.



Figure 6-34. Centerline Axle.

Figure 6-35. Test No. 36 Post-test.



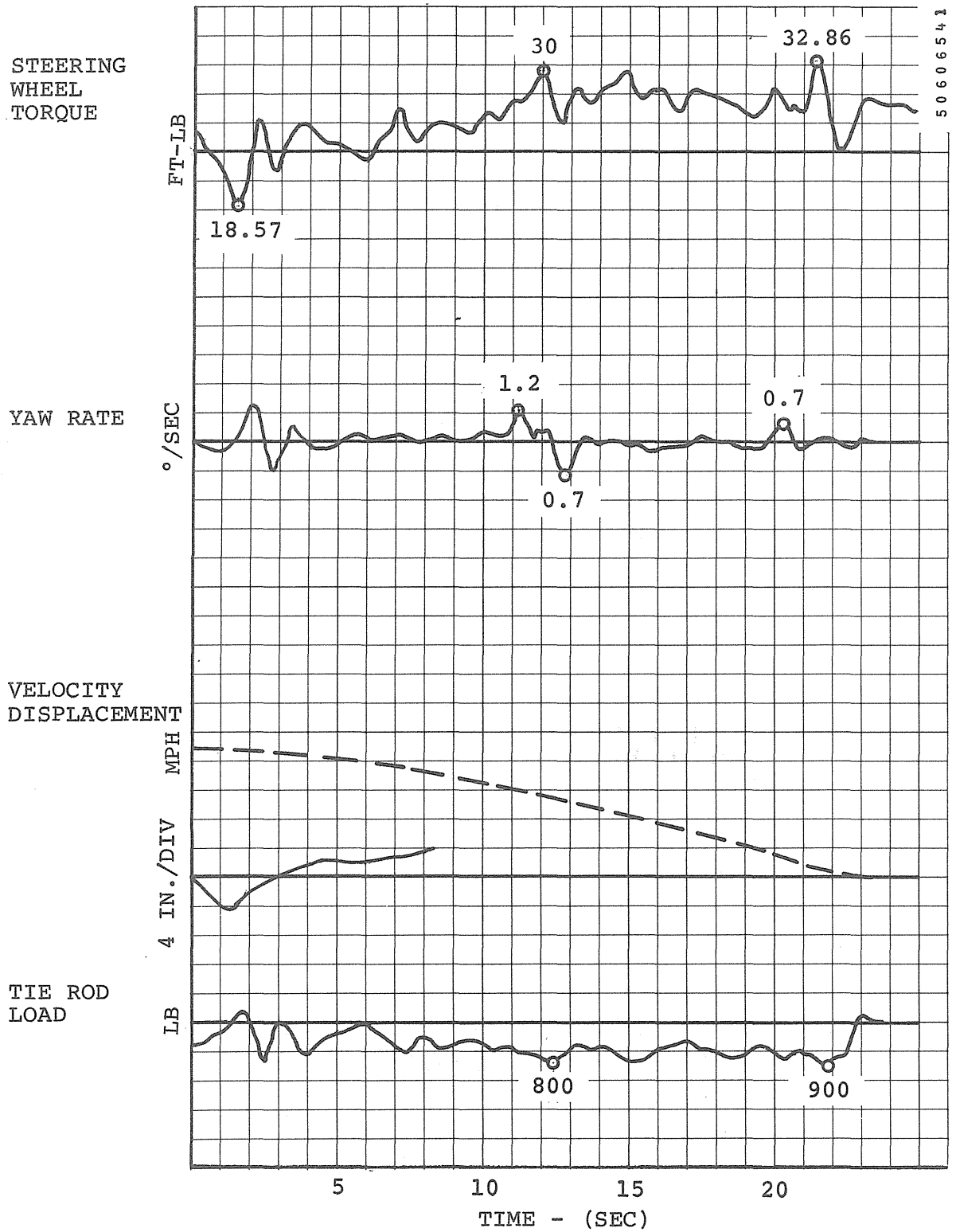


Figure 6-36. Test No. 35 - Centerline.

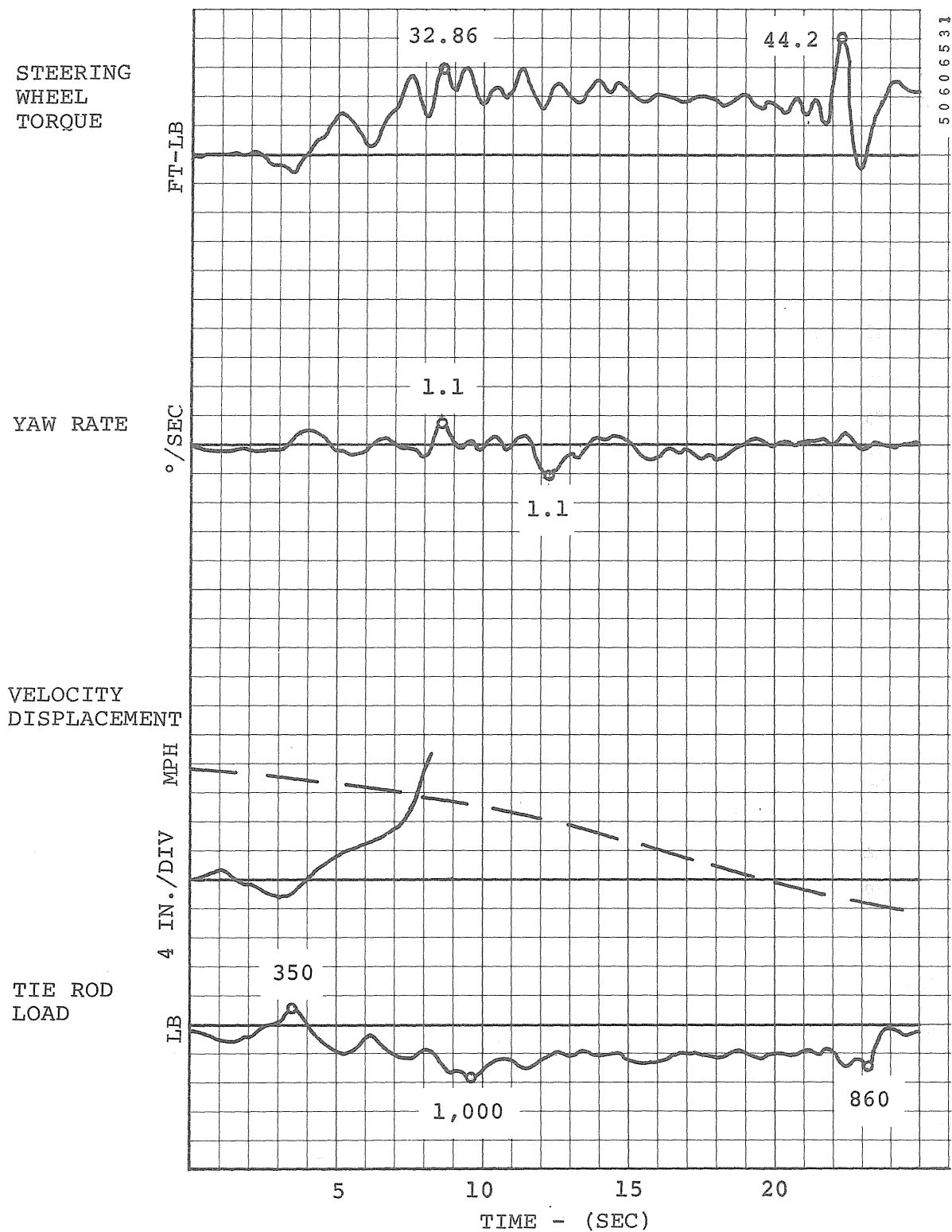


Figure 6-37. Test No. 36 - Centerline.

TABLE 6-XXXI. TEST NO. 35 DATA SUMMARY

Test Date: 24 April 1975 Test Number: 35Vehicle: International Truck Combination

Test Conditions:

Safety Device Centerline AxleVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard for this axle - 0 tow-in, 0 camber

Summary of Reduced Data

Time Averaged Steering Wheel Torque 9 ft-lbPeak Steering Wheel Torque 33 ft-lb at 18 secMaximum Steering Wheel Angle 180 deg at 18 secTime Averaged Tie Rod Force 400 lbPeak Tie Rod Force 900 lb at 24 secLateral Truck Deviation After 6 Sec .17 ftMaximum Lateral Deviation Within 6 Sec .5 ftRate of Lateral Deviation at 6 Sec .06 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .38 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 1.2 deg/sec at 11 secMaximum Tractor/Trailer Angle .34 in. at 14.5 secMaximum Longitudinal Acceleration .2 G at 14 secMaximum Lateral Acceleration .10 G at 15 sec

Driver and Observer Comments: Driver noted easier handling of
truck on track and on road irregularities. Truck controlled
throughout test.

TABLE 6-XXXII. TEST NO. 36 DATA SUMMARY

Test Date: 24 April 1975 Test Number: 36Vehicle: International Truck Combination

Test Conditions:

Safety Device Centerline AxleVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard for Centerline - 0 tow-in, 0 camber

Summary of Reduced Data

Time Averaged Steering Wheel Torque 13 ft-lbPeak Steering Wheel Torque 44 ft-lb at 22 secMaximum Steering Wheel Angle 140 deg at 18 secTime Averaged Tie Rod Force 550 lbPeak Tie Rod Force 1000 lb at 10.5 secLateral Truck Deviation After 6 Sec .42 ftMaximum Lateral Deviation Within 6 Sec .42 ftRate of Lateral Deviation at 6 Sec .16 ft/secMaximum Rate of Lateral Deviation Within 6 Sec 1.1 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 1.1 deg/sec at 8.5 secMaximum Tractor/Trailer Angle .38 in. at 12 secMaximum Longitudinal Acceleration .14 G at 12 secMaximum Lateral Acceleration .17 G at 16 secDriver and Observer Comments: No change from test 35.

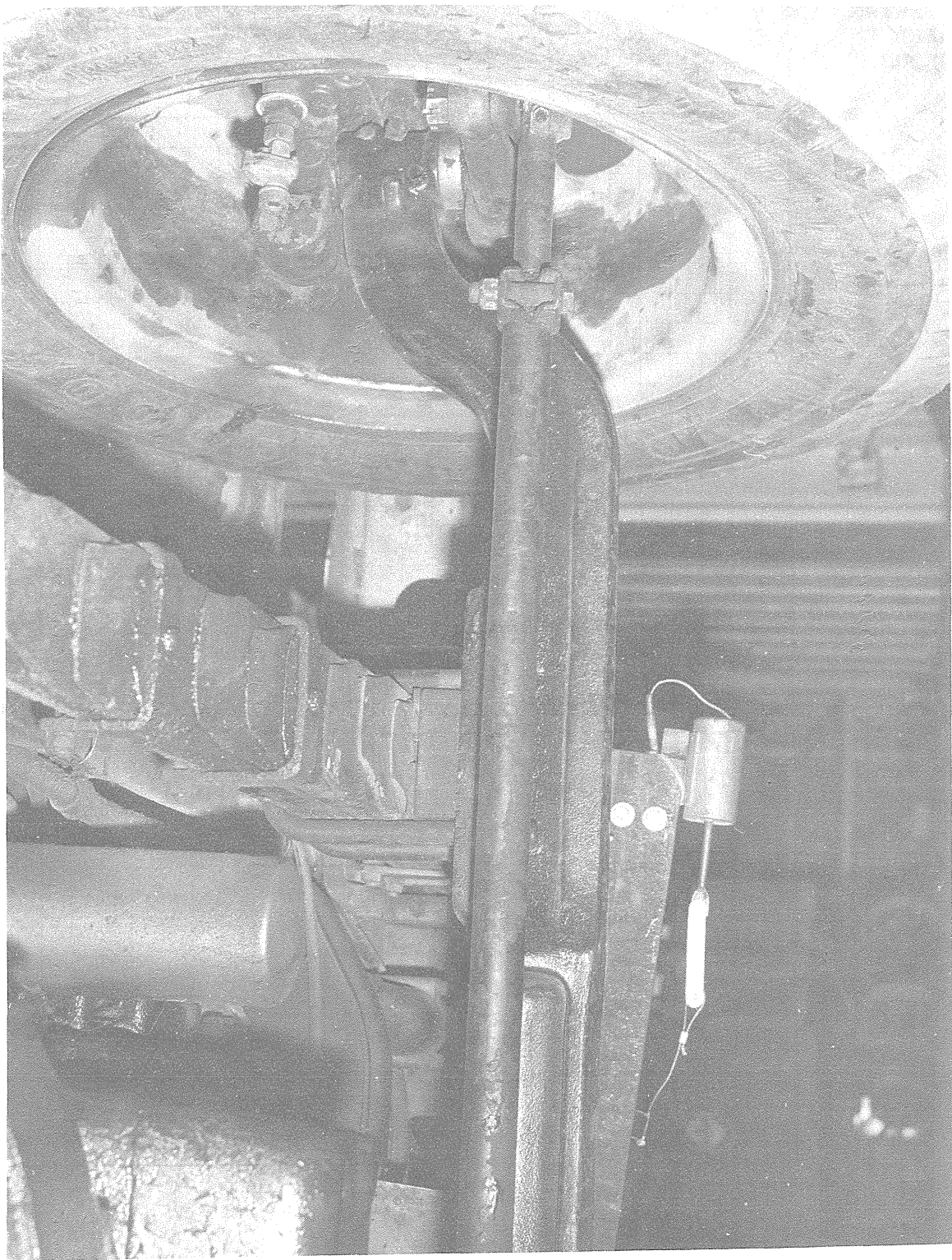


Figure 6-38. Centerpoint Axle as Seen Mounted on Truck Before Test.

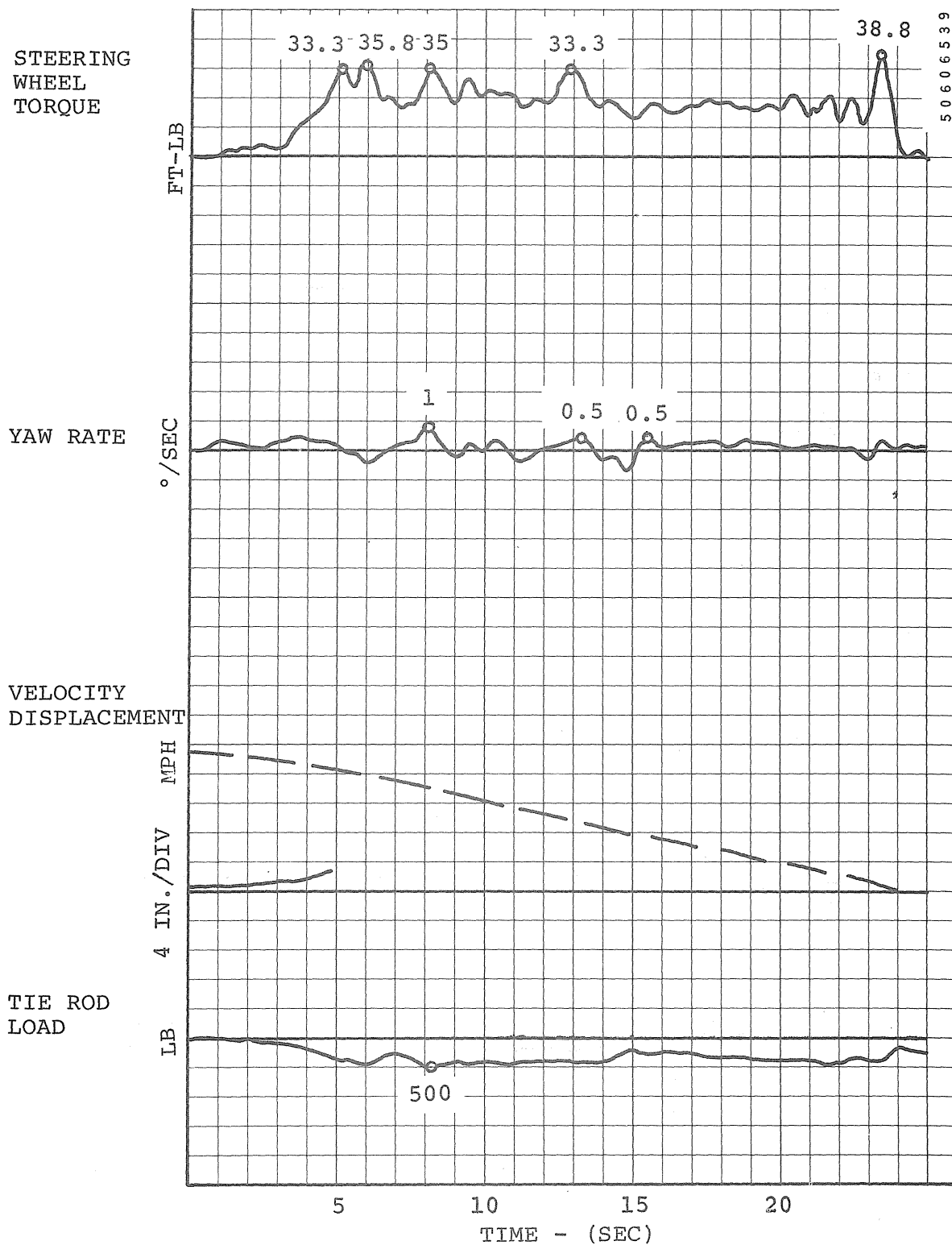


Figure 6-39. Test No. 37 - Centerpoint.

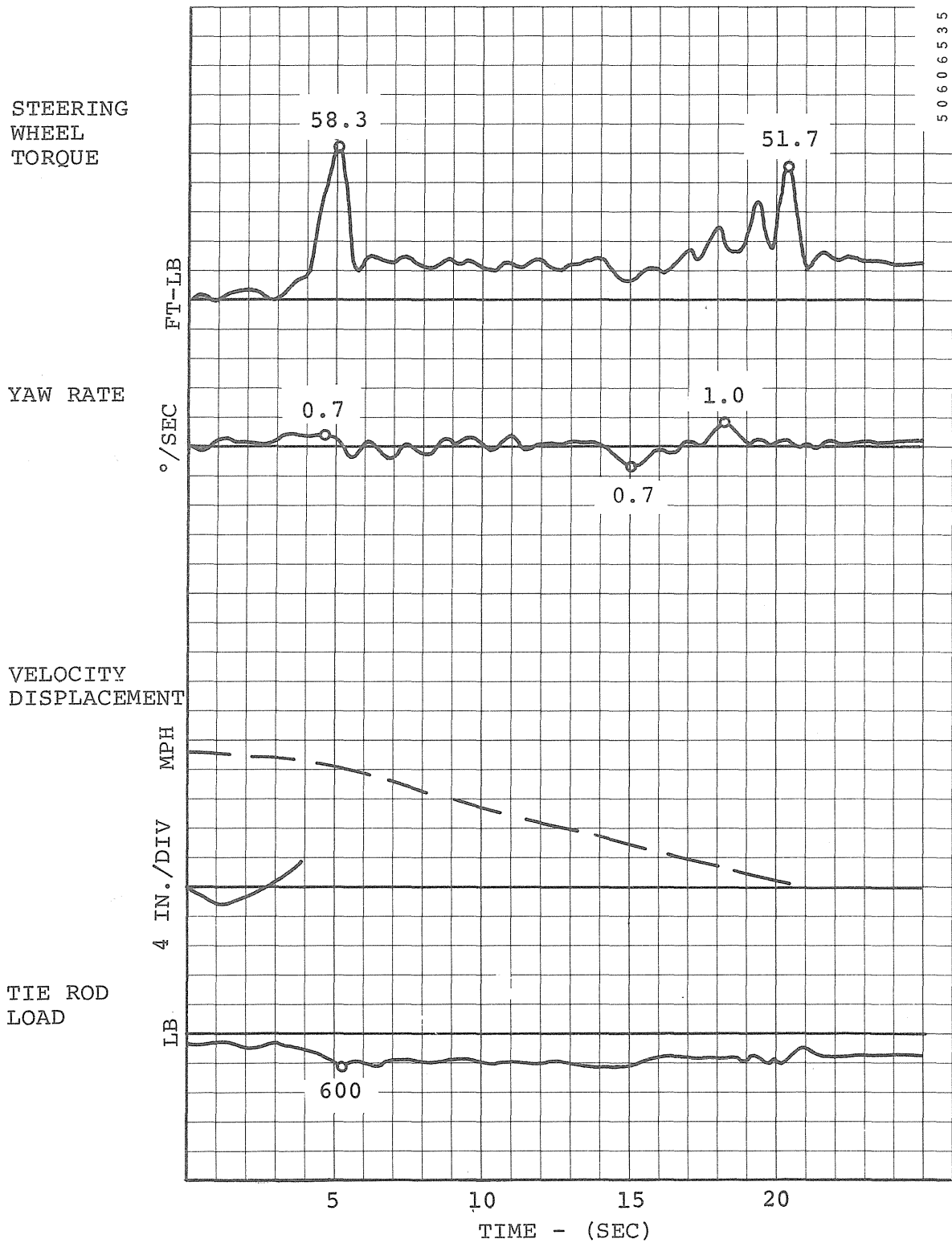


Figure 6-40.. Test No. 38 - Centerpoint.

TABLE 6-XXXIII. TEST NO. 37 DATA SUMMARY

Test Date: 28 April 1975 Test Number: 37

Vehicle: International Truck Combination

Test Conditions:

Safety Device Centerpoint Axle

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 18 ft-lb

Peak Steering Wheel Torque 36 ft-lb at 6 sec

Maximum Steering Wheel Angle 85 deg at 7 sec

Time Averaged Tie Rod Force 378 lb

Peak Tie Rod Force 500 lb at 8 sec

Lateral Truck Deviation After 6 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec .4 ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec .44 ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate 1.0 deg/sec at 10 sec

Maximum Tractor/Trailer Angle .46 in. at 15 sec

Maximum Longitudinal Acceleration .02 G at 14 sec

Maximum Lateral Acceleration .04 G at 10 sec

Driver and Observer Comments: Driver noted easier steering on
track and over road irregularities. Truck controlled through-
out test.

TABLE XXXIV. TEST NO. 38 DATA SUMMARY

Test Date: 28 April 1975 Test Number: 38

Vehicle: International Truck Combination

Test Conditions:

Safety Device Centerpoint Axle

Vehicle Weight (lb) 73280

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 15 ft-lb

Peak Steering Wheel Torque 58 ft-lb at 5 sec

Maximum Steering Wheel Angle 75 deg at 7 sec

Time Averaged Tie Rod Force 405 lb

Peak Tie Rod Force 600 lb at 5 sec

Lateral Truck Deviation After 6 Sec No Data ft

Maximum Lateral Deviation Within 4 Sec .4 ft

Rate of Lateral Deviation at 4 Sec No Data ft/sec

Maximum Rate of Lateral Deviation Within 4 Sec .44 ft/sec

Initial Vehicle Velocity 50 mph

Maximum Tractor Yaw Rate 1.0 deg/sec at 24 sec

Maximum Tractor/Trailer Angle .68 in. at 16.5 sec

Maximum Longitudinal Acceleration .02 G at 5 sec

Maximum Lateral Acceleration .04 G at 9.5 sec

Driver and Observer Comments: No change from test 37.

6.3.3 Safety Roller (Tests 45 and 49)

The Safety Roller is an annular ring that fits around the rim to serve as an auxiliary spare solid tire in the event of a tire deflation as described in Section 4.3 and depicted in Figure 6-41.



Figure 6-41. Safety Roller.

Figures 6-42 and 6-43 are data records from Tests 45 and 49 and Tables 6-XXXV and 6-XXXVI are summaries of the tests involving the Safety Roller.

Test data show that there was a significant improvement in truck performance during a front tire failure with this device installed.

6.3.4 Hydraulic Devices

6.3.4.1 HECO (Tests 25, 26, 16, 17, and 18)

The HECO device consists of a single hydraulic cylinder as described in Section 4.4.1. Figure 6-44 is a photograph of the device installed on the test truck. Figures 6-45 and 6-46 are data records from Tests 25 and 26 and Tables 6-XXXVII and 6-XXXVIII summarize the test data. Tests 16, 17, and 18 were also performed with the HECO device installed but were performed as per the preliminary baseline test procedure. For interest, the summary of data records from Tests 16, 17, and 18 are presented as Figures 6-47 through 6-49 and Tables 6-XXXIX through 6-XLI summarize the data.

While the driver reported less shimmy due to normal driving, there is no evidence of significant improvement in performance of the vehicle during a front tire deflation over a baseline test.

6.3.4.2 SteerLine (Tests 46 and 47)

The SteerLine device is a hydraulic device similar to the HECO device as described in Section 4.4.2. Figures 6-50 and 6-51 are data records from Tests 46 and 47 and Tables 6-XLII and 6-XLIII are data summaries from the tests with the SteerLine device installed.

Based on these test data, there was no significant change in truck performance during the tire deflation test over the baseline tests.

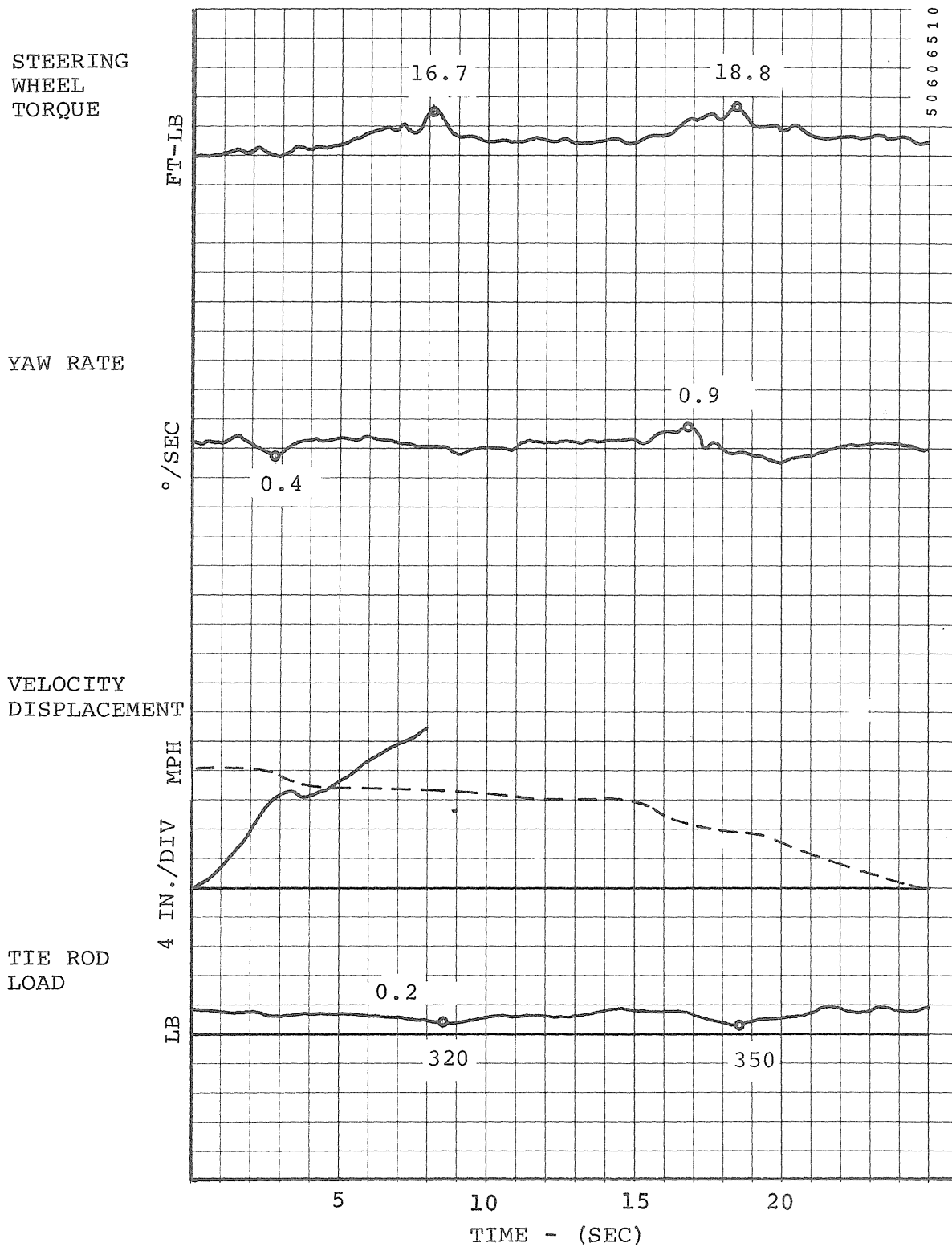


Figure 6-42. Test No. 45 - Safety Roller.

STEERING
WHEEL
TORQUE

FT-LB

21.7 21.7

YAW RATE

°/SEC

1.2

VELOCITY
DISPLACEMENT

MPH

4 IN./DIV

TIE ROD
LOAD

LB

300

5

10

15

20

TIME - (SEC)

50606533

Figure 6-43. Test No. 49 - Safety Roller.

TABLE 6-XXXV. TEST NO. 45 DATA SUMMARY

Test Date: 5 May 1975 Test Number: 45

Vehicle: International Truck Combination

Test Conditions:

Safety Device Safety Roller
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 12.8 ft-lb
 Peak Steering Wheel Torque 18.8 ft-lb at 19 sec
 Maximum Steering Wheel Angle 75 deg at 19 sec
 Time Averaged Tie Rod Force 180 lb
 Peak Tie Rod Force 350 lb at 19 sec
 Lateral Truck Deviation After 6 Sec 1.4 ft
 Maximum Lateral Deviation Within 6 Sec 1.4 ft
 Rate of Lateral Deviation at 6 Sec .28 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec .67 ft/sec
 Initial Vehicle Velocity 51 mph
 Maximum Tractor Yaw Rate .9 deg/sec at 21 sec
 Maximum Tractor/Trailer Angle .65 in. at 16 sec
 Maximum Longitudinal Acceleration .21 G at 16 sec
 Maximum Lateral Acceleration .15 G at 16 sec

Driver and Observer Comments: Driver easily controlled truck
throughout test. The wheel was out of balance prior to tire
deflation.

TABLE 6-XXXVI. TEST NO. 49 DATA SUMMARY

Test Date: 7 May 1975 Test Number: 49Vehicle: International Truck Combination

Test Conditions:

Safety Device Safety RollerVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 8 ft-lbPeak Steering Wheel Torque 21.7 ft-lb at 4 secMaximum Steering Wheel Angle 60 deg at 6 secTime Averaged Tie Rod Force 217 lbPeak Tie Rod Force 300 lb at 4.5 secLateral Truck Deviation After 6 Sec 1.42 ftMaximum Lateral Deviation Within 6 Sec 1.6 ftRate of Lateral Deviation at 6 Sec .59 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .59 ft/secInitial Vehicle Velocity 49 mphMaximum Tractor Yaw Rate 1.2 deg/sec at 8 secMaximum Tractor/Trailer Angle No Data secMaximum Longitudinal Acceleration .20 G at 12 secMaximum Lateral Acceleration .09 G at 8 secDriver and Observer Comments: Driver easily controlled truck
throughout test.



Figure 6-44. Pre-test View of HECO Device as Seen From Center of Tie Rod.

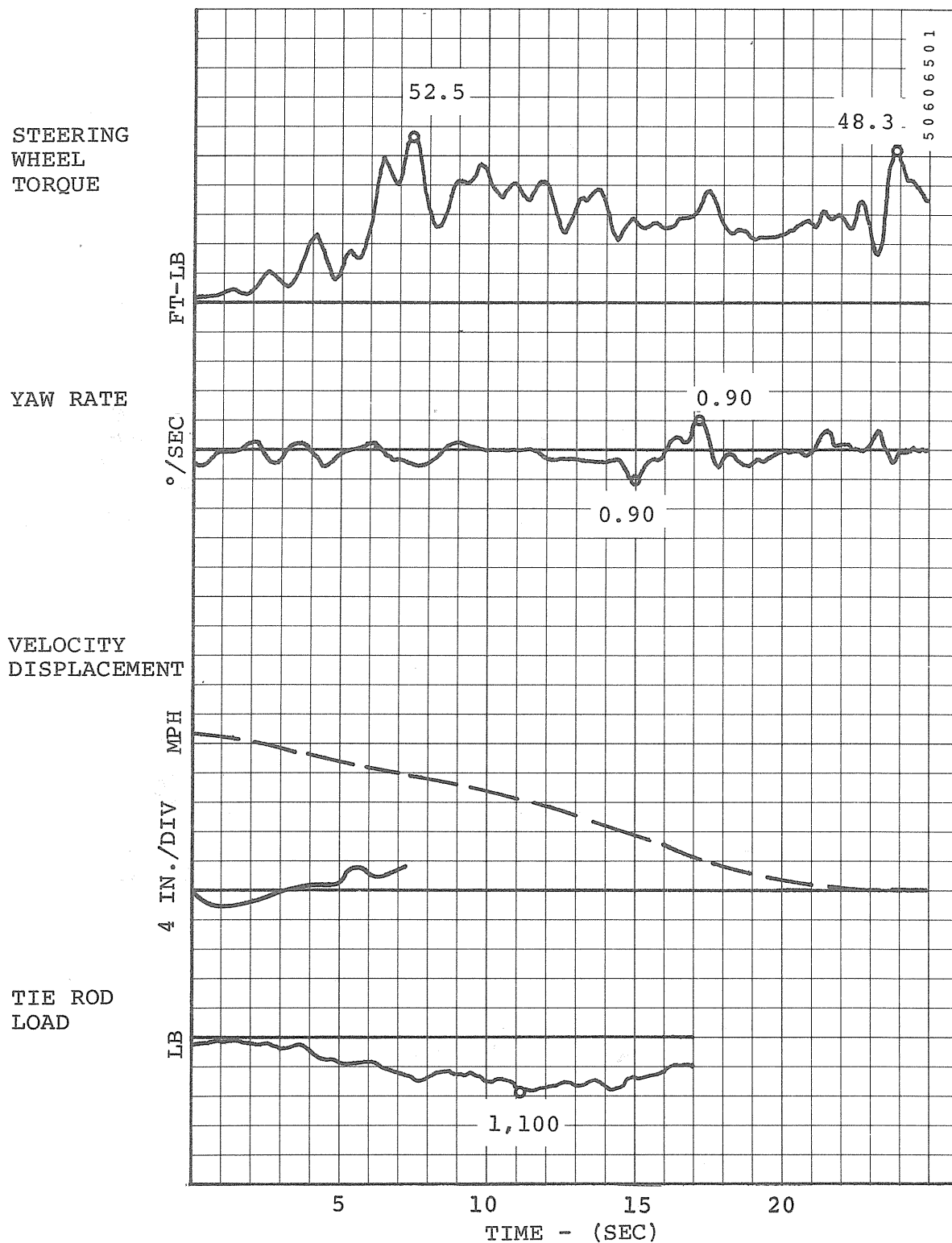


Figure 6-45. Test No. 25 - HECO.

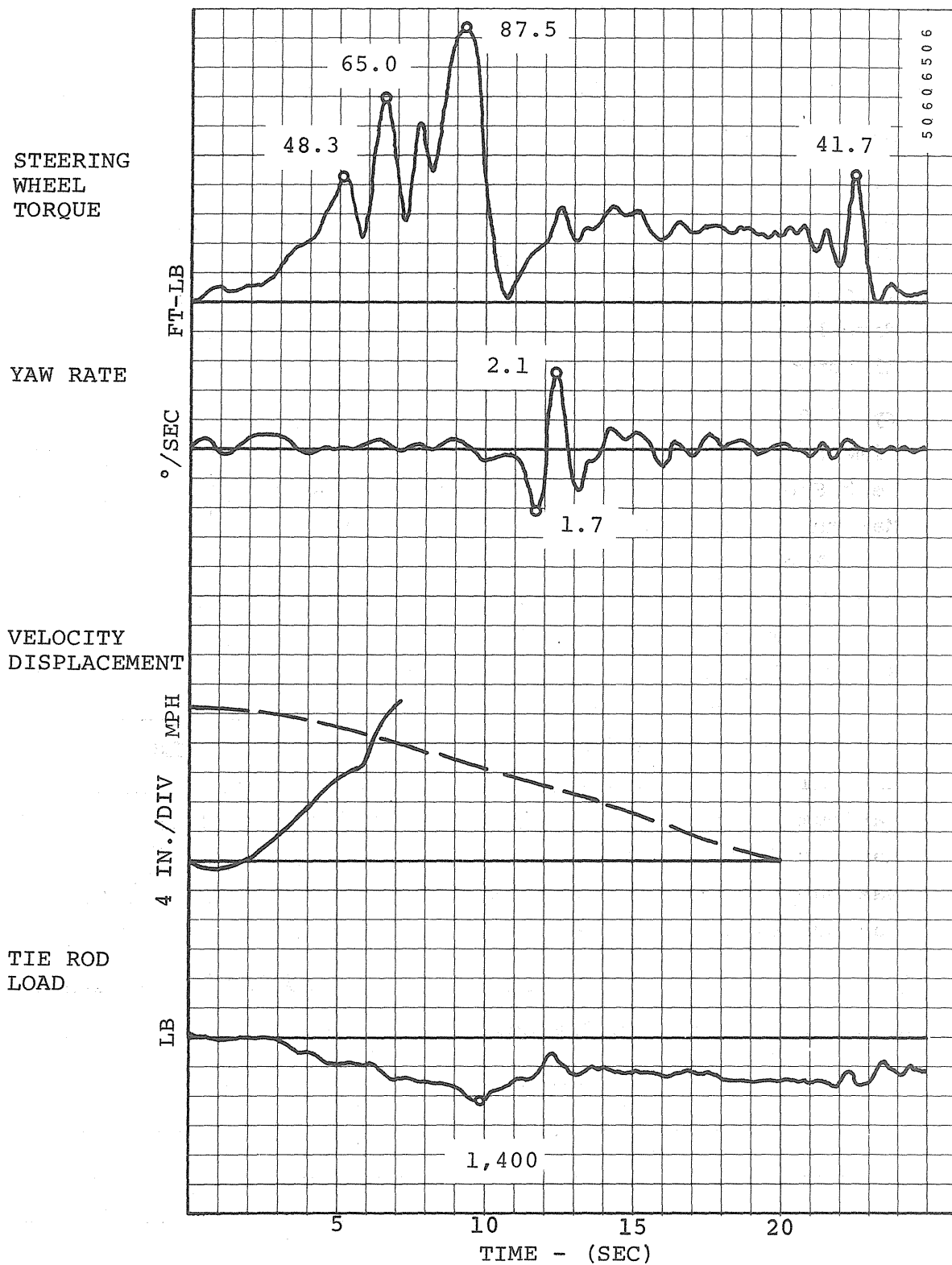


Figure 6-46. Test No. 26 - HECO.

TABLE 6-XXXVII. TEST NO. 25 DATA SUMMARY

Test Date: 3 April 1975 Test Number: 25

Vehicle: International Truck Combination

Test Conditions:

Safety Device HECO
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 25 ft-lb
 Peak Steering Wheel Torque 52.5 ft-lb at 7.5 sec
 Maximum Steering Wheel Angle 120 deg at 7.5 sec
 Time Averaged Tie Rod Force 825 lb
 Peak Tie Rod Force 1100 lb at 10 sec
 Lateral Truck Deviation After 6 Sec .3 ft
 Maximum Lateral Deviation Within 6 Sec .3 ft
 Rate of Lateral Deviation at 6 Sec .07 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec .18 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate .9 deg/sec at 14.5 sec
 Maximum Tractor/Trailer Angle .49 in. at 17.5 sec
 Maximum Longitudinal Acceleration .65 G at 17.5 sec
 Maximum Lateral Acceleration .75 G at 17.5 sec

Driver and Observer Comments: Truck controlled throughout test.

Vibration reduced due to device.

TABLE 6-XXXVIII. TEST NO. 26 DATA SUMMARY

Test Date: 3 April 1975 Test Number: 26

Vehicle: International Truck Combination

Test Conditions:

Safety Device HECO
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 29 ft-lb
 Peak Steering Wheel Torque 87.5 ft-lb at 9 sec
 Maximum Steering Wheel Angle 240 deg at 3 sec
 Time Averaged Tie Rod Force 770 lb
 Peak Tie Rod Force 1400 lb at 9.5 sec
 Lateral Truck Deviation After 6 Sec 1.3 ft
 Maximum Lateral Deviation Within 6 Sec 1.3 ft
 Rate of Lateral Deviation at 6 Sec .53 ft/sec
 Maximum Rate of Lateral Deviation Within 4 Sec .73 ft/sec
 Initial Vehicle Velocity 50 mph
 Maximum Tractor Yaw Rate 2.1 deg/sec at 12.5 sec
 Maximum Tractor/Trailer Angle .72 in. at 12 sec
 Maximum Longitudinal Acceleration .72 G at 15 sec
 Maximum Lateral Acceleration .70 G at 12 sec

Driver and Observer Comments: Truck controlled throughout test.

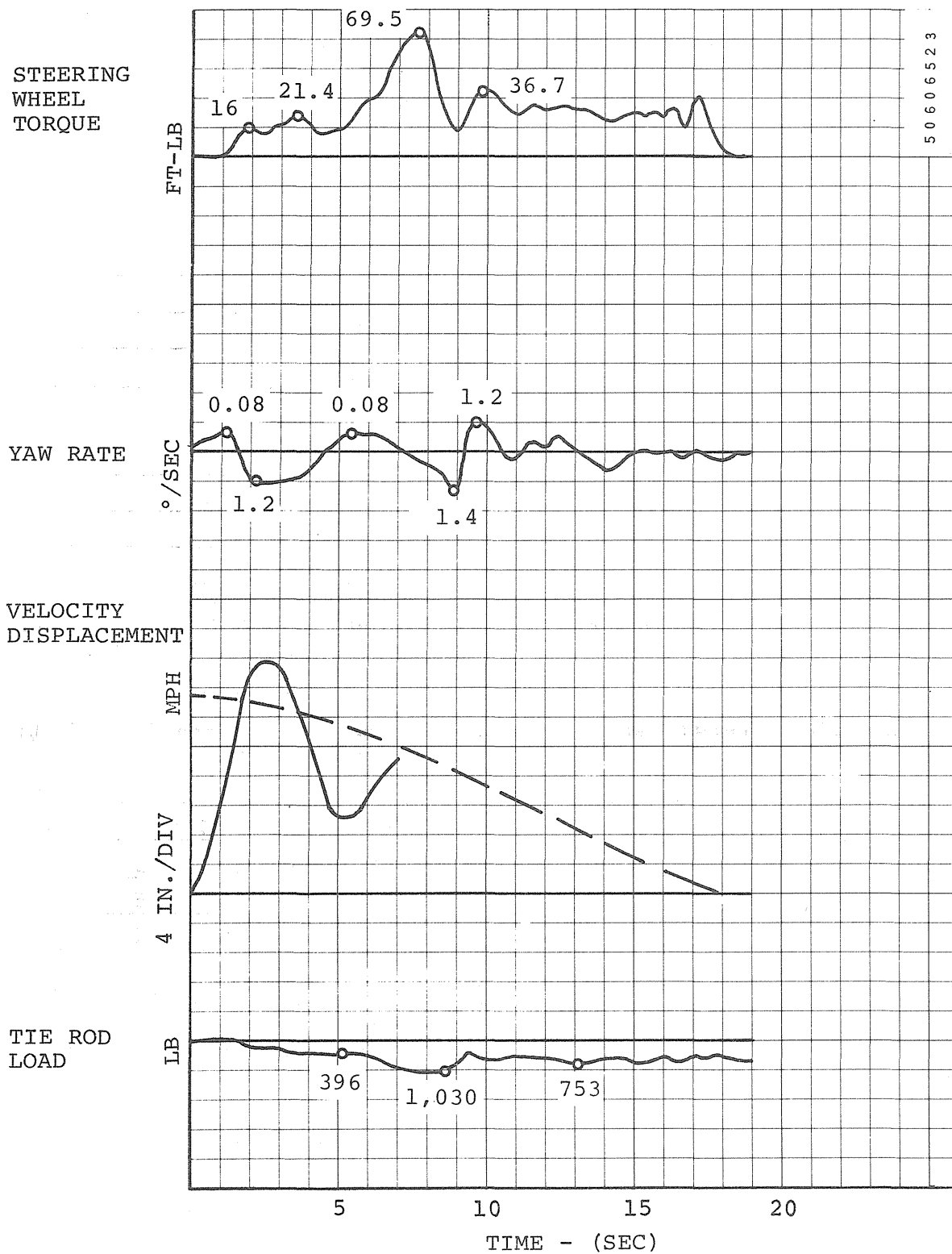


Figure 6-47. Test No. 16 - Preliminary HECO Test.

STEERING
WHEEL
TORQUE

FT-LB

50606503

YAW RATE

°/SEC

2.4

0.09

1.0

1.3

1.1

VELOCITY
DISPLACEMENT

MPH

4 IN./DIV

TIE ROD
LOAD

LB

238

594

1,188

990

TIME - (SEC)

Figure 6-48. Test No. 17 - Preliminary HECO Test.

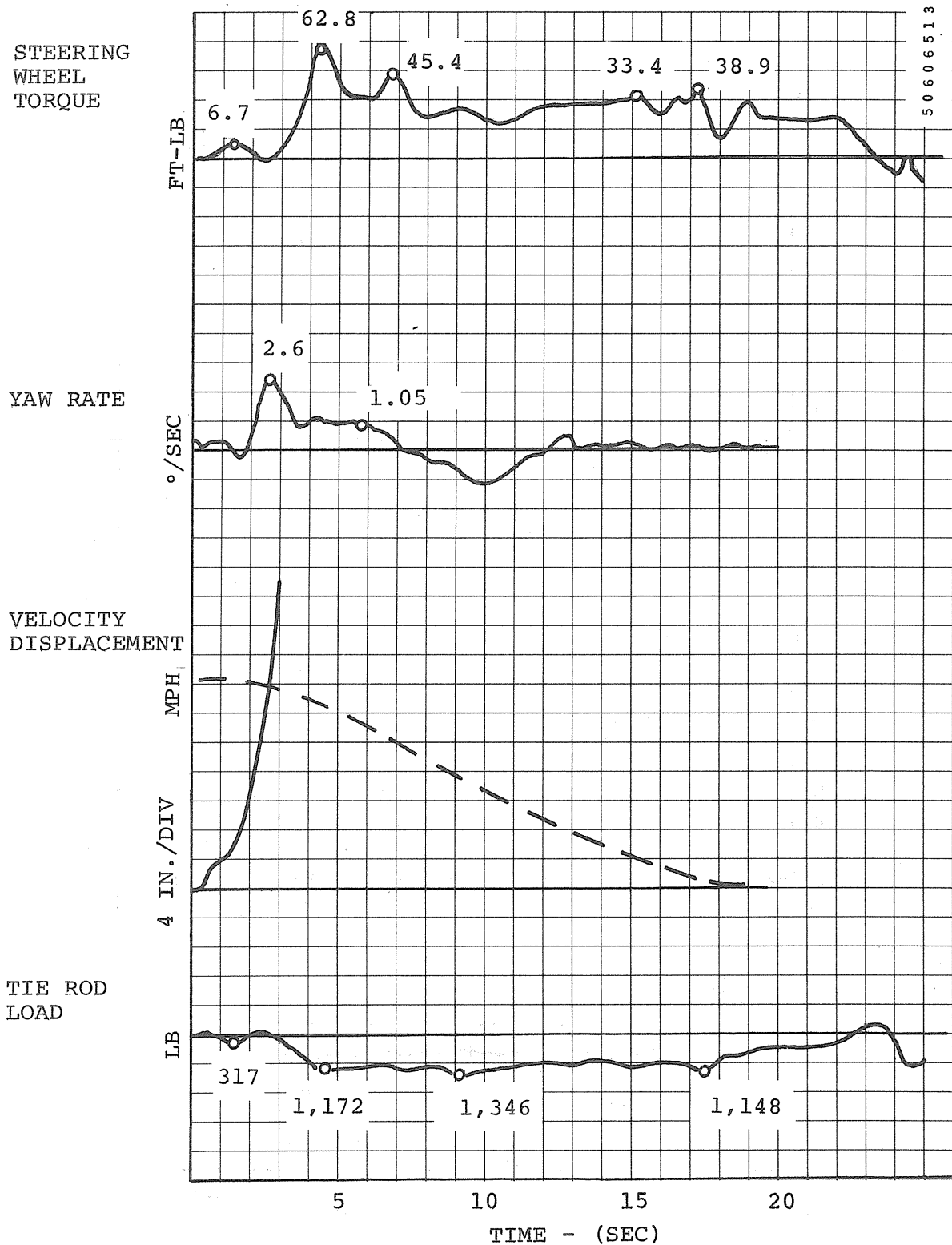


Figure 6-49. Test No. 18 - Preliminary HECO Test.

TABLE 6-XXXIX. TEST NO. 16 DATA SUMMARY

Test Date: 25 March 1975 Test Number: 16

Vehicle: International Truck Combination

Test Conditions:

Safety Device HECO

Vehicle Weight (lb) 28380

Tire Type Bias Ply

Tire Pressure (psi) 90

Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21.5 ft-lb

Peak Steering Wheel Torque 69.5 ft-lb at 7.7 sec

Maximum Steering Wheel Angle 200 deg

Time Averaged Tie Rod Force 543 lb

Peak Tie Rod Force 1030 lb at 8.3 sec

Lateral Truck Deviation After 6 Sec 1.2 ft

Maximum Lateral Deviation Within 6 Sec 2.6 ft

Rate of Lateral Deviation at 6 Sec .83 ft/sec

Maximum Rate of Lateral Deviation Within 6 Sec 1.38 ft/sec

Initial Vehicle Velocity 51 mph

Maximum Tractor Yaw Rate 1.4 deg/sec at 8.5 sec

Maximum Tractor/Trailer Angle 1.1 in. at 8.5 sec

Maximum Longitudinal Acceleration .65 G at 9.2 sec

Maximum Lateral Acceleration .50 G at 11.2 sec

Driver and Observer Comments: Steering control delayed for 2
seconds after initiation of tire deflation. Driver commented
he felt less vibration but higher average force in the steering
wheel.

TABLE 6-XL. TEST NO. 17 DATA SUMMARY

Test Date: 25 March 1975 Test Number: 17Vehicle: International Truck Combination

Test Conditions:

Safety Device HECO
Vehicle Weight (lb) 73280
Tire Type Bias Ply
Tire Pressure (psi) 90
Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 0 ft-lb
Peak Steering Wheel Torque No Data ft-lb at 0 sec
Maximum Steering Wheel Angle 240 deg
Time Averaged Tie Rod Force 760 lb
Peak Tie Rod Force 1188 lb at 6.3 sec
Lateral Truck Deviation After 4 Sec No Data ft
Maximum Lateral Deviation Within 4 Sec 7.5 ft
Rate of Lateral Deviation at 4 Sec 3.9 ft/sec
Maximum Rate of Lateral Deviation Within 4 Sec 4.0 ft/sec
Initial Vehicle Velocity 47 mph
Maximum Tractor Yaw Rate 2.4 deg/sec at 10.5 sec
Maximum Tractor/Trailer Angle .95 in. at 2 sec
Maximum Longitudinal Acceleration .65 G at 8.2 sec
Maximum Lateral Acceleration .60 G at 11 sec

Driver and Observer Comments: Steering wheel torque connector
not connected, test will be repeated.

TABLE 6-XLI. TEST NO. 18 DATA SUMMARY

Test Date: 25 March 1975 Test Number: 18Vehicle: International Truck Combination

Test Conditions:

Safety Device HECOVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 28.6 ft-lbPeak Steering Wheel Torque 62.8 ft-lb at 4.4 secMaximum Steering Wheel Angle 230 degTime Averaged Tie Rod Force 853 lbPeak Tie Rod Force 1346 lb at 9.2 secLateral Truck Deviation After 6 Sec No Data ftMaximum Lateral Deviation Within 4 Sec 8.8 ftRate of Lateral Deviation at 4 Sec 5.8 ft/secMaximum Rate of Lateral Deviation Within 4 Sec 5.8 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 2.6 deg/sec at 10 secMaximum Tractor/Trailer Angle 1.2 in. at 2.5 secMaximum Longitudinal Acceleration .5 G at 7 secMaximum Lateral Acceleration .25 G at 2.5 secDriver and Observer Comments: Delayed steering control for 2
seconds after initiation of tire deflation.

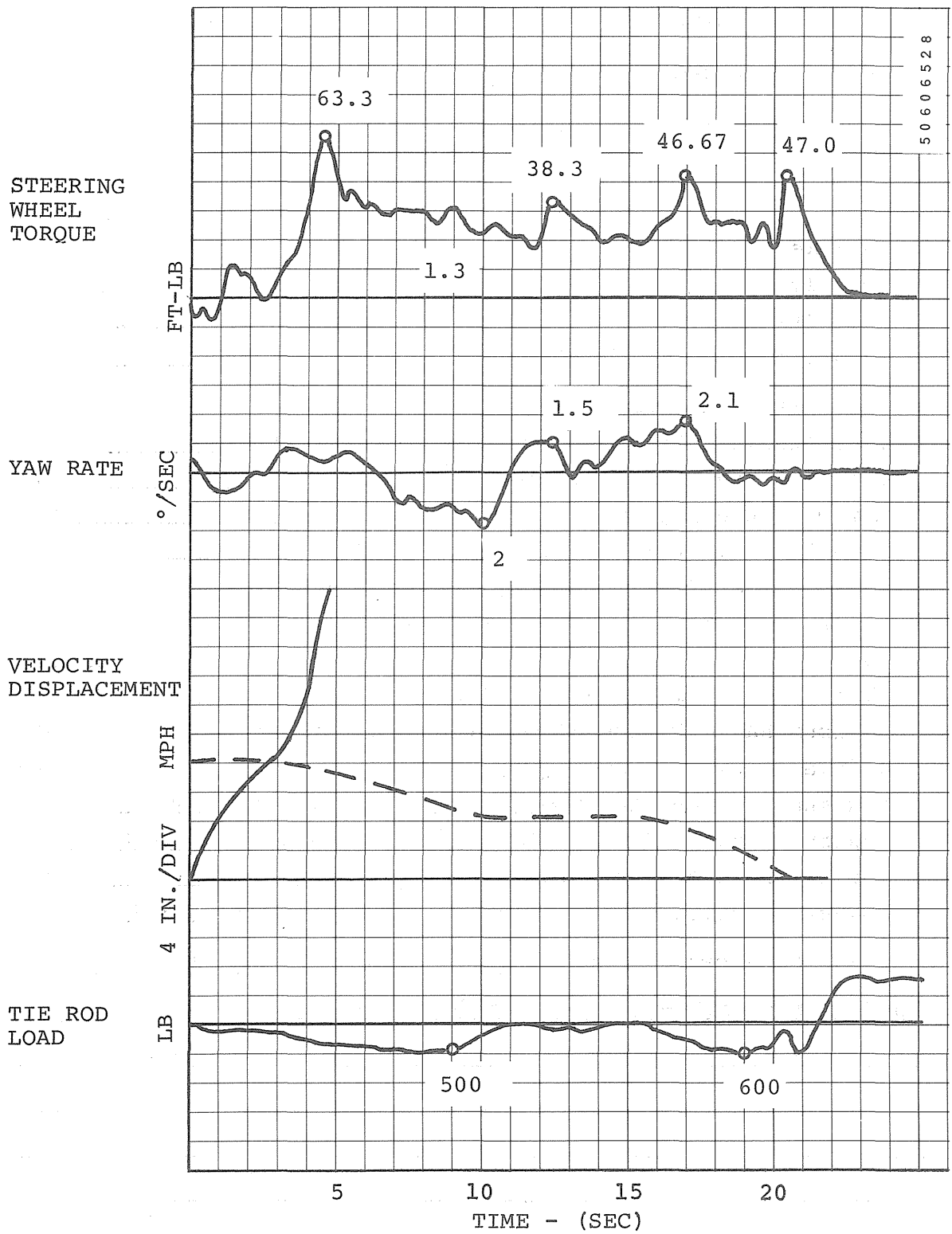


Figure 6-50. Test No. 46 - Steer Line.

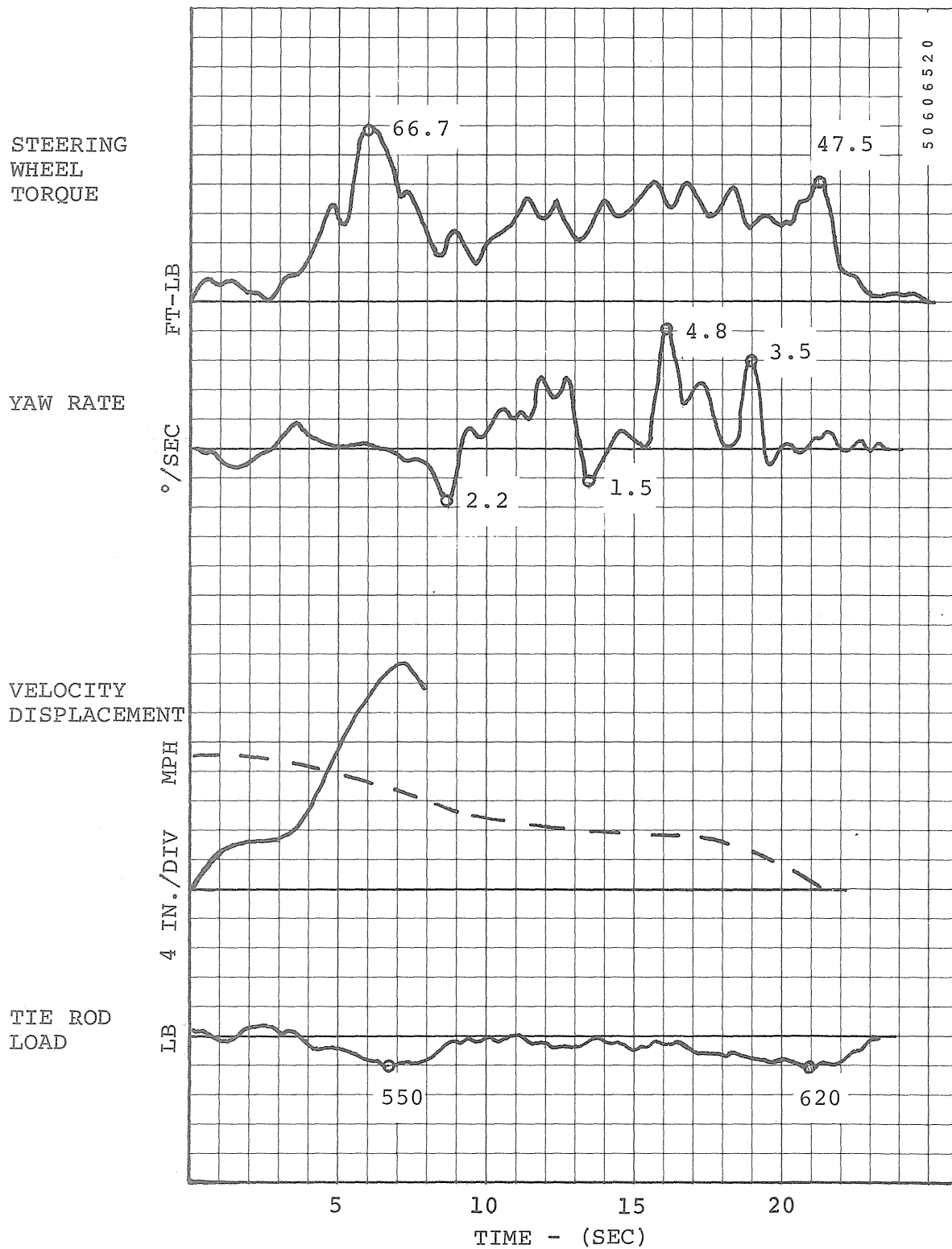


Figure 6-51. Test No. 47 - Steer Line.

TABLE 6-XLII. TEST NO. 46 DATA SUMMARY

Test Date: 6 May 1975 Test Number: 46Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer Line
Vehicle Weight (lb) 73280
Tire Type Bias Ply
Tire Pressure (psi) 90
Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 25 ft-lb
Peak Steering Wheel Torque 63.3 ft-lb at 5.5 sec
Maximum Steering Wheel Angle 100 deg at 5.5 sec
Time Averaged Tie Rod Force 375 lb
Peak Tie Rod Force 600 lb at 19 sec
Lateral Truck Deviation After 6 Sec 5.5 ft
Maximum Lateral Deviation Within 6 Sec 5.5 ft
Rate of Lateral Deviation at 6 Sec 1.9 ft/sec
Maximum Rate of Lateral Deviation Within 6 Sec 1.9 ft/sec
Initial Vehicle Velocity 50 mph
Maximum Tractor Yaw Rate 2.1 deg/sec at 22 sec
Maximum Tractor/Trailer Angle 1.86 in. at 10 sec
Maximum Longitudinal Acceleration .33 G at 7.5 sec
Maximum Lateral Acceleration .20 G at 7.5 sec

Driver and Observer Comments: Truck controlled throughout test.

TABLE 6-XLIII. TEST NO. 47 DATA SUMMARY

Test Date: 6 May 1975 Test Number: 47Vehicle: International Truck Combination

Test Conditions:

Safety Device Steer LineVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 27 ft-lbPeak Steering Wheel Torque 66.7 ft-lb at 6 secMaximum Steering Wheel Angle 120 deg at 6 secTime Averaged Tie Rod Force 300 lbPeak Tie Rod Force 620 lb at 22 secLateral Truck Deviation After 6 Sec 2.2 ftMaximum Lateral Deviation Within 6 Sec 2.2 ftRate of Lateral Deviation at 6 Sec .33 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .39 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 4.8 deg/sec at 20 secMaximum Tractor/Trailer* Angle 1.25 in. at 8.2 secMaximum Longitudinal Acceleration .30 G at 8 secMaximum Lateral Acceleration .34 G at 12.3 secDriver and Observer Comments: Truck controlled throughout test.

6.3.4.3 Cure Ride (Tests 23 and 24)

The Cure Ride device consists of a pair of hydraulic shock absorbers as discussed in Section 4.4.3. Figure 6-52 is a photograph of the Cure Ride system installed on the test truck. Figures 6-53 and 6-54 are data records from the tests with Cure Ride installed and Tables 6-XLIV and 6-XLV summarize the data from these tests.

While the driver reported less shimmy due to normal driving, there is no evidence of significant change in performance of the vehicle during a front tire deflation test over the baseline tests.

6.3.4.4 Positrol (Tests 27 and 28)

The Positrol device consists of two collinear springs as described in Section 4.1.3. Figure 6-55 is a photograph of the Positrol device installed on the test truck. Figures 6-56 and 6-57 are data records from the tire deflation test with the Positrol device installed. Tables 6-XLVI and 6-XLVII summarize the test data from these two tests.

During Test 27, the tire left the rim which eliminated the oscillations caused by the rim rolling over the folds of tire to be eliminated.

The driver noted additional effort required to steer the truck during normal driving maneuvers with the Positrol device installed.

Based upon the test data, there is no evidence of improved performance of the vehicle during a front tire deflation test over the baseline tests with the Positrol device installed.

6.3.5 Power-Assisted Steering

6.3.5.1 Air-O-Matic (Tests 52 and 53)

The Air-O-Matic is an air-power assisted steering system as described in Section 4.5.2 which includes a schematic of the system.

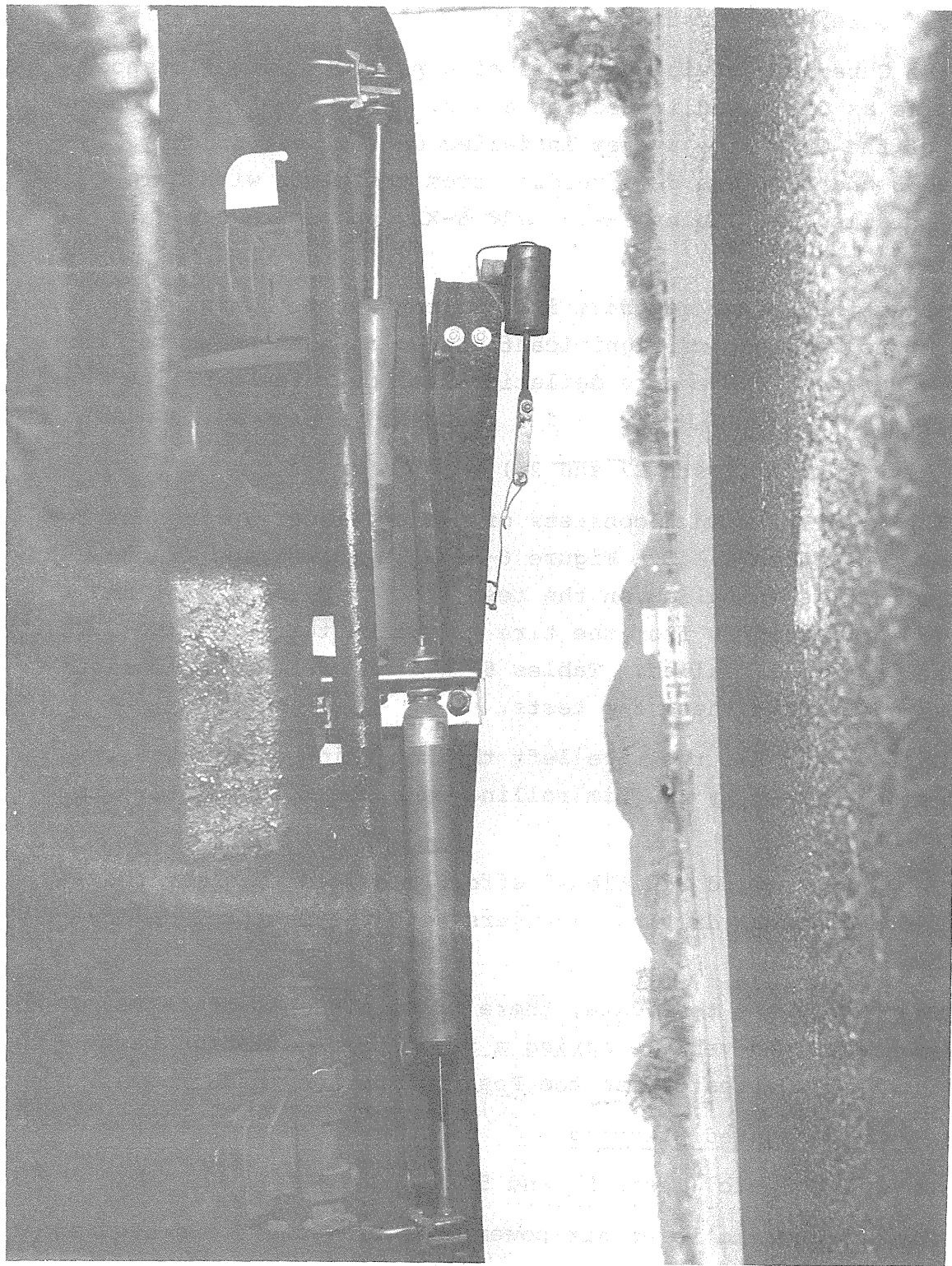


Figure 6-52. Cure Ride Device Mounted on Truck as Seen From Underside.

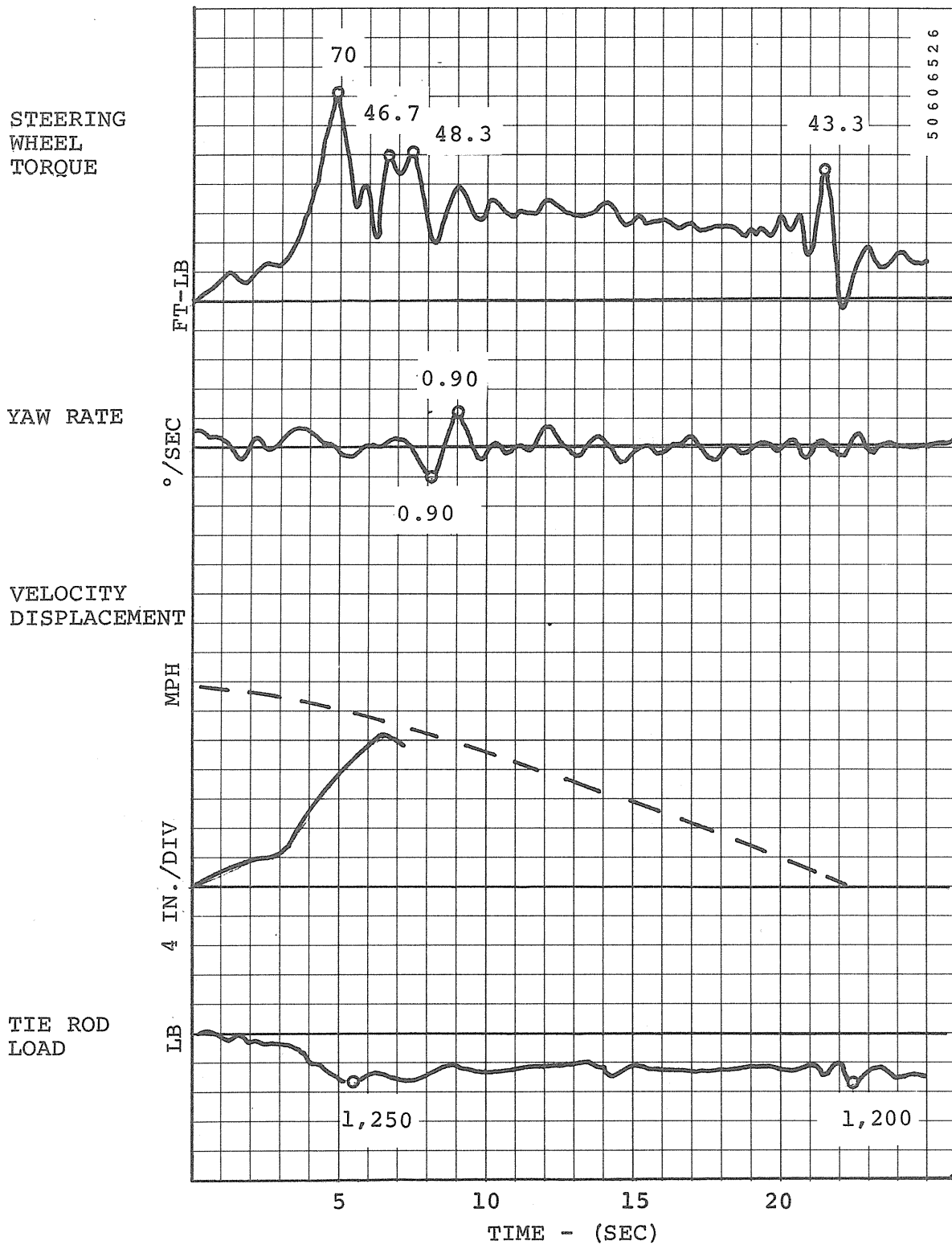


Figure 6-53. Test No. 23 - Cure Ride.

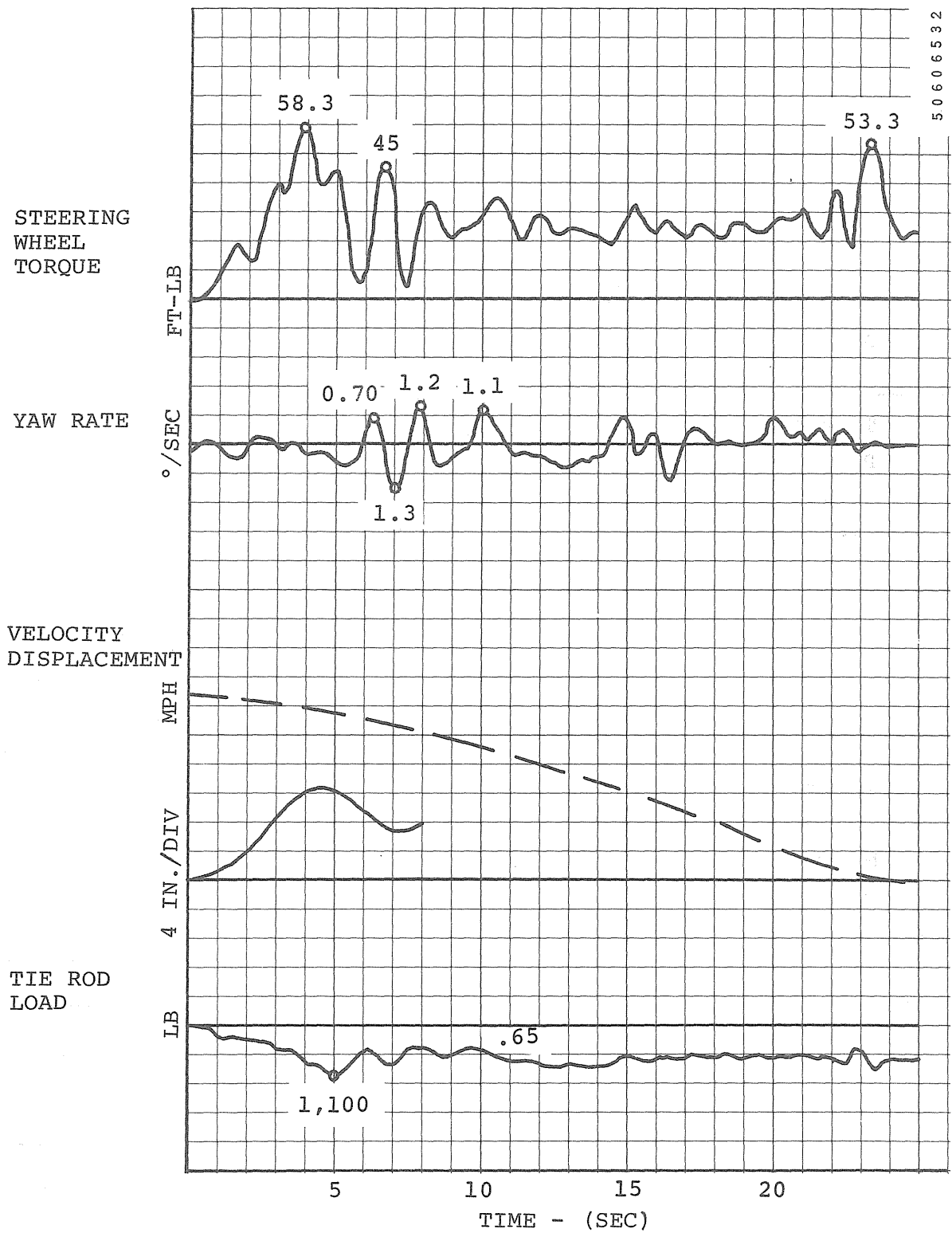


Figure 6-54. Test No. 24 - Cure Ride.

TABLE 6-XLIV. TEST NO. 23 DATA SUMMARY

Test Date: 2 April 1975 Test Number: 23Vehicle: International Truck Combination

Test Conditions:

Safety Device Cure Ride
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 23 ft-lb
 Peak Steering Wheel Torque 70 ft-lb at 4.5 sec
 Maximum Steering Wheel Angle 160 deg at 4.5 sec
 Time Averaged Tie Rod Force 583 lb
 Peak Tie Rod Force 1250 lb at 5 sec
 Lateral Truck Deviation After 6 Sec 1.6 ft
 Maximum Lateral Deviation Within 6 Sec 1.7 ft
 Rate of Lateral Deviation at 6 Sec .26 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec .49 ft/sec
 Initial Vehicle Velocity 52 mph
 Maximum Tractor Yaw Rate .9 deg/sec at 8 sec
 Maximum Tractor/Trailer Angle .57 in. at 8 sec
 Maximum Longitudinal Acceleration .6 G at 16 sec
 Maximum Lateral Acceleration .6 G at 14.7 sec

Driver and Observer Comments: Normal driving wheel vibration
reduced. Truck controlled throughout test.

TABLE 6-XLV. TEST NO. 24 DATA SUMMARY

Test Date: 2 April 1975 Test Number: 24Vehicle: International Truck Combination

Test Conditions:

Safety Device Cure Ride
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 21 ft-lb
 Peak Steering Wheel Torque 53.8 ft-lb at 3 sec
 Maximum Steering Wheel Angle 140 deg at 3 sec
 Time Averaged Tie Rod Force 758 lb
 Peak Tie Rod Force 1100 lb at 5 sec
 Lateral Truck Deviation After 6 Sec .8 ft
 Maximum Lateral Deviation Within 6 Sec 1.0 ft
 Rate of Lateral Deviation at 6 Sec .36 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec .38 ft/sec
 Initial Vehicle Velocity 48 mph
 Maximum Tractor Yaw Rate 1.3 deg/sec at 7 sec
 Maximum Tractor/Trailer Angle .42 in. at 7.5 sec
 Maximum Longitudinal Acceleration .63 G at 17.5 sec
 Maximum Lateral Acceleration .60 G at 16.7 sec

Driver and Observer Comments: Truck controlled throughout test.

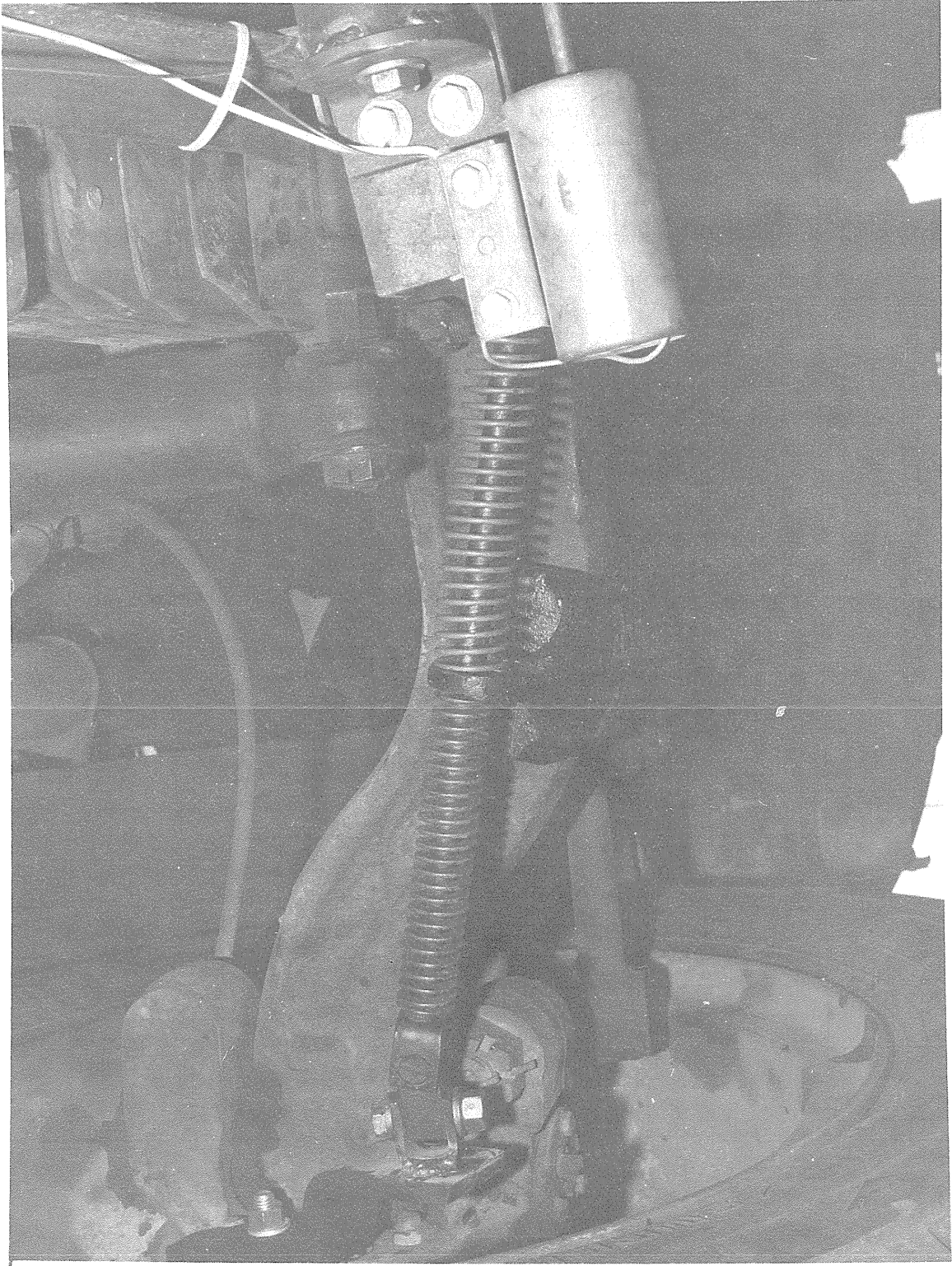


Figure 6-55. Positrol Device as Seen Mounted on Truck Axle.

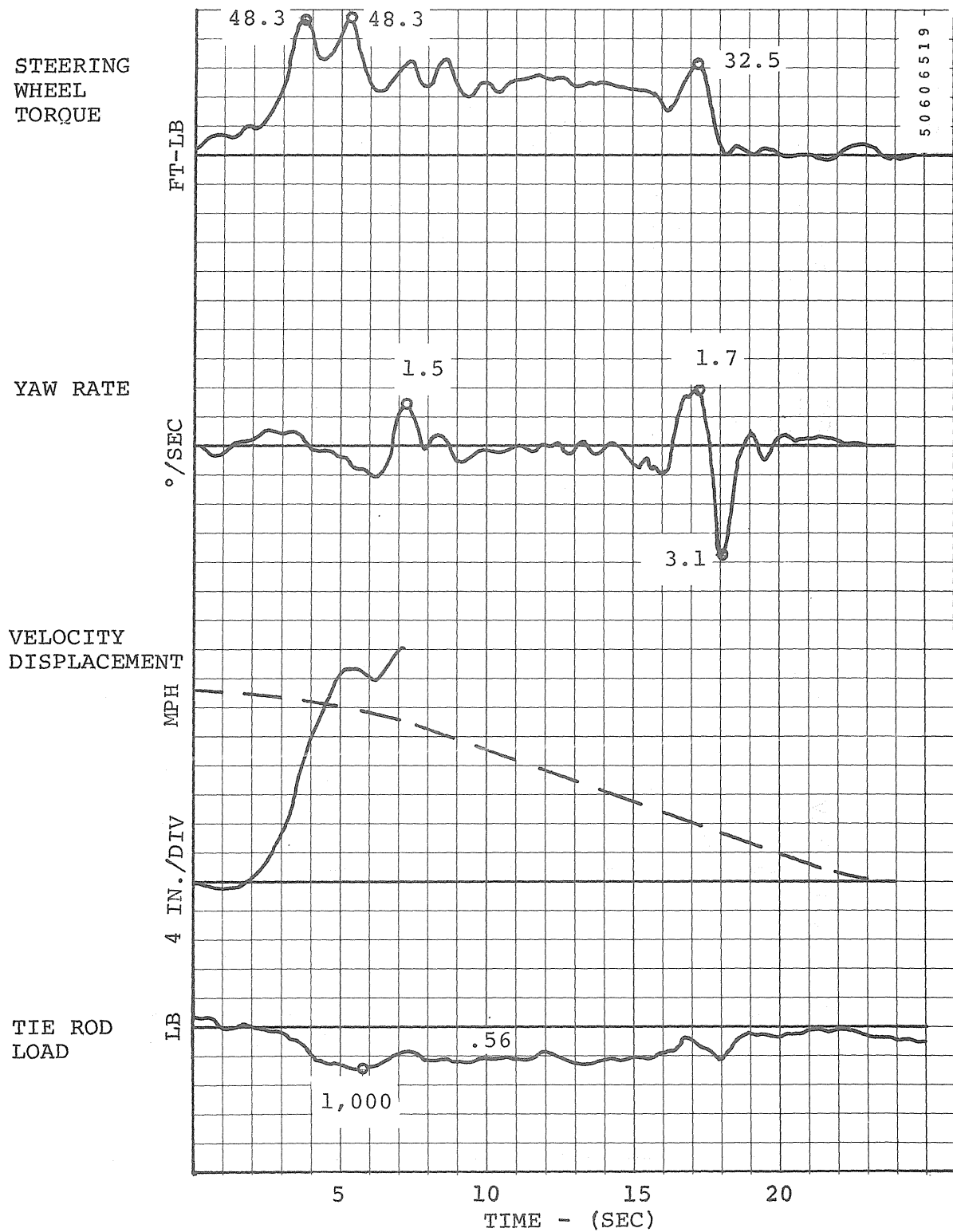


Figure 6-56. Test No. 27 - Positrol.

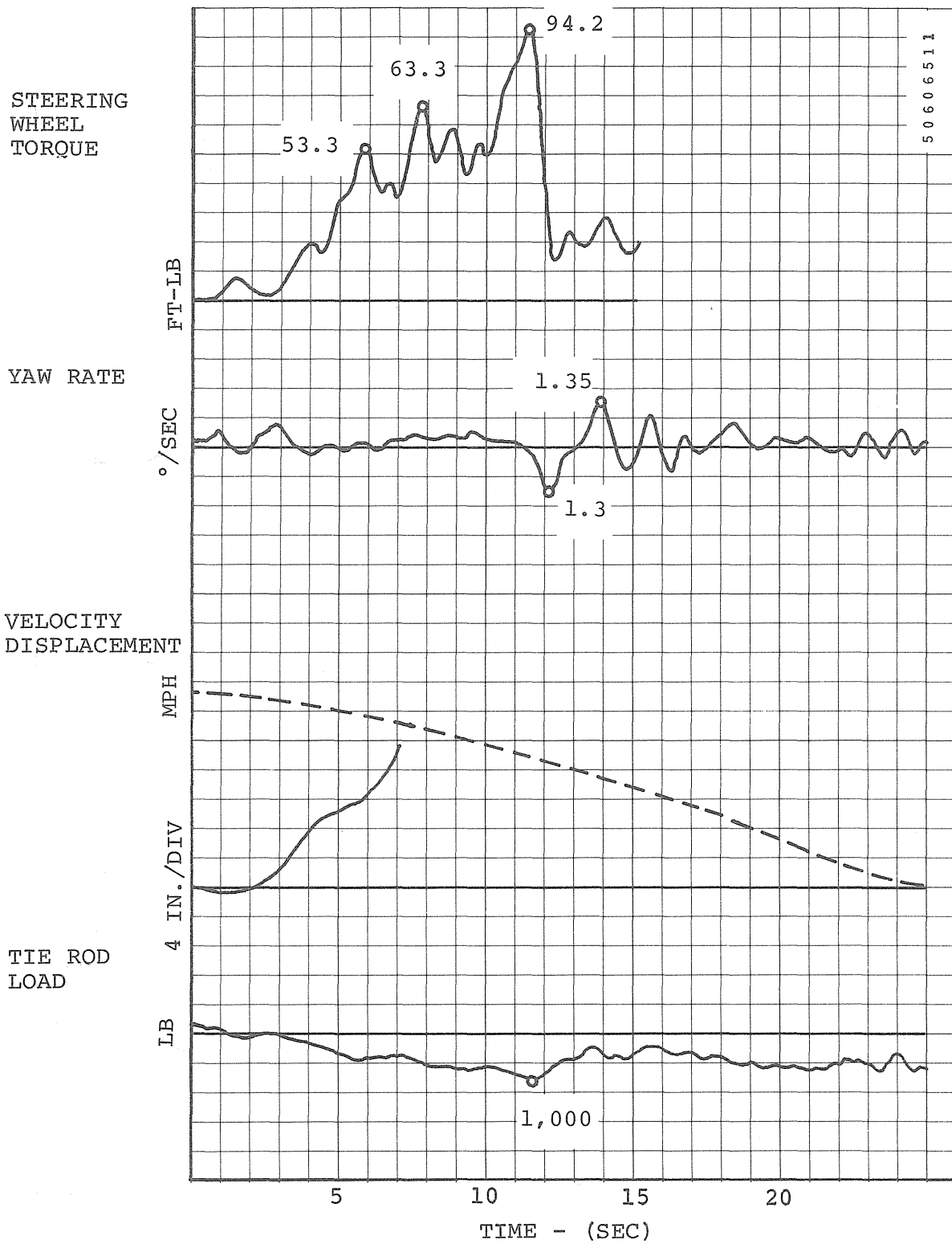


Figure 6-57. Test No. 28 - Positrol.

TABLE 6-XLVI. TEST NO. 27 DATA SUMMARY

Test Date: 8 April 1975 Test Number: 27

Vehicle: International Truck Combination

Test Conditions:

Safety Device Positrol
 Vehicle Weight (lb) 73280
 Tire Type Bias Ply
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 23 ft-lb
 Peak Steering Wheel Torque 48 ft-lb at 4 sec
 Maximum Steering Wheel Angle 210 deg at 4 sec
 Time Averaged Tie Rod Force 635 lb
 Peak Tie Rod Force 1000 lb at 5.5 sec
 Lateral Truck Deviation After 6 Sec 2.3 ft
 Maximum Lateral Deviation Within 6 Sec 2.5 ft
 Rate of Lateral Deviation at 6 Sec .03 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 1.02 ft/sec
 Initial Vehicle Velocity 51 mph
 Maximum Tractor Yaw Rate 3.1 deg/sec at 18 sec
 Maximum Tractor/Trailer Angle 1.03 in. at 18.5 sec
 Maximum Longitudinal Acceleration .82 G at 7.5 sec
 Maximum Lateral Acceleration .68 G at 13 sec

Driver and Observer Comments: Driver noticed additional effort
for normal steering. Tire left rim after deflation, causing
less oscillation of steering wheel force and vibration in cab.
Truck controlled throughout test.

TABLE 6-XLVII. TEST NO. 28 DATA SUMMARY

Test Date: 8 April 1975 Test Number: 28Vehicle: International Truck Combination

Test Conditions:

Safety Device PositrolVehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 30 ft-lbPeak Steering Wheel Torque 94 ft-lb at 10 secMaximum Steering Wheel Angle 110 deg at 8 secTime Averaged Tie Rod Force 465 lbPeak Tie Rod Force 1000 lb at 5.5 secLateral Truck Deviation After 6 Sec 1.0 ftMaximum Lateral Deviation Within 6 Sec 1.0 ftRate of Lateral Deviation at 6 Sec .18 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .95 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 1.4 deg/sec at 16 secMaximum Tractor/Trailer Angle .65 in. at 12 secMaximum Longitudinal Acceleration .50 G at 12.7 secMaximum Lateral Acceleration .60 G at 17 secDriver and Observer Comments: Truck controlled throughout test.

Figure 6-58 is a photograph of the air sensing valve and Figure 6-59 is a view of the power cylinder installed on the test truck.

Figures 6-60 and 6-61 are data records from Tests 52 and 53 and Tables 6-XLVIII and 6-XLIX are data summaries from the tests with the Air-O-Matic device installed.

While the tie rod forces are not significantly different from the baseline tests, the steering wheel torques are appreciably reduced.

6.3.6 Cantilever Tire (Tests 42 and 43)

The Cantilever Tire manufactured by Firestone is a low-profile, low-aspect ratio tire as described in Section 4.7. The tire also requires its own rim. Figure 6-62 is a post-test photo of the deflated tire. Figures 6-63 and 6-64 are data records from Tests 42 and 43 and Tables 6-L and 6-LI are data summaries of the tire deflation tests with the Cantilever Tire installed.

The test data show that the average steering wheel torque required to control the truck after a tire deflation is less than for the baseline tests.

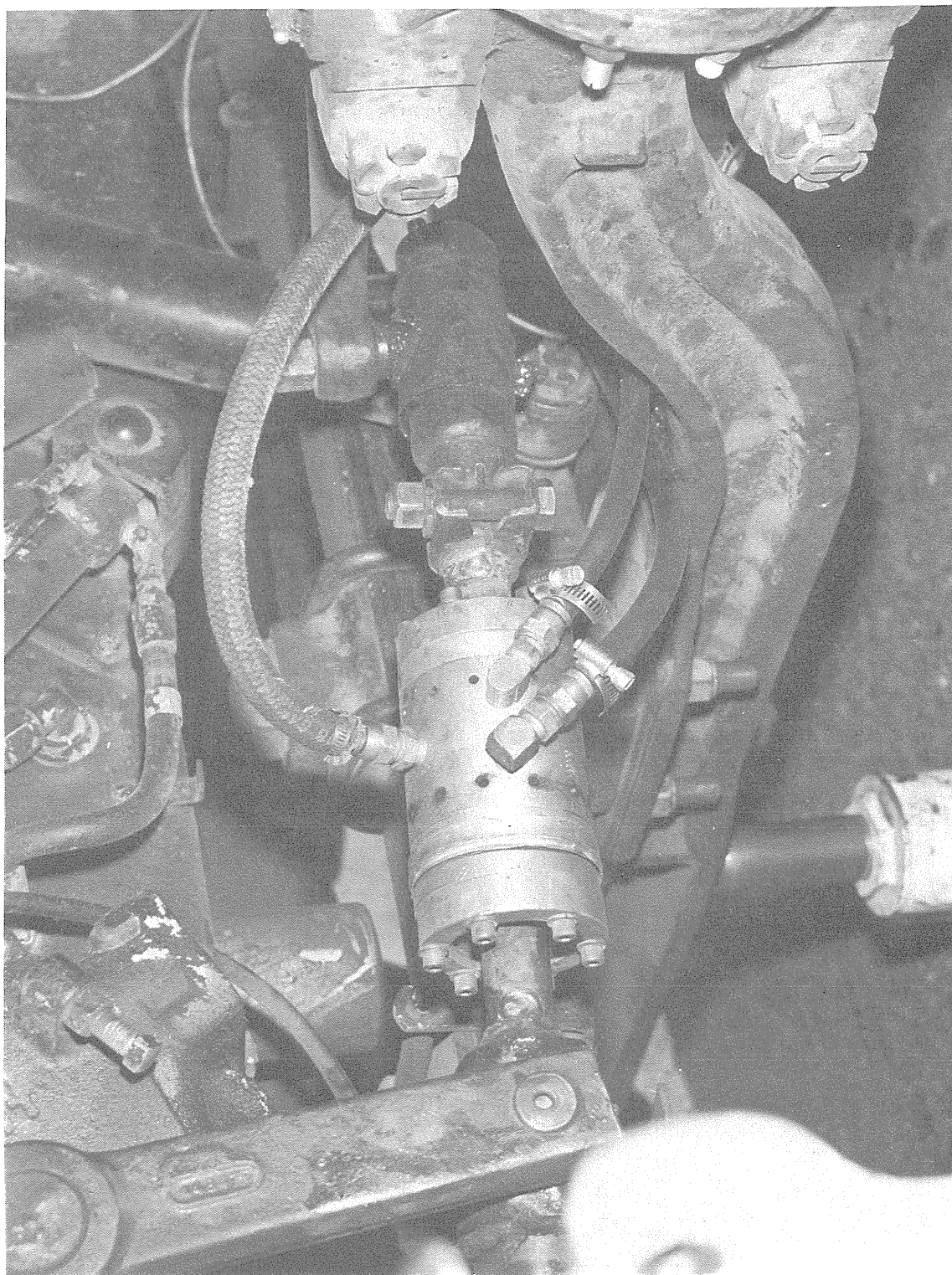


Figure 6-58. Air-O-Matic Air Sensing Valve.

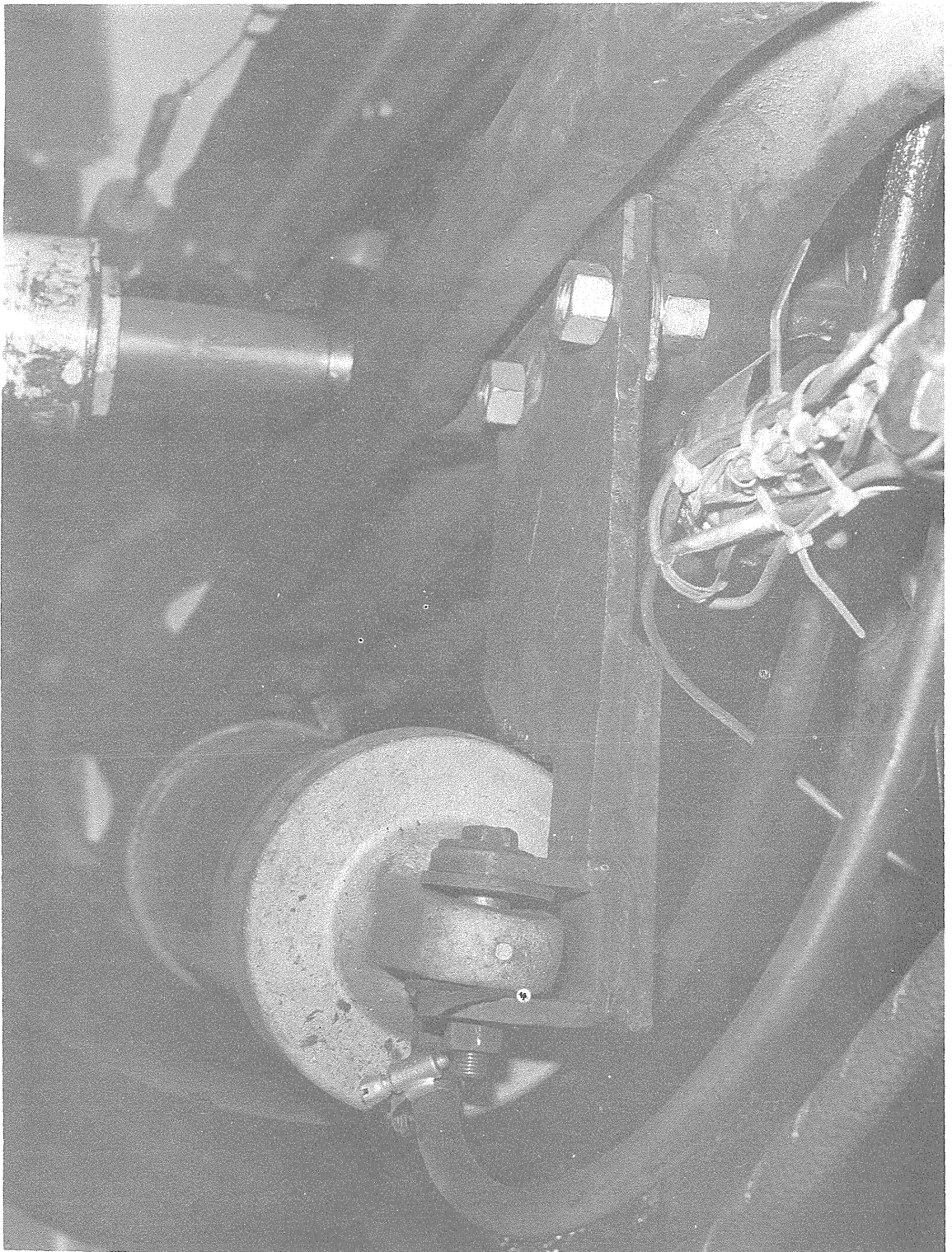


Figure 6-59. Air-O-Matic Power Cylinder Installed on Test Truck.

STEERING
WHEEL
TORQUE

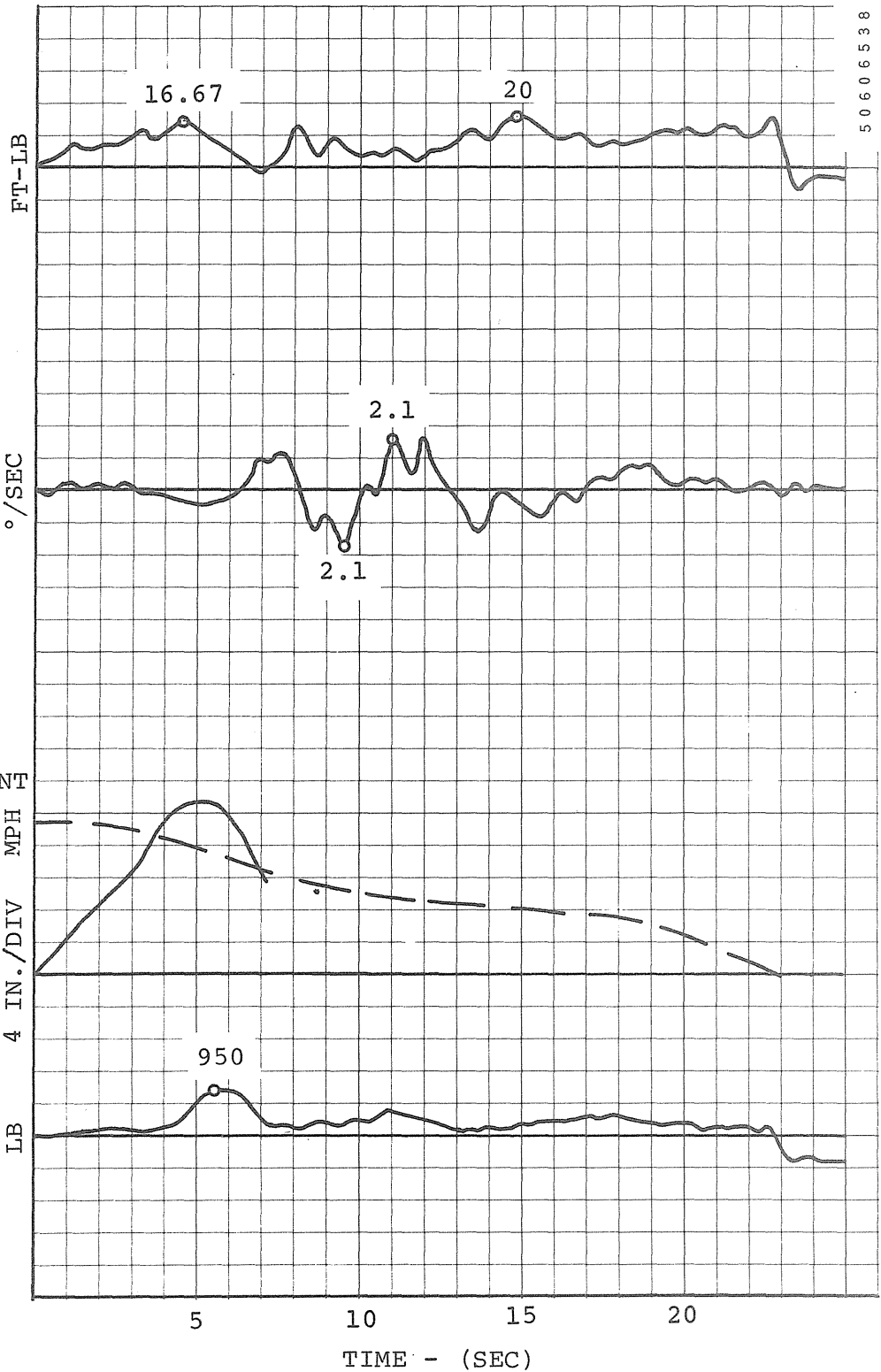


Figure 6-60. Test No. 52 - Power Steering.

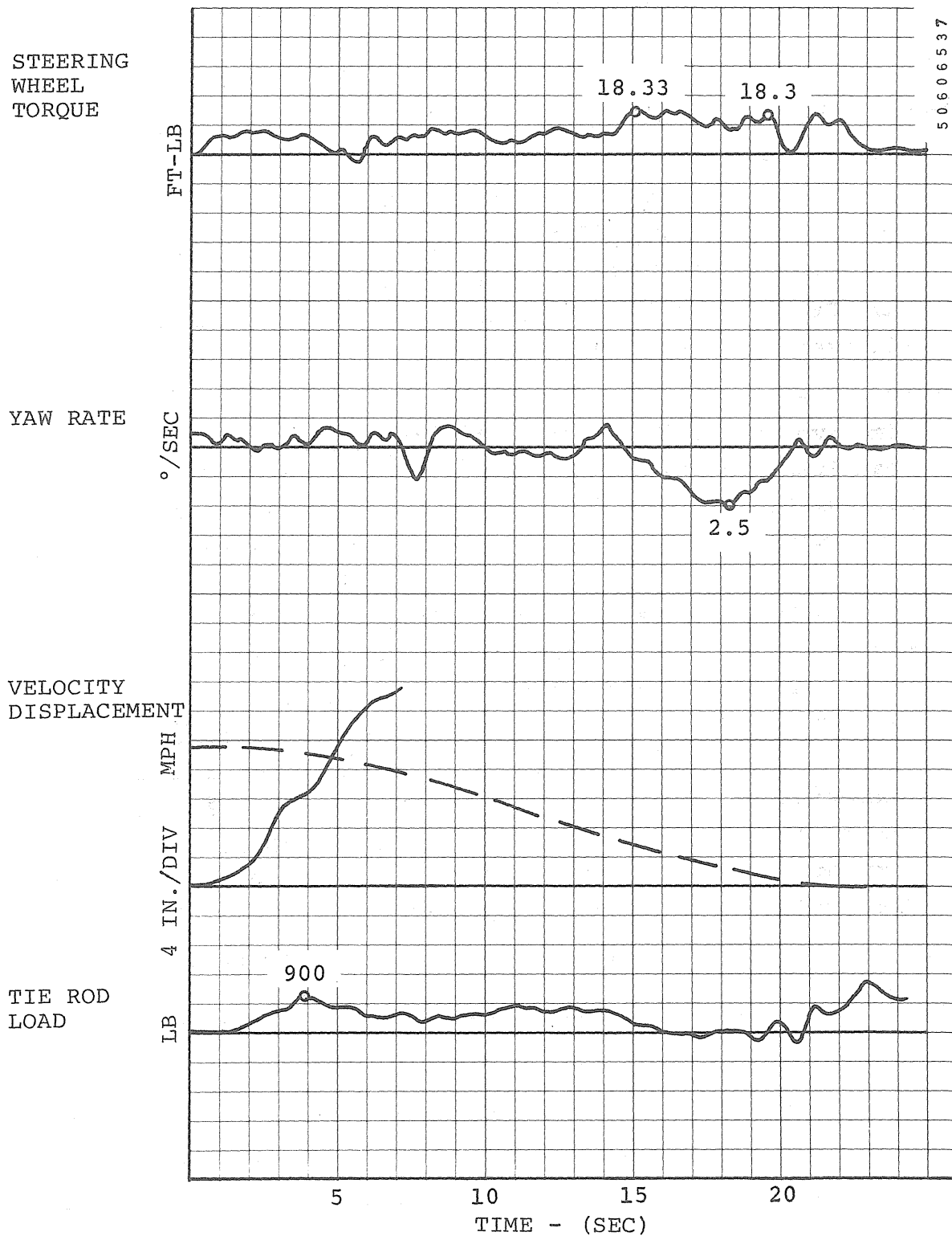


Figure 6-61. Test No. 53 - Power Steering.

TABLE 6-XLVIII. TEST NO. 52 DATA SUMMARY

Test Date: 16 May 1975 Test Number: 52Vehicle: International Truck Combination

Test Conditions:

Safety Device Power Steering (air)Vehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 11 ft-lbPeak Steering Wheel Torque 20 ft-lb at 15 secMaximum Steering Wheel Angle 145 deg at 8.5 secTime Averaged Tie Rod Force 793 lbPeak Tie Rod Force 950 lb at 5.5 secLateral Truck Deviation After 6 Sec 1.63 ftMaximum Lateral Deviation Within 6 Sec 1.7 ftRate of Lateral Deviation at 6 Sec .4 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .5 ft/secInitial Vehicle Velocity 49.5 mphMaximum Tractor Yaw Rate 2.1 deg/sec at 9.5 secMaximum Tractor/Trailer Angle No Data secMaximum Longitudinal Acceleration .09 G at 18 secMaximum Lateral Acceleration .20 G at 8.2 secDriver and Observer Comments: Truck easily controlled through-
out test.

TABLE 6-XLIX. TEST NO. 53 DATA SUMMARY

Test Date: 16 May 1975 Test Number: 53Vehicle: International Truck Combination

Test Conditions:

Safety Device Power Steering (air)Vehicle Weight (lb) 73280Tire Type Bias PlyTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 12 ft-lbPeak Steering Wheel Torque 18 ft-lb at 15 secMaximum Steering Wheel Angle 250 deg at 19 secTime Averaged Tie Rod Force 227 lbPeak Tie Rod Force 900 lb at 4 secLateral Truck Deviation After 6 Sec 2.0 ftMaximum Lateral Deviation Within 6 Sec 2.0 ftRate of Lateral Deviation at 6 Sec .3 ft/secMaximum Rate of Lateral Deviation Within 6 Sec .6 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 2.5 deg/sec at 24 secMaximum Tractor/Trailer Angle No Data secMaximum Longitudinal Acceleration .22 G at 9 secMaximum Lateral Acceleration .16 G at 11.2 secDriver and Observer Comments: Truck easily controlled through-
out test.



Figure 6-62. Test No. 42 Post-test View of Cantilever Tire.

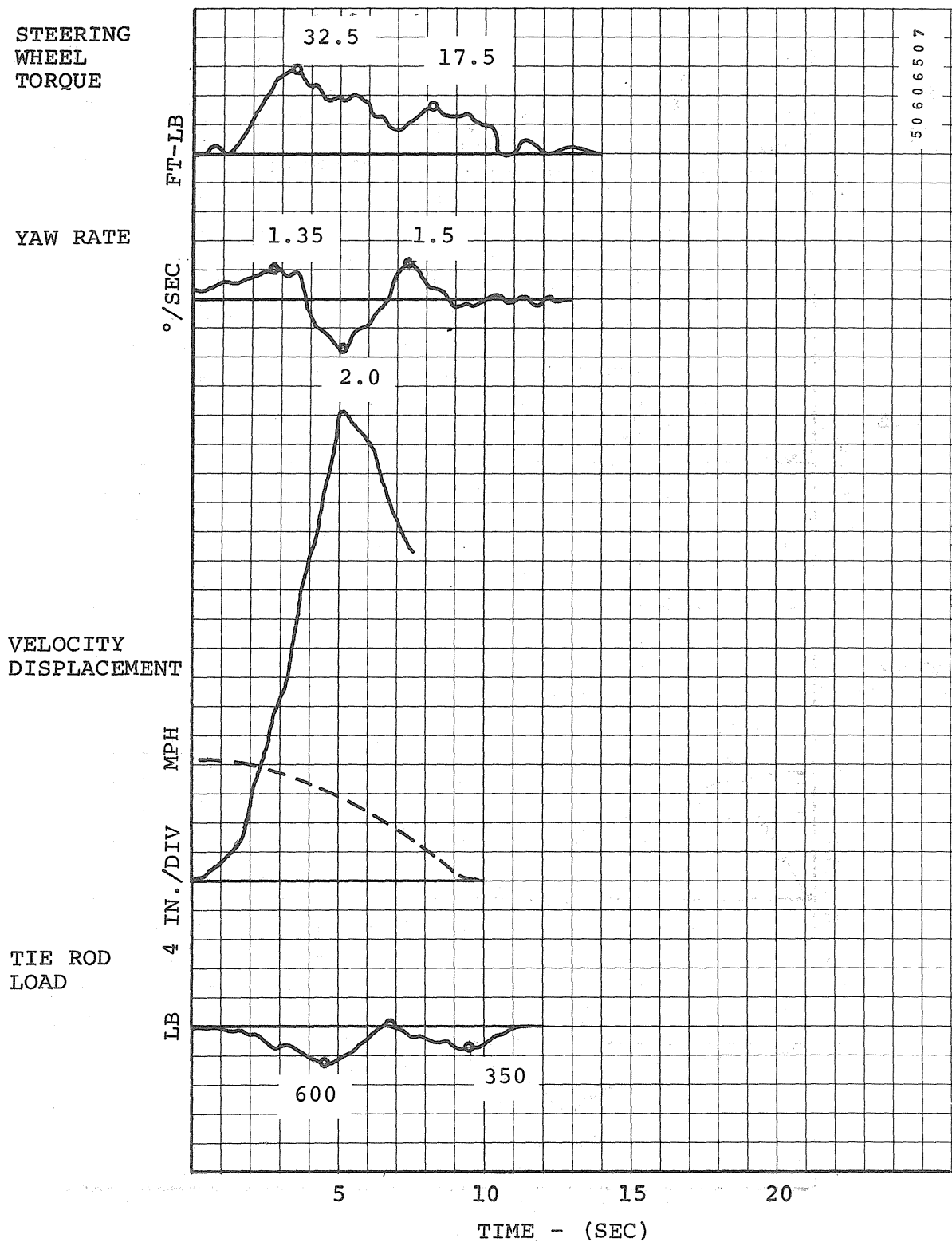


Figure 6-63. Test No. 42 - Firestone Cantilever.

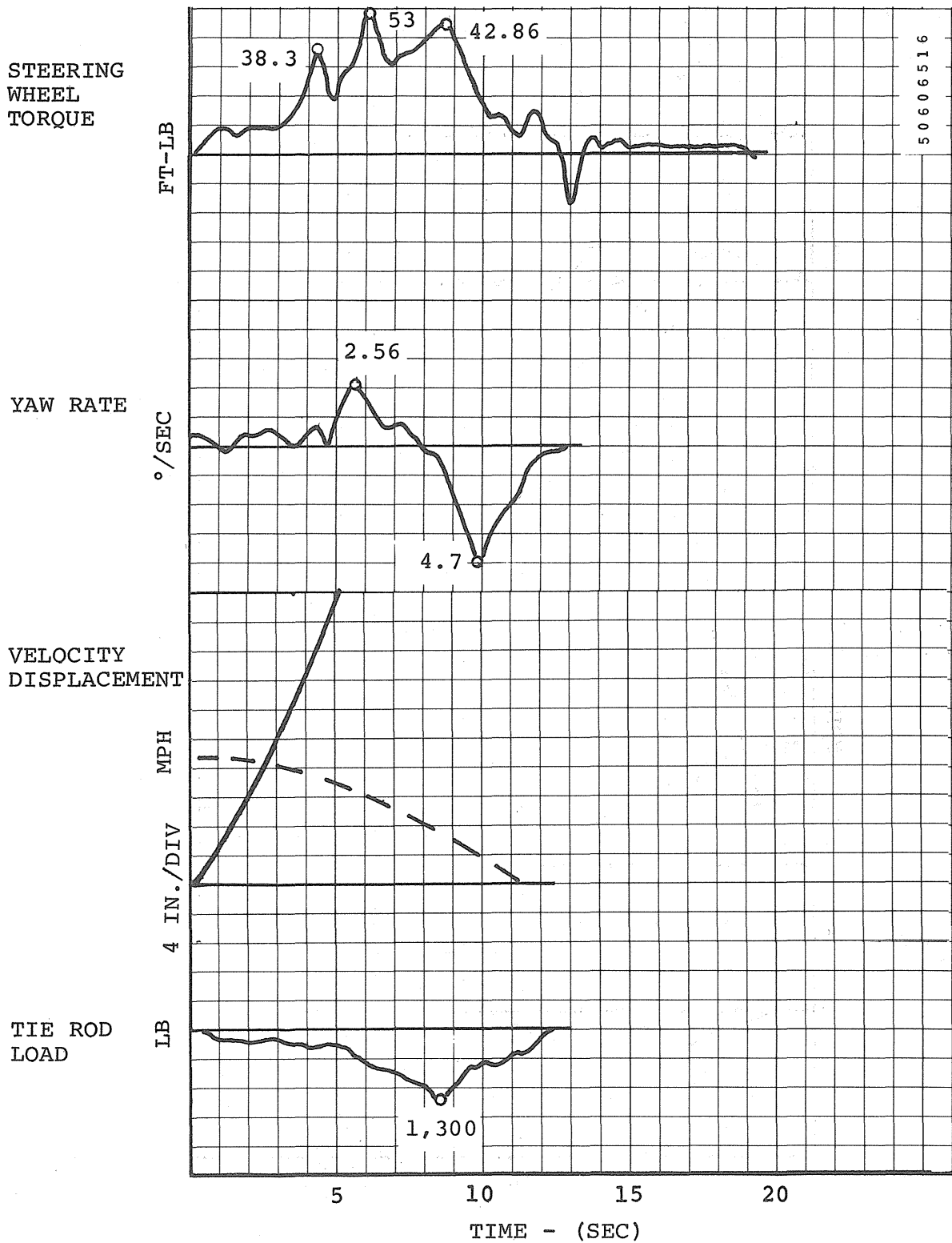


Figure 6-64. Test No. 43 - Firestone Cantilever.

TABLE 6-L. TEST NO. 42 DATA SUMMARY

Test Date: 5 May 1975 Test Number: 42

Vehicle: International Truck Combination

Test Conditions:

Safety Device Firestone Cantilever
 Vehicle Weight (lb) 73280
 Tire Type Cantilever
 Tire Pressure (psi) 90
 Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 10 ft-lb
 Peak Steering Wheel Torque 32.5 ft-lb at 4.5 sec
 Maximum Steering Wheel Angle 150 deg at 4.5 sec
 Time Averaged Tie Rod Force 162 lb
 Peak Tie Rod Force 600 lb at 10 sec
 Lateral Truck Deviation After 6 Sec 5 ft
 Maximum Lateral Deviation Within 6 Sec 5.4 ft
 Rate of Lateral Deviation at 6 Sec .69 ft/sec
 Maximum Rate of Lateral Deviation Within 6 Sec 2.1 ft/sec
 Initial Vehicle Velocity 49 mph
 Maximum Tractor Yaw Rate 2 deg/sec at 6.5 sec
 Maximum Tractor/Trailer Angle 1.3 in. at 6 sec
 Maximum Longitudinal Acceleration .37 G at 6 sec
 Maximum Lateral Acceleration .20 G at 3 sec

Driver and Observer Comments: Truck controlled throughout test,
tire remained aligned on rim.

TABLE 6-LI. TEST NO. 43 DATA SUMMARY

Test Date: 5 May 1975 Test Number: 43Vehicle: International Truck Combination

Test Conditions:

Safety Device Firestone CantileverVehicle Weight (lb) 73280Tire Type CantileverTire Pressure (psi) 90Alignment Standard

Summary of Reduced Data

Time Averaged Steering Wheel Torque 18 ft-lbPeak Steering Wheel Torque 53 ft-lb at 10 secMaximum Steering Wheel Angle 210 deg at 10 secTime Averaged Tie Rod Force 504 lbPeak Tie Rod Force 1300 lb at 10 secLateral Truck Deviation After 6 Sec 6.5 ftMaximum Lateral Deviation Within 6 Sec 6.5 ftRate of Lateral Deviation at 6 Sec 3.0 ft/secMaximum Rate of Lateral Deviation Within 6 Sec 3.0 ft/secInitial Vehicle Velocity 50 mphMaximum Tractor Yaw Rate 4.7 deg/sec at 12.5 secMaximum Tractor/Trailer Angle 1.33 in. at 5.8 secMaximum Longitudinal Acceleration .25 G at 7 secMaximum Lateral Acceleration .20 G at 5.7 secDriver and Observer Comments: Truck controlled throughout test.

7.0 TEST EVALUATION AND SUMMARY

Section 3.0 of this report contains a simplified analysis that estimates the steady-state truck response for some typical truck parameters. For the parameters and efficiencies assumed, the steady-state steering wheel force anticipated for the straight-line testing was 19.5 pounds.

The actual mean steering wheel torque was 23 ft-lb which corresponds to a steering wheel hand force of 25 pounds for the truck tested, based upon the mean of the baseline tests.

These steering control forces are below the hand force limit of 80 pounds for trucks and commercial vehicles cited by Taborek (1957).*

For the baseline tests, the test vehicle could be controlled by the average driver. Since accidents or uncontrollable situations occur as a result of front tire failure, other factors are involved. If the blowout occurred on a curve, the increased control forces required increase, depending upon many things: the radius of the intended path, vehicle speed, curve bank, and braking. The same analysis as presented in Section 3.0 estimates 61 pounds hand force or 3.1 times that for the straight line. In other words, it may be impossible to control a truck in the baseline configuration in a turn with the outside tire failed.

The forces that cause a truck to turn or deviate from a straight path are transmitted to the road surface through the tires. If the forces required to turn the truck exceed those that can be transmitted from the tire to the road, the tire slides and the truck "plows out" or understeers which means the vehicle does not respond quickly to a steering input. When a tire deflates, the ability of the tire to generate this lateral force is drastically reduced. In the event that the tire deflates on a wet road surface, the turning force that can be

*See References in Section 11.0.

generated between the tire and the road is further reduced. This means that the ability to steer a truck with a deflated tire on a wet surface may not be adequate to avoid an accident.

Road obstructions, in addition to a flat tire, also introduce complications in the ability to control the truck. There is some merit in testing the vehicle in a baseline configuration which is impossible to control and then install various devices and demonstrate the improvement in the ability to control the truck. However, configurations other than a flat, dry, straight track introduce additional variables that are not advisable to include for an initial investigation. Further investigation of promising devices may more dramatically point out their merits.

In any event, it is reasonable to evaluate the relative merit of various devices and concepts in proportion to their ability to make the front tire deflation less severe for the case of a flat, dry, and straight track.

Table 7-I is a compilation of all of the data summaries of all of the tests run during this program.

7.1 BASELINE TESTS

As discussed in Section 6.1, the three tests, 19, 22, and 48, form the basis of comparison for the concepts and devices.

Table 7-II summarizes the three baseline tests by listing the average steering wheel torque, average tie rod force, and the peak lateral displacement within 6 seconds.

The mean value and standard deviation for these parameters are listed for the population of three baseline tests.

The significance of each number, as defined in Section 7.3, is also tabulated for sample sizes 2 and 3. For a significance level of .1, assuming a normal probability distribution, there is a .9 probability that the mean value is greater than the value listed. For a significance level of .25, there is a .75 probability that the mean value is greater than the number listed.

TABLE 7-I. DATA SUMMARY TABLE¹

Test Number	1	2	3	4	5	6	7	8	9
Safety Device	None	None	None	None	None	None	None	None	None
Vehicle Weight	28,380	73,280	73,280	28,380	73,280	73,280	73,280	28,380	28,380
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Retread	Radial	Retread	Radial
Alignment	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Average Steering Wheel Torque (ft-lb)	No Data	No Data	No Data	No Data	5.3	17	16	14.3	18.8
Peak Steering Wheel Torque	35*	70*	55*	50*	16 @ 6.5 sec	43 @ 7 sec	32 @ 9.5 sec	38 @ 15 sec	49 @ 12 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	40	120	40	110	35	80	50	No Data	50
Average Tie Rod Force (lb)	No Data	No Data	No Data	No Data	217	271	433	313	157
Peak Tie Rod Force Filter	2,800**	No Data	2,800**	No Data	554 @ 16 sec	673 @ 16 sec	1663 @ 15 sec	554 @ 11.5 sec	357 @ 13 sec
Lateral Deviation After 6 Seconds (ft)	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Maximum Lateral Deviation Within 4 Seconds (ft)	No Data	No Data	5	No Data	2.05	1.03	9.26	1.6	6.8
Rate of Lateral Deviation at 4 Seconds (ft/sec)	No Data	No Data	4.84	No Data	2.74	2.25	No Data	1.31	7.10
Maximum Rate of Lateral Deviation at 4 Seconds (ft/sec)	No Data	No Data	7.41	No Data	4.95	5.42	6.56	3.71	7.10
Initial Vehicle Velocity	50	51	50	50	50	50	50	48	48
Maximum Tractor/Trailer Yaw Rate (deg/sec)	No Data	No Data	No Data	No Data	4.4 @ 9.5 sec	2.1 @ 6 sec	1.8 @ 5 sec	1.2 @ 9.5 sec	3.35 @ 5 sec
Maximum Tractor/Trailer Angle (in.)	2 @ 13 sec	.80	3.1 @ 15.75 sec	No Data	3 @ 15.5 sec	1 @ 6.5 sec	1.5 @ 5.5 sec	.3 @ 17 sec	3.35 @ 5.25 sec
Maximum Longitudinal Acceleration (G)	.38 @ 11 sec	.32	.48 @ 9 sec	.17 @ 3.25 sec	.47 @ 5.5 sec	.37 @ 3.5 sec	.37 @ 1 sec	.34 @ 11 sec	.35 @ 8.5 sec
Maximum Lateral Acceleration (G)	.80 @ 9 sec	.72	.90 @ 5.25 sec	.50 @ 16.25 sec	.50 @ 10 sec	.35 @ 6.5 sec	.45 @ 4 sec	.40 @ 12.75 sec	.50 @ 12 sec
Total Time of Run	16.5	22	17.5	20	16	16	16	17.5	14.5
Maximum Unfiltered Yaw Rate	No Data	No Data	13.4 @ 9 sec	No Data	12.3 @ 10.75 sec	7.5 @ 3.5 sec	6.0 @ 6 sec	10 @ 9 sec	5 @ 4.5 sec

*@ 50 Hz Filter (ft-lb)

**@ 50 Hz

TABLE 7-I. DATA SUMMARY TABLE (CONTD)

Test Number	10	11	12	13	14	15	16	17	18
Safety Device	None	None	None	None	None	None	HECO	HECO	HECO
Vehicle Weight	28,380	73,280	28,380	73,280	73,280	28,380	28,380	73,280	73,280
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply
Alignment	+2° Caster	+2° Caster	+2° Caster toe-in 1 in.	+2° Caster toe-in 1 in.	0° Caster toe-in 1 in.	0° Caster toe-in 1 in.	Standard	Standard	Standard
Average Steering Wheel Torque (ft-lb)	8.7	8.7	.72	14.4	14.4	17.3	21.5	0	28.6
Peak Steering Wheel Torque @ 50 Hz Filter (ft-lb)	35.4 @ 13.6 sec	34.7 @ 9.7 sec	8 @ 1.4 sec	22.7 @ 6.8 sec	30.7 @ 6.7 sec	44 @ 6 sec	69.5 @ 7.7 sec	0	62.8 @ 4.4 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	No Data	No Data	No Data	No Data	No Data	No Data	200	240	230
Average Tie Rod Force (lb)	388	465	155	310	654	545	543	760	853
Peak Tie Rod Force @ 50 Hz Filter	594 @ 12.2 sec	792 @ 11.3 sec	554 @ 12 sec	752 @ 7.5 sec	1030 @ 7.2 sec	792 @ 12.6 sec	1030 @ 8.3 sec	1188 @ 6.3 sec	1346 @ 9.2 sec
Lateral Deviation After 6 Seconds (ft)	No Data	No Data	No Data	No Data	No Data	No Data	1.2	No Data	No Data
Maximum Lateral Deviation Within 4 Seconds (ft)	3.1	1.5	7.8	8.2	7.6	9.2	2.6	7.5	8.8
Rate of Lateral Deviation at 4 Seconds (ft/sec)	2.14	2.75	No Data	6.85	No Data	No Data	.83	3.92	5.8
Maximum Rate of Lateral Devia- tion at 4 Seconds (ft/sec)	3.80	2.37	6.57	6.85	6.49	7.44	1.38	4.01	5.8
Initial Vehicle Velocity	50.3	50.3	49.7	49.2	50.3	51.3	51.0	47.0	50.0
Maximum Tractor/Trailer Yaw Rate (deg/sec)	3.8 @ 9.5	3.9 @ 5.5	4.9 @ 6	3.8 @ 9.5	2.6 @ 3.5	3.9 @ 8.5	1.4 @ 8.5	2.4 @ 10.5	2.6 @ 10
Maximum Tractor/Trailer Angle (in.)	2.4 @ 8.5 sec	2.3 @ 8 sec	4.9 @ 12 sec	2.6 @ 12.5 sec	1.3 @ 2.75 sec	2.7 @ 6 sec	1.1 @ 8.5 sec	.95 @ 2 sec	1.2 @ 2.5 sec
Maximum Longitudinal Accelera- tion (G)	.50 @ 9.25 sec	.22 @ 6 sec	.40 @ 6 sec	.55	.73 @ 3.25 sec	.67 @ 7 sec	.65 @ 9.25 sec	.65 @ 8.25 sec	.5 @ 7 sec
Maximum Lateral Acceleration (G)	.60 @ 7.75 sec	.75 @ 7.5 sec	.70 @ 6.25 sec	.80	.80 @ 4 sec	.78 @ 7 sec	.50 @ 11.25 sec	.60 @ 11 sec	.25 @ 2.5 sec
Total Time of Run	15.5	16.5	16.0	16.0	19.0	15.0	18.0	18.0	18.5
Maximum Unfiltered Yaw Rate Deg/sec	13.5 @ 9.5 sec	12.5 @ 5.5 sec	7.8 @ 6 sec	8.9 @ 9.5 sec	12.3 @ 3.5 sec	13.7 @ 8.5 sec	13.7 @ 8.5 sec	8 @ 10.5 sec	6 @ 10 sec

TABLE 7-I. DATA SUMMARY TABLE (CONTD)

Test Number	19	20	21	22	23	24	25	26	27
Safety Device	None	None	None	None	Cure Ride	Cure Ride	HECO	HECO	Positrol
Vehicle Weight	73,280	28,380	73,280	73,280	73,280	73,280	73,280	73,280	73,280
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply
Alignment	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Average Steering Wheel Torque (ft-lb)	21	21	32	21	23	21	25	29	23
Peak Steering Wheel Torque @ 50 Hz Filter (ft-lb)	58.3 @ 8 sec	46.7 @ 8 sec	67.5 @ 9 sec	60 @ 6 sec	70 @ 4.5 sec	58.3 @ 3 sec	52.5 @ 7.5 sec	87.5 @ 9 sec	48 @ 4 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	205° @ 8 sec	150° @ 8 sec	200° @ 11 sec	No Data	160° @ 4.5 sec	140° @ 3 sec	120° @ 7.5 sec	240° @ 3 sec	210° @ 4 sec
Average Tie Rod Force (lb)	581	433	587	747	583	758	825	770	635
Peak Tie Rod Force @ 50 Hz Filter	1000 @ 6 sec	1100 @ 24 sec	1400 @ 9 sec	1400 @ 5 sec	1250 @ 5 sec	1100 @ 5 sec	1100 @ 10 sec	1400 @ 9.5 sec	1000 @ 5.5 sec
Lateral Deviation After 6 Seconds (ft)	1.3	.6	1.0	3.7	1.6	.8	.3	1.3	2.3
Maximum Lateral Deviation Within 6 Seconds (ft)	1.3	.7	1.0	3.7	1.7	1.0	.3+	1.3	2.5
Rate of Lateral Deviation at 6 Seconds (ft/sec)	.03	.25	.32	.56	.26	.36	.07	.53	.03
Maximum Rate of Lateral Deviation at 6 Seconds (ft/sec)	.61	.40	.53	1.09	.49	.38	.18	.73	1.02
Initial Vehicle Velocity	50	52	51	48	52	48	50	50	51
Maximum Tractor/Trailer Yaw Rate (deg/sec)	1.5 @ 8 sec	1.0 @ 20 sec	1.8 @ 11.5 sec	1.3 @ 11 sec	.9 @ 8 sec	1.3 @ 7 sec	.9 @ 14.5 sec	2.1 @ 12.5 sec	3.1 @ 18 sec
Maximum Tractor/Trailer Angle (in.)	.49 @ 7.5 sec	.68 @ 18 sec	.50 @ 11.75 sec	.50 @ 13.5 sec	.57 @ 8 sec	.42 @ 7.5 sec	.49 @ 17.5 sec	.72 @ 12 sec	1.03 @ 18.5 sec
Maximum Longitudinal Acceleration (G)	.15 @ 17.5 sec	.5 @ 10.5 sec	.27 @ 12 sec	.30 @ 16 sec	.6 @ 16 sec	.63 @ 17.5 sec	.65 @ 17.5 sec	.72 @ 15 sec	.82 @ 7.5 sec
Maximum Lateral Acceleration (G)	.23 @ 14.75 sec	.35 @ 16.5 sec	.3 @ 11.75 sec	.20 @ 3 sec	.60 @ 14.75 sec	.60 @ 16.75 sec	.74 @ 17.25 sec	.70 @ 12 sec	.68 @ 13 sec
Total Time of Run	26	22.5	24	23	23	24	24	23	23

TABLE 7-1. DATA SUMMARY TABLE (CONTD)

Test Number	28	29	30	31	32	33	34	35	36
Safety Device	Positrol	Steer Safe	Steer Safe	Steering Stabi- lizer	Steering Stabi- lizer	Steer Safe	Steer Safe	Centerline	Centerline
Vehicle Weight	73,280	73,280	73,280	73,280	73,280	73,280	73,280	73,280	73,280
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply
Alignment	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Average Steering Wheel Torque (ft-lb)	30	15	15	23	26	24	28	9	13
Peak Steering Wheel Torque @ 50 Hz Filter (ft-lb)	94 @ 10 sec	48 @ 13 sec	50 @ 13 sec	60 @ 5 sec	60 @ 6 sec	54 @ 7 sec	65 @ 12.5 sec	33 @ 18 sec	44 @ 22 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	110° @ 8 sec	170° @ 20 sec	160° @ 18 sec	190° @ 6 sec	220° @ 9 sec	250° @ 6 sec	250° @ 11 sec	180° @ 18 sec	140° @ 18 sec
Average Tie Rod Force (lb)	465	342	293	391	558	475	735	400	550
Peak Tie Rod Force @ 50 Hz Filter	1000 @ 5.5 sec	1346 @ 20.7 sec	1200 @ 18 sec	850 @ 7 sec	1150 @ 24 sec	1000 @ 6 sec	1150 @ 13.5 sec	900 @ 24.5 sec	1000 @ 10.5 sec
Lateral Deviation After 6 Seconds (ft)	1.0	.1	.4	3.83	1.58	6.2	.83	.17	.42
Maximum Lateral Deviation Within 6 Seconds (ft)	1.0	.2+	.25	3.83	1.58	6.2	.83	.5+	.42
Rate of Lateral Deviation at 6 Seconds (ft/sec)	.18	.03	.13	1.39	.42	1.66	.26	.06	.16
Maximum Rate of Lateral Devia- tion at 6 Seconds (ft/sec)	.95	.05	.13	2.01	1.46	2.21	.86	.38	1.10
Initial Vehicle Velocity	50	51	51	50	50	50	50	50	50
Maximum Tractor/Trailer Yaw Rate (deg/sec)	1.4 @ 16 sec	2.8 @ 1.7 sec	.9 @ 4 sec	.9 @ 10 sec	1.1 @ 11 sec	1.2 @ 7 sec	8.5 @ 3.5 sec	1.2 @ 11 sec	1.1 @ 8.5 sec
Maximum Tractor/Trailer Angle (in.)	.65 @ 12 sec	.53 @ 3.75 sec	.61 @ 15 sec	.19 @ 8 sec	.53 @ 11 sec	.42 @ 7 sec	.61 @ 14 sec	.34 @ 14.5 sec	.38 @ 12 sec
Maximum Longitudinal Accelera- tion (G)	.50 @ 12.75 sec	.30 @ 12 sec	.30 @ 15 sec	.32 @ 7.75 sec	.62 @ 14 sec	.86 @ 9 sec	.30 @ 12 sec	.20 @ 14 sec	.14 @ 12 sec
Maximum Lateral Acceleration (G)	.60 @ 17 sec	.20 @ 2.75 sec	.25 @ 3.25 sec	.40 @ 3 sec	.27 @ 13.5 sec	.60 @ 8.5 sec	.30 @ 13.5 sec	.10 @ 15 sec	.17 @ 16 sec
Total Time of Run	25	22	22.5	21	22	20.5	20	23	24

TABLE 7-1. DATA SUMMARY TABLE (CONTD)

Test Number	37	38	39	40	41	42	43	44	45
Safety Device	Center-point	Center-point	Shure Guide	Shure Guide	Shure Guide	Firestone CTLR	Firestone CTLR	No Data	Safety Roller
Vehicle Weight	73,280	73,280	73,280	73,280	73,280	73,280	73,280		73,280
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Cantilever	Cantilever		Bias Ply
Alignment	Standard	Standard	Standard	Standard	Standard	Standard	Standard		Standard
Average Steering Wheel Torque (ft-lb)	18	15	35	14	21	10	18		12.8
Peak Steering Wheel Torque @ 50 Hz Filter (ft-lb)	36 @ 6 sec	58.3 @ 5 sec	53 @ 8.5 sec	40 @ 9 sec	48 @ 5.1 sec	32.5 @ 4.5 sec	53 @ 10 sec		18.8 @ 19 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	85° @ 7 sec	75° @ 7 sec	190° @ 8.5 sec	280° @ 9 sec	190° @ 10 sec	150° @ 4.5 sec	210° @ 10 sec		75° @ 19 sec
Average Tie Rod Force (lb)	378	405	304	130	392	162	504		180
Peak Tie Rod Force @ 50 Hz Filter	500 @ 8 sec	600 @ 5 sec	400 @ 5 sec	900 @ 14 sec	634 @ 7.4 sec	600 @ 10 sec	1300 @ 10 sec		350 @ 19 sec
Lateral Deviation After 6 Seconds (ft)	No Data	No Data	6.92	9.25	5.0	5.0	6.5		1.42
Maximum Lateral Deviation Within 6 Seconds (ft)	.4*	.4*	6.92	9.25	.50	5.4	6.5		1.42
Rate of Lateral Deviation at 6 Seconds (ft/sec)	Data Not Available	Data Not Available	4.14	1.92	1.92	.69	3.0		.28
Maximum Rate of Lateral Deviation at 6 Seconds (ft/sec)	.44*	.44*	5.8	2.82	2.82	2.13	3.0		.67
Initial Vehicle Velocity	50	50	50	50	47	49	50		51
Maximum Tractor/Trailer Yaw Rate (deg/sec)	1.0 @ 10 sec	1.0 @ 24 sec	3.1 @ 8 sec	1.7 @ 3 sec	2.0 @ 8.5 sec	2.0 @ 6.5 sec	4.7 @ 12.5 sec		.9 @ 21 sec
Maximum Tractor/Trailer Angle (in.)	.46 @ 15 sec	.68 @ 16.5 sec	2.2 @ 7.5 sec	.91 @ 2.5 sec	1.75 @ 11 sec	1.25 @ 6 sec	1.33 @ 5.8 sec		.65 @ 16 sec
Maximum Longitudinal Acceleration (G)	.02 @ 14 sec	.025 @ 5 sec	.37 @ 6.5 sec	.50 @ 6 sec	.20 @ 6 sec	.37 @ 6 sec	.25 @ 7 sec		.21 @ 16 sec
Maximum Lateral Acceleration (G)	.04 @ 10 sec	.04 @ 9.5 sec	.64 @ 6 sec	.11 @ 5.75 sec	.25 @ 6 sec	.20 @ 3 sec	.20 @ 5.75 sec		.15 @ 16 sec
Total Time of Run	25	21	15	11	16	11	12.5		27

*Data taken at 4 Seconds.

TABLE 7-I. DATA SUMMARY TABLE (CONTD)

Test Number	46	47	48	49	50	51	52	53
Safety Device	Steer Line	Steer Line	None	Safety Roller	Power Steering	Power Steering	Power Steering	Power Steering
Vehicle Weight	73,280	73,280	73,280	73,280	73,280	73,280	73,280	73,280
Tire Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply
Alignment	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Average Steering Wheel Torque (ft-lb)	25	27	27	8			11	12
Peak Steering Wheel Torque @ 50 Hz Filter (ft-lb)	63.3 @ 5.5 sec	66.7 @ 6 sec	68.3 @ 7 sec	21.7 @ 4 sec			20 @ 15 sec	18 @ 15 sec
Maximum Steering Wheel Angle @ 50 Hz Filter (deg)	100° @ 5.5 sec	120° @ 6 sec	155.25° @ 11 sec	60° @ 6 sec			145° @ 8.5 sec	250° @ 19 sec
Average Tie Rod Force (lb)	375	300	371	217			793	227
Peak Tie Rod Force @ 50 Hz Filter	600 @ 19 sec	620 @ 22 sec	750 @ 8.5 sec	300 @ 4.5 sec			950 @ 5.5 sec	900 @ 4 sec
Lateral Deviation After 6 Seconds (ft)	5.5	2.17	1.67	1.42	DATA LOST		1.63	2.0
Maximum Lateral Deviation Within 6 Seconds (ft)	5.5	2.17	1.67	1.6			1.72	2.0
Rate of Lateral Deviation at 6 Seconds (ft/sec)	1.88	.33	.23	.59			.4	.3
Maximum Rate of Lateral Deviation at 6 Seconds (ft/sec)	1.88	.39	.39	.59			.5	.6
Initial Vehicle Velocity	50	50	50	49			49.5	50
Maximum Tractor/Trailer Yaw Rate (deg/sec)	2.1 @ 22 sec	4.8 @ 20 sec	1.45 @ 15 sec	1.2 @ 8 sec			2.1 @ 9.5 sec	2.5 @ 24 sec
Maximum Tractor/Trailer Angle (in.)	1.86 @ 10 sec	1.25 @ 8.25 sec	1.4 @ 16 sec	No Data			No Data	No Data
Maximum Longitudinal Acceleration (G)	.33 @ 7.5 sec	.30 @ 8 sec	.32 @ 12.3 sec	.20 @ 12 sec			.09 @ 18 sec	.22 @ 9 sec
Maximum Lateral Acceleration (G)	.20 @ 7.5 sec	.34 @ 12.3 sec	.11 @ 15.2 sec	.09 @ 8 sec			.20 @ 8.25 sec	.16 @ 11.25 sec
Total Time of Run	21	23	20	18			23	22.6

TABLE 7-II. PARAMETERS FOR ASSUMED NORMAL DISTRIBUTION OF BASELINE DATA

Parameter	Average Steering Wheel Torque (ft-lb)	Average Tie Rod Force (lb)	Peak Displacement Within 6 Seconds (ft)
Measured Values	21	581	1.3
	21	747	3.7
	27	360	1.67
Estimated Population Mean, μ	23	562.7	2.22
Estimated Population Standard Deviation, σ	3.46	194.2	1.29
Value of Sample Mean for Significance Level = 0.1:			
N = 2 Samples	19.9	386.7	1.05
N = 3 Samples	20.4	419.0	1.27
Value of Sample Mean for Significance Level = 0.25:			
N = 2 Samples	21.4	470.1	1.61
N = 3 Samples	21.7	487.1	1.72

As discussed previously, the driver attempted to control the truck on a straight-line course. This test procedure minimized the lateral acceleration, yaw rate, tractor/trailer angle, and path deviation. The measure of truck performance becomes how easily the truck can be controlled as measured by the steering wheel torque. The tie rod force is a measure of the internal stresses seen by the truck steering system and the lateral deviation is a measure of how well the driver accomplished his task of keeping the truck in a straight path.

The preliminary baseline tests were performed using a different procedure, where the driver delayed control of the truck for two seconds before bringing the vehicle under control. The

preliminary baseline tests form the basis of comparison between the bias-ply, radial, and recap tires, as well as truck performance with gross alignment changes.

For the preliminary baseline tests and those tests performed to that procedure, the peak yaw rate is a measure of the severity of the front tire deflation. Based upon this measure, there is an improvement in the truck performance when either a radial tire or a recap tire is installed. The unfiltered peak yaw rate is reduced by about 50 percent due to the recap and radial tires. Most of this reduction in the peak yaw rate is due to the fact that both radial and recap tires have less of a tendency to develop folds in the tire for the rim to roll over when they are deflated which causes oscillation forces, displacement, and yaw rates of the truck which are superimposed upon the steady response of the truck.

The Firestone Cantilever Tire was tested as a concept to minimize the front tire failure response discussed in Section 6.3.9.

7.2 ALIGNMENT TESTING

Since the tests with the alignment changes (Tests 10 through 15) were performed to the same procedure as the preliminary baseline tests, the peak yaw rate is the measure of performance. The data show that there is no significant reduction in yaw rate for any of the tests where the alignment was changed. The tow-in alignment change causes one front wheel to react against the other. Since the deflated tire loses most of its ability to exert a lateral force, the tow-in adjustment is relatively meaningless after the tire loses air. Positive caster improves the returnability and feel of the road, but based upon these tests, the caster alignment change has no significant effect on the performance of the truck during a front tire deflation.

The Centerline and Centerpoint Axles represent a change in the alignment or front-end geometry. The results from tests involving these axles are discussed in Section 6.3.6 and Section 6.3.7.

7.3 DEVICE EVALUATION

As referenced in Section 7.0, Table 7-I summarizes the data from all tests run during the program. Table 7-III further reduces the data into columns of mean values of the parameters for the baseline tests and each device evaluated.

The lateral deviation from the intended path is a measure of the external performance of the vehicle and in principle, can be related to the probability of a single-vehicle accident under specific road conditions. The other parameters represent the internal dynamic behavior of the vehicle.

The steering wheel torque is the most important of these internal parameters and is a measure of the ability of the driver to control the truck with a front tire failed. The tie rod force is not directly related to vehicle performance but is a measure of the magnitude of the internal stresses in the truck which has the potential of causing additional failures and problems with excessive values. A dynamic model relating these parameters would require representation of many complex interactions including wheel - road surface forces, tire characteristics, truck properties, and human factors under stressed conditions and is not practical. Statistical analysis of the experimental data has been used both to investigate the feasibility of establishing empirical relationships between the parameters and to test for significant improvements in performance resulting from use of the safety devices.

The first relationship investigated was the correlation between the peak and average values for the steering wheel torque and for the tie rod force. Figures 7-1 and 7-2 are scatter diagrams showing the experimental values of these peak and average values plotted against each other, with each point representing an individual test run.

The two dashed lines on these curves are the least-squares curve fit, or regression lines. One line corresponds to a minimum of the sum of the squares of the deviations between the data

TABLE 7-III. DATA SUMMARY TABLE

Safety Device	Base-line	Cure Ride	HECO	Posi-trol	Steer Safe	Steer Stabi-lizer	Center-line	Center-point	Shure-Guide	Fire-stone CTLR	Safety Roller	Steer Line	Power Steering
Average Steering Wheel Torque (ft-lb)	23	23	27	26.5	26	24.5	11	16.5	23.3	14	10.4	25	11.5
Peak Steering Wheel Torque (ft-lb)	62.2	64.2	70	71	59.5	60	38.4	47.2	47	42.8	20.25	65	19
Maximum Steering Wheel Angle (Deg)	180	150	180	160	250	205	160	80	220	180	67.5	110	197.5
Average Tie Rod Force (lb)	717	670.5	797.5	550	605	474.5	475	391.5	275.3	333	198.5	337.5	510
Peak Tie Rod Force (lb)	1050	1175	1250.0	1000	1075	1000	950	550	664.7	950	325	610	925
Lateral Deviation After 6 Seconds (ft)	2	1.2	.8	1.6	3.5	2.71	.30	No Data	7.1	5.8	1.42	3.84	1.8
Maximum Lateral Deviation Within 6 Seconds (ft)	2.2	1.4	1.3	1.7	3.5	2.71	1.0	.4	7.1	6.1	1.42	3.84	1.86
Rate of Lateral Deviation at 6 Seconds (ft/sec)	.25	.31	.30	.11	2.7	.91	.11	No Data	2.66	1.85	.44	1.11	.35
Maximum Rate of Lateral Deviation Within 6 Seconds (ft/sec)	.70	.44	.46	.99	1.1	1.74	.46	.44	3.81	2.57	.63	1.14	.55
Initial Vehicle Velocity	49	50	50	50.5	50	50	50	50	49	49.5	50	50	49.8
Maximum Tractor Trailer Yaw Rate (deg/sec)	1.42	1.10	1.5	2.25	4.8	1.0	1.15	.1	2.3	3.35	1.05	3.45	2.3
Maximum Tractor Trailer Angle (in.)	.8	.50	.61	.84	.51	.36	.36	.57	1.62	1.29	.92	1.56	No Data
Maximum Longitudinal Acceleration (G)	.25	.62	.69	.66	.58	.47	.17	.02	.36	.31	.21	.32	.16
Maximum Lateral Acceleration (G)	.18	.60	.72	.64	.75	.34	.14	.04	.47	.20	.12	.27	.18
Total Time of Run (sec)	23	23.5	23.5	24	20.2	21.50	23.5	23	14	11.8	22.5	22	22.8

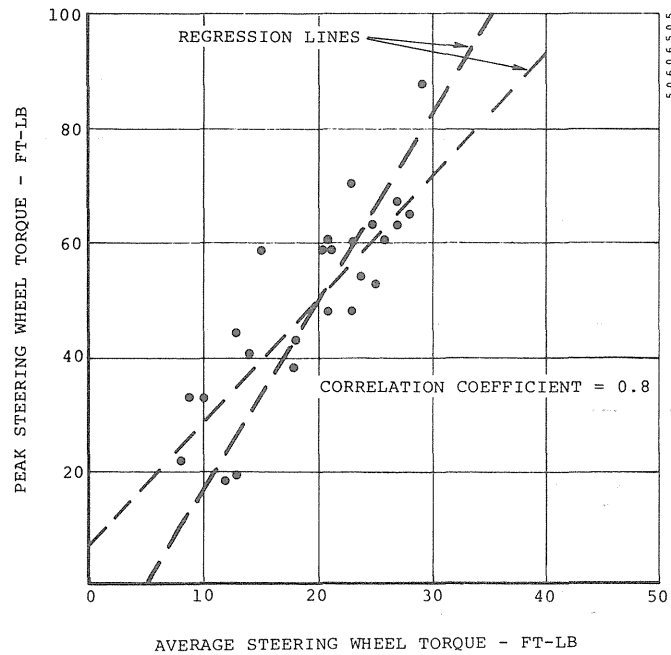


Figure 7-1. Correlation Between Peak and Average Steering Wheel Torque.

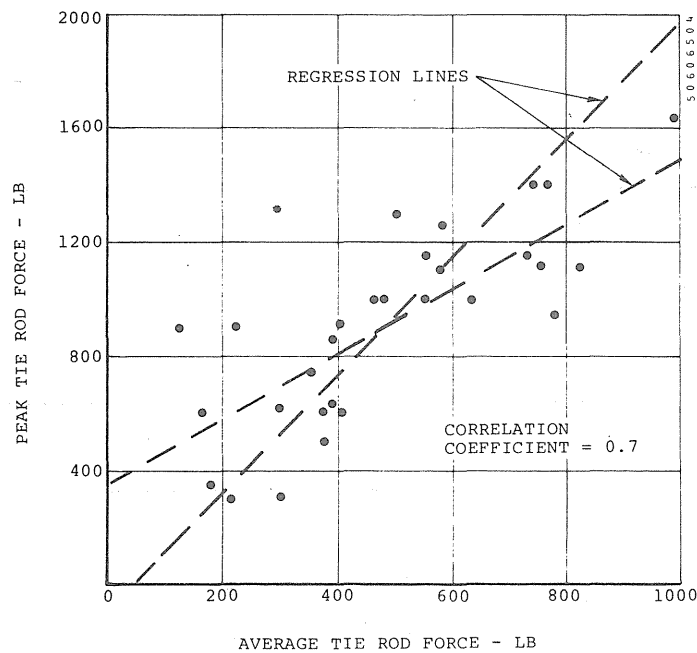


Figure 7-2. Correlation Between Peak and Average Tie Rod Force.

points and the line in the vertical direction. The other line corresponds to a minimum of the sums of the squared deviations in the horizontal direction.

Correlation between the peak and average values was examined by means of the Pearson correlation coefficient, given by:

$$r = \frac{N \sum X_i Y_i - \sum X_i \sum Y_i}{\sqrt{\left[N \sum X_i^2 - (\sum X_i)^2 \right] \left[N \sum Y_i^2 - (\sum Y_i)^2 \right]}}$$

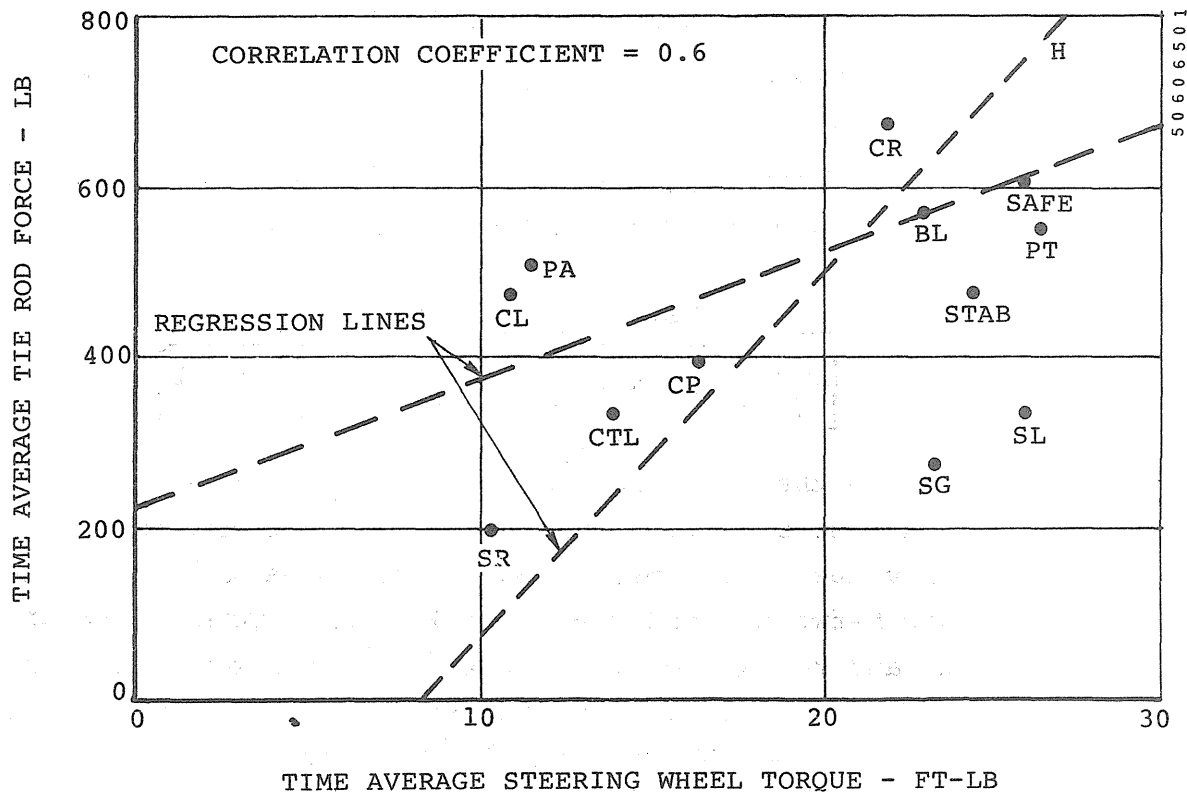
where X_i and Y_i are the peak and average values for the i^{th} test, N is the total number of pairs of points, and the summations go from 1 to N . A value of r close to unity indicates a nearly linear relationship between X and Y and a very small spread between the data points and regression lines. A value of r equal to zero indicates that X and Y are independent when the two variables are expected to have a normal or Gaussian distribution.

The correlation coefficients for the peak and average values are:

- Steering Wheel Torque: $r = 0.8$
- Tie Rod Force: $r = 0.7$

This indicates that the peak and average values are closely related, so that in subsequent analyses, the time average values are used.

Figures 7-3, 7-4, and 7-5 are scatter diagrams showing relationships between the experimental measurements of time average steering wheel torque, tie rod force, and displacement from the intended path. Each point represents the mean of the measured values for a single device identified by the coding shown at the bottom of Figure 7-3. The regression lines and correlation coefficients have the same meaning as previously discussed for the data of Figures 7-1 and 7-2. The following correlation coefficients were calculated:



BL: BASELINE	PA: POWER ASSIST
CL: CENTERLINE	SL: STEERLINE
CP: CENTERPOINT	SG: SHURE-GUIDE
CTL: CANTILEVER	SR: SAFETY ROLLER
CR: CURE RIDE	SAFE: STEER SAFE
H: HECO	STAB: STEERING STABILIZER
PT: POSITROL	

Figure 7-3. Relationship of Tie Rod Force and Steering Wheel Torque.

- Average Steering Wheel Torque - Average Tie Rod Force: $r = 0.6$
- Peak Displacement - Average Steering Wheel Torque: $r = 0.3$
- Peak Displacement - Average Tie Rod Force: $r = -0.2$

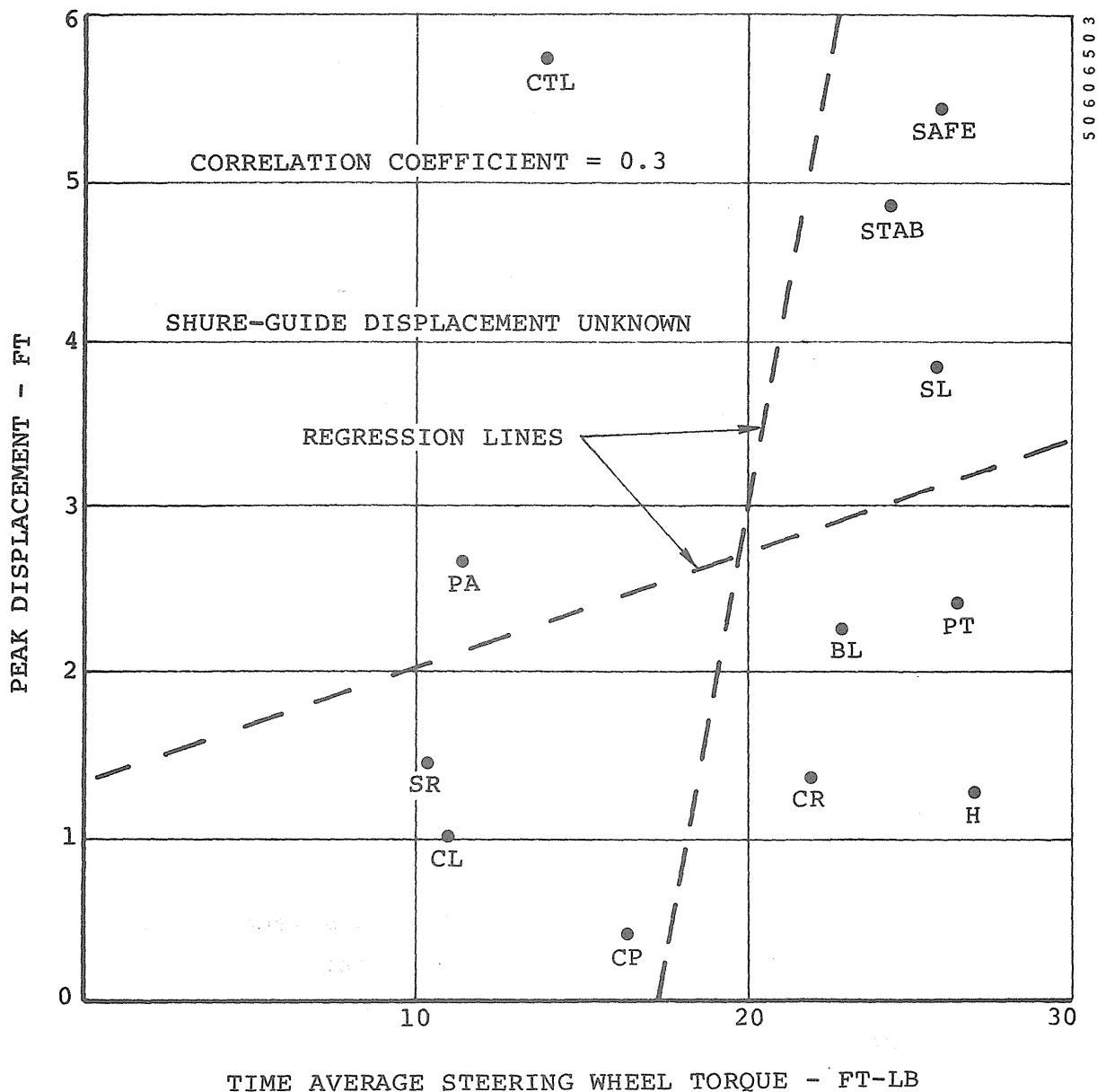


Figure 7-4. Relationship of Displacement and Steering Wheel Torque.

These values are relatively low. Furthermore, if there were a definite functional relationship between all three parameters, then it would not be possible for only one of the correlation coefficients to be negative, i.e., if displacement increases with increasing steering wheel torque, and steering wheel torque

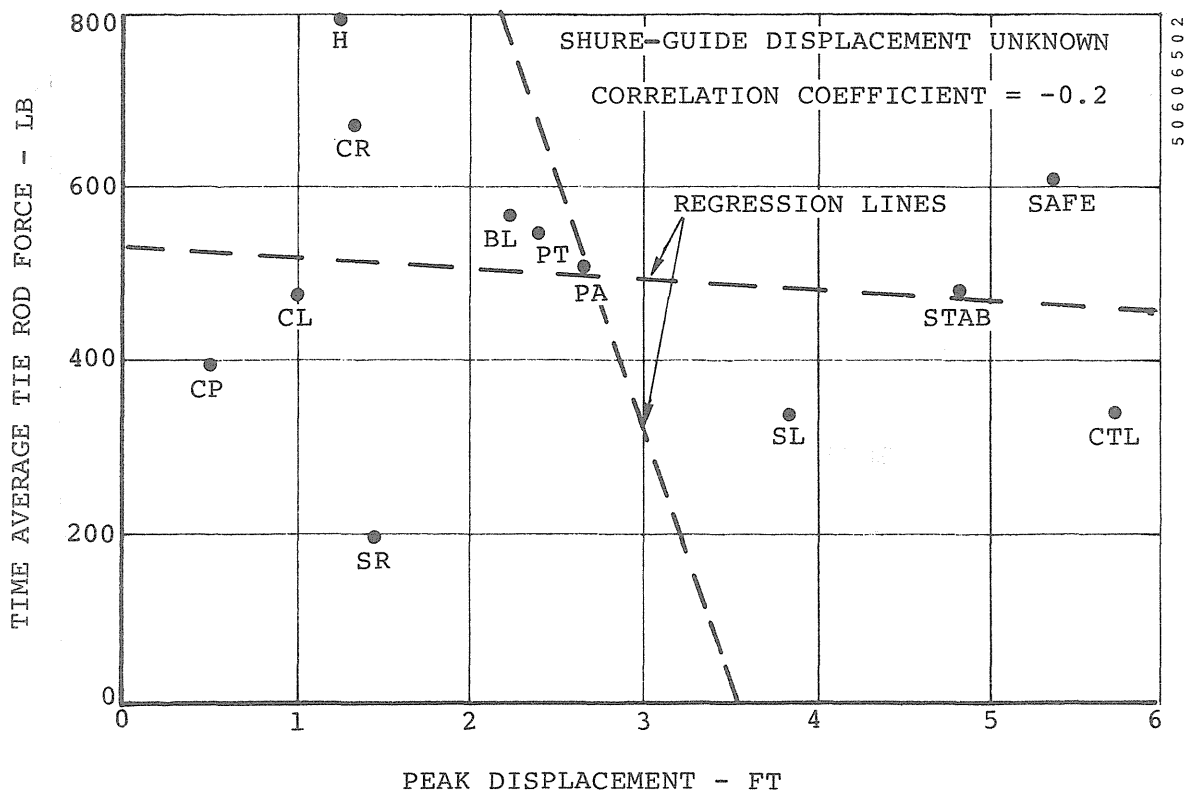


Figure 7-5. Relationship of Displacement and Tie Rod Force.

increases with increasing tie rod force, then displacement would not decrease with increasing tie rod force. Therefore, it appears that the measured data do not permit development of empirical relationships between these parameters. cursory examination of Figures 7-3 and 7-4 indicates that 5 of the devices (CL, CP, SR, CTL, PA) display a rather pronounced lowering of the steering wheel torque relative to the baseline and a slight lowering of the average tie rod force. Figures 7-4 and 7-5 show that a different group of devices (CL, CP, SR, H, CR) show a less pronounced lowering of the displacement, i.e., the centerline, centerpoint, and Safety Roller appear to produce an evident reduction of all three parameters.

To provide a more consistent basis for ranking the devices, a statistical test of the significance of the observed parameter deviations from the baseline has been performed. For this, it is assumed that the baseline data represent a sample from independent normal distributions for each of the 3 parameters, with the probability density for any one parameter X given by:

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp - \left[\frac{(X - \mu)^2}{2\sigma^2} \right] \quad (7-1)$$

For a sample of M baseline values, X_i , $i = 1, 2 \dots M$, estimates of the mean, μ , and variance, σ^2 , are given by:

$$\mu = \frac{1}{M} \sum_{i=1}^M X_i \quad (7-2)$$

$$\sigma^2 = \frac{1}{(M-1)} \sum_{i=1}^M (X_i - \mu)^2 \quad (7-3)$$

With μ and σ determined from the baseline data, the density function, $p(x)$, given by (7-1) can be used to determine whether the mean value of a subsequent sample of values for some device under evaluation represents a significant deviation from the baseline mean. If the device characteristics were not significantly different from the baseline so that the expected value of μ and σ were the same, then the probability of the mean of a subsequent sample of N values being less than X_0 would be:

$$P(\bar{X} < X_0) = \sqrt{\frac{N}{2\pi}} \cdot \sigma \int_{-\infty}^{X_0} \exp \left[\frac{-(X - \mu)^2 N}{2\sigma^2} \right] d\bar{X} \quad (7-4)$$

Suppose X_0 were chosen so that $P(\bar{X} < X_0)$ were 10 percent. This means that there would be only a 10-percent chance that a device having the same characteristics as the baseline would

produce a sample mean less than X_0 . Hence, if we state that a sample mean lower than X_0 represents a probability function different from $P(X)$ for the baseline, we will be wrong 10 percent of the time and right 90 percent of the time. The probability computed from (7-4) (i.e., 10 percent in this example) is referred to as the significance level.

This principle has been applied to establish a method of ranking the devices. Table 7-II shows the required statistical parameters computed for the three baseline values of average steering wheel torque, average tie rod force, and peak displacement. The estimated mean, μ , and standard deviation, σ , ($= \sqrt{\text{variance}}$) are calculated from equations (7-2) and (7-3) with $M = 3$. The following entries on the table are the values of X_0 corresponding to significance levels of 10 percent and 25 percent determined from tabulations of equation (7-4) using the above calculated values of μ and σ . Most of the testing provided two data points ($N = 2$) for each device, but since the Shure-Guide tests yielded three data points, the values of X_0 were computed for $N = 2$ and $N = 3$. In evaluating the devices, the reduction in steering wheel torque for a given device would then be considered significant at the 10-percent level if the mean value for 2 samples were less than 19.9 ft-lb.

Table 7-IV ranks the devices and their values of average steering wheel torque, average tie rod force, and peak displacement. The devices are grouped into four groups ranging from those with a significant reduction in all three parameters down to those with no significant reduction in any of the parameters. Those parameters with a 10-percent significance level (0.9 probability of being significantly better than the baseline) are boxed in with a solid line. Those with a 25-percent significance level are boxed in with a broken line, and those with no significant reduction of the parameter are left unboxed.

TABLE 7-IV. RANK ANALYSIS			
Device	Time Average Steering Wheel Torque (ft-lb)	Time Average Tie Rod Force (lb)	Peak Displacement Within 6 Seconds (ft)
Baseline*	23	563	2.2
Significant Reduction in All Three Parameters:			
Safety Roller	10.4	199	1.4
Center Point	16.5	392	0.4
Significant Reduction in Two Parameters:			
Cantilever Tire	14.0	333	5.8
Centerline	11.0	475	1.0
Significant Reduction in One Parameter:			
Power Assist	11.5	510	2.7
Shure-Guide*	23.3	275	Unknown
Steer Line	26.0	388	3.8
Cure Ride	22.0	671	1.4
HECO	27.0	798	1.3
No Significant Reduction:			
Steer Safe	26.0	605	5.4
Positrol	26.5	550	2.4
Steering Stabilizer	24.5	475	4.9
*Three samples, all other devices 2 samples.			
10% Significance Level		25% Significance Level	

As can be seen from Table 7-IV, the Safety Roller and the Centerpoint Axle rate the highest with a significant improvement in steering wheel torque, tie rod forces, and lateral displacements. The next group of devices, consisting of the Centerline Axle and Cantilever Tire, did not have a significant reduction in one category which was the lateral displacement and peak tie rod force for the tire and axle, respectively.

However, there was significant reduction for these two devices in the steering wheel torque which is the most important parameter.

The next group of devices showed a reduction in only one parameter, and only the power assist showed the reduction in the important steering wheel torque.

The remaining devices caused no significant variation in performance from the baseline tests.

8.0 COST-EFFECTIVENESS ANALYSIS

The final analysis as to whether the devices evaluated during this effort are feasible includes an evaluation of their cost effectiveness. Costs of possible devices, concepts, or inspection schemes shall be amortized over the vehicle depreciation life cycle and evaluated with regard to the benefits, including safety performance and economic saving, obtained over a similar time period.

Cost/benefit and cost-effectiveness concepts represent two distinct approaches to analyzing the value of a system. The term "cost" as used in this analysis has the obvious meaning of the monetary costs of implementing the system or program. "Benefits" represent the value of the system or program to society, or a segment thereof, expressed in the same monetary units as the cost. Thus, the difference of the benefits and costs represents the net monetary gain to society resulting from the course of action. "Effectiveness" is a measure of system or program value expressed in nonmonetary units. Cost-effectiveness analysis can be used for comparative evaluation of alternative systems, either on the basis of relative costs for a specified level of effectiveness, or in terms of a cost-effectiveness ratio in cases where the effectiveness measure is thought to be proportional to monetary benefits.

Cost/benefit analysis is naturally preferred since it provides an absolute rather than a comparative evaluation. However, due to the difficulty of assigning monetary values to some benefit components (e.g., value of lives saved), as well as the complexity of the relationships between monetary benefits and measurable test parameters, it often becomes necessary to resort to cost-effectiveness evaluation. This has proven to be the case in this program, and the following analysis steps have been performed:

- The costs of various devices and concepts, including initial investment and annual maintenance components, have been determined.
- Total accident costs based on generally accepted values for cost components have been determined. This would equal the benefits realized for a hypothetical device that completely eliminated front tire accidents.
- The statistical characteristics of the measured test data have been examined and used as a basis for qualitative ranking of the devices (see Section 7.0).

Table 8-I summarizes the devices along with their associated costs. Costs are actual or estimated high-volume production costs.

The interval between replacement of front tires is important in the cost analysis and is customarily determined by tread depth. BMCS Regulations specify a minimum tread depth of 4/32 inch, and new tires have a depth of 20/32 inch. Associated Truck Lines (ATL), a major carrier, replaces front tires at a depth of no less than 6/32 inch to 7/32 inch and Grow Chemical Company (GCC) replaces front tires at a depth of no less than 8/32 inch.

For 44 vehicles examined at the Odessa, Missouri I-70 scales in December 1971, all front tires were found to have a depth in excess of 7/32 inch and the average depth was 14.4/32 inch. ATL data on front tire wear on front axles are as follows:

	<u>Mileage Per 1/32 Inch of Wear</u>
Single-Axle-Drive Tractors	3,300-19,800
Tandem-Axle-Drive Tractors	2,700-10,800

Using an average value of 5,000 miles per 1/32 inch of wear, the mileage required to wear a new tire (20/32 inch) down to 7/32 inch is 65,000 miles. This value is used as the maintenance interval for the Cantilever Tire and Safety Roller in the cost analysis. Truck life has been determined from analysis of data on the number of trucks of various model years still operating in

TABLE 8-I. DEVICE COST SUMMARY

Type	Name	Manufacturer	Additional Investment Cost	Number if Service
Roller Within Tire	Safety Roller	Patecell Corporation	\$200	In Development
Axle	Centerline Steering	Centerline Corporation	\$200*	Unknown
Axle	Centerpoint Steering	North American Rockwell	\$200*	Unknown
Tire	Cantilever Tire	Firestone Tire and Rubber	\$20-\$25	In Development
Power Assist	Air-O-Matic	Sycon Corporation	\$470	Unknown
Spring	Shure-Guide	Steering Stabilizer Corporation	\$135	16,000
Spring	Steering Stabilizer	Safety Products, Inc.	\$125	Unknown
Spring	Steer Safe	Steer Safe, Inc.	\$120	8,000
Spring	Positrol	Fleet Industries	\$150	Unknown
Hydraulic	Steerline	Triple S	\$100	Unknown
Hydraulic	Cure Ride	Air Shox, Inc.	\$100	Unknown
Hydraulic	HECO	Heckethon Products	\$100	7,500
*Based on factory installation of special axle. Replacement cost would be \$1,200.				

1973 for large truck manufacturers (Mack, Diamond Reo, and White). This indicates that the median truck life is 10 years, and this value will be used as the lifetime for amortization of initial investment costs.

As discussed in Section 7.0, four of the twelve devices tested exhibited a significant improvement in at least two of the measured test parameters. It has not been feasible to establish quantitative benefit measures for each device. It should be noted, however, that even the least expensive of the five devices showing significant improvement have a cost comparable with the estimated average accident cost per truck for the total population of large combination cargo trucks. However, this estimated accident cost includes a component for the societal costs of injuries and deaths arbitrarily based only on lost personal income and other readily identifiable direct costs. This, then, represents a very conservative, or minimum, value for accident cost, since many individuals consider human life and well being (especially their own) to have a substantially higher value. Therefore, the evaluation of these devices indicates the following:

1. Some of the devices do improve the control of the truck in the event of a front tire failure.
2. The costs of purchasing and maintaining these devices is not substantially less than the minimum savings of accident costs that could be realized if the devices completely eliminated accidents due to front tire failures.

If a larger value were used for the accident costs, then some of the devices might have an advantageous benefit/cost ratio. Also, some subgroups of the total truck population considered here may have a more advantageous benefit/cost ratio due to higher than average accident rates, more valuable cargo, a greater truck lifetime for depreciation of investment costs, or other factors.

8.1 COST ANALYSIS

The cost measure used in this analysis is the total device cost expressed on an annual or per mile basis. The total annual cost includes two components, an annualized investment cost and the maintenance costs. These are expressed by the following relationship:

$$\text{Total Annual Cost} = A + M \quad (8-1)$$

where A = effective annual investment cost

M = annual maintenance and operating costs

The effective annual investment cost is the annual cost of the principal and interest required to repay a loan equal to the initial investment within the lifetime of the equipment and is given by:

$$A = I \times \frac{i (1 + i)^n}{(1 + i)^n - 1} \quad (8-2)$$

where I = initial investment in the device, i.e., purchase price plus installation cost

i = annual interest rate

n = economic or useful life (in years) of the device

M = annual maintenance and operating costs

I equals only the additional cost required to implement the safety device. For example the Centerline and Centerpoint Axles have a total cost of \$1,200, but if they are installed at the factory, this would exceed the cost of a conventional axle by only \$200, so $I = \$200$ in this case.

The cost computed from equations (8-1) and (8-2) does not include depreciation costs or taxes; however, based on the purchase prices considered, this will have little effect on the equivalent annual cost.

As discussed earlier, the economic or useful life is taken to be the median life for large trucks (i.e., the length of time required for the number of trucks remaining from a given model year to be one-half the initial value). This lifetime is 10 years.

For most of the devices, the maintenance costs are more readily expressed on a per mile basis, although some operators might use maintenance schedules based on a fixed period of time. Of course, the interest is an annual charge. Therefore, the average annual truck mileage becomes an important parameter in computing the annual cost, and is assumed to be 47,000 miles in this analysis.

Table 8-II shows the initial investment cost and the effective annual investment cost, A , per truck for the devices tested, for $n = 10$ years and for an interest rate of $i = 13$ percent computed from equation (8-2). Table 8-III shows the annual maintenance costs, M , per truck, and Table 8-IV summarizes the total annual costs per truck and for the total population of 990,000 trucks, as well as the cost per million vehicle-miles. The latter is derived from the annual cost per truck, again assuming an average annual mileage of 47,000 miles per truck.

The accident costs due to front tire failure from Table 2-IX, which are really the monetary benefits that could be realized with a perfect device, are shown at the bottom of Table 8-IV. Note that in all cases the device costs exceed the accident costs to the operator, and that the top four ranked devices from Table 8-IV have a device cost at least comparable to the total costs (= operator costs + societal costs).

The rationale underlying the data of these tables is contained in the following paragraphs.

8.1.1 Safety Roller

The Safety Roller device is still under development. An evaluation unit of the device was purchased for \$1,595. The manufacturer reports that a limited production run of 300 units has been made with a price of \$750 each. The manufacturer has estimated that in large-scale production, the price would be \$200 per unit, or \$400 for both front wheels.

TABLE 8-II. SAFETY DEVICE INVESTMENT COST COMPONENTS (PER TRUCK)

		Annual Cost Amortized Over 10 Years
	Initial Cost	Interest Rate at 13 Percent
Safety Roller	\$400	73.72
<u>Axle</u>		
Centerpoint	\$200	
Centerline	Factory Installed	36.86
Cantilever Tire	NA	
Power Assist	\$470	86.62
<u>Spring</u>		
Shure-Guide	\$140	25.80
Positrol	\$150	27.64
Steering Stability	\$125	23.03
Steer Safe	\$120	22.11
<u>Hydraulic</u>		
Cure Ride	\$100	18.43
HECO	\$100	18.43
Steerline	\$100	18.43

Maintenance costs arise from the increased time required to change a tire when the device is in use with the front tire change interval assumed to be 65,000 miles as discussed in Section 2.0. Three to four hours of additional time for tire changes were required by test facility personnel with the present design, but the manufacturer has indicated that with practice the time can be reduced and that modifications are being developed that will substantially reduce this additional time.

TABLE 8-III. ANNUAL MAINTENANCE/REPLACEMENT COSTS (PER TRUCK)

Device	Maintenance Interval (kmi)	Cost Per Maintenance	Cost Per Year at 47,000 Miles/Year
Safety Roller	65	\$10	\$7.23
<u>Axle</u>			
Centerpoint } Centerline }	200	\$10	\$2.35
Cantilever Tire	65	\$50 - \$75	\$36 - \$54
Power Assist	100	\$50	\$24
<u>Spring</u>			
Shure-Guide } Positrol } Steering Stability } Steer Safe }	---	Negligible	---
<u>Hydraulic</u>			
Cure Ride	100	\$60	\$28
HECO	100	\$60	\$28
Steerline	100	\$60	\$28

Independent examination of the Safety Roller used in the test indicates that the production cost might be somewhat lower than \$200 per unit. However, this value is used in the analysis as a conservative figure and since the modifications mentioned above might increase the cost somewhat.

A possible secondary cost of the device would result from increased tire wear under conditions of a partially deflated tire with the roller touching the inner lining. However, good practice requires frequent checking of tire pressure and prohibits driving on partially deflated tires, so that this additional cost should not be significant.

TABLE 8-IV. SAFETY DEVICE COST SUMMARY

	Total Costs		
	Dollars Per Truck Per Annum	Millions of Dollars for 990,000 Trucks Per Annum	Dollars per Million Truck- Miles (at 47 kmi Per Truck Per Annum)
	Interest Rate at 13 Percent	Interest Rate at 13 Percent	Interest Rate at 13 Percent
Safety Roller	74	73	1555
<u>Axle</u>			
Centerpoint	37	36	765
Centerline			
Cantilever Tire	36-54	36-53	766-1150
Power Assist	87	86	1830
<u>Spring</u>			
Shure-Guide	26	26	553
Positrol	28	27	575
Steering Stabilizer	23	23	490
Steer Safe	22	22	468
<u>Hydraulic</u>			
Cure Ride	18	18	383
HECO	18	18	383
Steerline	18*	18	383
Accident Costs (Table 2-IX)	Operator: \$12 Total: \$28	Operator: \$12 Total: \$28	Operator: \$248 Total: \$600

8.1.2 Centerline and Centerpoint Axles

The initial cost of the Centerline and Centerpoint Axles would be quite high, about \$1,200, if installed as a retrofit. However, if these devices are factory installed upon initial construction of the truck, the additional cost over a conventional axle would be only about \$200.

Secondary cost savings would result from reduced shimmy, vibration, and corresponding tire wear. In addition, the Center-line device does not employ a kingpin, but rather a trunion configuration. The trunions can be adjusted to compensate for normal wear, whereas the kingpins require replacement after they have become sufficiently worn. Less tow-in and camber are required for these axles than for a conventional axle, which also contributes to reduced tire wear.

8.1.3 Cantilever Tire

The Cantilever Tire is still under development, and the market price estimated by Firestone is about 10 percent greater than a conventional tire of comparable quality, or between \$18 to \$25 for the range of tires used on large trucks. As discussed earlier, the average mileage between front tire changes is 65,000 miles, only slightly greater than the average annual truck mileage of 47,000 miles. Therefore, the Cantilever Tire costs are treated entirely as annual maintenance costs rather than initial investment costs. Normal practice for truck operators is to replace the front tires when the tread depth has worn from the new tire value of 20/32 inch to a value of 7/32 to 8/32 inch. The worn front tires are then moved to the back tires of the tractor, and then possibly recapped and/or used on a trailer. The feasibility of using a Cantilever Tire on dual rear wheels should be considered; however, the spacing requirements of dual wheels may prevent this type of use. This analysis assumes that the Cantilever Tires cannot be used on the back wheels and that the corresponding loss is 20 percent of the tire cost. The total additional maintenance cost occurring every 65,000 miles is then about 30 percent of the tire cost or \$50 to \$75.

8.1.4 Power-Assisted Steering (Air-O-Matic)

The Air-O-Matic is a power-assist steering system available as a retrofit option after manufacture. The initial cost including installation is \$470 for a unit that uses compressed air from the existing vehicle supply. The maintenance costs shown in

Table 8-II for this system are typical for those of power steering systems.

8.1.5 Spring Devices

The spring devices tested include the Shure-Guide, Positrol, Steering Stabilizer, and Steer Safe. For all of these devices, the installation is simple and requires essentially negligible maintenance.

8.1.6 Hydraulic Devices

The hydraulic (damping) devices tested in this program are the Cure Ride, the HECO, and the Steerline. The installation of these devices is quite simple, and maintenance consists of cylinder replacement at approximately \$25 per cylinder.

8.2 COST/BENEFIT AND COST-EFFECTIVENESS ANALYSES

Cost/benefit and cost-effectiveness concepts represent two distinct approaches for system evaluation. A cost/benefit analysis attempts to determine the value of the system in monetary terms compatible with the monetary costs of implementing the system. When the system can be so quantified, the difference of the benefits and costs then represents the net monetary gain to society from implementing the system.

Cost-effectiveness analysis uses a much broader definition of terms. Effectiveness is usually a measure of system value expressed in nonmonetary terms. If the costs are quantified in monetary terms, then cost-effectiveness analysis can be used for comparative system evaluation, either on the basis of relative costs for a specified level of effectiveness, or in terms of a cost-effectiveness ratio in cases where effectiveness is expected to be proportional to monetary benefits.

The selection of benefit and effectiveness measures and the question of whether a particular parameter constitutes a cost or a benefit, depends strongly on the objectives of the evaluation program. If the objective of a program were to evaluate devices

or systems for reducing fuel consumption, then an obvious benefit measure would be the fuel cost savings per mile (or other unit of travel). If the objective were to evaluate various systems for achieving a specified level of performance (e.g., acceleration), then the specified performance parameter would be the effectiveness measures. The cost measure used for comparing systems could then include a component of increased fuel costs per mile required to achieve the specified effectiveness.

In cost-effectiveness evaluation, the cost is not necessarily in monetary units. In the example just mentioned, a possible (nonmonetary) cost component associated with meeting a specified level of performance could be an increased level of engine noise. In this case, the cost-effectiveness evaluation would rely on subjective evaluation of alternative approaches.

In summary, cost/benefit analysis employs cost and benefit measures having the same quantitative (usually monetary) units of measure and is usually preferred for absolute evaluation of systems; cost-effectiveness analysis uses nonmonetary measures for the effectiveness and possibly for the cost and is used for comparative evaluation of systems.

A common objection to the use of cost/benefit analysis for evaluating safety devices arises from the necessity of assigning monetary values to the costs of injuries and fatalities, and it is usually argued that assigned costs based on lost income, funeral costs, or other direct costs are too low. An alternative approach, not currently feasible due to lack of adequate survey data, would be to base accident costs on peoples' own assessment of the value of their life and well being, i.e., the amount they would be willing to pay for greater safety through taxes, increased vehicle costs, or increased costs of transported goods.

This program has established estimates of the monetary costs of implementing the devices tested.

It has also established estimates of accident costs to truck operators and to society as a whole. These accident costs constitute the maximum monetary benefits that could be realized with a perfect device completely eliminating front tire failure accidents, although the components due to injury and fatality costs may be subject to the criticisms mentioned above.

The following paragraphs indicate some of the basic considerations for conducting cost/benefit analysis if further data were available that could be related to accident probability.

8.2.1 Determination of Expected Accident Costs

The expected costs associated with accidents resulting from front tire failure are given by the following relationships:

Cost per vehicle-mile. = cost per accident x accident rate per vehicle-mile

Cost per truck-year = cost per vehicle-mile x average truck-miles per year

Cost to trucking industry = cost per vehicle-mile x total industry truck-miles per year
= cost per accident x total number of accidents per year

The monetary benefit resulting from use of a safety device is then the reduction of accident costs corresponding to the reduced accident rate per vehicle-mile. Table 2-IX shows the maximum benefits computed from the above relationships for a rate of 0.02 tire failure accidents per million miles and 47,000 miles per truck annually. In principle, the accident rate per vehicle-mile can be computed from a combination of test parameters, vehicle characteristics, traffic and road engineering data, and driver characteristics. The relationship used in such a calculation could be written as:

$$\text{Accident Rate Per Vehicle-Mile} = \bar{F} \left(\begin{array}{l} \text{Test parameters, road conditions,} \\ \text{vehicle and driver characteristics} \end{array} \right)$$

where F is a function of the variables within the parentheses. The bar over F indicates averaging over nationwide distributions of the variables where appropriate. Baseline test data with no device could be used to calibrate this functional relationship, i.e., to establish the value of constants in the mathematical relations. Alternatively, the accident rate for various devices could be established relative to the baseline case by:

$$\frac{\text{Accident Rate per Vehicle-Mile With Device}}{\text{Accident Rate Per Vehicle-Mile With No Device}} \times \frac{\bar{F} \text{ with device}}{\bar{F} \text{ without device}}$$

In some cases, taking the ratio of the two F 's would cancel some of the constants in the expression. The accident rate per vehicle-mile with no device would be the value determined from current accident statistics.

8.2.2 Determination of Accident Probability From Test Data

The displacement from the intended path is a measure of the external physical performance of the vehicle, while the other parameters represent internal behavior. Thus, it is natural to consider the possibility of relating probability of accident to the deviation. Since most front tire failure accidents involve a single vehicle going off the road, one simple approach is to assume that the probability of an accident is proportional to the probability of swerving out of the lane. This, in turn, depends on the probability distribution of the distance between the truck wheels and the edge of the road under normal driving conditions as well as the probability distribution of the displacements caused by front tire failures. Referring to Figure 8-1A, let

d = Displacement from the intended path caused by front tire failure

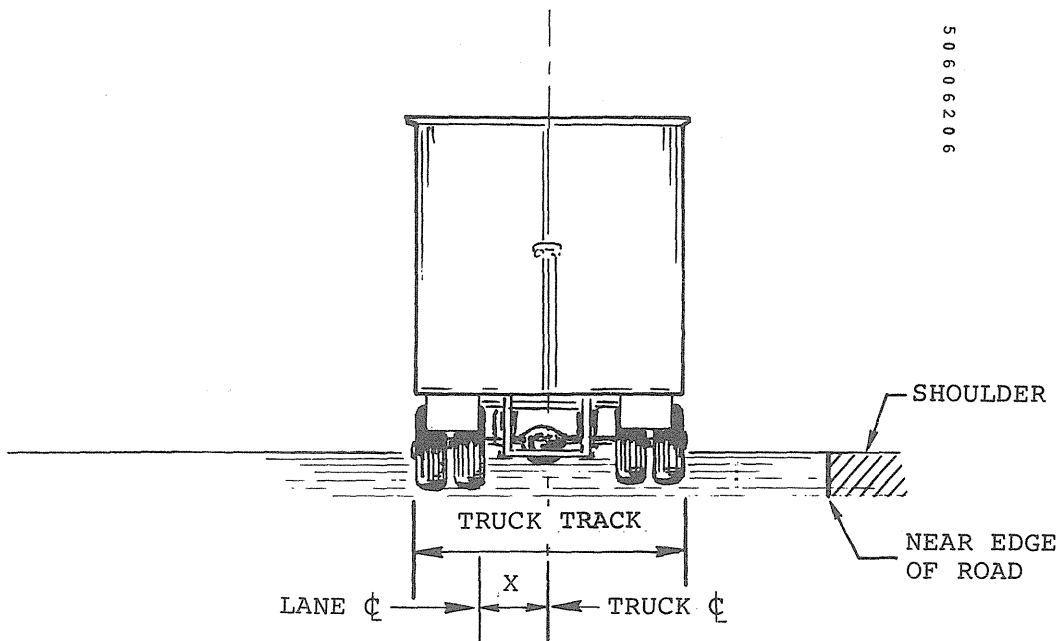
D = Lateral distance the truck can travel from its mean position without running off the road

The probability of leaving the road as a result of the displacement is then a function of d/D . Assume that under normal driving (pre-failure) conditions, the driver will attempt to hold the truck centered in the lane. Then

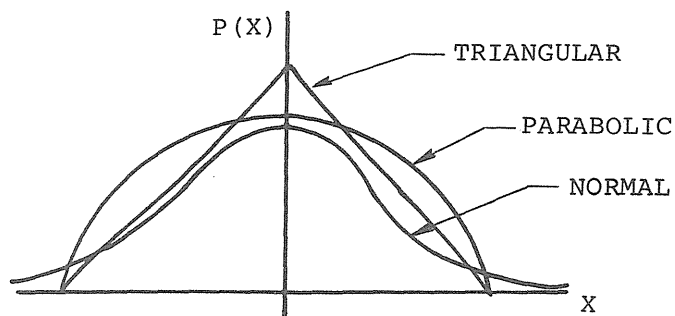
$$D = \text{Distance from lane} \pm 1/2 \text{ wheelbase}$$

where the + sign refers to both wheels running off the road and the - sign to only the outside wheels running off. Some plausible probability distributions for the normal driving distance between the truck centerline and the lane centerline under pre-failure conditions are as shown in Figure 8-1B. For the triangular distribution, the probability of the truck leaving one side of the road as a result of a fixed value of displacement is $1/2 d^2/D^2$, and this also closely approximates the probabilities for the parabolic and normal distributions. If the displacement also has a normal distribution, the probability of leaving the road will still be closely proportional to $\bar{d}^2$ where $\bar{d}$ is the mean displacement.

The average of the peak displacement observed within 6.0 seconds in three baseline trials was $\bar{d} = 1.29$ feet. With a typical value of $D = 2$ feet for the distance between the outside wheels and the shoulder. The probability of the outside wheels going onto the shoulder is $1/2 d^2/D^2 = 21$ percent. Similarly, with $\bar{d} = 10$ feet for the distance between the inside wheels and the shoulder, the probability of completely running off the road is 0.8 percent. These values bracket the 1.4-percent probability of a front tire failure causing an accident and indicate that shoulder characteristics, road curvature, two-lane geometries, and the probability distribution of the deviations should all be considered in determining the probability for running completely off the road. The complexity resulting from use of these additional factors implies that the displacement would be most useful as a relative measure. The corresponding effectiveness measure would then be:



A. Geometry



B. Probability Distributions of X Under Normal Driving Conditions.

Figure 8-1. Factors Affecting Probability of Leaving the Lane.

$$\text{Accident Rate per Mile With Device} = \left(\frac{\text{Displacement With Device}}{\text{Baseline Displacement (No Device)}} \right)^2 \times \text{Accident Rate per Mile Without Device}$$

The analysis of Section 7.0 indicates considerable scatter in the values of the peak deviation within 6 seconds. For example, note the relatively large ratio of standard deviation to the mean for the baseline peak displacement in Table 7-II ($\mu - 3\sigma < 0$). The scatter was a result of the test being manually controlled and of a low enough severity that large lateral displacements did not occur even during the baseline tests. For this reason, displacement by itself was not considered a suitable measure for determining device effectiveness in this program.

8.2.3 Measures of Internal Behavior

Examination of the test data has shown that the time average steering wheel torque and time average tie rod force have relatively well-defined values (little scatter) for each device, while indicating significant variations from one device to another. However, it does not appear feasible to relate an absolute measure of accident probability to these parameters. The complexity of the relationships between the internal parameters and the vehicle dynamics is partially indicated in the simplified functional diagram of Figure 8-2. To develop a model adequately representing all of these functions would require a large amount of data on interactions between the many system components including the human operator. Even if such a model of the vehicle dynamics was available, computation of the accident probability would still require consideration of varying road and traffic conditions. Therefore, future evaluation programs should rely on relationships between accident probability and measured external performance parameters, such as peak displacement, as outlined in Section 8.2.2, conducted under a representative range or distribution of conditions such as road widths, curves, shoulder conditions, and driver characteristics.

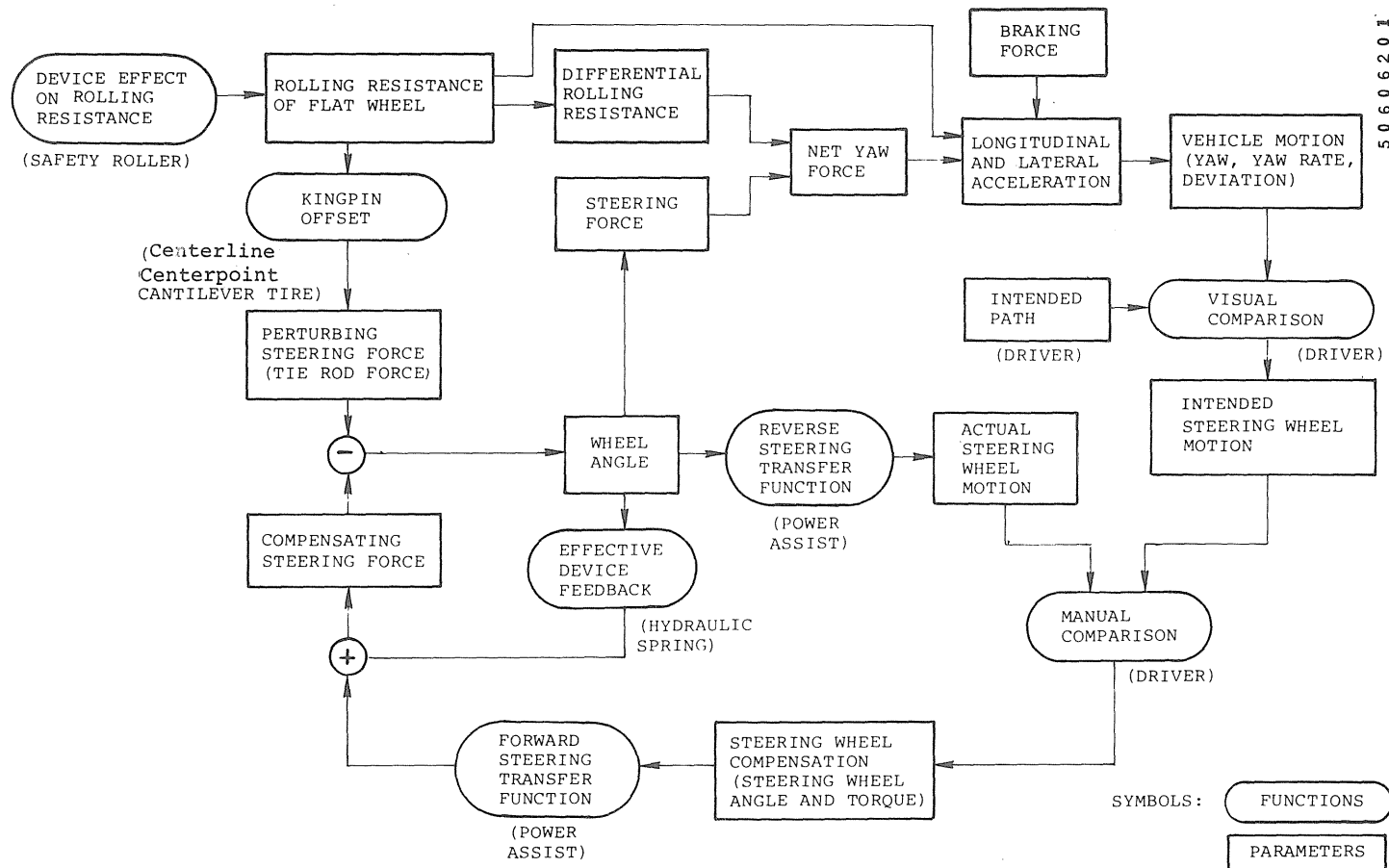


Figure 8-2. Functional Relationships for Control of Front Tire Failure Effects.

9.0 CONCLUSIONS

Although it was not possible to assess the reduction in accident probability that would be expected from the devices tested, some of them did exhibit a significant improvement relative to the baseline in some of the measured test parameters. In particular, the Safety Roller, Centerpoint Axle, Cantilever Tire, and Centerline Axle devices exhibited an improvement in at least two of the parameters (see Table 7-IV), and the power assist showed a significant reduction in the required steering wheel torque to control the vehicle.

Monetary benefits could not be established for the devices on an individual basis, but the maximum total benefit (annual accident cost) of \$28 per truck compares reasonably well with the computed annual cost per truck of the factory-installed Centerline and Centerpoint Axles \$37 and is not substantially less than the cost of the Cantilever Tire (\$36 - \$54) see Table 8-IV. The estimated annual cost of the Safety Roller is about twice the additional cost of the factory-installed Centerline and Centerpoint axles. However, since the Safety Roller is still under development, its ultimate large-scale production costs are somewhat uncertain.

The maximum benefit, or accident cost, to the operator would be \$12 per year per truck which is less than the computed costs for any of the devices. Furthermore, the maximum operator benefits of \$12 per year per truck would be realized only for a perfect device that reduces the accident probability almost to zero, so the benefits realized for actual devices would be somewhat less. This implies that additional incentives would be required to make regulations for these devices more acceptable to the operators.

10.0 RECOMMENDATIONS

To completely evaluate the front tire failure problem, it is, of course, necessary to look at costs of the devices and concepts and the potential payoff. Payoffs will be different for segments of the truck population than for the large combination truck population as a whole. For example, trucks operating in mountainous terrain in bad weather or carrying hazardous or valuable cargo have special problems that affect the benefit and cost picture.

In order to improve this cost/benefit analysis, the investigation into truck performance during a front tire failure should be expanded. In order to expand the investigation of the front tire problem, additional aspects of the problem should be evaluated.

Additional testing of promising devices or concepts on single-unit trucks would establish their merits for this important class of vehicles.

Since tire failures on a curve and tire failures with a road obstruction impact can be more severe than a flat, straight road, changes in performance of the vehicle and devices should be evaluated on a curve and in conjunction with a road obstruction.

Testing on a wet surface, especially on a curve, should also be investigated to evaluate the truck performance under those conditions.

Further investigation may show that a combination of devices is justified to improve the performance of the truck in a front tire failure situation.

Additional supporting information which would increase the credibility of a cost/benefit analysis would be to put into service a statistically significant sample of the devices and compare the maintenance costs, accident reduction costs, and miscellaneous benefits and liabilities.

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