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RADIAL AXLE TRUCK TEST RESULTS REPORT

Prepared for:

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This report describes the performance tests conducted on a pair of prototype radial axle trucks developed by GSI. The trucks tested were purchased from GSI by Amtrak and tested by FRA as a joint FRA/Amtrak project. The results of this test show that, as configured for this test, the trucks negotiated curves very well but did not have adequate high speed stability. The truck ran in curves up to 7.5 degrees with near zero wheel to rail angle-of-attack and exhibited no flange wear. Conventional trucks incurred significant flange damage from the constant operation at speeds above the balance speeds for the 0°50' curves on the test center RTT track. The radial trucks appeared to have adequate stability at speeds up to 120 mph when the wheels were new but the wheel profiles deteriorated within 10,000 miles. Wheel wear caused deterioration in the stability resulting in severe oscillations of the axles.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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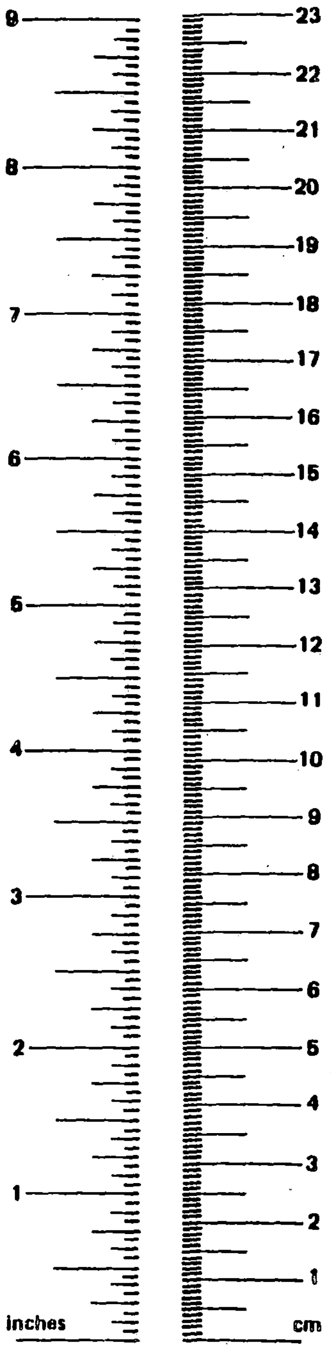
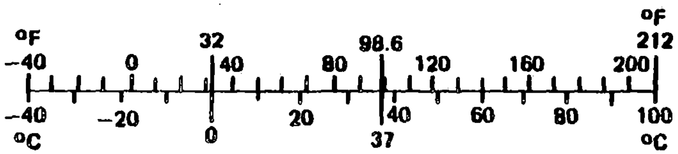
*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

The Radial Axle Truck Test was performed to evaluate a cross-linked radial axle truck designed and produced by General Steel Industries Incorporated (GSI) for Amtrak. This was a joint FRA/Amtrak project performed to evaluate the potential of the radial axle truck concept for high-speed passenger service. The test was conducted at the Transportation Test Center (TTC), Pueblo, Colorado. ENSCO, Inc. conducted the Performance Tests and was supported by TTC/Boeing Services International (BSI). TTC/BSI conducted the Life Tests. Both tests were supported by Amtrak and GSI.

The radial axle trucks experienced a number of problems at the beginning of the testing, which delayed the schedule, but were corrected. Planned tests were condensed and the essence of the original test plan was accomplished. In the end, the test showed that the cross-linked radial truck had very good curving ability, but, as configured, the truck did not have adequate stability. Minor oscillations of the axles seemed to cause wheel wear which in turn reduced the stability. When the wheel treads were new the truck was judged to have adequate stability with a slight tendency to display axle oscillations. The truck was tested at speeds up to 126 mph. Within 10,000 miles of operation, the wheels developed a detectable wear which increased the effective conicity. As the wear increased, the operating speed had to be reduced to avoid violent oscillation of the axles.

The results seem to indicate that the optimum trade-off between curving and stabilitiy was not achieved despite attempts by GSI to modify the truck. The trucks maintained near perfect radial alignments with zero angle of attacks between the wheels and rail on all curves up to and including the 7.5 degrees balloon loop curve (which was the sharpest curve at the test center). GSI made several attempts to increase the truck primary spring longitudinal stiffness to improve the stability but each time the initial success was quickly negated by the deterioration of the wheel profiles. The hollowing of the wheels increased the effective conicity leading to marked reduction in the critical speed.

The results seem to indicate that radial trucks have potential, but that they are very sensitive to alignment and wheel wear. The linked radial truck concept would appear to be a good candidate for service which demands good curving performance at slower speeds. If the radial truck can be made to have adequate high-speed stability it may have potential for operations when the equipment operates at speeds significantly above balance speeds. In high-speed operation on the 14 mile closed loop Railroad Test Track (RTT) at the test center, the Pioneer III truck (which is the truck presently used on the Amcoach cars) developed substantial flange wear. In contrast, the radial truck displayed no flange wear and in fact, seldom, if ever, were the flanges in contact with the rail.

1.0 INTRODUCTION

Amtrak and FRA sponsored a joint program to test and evaluate the radial axle truck concept for high speed passenger service. The performance related radial axle truck tests were started in the spring of 1980 and were completed in the fall of the same year. The life (endurance) tests began in November 1980 and ended in June 1981. The radial axle truck tests were performed at the Transportation Test Center (TTC) for the Office of Passenger Systems, Federal Railroad Administration/Department of Transportation. The performance tests were conducted by ENSCO, Inc. under contracts with DOT/FRA with support from the truck manufacturer (GSI), Amtrak and TTC. Other portions of the overall radial axle truck test and the life tests, were conducted by TTC with assistance from other parties.

The radial axle truck concept has been around for more than 100 years. Within the past 20 years, there has been a growing interest in this truck concept. The general definition of a radial truck is a truck constructed so that the axles align, perpendicular to the rail as the truck negotiates curved sections of track.

Two types of linkages have been developed for frictional force steering and are presently being used for freight radial axle trucks. These truck configurations are shown by Figures 1-1 and 1-2. The passenger trucks tested by this program are cross linked radial trucks. The leading and trailing axles are connected by cross linkages as shown in Figure 1-1. To allow the axles to align to the curve as desired, the longitudinal stiffness of the journal must be made relatively soft which results in partial decoupling of the wheels and axles from the truck frame reducing the effective mass of the wheels and axles. This normally makes a truck unstable because the kinematic oscillation of the wheelsets occurs at a speed within the range of the desired operating speed. Therefore, the relatively soft longitudinal spring stiffness of this radial truck allows curving and crosslinks allow curving while the crosslinks provide longitudinal stiffness between axles and thus improve stability. The radial axle truck concept has been analyzed in many of the truck dynamics studies. The result of these studies are reported in recent papers. Papers prepared by the Massachusetts Institute of Technology and by Battelle Memorial Institute provide a review of the theory which supports the radial truck concept.

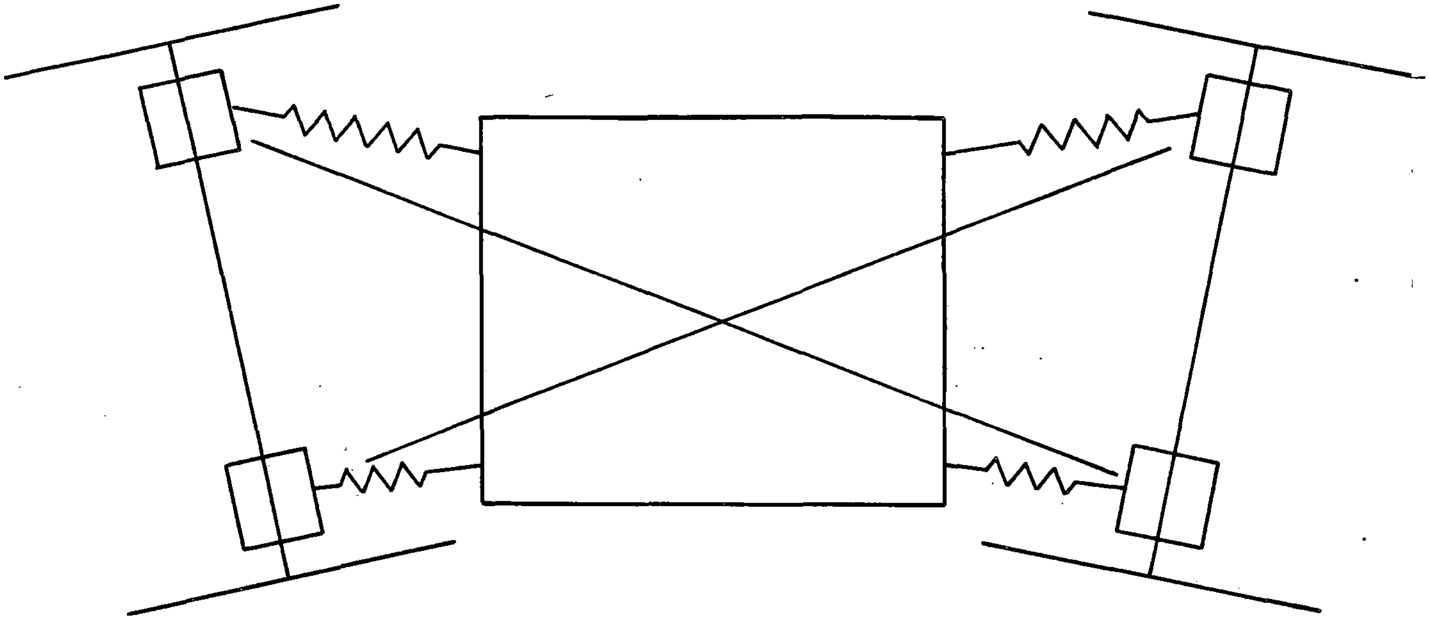

Figure 1-1. Cross Linked Radial Truck

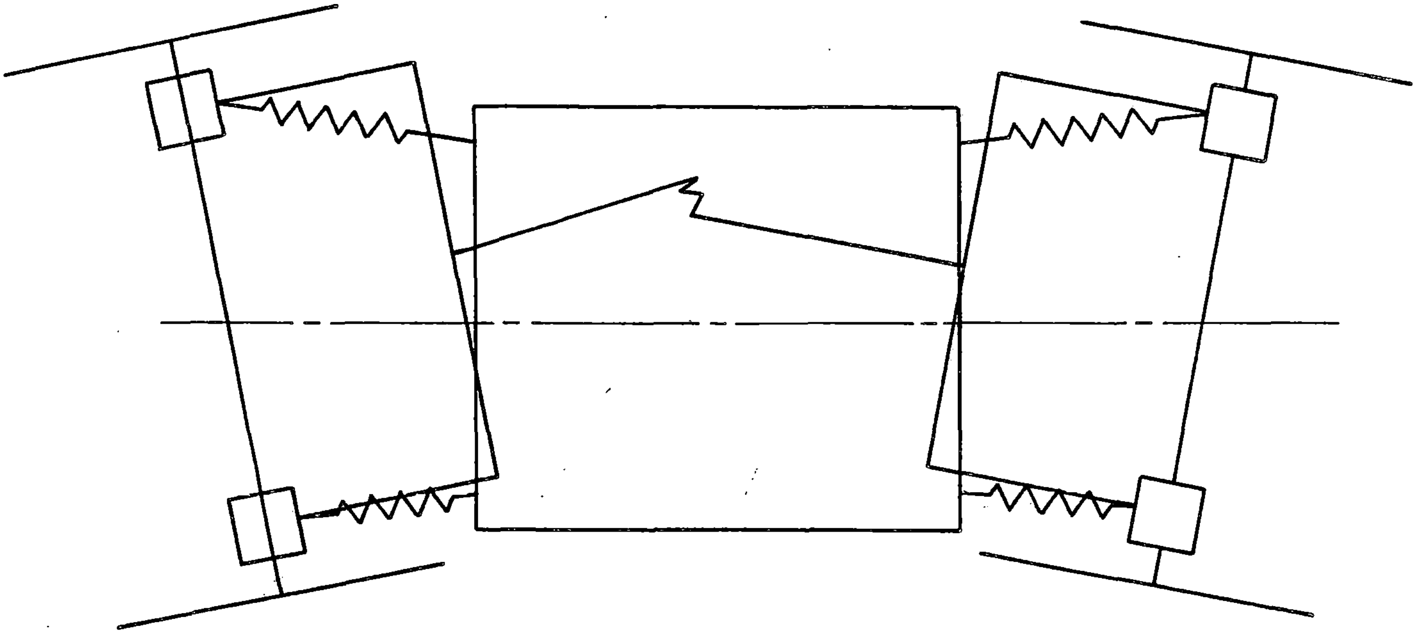

Figure 1-2. Straight Linked Radial Truck

2.0 TECHNICAL APPROACH

This program was designed to evaluate the use of the radial axle truck concept for high speed passenger car applications. The prototype radial trucks were installed under The Budd Company built Amcoach car specially modified to receive the trucks. The Amcoach car equipped with the radial trucks was run in the test with another Amcoach equipped with Pioneer III trucks (normally provided by The Budd Corporation for the Amcoach fleet). Results of the radial truck performance were compared in many of the tests to the data obtained from the reference car trucks. The performance tests shown below were conducted by ENSCO with TTC assistance. The life tests (presented in a different report) were conducted by TTC.

The radial truck test was originally divided into seven test series. However, due to the performance problems of the radial trucks the technical approach was modified to the following five tests:

● Shop Test	Performance Tests
● Shakedown Test	
● Cutaway Braking Test	
● Concept Demonstration/Performance Test	
● Life Test	Life Test

2.1 TEST SEQUENCE

2.1.1 SHOP TESTS

The shop tests were performed to confirm that the new trucks were rail-worthy. The shop test consisted of:

- Carbody clearance test
- Truck to car clearance test
- Suspension centering test
- Handbrake test

2.1.2 SHAKEDOWN TEST

The shop test was followed by the shakedown test to first wear-in the brake pads and to test the truck at successively increased speeds. In the process of increasing the speed, both truck and axle stability and axle alignment were monitored in curved and tangent sections of track and during brake applications. The initial test on the Railroad Test Track (RTT) showed that the car leaned to one side excessively in the curves. When first tested at low speeds, the carbody roll was as high as 12 degrees. At the same time the curving data showed that the wheels of the radial truck remain flanged to the right on both the right and left hand curves. Both of these problems had to be resolved before the other tests could be performed properly. The carbody leveling corrections and truck axle/link alignment are discussed in the TTC test report.

The shakedown test series gave the truck manufacturer an opportunity to make adjustments to the truck. Through pre-test plan development meetings, procedures were developed for bringing the truck up to full operational performance. The truck manufacturer requested tests to evaluate the following aspects:

- Truck Longitudinal Stiffness -- The manufacturer had three different longitudinal shear sandwiches available for the primary suspension system to check variation to stability.
- External Axle Yaw Damping -- External yaw dampers were installed to check stability increase at high speeds (120 + mph).
- Journal Box Tilt -- The truck journal box tilt was checked to determine if braking causes excessive rotation of the journal boxes.
- Bump Stop Clearance -- The carbody lateral acceleration was measured to evaluate the lateral bump stop clearance.
- Braking Rate -- The braking rate and the disk to tread brake ratio were varied.

These checks were incorporated into the testing schedule for the shakedown test series. The shakedown tests were scheduled to be conducted on both the 14 mile (closed loop) Railroad Test Track (RTT), the balloon loop, and on the smaller FAST oval. In addition, tests were performed on the screech loop.

2.1.3 CUTAWAY BRAKING TEST

After the truck stability had been checked, cutaway braking tests were performed to evaluate the braking rate and disk to tread ratio. These tests were performed to confirm that the brake rate of the new trucks matched conventional Amcoach cars. The disc and wheel temperatures were checked during the speed upgrade to insure that the brake components were not overheating.

2.1.4 CONCEPT DEMONSTRATION TEST

On completion of the cutaway brake test, concept demonstration tests were performed. This series of tests were designed to demonstrate and evaluate the curving characteristics and high speed stability of the radial truck and to compare its performance to the manufacturer's claims.

The primary performance claims were:

- Less wheel tread and flange wear
- Increased high speed stability
- Better ride qualty
- Less component wear
- Less rail wear (no data collected)
- Lower noise levels on curves (observed only)
- Reduced traction power (no data collected)

The concept demonstration tests were designed to evaluate the first four of the performance features.

2.1.5 PERFORMANCE TEST

After the concept demonstration test, a similar series of tests were performed to document the truck performance under a variety of different speeds and curve conditions. The tests were performed on the RTT track at speeds up to 120 mph and on the FAST curves at speeds which correspond to cant deficiencies from 3 inches under balance to 3 inches over balance. In addition to the normal running test, the performance test series included a simulated cross link failure test and a deflated air bag test.

2.1.6 LIFE TEST

The life test series was intended to include enough mileage to determine if the truck had any severe wear problems and to evaluate the effects of wheel and component wear. The high speed performance was scheduled to be checked at the beginning of the life test and after 40,000 miles and again after another 40,000 miles at the completion of the life test. The primary responsibilities for the life test were assigned to TTC, therefore, the details on this phase of the program will be covered in a separate report published by TTC.

2.2 INSTRUMENTATION

The instrumentation system (Figure 2-1) used for the radial truck test utilized the data acquisition and processing system of the T-7 test coach. The heart of this system is a Hewlett-Packard 21MX Minicomputer. The HP 21MX was equipped with a 1600 BPI tape drive, a disk drive mass storage unit, a graphics terminal and a Versatec video printer. The data were multiplexed and digitized by an Analogic 5400 data acquisition system. Sample timing was controlled by an ENSCO real-time clock interface.

Signal conditioning for the transducers was housed in racks adjacent to the computer and signals to and from the signal conditioners were routed by means of patch panels to anti-aliasing filters.

Four junction boxes located on the ends of the Amcoaches connected the signals from the individual transducers to the Dekeron cables which carried signals to T-7's bulkhead connectors. Location of A-end radial coach junction boxes, typical of all installations may be seen in Figure 2-3.

Typical truck instrumentation is seen in Figure 2-4, while a schematic location of truck mounted transducers is shown in Figure 2-2. A listing of data channels, location, full scale sensitivities, transducer type, filter frequency, etc., is in Table 2-1.

A data acquisition operating system software was written for the Radial Truck Test. This system, ENSCO Digital Data Acquisition System (EDDAS), allows versatile operation and the display of pre-programmed real-time calculations while continuing to gather data at a high rate. The channels, once programmed, are treated as if they were raw data supplied by transducers and can be displayed beside directly produced data. Since the calculated channels are produced from raw channels the calculations were not recorded on tape. Calculated channels are identified by "200 level" channel numbers, i.e., 210, 212, etc.

Some channels were used directly or scaled with the signal conditioning. These channels and their analysis is shown in Table 2-2.

For data reduction the EDDAS system had a playback-only version named Reduction Digital Data Acquisition System (RDDAS). RDDAS allowed measured or calculated analog data to be played back on pen recorders along with indications of manually entered milepost and event data, automatic location detector and a count of the

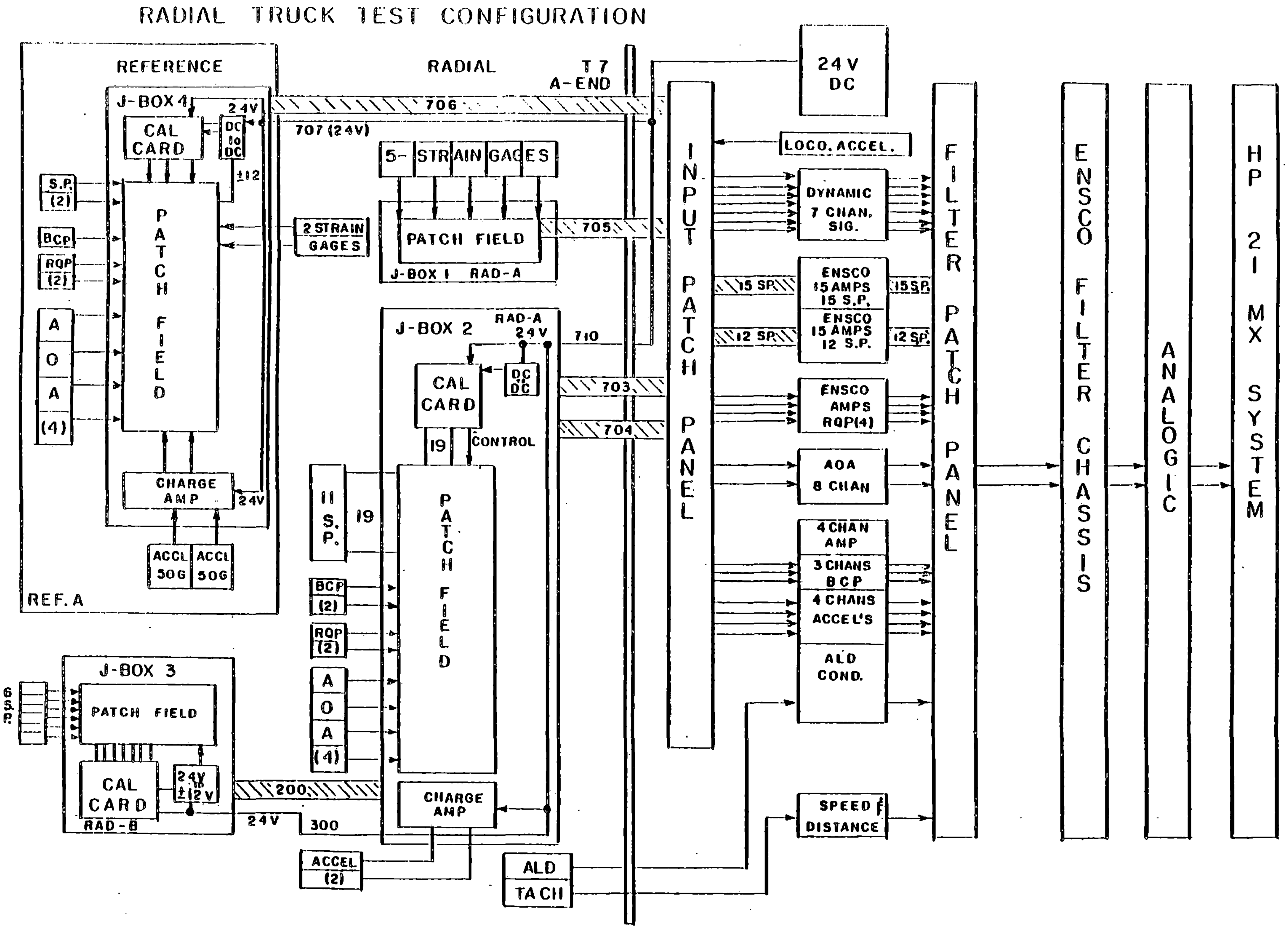

Figure 2-1. Radial Truck Test Instrumentation Configuration

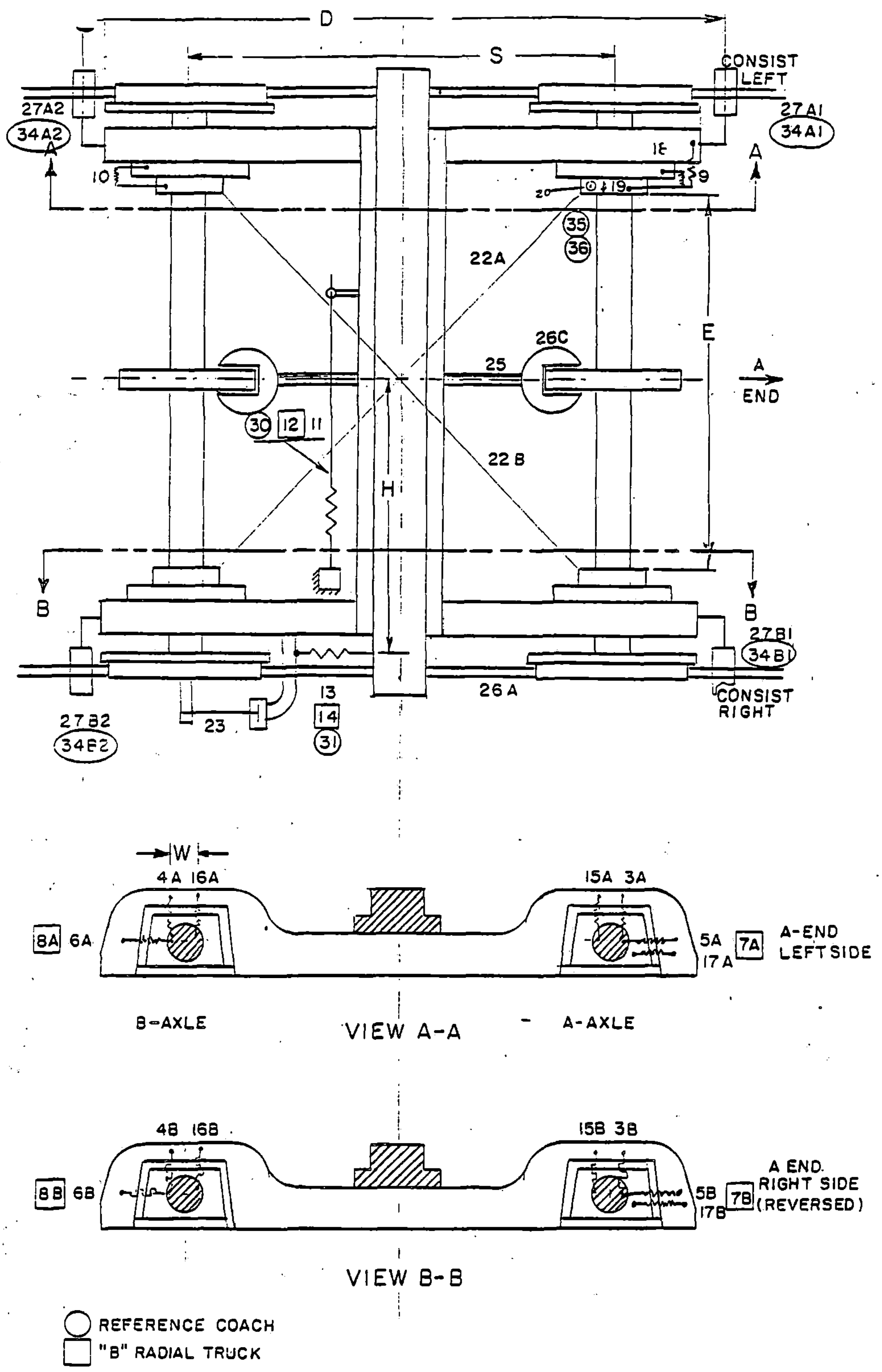

Figure 2-2. Transducer Locations

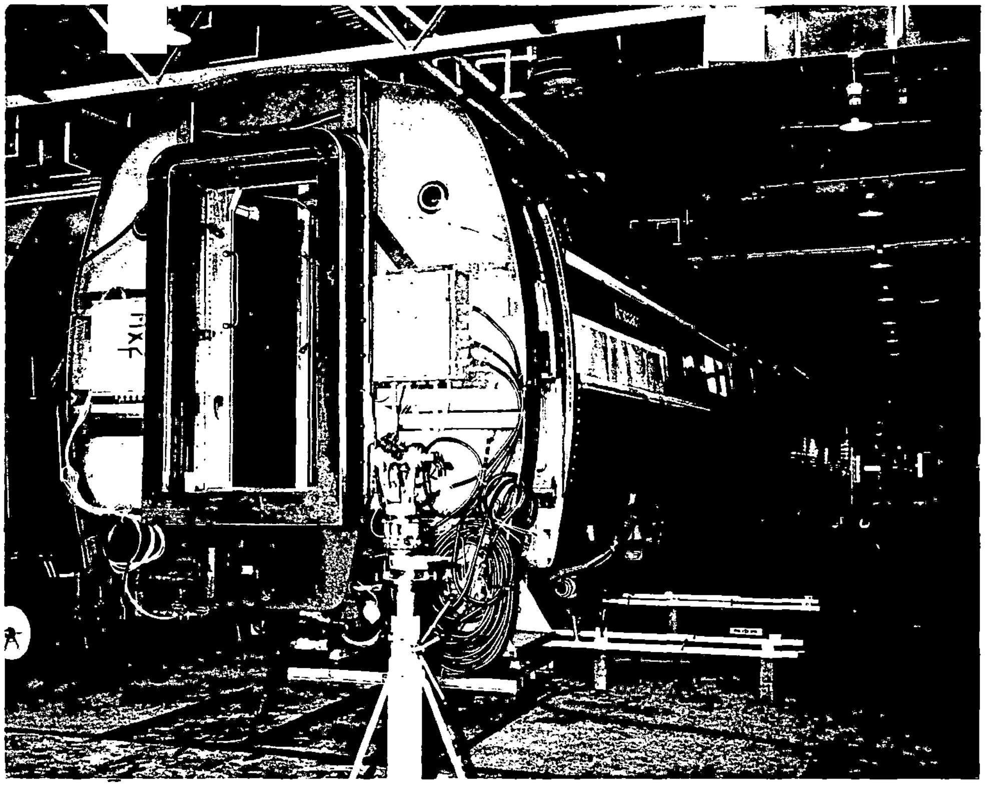

Figure 2-3. Location of A-End Junction Boxes

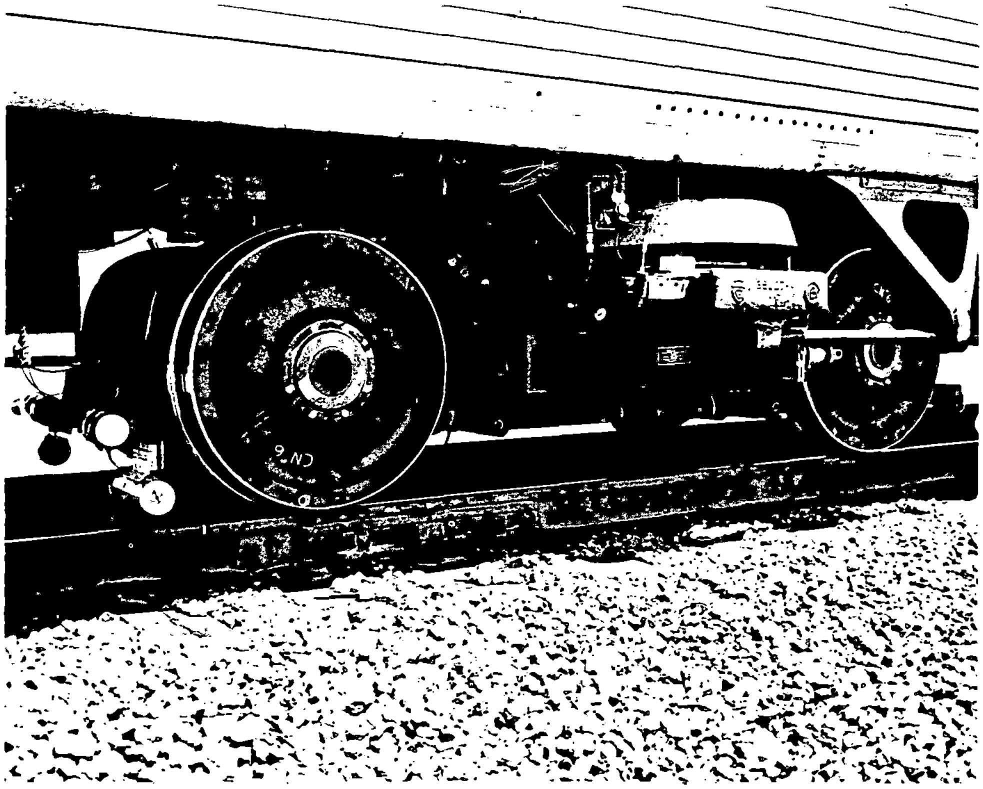

Figure 2-4. Truck Instrumentation

TABLE 2-1
INSTRUMENTATION CHANNEL ASSIGNMENT

CHANNEL	TRANSDUCER NUMBER	MEASUREMENT	TRANSDUCER TYPE	LOCATION
0	3A	Vertical Motion of Primary Suspension	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Left Side
1	3B	Vertical Motion of Primary Suspension	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Left Side
2	4A	Vertical Motion of Primary Suspension	±5" Bridge Type String Pot	A-End Radial Truck B-Axle Left Side
3	4B	Vertical Motion of Primary Suspension	±5" Bridge Type String Pot	A-End Radial Truck B-Axle Left Side
4	5A	Longitudinal Motion of Frame to Journal	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Left Side
5	5B	Longitudinal Motion of Frame to Journal	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Right Side
6	6A	Longitudinal Motion of Frame to Journal	±5" Bridge Type String Pot	A-End Radial Truck B-Axle Left Side
7	6B	Longitudinal Motion of Frame to Journal	±5" Bridge Type String Pot	A-End Radial Truck B-Axle Right Side
8	7A	Longitudinal Motion of Frame to Journal	±5" Bridge Type String Pot	B-End Radial Truck A-Axle Left Side
9	7B	Longitudinal Motion Frame to Journal	±5" Bridge Type String Pot	B-End Radial Truck A-Axle Right Side
10	8A	Longitudinal Motion Frame to Journal	±5" Bridge Type String Pot	B-End Radial Truck B-Axle Left Side
11	8B	Longitudinal Motion Frame to Journal	±5" Bridge Type String Pot	B-End Radial Truck B-Axle Right Side
12	9	Lateral Motion of Frame to Journal	Reed Gage	A-End Radial Truck A-Axle Right Side
13	10	Lateral Motion of Upper Box to Journal	Reed Gage	A-End Radial Truck B-Axle Left Side
14	11	Lateral Motion Truck Bolster to Carbody	±5" Bridge Type String Pot	A-End Radial Truck
15	12	Lateral Motion Truck Bolster to Carbody	±5" Bridge Type String Pot	B-End Radial Truck
16	13	Truck Frame to Bolster Swivel	±15" Bridge Type String Pot	A-End Radial Truck
17	14	Truck Frame to Bolster Swivel	±15" Bridge Type String Pot	B-End Radial Truck
18	15A	Journal Tilt	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Left Side

TABLE 2-1 (cont)

INSTRUMENTATION CHANNEL ASSIGNMENT

CHANNEL	TRANSDUCER NUMBER	MEASUREMENT	TRANSDUCER TYPE	LOCATION
19	15B	Journal Tilt	±5" Bridge Type String Pot	A-End Radial Truck A-Axle Right Side
20	16A	Journal Tilt	±5" Bridge Type String Pot	A-End Radial Truck B-Axle Left Side
21	16B	Journal Tilt	±5" Bridge Type String Pot	A-End Radial Truck B-Axie Right Side
22	17A	Longitudinal Motion Truck Frame to Upper Box	Reed Gage	A-End Radial Truck A-Axle Left Side
23	17B	Longitudinal Motion Truck Frame to Upper Box	Reed Gage	A-End Radial Truck A-Axle Right Side
24	18	Lateral Motion Upper Box to Journal	Reed Gage	A-End Radial Truck A-Axle Left Side
25	19	Lateral Acceleration of Journal	'PCB' Brand Piezo ±50g Accelerometer	A-End Radial Truck A-Axle Left Side
26	20	Vertical Acceleration of Journal	'PCB' Brand Piezo ±50g Accelerometer	A-End Radial Truck A-Axle Left Side
27	21A	Vertical Acceleration of Carbody	RQP #1	A-End Radial Coach
28	21B	Lateral Acceleration of Carbody	RQP #1	A-End Radial Coach
29	22A	Longitudinal Force on Steering Rod	Strain Gage supplied by MFR	A-End Radial Coach
30	22B	Longitudinal Force on Steering Rod	Strain Gage supplied by MFR	A-End Radial Coach
31	23	Longitudinal Force on Damper Link	Strain Gage supplied by MFR	A-End Radial Truck A-Axle Right Side
32	24	Vertical Strain on Bolster	Strain Gage supplied by MFR	A-End Radial Truck
33	25	Strain on Disc Brake Rigging	Strain Gage supplied by MFR	A-End Radial Truck
34	26A	Brake Cylinder Pressure on Tread Brakes	2000 psi Gulton	A-End Radial Truck A-Axle Left Side

TABLE 2-1 (cont)
INSTRUMENTATION CHANNEL ASSIGNMENT

CHANNEL	TRANSDUCER NUMBER	MEASUREMENT	TRANSDUCER TYPE	LOCATION
35	37	Loco Carbody Lateral Acceleration	Schavitz	
36	26C	Brake Cylinder Pressure on Disc	2000 psi Gulton	A-End Radial Truck A-Axle
37	27A1	Angle-of-Attack	ENSCO Sensor	A-End Radial Truck A-Axle Left Side
38	27B1	Angle-of-Attack	ENSCO Sensor	A-End Radial Truck A-Axle Right Side
39	27A2	Angle-of-Attack	ENSCO Sensor	A-End Radial Truck B-Axle Left Side
40	27B2	Angle-of-Attack	ENSCO	A-End Radial Truck B-Axle Right Side
41	30	Lateral Motion Truck Bolster to Carbody	±5" Bridge Type String Pot	A-End Reference Coach
42	31	Truck Frame to Bolster Swivel	±15" Bridge Type String Pot	A-End Reference Coach
43	32A	Vertical Acceleration of Carbody	RQP #2	A-End Reference Coach
44	32B	Lateral Acceleration of Carbody	RQP #2	A-End Reference Coach
45	33	Brake Cylinder Pressure	200 psi GS615 Gulton	A-End Reference Coach A-Axle Left
46	34A1	Angle-of-Attack	ENSCO Sensor	A-End Reference Coach A-Axle Left
47	34B1	Angle-of-Attack	ENSCO Sensor	A-End Reference Coach A-Axle Right
48	34A2	Angle-of-Attack	ENSCO Sensor	A-End Reference Coach B-Axle Left
49	34B2	Angle-of-Attack	ENSCO Sensor	A-End Reference Coach B-Axle Right
50	35	Lateral Acceleration of Journal	'PCB' ±50g Piezo Accelerometer	A-End Truck Ref. Coach A-Axle Left

TABLE 2-1 (cont)
INSTRUMENTATION CHANNEL ASSIGNMENT

CHANNEL	TRANSDUCER NUMBER	MEASUREMENT	TRANSDUCER TYPE	LOCATION
51	36	Vertical Acceleration of Journal	'PCB' ±50 g Accelerometer	A-End Truck Ref. Coach A-Axle Left
52	28	Dist.	Wheel Tach 1000 CPR	T-7
53	29	ALD	ENSCO ALD Sensor	T-7
54		Reference 5V p-p 10 Hz. sq. wave	Oscilloscope Calibrator	T-7
55	38A	Long Force on Cross Link	Strain Gage	B-End Radial Coach
56	38B	Long Force on Cross Link	Strain Gage	B-End Radial Coach

TABLE 2-2

RADIAL TRUCK DIRECT AND SCALED OUTPUTS

CHANNEL NUMBER	MEASURE NUMBER	PARAMETER	DEFINITION	SET UP NOTES	TANGENT	CURVING
29	22A	F_1	Force in Crosslink 1, A-Rad Tr		Mean, 3σ, P.S.D.	Max, Min
30	22B	F_2	Force in Crosslink 2, A-Rad Tr		Mean, 3σ, P.S.D.	Max, Min
16	13	$\Delta\theta AC$	Radial Car A End Truck Angle WRT Carbody	$\frac{\text{Bolster Swivel}}{\text{II}_A} * 57.3$	RMS, 2σ	RMS, 2σ
17	14	$\Delta\theta BC$	Radial Car B End Truck Angle WRT Carbody	$\frac{\text{Bolster Swivel}}{\text{II}_A} * 57.3$	RMS, 2σ	RMS, 2σ
42	31	$\Delta\theta NC$	Reference Car A End Truck Angle WRT Carbody	$\frac{\text{Bolster Swivel}}{\text{II}_A} * 57.3$	RMS, 2σ	RMS, 2σ
12	9	$\Delta Y_1 A$	Axle 1 Lateral Motion WRT Truck, Radial Coach		Max, Min 3σ	Max, Min 3σ
13	10	$\Delta Y_2 A$	Axle 2 Lateral Motion WRT Truck, Radial Coach		Max, Min 3σ	Max, Min 3σ
34	26A		Radial Truck Tread BCP		Mean, 3σ	Mean, 3σ
36	26C		Radial Truck Disc BCP		Mean, 3σ	Mean, 3σ
45	33		Reference Coach BCP		Mean, 3σ	Mean, 3σ
27	21A		Vertical Carbody Accel. Radial Coach		RMS, 2σ, 3σ PSD, R-Q	RMS, 2σ, 3σ PSD, R-Q
28	21B		Lateral Carbody Accel. Radial Coach		RMS, 2σ, 3σ PSD, R-Q	RMS, 2σ, 3σ PSD, R-Q
43	32A		Vertical Carbody Accel. Reference Coach		RMS, 2σ, 3σ PSD, R-Q	RMS, 2σ, 3σ PSD, R-Q
44	32B		Lateral Carbody Accel. Reference Coach		RMS, 2σ, 3σ PSD, R-Q	RMS, 2σ, 3σ PSD, R-Q
25	19		Lateral Journal Accel. Radial Coach		RMS, 2σ, 3σ PSD	RMS, 2σ, 3σ PSD

[redacted]

TABLE 2-2 (cont)

RADIAL TRUCK DIRECT AND SCALED OUTPUTS

CHANNEL NUMBER	MEASURE NUMBER	PARAMETER	DEFINITION	SET UP NOTES	TANGENT	CURVING
26	20		Vertical Journal Accel. Radial Coach		RMS, 2σ, 3σ PSD	RMS, 2σ, 3σ PSD
50	35		Lateral Journal Accel. Reference Coach		RMS, 2σ, 3σ PSD	RMS, 2σ, 3σ PSD
51	36		Vertical Journal Accel. Reference Coach		RMS, 2σ, 3σ PSD	RMS, 2σ, 3σ PSD
31	23		Force in Damper Link		Mean, 3σ, PSD	Mean, 3σ, PSD
32	24		Strain in Bolster		Mean, 3σ, PSD	Mean, 3σ, PSD
33	25		Strain in Brake Rigging		Mean, 3σ, PSD	Mean, 3σ, PSD
53	29		ALD		None	None
35	37		Lateral Carbody Accel, Loco.		RMS, PSD, Max.	RMS, PSD, Max.
55	38A	F3	Force in Crosslink 3 B-Radial Truck		Mean, 3σ, P.S.D.	Max, Min
56	38B	F4	Force in Crosslink 4 B-Radial Truck		Mean, 3σ, P.S.D.	Max, Min

current data record in which the data were stored. Playback in the EDDAS mode produces an analog map that allows the analyst to select data from a lengthy tape for intensive analysis.

A tape duplication program allowed selected records to be recorded on another tape to provide a condensed data tape to minimize tape handlng.

Another program developed for this test, ENSCO Data Analysis Program (EDAP), provided digital data analysis of an EDDAS data tape. EDAP allowed the analyst to digitally map a data tape. The map provides distance, event type and number, speed, time of day, and position in the tape information which can be combined with the analog map to provide an accurate location of test phenomena. A sample digital map is shown in Table 2-3.

Another feature of EDAP is the channel table, shown in Table 2-4. The channel table is interactive with the data analysis program in that a change in the scale or equation will change the output value. This feature is useful for correcting errors in the setup that are detected at a later date.

Once the analyst has decided what data are to be analyzed, he can select the analysis start and stop points from any record, ALD, milepost, or event plus up to 9999 feet to any other or the same record. Thus, the same distance, time or area track loction can be selected as the analysis base and specific start and stop points such as ALD's are not needed.

The analyst has the choice of analyzing all measured and calculated channels at one time for maximum, minimum, mean, RMS and standard deviation or any 16 channels for all of the above analysis plus 1st, 5th, 95th and 99th percentile values.

2.3 DETAILED DESCRIPTION OF TEST ARTICLE

The radial truck used in this test has the following features:

- Each truck has a cast rigid frame.
- Summiride air bags are used for the secondary suspension and the bolster serves as the reservoir for the air suspension and leveling system.

TABLE 2-3
SAMPLE DIGITAL MAP FROM EDAP

```
EDAP REPORT:                                         11/23/80 PGE:   1

SR=   32,NC=  64,MS=  58,TAPE=03
DATE= 0/00/80,FILE= 1,TEST=   5
SERIES=  19,RUN=    1,TRACK 0,CD= A,TD=UP,PPFT= 215
(OPERATOR ENTERED INFORMATION 70   CHARACTERS MAXIMUM                   )

      EVENT       EDDAS     DSTNC      DSTNC      DSTNC       AVRG    EDDAS  RCRD  DSTNC     TOD
    TYPE-NMBR      WRD      START      LAST       LAST        SPEED   RCRD   SCAN  START
                            MAP        EVENT      TYPE        MPH                  RCRD
   1) CRVL-    1     0        4.7        0.0        0.0      103.2      0      1     4.7    9:50: 4
   2) MPST-    1     9      945.7      941.0        0.0      103.2      3     26   123.0    9:50: 9
   3) MSSG-    1    16     1943.5      997.7        0.0      103.2      7      5    23.7    9:50:16
   4) MSSG-    2    17     2506.2      562.8      562.8      103.1      9      8    37.8    9:50:20
   5) CRVR-    1     0     3102.0      595.8        0.0      103.1     11     18    85.1    9:50:24
   6) TANG-    1     0     3764.0      662.0        0.0      103.2     13     42   198.6    9:50:27
   7) MPST-    2    10     4837.5     1073.5     3891.8      103.2     17     37   175.0    9:50:34
   8) MPST-    3    11     5286.8      449.3      449.3      103.2     19     16    75.7    9:50:38
   9) MSSG-    3    18     5920.4      633.6     3414.2      103.2     21     34   160.8    9:50:42
      END                  6582.6                                   23

RQSTD     CRITERIA COUNT     FEET          ACTUAL     FEET  RCRD   SCAN
START       RM        0       0.0                      0.0    0      1
END         RM    32766       0.0                      0.0   23     58


TAPE FILE NUM:          1
TAPE HDR RCRD:          1 @  100 WRDS/RCRD
1ST TAPE DATA RCRD:     0 @ 3840 WRDS/RCRD
LST TAPE DATA RCRD:    23

TOTALS:
MSSG      3
MPST      3
TANG      1
CRVL      1
CRVR      1
ALD       0
RPDF      0
```

TABLE 2-4

CHANNEL TABLE FROM ED

```
PGE: 1
FILE:CA0825
HEADER TEXT(A72):          CORRECTIONS FOR TAPES 31, 32
EFFCTV DATE(MM/DD/YY):     1/27/81
EFFCTV TEST(A4):           10
EFFCTV SERIES(A4):         7
EFFCTV RUN(A4):            1

CHN MSR#  TYPE               LOCATION             SOURC
  0 3A    VERT PRI SUSP     A-E RT A-A LEFT    5" S-P
  1 3B    VERT PRI SUSP     A-E RT A-A RIGHT   5" S-P
  2 4A    VERT PRI SUSP     A-E RT B-A LEFT    5" S-P
  3 4B    VERT PRI SUSP     A-E RT B-A RIGHT   5" S-P
  4 5A    LONG. FRM-TO-JRN  A-E RT A-A LEFT    5" S-P
  5 5B    LONG. FRM-TO -JR  A-E RT A-A RIGHT   5" S-P
  6 6A    LON. FRM-TO-JRN   A-E RT B-A LEFT    5" S-P
  7 6B    LON. FRM-TO-JRNL  A-E RT B-A RIGHT   5" S-P
  8 7A    LON. FRM-TO-JRNL  B-E RT A-A LEFT    5" S-P
  9 7B    LON. FRM-TO-JRNL  B-E RT A-A RIGHT   5" S-P
 10 8A    LON. FRM-TO-JRNL  B-E RT B-A LEFT    5" S-P
 11 8B    LON. FRM-TO-JRNL  B-E RT B-A RIGHT   5" S-P
 12 9     LAT. FRM-TO-JRNL  A-E RT A-A RIGHT   REED G
 13 10    LAT. UP-BX TO JR  A-E RT B-A LEFT    REED G
 14 11    LAT. TBOL-TO-CBD  A-END RT           5" S-P
 15 12    LAT. TBOL-TO-CBD  B-END RT           5" S-P
 16 13    TRK-FRM SVL-BOL   A-END RT           15" S-P
 17 14    TRK-FRM SVL-BOL   B-END RT           10" S-P
 18 15A   JOURNAL TILT      A-E RT A-A LEFT    5" S-P
 19 15B   JOURNAL TILT      A-E RT A-A RIGHT   5" S-P
 20 16A   JOURNAL TILT      A-E RT B-A LEFT    5" S-P
 21 16B   JOURNAL TILT      A-E RT B-A RIGHT   5" S-P
 22 17A   LON. TRK-FRM UP   A-E RT A-A LEFT    REED G
 23 17B   LON. TRK-FRM UP   A-E RT A-A RIGHT   REED G
 24 18    LAT. UP-BX TO JR  A-E RT A-A LEFT    REED G
 25 19    LAT. ACCL JRNL    A-E RT A-A LEFT    50G ACCL
 26 20    VERT ACCL JRNL    A-E RT A-A LEFT    50G ACCL
 27 21A   VERT ACCL CARBDY  A-E RADIAL COACH   RQP #1
 28 21B   LAT ACCL CARBDY   A-E RADIAL COACH   RQP #1
 29 22A   LON.FRC CRSS LNK  A-E RADIAL COACH   S-GAGE
 30 22B   LON.FRC CRSS LNK  A-E RADIAL COACH   S-GAGE
 31 23    LON.FRC DAMPER L  A-E RT A-A RIGHT   S-GAGE
 32 24    VERT STRN BOLSTR  A-END RT           S-GAGE
 33 25    STRN DISC BRK     A-END RT           S-GAGE
 34 26A   BRK CYL PRES TRD  A-E RT A-A LEFT    2K P-G
 35 37    LOCO CBDY ACCL    LOCO               2G ACCL
 36 26C   BRK CYL PRES DIS  A-E RADIAL COACH   2K P-G
 37 27A1  ANGLE OF ATTACK   A-E RT A-A LEFT    EAOAS
 38 27B1  ANGLE OF ATTACK   A-E RT A-A RIGHT   EAOAS
 39 27A2  ANGLE OF ATTACK   A-E RT B-A LEFT    EAOAS
 40 27B2  ANGLE OF ATTACK   A-E RT B-A RIGHT   EAOAS
 41 30    LAT. TRK-BOL-CRB  A-E REF COACH      5" S-P
 42 31    TRK-FRM TO BOL S  A-END REF COACH    15" S-P
 43 32A   VERT ACCL OF CBD  A-END REF COACH    RQP #2
 44 32B   LAT ACCL OF CBD   A-END REF COACH    RQP #2
 45 33    BRAKE CYL    ES   A-E RC A-A LEFT    200 P-G
```

AP

1/27/81

```
+10V RNG   UNITS CTF FRQ   EL CAL      PH CAL
    2.5     IN     10.0    -9.05 V     0.00 V
    2.5     IN     30.0.   -9.05 V     0.00 V
    2.5     IN     30.0.    0.00 V     0.00 V
    2.5     IN     30.0    -9.31 V     0.00 V
    2.5     IN     10.0.    0.00 V     0.00 V
    2.5     IN     30.0.    0.00 V     0.00 V
    2.5     IN     30.0.    9.12 V     0.00 V
    2.6     IN     30.0.   -9.22 V     0.00 V
    2.4     IN     30.0    -9.22 V     0.00 V
    2.5     IN     30.0.   -9.25 V     0.00 V
    2.5     IN     30.0.    9.56 V     0.00 V
    2.5     IN     30.0.    9.35 V     0.00 V
    4.6     IN     30.0.   10.10 V     0.00 V
    9.4     IN     30.0.   -6.69 V     0.00 V
    2.4     IN     30.0.    9.23 V     0.00 V
    2.4     IN     30.0.    9.29 V     0.00 V
   10.0     DEG    30.0    -5.39 V     0.00 V
    3.2     DEG    30.0    10.71 V     0.00 V
    2.5     IN     10.0.    8.77 V     0.00 V
    2.5     IN     30.0:   -9.23 V     0.00 V
    2.5     IN     30.0.   -9.05 V     0.00 V
    2.4     IN     30.0.   -9.26 V     0.00 V
    4.7     IN     30.0.    8.26 V     0.00 V
    5.1     IN     30.0.    6.05 V     0.00 V
    9.1     IN     30.0.   10.54 V     0.00 V
   50.0     G      30.0     0.00 V     0.00 V
   50.0     G      30.0     0.00 V     0.00 V
    1.3     G      30.0     0.00 V     7.50 V
    1.3     G      30.0     0.00 V     7.50 V
   20.0     KIP    30.0     3.39 V     0.00 V
   20.0     KIP    30.0     3.39 V     0.00 V
   25.0     KIP    30.0     3.64 V     0.00 V
 2000.0     USTN   30.0     5.00 V     0.00 V
   50.0     KIP    30.0     3.45 V     0.00 V
 1000.0     PSI    30.0     0.00 V     0.00 V
    2.0     G      30.0     0.00 V     0.00 V
 1000.0     PSI    30.0     0.00 V     0.00 V
    2.0     IN     30.0.    0.00 V     0.00 V
    2.0     IN     30.0.    0.00 V     0.00 V
    2.0     IN     30.0:    0.00 V     0.00 V
    2.0     IN     30.0:    0.00 V     0.00 V
    2.4     IN     30.0:    0.00 V     0.00 V
    5.0     DEG     2.0:    0.00 V     0.00 V
    1.3     G      30.0     0.00 V     7.50 V
    1.3     G      30.0     0.00 V     7.50 V
  200.0     PSI    30.0     0.00 V     0.00 V
```

[redacted]

TABLE 2-4 (cont)

```
PGE: 2                                                                    1/27/81
FILE:CA0025
HEADER TEXT(A72):      CORRECTIONS FOR TAPES 31, 32
EFFCTV DATE(MM/DD/YY): 1/27/81
EFFCTV TEST(A4):       10
EFFCTV SERIES(A4):     7
EFFCTV RUN(A4):        1

CHN MSR#  TYPE              LOCATION          SOURC      +10V RNG  UNITS CTF FRQ  EL CAL    PH CAL
 46 34A1 ANGLE OF ATTACK  A-E RC A-A LEFT  EAOAS          2.0     IN     30.0.   0.00 V   0.00 V
 47 34B1 ANGLE OF ATTACK  A-E RC A-A RIGHT EAOAS          2.0     IN     30.0.   0.00 V   0.00 V
 48 34A2 ANGLE OF ATTACK  A-E RC B-A LEFT  EAOAS          2.0     IN     30.0    0.00 V   0.00 V
 49 34B2 ANGLE OF ATTACK  A-E RC B-A RIGHT EAOAS          2.0     IN     30.0.   0.00 V   0.00 V
 50 35   LAT ACCL JRNL    A-E RC A-A LEFT  50G ACCL      50.0     G      30.0    0.00 V   0.00 V
 51 36   VERT ACCL JRNL   A-E RC A-A LEFT  50G ACCL      50.0     G      30.0    0.00 V   0.00 V
 52 28   DISTANCE         T-7              TACH           1.0            30.0    0.00 V   0.00 V
 53 29   AUTO LOC DET PUL T-7              E-ALD          1.0     EVNT   30.0    0.00 V   0.00 V
 54      REF 10 HZ 5V P-P T-7              CALIB          2.0     SQWV   30.0    0.00 V   0.00 V
 55 38A  LON.FRC DRSS LNK B-E RADIAL COACH (DEAD)        20.0     KIP    30.0    3.54 V   0.00 V
 56 38B  LON.FRC DRSS LNK B-E RADIAL COACH S-GAGE        20.0     KIP    30.0    3.38 V   0.00 V
 57 39A  AUTO LOC DET RAW RADIAL COACH LFT E-ALD          1.0     EVNT   30.0    0.00 V   0.00 V
 58 39B  AUTO LOC DET RAW RADIAL COACH RT  E-ALD          1.0     EVNT   30.0    0.00 V   0.00 V
 59 40A  VRT BOL TO CRBY  A-E RT LEFT      15" S-P       10.0     IN     30.0.   6.63 V   0.00 V
 60 40B  VRT BOL TO CRBY  A-E RT RIGHT     15" S-P       10.0     IN     30.0.   7.01 V   0.00 V

CHN MSR# TYPE              10V RNG    UNITS FORM
DEFINITION

201 201  AXL1 ANGL WRT TR     5.000 DEG    POLY
DEF=  C1   ,5B   ,C-1 ,5A   ,C0   ,C0   ,C0   ,C0   ,C1   ,E    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

202 202  AXL2 ANGL WRT TR     5.000 DEG    POLY
DEF=  C1   ,6B   ,C-1 ,6A   ,C0   ,C0   ,C0   ,C0   ,C1   ,E    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

203 203  RDTRK-A AOA          1.000 DEG    POLY
DEF=  C1   ,27A1,C-1 ,27B1,C-1 ,27A2,C1   ,27B2,C2   ,DA   ,C0   ,C0   ,C-1 ,RDEG,C0   ,C0

204 204  RD AXL1 AOA          5.000 DEG    POLY
DEF=  C1   ,203  ,C1   ,201  ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,K.01,C7

205 205  RD AXL2 AOA          5.000 DEG    POLY
DEF=  C1   ,203  ,C1   ,202  ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,K.01,C7

206 206  RF TRK ANG WRT R     1.000 DEG    POLY
DEF=  C1   ,34A1,C-1 ,34B1,C-1 ,34A2,C1   ,34B2,C2   ,DN   ,C0   ,C0   ,C-1 ,RDEG,C0   ,C0

207 207  AX TO AX ANGL       10.000 DEG    POLY
DEF=  C1   ,201  ,C-1 ,202  ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0

208 208  RDTRK Y WRT RL       2.000 IN     POLY
DEF=  C1   ,27A2,C-1 ,27B2,C1   ,27A1,C-1 ,27B1,C1   ,C2   ,C1   ,C2   ,C1   ,C1   ,C0   ,C0

209 209  DEAD                 1.000 DEG    POLY
DEF=  C0   ,C0   ,C0   ,C0   ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C0   ,C0   ,C0   ,C0

210 209  REF TRK Y WRT RL     2.000 IN     POLY
DEF=  C1   ,34A2,C-1 ,34B2,C1   ,34A1,C-1 ,34B1,C1   ,C2   ,C1   ,C2   ,C1   ,C1   ,C0   ,C0
```

TABLE 2-4 (cont)

```
PGE: 3
FILE:CA0825
HEADER TEXT(A72):        CORRECTIONS FOR TAPES 31,
EFFCTV DATE(MM/DD/YY):  1/27/81
EFFCTV TEST(A4):         10
EFFCTV SERIES(A4):       7
EFFCTV RUN(A4):          1

CHN MSR# TYPE                   10V RNG    UNITS FORM
DEFINITION

211 211  RD AX1 DY VRT RL        2.000 IN     POLY
DEF=  C3  ,27A2,C5  ,27B2,C1   ,200 ,C1  ,10  ,C1

212 212  DEAD                    1.000 DEG    POLY
DEF=  C0  ,C0  ,C0  ,C0  ,C0   ,C0  ,C0  ,C0  ,C1

213 213                          1.000 DEG    POLY
DEF=  C0  ;C0  ,C0  ,C0  ,C0   ,C0  ,C0  ,C0  ,C1

214 214  RF AX1 DY VRT RL        2.000 IN     POLY
DEF=  C1  ,34A1,C-1 ,34B1,C0   ,C0  ,C0  ,C0  ,C2

215 215  RF AX2 DY VRT RL        2.000 IN     POLY
DEF=  C1  ,34A2,C-1 ,34B2,C0   ,C0  ,C0  ,C0  ,C2

216 216  RT AX1-R JBX TLT       10.000 DEG    POLY
DEF=  C1  ,15B ,C-1 ,3B  ,C0   ,C0  ,C0  ,C0  ,C1

217 217  RT AX2-R JBX TLT       10.000 DEG    POLY
DEF=  C1  ,4B  ,C-1 ,16B ,C0   ,C0  ,C0  ,C0  ,C1

218 218  SPEED                 200.000 MPH    SPED
DEF=
          ,     ,     ,     ,     ,     ,     ,     ,

219 219  RT AX1L VRTMO PS!       2.500 IN     POLY
DEF=  C1  ,15A ,C1  ,3A  ,C0   ,C0  ,C0  ,C0  ,C1

220 220  RT AX1R VRTMO PS;       2.500 IN     POLY
DEF=  C1  ,15B ,C1  ,3B  ,C0   ,C0  ,C0  ,C0  ,C1

221 221  RT AXL2 VRTMO PS:       2.500 IN     POLY
DEF=  C1  ,16A ,C1  ,4A  ,C0   ,C0  ,C0  ,C0  ,C1

222 222  AXLE 2 RT PRI SP        2.500 IN     POLY
DEF=  C1  ,16B ,C1  ,4B  ,C0   ,C0  ,C0  ,C0  ,C1

223 223  GAGE (0=56.5 IN)        2.000 IN     POLY
DEF=  C1  ,27A1,C1  ,27B1,C0   ,C0  ,C0  ,C0  ,C1

224 224  AX1L LNMO UBX/JRI       2.000 IN     POLY
DEF=  C1  ,6A  ,C-1 ,17A ,C0   ,C0  ,C0  ,C0  ,C1

225 225  AX1R LNMO UBX/JRI       2.000 IN     POLY
DEF=  C1  ,6B  ,C-1 ,17B ,     ,C0  ,C0  C0   ,C1
```

```
,C1   ,C1   ,C1   ,C1   ,C1   ,C0   ,C0

,C1   ,C0   ,C0   ,C0   ,C0   ,C0   ,C0

,C1   ,C0   ,C0   ,C0   ,C0   ,C0   ,C0

,DN   ,C0   ,C0   ,C1   ,SM   ,C1   ,209

,DN   ,C0   ,C0   ,C1   ,SM   ,C1   ,209

,W    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

,W    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

,     ,     ,     ,     ,     ,     ,

,C1   ,C1   ,C1   ,C1   ,C1   ,C0   ,C0

,C1   ,C1   ,C1   ,C1   ,C1   ,C0   ,C0

,C1   ,C1   ,C1   ,C1   ,C1   ,C0   ,C0

,C1   ,C1   ,C1   ,C1   ,C1   ,C0   ,C0

,C1   ,C0   ,C0   ,C1   ,C1   ,C1   ,GAGE

,C1   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0

  1               ,     ,C    ,C    ,C0
```

TABLE 2-4 (cont)

```
PGE: 4                                                                    1/27/81
FILE:CA0025
HEADER TEXT(A72):          CORRECTIONS FOR TAPES 31, 32
EFFCTV DATE(MM/DD/YY):  1/27/81
EFFCTV TEST(A4):        10
EFFCTV SERIES(A4):      7
EFFCTV RUN(A4):         1

CHN MSR# TYPE                   10V RNG    UNITS FORM
DEFINITION

226 226  RT AX1 LAT FRC           15.000 KIPS  POLY
DEF=  SINA,22A ,PK  ,18   ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0

227 227  RT AX2 LAT FRC           15.000 KIPS  POLY
DEF=  SINA,22A ,PK  ,10   ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0

228 228  AX3 WRT TRUCK             0.000 DEG   POLY
DEF=  C1  ,7B  ,C-1 ,7A   ,C0   ,C0   ,C0   ,C0   ,C1   ,E    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

229 229  AX4 WRT TRUCK             0.000 DEG   POLY
DEF=  C1  ,8B  ,C-1 ,8A   ,C0   ,C0   ,C0   ,C0   ,C1   ,E    ,C0   ,C0   ,C1   ,RDEG,C0   ,C0

230 230  AXL-AXL B-TRUCK           0.000 DEG   POLY
DEF=  C1  ,228 ,C-1 ,229 ,C0   ,C0   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0   ,C1   ,C1   ,C0   ,C0

CHN MSR# TYPE                   VALUE       UNITS
400 C1   CMPT CON-UTILITY         1.0000
401 C0   CMPT CON-UTILITY         0.0000
403 C-1  CMPT CON-UTILITY        -1.0000
404 C2   CMPT CON-UTILITY         2.0000
405 RDEG RADIANS TO DEGRE        57.3000 D/R
406 E    LONG AXLE DISDNC        27.0000 IN
407 DA   LONG SPC AOA RT        147.7500 IN
408 DN   LONG SPC AOA RE        144.0000 IN
409 K.01 CUVING CONST             0.0000.
410 SA   AXLE SPACING RT        102.0000 IN
411 SN   AXLE SPACING REF       102.0000 IN
412 V    VERT/TILT SPC            9.2500 IN
413 GAGE TRACK GAGE              56.5000 IN
414 PK                        17666.0000 LB/I
415 SINA 2*SIN(A)                  .8430
416 C3   SA/DA                     .6904
417 C4   SN/DN                     .7083
418 C5   -SA/DA                   -.6904
419 C6   -SN/DN                   -.7083
420 C7   SA/2                    51.0000 IN

HN MSR#      EQTN FORM
500 POLY FRM=((C1*X1+C2*X2+C3*X3+C4*X4)/(C5*X5+C6*X6))*(C7*X7)+(C8*X8).
501 SPED =SPEED
502 WPRV =MAX(ABS(A)+ABS(B)),ABS(A),ABS(B))
```

- The secondary suspension has both air damping provided within the reservoir and hydraulic shock absorbers.

- The primary suspension is arranged in two stages and allows for adjusting the spring rate of the longitudinal spring independently of the vertical spring rate. The upper section is supported by special metalastic chevron springs to the upper box and is relatively stiff in lateral and longitudinal motion. Coil springs located above the upper journal box supplement the chevron springs. The axles are attached by the lower spring journal box assembly so they are capable of aligning in a radial mode. This lower journal is suspended from the upper journal by shear sandwiches specially developed to provide the desired longitudinal and lateral spring rate.

- The cross-links which connect diagonally between the lower journal boxes connect the front and rear axles are shown in Figure 2-5.

- The other unique feature of the radial truck is the wheel profile. Figure 2-6 shows one of the radial truck wheels being checked with a profile gage. The taper near the flange is about 1:13 while the taper near the outer edge increases to about 1:10. The wheel tread tapers are not straight lines. These ratios were obtained from a least squares fit, and they are approximations to give the reader a feel for the wheel contours.

- These radial trucks require a special brake system so that the braking will not disrupt the radial alignment and truck steering. The GSI trucks used both disc and tread brakes. A single disc is in the center of each axle. The disc calipers are suspended from arms extended from the lower journal box assemblies. With this arrangement, braking forces developed by the disc do not disturb the axle alignment. Each wheel has a single tread brake suspended from the truck frame allowing lateral flexures. These flexure fixtures are stiff in the longitudinal direction but very complaint in the lateral direction. The tread brakes on each side are actuated by a common hydraulic cylinder located on the same side of the truck frame. The hydraulics are crossfed so that the forces on each side of the truck are equalized. If perfectly equalized, the braking forces will not affect the radial wheel alignment.

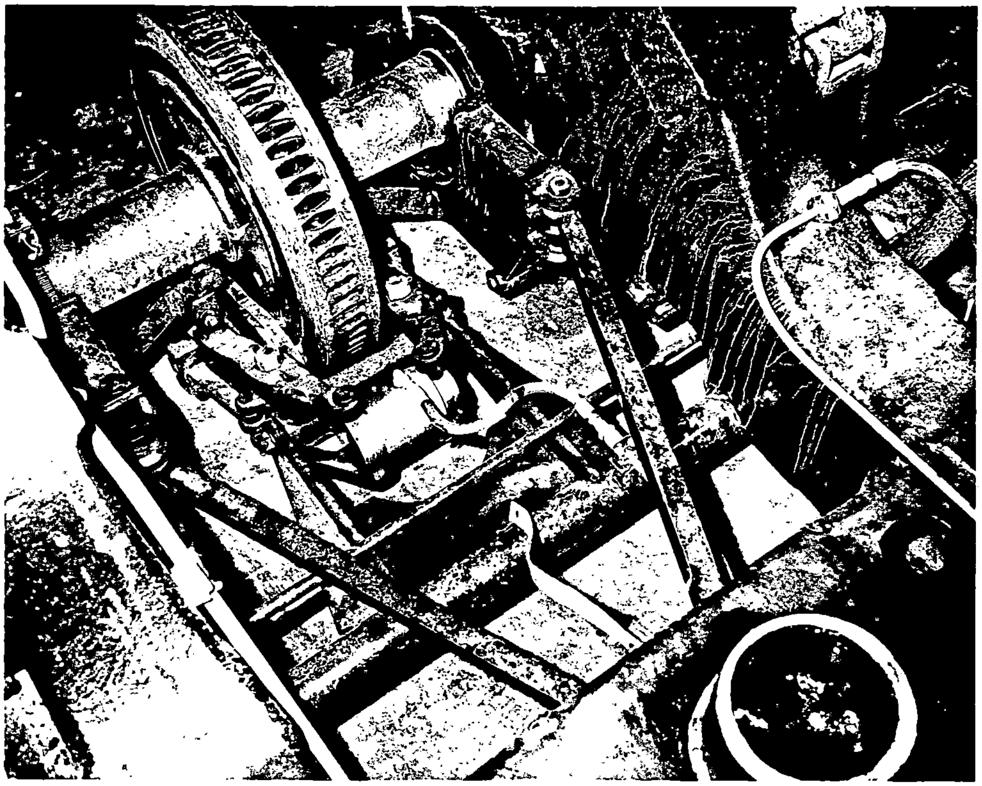

Figure 2-5. Truck Cross-Links

Figure 2-6. Wheel Profile

3.0 TEST DESCRIPTION

Since many of the results are easier to understand when related to the test description, the results of the shop tests have been combined with the Test Description and are, therefore, included in this section.

3.1 SHOP TESTS

3.1.1 PURPOSE

The shop tests were designed to ensure that an Amcoach equipped with the Radial Truck would be compatible with existing Amtrak equipment and general truck requirements. The shop tests were conducted along the guidelines of the Radial Truck Test Plan. However, changes in the plan were made to adapt to unforeseen circumstances. Two tests, axle alignment and leveling system tests, were added to the shop test sequence.

3.1.2 CARBODY CLEARANCE

A wooden clearance template was constructed to check that portion of the car below the car floor level and the trucks and underbody equipment. The template was positioned along the carbody and lateral clearance was checked according to instructions and dimensions in Amtrak drawing D-322C. The car was tested on level, tangent track since the clearance allowance compensates for lean, crosslevel variation and rail curvature.

At Amtrak's request, an additional test was added to the carbody clearance test. The added test procedure measured the excursion of the side of the carbody as the car was tilted. On a classical rail passenger car the point of interest would be the "eave" at the top of the vertical side of the car. On the Amcoach the outermost portion of the car was two trim strips above and below the windows at 111 inches and 76 inches above the railhead.

The vertical and lateral coordinates of these two strips were measured for each end of the radial truck equipped Amcoach and for the reference Amcoach. These measurements would be used for relative comparisons and no limits were established.

The Amcoach body did not pass through the template built to Amtrak Drawing D-322C "Clearance Diagram, Electrified and Third Rail." Since the interference was not related to the radial trucks the template was cut off at the lower edge of the car and

TABLE 3-1

CARBODY ROLL DATA ON 6-1/4 INCH CROSSLEVEL

	RADIAL COACH	REFERENCE COACH
Car Roll	06.26°	06.26°
Lateral Translation Bolter to Car	00.901"	00.712"
Upper Eave Displacement	13.88"	14.38"
Lower Eave Displacement	09.28"	09.16"

used only to measure clearance of those parts unique to the radial truck. There was no violation of the clearance profile. Therefore, the radial truck met the applicable clearance specifications.

Carbody lean and lateral displacement measurements were made by GSI. These measurements indicate that the radial truck equipped Amcoach lean characteristics are not substantially different from a conventional Amcoach. A summary of this test is shown in Table 3-1.

3.1.3 TRUCK TO CARBODY CLEARANCE

Truck rotation was verified by splitting a switch, putting one end of the car on one track and realigning the switch to put the other end of the car on an adjacent track. The car was pushed only far enough to give the desired truck swival for possible truck-carbody interferences. The motion of the truck relative to the carbody was measured and angle of rotation was calculated.

Truck to carbody clearance obtained by splitting the yard switch produced truck rotation of ±7°. There was no interference with undercar components or binding of brake lines so the trucks met the rotation requirement.

Truck rotation and track negotiation was also measured by pushing one end of the Amcoach with the radial truck into the screech loop. The screech loop has an entrance curve of 18° track and the curvature of the screen loop is 39°.

The Amcoach must negotiate a 23° curve. The minimum truck rotation for the Amcoach carbody geometry is ±7° for ±23° curves. The test confirmed that the radial truck could rotate sufficiently and negotiate the 23° curve.

3.1.4 SUSPENSION SYSTEM CENTERING

The car, equipped with radial trucks, was pushed back and forth on level, tangent track. At each end of travel the relative lateral position of the truck and carbody was measured by TTC personnel. The draft specification stated that the truck was required to be laterally centered with respect to the carbody, ±0.125 inches was acceptable.

Table 3-2 contains data from this test. L_1 and R_1 were measurements made from the left and right side of the truck near Axle 1 to the Amcoach body. A similar point was measured on L_2 and R_2. Axle 1 and Axle 2 are on the B-end truck. The measurements L_1 and L_2 were averaged to derive lateral truck motion for the left side of the B-truck.

The right and left sides of each truck are rigidly tied together so the motion of each side of the truck must be identical. Therefore, the excessive motion of the B-truck right side appears to be in error. On this basis the right and left side measurements of the A-truck are within the error of measurement of 1/32", and the truck centering appears to be within the lateral centering of ±0.125" established by the test plan.

3.1.5 HANDBRAKE TEST

The handbrake test was to determine the ability of the braking equipment installed on the radial truck to prevent the coach from rolling on a five percent grade. The disc/tread braking equipment supplied by New York Air Brake is activated by an air over hydraulic system. The handbrake consists of a valve rotated 90° to activate or release. There is no operator adjustment of braking force.

There is not a five percent grade track available at TTC. Therefore, a two and one-half percent grade track in front of the Central Services Building (CSB) was used. Two Amcoaches were ballasted with 10,000 pounds of lead. The handbrake of just the radial truck equipped coach were used to hold both coaches.

The handbrake held the radial truck equipped Amcoach and the reference coach, each ballasted with 10,000 pounds, thereby meeting the specification.

TABLE 3-2

CENTERING TEST DATA

RAW LATERAL TRUCK MOTION DATA

Reading	L_1	L_2	R_1	R_2	L_3	L_4	R_3	R_4
1	22.938	24.875	22.063	24.000	25.025	23.375	23.750	22.125
2	22.813	24.750	22.188	24.063	25.063	23.125	23.813	22.188
3	22.938	24.875	22.125	23.875	25.188	23.188	23.750	22.125
4	22.813	24.750	22.813	24.125	25.250	23.188	23.875	22.188
5	22.875	24.875	22.125	23.938	25.250	23.188	23.875	22.188

TRUCK LATERAL MOTION

	B-Truck Left	B-Truck Right	A-Truck Left	A-Truck Right
1	23.907	23.032	24.200	22.938
2	23.782	23.126	24.094	23.001
3	23.901	23.000	24.188	22.938
4	23.782	23.469	24.219	23.032
5	23.875	23.032	24.219	23.032
Lateral Motion	.125 ±.063	.469 ±.235	.125 ±.063	.094 ±.047
B-Truck Right Lateral Motion Excluding Reading 4		.126 ±.063		

3.1.6 EQUALIZATION TEST

The equalization test determined the ability of the truck to distribute the weight of the carbody and truck to the eight wheels in uneven track conditions.

All wheels were placed on load cells and the load on each wheel was measured. Each wheel was raised individually by means of jacks and load distribution was measured. The load at the wheels was equally distributed within 9.5 percent at an unbalance of 1 inch and within 18.5 percent at an unbalance of 2 inches.

3.1.7 LEVELING SYSTEM TEST

During initial installation of the radial trucks under Amcoach car number 21091, the leveling system caused the carbody to oscillate with a three to ten second period. The air bag on one side would inflate then deflate again so that the coach continued to rock as the air bags alternately inflated and deflated.

In addition to the initial leveling problems, test runs showed that there were other problems with the carbody leveling system. As the car negotiated high banked curves, the carbody leaned from 6 to 10 degrees and was very slow to recover. In the early tests the leaning exceeded the limits of travel allowed for by the leveling system and broke the leveling valve linkages. To evaluate this problem, a test was made on various spirals and high banked curves. The data from this test were provided to GSI to aid them in evaluating the carbody lean problem and develop modifications to the carbody leveling system.

To reduce the lean problem GSI changed the bidirectional check valves and modified the leveling valves to reduce the delay time. These changes did not totally eliminate the lean problem but improvements were adequate to allow the test to be conducted.

The results of the leveling system tests were used to modify their airbag suspension system. After the system response was altered to prevent damage to the system and prevent oscillations no further data from this test were reduced and no data are included in this report.

3.1.8 AXLE ALIGNMENT

The shakedown test showed that both trucks on the the radial truck test car tended to run flanged toward the right rail when the A-end truck was leading. The right bias occurred whether the coach was in buff or draft. A review of this problem indicated that the steering deficiency was caused by one or more of the following:

- Unbalanced weight distribution
- Unequal wheel size
- Axle misalignment
- Coupler misalignments

Tests were made to determine which, if any, of the suspected causes produced the steering defect. To check for problems caused by unequal weight distribution, the ballast in the radial coach was shifted from the left side to the right side of the coach. Over shifting the ballast in the radial coach and reversing position of the radial truck equipped coach and the reference coach produced no change in running characteristics.

To confirm that the wheels on each axle were the same diameter they were checked on the Hegenscheigt wheel truing machine. It showed that the maximum variation was 0.020 inches against the specification of 0.050 inches. Although the wheels were the same diameter, their profile did not match that specified by GSI because they provided the wrong truing template. The wheels were retrued to the correct profile. This improved the performance but the truck continued to run with a right bias.

Mechanical measurements produced no noticeable difference in dimensions, but TTC personnel proposed an optical measurement technique developed by British Railways that could detect small misalignments. This technique produced data that indicated the A-truck was misaligned enough to cause the steering problem while the B-truck was very nearly perfectly aligned. The chevron primary springs were shimmed to align the axles. Axle alignment was remeasured each time major work was done on the radial truck. Reference coach axle alignment was also measured.

The results of the running test indicated that the axles must be aligned very carefully to obtain proper steering. These tests show that the axles must be aligned within 1.5 milliradians to achieve acceptable steering of the radial trucks.

3.2 SHAKEDOWN TEST

3.2.1 PURPOSE

The shakedown test series was designed to allow the truck manufacturer to make adjustments to tune the radial truck. The series also provided a checkout of instrumentation and test procedures.

Shakedown testing was scheduled to duplicate the test plan. It involved testing on the Railroad Test Track (RTT), Train Dynamics Track (TDT), the Facility for Accelerated Service Testing Track (FAST), and the Balloon Loop.

3.2.2 TEST SEQUENCE

Shakedown testing was conducted as described below:

Day 1:	Verify instrumentation and conduct high speed stability runs up to 120 mph.
Day 2:	High speed stability runs with longitudinal dampers removed.
Day 3:	Curving runs on TDT and Balloon Loop.
Day 4:	Curving tests on FAST Track.
Day 5:	Install "soft" longitudinal/lateral primary spring suspension sandwiches.
Day 6:	Data analysis and axle alignment measurement.
Day 7:	Balloon Loop curving data and high speed stability on RTT to 105 mph.

3.2.3 TRACK MAPPING

Automatic Location Detector (ALD) targets were placed on the tracks used for the radial truck testing: the RTT, TDT, FAST and the Balloon Loop. ALD targets provide location information which can be related to track conditions and items of interest around the test zones.

The targets were placed at the entrance and exit of spirals, at switch locations, and at every 5000 feet around the track. Identifier patterns were placed every 10,000 feet on the RTT. Table 3-3 lists locations of crosslevel and degree of curvature for the test zones used in this test.

TABLE 3-3
TTC CURVE CRITERIA

TRACK	DEGREE OF CURVATURE	SUPER-ELEVATION INCHES	START LOCATION	END LOCATION	SPEED MPH 3" UNDER BALANCE	SPEED MPH BALANCE	SPEED MPH 3" OVER BALANCE
RTT	0° 50' R	5.95	R55+30	R103+29	71	101	124
			R191+19	R329+10			
			R397+53	R466+52			
	0° 50' L		R515+39	R530+39			
RTT	0° 50' R	5.95	R543+46	R702+46	71	101	124
Balloon	7° 30' L	5.4	B3073+90	B3101+65	21	32	40
Balloon	5° R	2.7	B3115+28	B3121+83		28	40
FAST	5° L	4.0	F1492+49	F1529+22	17	34	45
FAST	5° R	4.0	F1537+22	F1547+22	17	34	45
FAST	4° L	3.0	F1580+95	F1597+20		33	47
FAST	5° L	4.0	F1622+88	F1625+84	17	34	45
FAST	3° L	2.0	F1653+86	F1675+12		31	49
TDT	1° 30' R	3.03	D1630+57	D1720+00	29	54	76

3.2.4 SHAKEDOWN TEST

The results for the shakedown test have been combined with results from the other performance tests and are presented in Section 4 as part of the curving and stability reports.

3.3 CUTAWAY BRAKING TEST

3.3.1 PURPOSE

The cutaway braking test was performed to determine the single car stopping distance of the disc/tread braking system as installed by New York Air Brake on the radial truck.

The cutaway test was run after the shakedown series. Its purpose was to set the braking rate of the radial truck equipped coach to match the braking rate of a conventional Amcoach.

3.3.2 INSTRUMENTATION

A data collection system was installed on the radial coach to record the necessary parameters for braking rate. An eight channel analog strip chart recorder with two event pens was used to make a permanent record of data. Parameters measured were:

- Speed with 100-foot pulses superimposed
- Slip/slide indication for either A or B truck or both
- Tread brake hydraulic pressure
- Disc brake hydraulic pressure
- Lead axle tread temperature
- Lead axle disc temperature
- Train line air pressure
- ALD or ground mounted distance markers
- One-second time ticks

In addition to the optical temperature transducers, a hand-held pyrometer was used to measure temperature of all disc and treads after the car had stopped to provide a reference for the data collecting optical pyrometer. Distance of the automatic location detector sensor to the nearest distance marker was also measured to provide a zero speed/distance data point.

3.3.3 TEST PROCEDURE

The cutaway test was designed to produce data compatible with the dual brake test program data as reported in DOT-FR-80-22, "Dual Disc/Tread Braking and Reduced Pressure Braking Evaluation Program."

For each test the instrumented Amcoach was accelerated to a speed five to ten miles higher than the selected test speed. As instrumented Amcoach approached the test zone the locomotive engineer applied the brakes slightly and activated a remote uncoupling device. The brakes were released and the locomotive accelerated away from the test vehicle. As the test vehicle entered the test zone the brakes on the coach were applied and the stopping distance was recorded. Target speeds were 60, 80, 100, and 110 mph. The dual brake test also included speeds of 40 and 120 mph but it was decided from previous experience that the four target speeds provide enough information to determine if the brakes being tested adequately fit the braking profile curve. Initially, the tests were to be run at full service reduction, one-half full service reduction, and emergency service braking rates; however, difficulties in setting brake rates allowed only full service and emergency reductions. Experience in the dual brake program indicates that one-half service braking follows full service braking and that this test only verifies the braking rate.

The test zone was on the Railroad Test Track (RTT) at the Transportation Test Center between stations R14.5 to R25.5. Warning automatic location detector markers were placed 1000 feet and 200 feet before the test zone. ALD markers were placed every 50 feet for the first 1000 feet of the test zone. The track was measured and marked every 100 feet throughout the 11,000 foot test zone. Additional braking tests were run by TTC and New York Air Brake after the attachment fitting of the braking system was rebuilt in January 1981. The original braking system had brake proportioning of 60/40 disc/tread. Because of heat cracking of the single discs the proportioning was changed to 50/50 to reduce thermal load on the disc.

The braking curves for the 60/40 disc/tread tests are shown in Figure 3-1 for full service and in Figure 3-2 for emergency braking.

Temperature and raw speed/distance/time data are given in Table 3-4 for full service braking and Table 3-5 for emergency braking.

To reduce the thermal load carried by the single disc, the ratios were changed to 50/50.

3.4 CONCEPT DEMONSTRATION AND PERFORMANCE

3.4.1 PURPOSE

The concept demonstration was envisioned as an in-depth test of the final truck configuration developed during shakedown testing. This test used the same test procedures used in the shakedown test but included higher speeds.

The performance test sequence included ride quality, component failure and additional repeat testing of the runs in the concept demonstration.

Because of difficulties in configuring the truck during shakedown the concept demonstration tests and performance tests were combined and the scope of testing was reduced.

3.4.2 ACTUAL TEST SEQUENCE

The concept demonstration and performance testing sequences were combined. In addition, only one day of testing on the FAST track was allowed because of the possibility of excessive wear and rail forces that the radial truck test consist might impose upon the

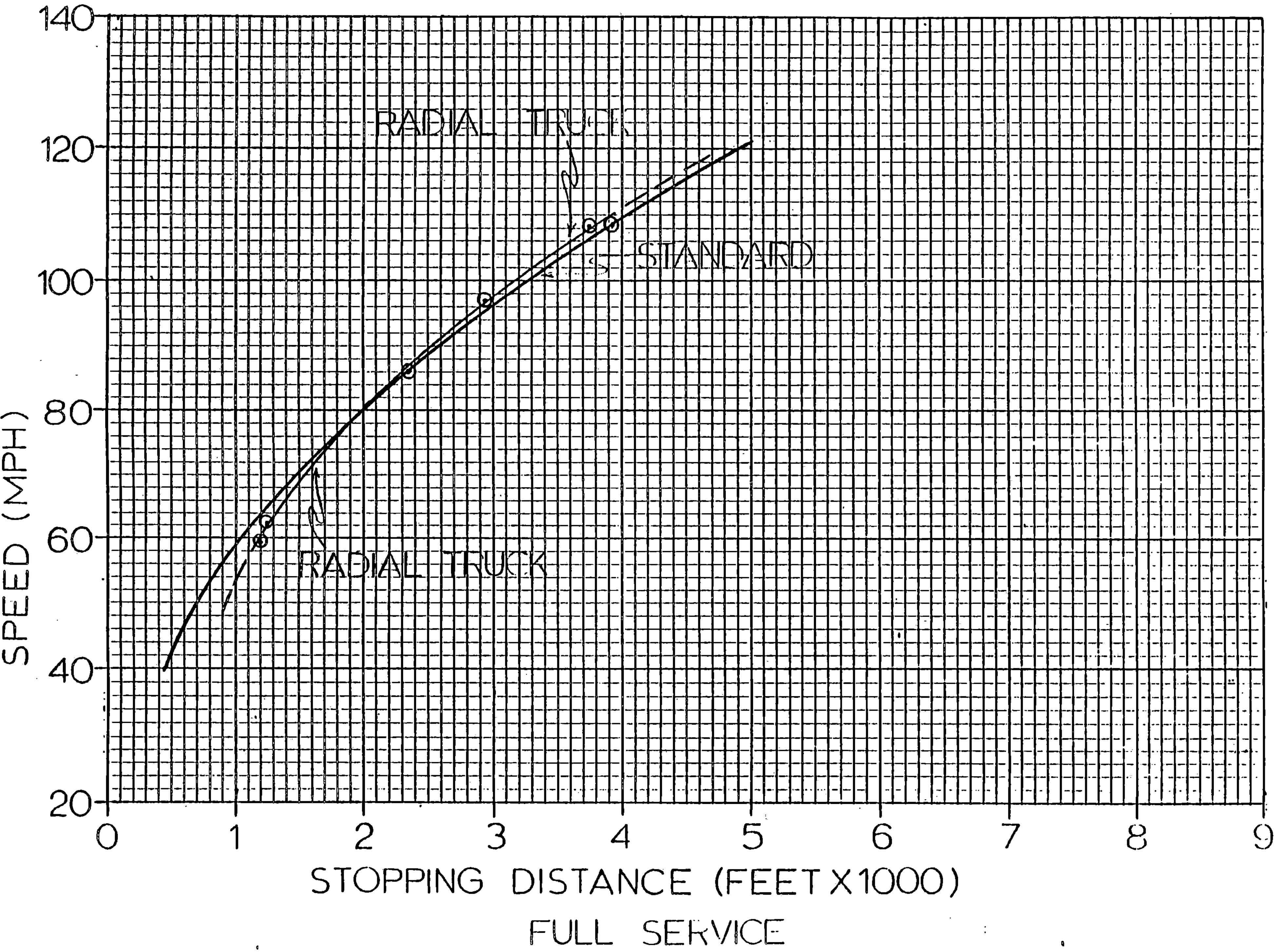

Figure 3-1. Braking Curves for Full Service

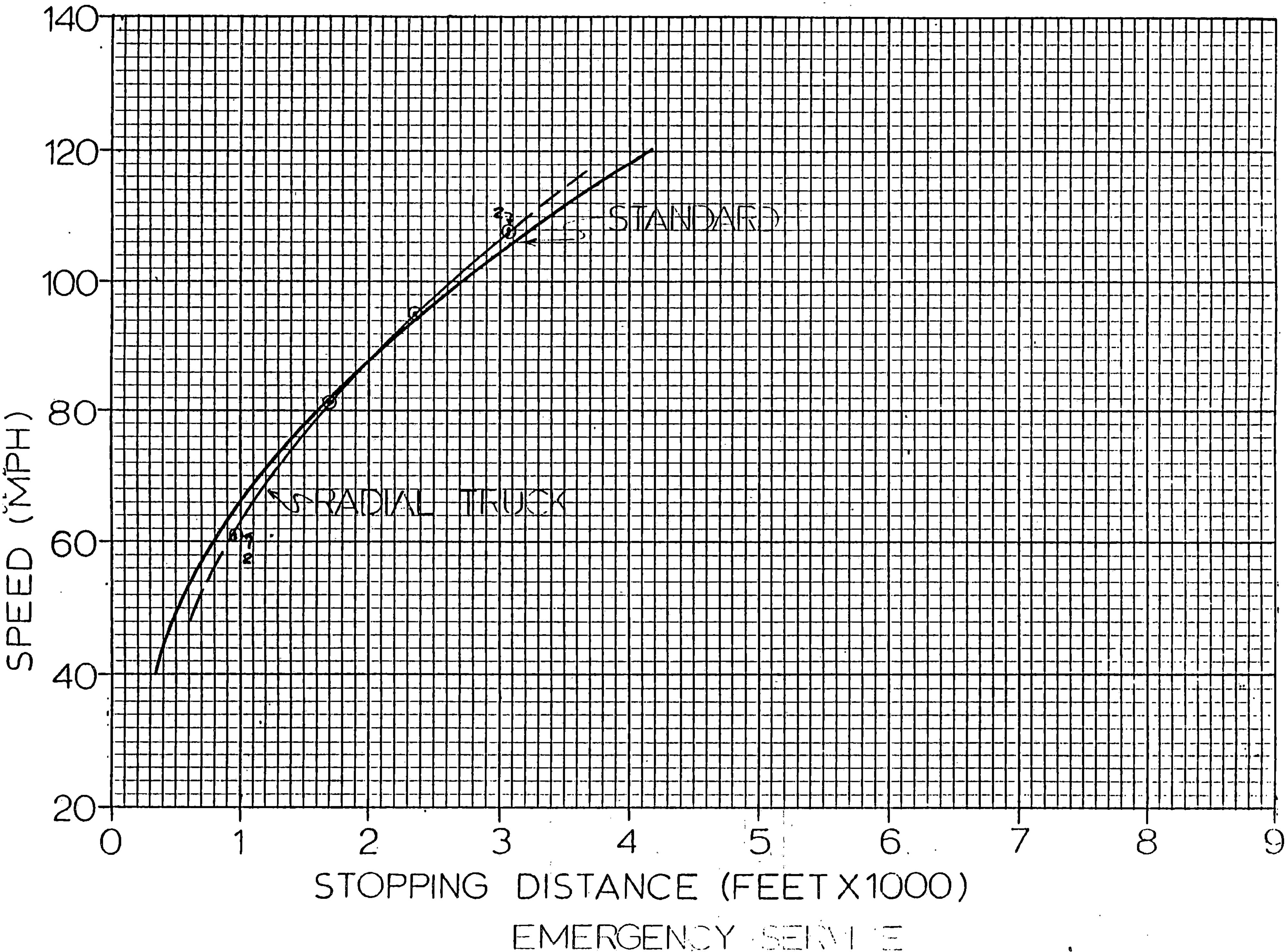

Figure 3-2. Braking Curves for Emergency Service

TABLE 3-4

FULL SERVICE BRAKING DATA*

Car No./Manufacturer: 21091/NYAB
Brake Service: Full Service
Disc/Tread Ratio: 60/40

Run No.		Speed$_1$	Speed$_2$	TLP	TPD$_1$	TPD$_1$	DIST$_0$	DIST$_p$	DIST	D.TEMP	T.TEMP	TIME	DTEMP$_s$	DTEMP$_N$	TEMP$_0$	TTEMP$_0$	TTEMP$_n$	TEMP$_X$
92701		59.5	59.0	111	54	57	254	1450	1196	230	220	25.3	220	200	+20	120	160	-40
	DBCP	635	650	655	660													
	TBCP	430	430	430	430													
92702		108.5	107	109.5	53	56.5	513	4263	3750	610	265	45.8	410	405	+5	220	180	+40
	DBCP	?	655	680	695	700												
	TBCP	435	435	440	430	450												
92703		86	84.5	110	53.5	56.5	993	3346	2353	305	240	36.3	350	240	+90	210	180	+30
	*DBCP	650	670	685	695	695												
	*TBCP	440	455	460	460	460												
92704		97	95.8	112	53.5	58.5	1088	4025	2937	260*	260	39.8	-	480	-	230	190	+40
	DBCP	655	680	695	710	710												
	TBCP	450	450	460	450	460												
92709		62.5	61.5	111	54.5	56.5	822	2074	1252	255	235	25.0	240	240	0	210	170	+40
	DBCP	660	675	680	680													
	TBCP	430	450	450	450													
92710		108.5	107.5	110	56.5	53.5	1089	5020	3931	445	280	471	360	350	10	230	210	+20
	DBCP	660	680	695	710	720												
	TBCP	440	450	460	460	460												

---

*"Zero" wrong

TABLE 3-5

EMERGENCY SERVICE BRAKING DATA*

Car No./Manufacturer: 21091/NYAB
Brake Service: Emergency
Disc/Tread Ratio: 60/40

Run No.		Speed$_1$	Speed$_2$	TLP	TPD$_1$	TPD$_1$	DIST$_0$	DIST$_p$	DIST	D.TEMP	T.TEMP	TIME	DTEMP$_s$	DTEMP$_N$	TEMP$_0$	TTEMP$_0$	TTEMP$_n$	TEMP$_X$
92705		81.5	81	112	ATM	-	1161	2862	1701	380	250	26.9	320	380	-60	220	190	+30
	DBCP	840	850	870	870													
	TBCP	570	570	570														
92706		108	107	111	ATM	-	553	3631	3078	635	310	38.0	480	520	-40	260	230	+30
	DBCP	835	855	880	890	890												
	TBCP	-	-	-	560	560												
92707		61	60	111	ATM	-	325	1277	952	335	230	19.7	290	340	-50	210	190	+20
	DBCP	840	850	860														
	TBCP	570	570	570														
92708		95	94	111	ATM	-	1960	4328	2368	305	270	32.0	290	400	-110	250	205	+45
	DBCP	835	840	860	870	870												
	TBCP	560	560	570	570	570												
92711		60.5	59.5	111	ATM	-	1566	2535	969	370	240	20.1	240	300	-60	210	160	+50
	DBCP	820	830	830														
	TBCP	560	560	560														
92712		107.5	106	109	ATM	-	547	3633	3086	570	280	37.7	410	480	-70	240	220	+20
	DBCP	840	855	875	880	890												
	TBCP	560	560	560	560	560												

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*Units for:
Speed - mph
Dist - feet
Disc Temp - ^{o}F
Tread Temp - ^{o}F
Time - sec.

track. Track speeds were limited to 45 mph for the same reason. Maximum speeds were limited because the available locomotive was not running at rated power during the test time. The actual run sequence was:

Day 1: Performance curving and brake interaction on RTT, speeds to 120 mph CW direction.

Day 2: Finished performance curving and brake interaction on RTT, speeds to 120 mph CCW direction.

Day 3: Started failed airbag tests.

Day 4: Completed failed airbag tests.

Day 5: Curving, braking interaction on FAST.

Day 6: Data reduction.

Day 7: Ride quality 60, 90, 110 mph on RTT. Both directions and consist interaction.

Day 8: Failed crosslink test to 120 mph. Carbody lean test.

No damper failure test was run since dampers were not used on the final configuration.

3.4.3 INSTRUMENTATION

The onboard instrumentation for the concept demonstration test is described in Section 2.2. During the FAST testing, in addition to the onboard instrumentation, an instrumented rail section was used to measure lateral and vertical forces on the high rail. The instrumentation was located in section 7 of FAST in the reverse 5° curve. The wayside instrumented rail site was installed for previous tests by TTC personnel. Details on the gaging and results are shown in a separate report published by TTC.

3.4.4 TEST RESULTS

The results from the concept demonstration are described in Section 4.

3.5 RIDE QUALITY TEST

3.5.1 PURPOSE

The ride quality test was designed to give comparative ride quality data between the Amcoach equipped with GSI radial trucks and a standard Amcoach equipped with Pioneer III trucks.

3.5.2 TEST SEQUENCE

Ride quality measurements were taken as the last part of performance testing. Additional ride quality tests were to be run at 40,000 miles and 80,000 miles of the life test. Because of the instability problems encountered due to premature wheel wear the life test II sequence was terminated after a little more than 21,000 miles on the wheel profiles. The radial truck suspension was altered by installing stiffer longitudinal sandwiches in the primary spring system.

Stability, curving performance, truck frame strains and ride quality testing was conducted by TTC personnel with ENSCO personnel observing. Additional ride quality testing was planned after 20,000 miles of life testing with the stiffer sandwiches. Again wheel wear caused truck instability at 14,346 miles. The radial truck life test was again terminated after a final ride quality test sequence was performed by TTC personnel.

3.5.3 TEST PROCEDURES

Ride quality parameters along with all radial truck test measurements were measured and recorded using the T-7 data acquisition system. The test measurements for ride quality were vertical and lateral carbody accelerations of the radial truck equipped Amcoach, longitudinal motion of the A-end radial truck axles and vertical and lateral carbody accelerations of the reference Amcoach. These measurements along with speed and automatic location detector channels were recorded by the T-7 data system on an analog tape recorder for use by TTC in their ride quality data reduction. The consist was run at speeds of 60, 90 and 110 mph around the RTT clockwise and counterclockwise. The locomotive was then moved to the other end of the consist and coupled to the buffer car. The consist was pulled clockwise and counterclockwise around the RTT at 60, 80 and 110 mph.

3.5.4 RIDE QUALITY DATA ANALYSIS

The ride quality data produced by the radial test car and the reference car was reduced by the TTC computer facility and results analyzed by ENSCO to develop a comparison of the car equipped with the radial truck to the car equipped with standard Pioneer III trucks. The results of the analysis is shown in

TABLE 3-6
COMPARISON OF RADIAL TRUCK EQUIPPED CAR AND CAR EQUIPPED WITH PIONEER III TRUCKS

	Radial Coach Carbody Acceleration A End of 21091		Reference Coach Carbody Acceleration A End of 21018	
Speed	Vertical	Lateral	Vertical	Lateral
60 MPH				
Standard Deviation	.015	.042	.015	.039
95% of value	.030	.074	.030	.064
99% of value	.041	.092	.039	.074
90 MPH				
Standard Deviation	.017	.026	.021	.027
95% of value	.034	.052	.043	.052
99% of value	.048	.070	.058	.069
110 MPH				
Standard Deviation	.023	.029	.0303	.028
95% of value	.046	.058	.059	.055
99% of value	.067	.079	.080	.075

Table 3-6. This table shows the lateral and vertical accelerations from the accelerometers located at the end of Amcoach 21091 (the radial test car) and Amcoach car 21018 (used as the reference car). The data selected for this comparison were data taken from the test run on the TTC at speeds of 60, 90 and 110 miles per hour. The table shows both vertical and lateral acceleration data. The summary of results shown in Table 3-7 give standard deviation of the carbody acceleration levels and 95 and 99 percent values of the normalized data based on removing the mean values. These data show that at 110 mph the vertical ride of the Amcoach car equipped with the radial trucks was slightly better than the other Amcoach, however, at 60 mph the lateral acceleration on the reference Amcoach was lower than from the coach with radial trucks.

3.6 LIFE TEST

3.6.1 PURPOSE AND PLANNED SEQUENCE

Life testing was planned to allow the radial truck to experience as many miles as possible in the shortest length of time.

The radial truck equipped Amcoach and the reference Amcoach were placed in an AEM-7 consist with the intention that they would remain for a total of 100,000 miles including performance testing mileage. The AEM-7 tests involved running around the RTT 16 hours per day. Consist speeds and stop times were set to follow a New York City to Washington northeast corridor profile. Running speeds were determined by an ENSCO designed and built "Profile Simulator" originally used in the life test portion of the Dual Brake Test. Car positions and directions were varied throughout the test.

The truck components were inspected daily and tread profiles taken every 10,000 miles. At 60,000 (20,000 performance and 40,000 life) high speed stability and ride quality were to be measured using a portable data acquisition system. Ride quality and stability tests were run again at 100,000 total miles. This assumed that 20,000 miles of test were run in performance testing; only 3,397 were actually run in performance tests.

3.6.2 ACTUAL LIFE TESTS

The radial truck equipped Amcoach test was stopped the second time at 21,000 (life test) miles because of excessive wheel wear which caused the radial truck to become unstable. No ride quality testing was performed prior to this stopping point in the test, but wheel profiles were taken.

GSI installed stiffer longitudinal primary suspension sandwiches in the radial truck. High speed stability testing with the old wheel profiles and stiffer sandwiches indicated instability at 105 mph. It was estimated that the stiffer sandwiches increased stable speed by 30 mph. Curving, stability, ride quality and truck frame structural data were measured by TTC. A list of test measurements is included in Table 3-7.

The test was planned to run for an additional 20,000 miles followed by run ride quality testing to measure truck performance deterioration; however, truck testing was terminated after 14,346 additional miles due to truck instability caused by wheel wear. Ride quality testing was conducted by TTC just prior to test

TABLE 3-7

DATA CHANNELS FOR STIFF SANDWICH TEST

1. Longitudinal Motion, Frame to Journal, A-Radial Truck Lead Axle, Left
2. Longitudinal Motion, Frame to Journal, A-Radial Truck Lead Axle, Right
3. Longitudinal Motion, Frame to Journal, A-Radial Truck Trailing Axles, Left
4. Longitudinal Motion, Frame to Journal, A-Radial Truck Trailing Axle, Right
5. Longitudinal Motion, Frame to Journal, A-Reference Truck, Lead Axle, Left
6. Longitudinal Motion, Frame to Journal, A-Reference Truck, Lead Axle, Right
7. Longitudinal Motion, Frame to Journal, A-Reference Truck, Trailing Axle, Left
8. Longitudinal Motion, Frame to Journal, A-Reference Truck, Trailing Axle, Right
9. Lateral Motion, Frame to Journal, A-Radial Truck, Lead Axle
10. Lateral Motion, Upper Box to Journal, A-Radial Truck, Lead Axle
11. Lateral Motion, Frame to Journal, A-Radial Truck, Trailing Axle
12. Lateral Motion, Uppper Box to Journal, A-Radial Truck, Trailing Axle

13 Truck Swivel, A-Radial Truck

14. Truck Swivel, B-Radial Truck
15. Truck Swivel, A-Reference Truck
16. Vertical Carbody Acceleration, Radial Coach A-End
17. Lateral Carbody Acceleration, Radial Coach A-End
18. Vertical Carbody Acceleration, Reference Coach A-End
19. Lateral Carbody Acceleration, Reference Coach A-End
20. Longitudinal Force in Crosslink, A-End Radial Coach
21. Longitudinal Force in Crosslink, A-End Radial Coach
22. Radial Truck Frame Strain
23. Radial Truck Frame Strain
24. Radial Truck Frame Strain
25. Radial Truck Frame Strain
26. Speed
27. Distance
28. Automatic Location Detector

termination. One additional life test was run with even stiffer longitudinal primary suspension sandwiches and was terminated after 5,322 miles because test funds were exhausted.

3.7 FATIGUE TEST

It was planned to conduct fatigue tests at GSI facilities. The purpose was to determine the suitability of the truck frame for long term inter-city service.

Since observed strain levels from TTC running tests were very low and running tests in revenue service on a similar design prototype truck were being conducted, it was decided to eliminate fatigue testing from the test program.

Additional strain gage channels were added to the frame on the stiffer sandwich tests to confirm the low strain levels and provide additional data.

4.0 TEST RESULTS

4.1 INTRODUCTION

The results of these tests on the radial trucks indicate that the curving performance was excellent but the stability was unacceptable. The stability was judged to be marginally acceptable during the performance test but it deteriorated rapidly during the life test series. The source of the instability was related to wheel wear. A hollow developed near the center of the wheel tread, increasing the effective conicity (inverse to the wheel taper ratio taking into account the rail head taper at the point of contact) so that the critical speed dropped below the maximum test speed (120 mph). This result indicated that the truck, as configured for the first series of tests, did not have sufficient margin of stability.

The performance and first two life test results show that the radial trucks operated with minimal flange contact. While the flanges on the reference car truck showed considerable flange wear in 10,000 miles of operation, the radial truck wheels showed no flange wear. Other data indicates that the wheels on the radial truck ran consistently with very small angles of attack. These characteristics are major points in favor of the radial concepts but at the same time the good curving performance may have contributed to the tread wear. The TTC track has a very consistent gage so that when combined with the excellent curving performance the wheels ran on only a narrow band of the wheel tread. Therefore, all of the wheel wear was concentrated in one region of the tread. Ideally there would be uniform wear, but in this case it was concentrated to a narrow surface area and a hollow was worn in the tread contour. The trucks allowed some synchronized axle oscillations as the axles are cross tied together and, although these oscillations are relatively small in amplitude when the wheels are new, this appeared to result in wheel tread wear which increased the amplitude of the oscillations to and correspondingly increased tread wear. The mode of the axle oscillation is primarily in pure yaw, causing longitudinal slippage at the contact point on the tread. This oscillating process in too few miles (10-20,000 miles) deteriorates the stability to the point that the maximum operating speed (120 mph) must be reduced to avoid serious hunting conditions which could lead to derailment.

4.2 SHOP TESTS

Since the results of the shop tests are much clearer when presented along with the test description, the shop test results are located in Section 3 at the end of the description of each test.

4.3 CUTAWAY BRAKING TESTS

The results for the cutaway braking test are combined with the description of the test and can be found in Section 3.

4.4 SHAKEDOWN TEST

The results from the shakedown test are combined with results of the other performance tests. These results are described in the following sections.

4.5 TRUCK PERFORMANCE

Since the performance of any truck is a trade off between achieving good curving and maintaining adequate stability over the range of operating speeds for a reasonable number of service miles, the truck performance is presented in three sections. The curving report in Section 4.5.1 describes the results from both the shakedown and the combined concept demonstration/performance test. This section presents the measurements of axle alignment and the angle-of-attack which show how well the truck negotiated the various curves at a wide range of speeds. Section 4.5.2 describes the truck stability and Section 4.7 summarizes the results of the life test. The detailed results of the life test will be reported in a separate report published by TTC.

In addition to these sections, Sections 4.8, 4.9, 4.10, 4.11, and 4.12 describe damage to truck components which occurred during the life test. Detailed reports on the damage will be included in the TTC report of the life test.

4.5.1 CURVE NEGOTIATION

The capability of negotiating curved sections of track was determined by monitoring the alignment between the axles and the angle-of-attack of the wheels.

4.5.1.1 Angular Alignment Results

The following set of figures show results from tests run on FAST (3°, 4°, and 5°) the Balloon Loop (5° and 7.5° curves) and the TDT (1-1/2° curve). Figure 4-1 shows data for the axle alignment in relation to the truck frame, and axle-to-axle angles in relation to each other. These data were obtained by analysis of the radial truck from repeated tests on 3, 4, 5 and 7.5 degree curves. In this figure the alignment results are plotted against the operating speed.

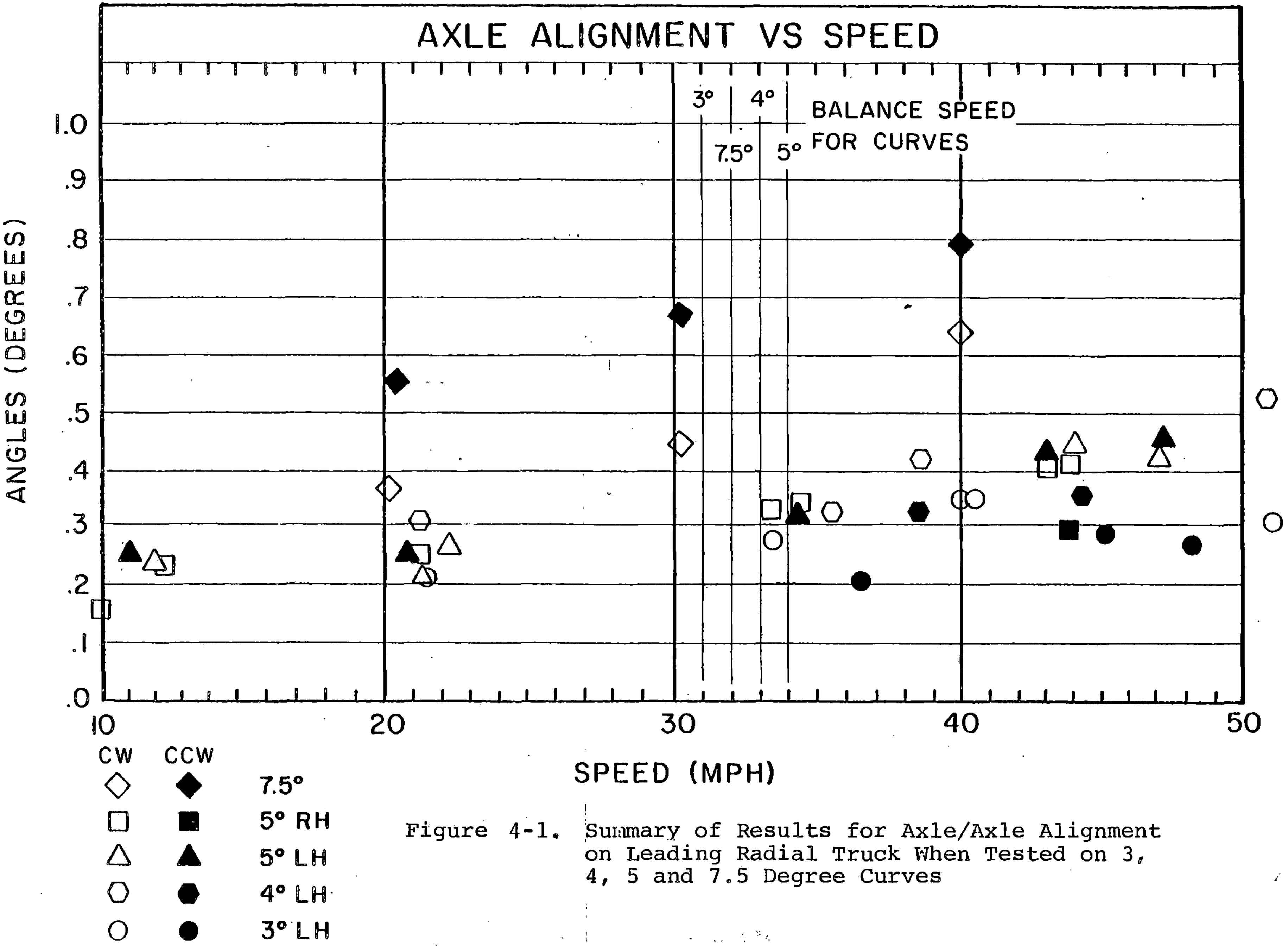


Figure 4-1. Summary of Results for Axle/Axle Alignment on Leading Radial Truck When Tested on 3, 4, 5 and 7.5 Degree Curves

Figure 4-2 shows the same axle to axle angle data as in Figure 4-1 except the alignment data have been plotted against the cant deficiency which corresponds to the operating speed for each particular curve.

The axle alignment data from the leading radial truck is presented in another form in Figure 4-3 and 4-4. Perfect radial alignment exists if each of the axles is aligned perpendicular to the track at the wheel location.

Based on the geometry data for each of the TTC curves the ideal axle alignments are shown by Figure 4-5 and the associated Table 4-1. In Figure 4-3 and 4-4 the alignment achieved by the radial truck has been compared to the ideal angles as shown in Table 4-1. These graphs show the axle to axle angular alignment plotted as a percentage of the ideal angle for the particular test curve.

The same set of figures show angular alignment for the trailing radial truck and are shown in Figures 4-6, 4-7, 4-8, and 4-9. The axle to axle alignment data plotted against cant deficiency which corresponds to Figure 4-2 is shown in Figure 4-7 and the set of alignment figures showing the alignment of the axles on the trailing truck plotted as a percentage of the ideal radial alignments are shown in Figure 4-8 and 4-9.

4.5.1.2 Alignment Results

In this report all angular alignment data are shown as having a positive sign. The actual angular alignment test data have both positive and negative values since the data were obtained from tests run in both right and left hand curves and for both clockwise and counterclockwise operations. In all observed cases (except for data from the 1.5 degree TDT curve), the angular alignment of both the leading and trailing axle was in the proper direction for a well behaved radial truck (see Figure 4-10 and 4-11). Therefore, all of the data has been converted to have a positive sign so that the results can be combined and compared.

The angular alignment data show that at 10 mph the alignment of the leading and trailing axle relative to the truck frame was approximately 0.15 degree for the 3, 4 and 5 degree curves. Both the leading and trailing axles rotated to become more radial as the speed increased. The angle of the leading axle (relative to

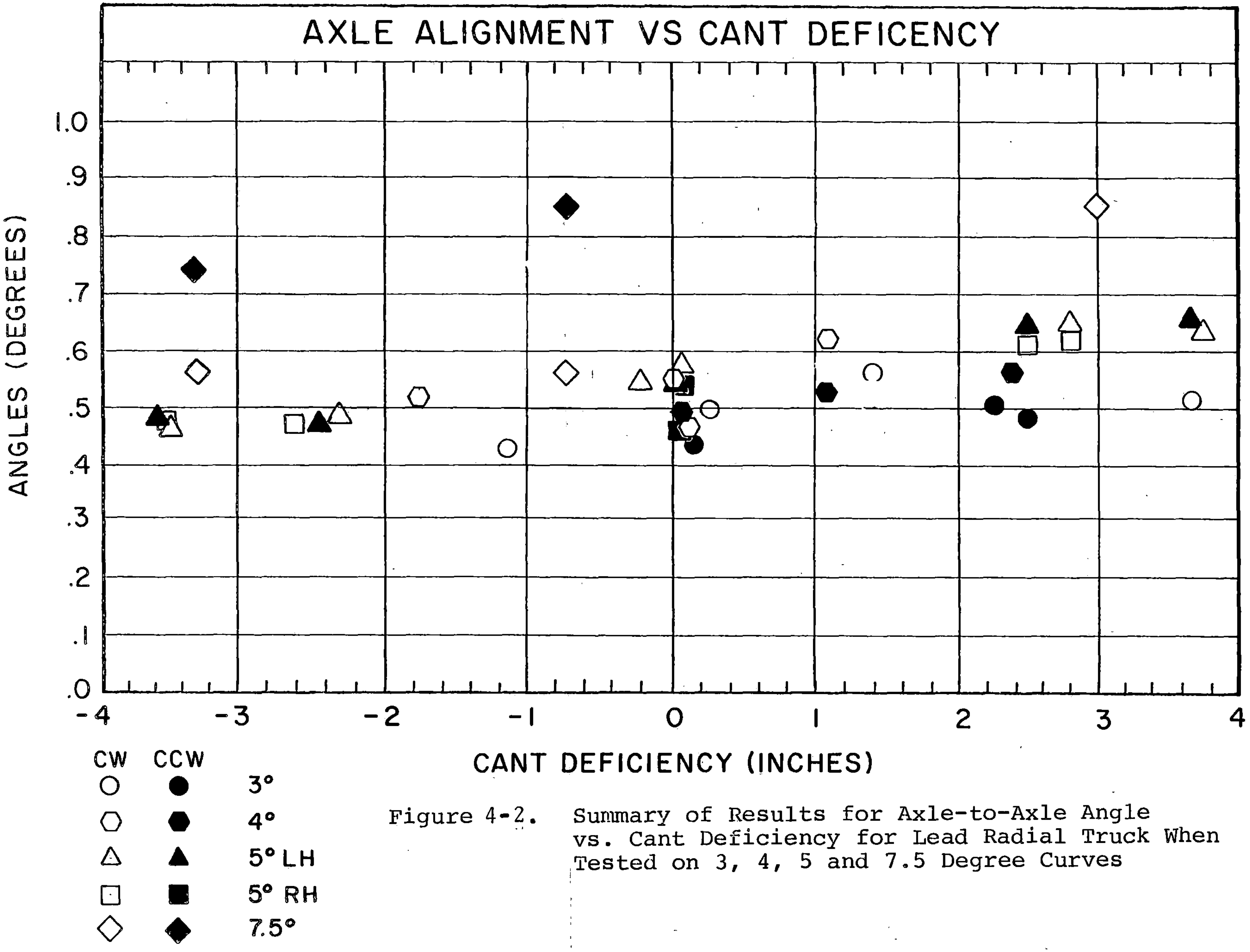


Figure 4-2. Summary of Results for Axle-to-Axle Angle vs. Cant Deficiency for Lead Radial Truck When Tested on 3, 4, 5 and 7.5 Degree Curves

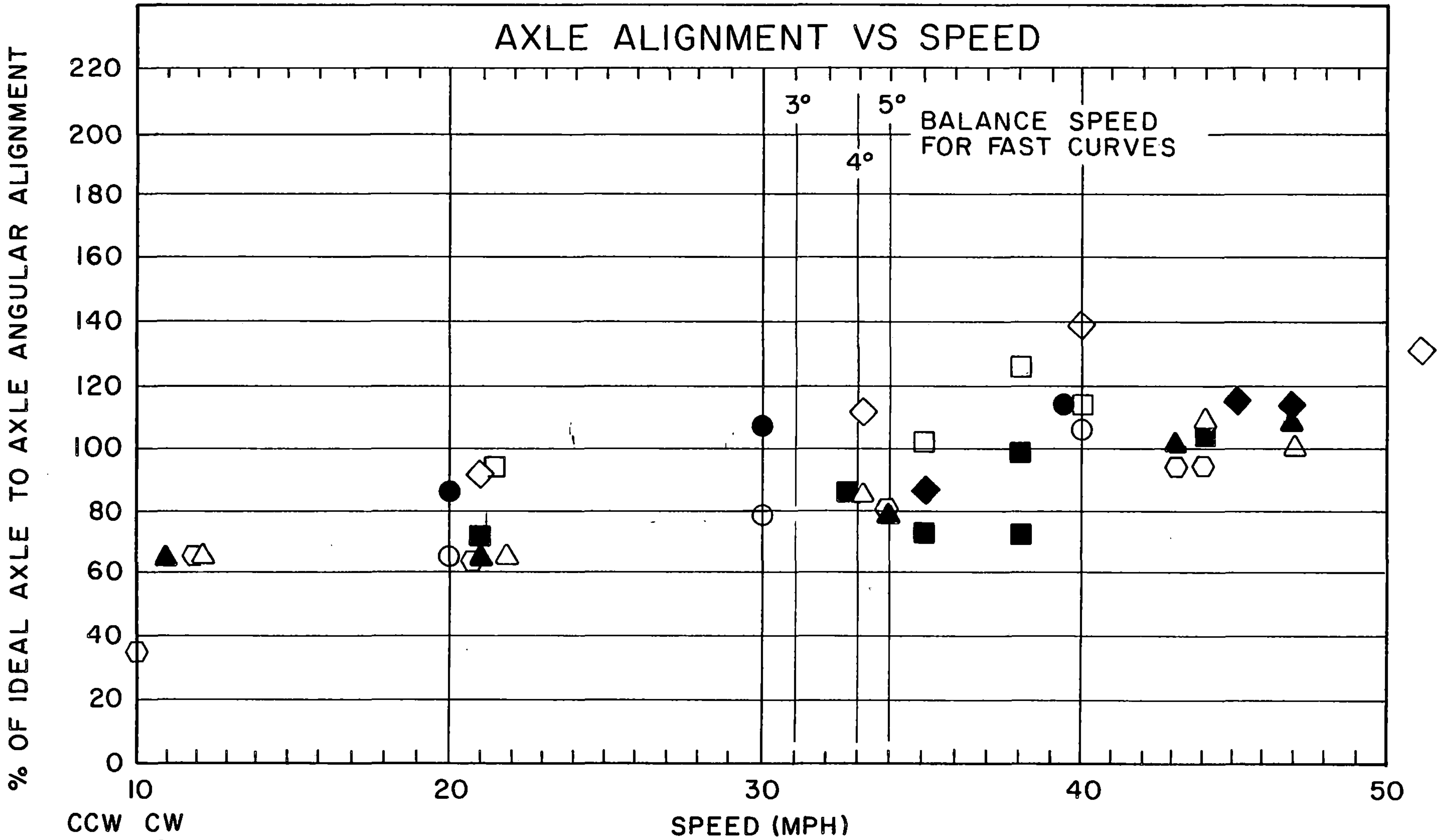


Figure 4-3. Summary Results of Axle Alignment of Leading Truck on Radial Truck Car for Tests on 3, 4, 5 and 7.5 Degree Curves

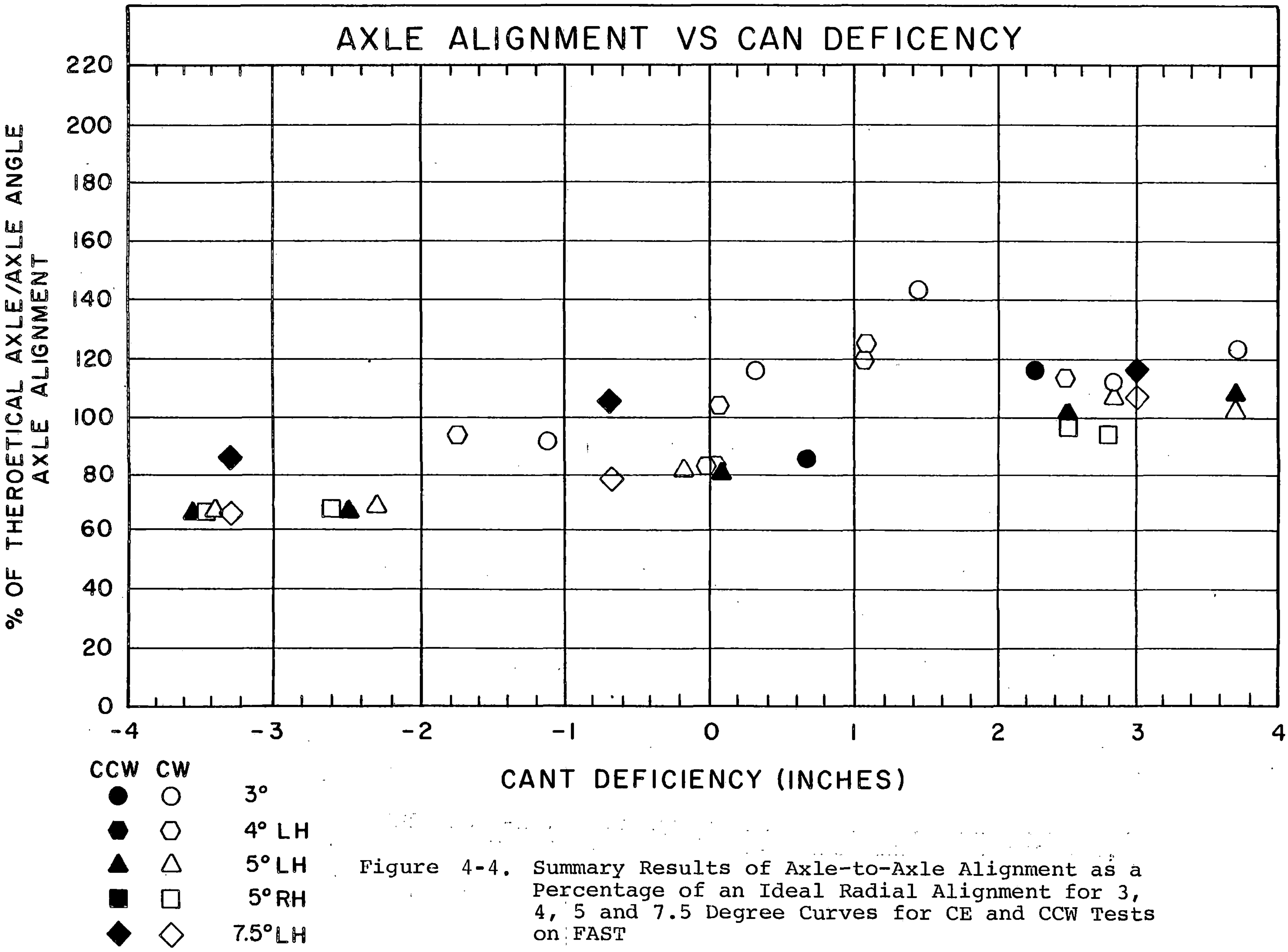


Figure 4-4. Summary Results of Axle-to-Axle Alignment as a Percentage of an Ideal Radial Alignment for 3, 4, 5 and 7.5 Degree Curves for CE and CCW Tests on FAST

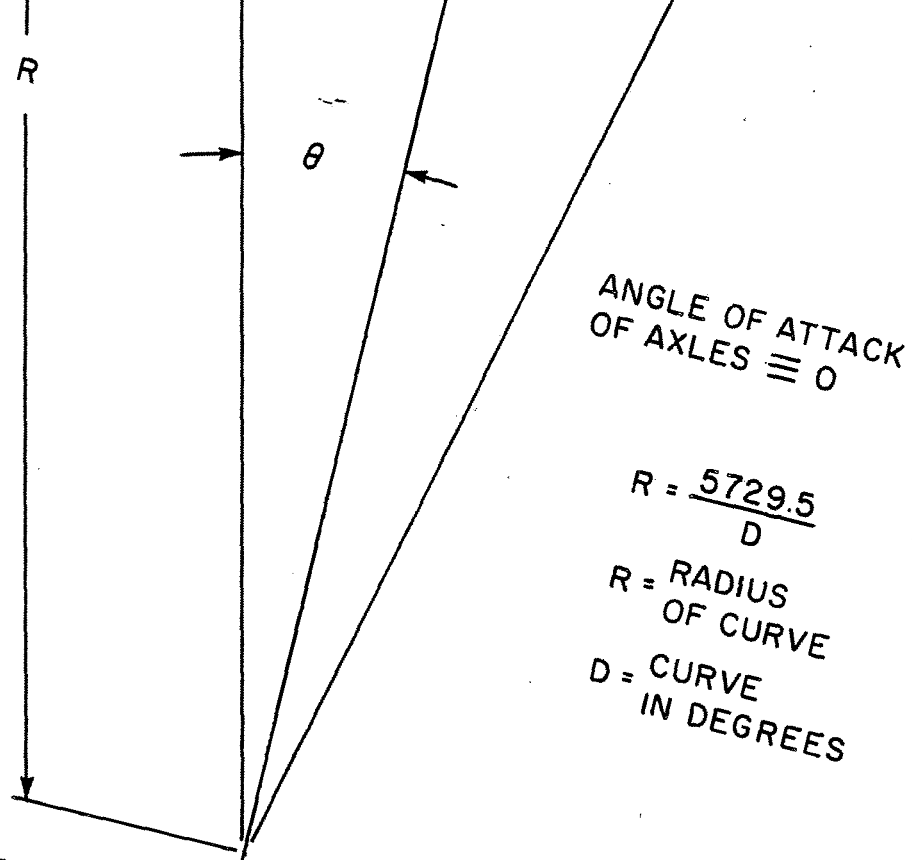
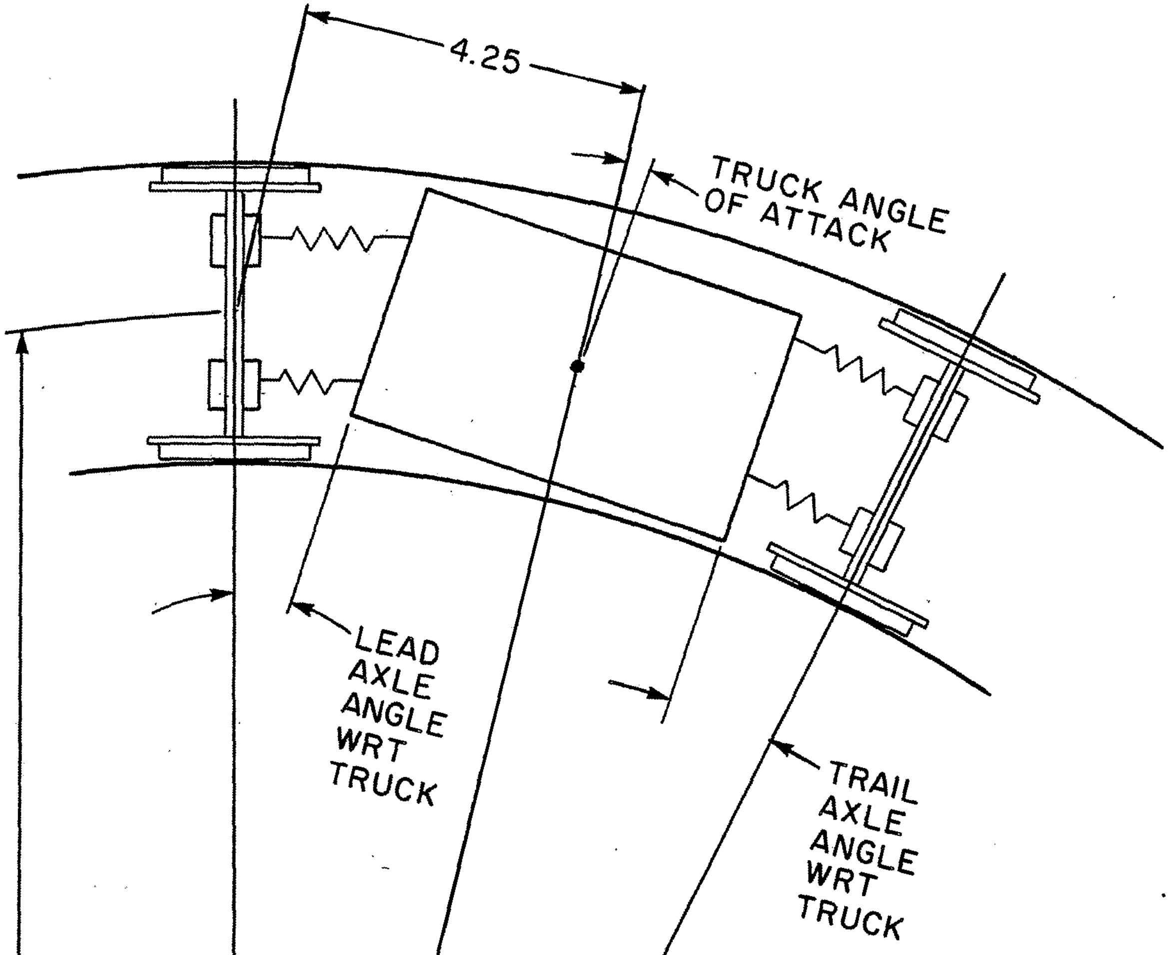


Figure 4-5. Ideal Axle Alignment


4.25
TRUCK ANGLE OF ATTACK
LEAD AXLE ANGLE WRT TRUCK
TRAIL AXLE ANGLE WRT TRUCK

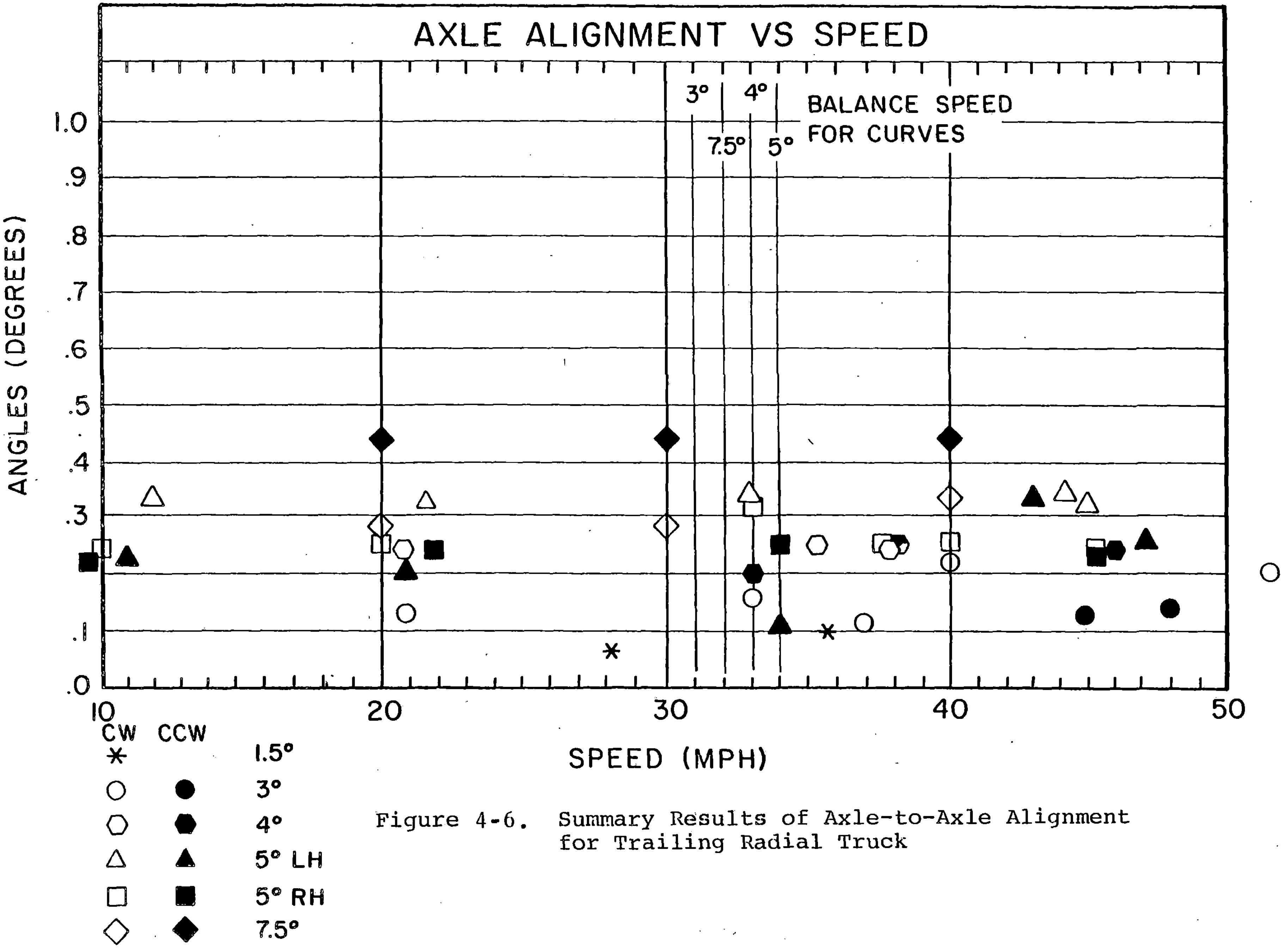


Figure 4-6. Summary Results of Axle-to-Axle Alignment for Trailing Radial Truck

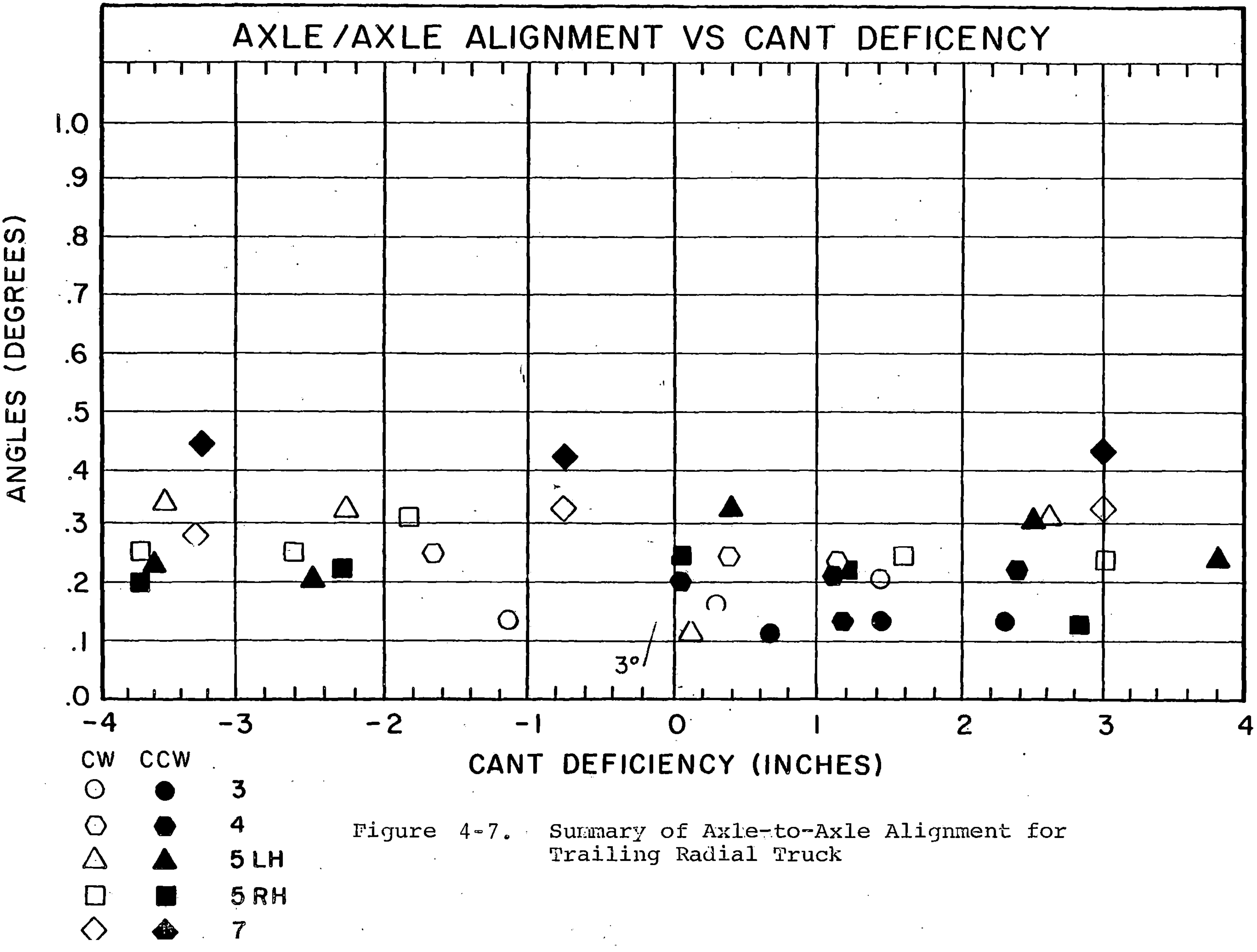


Figure 4-7. Summary of Axle-to-Axle Alignment for Trailing Radial Truck

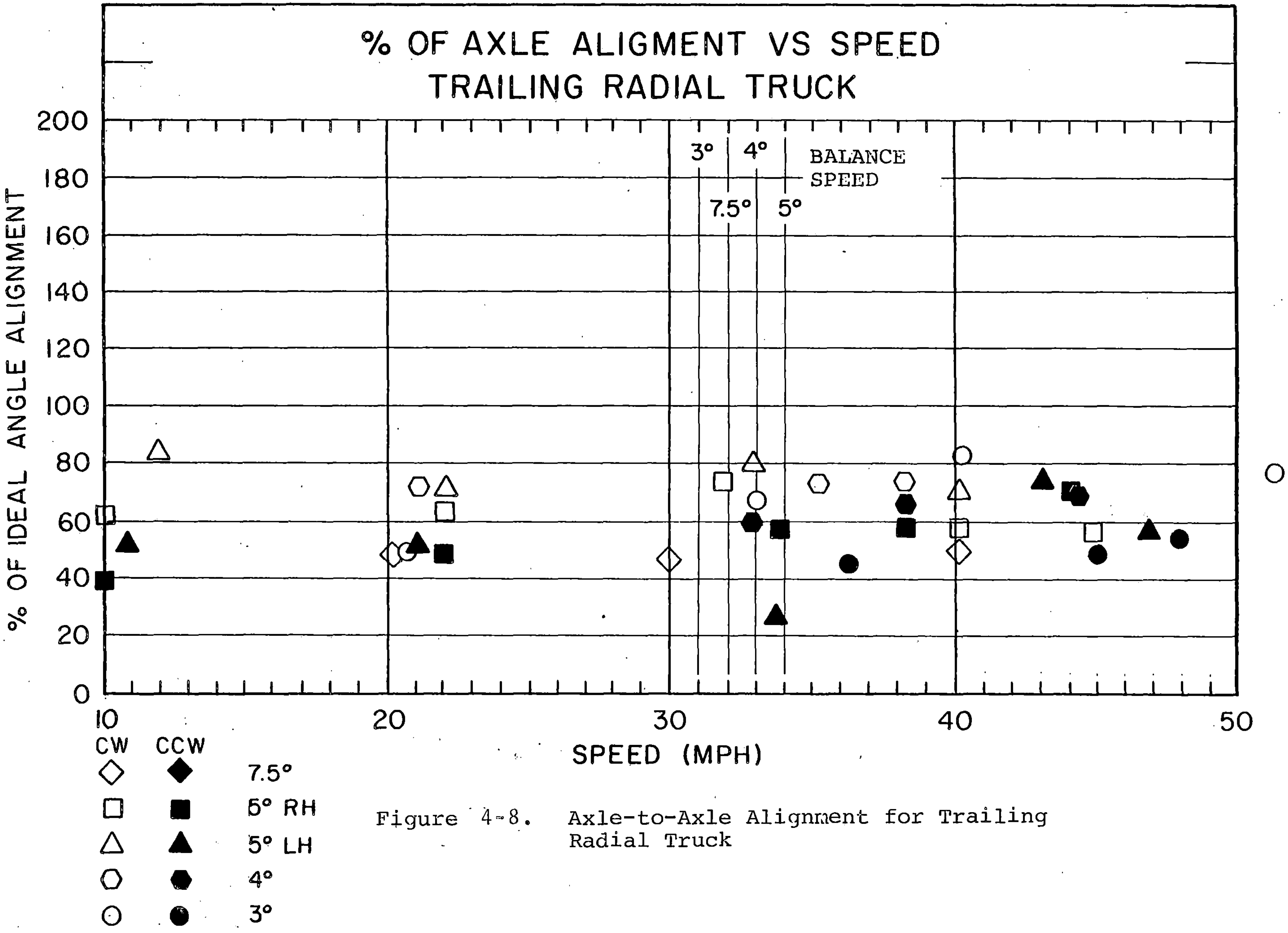


Figure 4-8. Axle-to-Axle Alignment for Trailing Radial Truck

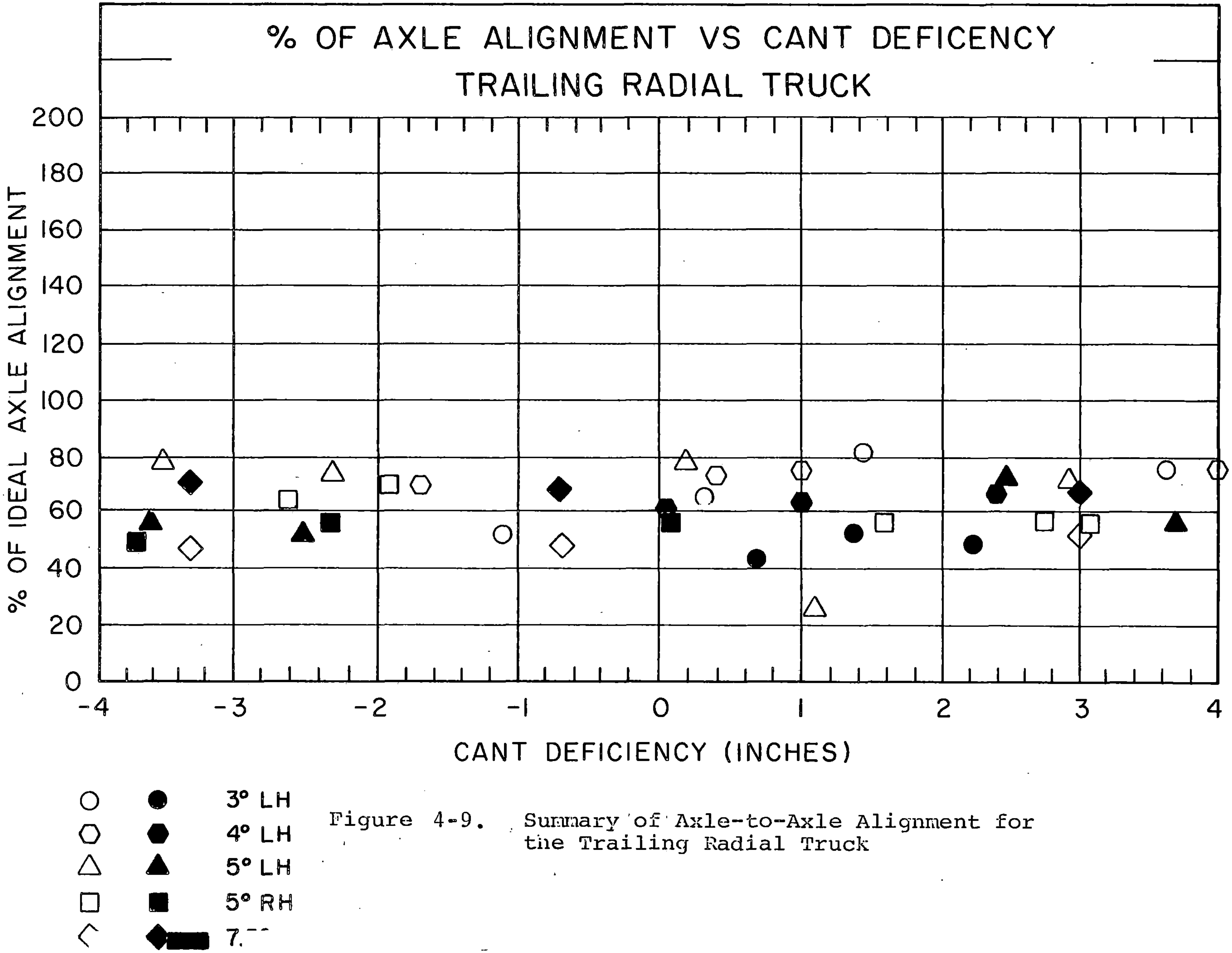


Figure 4-9. Summary of Axle-to-Axle Alignment for the Trailing Radial Truck

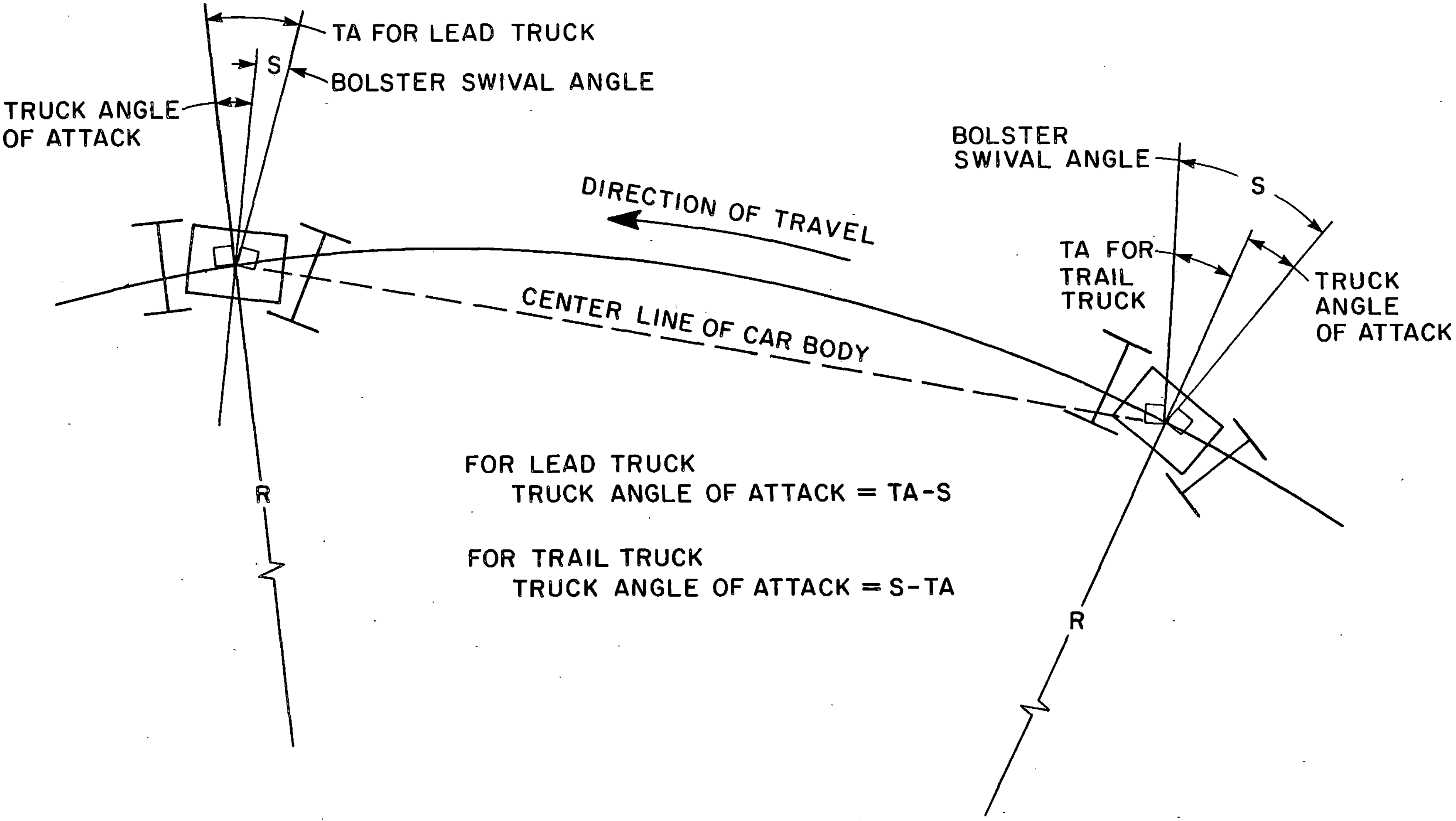
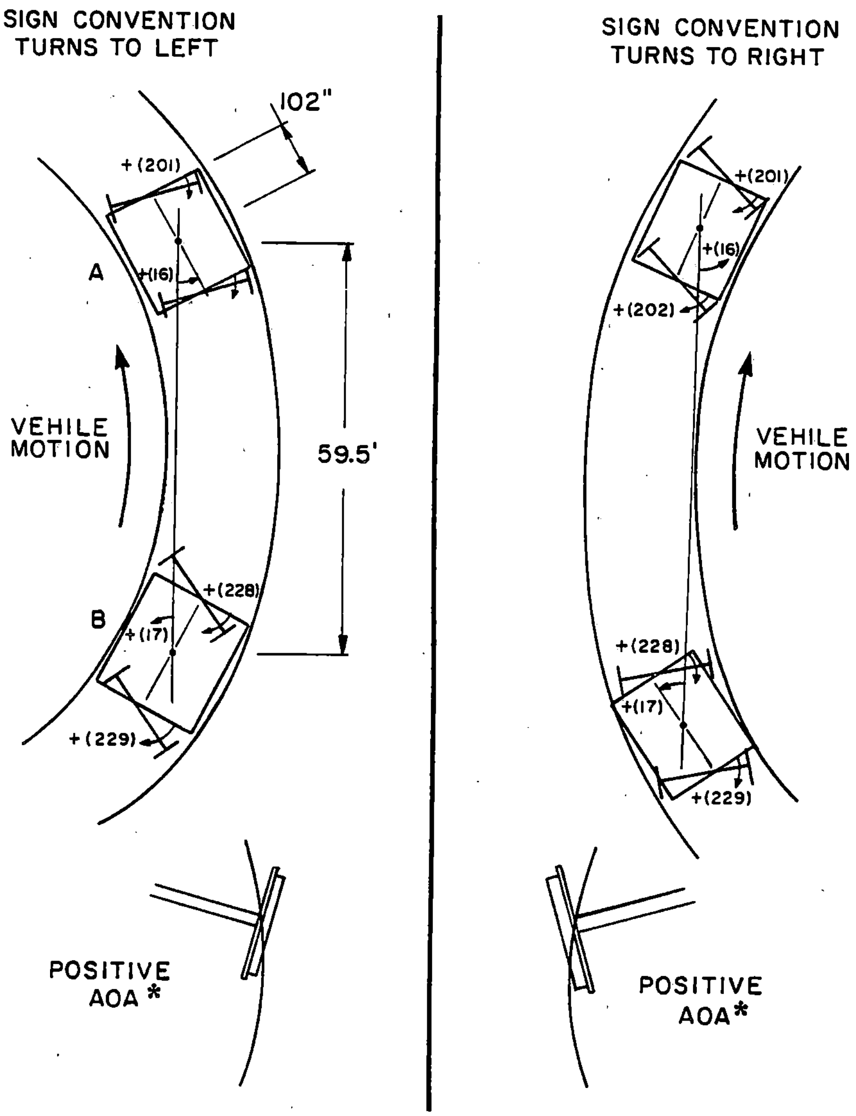


Figure 4-10. Geometry for Calculating Truck Angle-of-Attack from Bolster Swival Angle and Curvature



$$\left.\begin{array}{l}\text{WHEEL GAGE = 4' 5 1/4" + 2" = 55.25"}\\ \text{TRACK GAGE = 4' 5 5/8" = 56.62"}\end{array}\right\rangle \quad \text{1.37" FREE PLAY}$$

MAXIMUM TRUCK ANGLE ON TANGENT : $\frac{1.37''}{102''+10''} = 0.70^\circ$

FOR 5° CURVE, NOMINAL ANGLE = $1/2 \ \frac{59.5}{100} \times 5 = 1.49^\circ$

RANGE OF ANGLE = 1.49° ± 0.7° = 0.79° → 2.19°

NOTE: Numbers in parentheses are instrumentation channels.

*Angles of attack are (+) when attacking rail.

Figure 4-11. Range of Wheel Angle-of-Attack

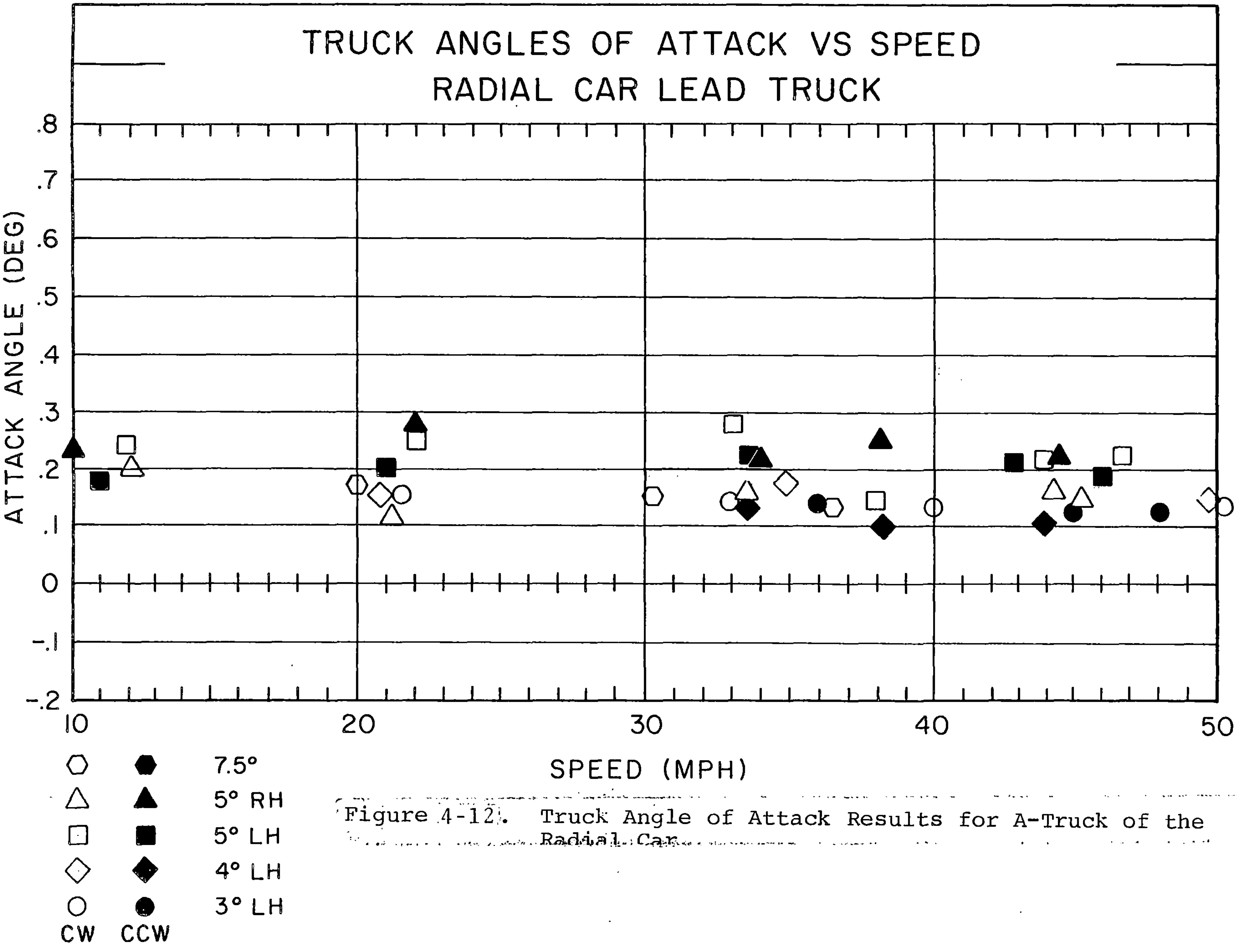


Figure 4-12. Truck Angle of Attack Results for A-Truck of the Radial Car.

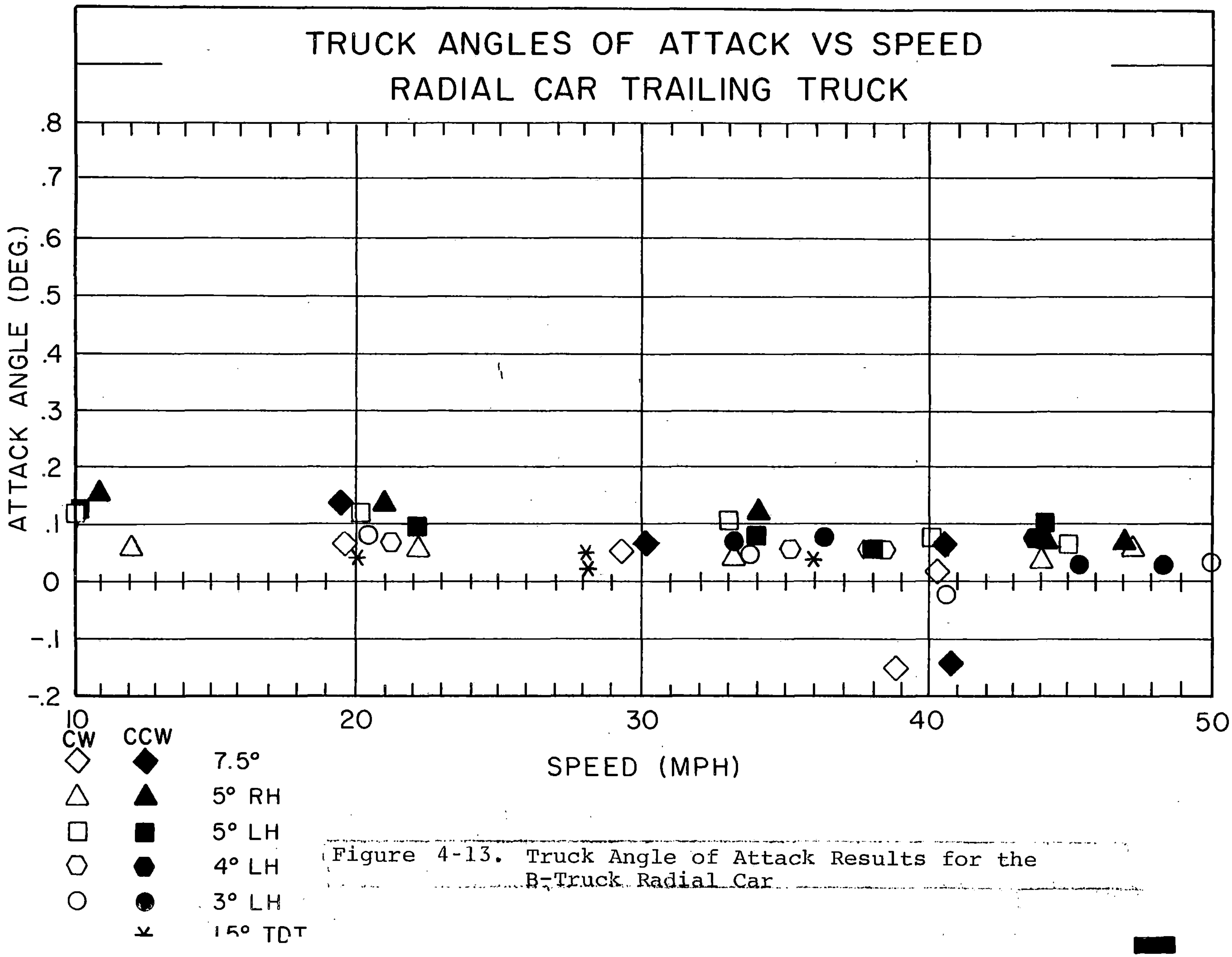


Figure 4-13. Truck Angle of Attack Results for the B-Truck Radial Car

[redacted]

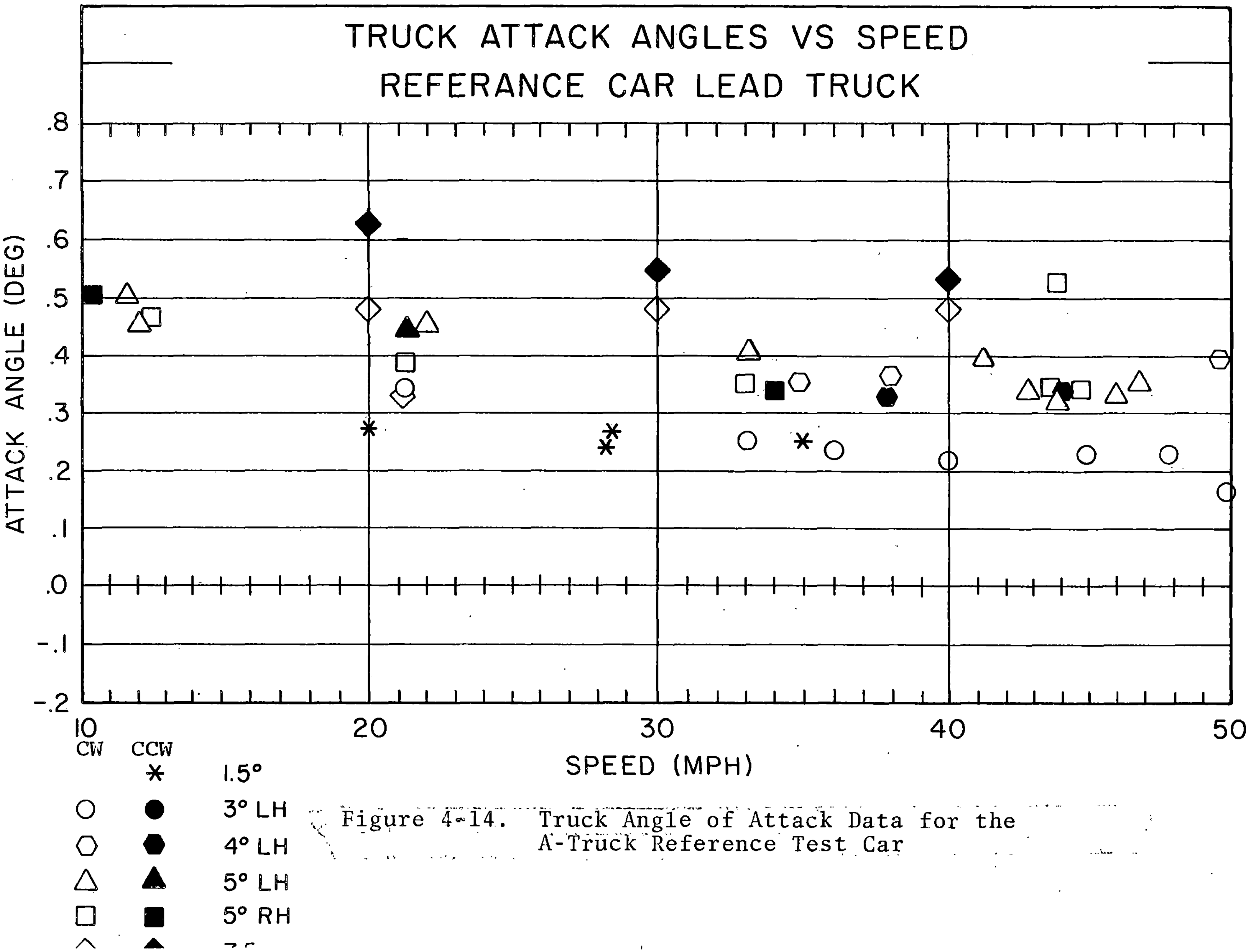


Figure 4-14. Truck Angle of Attack Data for the A-Truck Reference Test Car

TABLE 4-1
IDEAL AXLE ALIGNMENT DATA

DEGREE OF CURVE	RADIUS (FOOT)	AXLE/AXLE ANGLE FOR IDEAL RADIAL ALIGNMENT IN DEGREES
0° 50'	6876	.071
1° 00'	3820	.128
3° 00'	1910	.255
4° 00'	1432	.340
5° 30'	1146	.425
7° 30'	764	.638

the truck frame) increased to 0.25 degree at the higher speeds (45-50 mph) while the rear axle (relative to the truck frame) rotated to approximately 0.18 degree at the same high speed operation. These data show that the axle alignment corresponded with the curves and in each case increased with the speed. The results show that at the respective balance speeds the axle to axle alignment was related to the curvature. The angle between axles at the balance speeds was as follows:

Degree of Curve	Balance Speed	Axle/axle Angle
3°	31	0.25
4°	33	0.31
5°	34	0.37

The largest variation from trends on the axle to axle and axle to truck frame alignment data was observed in the results for the 5 degree right hand curve. The data from this curve appear to be consistently lower than the angles measured for the other similar curved sections. The brush chart records show that this trend was caused by a local perturbation. The truck tended to react to a deviation in this particular curve so that the data from the truck swival and axle angular alignments changed for a short section of the curve body.

The angular alignment data shows that at balance speeds the trucks negotiated the curves with a high percentage of theoretical radial alignment for all curves from the 1.5 degree to the 7.5 degree curve. The alignment was generally proportional to curvature and the ratio of actual radial alignment to ideal radial alignment did not vary significantly with curvature.

The alignment data shows a consistant trend when the axle-to-axle alignment data are graphed as a function of the cant deficiency as is shown in Figure 4-4.

As previously described, Figures 4-3 and 4-4 show the alignment data for the A-truck (lead) plotted as the percentage of the ideal radial alignment. Figure 4-3 shows the percentage of radial alignment vs speed and Figure 4-4 shows the percentages plotted vs cant deficiency. These plots clearly show that the truck alignment approached the ideal alignment at the higher speeds in an overbalance condition. This is ideal since the best station to station trip time would most likely be run in overbalance on every curve possible.

The test results for the B-truck (trailing) of the radial test car are shown in Figures 4-6 through 4-7.

The axle-to-axle angular alignment data from the B-truck have been compared to the ideal alignment data for each of the test curves as was the data from the A-truck and the results were plotted against speed and cant deficiency. The percentage of ideal axle alignment vs speed is shown in Figure 4-8 and the percentage plotted against cant deficiency is shown in Figure 4-9. The tests showed that a radial truck is very sensitive to axle to frame and axle to axle alignment.

The B-truck data show that the actual alignment expressed as the percentage of ideal alignment remained constant as the speed was increased. Since the results were independent with speed the results were also independent of the cant deficiency. All of the percentage results fell between 40 and 80 percent except for one data point. The data indicate that the axle angular alignment was more nearly radial for the smaller degree curves and was not as completely radial for the 5 and 7.5 degree curves.

4.5.1.3 Truck Angle-of-Attack

The angle-of-attack for both the A- and B-trucks of the radial test car and the A-truck of the reference test car were computed from the truck swival data and the curving geometry as shown in Figure 4-10. If the truck negotiates the curved section with a zero angle of attack, the truck is aligned perpendicular to the radial line passing through the center of the truck. In this condition, the swivel angle will agree with angle TA in Figure 4-10. The difference between angle TA and the swival angle gives the truck angle of attack. The major error in this assumption occurs when the truck is not actually centered on the track gage. The error resulting from this assumption turns out to be very small because the angle is created by the carbody length. When the truck has an angle-of-attack, the maximum error is further reduced because the truck must be closer to the center of the track because of the truck angle.

The truck angle of attack results are shown in Figures 4-12, 4-13, and 4-14. Figure 4-12 shows the attack angle results for the A-truck of the radial car and Figure 4-14 shows similar angle-of-attack data for the A-truck of the reference test car.

The results for the truck angle of attack for the A- and B-truck radial trucks were quite similar. In both cases, the angle of attack decreased with increased speeds. All of the data are closely grouped about a common trend line. The only major difference in the A- and B-truck is that the A-truck attack angles were approximately 0.1 degree greater than the B-truck data. The truck angle-of-attack data for the lead truck of the reference car shown in Figure 4-14 has the same general trend but in this case the results from the different curves are significantly different. The results show a definite order in relationships based on the degree of curvature. The truck angles-of-attack for the 7.5 degree balloon loop curve ran between 0.5 and 0.6 degree while the attack angle for the 1.5 degree curves was less than 0.3 degree. In addition, the reference truck angle-of-attack changed by approximately 0.1 degree. The results show that the truck angle for the reference truck was much larger and more dependent on the operating speeds.

4.5.1.4 Wheel Attack Angles

For the radial trucks, the wheel angle-of-attack is a combination of three factors. The truck angle-of-attack, the axle alignment relative to the truck and the heading of the rail. The truck angle-of-attack and axle angles are both relative to the center of the truck, therefore, the angle of the wheel relative to the rail (wheel angle-of-attack) at the point of contact between the wheel and rail must include the change in heading of the rail for the distance of half the truck length (from the center of the truck to the center of one axle). As with the angular alignment data, the attack angle data have always been displayed as having a positive sign. The attack angles were positive when the wheel was attacking the right rail and negative for attacking the left rail. The angle-of-attack data shown in the following charts and tables was obtained by summing the truck attack data and the angular alignment data as illustrated in Figure 4-10.

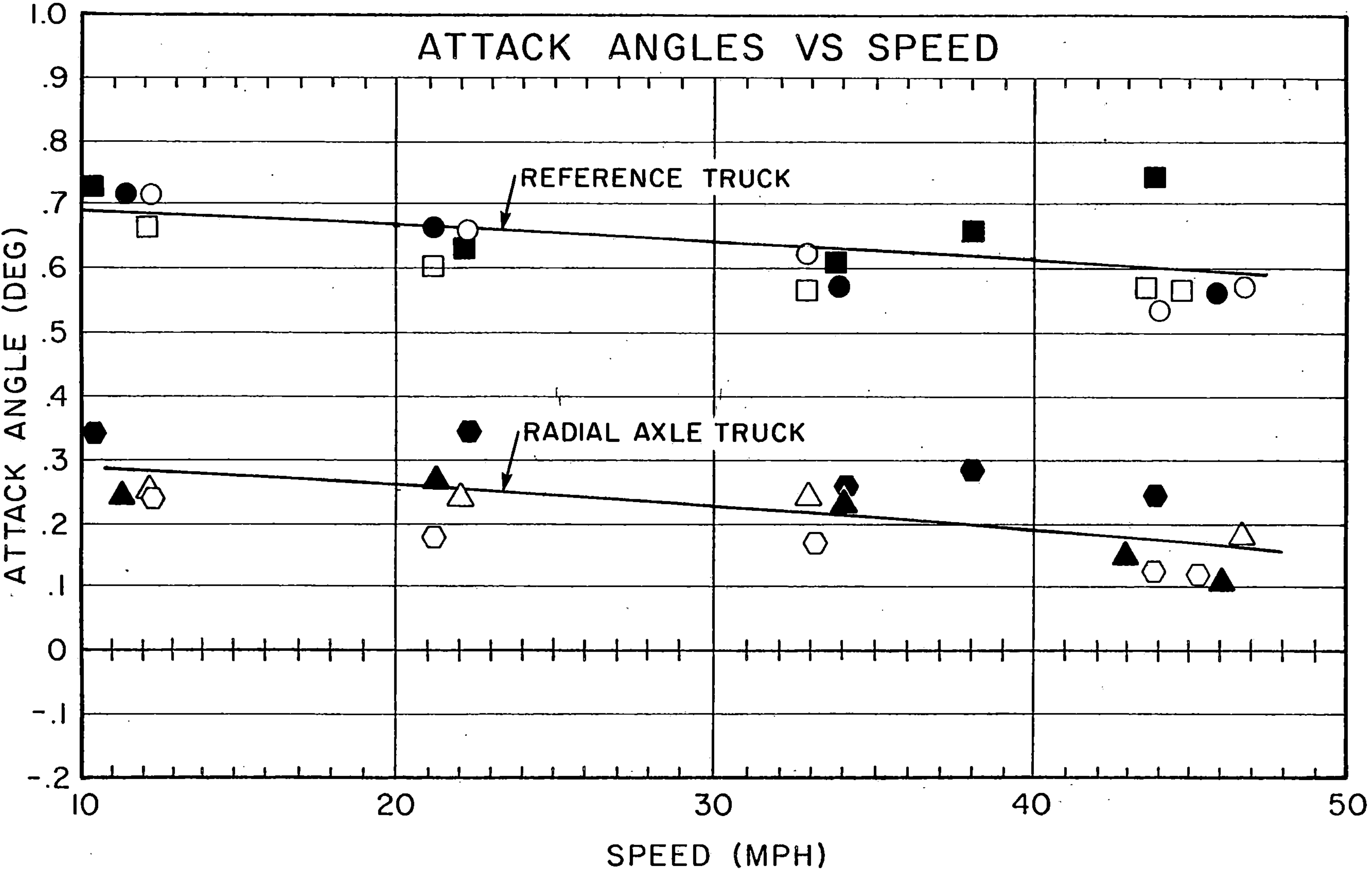
4.5.1.5 Angle-of-Attack Detailed Results

The following figures show summaries of the angle-of-attack data. For these figures, the detailed results from the FAST and Balloon Loop tests have been combined to illustrate the truck performance. The four summary figures, Figure 4-15, 4-16, 4-17, and 4-18, show the results from the 5 degree right hand and 5 degree left hand FAST curves. These data show the variation in test results from similar right and left hand curves negotiated at different speeds and in both clockwise and counterclockwise operations. Figures 4-15 and 4-16 show results from both the radial truck and the reference car truck. The data from the leading axle of the radial and reference car for 3, 4, 5 and 7.5 degree curves are all shown in Figure 4-19. Figure 4-16 shows a similar summary of the test results showing the truck angle of attack vs. speed.

Figure 4-15 shows that the radial truck operated with a substantially lower angle-of-attack than the reference truck on both 5 degree left-hand and 5 degree right-hand curves in both CW and CCW tests. Both the radial and reference trucks angles-of-attack decreased slightly with increasing speed. Both show some scatter but the maximum deviation from the trend appears to be less than 0.1 degree. At low speeds (10 miles per hour) the lead wheel of the reference truck operated with approximately 0.7 degrees of attack angle while the radial truck negotiated the same 5 degree curve with a 0.3 degree angle-of-attack. At the higher speeds (45 mph) the angle-of-attack of the radial truck decreased to approximately 0.2 degrees. The reference car leading wheel angle-of-attack was 0.6 degrees.

Figure 4-16 and 4-17 shows similar data to Figure 4-15. In these figures, the data from the CCW and CW operations are presented. The figures show that the radial truck displays minor differences in angle-of-attack for the clockwise and counterclockwise tests. To account for this difference, the strip chart of the data was reviewed. The difference developed because of a local distrubance which repeatedly occurred as the truck negotiated the particular section of the curve used for this analysis.

Figure 4-18 shows a least squares fit of the angle-of-attack data for the leading and trailing wheels of the leading truck of each car for a 5 degree curve. This curve set shows that the leading and trailing axle of the radial truck ran at the same angle-of-attack while the angle-of-attack for the lead and trailing axle of the reference truck car is very different. The lead wheels have an angle-of-attack of nearly 0.7 degree while the trailing axle has an angle of nearly 0.25 degree. This difference in the reference truck is caused by the change in the heading of the curved section of track over the wheel base of the truck since the reference truck attack angle is fixed by the rigid primary



REF CW	REF CCW	RAD CW	RAD CCW	
○	●	△	▲	5 DEGREE RH SECTION 7
□	■	⬡	⬢	5 DEGREE LH SECTION 3

Figure 4-15. Angle-of-Attack Results from the Leading Axle of the Radial and Reference Truck from 5 Degree Right and 5 Degree Left Hand FAST Curves

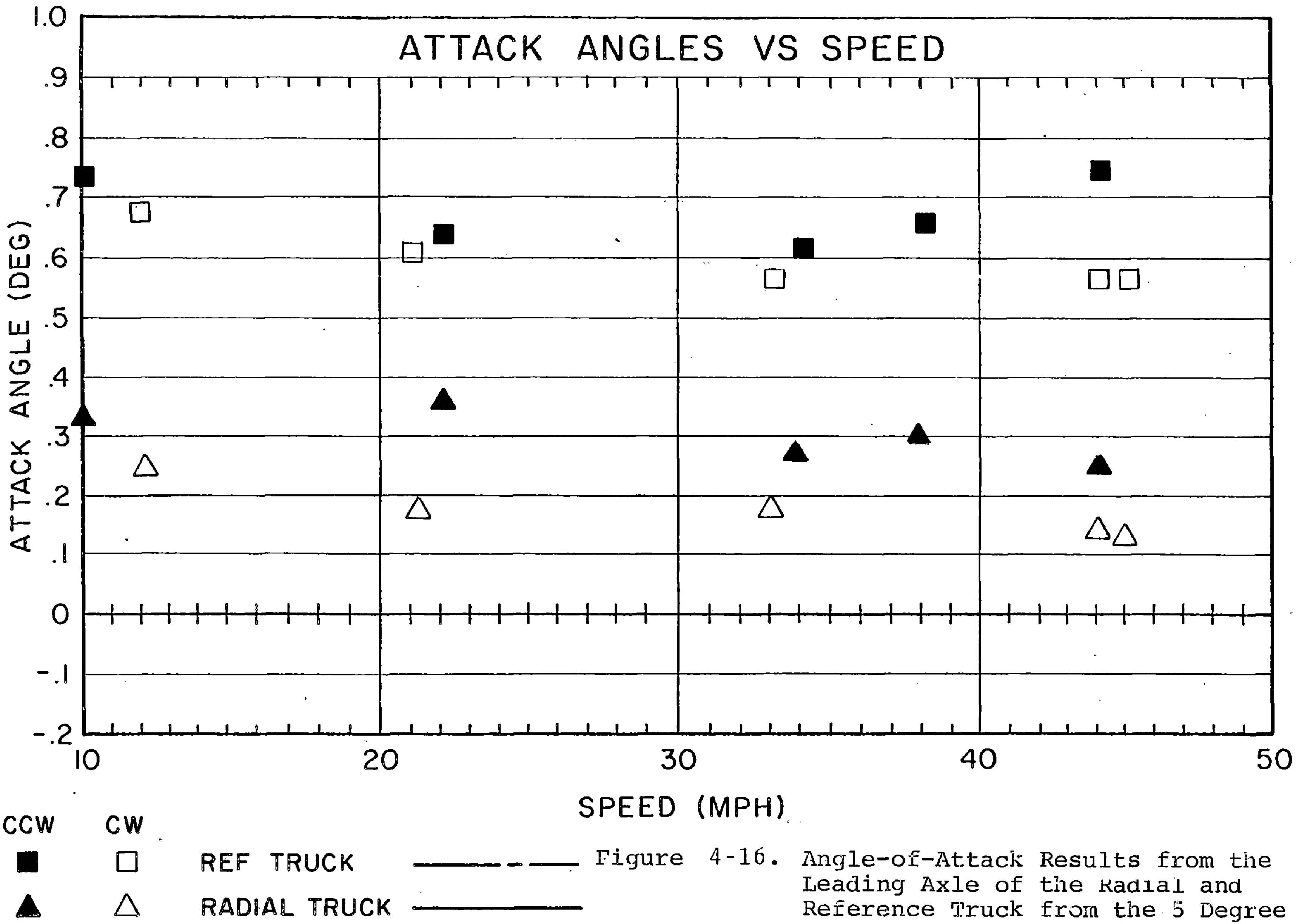


Figure 4-16. Angle-of-Attack Results from the Leading Axle of the Radial and Reference Truck from the 5 Degree Right Hand and 5 Degree Left Hand FAST Curves

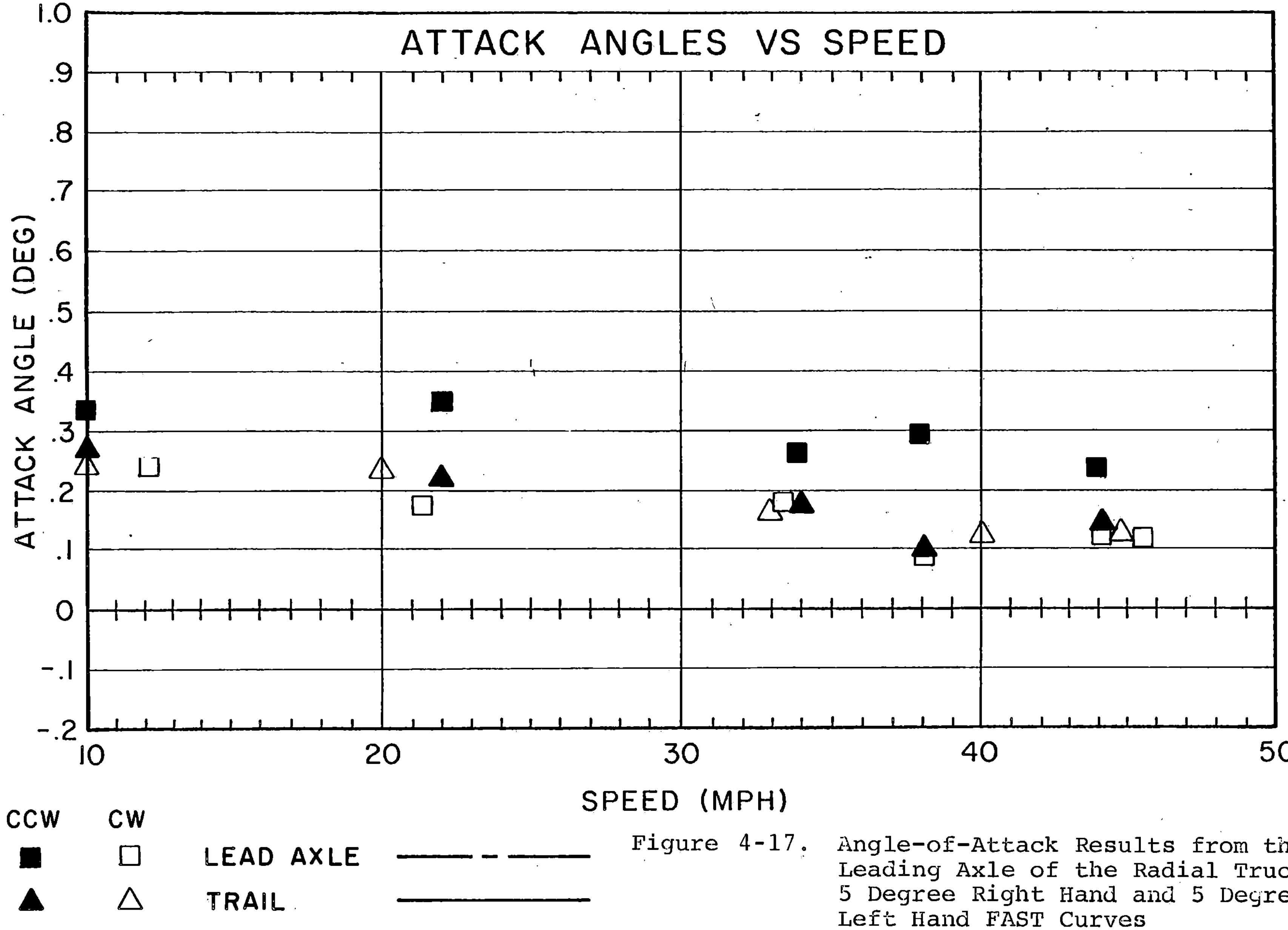


Figure 4-17. Angle-of-Attack Results from the Leading Axle of the Radial Truck from 5 Degree Right Hand and 5 Degree Left Hand FAST Curves

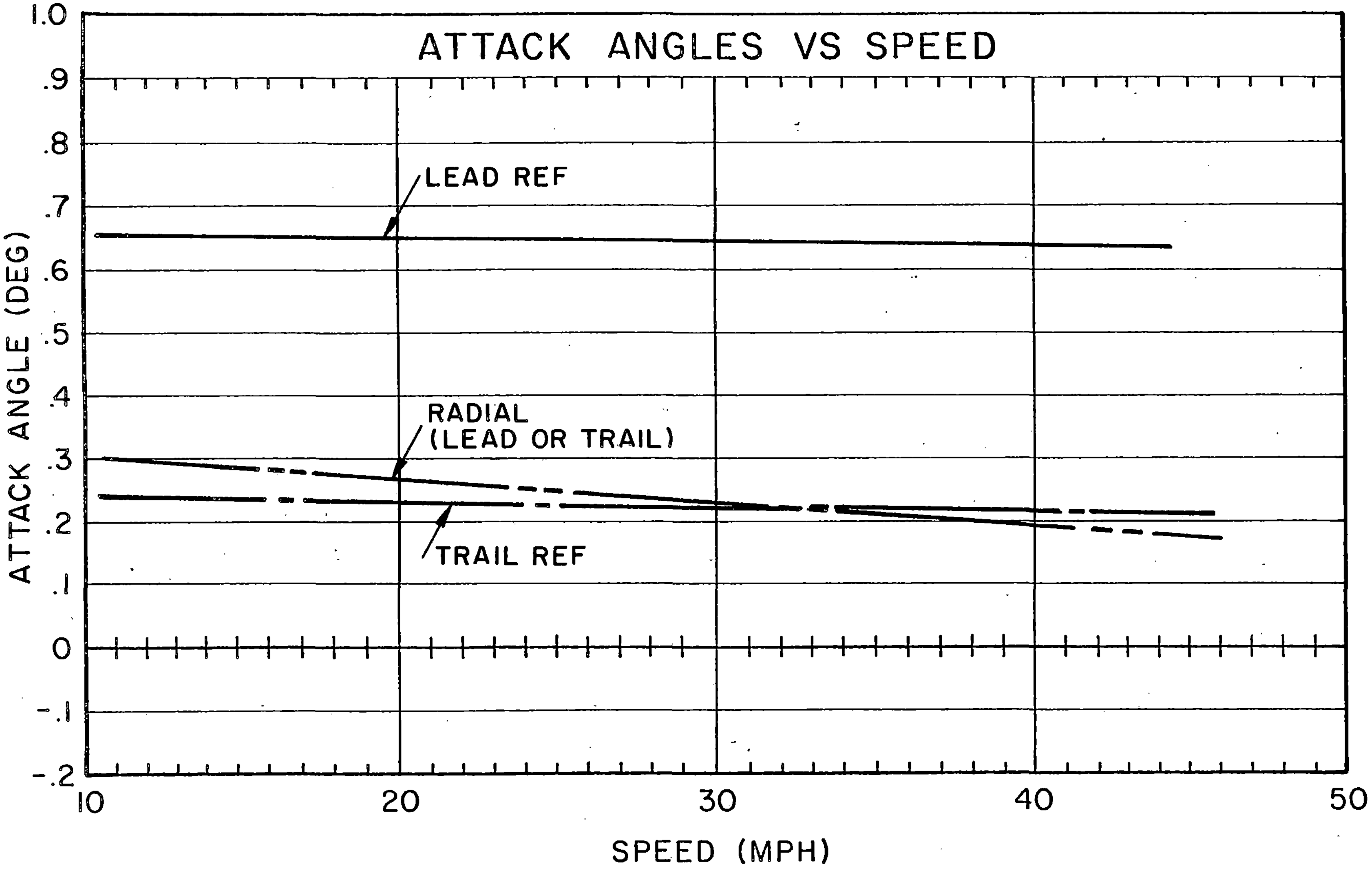


Figure 4-18. Angle-of-Attack Results from the Leading Axle of the Radial and Reference Truck from 5 Degree Right Hand and 5 Degree Left Hand FAST Curves

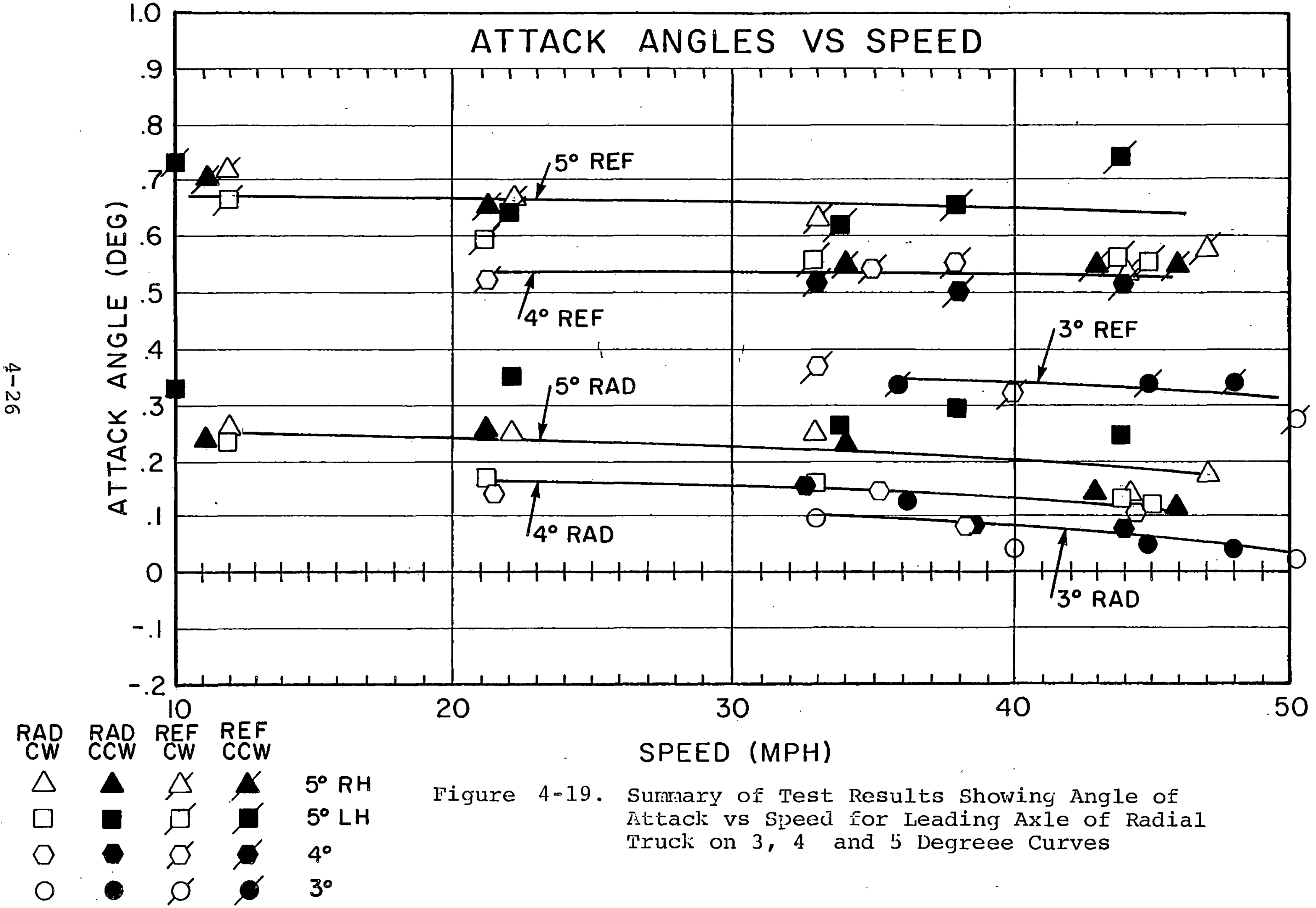


Figure 4-19. Summary of Test Results Showing Angle of Attack vs Speed for Leading Axle of Radial Truck on 3, 4 and 5 Degreee Curves

suspension of the truck. The radial truck allows the axles to adjust to the curvature so both lead and trailing axles can have a favorable attack angle as shown by this figure.

The summary shown in Figure 4-19 shows the angle-of-attack data for the 3, 4, 5 and 7.5 degree curves. This figure shows that the radial truck negotiated all the curves with nearly the same angle-of-attack. The attack angle for the 5 degree curve was slightly higher than the attack angle of the 3 and 4 degree curves but all were within plus or minus 0.15 degrees from the mean for all curves. The angle-of-attack for the lead wheel of the truck on the reference car was also much the same for the 4 and 5 degree curves but the data for the 3 degree curve were significantly lower.

4.5.2 STABILITY

The overall test results indicate that the curving performance of the radial trucks was excellent but the stability was marginal. During the performance tests, the truck was operated at speeds up to 126 mph with acceptable stability but these tests were made while the wheels were still unworn, i.e. less than 3,397 miles on the wheel treads. Axle oscillations were detected during the performance tests but the amplitude of the axle motion was within the safety limits which had been established as being acceptable. With new wheel profiles, the axles experienced oscillations which varied with track location and in some locations the oscillations decreased to almost unperceptable levels while in the other locations a slight motion could be seen.

During the life test, the axle oscillations increased in amplitude and persistance. The running speeds had to be reduced from 120 mph to less than 100 miles per hour because of severe oscillations of the axles and trucks. The life test was stopped at about 21,000 miles.

The wheels were reprofiled and stiffer longitudinal (and lateral) shear sandwiches (stiffness "D") were installed in the primary springs and a third series of life tests were performed. This life test series was conducted by TTC personnel and will be covered by separate reports issued by the Transportation Test Center. The progress reports on the third series of life tests indicate that the truck ran well while the wheel profiles were still new but that higher amplitude axle oscillations returned after about 10,000 miles of high speed operation on the RTT track. The third life test series was stopped with 14,346 miles on the wheel treads. This was still not an acceptable result. The wheels had worn to the point that the conicity changed enough to cause axle hunting after only 10,000 miles at operating speeds. This suggests that the wheel wear rate is excessive and that the truck performance is sensitive to wheel wear.

GSI originally prepared three different shear sandwiches for the lower section of the primary suspension. The shear sandwich controls the longitudinal and lateral spring rate of the primary suspension since the longitudinal and lateral rates of the upper section of the journal box are much higher than the shear rates for the shear sandwiches.

In addition to the shear sandwich option, the truck was equipped with dampers between the ends of the axles and the truck frame. The external axle yaw dampers were designed to dampen the axle oscillations if needed for high speed operations.

4.5.2.1 Shakedown/Stability

Shakedown tests were run on the firm primary suspension longitudinal shear sandwich with dampers, with firm sandwich and no external axle yaw dampers, and on the softest of the three sandwiches. The spring rates are referenced as follows:

● Softest sandwich stiffness A	Available during shakedown and performance test
● Medium sandwich stiffness B	
● Firm sandwich stiffness C	
● Stiff sandwich stiffness D	Manufactured later in life tests*
● Very stiff sandwich stiffness E	

When the wheel profiles were still new the trucks were stable. Speeds of 126 mph were achieved on one section of the RTT. The speed elsewhere on the RTT loop was limited by the locomotive power. Small axle oscillations were observed, but the axle oscillations appeared to be related to particular track conditions at different sections of the RTT. The amplitude of the axle motion in these test sections was less than one degree peak to peak.

Tests were made with the softest shear sandwich (stiffness A) without dampers. No tests were made with the soft sandwich and

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*TTC report contains the results of truck spring stiffness test.

dampers because if the soft sandwiches with dampers proved effective the stiffness would be increased to avoid the requirement for the additional dampers.

The results of the test with "stiffness A" shear sandwiches and no damper showed that this configuration did not have adequate stiffness. The test speed was increased in steps up to 115 mph but at this point the amplitude of the axle oscillation approached the safety limit criteria so the tests were discontinued. With these shear sandwiches, the amplitude of the axle oscillations increased by 60 percent and the oscillation were almost continuous.

For the balance of the shakedown and the performance tests, the "stiffness C" shear sandwiches were installed. The results of these tests without the external longitudinal damper were similar to the results obtained with the damper installed. The only significant differences observed were the axle oscillations were about 5 percent larger for the firm sandwich with no dampers.

4.5.2.2 Axle and Truck Oscillation Detailed Results

Selected channels of data were reproduced on paper charts from digital tape for analyzing axle and truck oscillations.

It was observed that in both radial trucks, the axle-to-truck angle, axle-to-axle angle and the lateral axle position (as measured by the angle-of-attack sensors) exhibited oscillations at all speeds. The amplitude as well as the percent of time in sustained oscillation increased with speed. At speeds above 100 mph, the axles are essentially in oscillation 100 percent of the time. The two axles in a truck oscillate out of phase with each other as they are cross-linked.

The wavelength of the oscillations is almost independent of speed. Measured from the chart, the wavelength falls between 37.9 feet and 39.2 feet with an average of about 38.5 feet.

This wavelength is most likely a function of the geometric input inherent to the design of the tread profile, the railhead shape and the stiffness characteristics of the truck primary spring. This wavelength was not affected even when the spring and damping were changed. Regardless of the fact that 38.5 feet almost equals the standard rail length, it is unlikely that the oscillations are induced by track geometry inputs. Above a certain theshold level of axle oscillations, the truck to carbody swivel angle is greatly amplified. Until the axle oscillation amplitude reaches a certain level, the truck amplitude swivel angle remains relatively low. When the axle oscillation exeeds this level the trucks begin to swivel at the same wavelength. This behavior can be explained by the breaking of centerplate friction.

Figures 4-20 and 4-21 are representative data from a 105 mph, counterclockwise run using the soft sandwich stiffness "A". This data is for track between locations 550 and 450 on the RTT (see Figure 4-22), where a short right hand curve is located between two left hand curves. It can be seen that:

- Axle-to-axle oscillatory motion reached 1.5 degrees peak-to-peak (channel 207).
- The lead radial truck oscillates more than the trailing radial truck.
- The axle lateral oscillation reached 1.4 inches peak-to-peak.
- The lead radial truck seems to oscillate much less on right hand curves.

4.5.2.3 Comparison of the Three Suspension Configurations

Since it is difficult to develop an overall quantative measure to compare the relative tendency for axle and truck oscillation, a particular location on the track was chosen to make the comparison. Near location 460 on the RTT, all counterclockwise runs are excited into a well recognizable oscillation. The maximum peak-to-peak amplitude of this oscillation for the three suspension configurations is plotted in Figure 4-23.

The soft "stiffness A" suspension has the largest amplitude followed by the firm suspension, "stiffness C", and then the firm suspension with damping, "stiffness C". Two interesting observations should be pointed out:

- The firm suspension "A" without dampers appears to "catch up" with the soft suspension "C" at high speeds.
- The damper is not effective at low speeds (and also low oscillation amplitudes). Its effect at higher speeds is quite impressive which is to be expected for viscous-type dampers.

Even though the oscillation amplitudes were different for the three suspension configurations, the basic wavelength (38-39

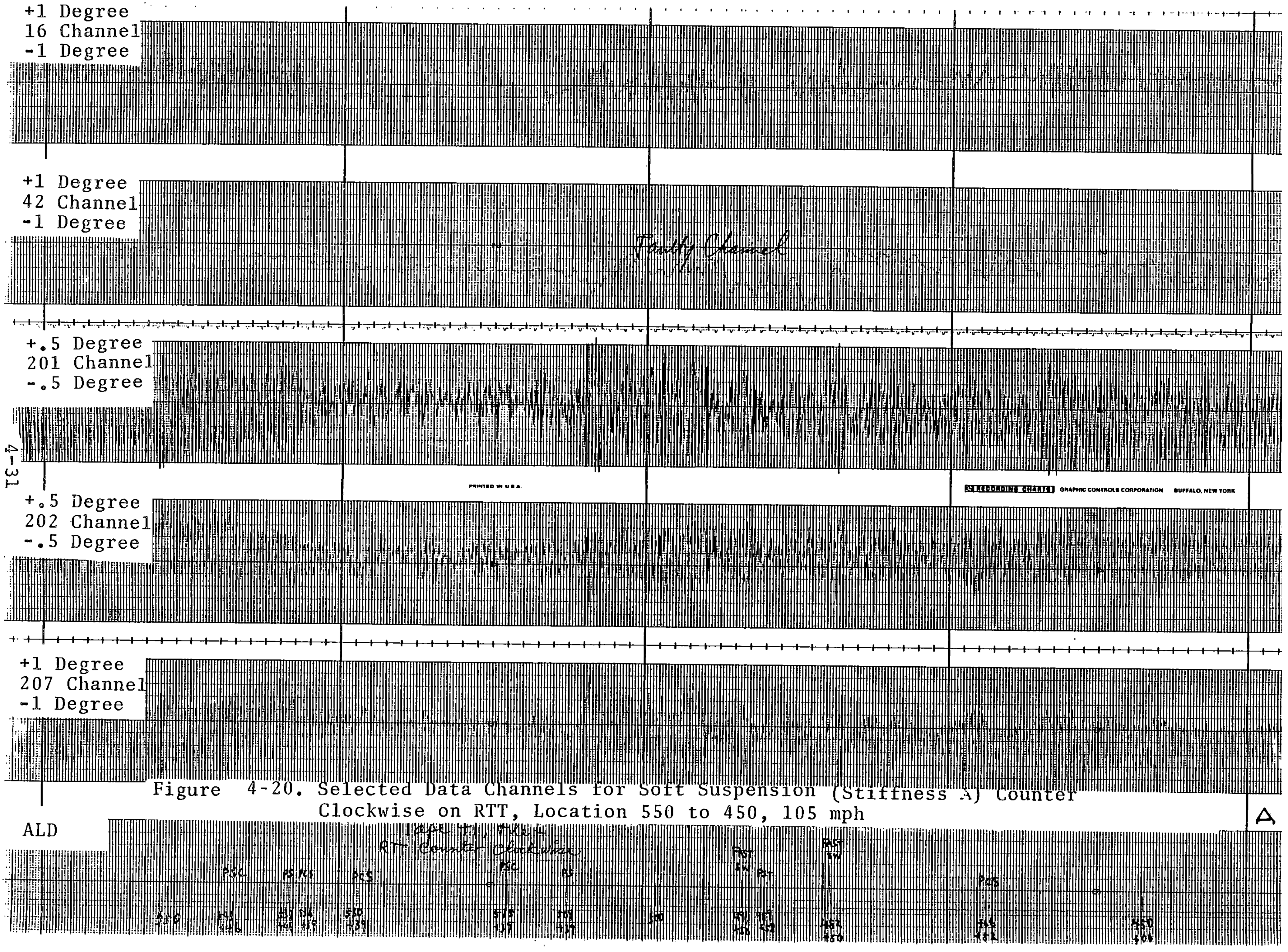


Figure 4-20. Selected Data Channels for Soft Suspension (Stiffness A) Counter Clockwise on RTT, Location 550 to 450, 105 mph

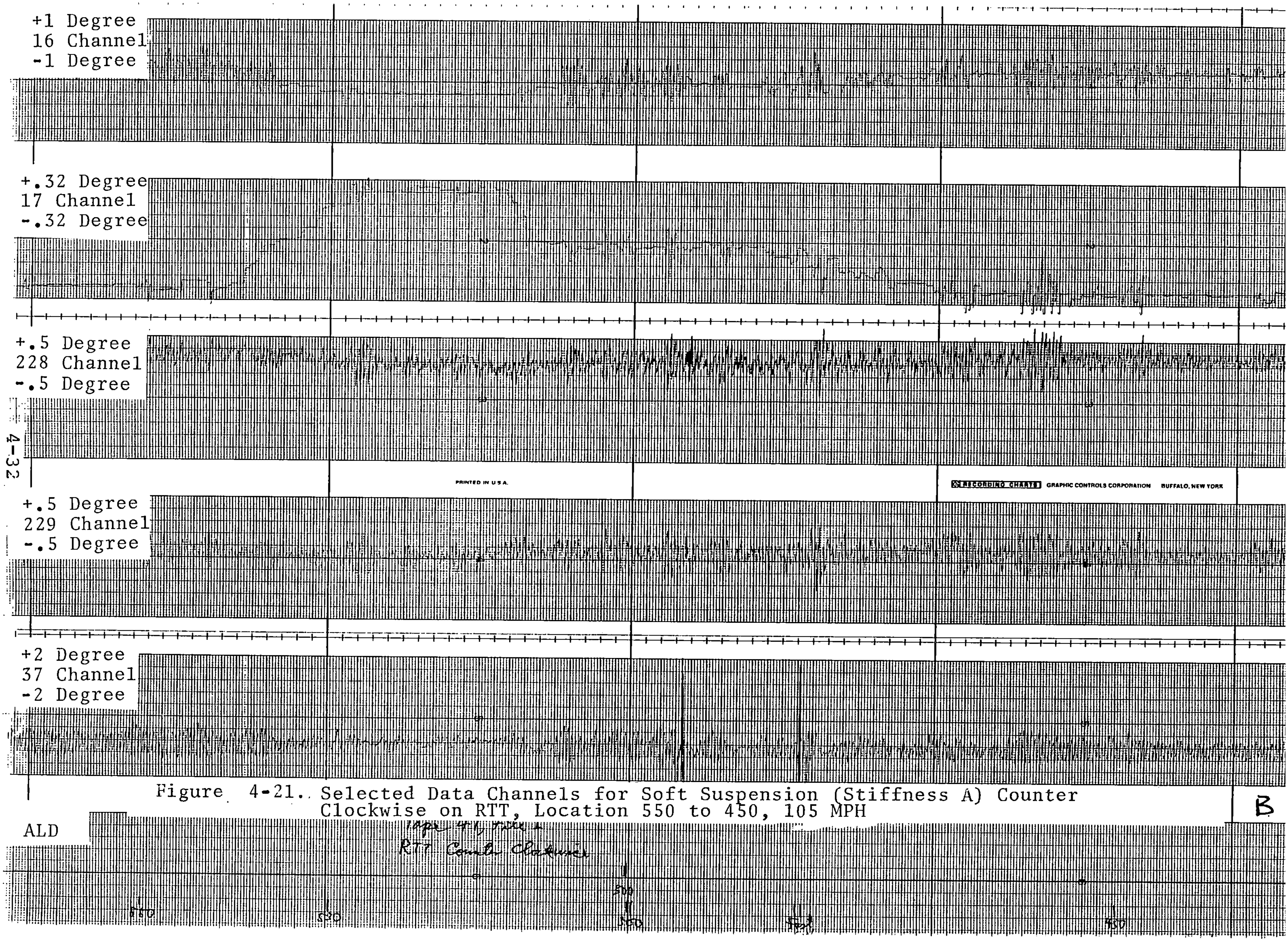


Figure 4-21. Selected Data Channels for Soft Suspension (Stiffness A) Counter Clockwise on RTT, Location 550 to 450, 105 MPH

B

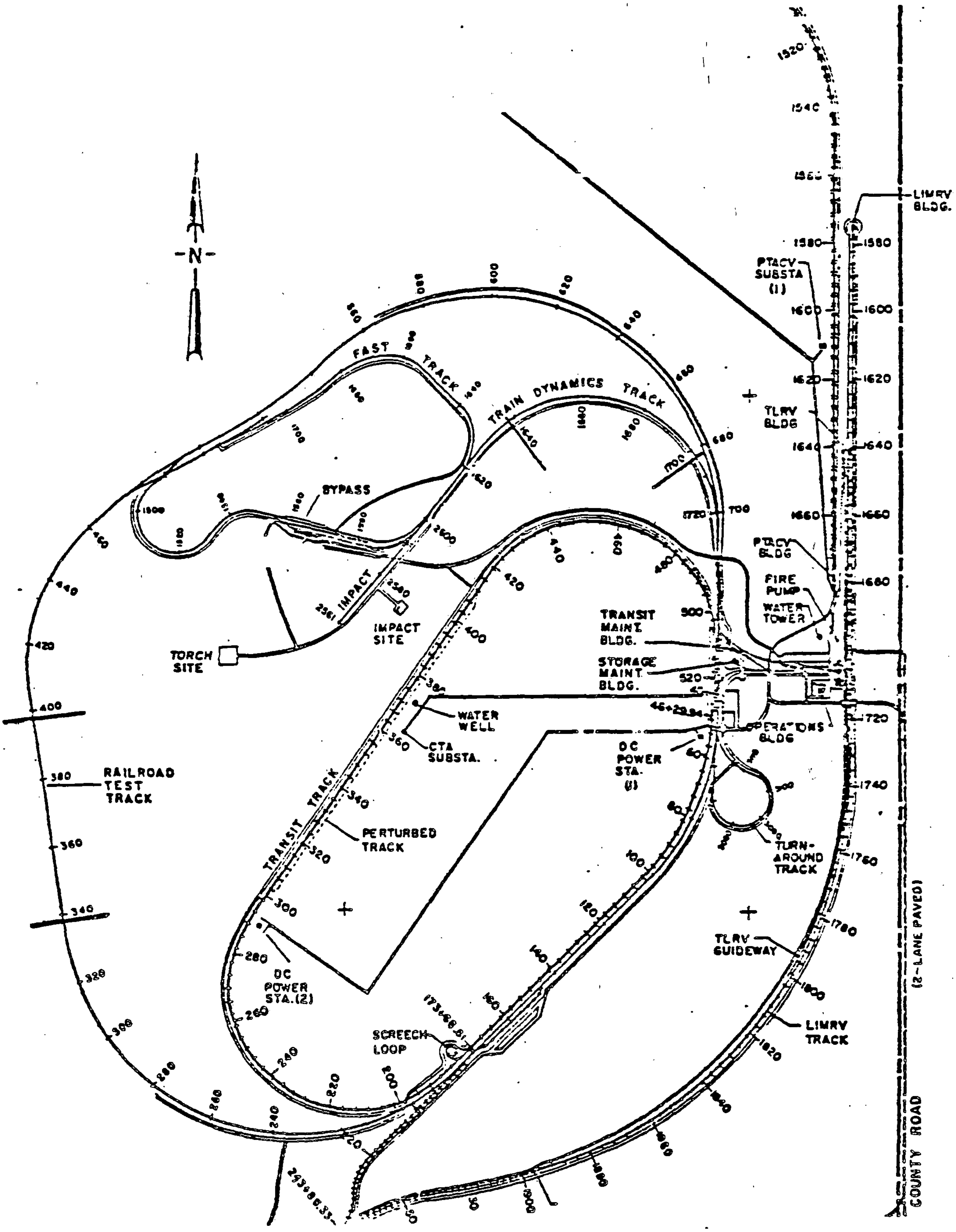


Figure 4-22. RTT and Balloon Loop

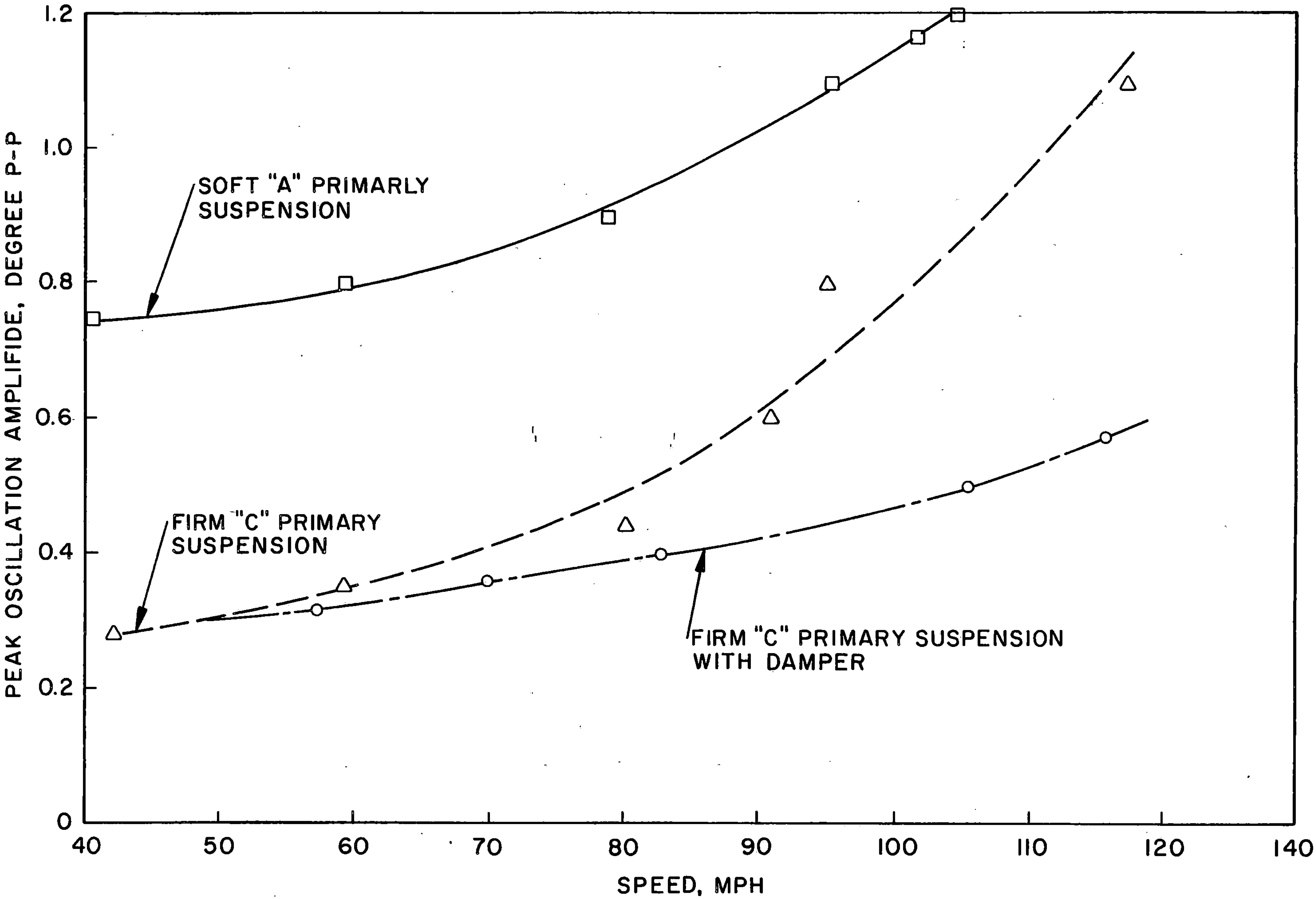


Figure 4-23. Axle-to-Axle Oscillation Amplitude, Lead Radial Truck (Counterclockwise RTT Runs at Location 460)

[redacted]

feet) is not changed and the signature of the oscillations persisted no matter which configuration was used.

Figures 4-24 and 4-25 compare the soft "A" and the firm "C" suspensions passing through the same area (location 550 to location 450 on the RTT) at the same speed (95 mph).

Figure 4-26 gives the same data channels for a firm suspension with dampers going through the same test area at a higher speed (116 mph). The dampers are effective in controlling the oscillation such that at 116 mph the amplitudes are smaller than those associated with either of the other two suspension configurations.

4.5.3 STEERING BIAS IN THE LEAD TRUCK

The non-symmetric behavior at the lead radial truck was pointed out earlier. When making counterclockwise runs on the RTT, the levels of axle and truck oscillation are smaller on right hand turns than on left hand turns.

When firm "C" suspension was used (without dampers), test runs were made both clockwise and counterclockwise on the RTT. Figures 4-27 and 4-28 provide the comparison of a counterclockwise run and a clockwise run through the same area where there is a reverse curve (location 550 to 450). Even though the two runs were made at different speeds (118 mph and 109 mph), the reversal in the non-symmetric curving behavior is quite apparent. The quieter right hand curve during the counterclockwise run has become the more violent curve when it became a left hand curve during the clockwise run. This pair of runs show that the bias is not due to track input, rather, it is caused by lack of symmetry in the truck. This could be due to geometry or elasticity or both.

Because both the left and right hand curves have rather shallow curvature ($0^{\circ}50'$), the bias is brought out more sharply. It is expected that a much less significant difference will be found between left and right hand curves of higher curvature. Data from the Balloon loop and FAST (3° to 7.5° curves), indicated the non-symmetry was much less pronounced.

4.5.4 EFFECTS ON TREAD WEAR

Axle oscillations were observed on tests of all three suspension configurations ("A", "C" and "C" with dampers). The amplitudes may have been acceptable from safety and ride qualty points of view, but these oscillations do induce wear.

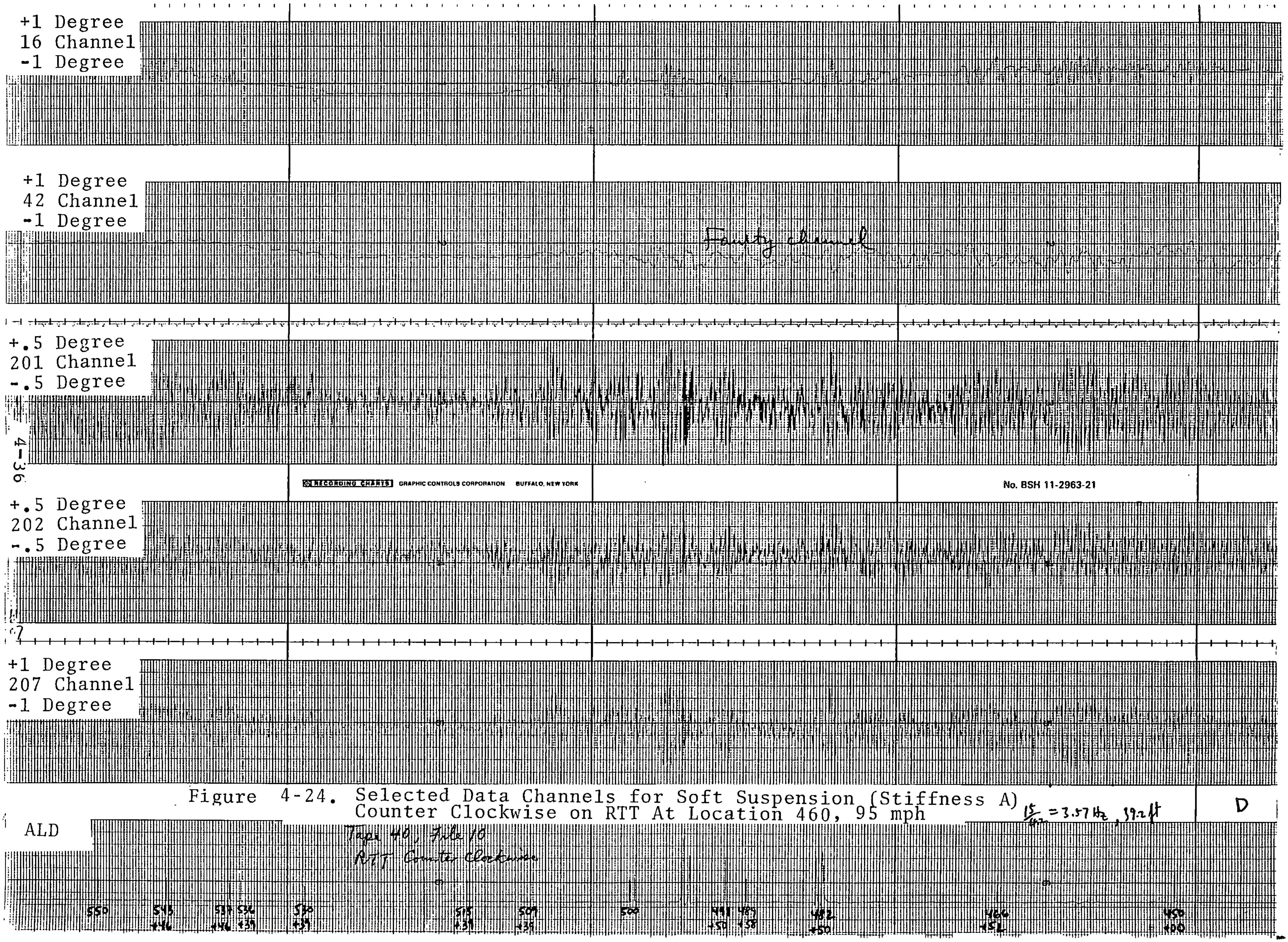


Figure 4-24. Selected Data Channels for Soft Suspension (Stiffness A) Counter Clockwise on RTT At Location 460, 95 mph

$\frac{15}{4.2} = 3.57$ Hz, 39.2 ft

D

Tape 40, File 10
RTT Counter Clockwise

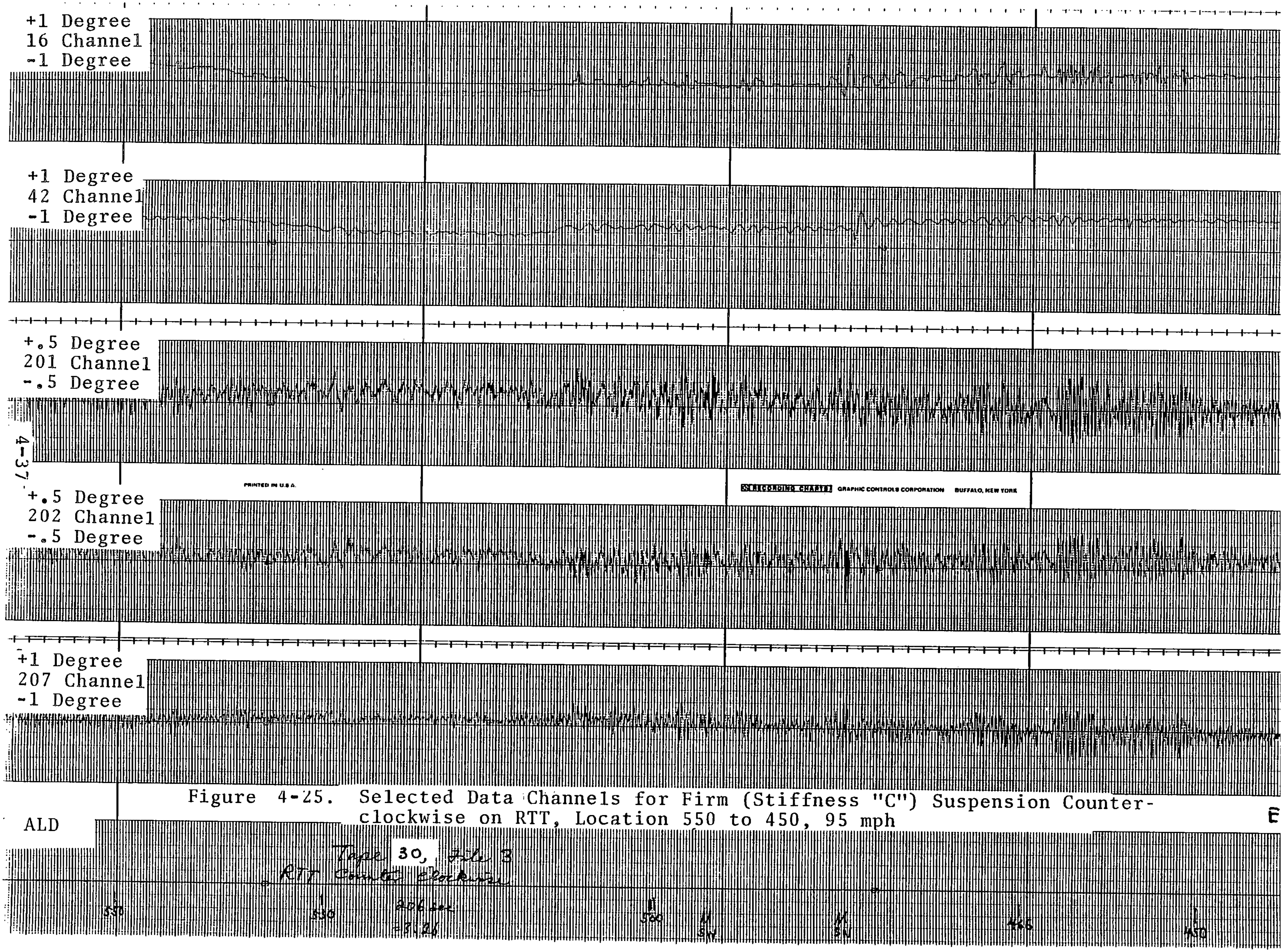


Figure 4-25. Selected Data Channels for Firm (Stiffness "C") Suspension Counterclockwise on RTT, Location 550 to 450, 95 mph

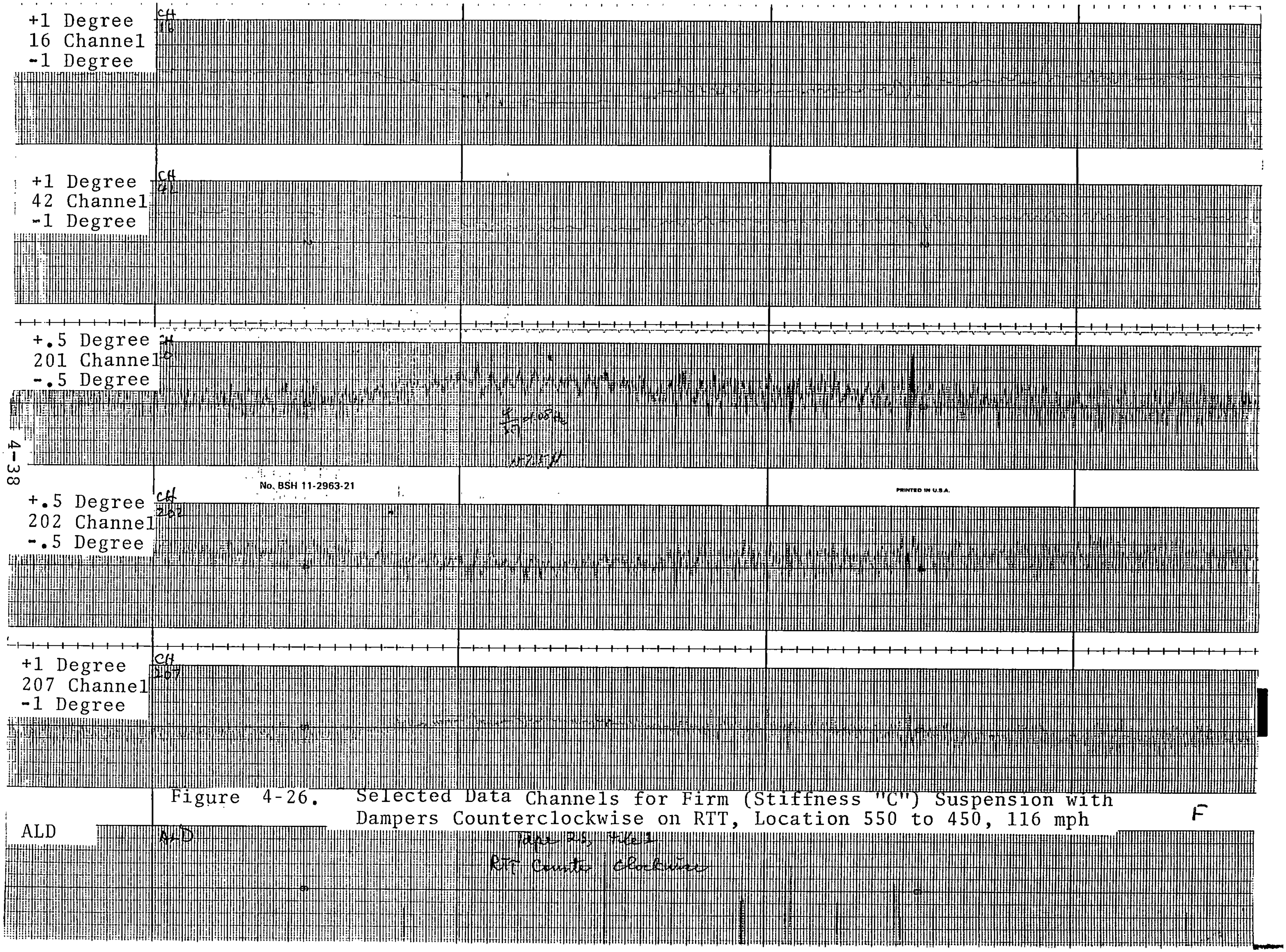


Figure 4-26. Selected Data Channels for Firm (Stiffness "C") Suspension with Dampers Counterclockwise on RTT, Location 550 to 450, 116 mph

F

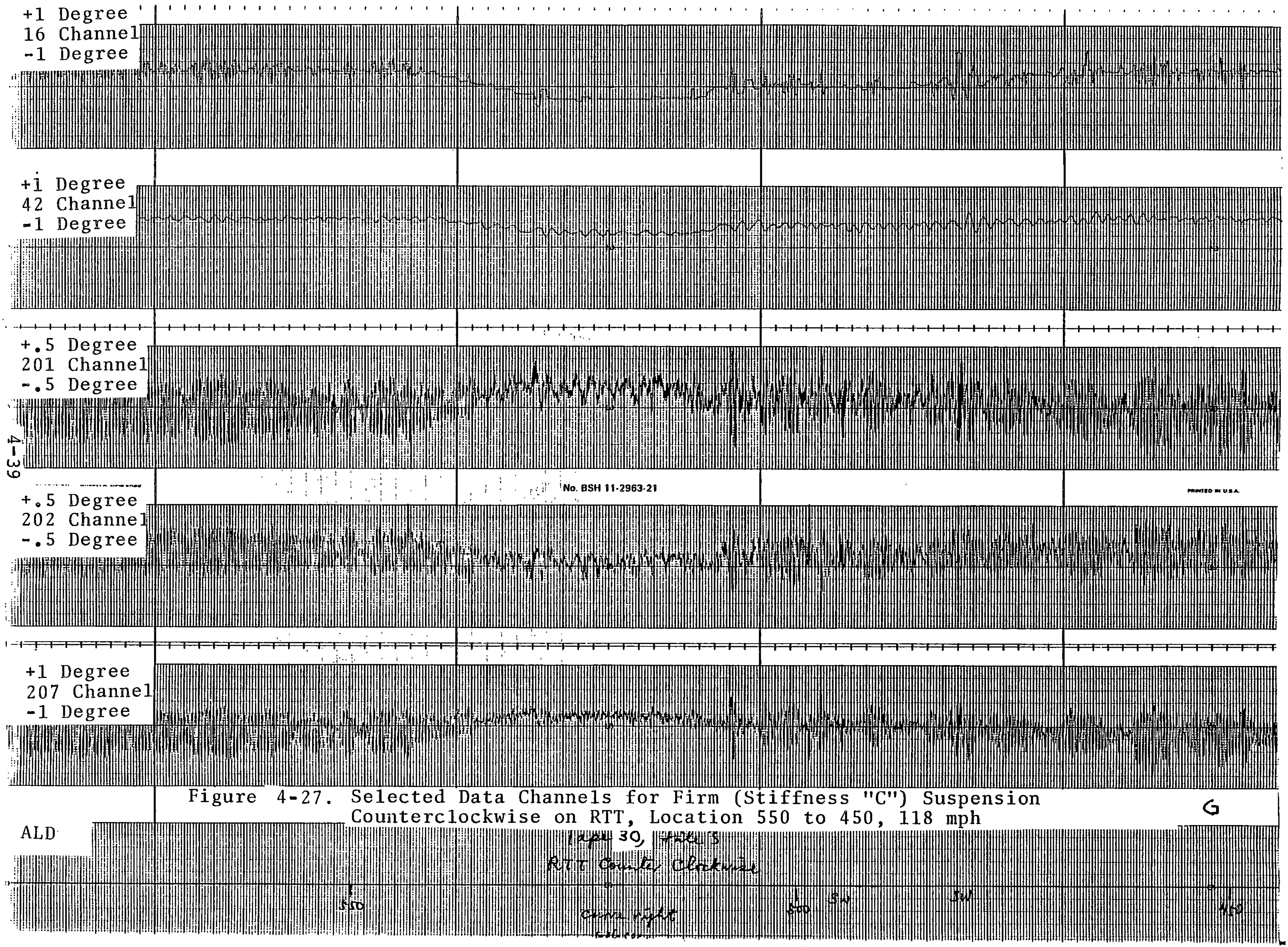


Figure 4-27. Selected Data Channels for Firm (Stiffness "C") Suspension Counterclockwise on RTT, Location 550 to 450, 118 mph

G

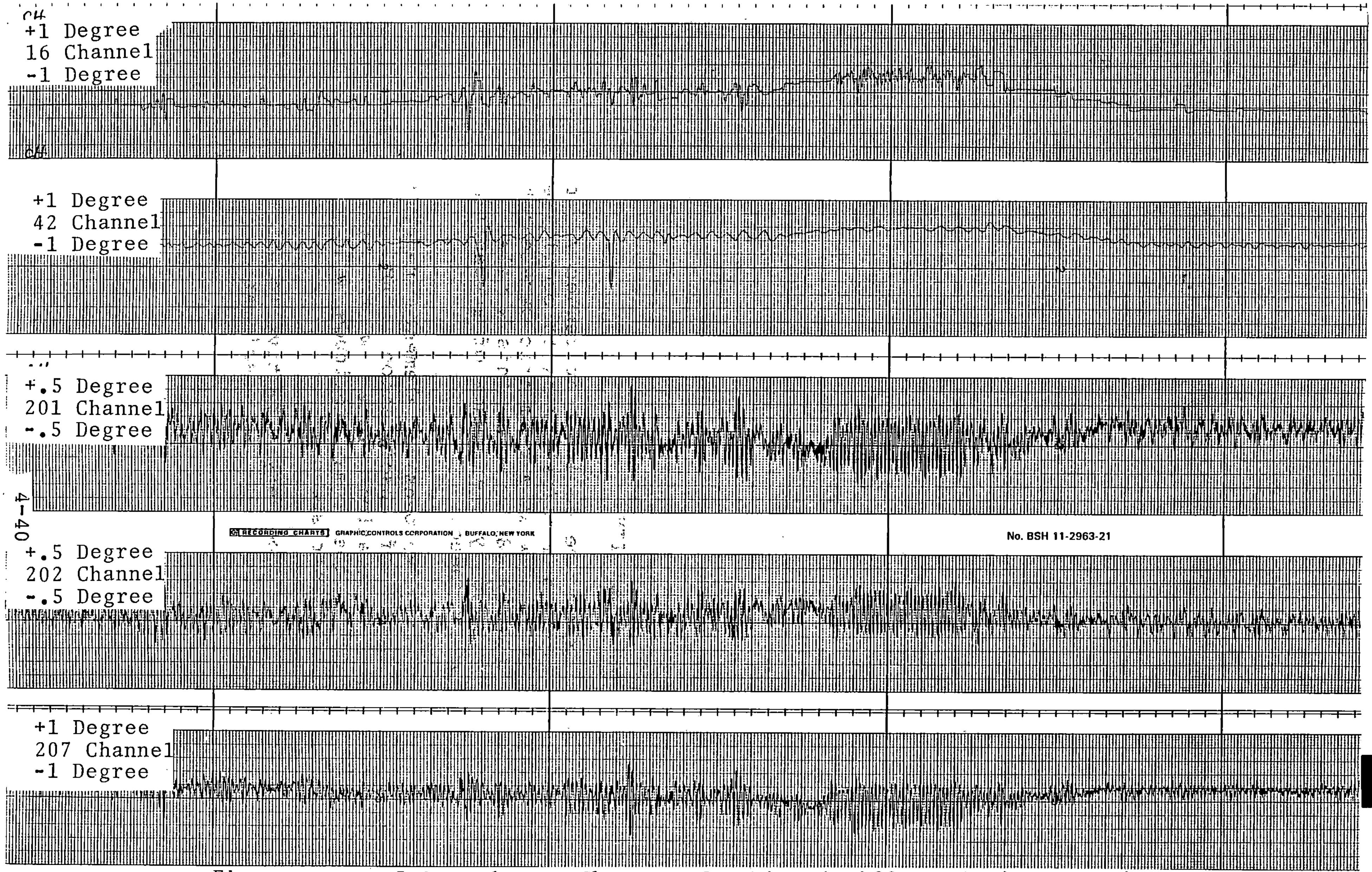
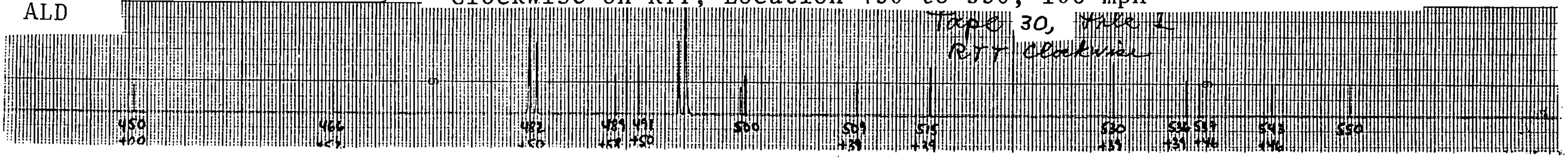


Figure 4-28. Selected Data Channels for Firm (Stiffness "C") Suspension Clockwise on RTT, Location 450 to 550, 108 mph

H



Tape 30, [illegible] 1
RTT Clockwise

Axle yaw, which was the primary oscillatory mode observed, reached peak-to-peak amplitudes of greater than 1° above 110 mph for the firm "C" suspension without damping (the configuration used initially in life testing). At this yaw rate, assuming that each of the two axles is producing half of the amplitude, the equivalent longitudinal displacement is approxmately 0.25 inch peak-to-peak at each wheel-rail contact point. since a complete cycle of oscillation is accomplished in 38 feet, the total longitudinal slip would be approximately 0.5 inch over a 38-foot distance of travel. Such slip would be producing oscillatory longitudinal adhesive forces which would not be normally present.

Combined with the longitudinal slippage, the lateral position oscillation was typically measured at 1 inch peak-to-peak somewhat independent of suspension configurations or speed. Even through the position change (measured relative to the rail by a single AOA position transducer) may be partially due to rolling with changing axle heading, there will be a contribution due to lateral creep. The creep force will be added vectorially to the longitudinal shear load on the contact patch.

The presence of significant longitudinal slippage caused by oscillatory axle yaw may be the cause of the unusual wear pattern of a narrow, polished line near the center of the tread observed during the initial life tests.

4.5.5 CONCLUSIONS ON STABILITY

- There appears to be an inherent tendency for the two axles in a radial truck to oscillate in out-of-phase yaw at a geometric wavelength of approximately 38.5 feet. This wavelength was not effected by the change of suspension elements or by speed.
- Stiffer primary suspension elements reduced the amplitude of oscillation, but the increased oscillation rate with speed indicates that the same amplitude will be reached at a higher speed.
- Dampers appear to be very effective in limiting (not eliminating) the oscillation at higher speeds.
- As axle yaw oscillation attains higher amplitudes, the truck swivels with the axles.
- A slight non-symmetry was observed in the lead radial truck. The axles on the truck tend to oscillate on left hand $0^{\circ}50'$ curves

rather smoothly. This bias was no longer noticeable on curves of higher curvature (FAST track and Balloon Loop).

- Sustained axle yaw oscillations and longitudinal slippage may be the cause of rapid wheel tread wear lowering of the critical speed experienced during life testing.

4.6 RIDE QUALITY TEST RESULTS

At the end of the performance test, a special ride quality test was conducted. The ride quality test was scheduled to be repeated at the completion of the 40,000 miles of life tests and again at the end of the 80,000 mile life test series. The plan was to compare the acceleration data and the axle and truck swivel data to determine whether the truck performance had deteriorated as a result of the running tests. Since the truck performance did not meet earlier expectations, the truck was not expected to be operated for the full life test. Therefore, a final ride quality test was to be conducted when the truck completed 40,000 miles of operation or when the operation speed deteriorated to the point that no more benefit could be derived from further testing. Data from this second ride quality measurement was to be compared to the results from the earlier tests. The life test was terminated prior to the completion of the required mileage so the second ride quality test was not performed.

Radial Axle Truck Test Results Report, 1982
US DOT, FRA, ENSCO, Inc, M Liles, R Scofield