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ENGINEERING TESTS FOR ENERGY STORAGE CARS AT THE TRANSPORTATION TEST CENTER
Volume II - Performance Power Consumption and Radio Frequency Interference Tests

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FINAL REPORT

Prepared for

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16. Abstract

The primary purpose of the tests documented herein was to demonstrate the principles and feasibility of an energy-storage-type propulsion system, and its adaptability to an existing car design. The test program comprised four phases of tests on two New York City Transit Authority R-32 cars where propulsion system was repolaced by an energy storage system. The four test phases were: verification of safe arrival, debugging procedures, performance verification tests, and expanded test program. This report contains test data collected during the performance verification and expanded test program phases. Testing was conducted at the DOT Transportation Test Center, Pueblo, Colorado. The data was collexted and processed in accordance with the General Vehicle Test Plan for Urban Rail Testing.

Volume I of this report covers the Program Description and Test Summary; Performance, Power Consumption, and Radio Frequency Interference Tests; Volume III, Noise Tests; and Volume IV, Ride Roughness Tests.

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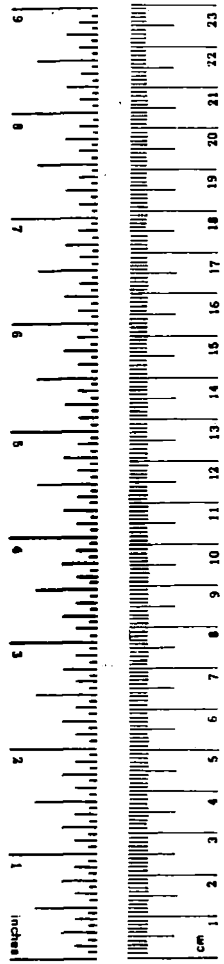
METRIC CONVERSION FACTORS

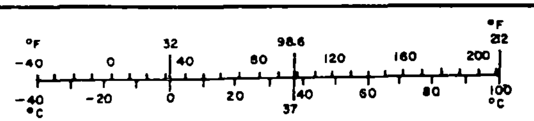
Approximate Conversions to Metric Measures

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



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	35	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



CONTENTS

ILLUSTRATATIONS

ILLUSTRATIONS (CONTINUED)

ILLUSTRATIONS (CONTINUED)

1. INTRODUCTION

1.1 GENERAL

The test report on the energy storage cars is presented in four volumes.

Volume I	Program Description and Test Summary
Volume II	Performance, Power Consumption and Radio Frequency Interference Tests
Volume III	Noise Tests
Volume IV	Ride Roughness Tests

The information contained in this volume is related to the power consumption, radio frequence interference and the performance data tests consisting of acceleration, blended braking and service friction deceleration, traction resistance and friction braking duty cycle tests.

These tests were performed by AiResearch at the Transportation Test Center in Pueblo, Colorado. The tests were conducted in accordance with AiResearch Test Program 73-9373 and Expanded Test Procedures, 74-10441 to comply with Transportation System Center General Vehicle Test Plan, GSP-064.

1.2 SCOPE

Each section of this volume is devoted to the tests covered by a specific GSP-064 Test Set. The test procedures for each test set and a description of the AiResearch tests are also included.

1.3 INSTRUMENTATION

The instrumentation required for the data acquisition system is shown in figure 1-1, the data recovery system instrumentation in figure 1-2. Figures 1-3 through 1-8 show in detail the specific instrumentation required for each of the tests included in this volume of the report.

1.4 TEST SET SUMMARY SHEETS

A summary of each GSP-064 Test Set related to the tests covered by this volume is provided in this section as a convenience for the reader.

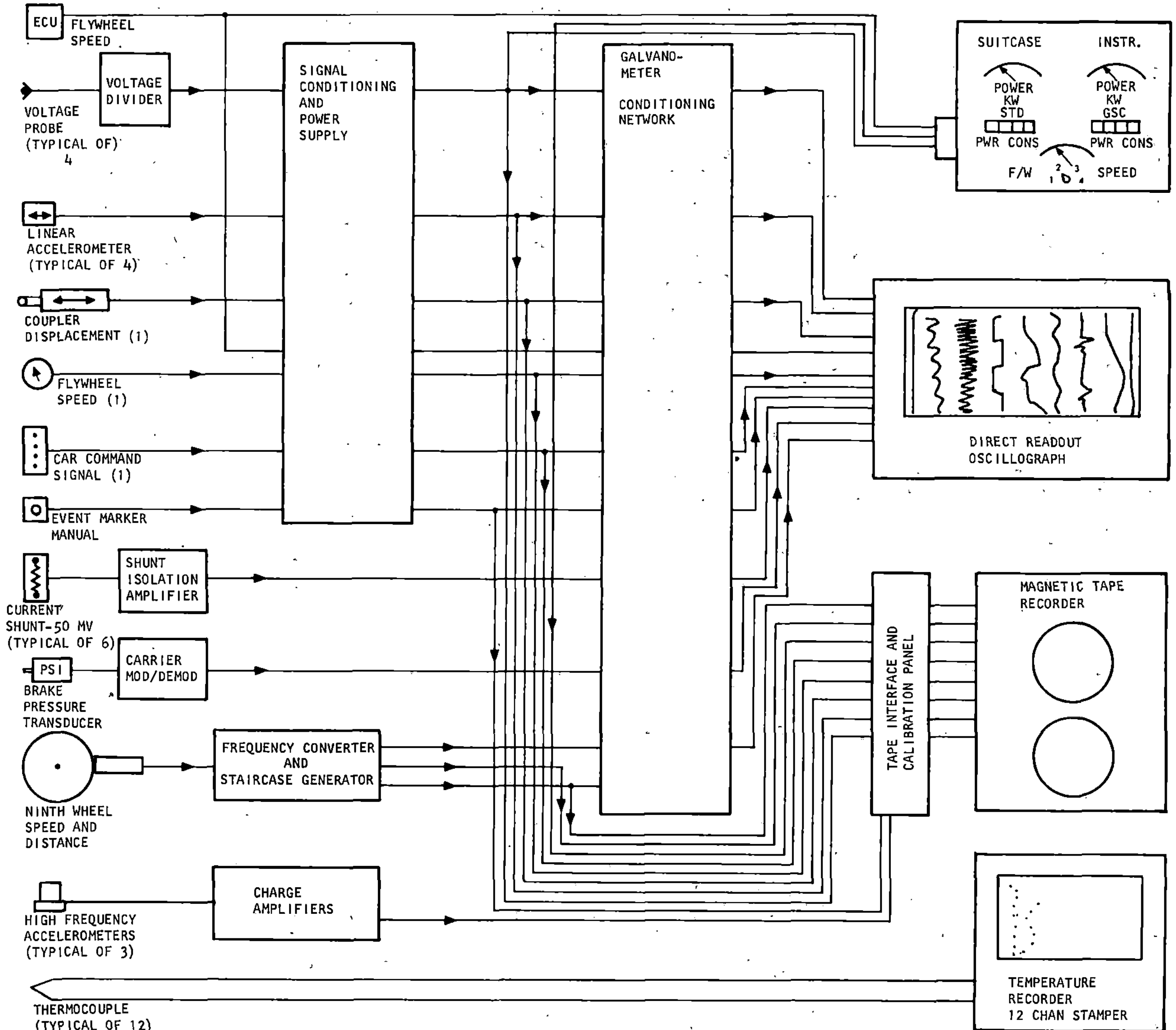


Figure 1-1. Data Acquisition System

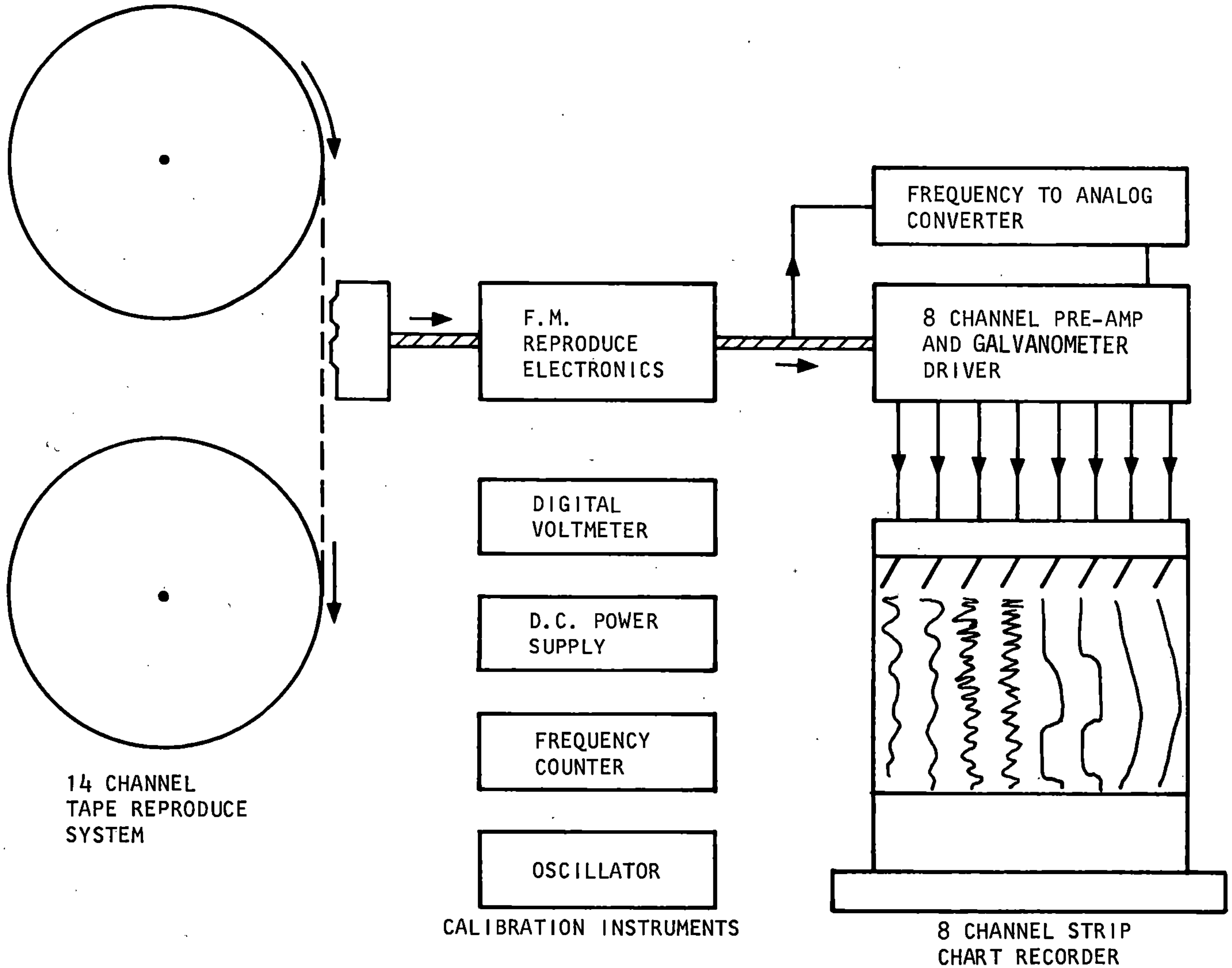


Figure 1-2. Data Recovery System

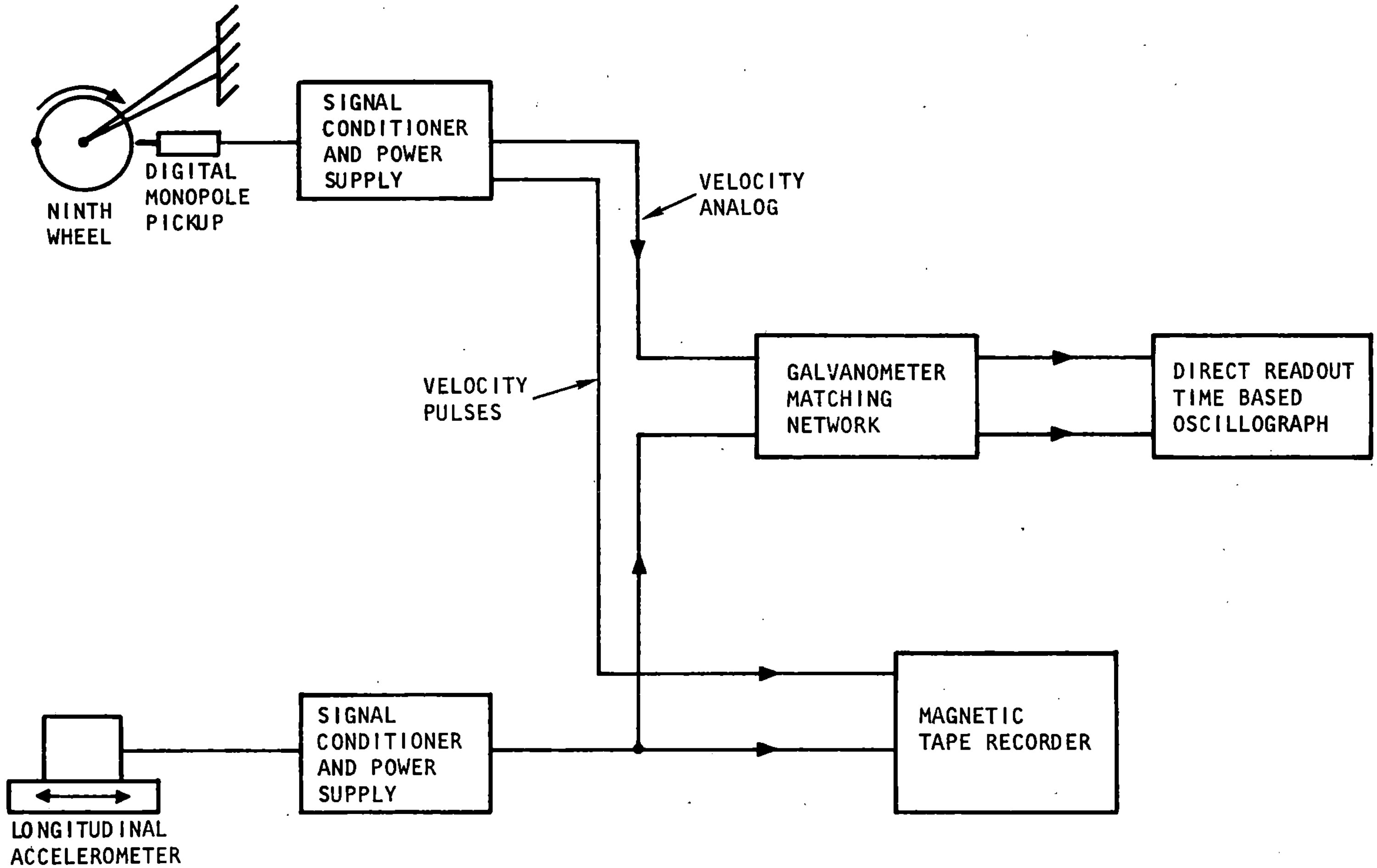


Figure 1-3. Acceleration, Deceleration and Drift Test Instrumentation

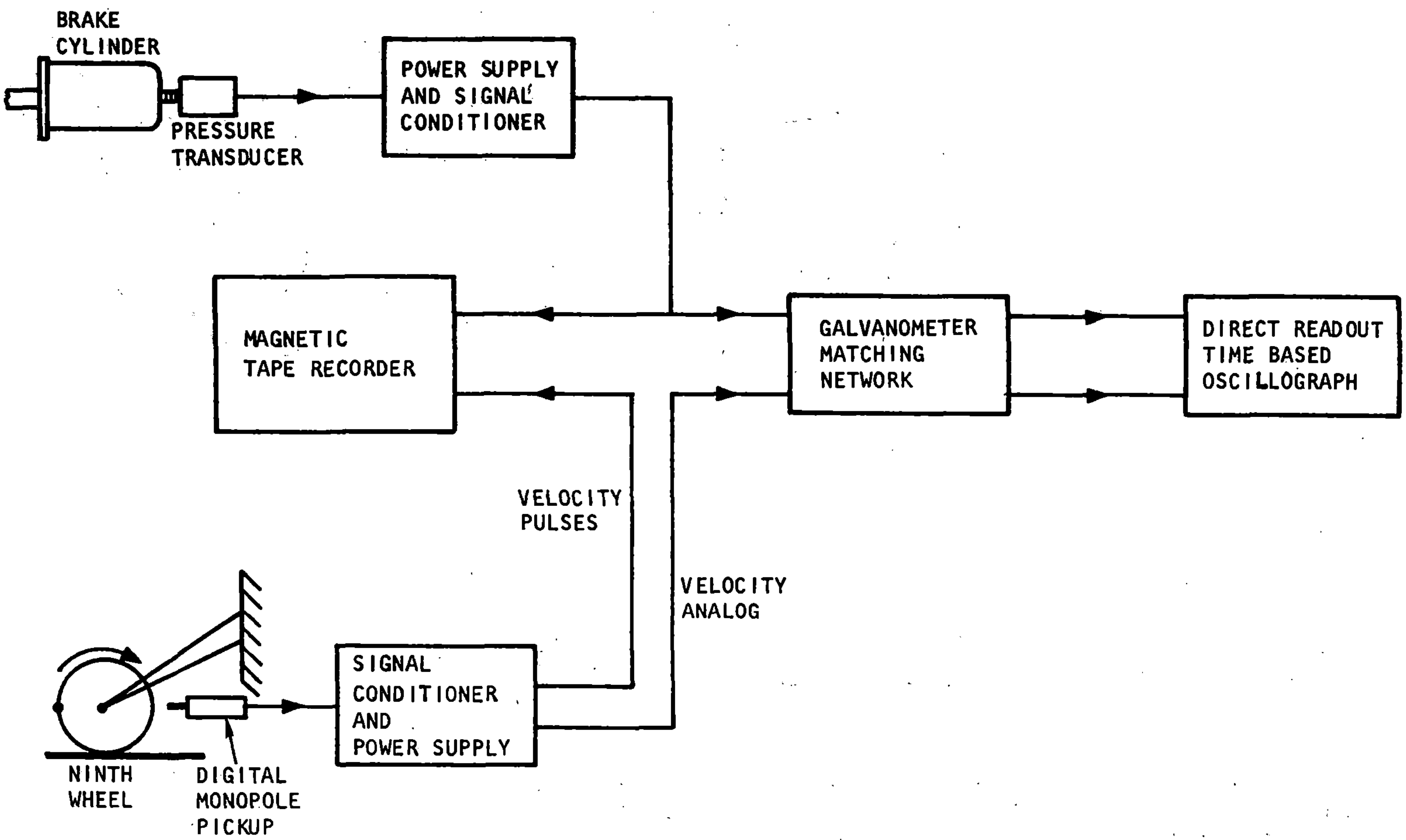


Figure 1-4. Service Friction Deceleration Test Instrumentation

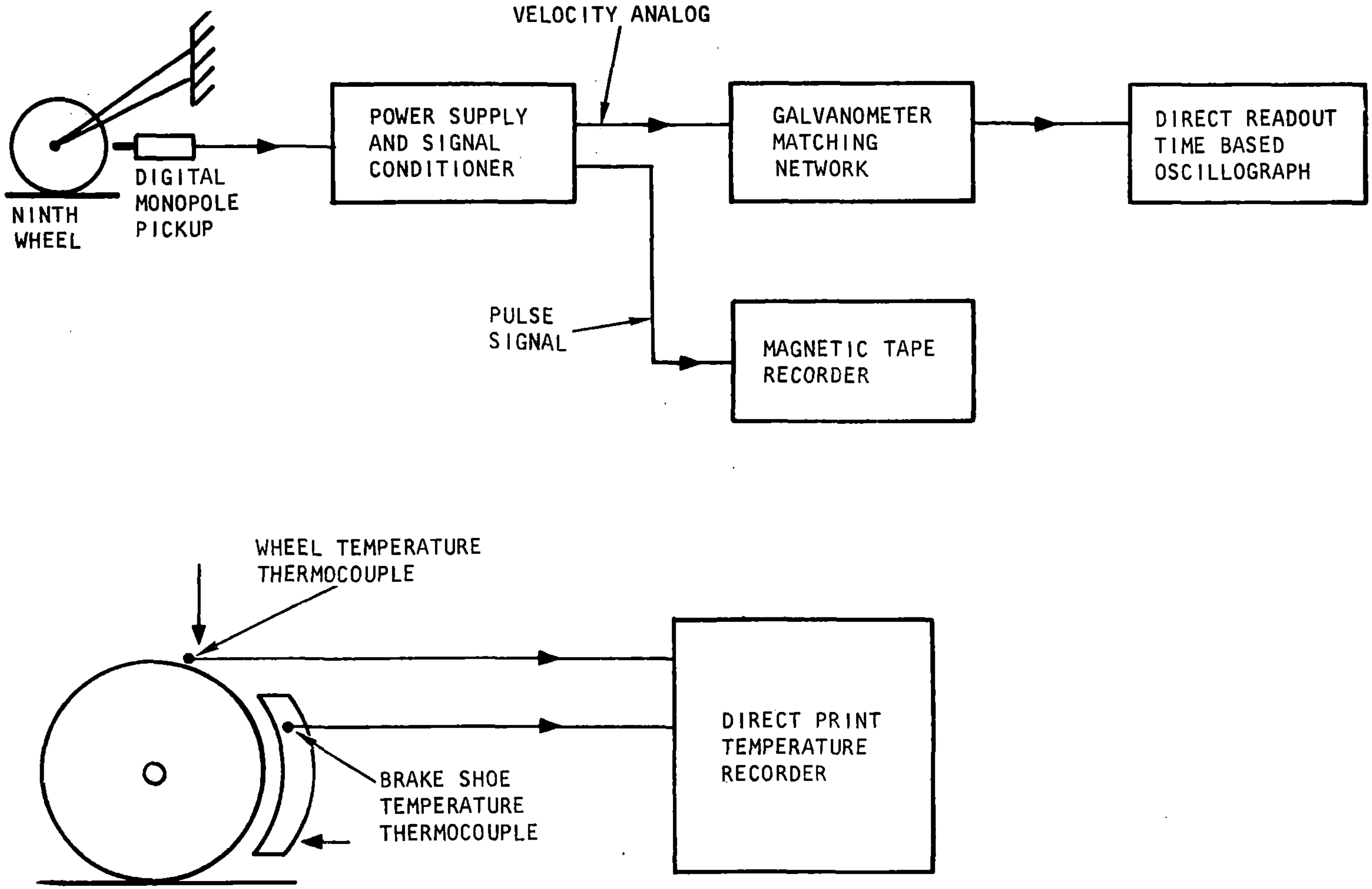


Figure 1-5. Friction Brake Duty Cycle Test Instrumentation

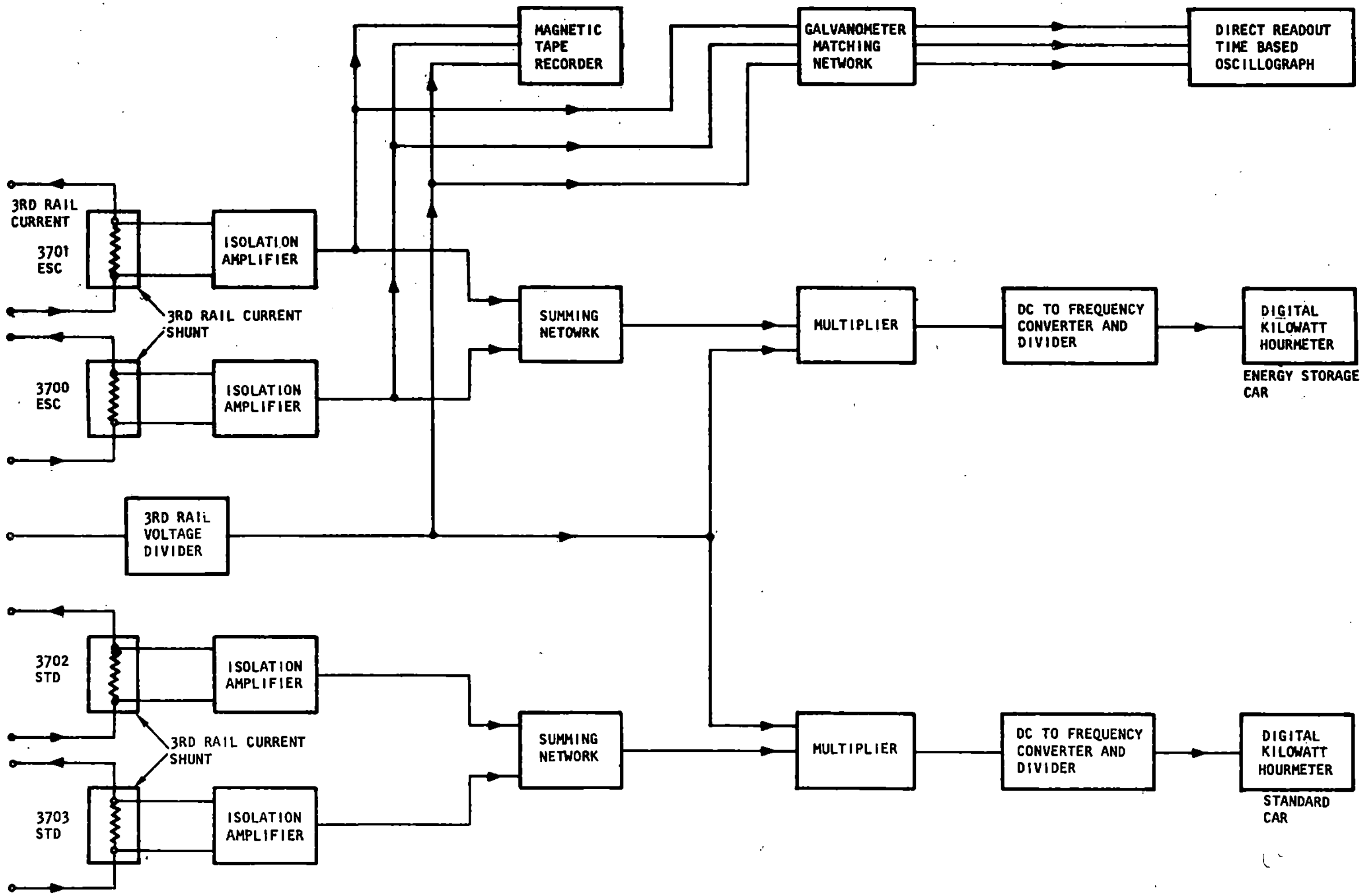


Figure 1-6. Power Consumption Test Instrumentation

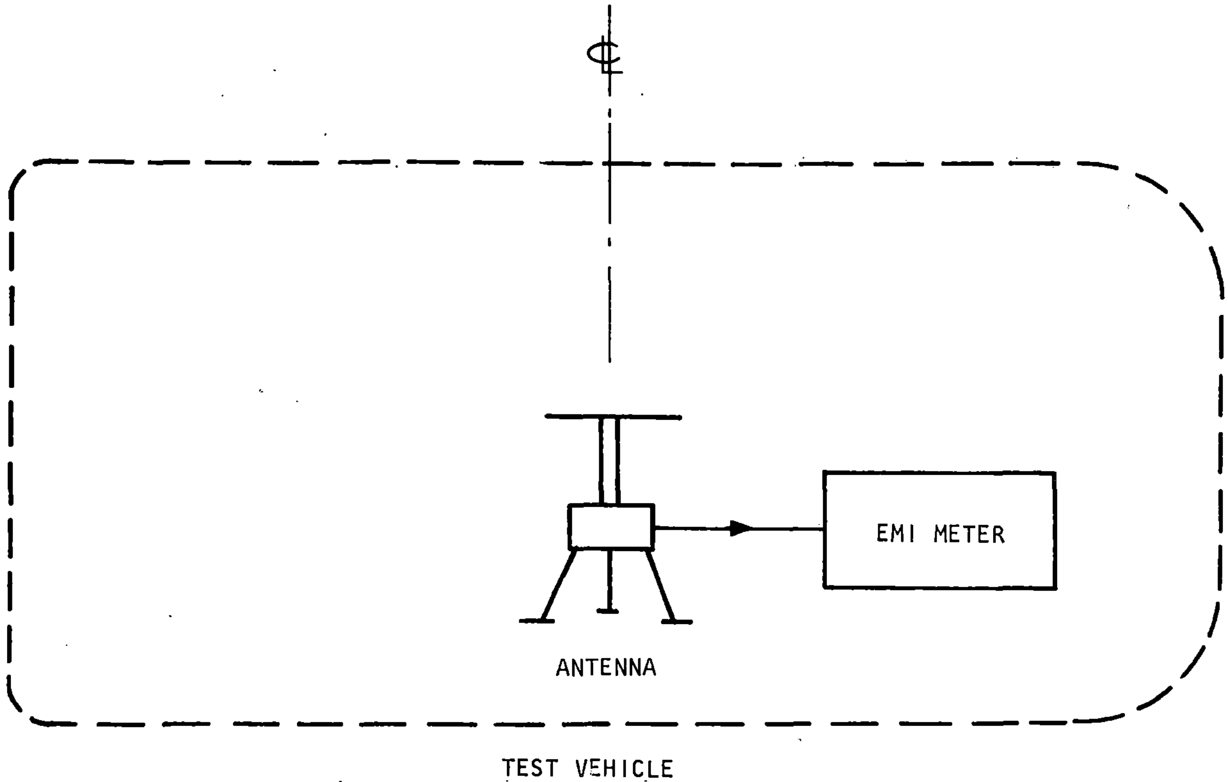


Figure 1-7. Radio Frequency Interference - Interior Test Instrumentation

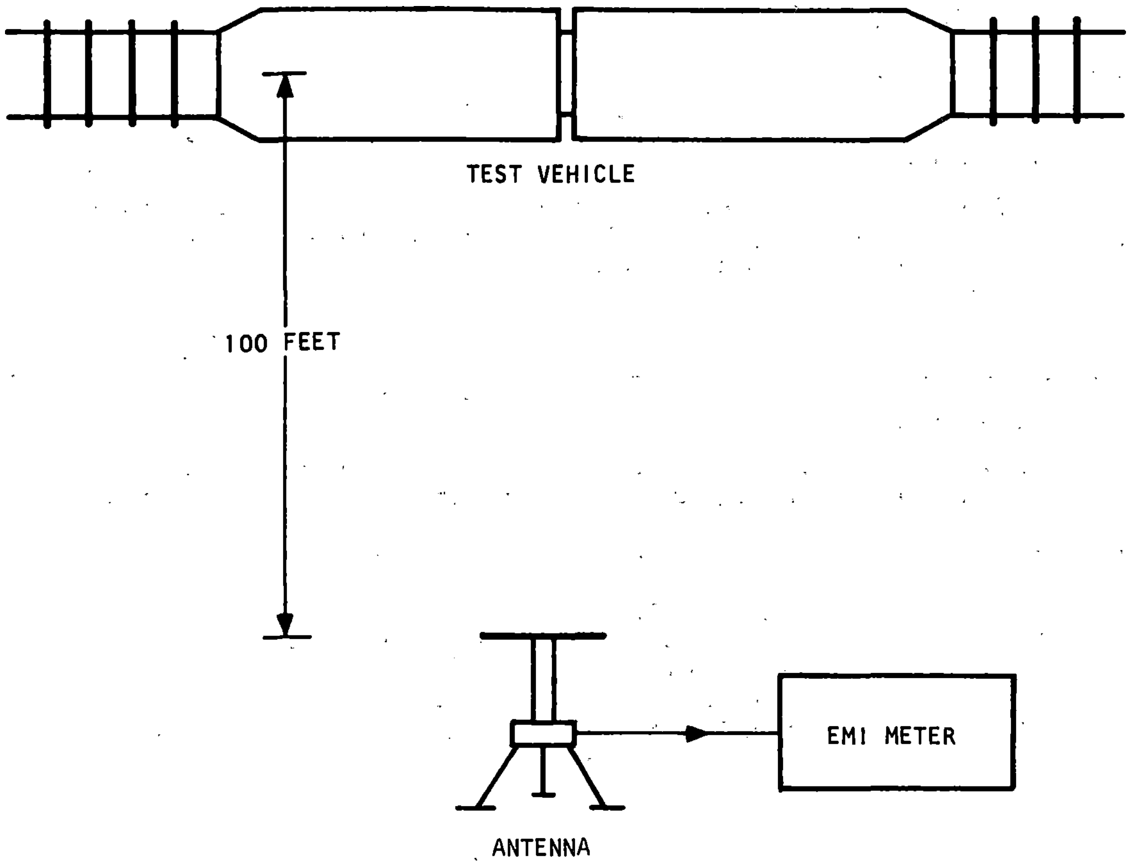


Figure 1-8. Radio Frequency Interference - Exterior Test Instrumentation

TEST TITLE: ACCELERATION

TEST SET NUMBER: ESC-P-2001-TT

(Options 1 and 2)

TEST OBJECTIVE:

To determine the overall acceleration characteristics of the test vehicle as affected by controller input level, line voltage, car weight (load weighing, car direct, and train consist.

TEST DESCRIPTION:

The test vehicle will be accelerated at the required controller command on level tangent track. The following (example) combinations will be tested:

Procedure Option	Prime Variable	Test Conditions
(4)	Controller level	Half and full power
(6)	Line voltage	Min: 600: and max. volts
(5)	Car weights	AWO; AW2; AW3
(3)	Car direction	Forward and reverse
(7)	Train consists	Single car and 4-car train

STATUS:

The energy storage cars successfully completed the acceleration tests as prescribed by the conditions specified in paragraph 2.1.2. Refer to test log runs 49 and 55 presented in Volume I, Appendix C of this report.

TEST TITLE: DECELERATION-BLENDED BRAKING

TEST SET NUMBER: ESC-P-3001-TT

(Options 1 through 3)

TEST OBJECTIVE:

To determine the overall deceleration characteristics of the test vehicle utilizing the blended braking system as affected by controller input level, line voltage, car weight (load weighing), car direction, and train consist. Regeneration capability will be tested at varying line "load".

TEST DESCRIPTION:

The test vehicle will be decelerated at the required controller command on level tangent track. The following (example) test combinations will be tested:

Procedure Option:	Prime Variable	Test Conditions
(5)	Controller Level	Half and full brake
(6)	Car weights	AW0; AW2; AW3
(7)	Line voltage	Min; 600; and max. volts
(8)	Train consists	Single car and 4-car train
(4)	Car direction	Forward and reverse
(10)	Regeneration "load"	100 percent and 50 percent line receptivity

STATUS:

The energy storage cars successfully completed the blended braking deceleration tests as prescribed by the conditions specified in paragraph 3.1.2. Refer to test log runs 55 and 76 presented in Volume I, Appendix C of this report.

TEST TITLE: DECELERATION - SERVICE FRICTION

TEST SET NUMBER: ESC-P-3002-TT

(Options 1 through 3)

TEST OBJECTIVE:

To determine the overall deceleration characteristics of the test vehicle utilizing the friction braking only system as affected by controller input level, car weight (load weighing), car direction, and train consist.

TEST DESCRIPTION:

The test vehicle will be decelerated at the required controller command on level tangent track. The following (example) test combinations will be tested:

Procedure Option	Prime Variable	Test Conditions
(5)	Controller level	Half and full brake
(6)	Car weights	AW0; AW2; AW3
(7)	Train consists	Single car and 4-car train
(4)	Car direction	Forward and reverse

STATUS:

The energy storage cars successfully completed the service friction deceleration tests as prescribed by the conditions specified in paragraph 4.1.2. Refer to test log runs 54, 55, 67 and 76 presented in Volume I, Appendix C of this report.

TEST TITLE: TRACTION RESISTANCE (DRIFT)

TEST SET NUMBER: ESC-P-4001-TT

(Option 1)

TEST OBJECTIVE:

To determine the traction (train) resistance of the test vehicle for use in the analysis of adhesion test data, to check the coefficients used to calculate the design performance of the vehicle, and as a baseline for analysis of the vehicle tractive and braking effort values.

TEST DESCRIPTION:

During the drift tests the test consists will be allowed to coast from an initial speed on level tangent track. Both propulsion and friction brake systems will be disabled to attain a true coast. The speed-time-distance data will be the source of the final resistance values.

Procedure Option	Prime Variable	Test Conditions
(2)	Car weight	AW0 and AW2
(3)	Train consist	Single car and 4-car train

STATUS:

The energy storage cars successfully completed the traction resistance tests as prescribed by the conditions specified in paragraph 5.1.2. Refer to test log runs 34, 71, 74 and 76 presented in Volume I, Appendix C of this report.

TEST TITLE: FRICTION BRAKE DUTY CYCLES

TEST SET NUMBER: ESP-P-5001-TT

TEST OBJECTIVE:

To determine the thermal capacity of the vehicle's friction braking system during a sample service run. The dynamic brake system will be inoperative during the tests with the friction brake providing all of the decelerating force, as applicable.

TEST DESCRIPTION:

The test vehicle will be accelerated to a target cruise speed, cruise for a defined time, and brake to a simulated station stop. Following a defined station dwell the cycle will be repeated.

Procedure Option	Prime Variable	Test Conditions
(1)	Cruise speed and time	35 mph for 45 sec. 50 mph for 55 sec.
(2)	Car weight	AW2 (or AW3)
(3)	Brake type	Solid and resilient wheels
(5)	Brake blending	Blended and frict. only

STATUS:

The energy storage cars successfully completed the friction brake duty cycle tests as prescribed by the conditions specified in paragraph 6.1.2. Refer to test log runs 77 and 81 presented in Volume I, Appendix C of this report.

TEST TITLE: POWER CONSUMPTION

TEST SET NUMBER: ESC-PC-5011-TT

TEST OBJECTIVE:

To determine the power consumption of the test vehicle while operating on a sample service route at a defined level of schedule performance. The tests will provide a measure of car schedule performance, power consumption (regeneration), and overall traction system efficiency.

TEST DESCRIPTION:

The car(s) will be operated over a simulated route with stops at specified stations. Normal service performance will be used. Power consumed by the traction and auxiliaries will be measured for each stop and the round-trip

Examples of test conditions

Procedure Options	Prime Variable	Test Conditions
(1)	Car weight	AW2
(2)	Regeneration	100 percent and 0 percent
(3)	Regenerative "load"	100 percent and 50 percent
(4)	Line voltage	Min; 600; max. volts
(5)	Train consists	Single car and 4-car train

STATUS:

The energy storage cars successfully completed the power consumption tests as prescribed by the conditions specified in paragraph 7.1.2. Refer to test log runs 35 through 48 presented in Volume I, Appendix C of this report.

TEST TITLE: RADIO FREQUENCY INTERFERENCE

TEST SET NUMBER: ESC-PSI-6001-TT

TEST OBJECTIVE:

To determine levels of broadband radiated electromagnetic emission from the test vehicle to the wayside.

TEST DESCRIPTION:

This test to be performed with test vehicle passing by a wayside station ujder each of the following conditions:

(a) Acceleration above and below base speed
(b) Constant speed
(c) Braking

STATUS:

The energy storage cars successfully completed the radio frequency interference tests as prescribed by the conditions specified in paragraph 8.1.2. Refer to test log runs 80 through 82 presented in Volume I, Appendix C of this report.

2. ACCELERATION
(ESC-P-2001-TT)

2.1 SUMMARY

The performance acceleration test for the energy storage cars was conducted in compliance with Test Set Number ESC-P-2001-TT (options 1 and 2) of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 2.1.1 through 2.2.2. Refer to paragraph 2.3 for a description of the test, instrumentation used, and for the test results.

2.1.1 TEST OBJECTIVE

To determine the overall acceleration characteristics of the test vehicle as affected by controller input level, line voltage, car weight (load weighing), car direction, and train consist.

2.1.2 TEST DESCRIPTION

The test vehicle will be accelerated at the required controller command on level tangent track. The following combinations will be tested.

Procedure Option	Prime Variable	Test Conditions
(4)	Controller level	Half and full power
(6)	Line voltage	Min., 600, and max, volts
(5)	Car weights	AW0, AW2, and AW3
(3)	Car direction	Forward and reverse
(7)	Train consists	Single car and 4-car train
(1 & 2)	See procedure	See procedure

2.1.3 STATUS

The energy storage cars successfully completed the acceleration tests as prescribed by the conditions specified in paragraph 2.1.2. Refer to test log runs 49 and 55 presented in Volume I, Appendix C of this report.

2.2 PROCEDURES

The following test procedures are included as part of the ESC-P-2001-TT Test Set. These procedures were used, unless otherwise noted in paragrah 2.3, for the energy storage car acceleration tests.

2.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop.

(b) Add ballast weights to simulate desired car weight.

(c) Check out and calibrate instrumentation.

(d) Photograph instrumentation (location of transducers/sensors, etc.)

(e) Make up desired train consist.

(f) Proceed to test zone.

(g) Make inspection passes over test zone; check out vehicle and track.

(h) Record ambient conditions as required.

(i) Make several full-power accelerations on test zone such that line voltage at full power can be adjusted to the desired value for testing.

2.2.2 TEST PROCEDURE

(a) Position car for testing from Station 300 to Station 340 (clockwise): forward anticlimber at Station 300. Identify test record.

(b) Start recording instrumentation.

(c) Move controller to desired input position as rapidly as possible (step input).

(d) Start timing devices and put event mark on recorders at time of control input <u>or</u> "first sensed car motion" as required by specific test program.

(e) Accelerate vehicle at the fixed input command for the full 4000 foot test zone.

(f) If required, put event mark on recorders at each track distance marker as forward anticlimber passes each point. (Required if carborne distance instrumentation is not in use.

(g) After passing Station 340, note car speed and stop recorders.

(h) Stop vehicle and reposition for next test record.

Option 1 If car weight or input command result in less than maximum car speed at Station 340, the next test record will be an acceleration at the previous input command but from the speed at test zone exit (step g) instead of from a standing start. The following procedure applies:

(1-a) Position car such that the speed attained in step g can be obtained at Station 300. Identify test record.

(1-b) Put controller in desired input position and accelerate car to test entry speed. Maintain test entry speed as test zone is approached.

(1-c) Start recording instrumentation prior to entering test zone.

(1-d) Start timing devices, put event mark on recorders, and move controller to desired input command as forward anticlimber passes Station 300.

(1-e through 1-h) Repeat steps e through h.

Option 2 Report steps a through 1-h as required to provide sufficient confidence in data accuracy.

Option 3 Repeat steps a through 1-h in reverse direction; Station 340 to Station 300, as required.

Option 4 Repeat steps a through 1-h at the desired input command positions.

Option 5 Repeat steps a through 1-h at the desired car weights.

Option 6 Repeat steps a through 1-h at the desired line voltages.

Option 7 Repeat steps a through 1-h with the desired train consists.

2.3 TEST DESCRIPTION AND RESULTS

The energy storage car (ESC) acceleration tests were conducted in accordance with AiResearch Documents 73-9373 and 74-10441 as defined in paragraph 2.3.1 and in compliance with GSP-064 Test Set ESC-P-2001-TT, described in paragraphs 2.1.1 and 2.1.2.

2.3.1 DESCRIPTION

The ESC acceleration tests were performed at AW0, AW2 and AW3 car weights to determine the acceleration characteristics of the two-car train for each of the three acceleration operating modes; switching, series and parallel in both forward and reverse directions. These modes are only simulated in the ESC system so that the tractive effort is matched to the original R-32 cars for corresponding trainline signals generated by the master controller.

Initially, the cars were located at the beginning of the level tangent track, with the flywheel operating at a steady state value. Thereupon, the cars were accelerated to approximate balance speed and then stopped. With sufficient level tangent track still available, the test was repeated as soon as practical. A minimum of three runs were made for each accelerating mode in each direction. Each mode sequence was accomplished in as short a time period as practical to minimize effects of ambient wind changes.

The following parameters were recorded for each of the runs using the test procedures described in paragraph 2.2:

(a) Third rail voltage

(b) Third rail current

(c) Flywheel armature voltage

(d) Flywheel armature current

(e) Traction armature current

(f) Car distance

(g) Car speed

(h) Flywheel speed

(i) Car command signal

(j) Acceleration

2.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of instrumentation related to the ESC acceleration tests is shown in figure 1-3. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

2.3.3 RESULTS

Representative samples of the ESC acceleration test results are presented in figures 2-1 through 2-10.

Vehicle acceleration performance extracted from the test data are shown in figures 2-1 through 2-4 in the form of speed, distance and acceleration plotted against time. Figure 2-5 shows distance plotted against time; figure 2-6 shows acceleration plotted aginst speed and figure 2-7 shows a time history of an acceleration run with vehicle performance parameters versus time.

Corresonding electrical system parameters for accelerating conditions at different car weights are shown in figures 2-8 and 2-9. Figure 2-10 shows representative component temperatures for an extended series of accelerations in the switching, series and parallel modes.

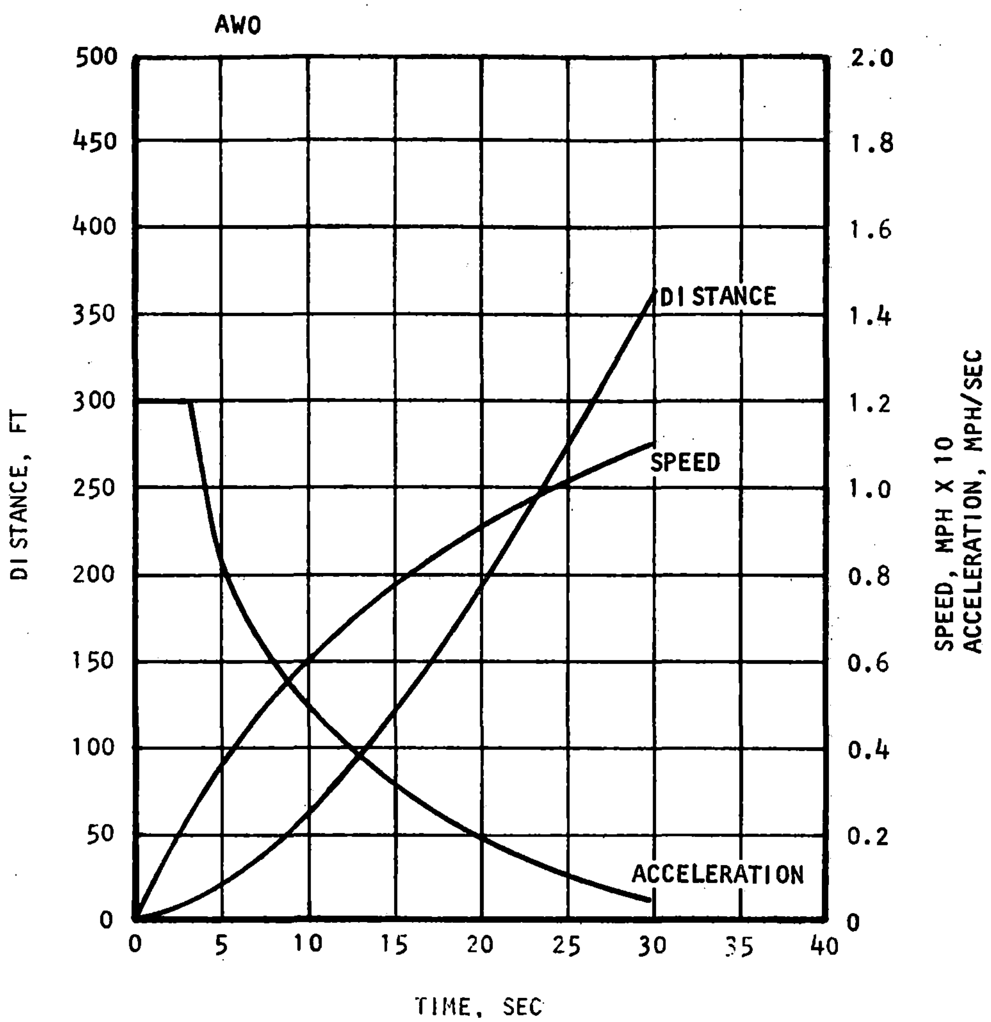


Figure 2-1. Switching Mode Forward Acceleration

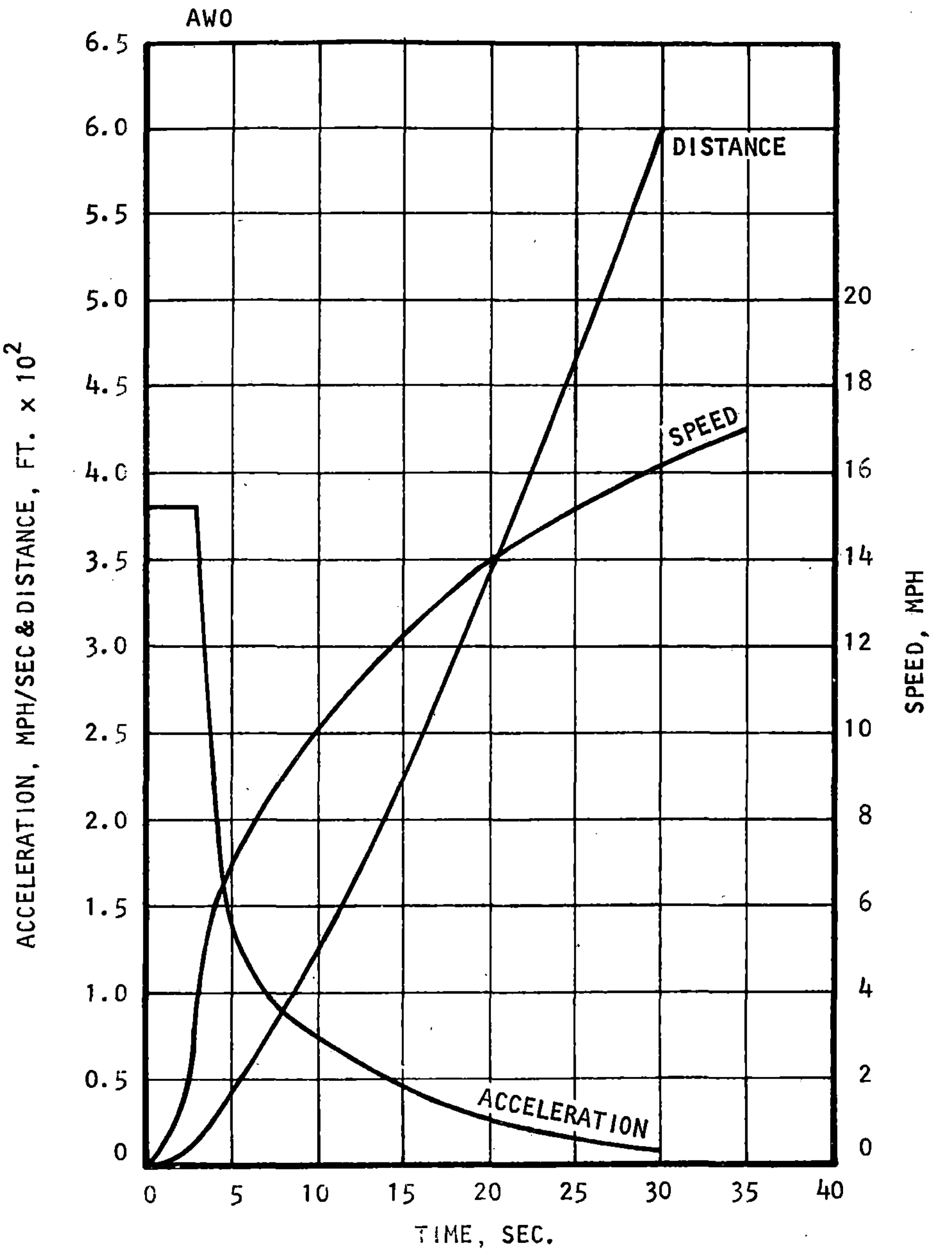


Figure 2-2. Series Mode Forward Acceleration

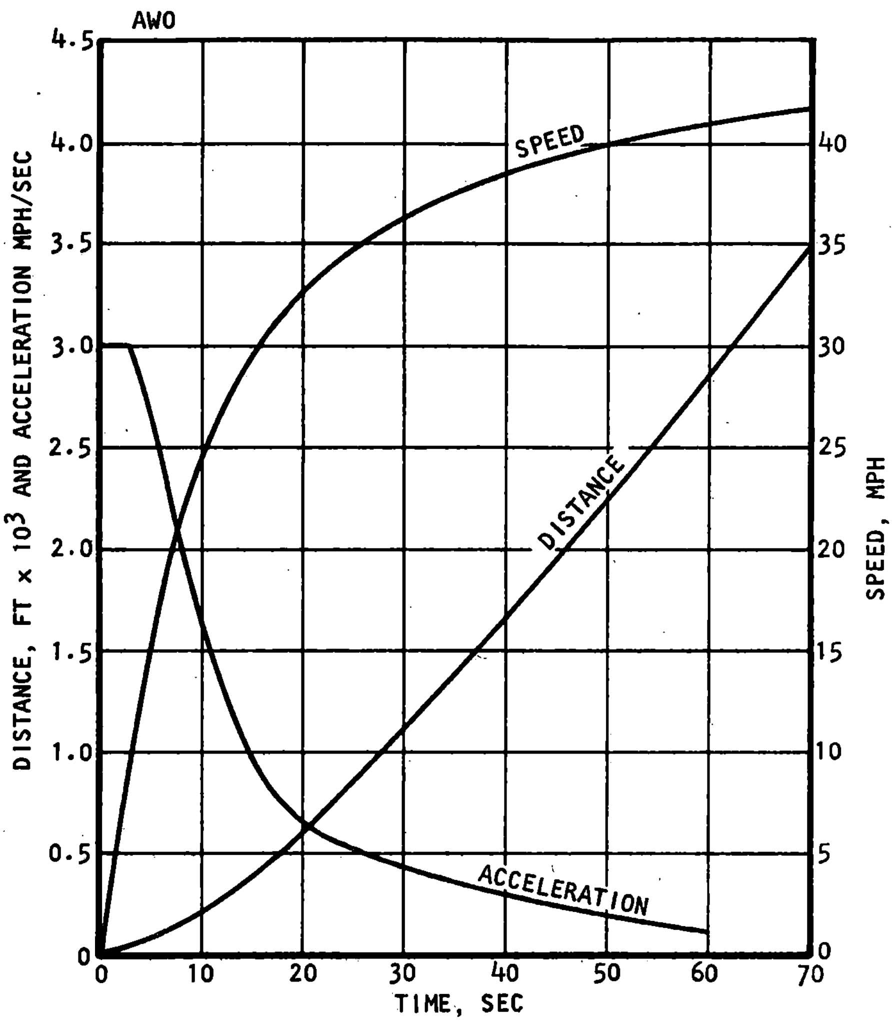
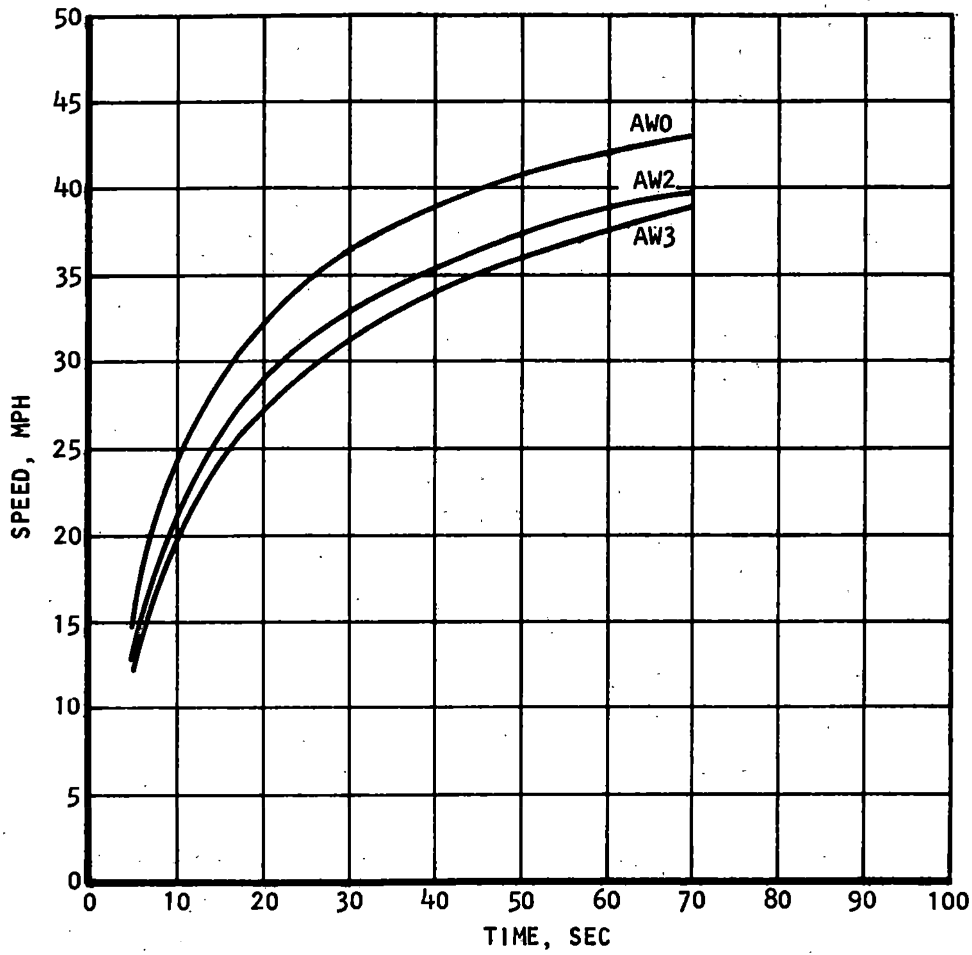


Figure 2-3. Parallel Mode Forward Acceleration



NOTE: Forward operation is approximately 0.5 to 1.0 mph faster than reverse operation.

Figure 2-4. Parallel Mode Reverse Acceleration

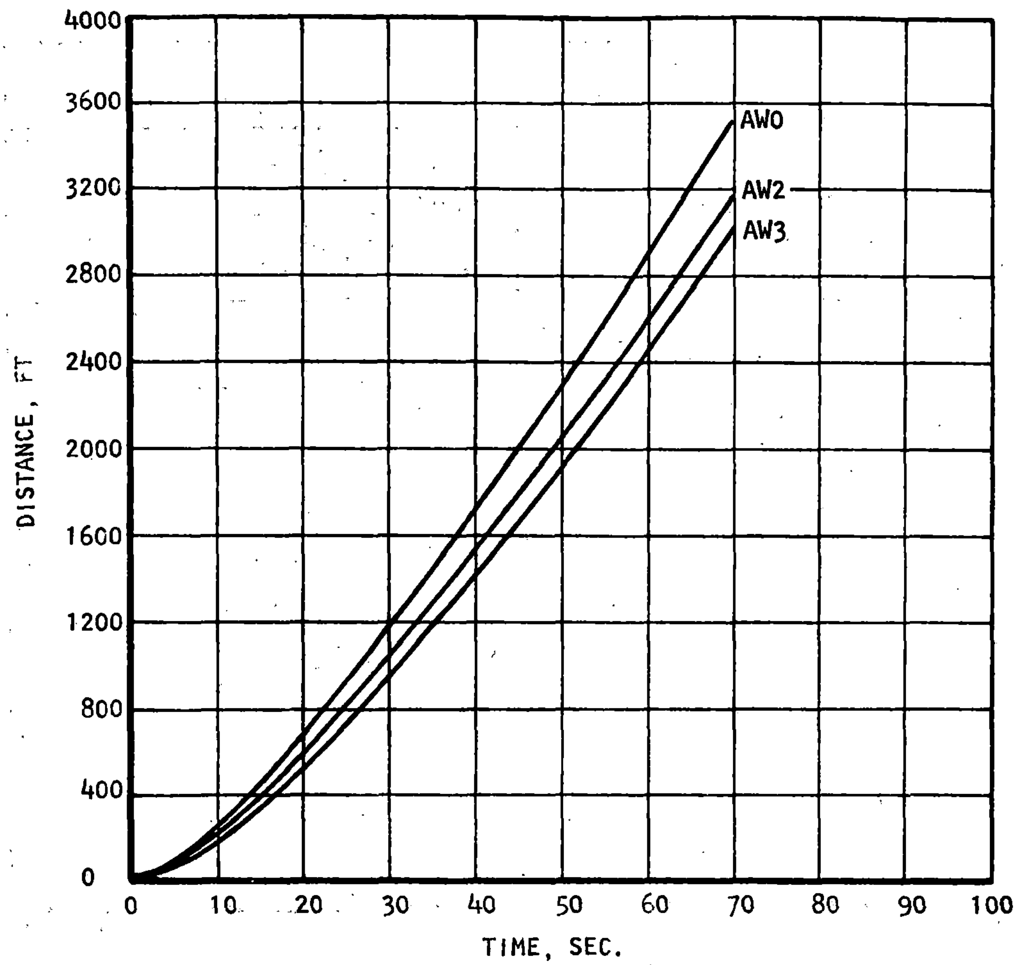


Figure 2-5. Parallel Mode Distance vs Time

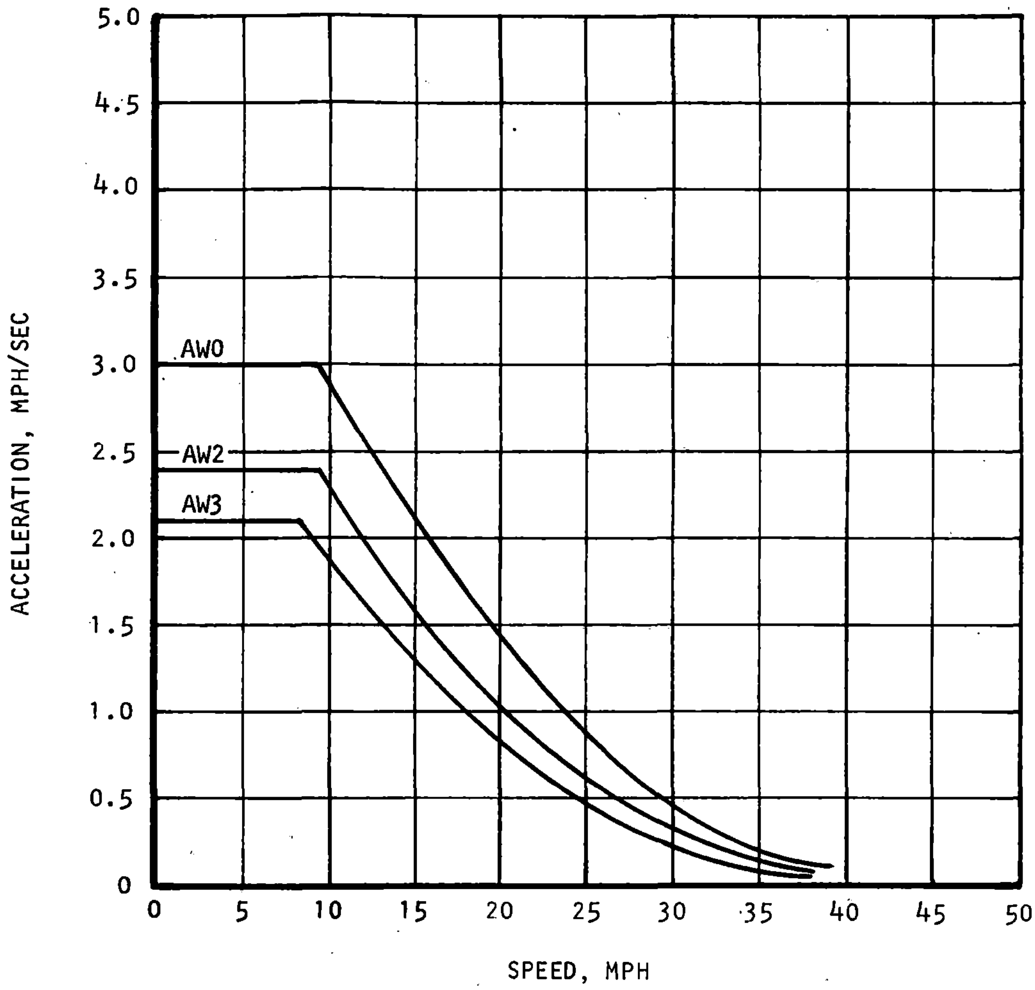


Figure 2-6. Parallel Mode Acceleration vs Speed

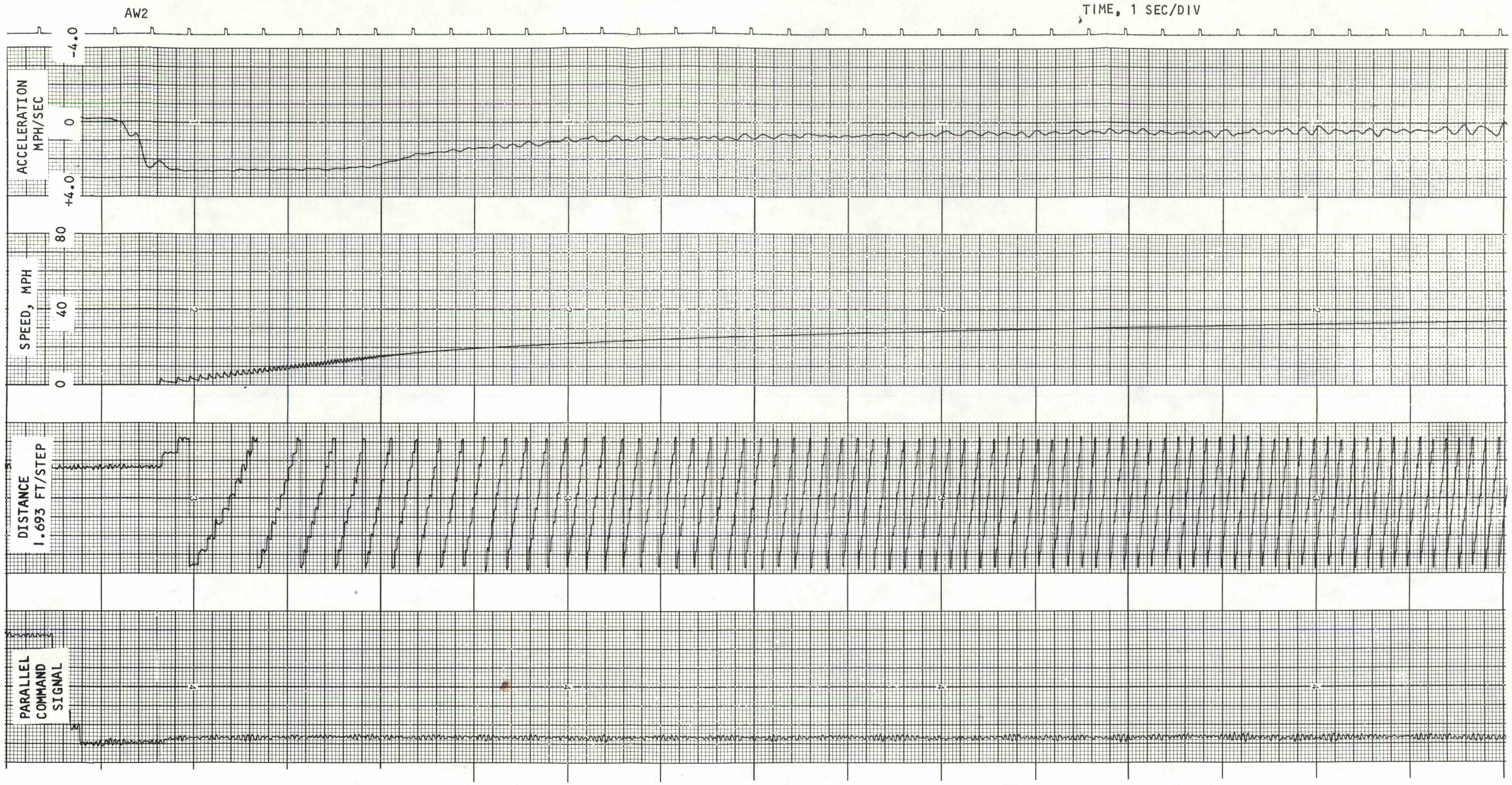


Figure 2-7. Parallel Mode Reverse Acceleration

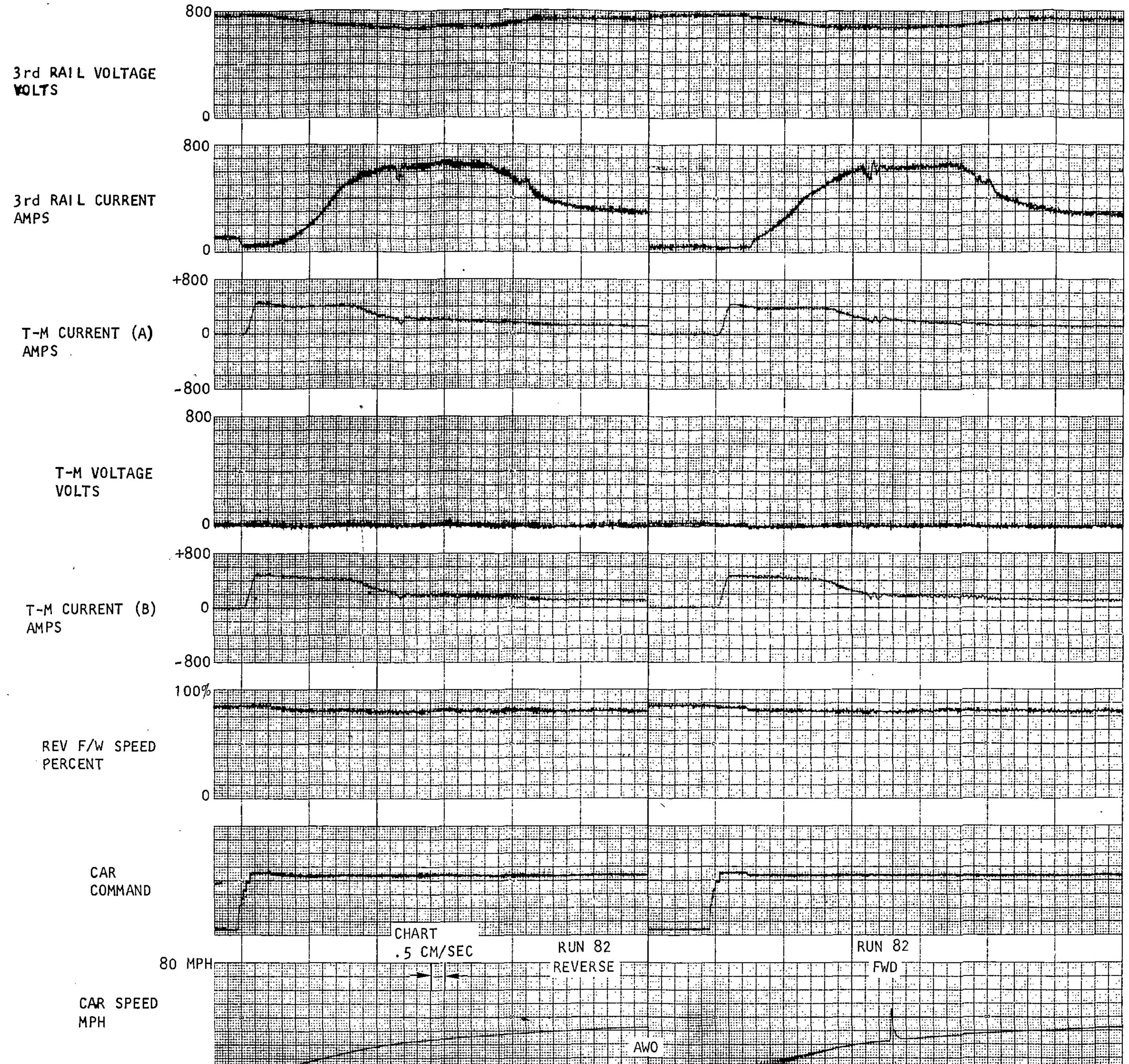


Figure 2-8. Full Parallel Mode AWO Acceleration

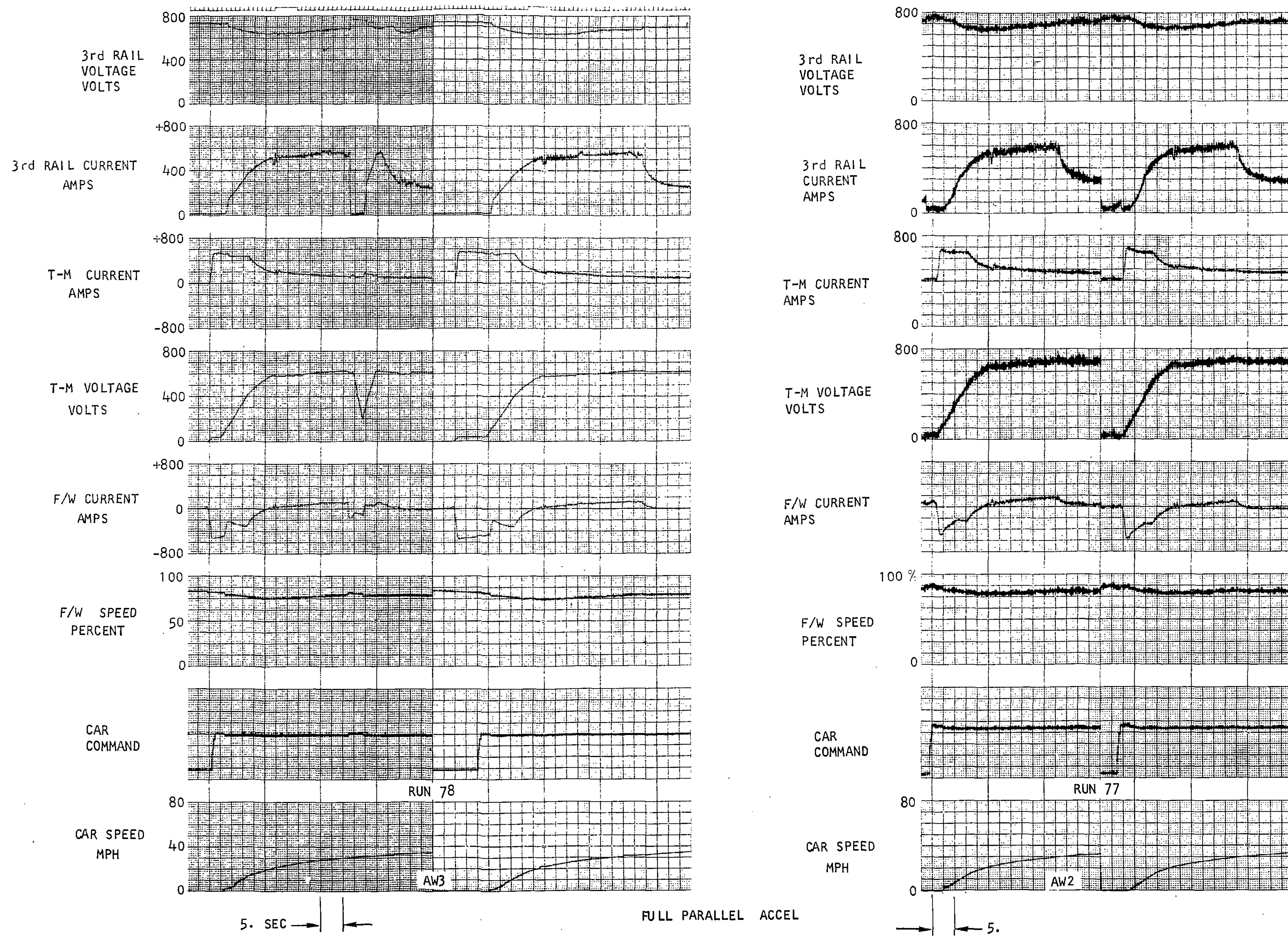


Figure 2-9. Full Parallel Mode AW2 and AW3 Acceleration

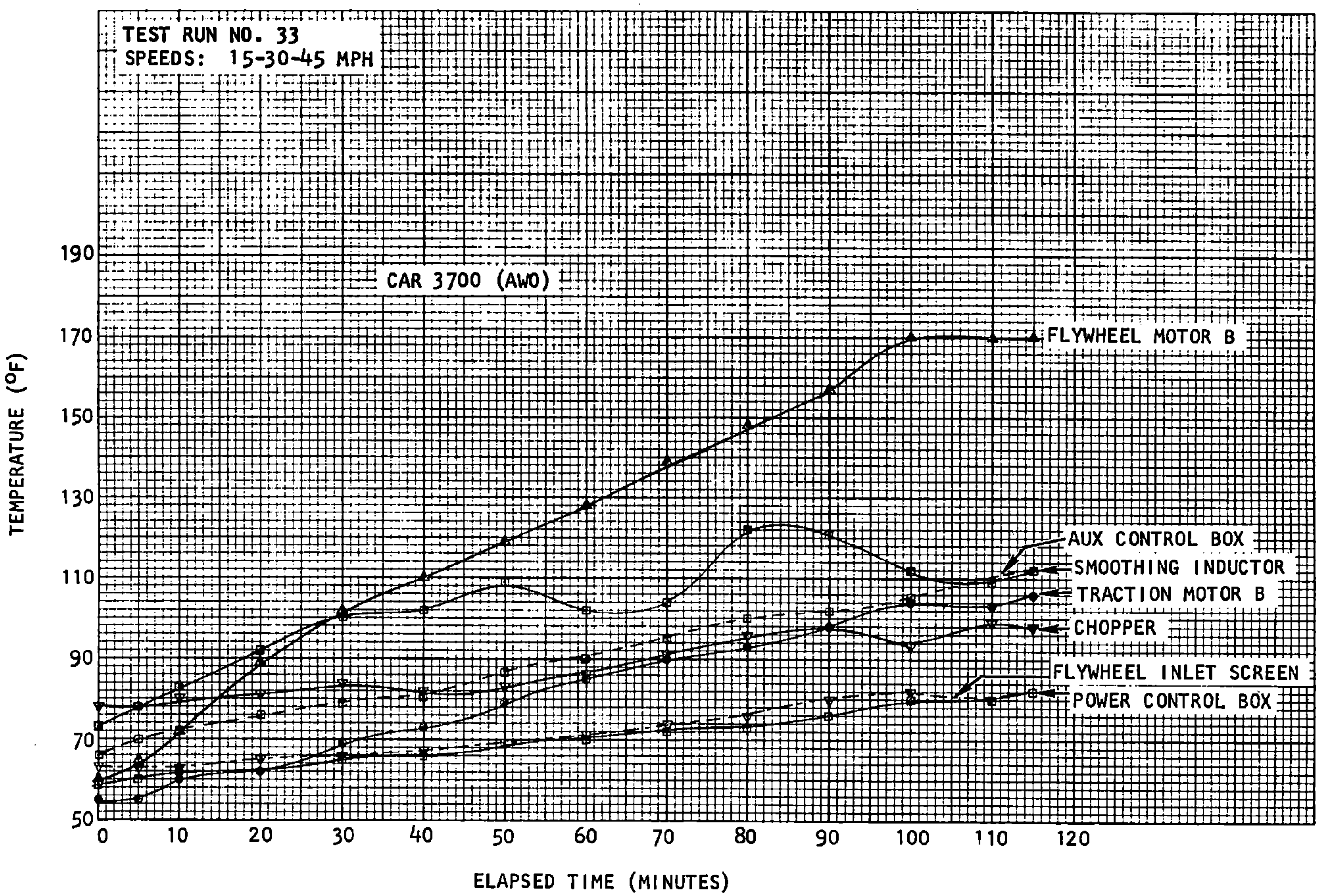


Figure 2-10. Component Temperatures vs Time

3. DECLERATION - BLENDED BRAKING (ESC-P-300L-TT)

3.1 SUMMARY

The performance blended-braking decleration test for the energy storage cars was conducted in compliance with Test Set Number ESC-P-3001-TT (options 1 through 3) of the General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 3.1.1 through 3.2.2. Refer to paragraph 3.3 for a description of the test, instrumentation used, and for the test results.

3.1.1 TEST OBJECTIVE

To determine the overall deceleration characteristics of the test vehicle utilizing the blended braking system as affected by controller input level, line voltage, car weight (load weighing), car direction, and train consist. Regeneration capability will be tested at varying line load.

3.1.2 TEST DESCRIPTION

The test vehicle will be decelerated at the required controller command on level tangent track. The following test combinations will be tested.

Procedure Option	Prime Variable	Test Conditions
(5)	Controller level	(Half and full brake)
(6)	Car weights	(AWO, AW2, and AW3)
(7)	Line voltage	(Min., 600, and max. volts)
(8)	Train consists	Single car and 4-car train
(4)	Car direction	Forward and reverse
(10)	Regeneration load	100% and 50% line receptivity
(1 thru 3)	See procedure	See procedure

3.1.3 STATUS

The energy storage cars successfully completed the blended braking deceleration tests as prescribed by the conditions specified in paragrah 3.1.2. Refer to test log runs 55 and 76 presented in Volume I, Appendix C of this report.

3.2 PROCEDURES

The following test procedures are included as part of the ESC-P-3001-TT Test Set. These procedures were used, unless otherwise noted in paragraph 3.3, for the energy storage car blended braking deceleration tests.

3.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop.

(b) Add ballast weights to simulate desired car weight.

(c) Check out and calibrate instrumentation.

(d) Photograph instrumentation (location of transducers/sensors, etc.).

(e) Make up desired train consist.

(f) Proceed to test zone.

(g) Make inspection passes over test zone. Check out vehicle and track.

(h) Record ambient conditions as required.

(i) Adjust track voltage as required for specifed tests. (Track voltage will affect brake blending during regenerative brake tests.)

(j) Adjust line receptivity (load) for regenerated power as required (substation load banks).

3.2.2 TEST PROCEDURE

(a) Test zone is track Station 300 to Station 340 for level tangent track tests. Brake "mark" will be at Station 300 or Station 340 depending on car direction. Car reference point will be the forward anticlimber location.

(b) Accelerate car to target test speed and approach test zone--(Station 300, clockwise) at constant target speed.

(c) Identify test record and start recorders.

(d) As anticlimber passes the brake "mark" (Station 300 clockwise or Station 340 counterclockwise) initiate blended service braking by putting master controller in the desired input position as rapidly as possible (step input).

(e) Start timing devices and put event mark on recorders at time of "brake" input.

(f) Decelerate car to a full stop with master controller in the required input position.

(g) Put event marks on recorders as each off-car distance reference is passed by the forward anticlimber. (Required if distance data is needed and if carborne distance instrumentation is not in use.)

(h) Vehicle Stops: Stop timing devices, put event mark on recorders, stop recorders.

(i) Measure off-car stopping distance as required. (Measure to nearest foot from adjacent 100-foot track station painted on rail.)

(j) Reposition vehicle for next test record.

<u>Option 1</u> If the input command calls for low braking rate, the car may not come to a complete stop in the 4000-foot test zone. In this case the target entry speed for the next record will be the exit speed from the 4000-foot course during the previous record. The following applies:

(k) Repeat steps a through j with target entry speed as defined above.

<u>Option 2</u> Repeat steps a through k as required to provide sufficient confidence in accuracy.

<u>Option 3</u> Repeat steps a through k such that target speeds of 80, 60, 40 and 20 mph are tested (as required).

<u>Option 4</u> Repeat steps a through k in the reverse car direction as required. Station 340 becomes the "brake" mark.

<u>Option 5</u> Repeat steps a through k at the desired input command positions.

<u>Option 6</u> Repeat steps a through k at the desired car weights.

<u>Option 7</u> Repeat steps a through k at the desired line voltages.

<u>Option 8</u> Repeat stpes a through k with the desired train consists.

<u>Option 9</u> Repeat steps a through k with the desired brake blending ratios (dynamic/friction).

<u>Option 10</u> Repeat steps a through k with the desired line receptivity (regeneration "load") as applicable.

3.3 TEST DESCRIPTION AND RESULTS

The energy storage car (ESC) blended braking deceleration tests were conducted in accordance with AiResearch Documents 73-9373 and 74-10441 as defined in paragraph 3.3.1 and in compliance with GSP-064 Test Set ESC-P-3001-TT, described in paragraphs 3.1.1 and 3.1.2.

3.3.1 DESCRIPTION

The ESC blended braking deceleration tests were performed at AW0, AW2 and AW3 car weights to measure the deceleration characteristics of the two-car train as a function of applied brake pipe pressures.

The cars were accelerated to at least 45 mph prior to reaching the level tangent track section; brake pipe pressure was then set to 15 psig. The run was repeated in the opposite direction for the same pressure setting. This procedure was repeated for 20, 30, and 50 psi pressure and for maximum available pressure.

The following parameters were recorded for each of the runs using the test procedures described in paragraph 3.2:

(a) Third rail voltage

(b) Third rail current (car 3700)

(c) Third rail current (car 3701)

(d) Flywheel armature voltage

(e) Flywheel armature current

(f) Traction armature voltage

(g) Traction armature current

(h) Brake cylinder pressure

(i) Lockout magnetic excitation voltage

(j) Draft gear displacement

(k) Car braking distance

(l) Car speed

(m) Flywheel speed

(n) Car command signal

(o) Deceleration

3.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of instrumentation related to the ESC blended braking deceleration tests is shown in figure 1-3. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

3.3.3 RESULTS

Representative samples of the ECS blended braking deceleration test results are presented in figures 3-1 through 3-7.

Full service braking performance test data is summarized with respect to vehicle weight and shown in figure 3-1. The blended brake performance as a function of air pressure and car weight (AW0, AW2 and AW3) is plotted and shown in figures 3-2 through 3-5. Figure 3-2 (sheets 1 through 3) shows deceleration rate versus car speed; figure 3-3 (sheets 1 and 2) shows stopping time versus car speed; figure 3-4 (sheets 1 and 2) shows stopping distance versus car speed and figure 3-5 shown the deceleration rate plotted against brake setting (pressure).

Time histories showing vehicle performance and corresponding electrical system parameters are shown in figures 3-6 and 3-7. In the blended braking mode of operation, the system is actually braking in the dynamic mode with energy being transferred to the flywheel. The rate of energy transfer is controlled and commanded by the brake air pressure which is locked out. By observing the traction motor and flywheel motor armature current values shown in figure 3-7, the relationship to brake pressure command can readily be seen.

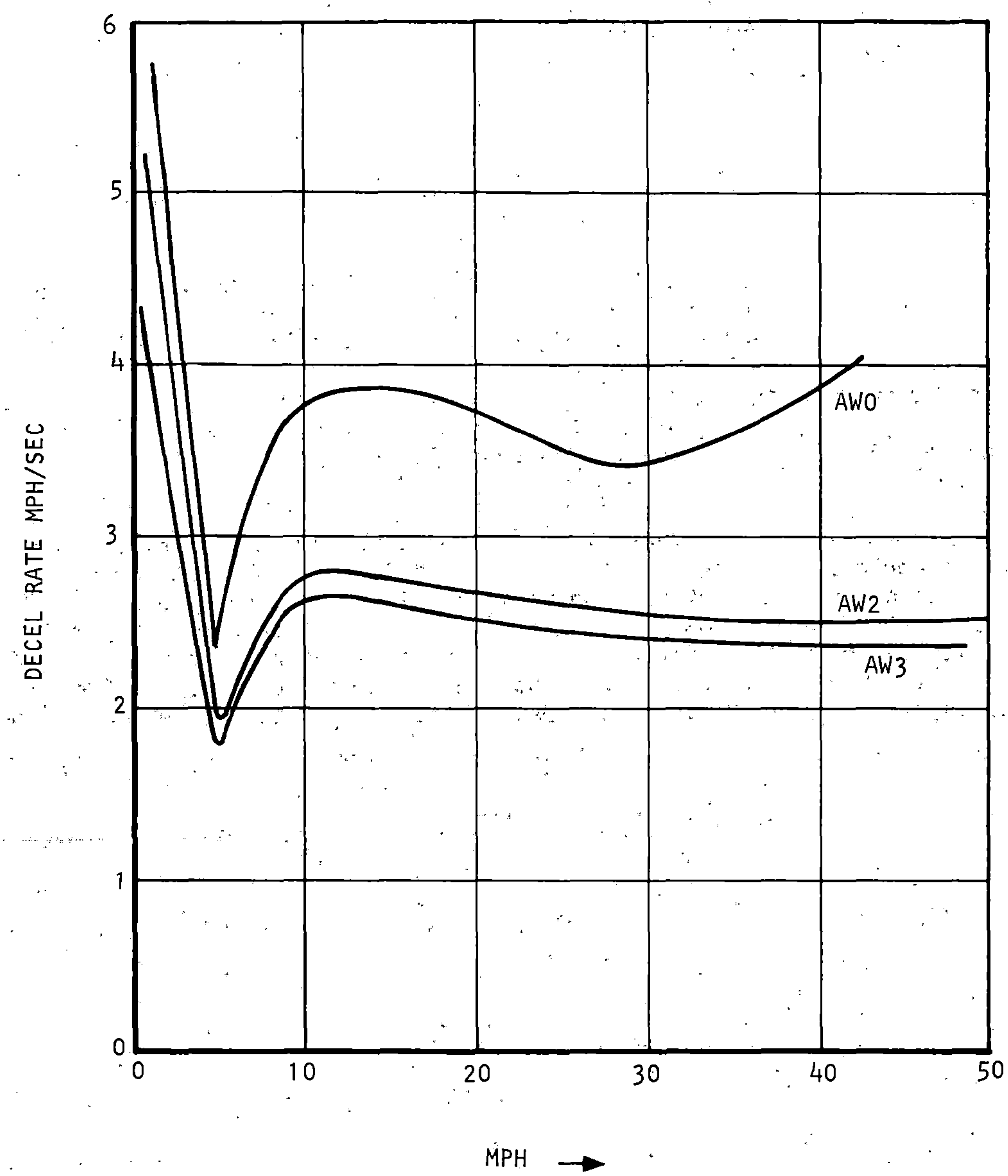


Figure 3-1. Deceleration as a Function of Car Weight - Full Service Brake

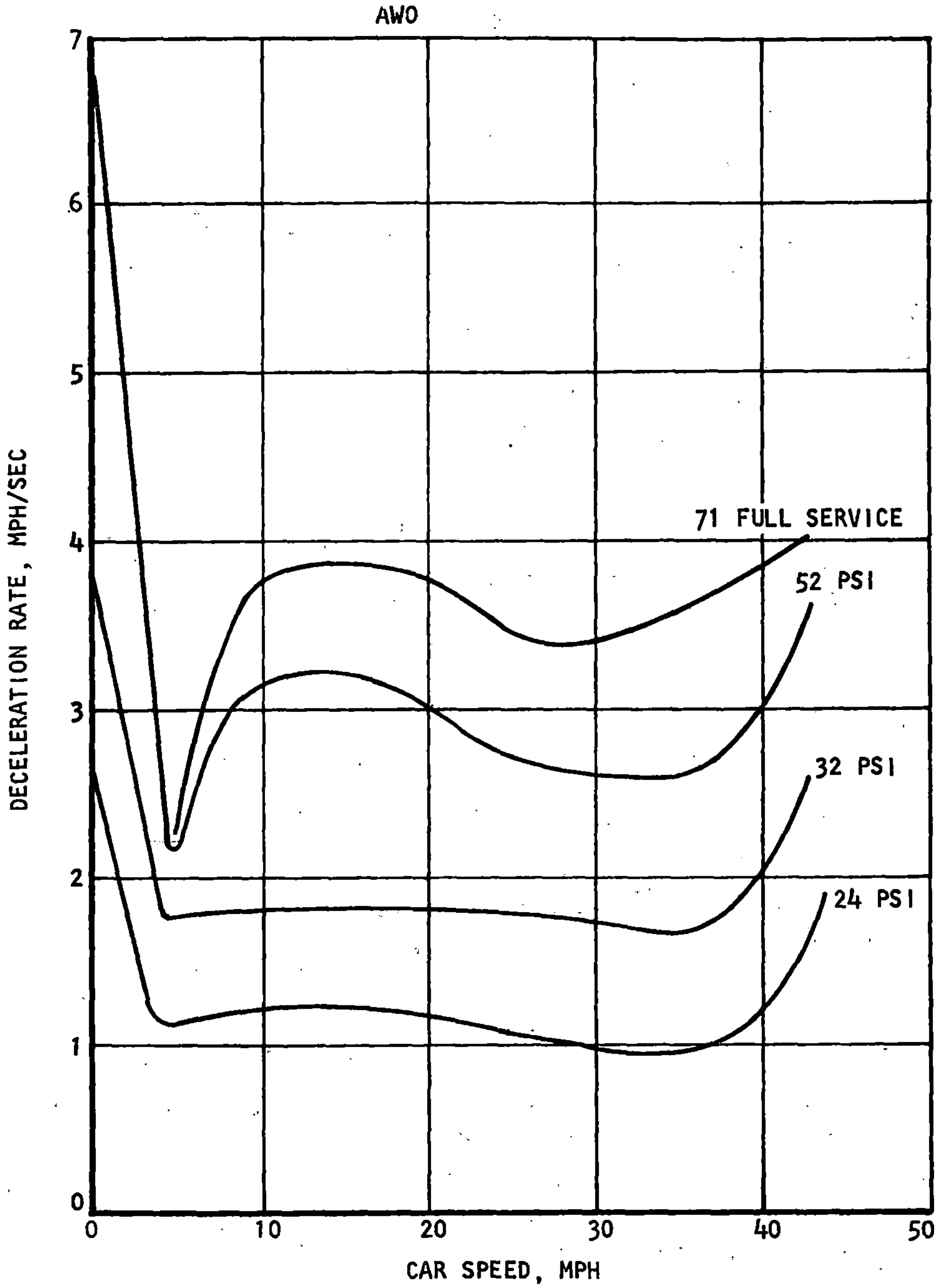


Figure 3-2. Blended Braking - Deceleration vs Speed (Sheet 1)

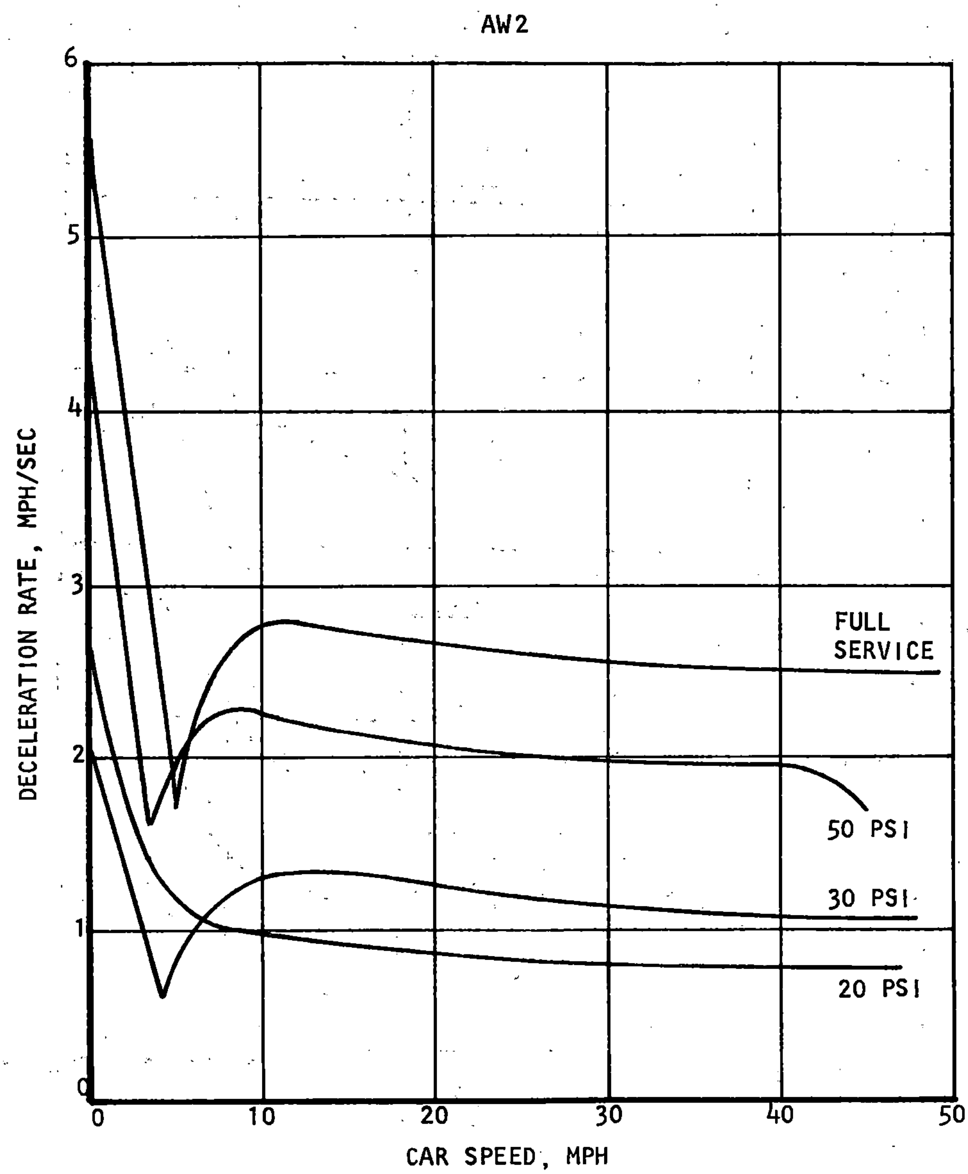


Figure 3-2. Blended Braking - Deceleration vs Speed (Sheet 2)

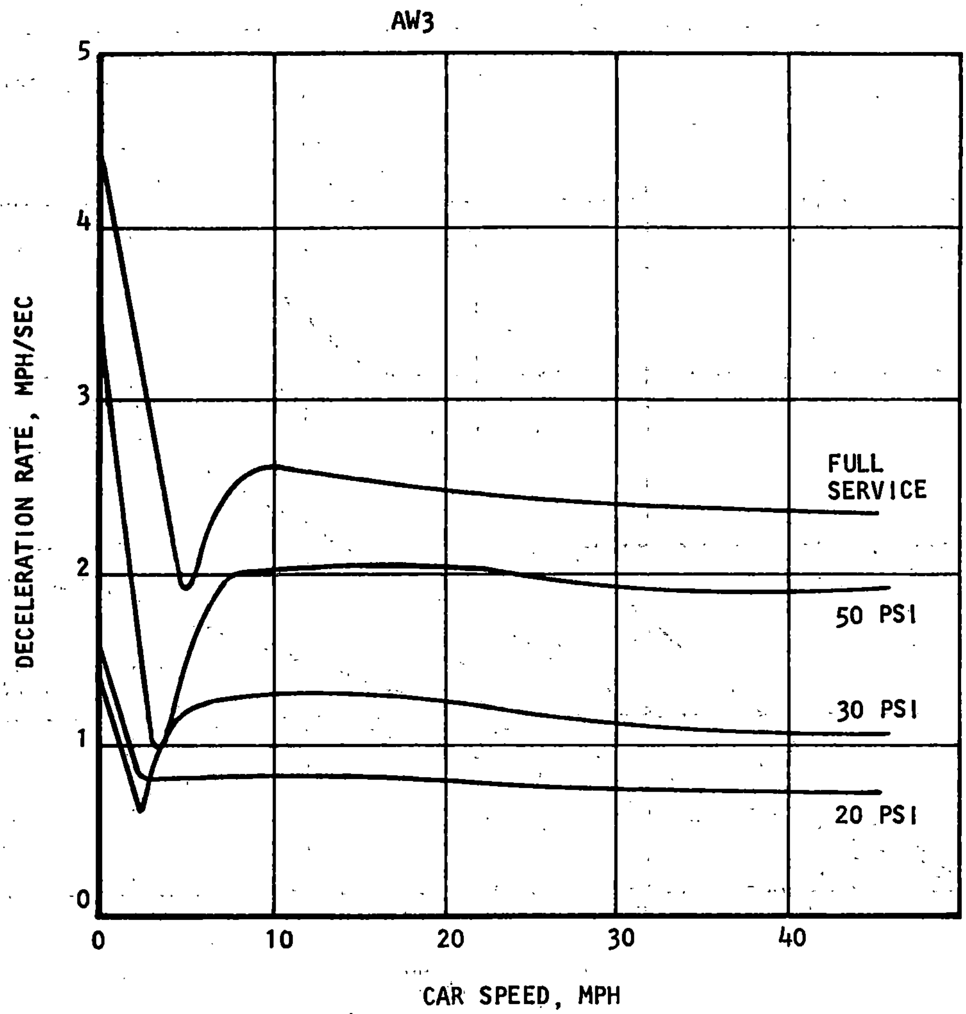


Figure 3-2. Blended Braking - Deceleration vs Speed (Sheet 3)

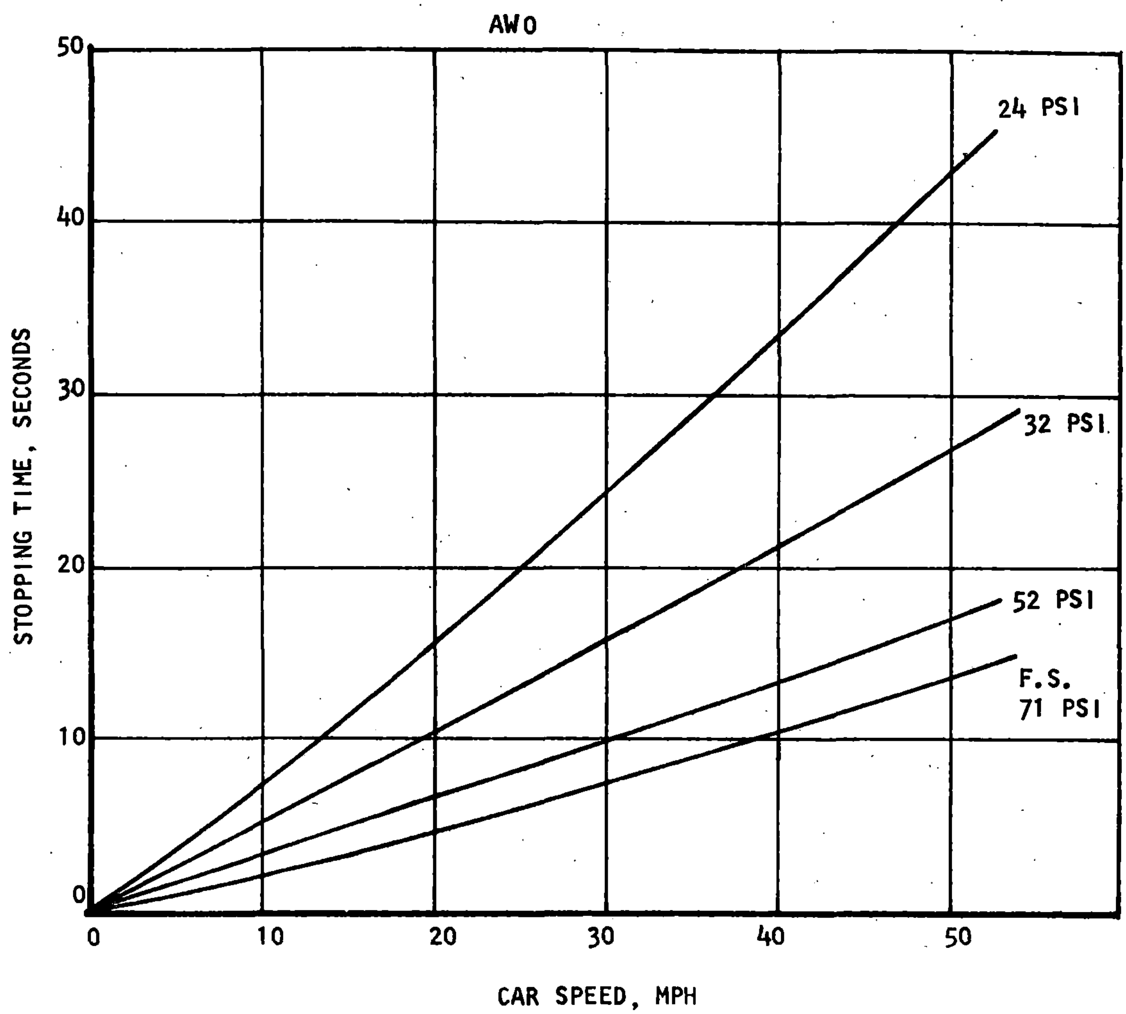


Figure 3-3. Blended Braking - Stopping Time vs Car Speed (Sheet 1)

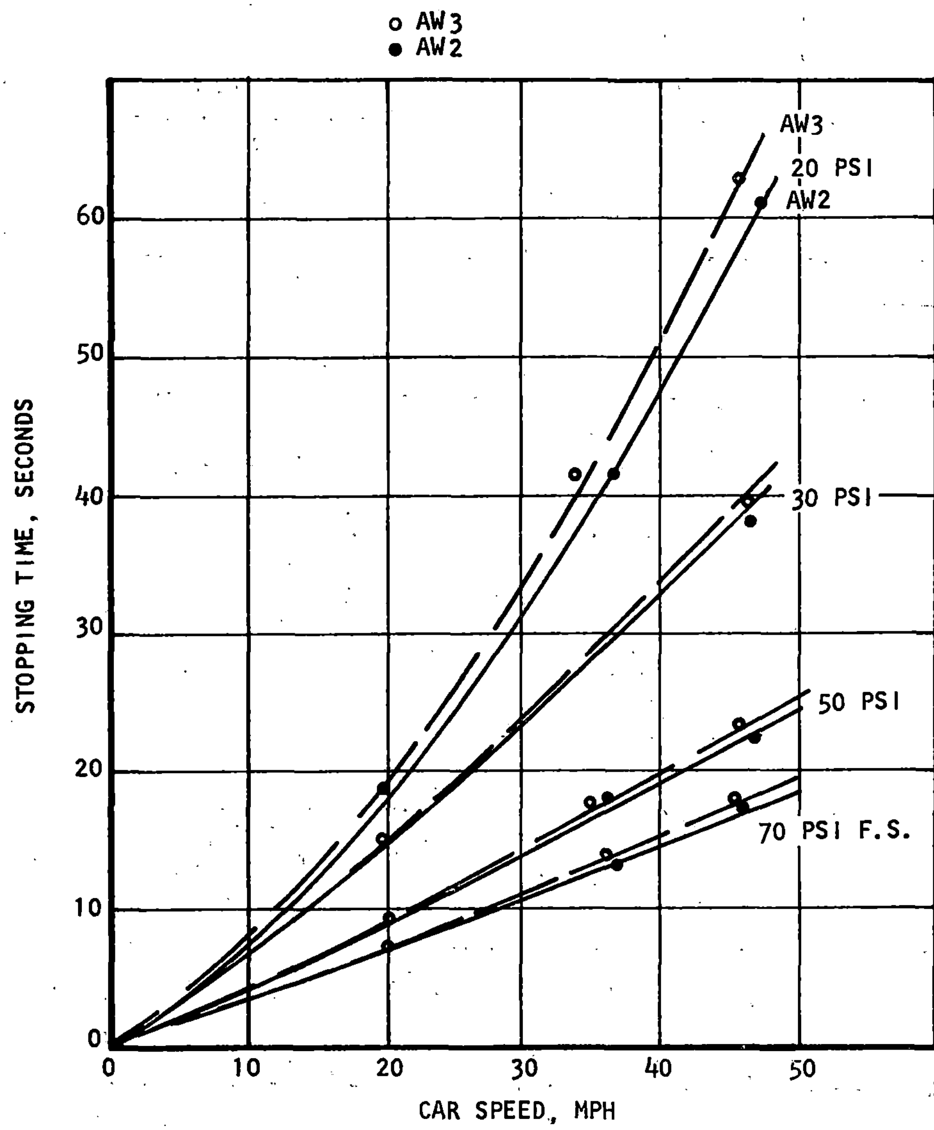


Figure 3-3. Blended Braking - Stopping Time vs Car Speed (Sheet 2)

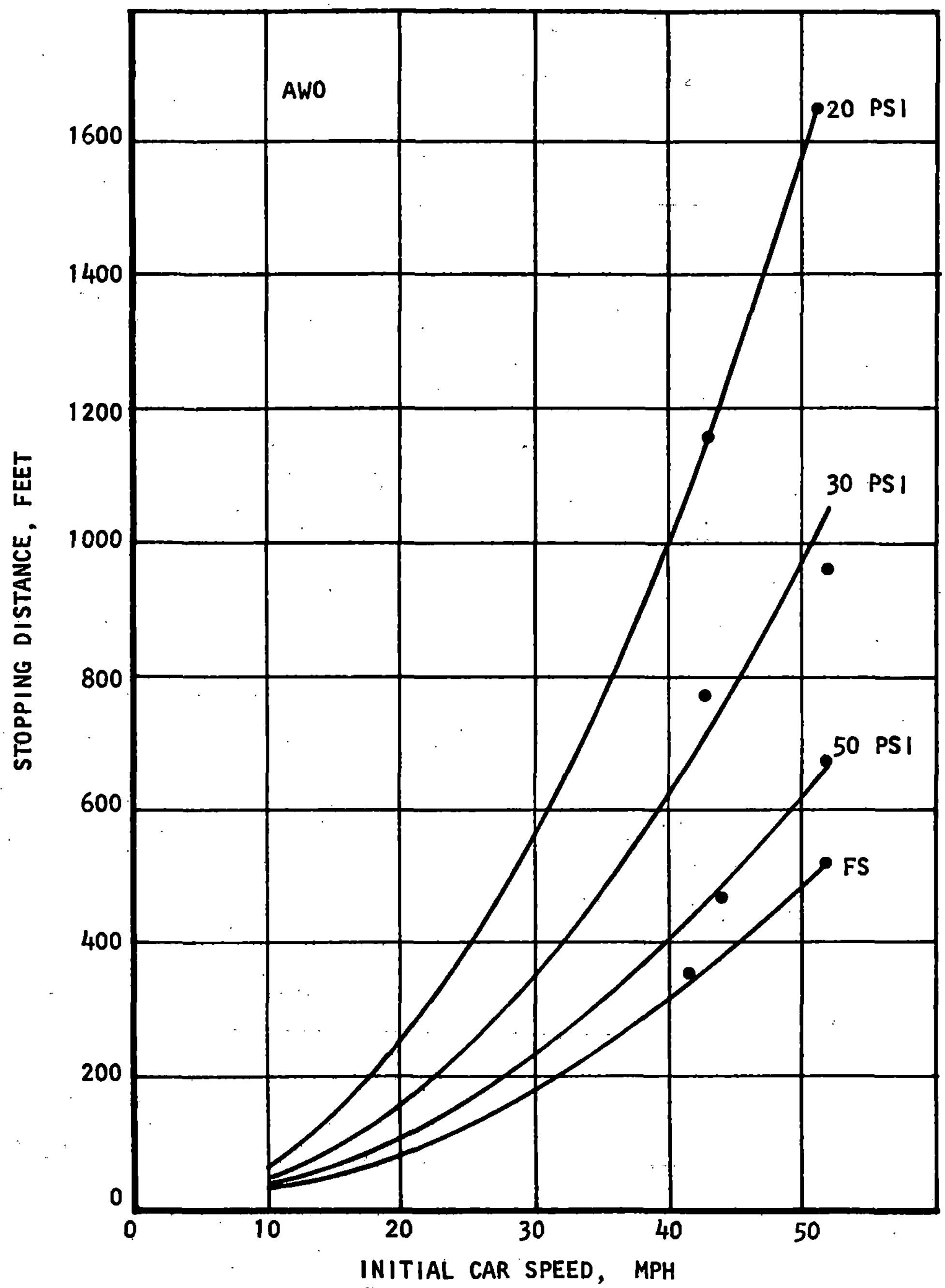


Figure 3-4. Blended Braking - Stopping Distance vs Car Speed (Sheet 1)

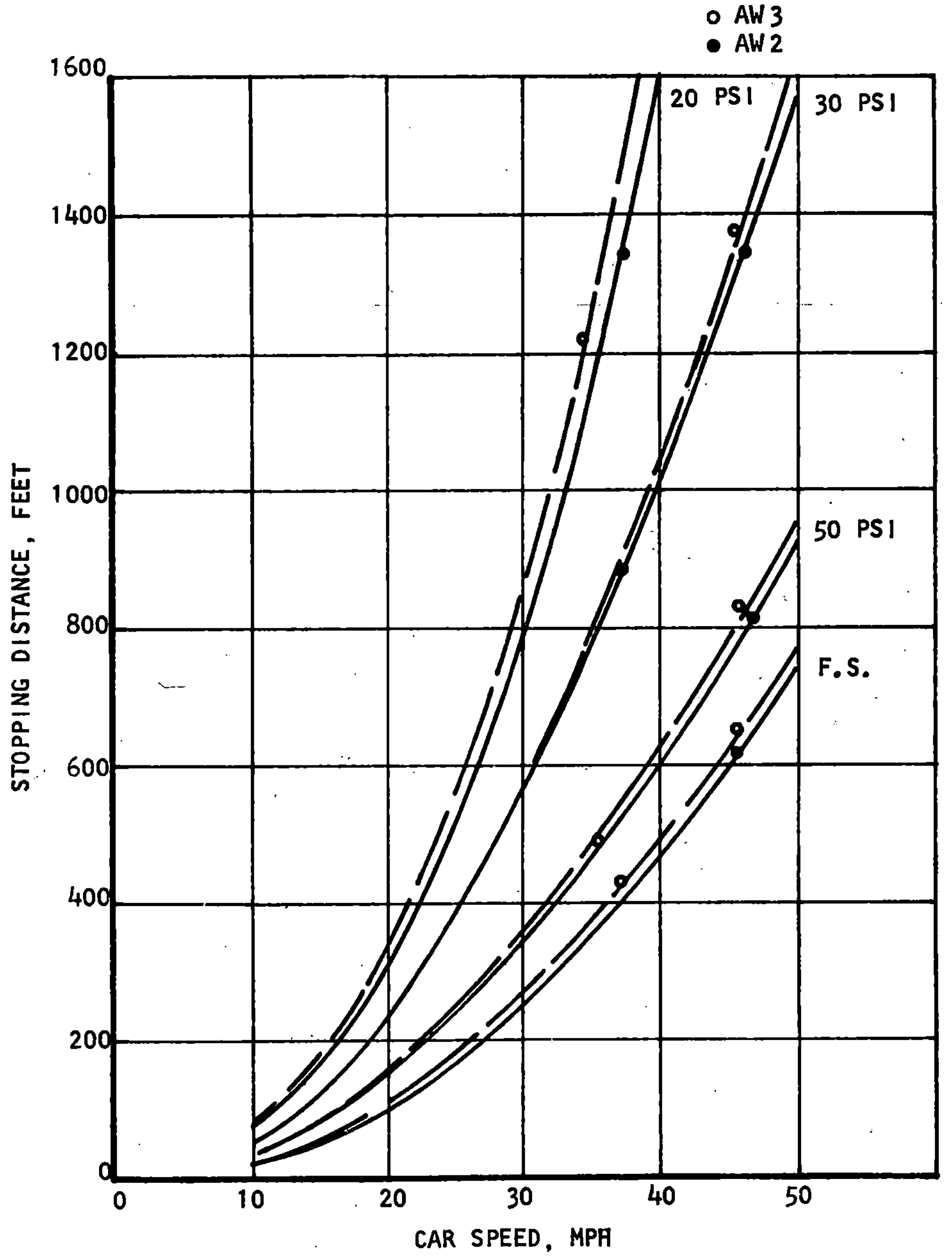


Figure 3-4. Blended Braking - Stopping Distance vs Car Speed (Sheet 2)

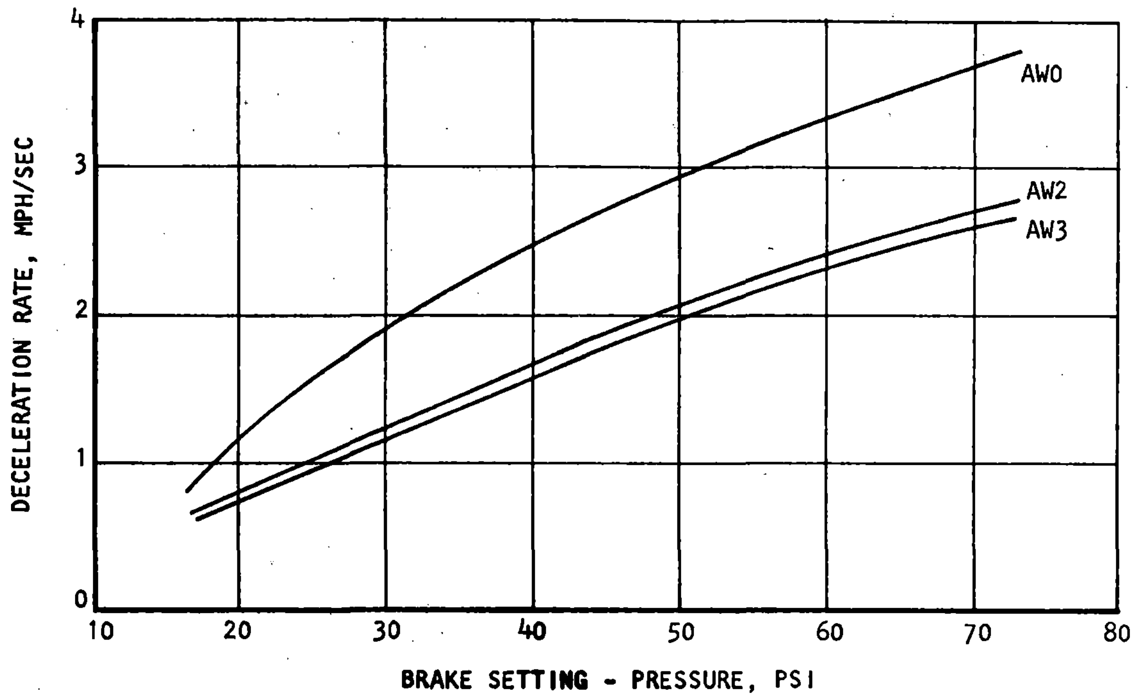


Figure 3-5. Blended Braking - Deceleration Rate vs Brake Setting

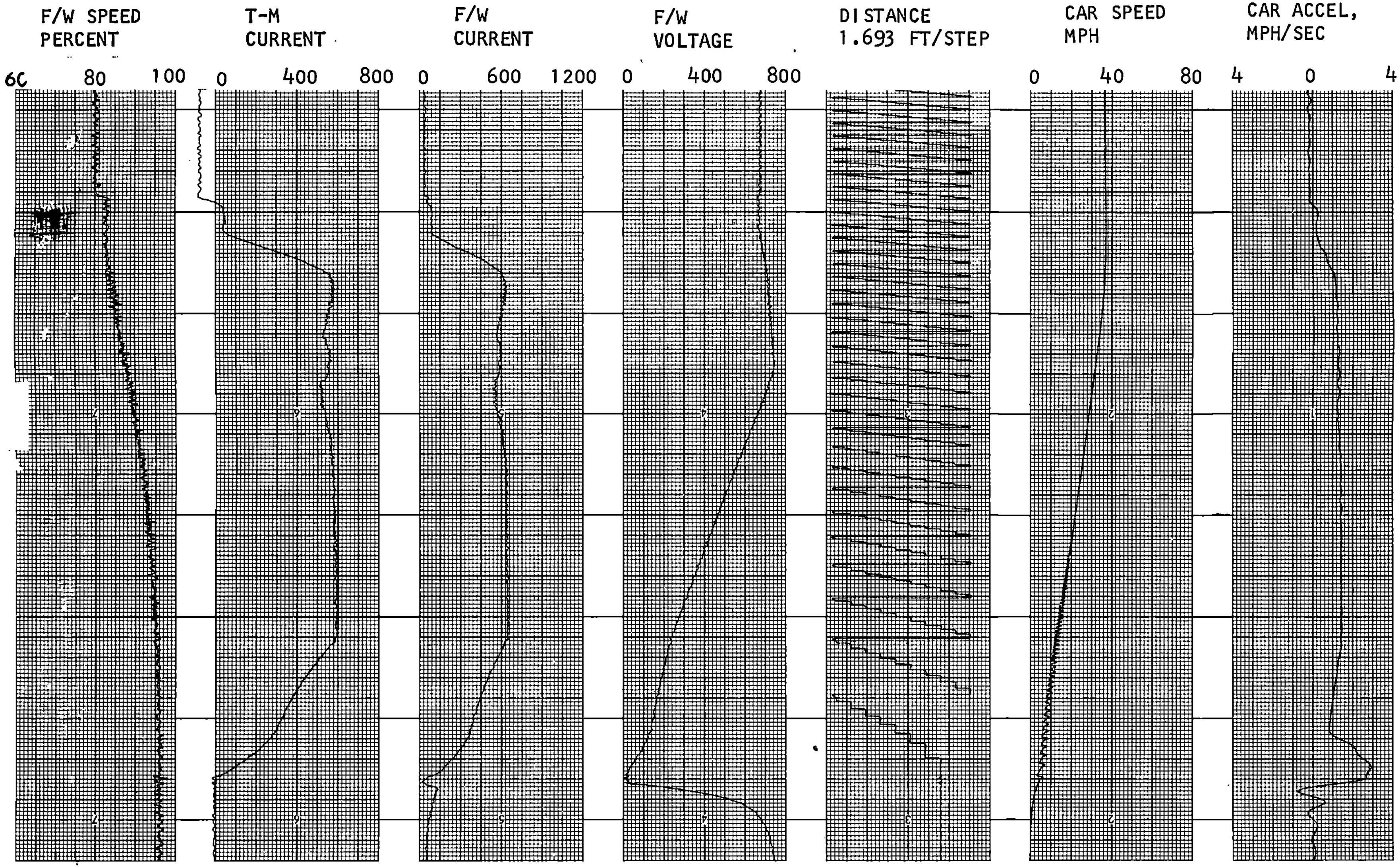


Figure 3-6. Blended Braking Reverse Direction Deceleration

F/W
VOLTAGE

LOCKOUT
MAGNET

T-M
CURRENT

T-M
VOLTAGE

F/W
CURRENT

F/W SPEED
PERCENT

CAR
COMMAND

CAR SPEED
MPH

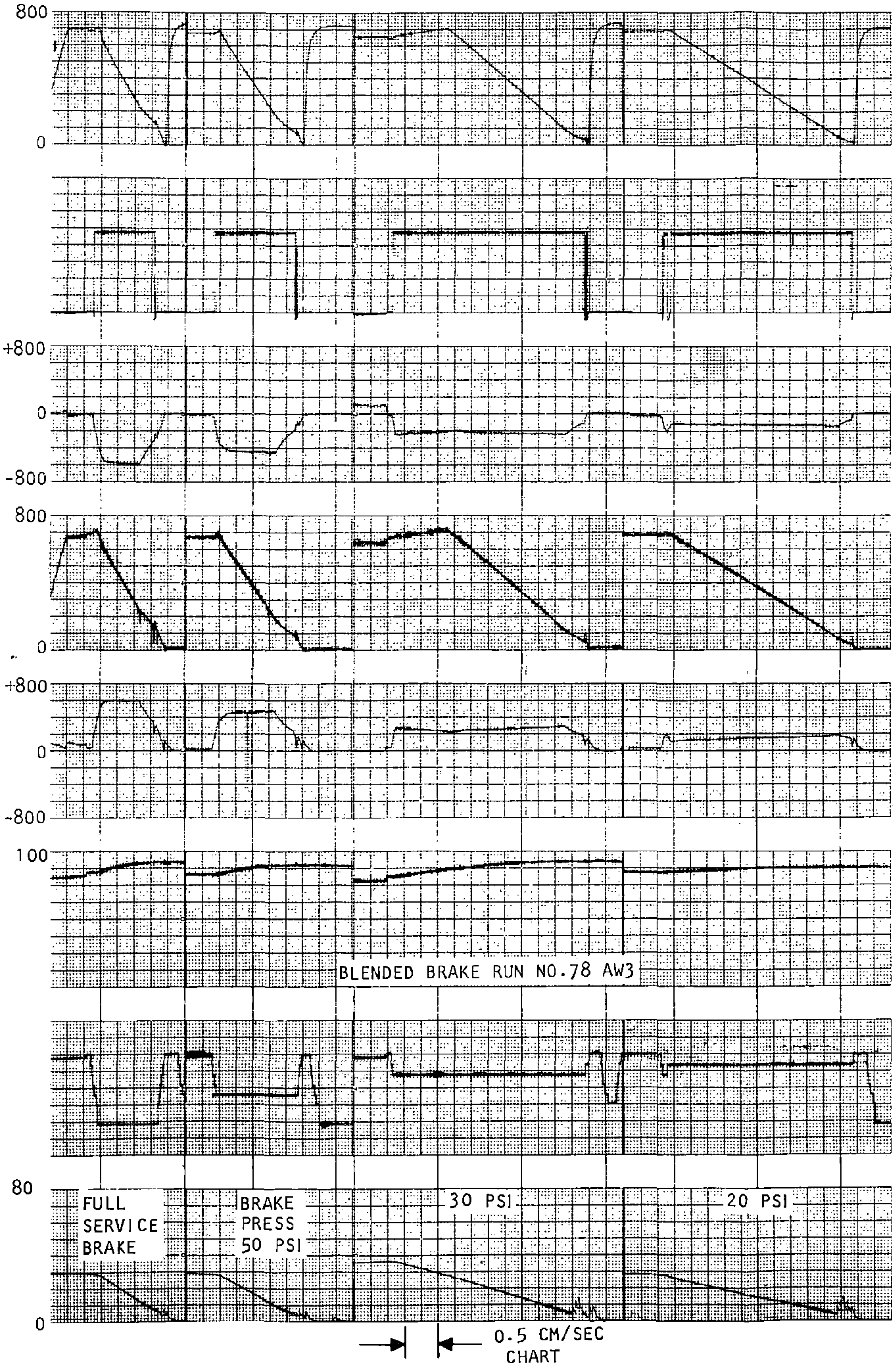


Figure 3-7. Blended Braking Deceleration Tests (Sheet 1)

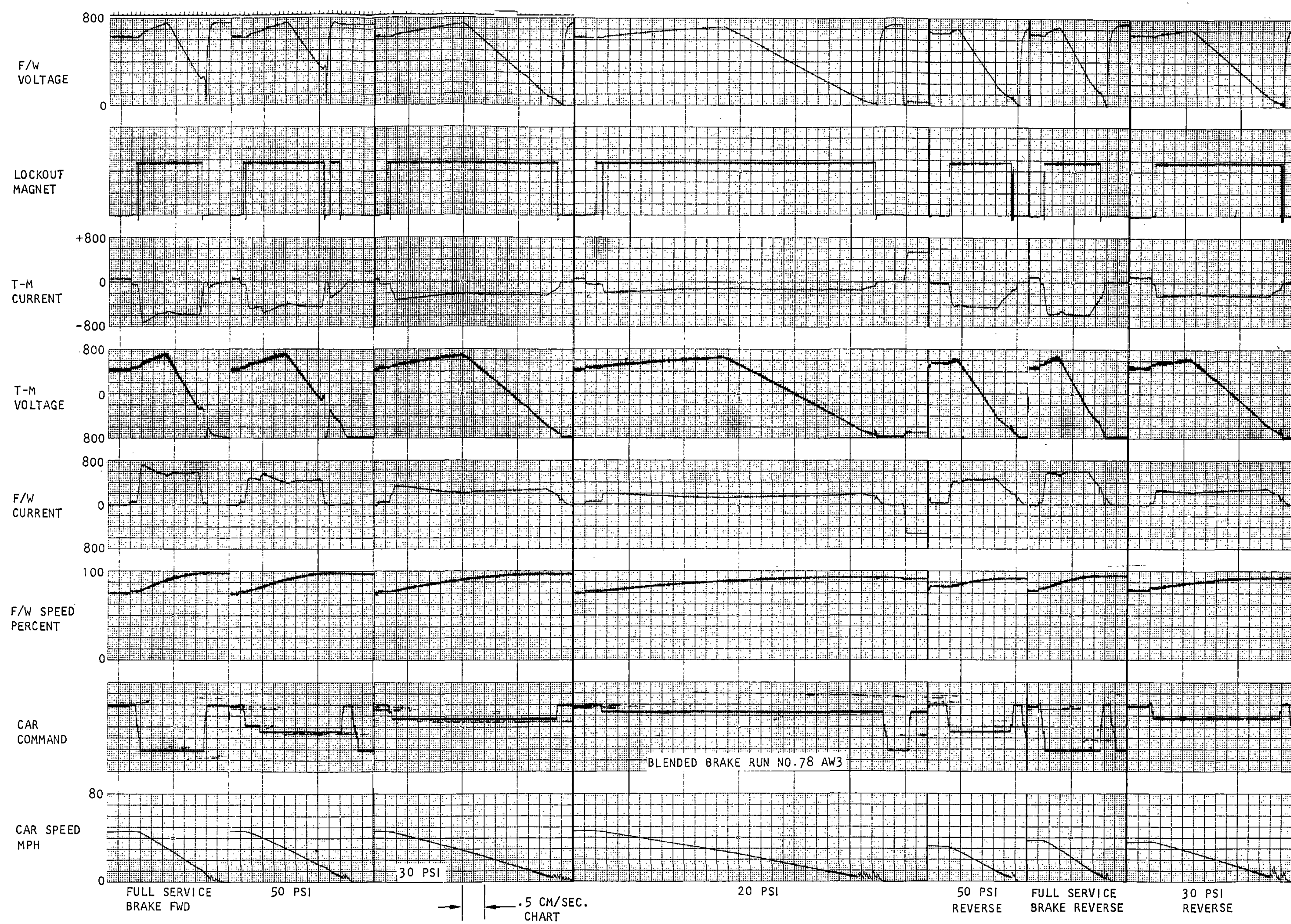


Figure 3-7. Blended Braking Deceleration Tests (Sheet 2)

4. DECLERATION - SERVICE FRICTION (ESC-P-3002-TT)

4.1 SUMMARY

The performance service friction deceleration test for the energy storage cars was conducted in compliance with Test Set Number ESC-P-3002-TT (options 1 through 3) of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 4.1.1 through 4.2.2. Refer to paragraph 4.3 for a description of the test, instrumentation used, and for the test results.

4.1.1 TEST OBJECTIVE

To determine the overall deceleration characteristics of the test vehicle utilizing the friction braking system only as affected by controller input level, car weight (load weighing), car direction, and train consist.

4.1.2 TEST DESCRIPTION

The test vehicle will be decelerated at the required controller command on level tangent track. The following test combinations will be tested.

Procedure Option	Prime Variable	Test Conditions
(5)	Controller level	Half and full brake
(6)	Car weights	AW0, AW2, and AW3
(7)	Train consists	Single car and 4-car train
(4)	Car direction	Forward and reverse
(1 thru 3)	See procedure	See procedure

4.1.3 STATUS

The energy storage cars successfully completed the service friction deceleration tests as prescribed by the conditions specified in paragraph 4.1.2. Refer to test log runs 54, 55, 67 and 76 presented in Volume I, Appendix C of this report.

4.2 PROCEDURES

The following test procedures are included as part of the ESC-P-3002-TT Test Set. These procedures were used, unless otherwise noted in paragraph 4.3, for the energy storage car service friction deceleration tests.

4.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop.

(b) Add ballast weights to simulate desired car weight.

(c) Check out and calibrate instrumentation.

(d) Photograph instrumentation (location of transducers/sensors, etc.).

(e) Make up desired train consist.

(f) Proceed to test zone.

(g) Make inspection passes over test zone. Check out vehicle and track.

(h) Record ambient conditions as required.

(i) Adjust track voltage as required for specified tests.

(j) Adjust car such that dynamic brakes can be disabled at the same time braking is initiated.

4.2.2 TEST PROCEDURE

(a) Test zone is track Station 300 to Station 340 for level tangent track tests. Brake "mark" will be at Station 300 or Station 340 depending on car direction. Car reference point will be the forward anticlimber location.

(b) Accelerate car to target test speed and approach test zone -- (Station 300, clockwise) at constant target speed.

(c) Identify test record and start recorders.

(d) As anticlimber passes the brake "mark" (Station 300 clockwise or Station 340 counterclockwise) initiate service friction braking by disabling the dynamic brakes at the same time the master controller is put in the desired position.

(e) Start timing devices and put event mark on recorders at time of "brake" input.

(f) Decelerate car to a full stop with master controller in the required input position.

(g) Put event marks on recorders as each off-car distance reference is passed by the forward anticlimber. (Required if distance data is needed and if carborne distance instrumentation is not in use.)

(h) Vehicle Stops: Stop timing devices, put event mark on recorders, stop recorders.

(i) Measure off-car stopping distance as required. (Measure to nearest foot from adjacent 100-foot track station painted on rail.)

(j) Reposition vehicle for next test record

Option 1 If the input command calls for low braking rate, the car may not come to a complete stop in the 4000 foot test zone. In this case the target entry speed for the next record will be the exit speed from the 4000 foot course during the previous record the following procedures applies:

(k) Repeat steps a through j with target entry speed as defined above.

Option 2 Repeat steps a through k as required to provide sufficient confidence in data accuracy.

Option 3 Repeat steps a through k such that target speeds of 80, 60, 40 and 20 mph are tested (as required).

Option 4 Repeat steps a through k in the reverse car direction as required. Station 340 becomes the "brake" mark.

Option 5 Repeat steps a through k at the desired input command positions.

Option 6 Repeat steps a through k at the desired car weight.

Option 7 Repeat steps a through k with the desired train consists.

4.3 TEST DESCRIPTION AND RESULTS

The energy storage car (ESC) service friction tests were conducted in accordance with AiResearch Document 74-10441 as defined in paragraph 4.3.1 and in compliance with GSP-064 Test Set ESC-P-3002-TT, described in paragraphs 4.1.1 and 4.1.2.

4.3.1 DESCRIPTION

The ESC service friction deceleration tests were performed to measure the overall deceleration characteristics of the two-car train using only the friction brake system. The test was conducted with car weights of AW0, AW2 and AW3 at 50 percent and 100 percent brake commands.

The following parameters were recorded for each of the runs using the test procedures described in paragraph 4.2:

(a) Acceleration

(b) Speed

(c) Braking distance

(d) Car command signal

(e) Brake pressure

4.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of the instrumentation related to the ESC service friction deceleration tests is shown in figure 1-4. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

4.3.3 RESULTS

The results of the service friction deceleration tests are summarized for three car weights and two brake pressure settings. No stopping time tests were performed using full service pressure because of wheel slide at the low speeds where the coefficient of friction between the shoe and wheel increases rapidly.

Representative samples of the ESC service friction deceleration test results are presented in figures 4-1 through 4-3. Deceleration tests, performed at each car weight for two different brake pressure settings are shown in sheets 1 and 2 of figure 4-1. Figure 4-2 shows stopping distance plotted against car speed and time and figure 4-3 shows a time history of the parameters listed in paragraph 4.3.1.

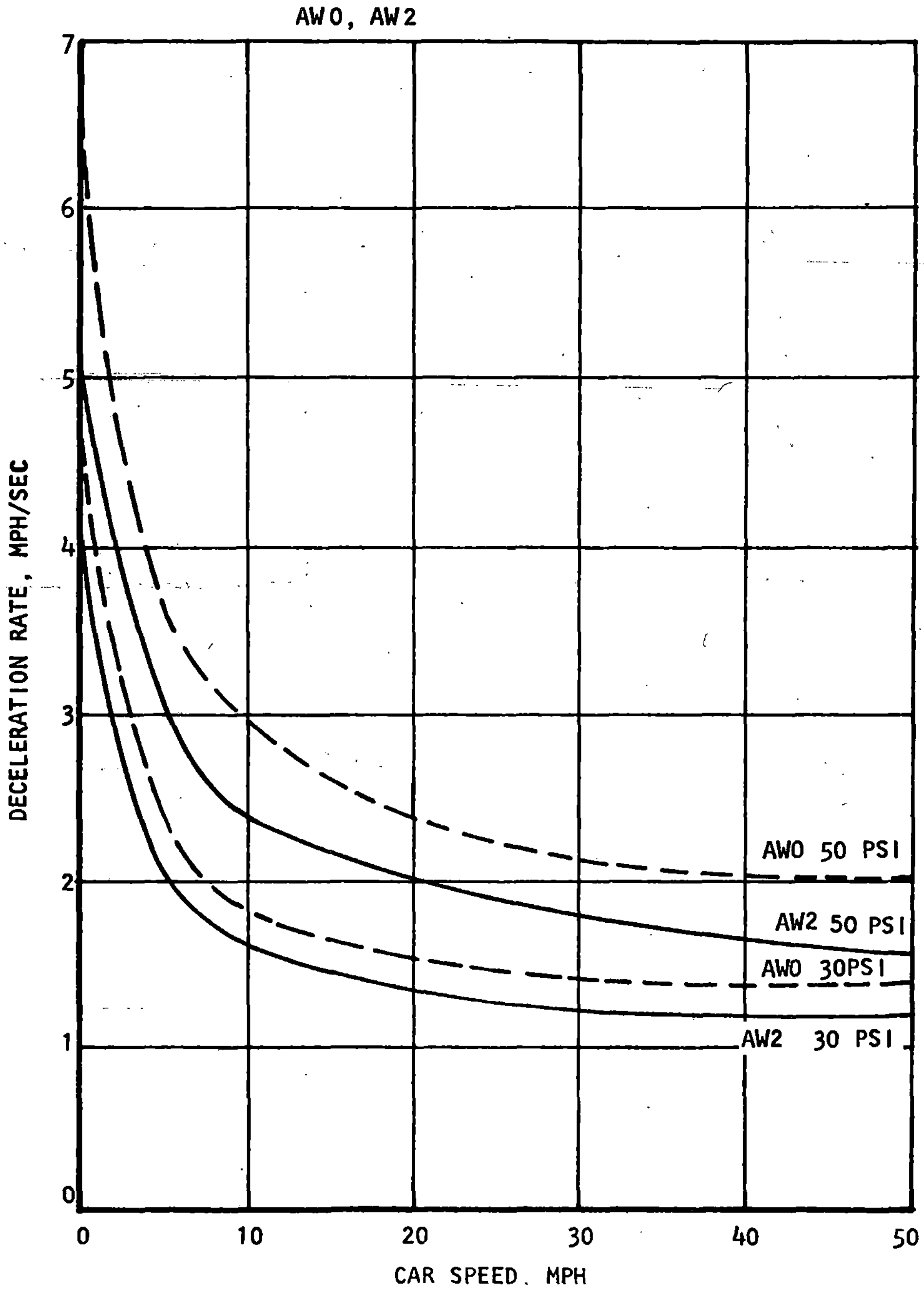


Figure 4-1. Service Friction Brake - Deceleration vs Speed (Sheet 1)

AW3

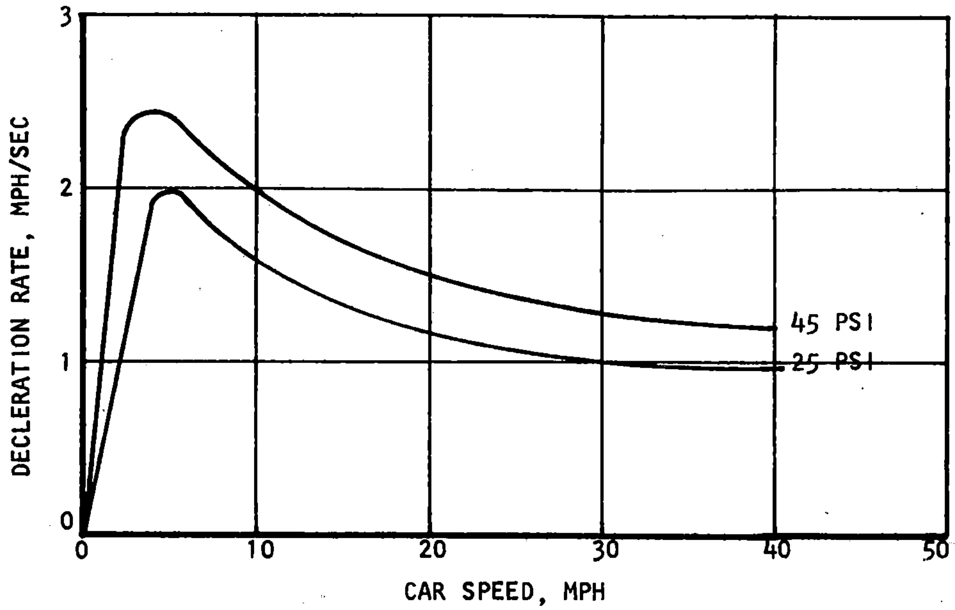


Figure 4-1. Service Friction Brake - Deceleration vs Speed (Sheet 2)

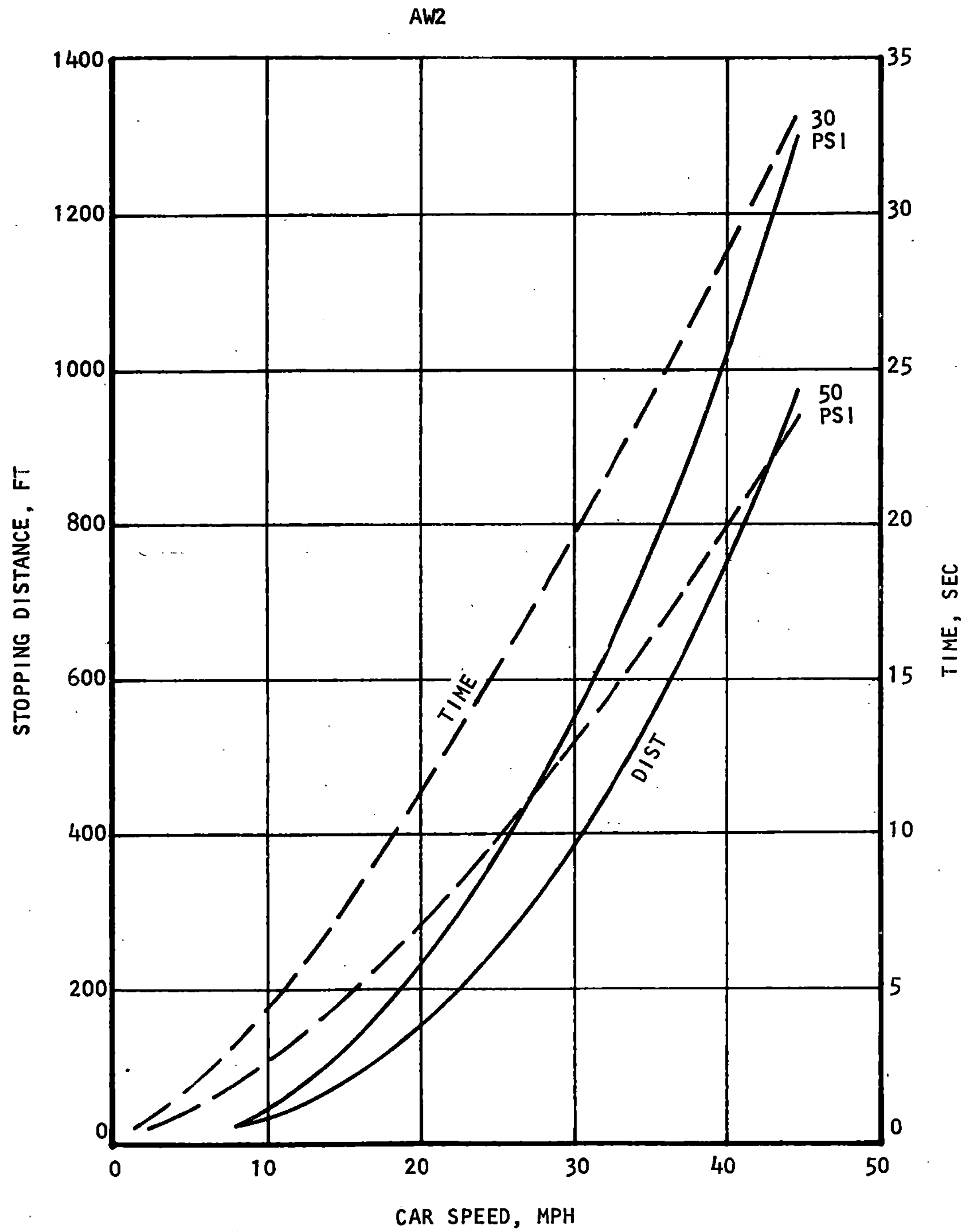


Figure 4-2. Service Friction Brake - Stopping Distance vs Car Speed and Time

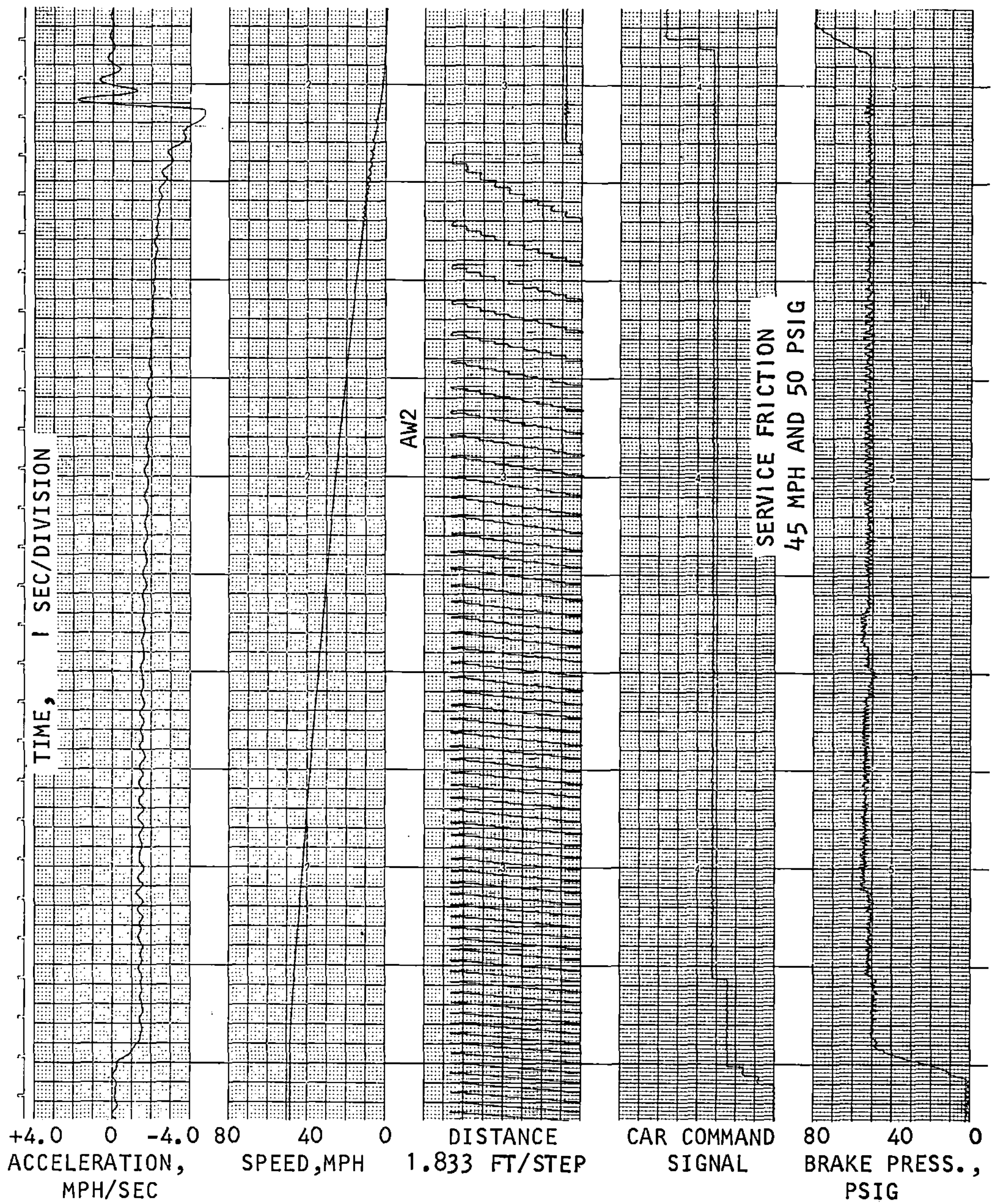


Figure 4-3. Service Friction Deceleration Tests (Sheet 1)

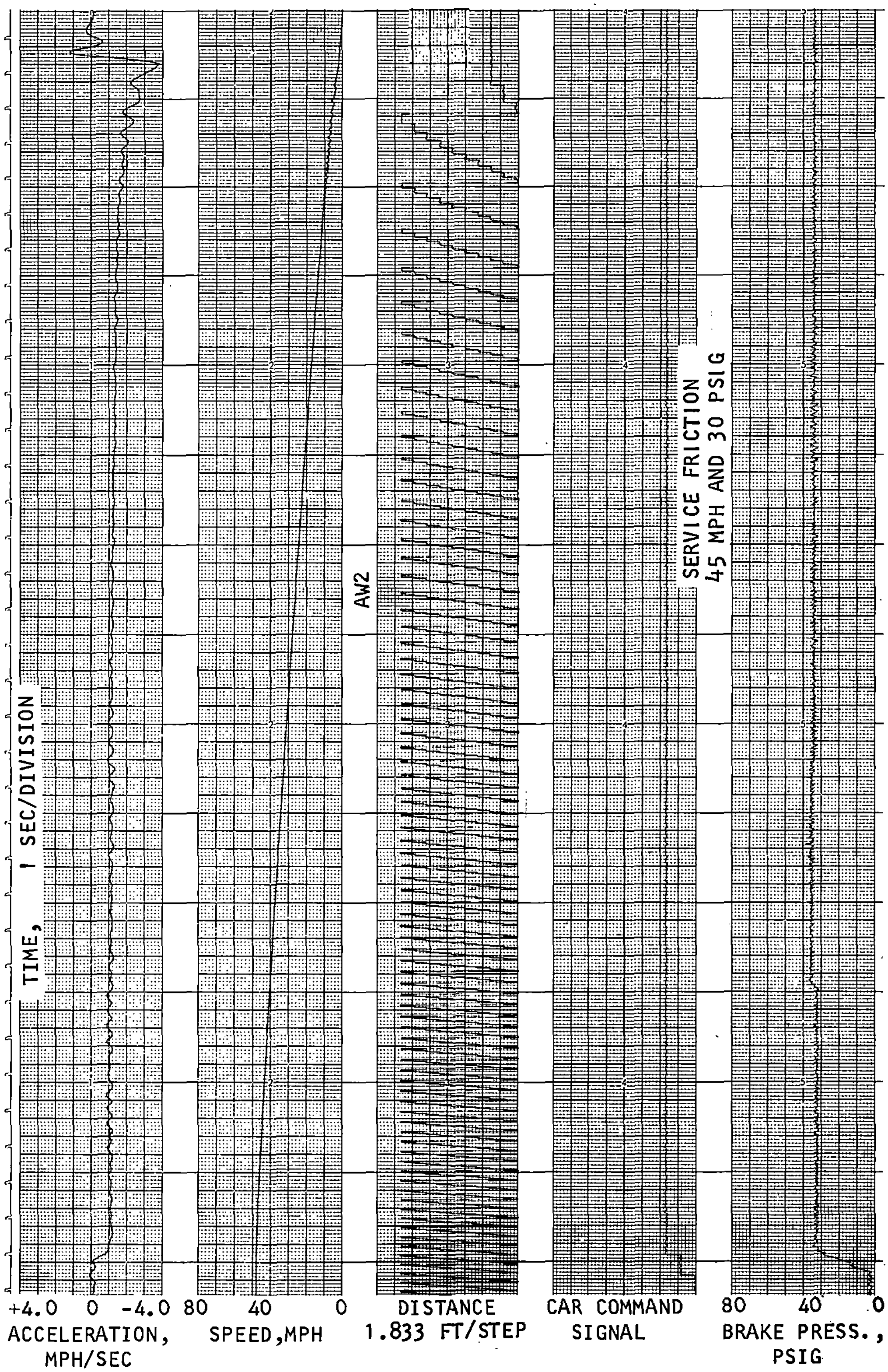


Figure 4-3. Service Friction Deceleration Tests (Sheet 2)

5. TRACTION RESISTANCE (ESC-P-4001-TT)

5.1 SUMMARY

The performance traction resistance (drift) test for the energy storage cars was conducted in compliance with Test Set Number ESC-P-4001-TT (option 1) of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 5.1.1 through 5.2.2. Refer to paragraph 5.3 for a description of the test, instrumentation used, and for the test results.

5.1.1 TEST OBJECTIVE

To determine the traction (train) resistance of the test vehicle for use in the analysis of adhesion test data. To check the coefficients used to calculate the design performance of the vehicle, and as a baseline for analysis of the vehicle tractive and braking effort values.

5.1.2 TEST DESCRIPTION

During the drift tests the test consist will be allowed to coast from an initial speed on level tangent track. Both propulsion and friction brake systems will be disabled to attain a true coast. The speed-time-distance data will be the source of the final resistance values.

Procedure Option	Prime Variable	Test Condition
(2)	Car weight	AW0 and AW2
(3)	Train consist	Single car and 4-car train
(1)	See procedure	See procedure

5.1.3 STATUS

The energy storage cars successfully completed the traction resistance tests as prescribed by the conditions specified in paragraph 5.1.2. Refer to test log runs 34, 71, 74 and 76 presented in Volume I, Appendix C of this report.

5.2 PROCEDURES

The following test procedures are included as part of the ESC-P-4001-TT Test Set. These procedures were used, unless otherwise noted in paragraph 5.3, for the energy storage car traction resistance tests.

5.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop.

(b) Add ballast weights to simulate desired car weight

(c) Check out and calibrate instrumentation

(d) Photograph instrumentation (location of transducers/sensors etc.)

(e) Make-up desired train consist

(f) Proceed to test zone

(g) Make inspection passes over test zone; check out vehicle and track.

(h) Record ambient conditions as required (air temperature, wind speed, direction)

(i) Determine if ambient conditions are within the maximum allowables for the drift tests.

(j) Insure that a true "coast" condition can be obtained, i.e., disabled propulsion system, no "inshot" brake pressure from service brakes.

5.2.2 TEST PROCEDURE

(a) The test zone is the 4000 foot level tangent track from Station 300 to Station 340.

(b) Approach test zone at maximum train speed in clockwise direction.

(c) Start recorders, disable traction system and obtain a true coasting mode with no airbrake INSHOT. Leave master controller slightly above coast position in POWER mode.

(d) At beginning of test zone (Station 300 clockwise; Station 340 counterclockwise) put event mark on recorders for distance reference with off-car distance markers or identify ZERO distance on car-borne distance instrumentation.

(e) Put event mark on recorders as each off-car distance reference is passed.

(f) At end of 4000 foot test zone stop recorders, note exit speed, engage the traction system, and position car for next test record in opposite direction.

(g) Approach test zone from opposite direction at maximum car speed. (counterclockwise).

(h) Repeat steps c through f for records in each car direction

(i) Repeat steps b through g, but with a test zone entry speed equal to the exit speed of step f less 5 mph. (one record in each direction)

(j) Repeat step i until an exit car speed less than 10 mph in each direction is obtained

<u>Option 1</u> Repeat steps a through j as required to provide sufficient confidence in data accuracy.

<u>Option 2</u> Repeat steps a through j at the desired car weights.

<u>Option 3</u> Repeat steps a through j with the desired train consists.

5.3 <u>TEST DESCRIPTION AND RESULTS</u>

The energy storage car (ESC) traction resistance (drift) tests were conducted in accordance with AiResearch Documents 73-9373 and 74-10441 as defined in paragraph 5.3.1 and in compliance with GSP-064 Test Set ESC-P-4001-TT, described in paragraphs 5.1.1 and 5.1.2.

5.3.1 DESCRIPTION

The ESC drift tests were performed at AW0 and AW2 car weights in both the forward and reverse directions. Parameters of speed, time, distance and acceleration were recorded for this test. The noise level on the acceleration data was very high however, and consequently the speed and distance data was used to derive the deceleration rates. (See figure 4-1). The tests were performed using the test procedures described in paragraph 5-2.

5.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of the instrumentation related to the ESC drift tests is shown in figure 1-3. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

5.3.3 RESULTS

The result of deceleration rate plotted against car speed for AW0 and AW2 car weights is shown in figure 5-1. Figure 5-2 shows time histories of flywheel vibration measurements taken during drift test at various car speeds. The deceleration rates shown in figure 5-1 were derived as follows.

The curved solid lines shown in figure 5-1 are based on data generated using the Davis Drag equation and traction motor drag. The points indicated by X and O are reduced test data.

There is a moderately large scatter in the acceleration plot and this is due in part to data resolution for the low level of deceleration and may be in part due to an external influence such as wind.

The plot points include runs in both directions on the level tangent track at two weights. The AW0 average weight per car including on board instrumentation was 42.0 tons and the AW2 weight, 58.8 tons. To estimate Davis Drag, 6.2 tons of rotational equivalent is added. Also, the friction and windage contributions of the traction motors will be approximately as shown below

$$Dm = 99.3 + .0746V^2 \text{ lbs/car}$$

where V = mph

The curves were generated using the conventional form for the Davis Drag but with some of the coefficients altered to provide a better match to the test data as follows:

Drag force (lbs) per car =

$$\underline{190} + (\underline{2.0} + \underline{.015}V)W + (.24 + .034\ (N-1))\frac{AV^2}{100\ N} + Dm$$

where W = car weight (tons)

N = 2 (No. of cars)

V = speed (mph)

A = 121 sq. ft.

Dm = as indicated above

and the equivalent initial masses for AW0 and AW2 are

M_0 = 2994 (42.0 + 6.2 tons)

M_2 = 3037 (58.8 + 6.2 tons)

The underlined coefficients in the above equation are the ones modified to get a good match for both the AW0 and AW2 test data as shown. In the conventional form these three coefficients are 116, 1.3 and .045 respectively.

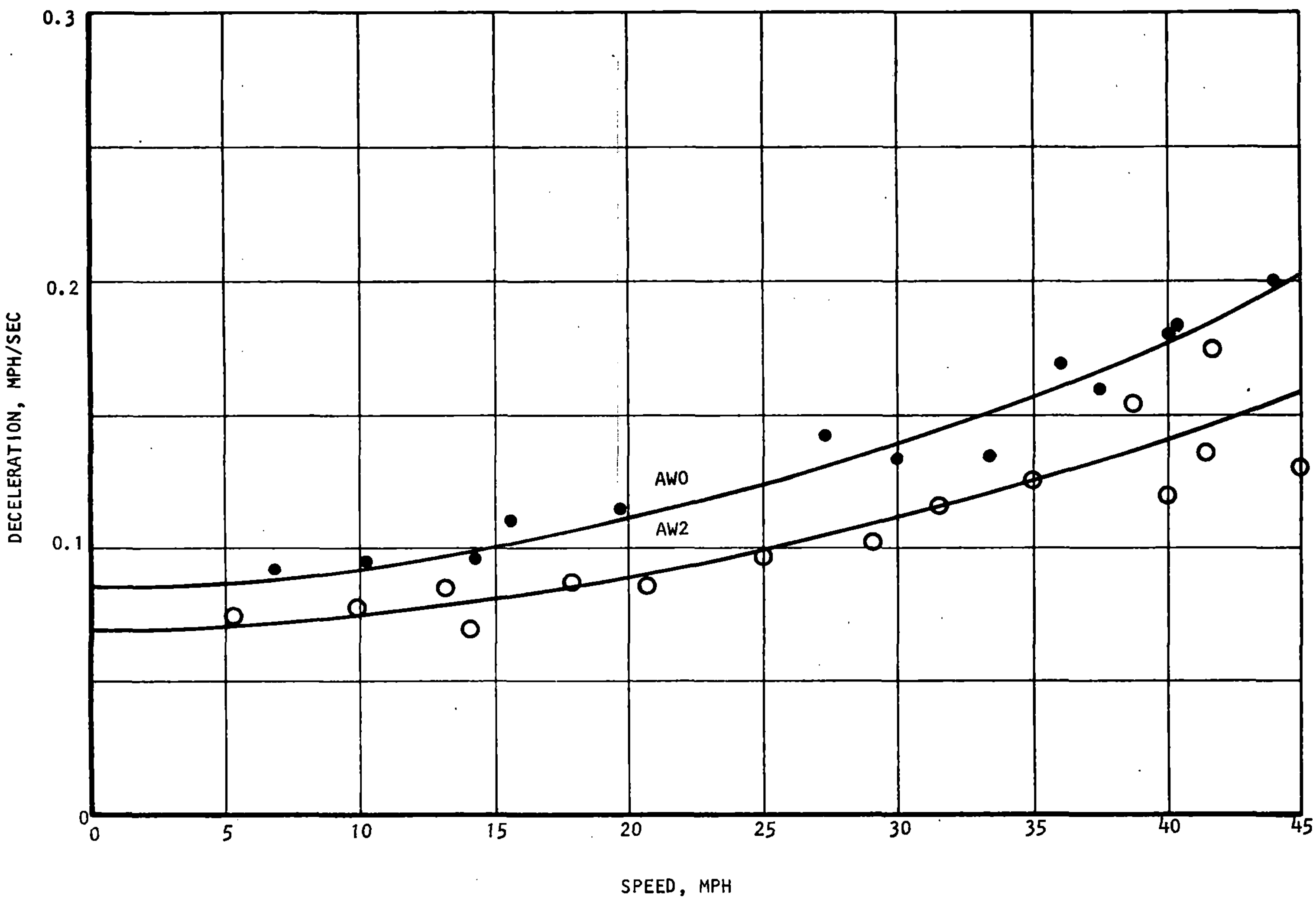


Figure 5-1. Traction Resistance Decelerat.on vs Speed

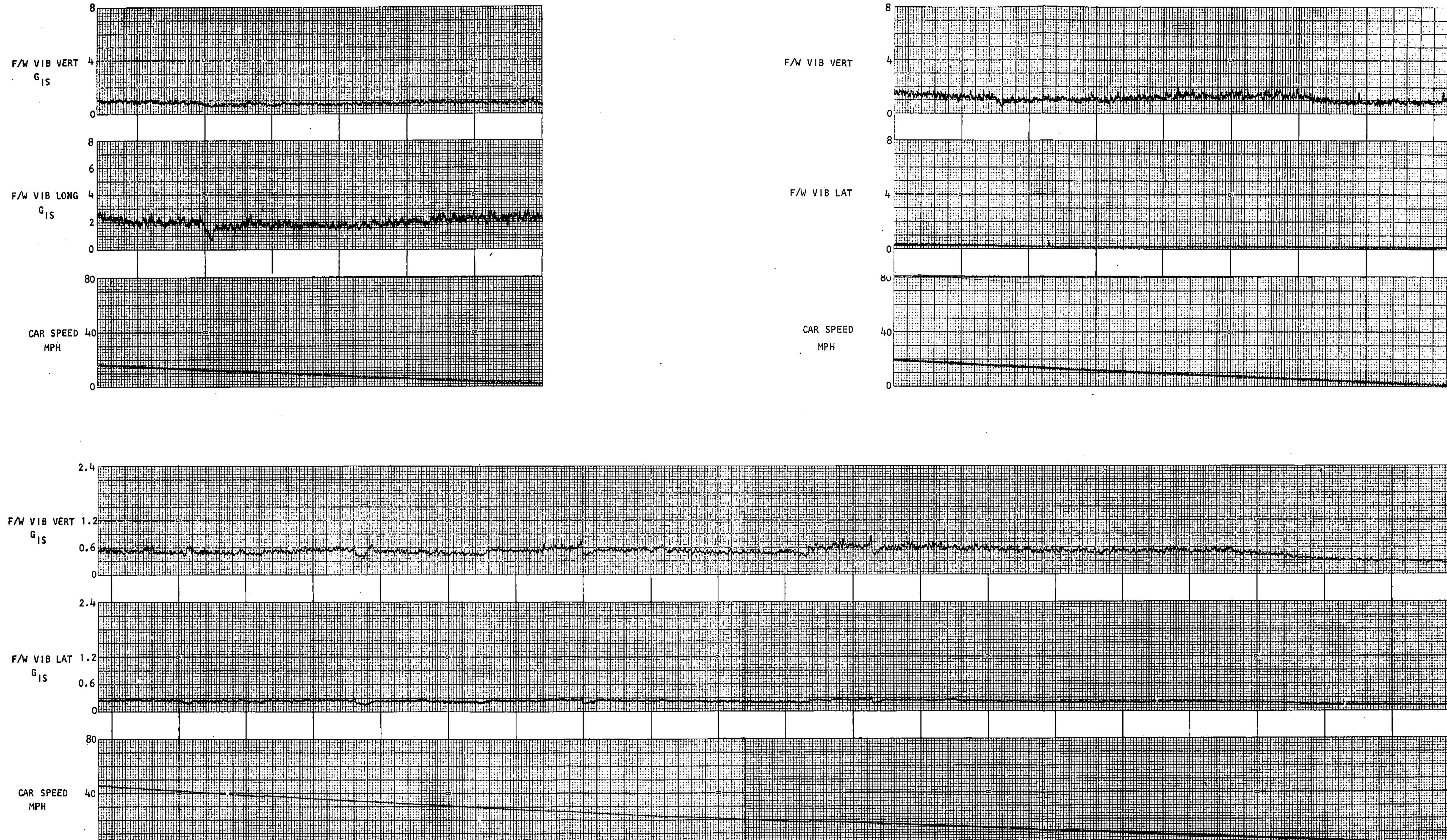


Figure 5-2. Traction Resistance Vibration Tests

6. FRICTION BRAKE - DUTY CYCLES (ESC-P-5001-TT)

6.1 SUMMARY

The performance friction brake duty cycle test for the energy storage cars was conducted in compliance with Test Set Number ESC-P-5001-TT of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 6.1.1 through 6.2.2. Refer to paragraph 6.3 for a description of the test, instrumentation used, and for the test results.

6.1.1 TEST OBJECTIVE

To determine the thermal capacity of the vehicle's friction braking system during a sample service run. The dynamic brake system will be inoperative during the tests with the friction brake providing all of the decelerating force, as applicable.

6.1.2 TEST DESCRIPTION

The test vehicle will be accelerated to a target cruise speed, cruise for a defined time, and brake to a simulated station stop. Following a defined station dwell the cycle will be repeated.

Procedure Option	Prime Variable	Test Condition
(1)	Cruise speed and time	35 mph for 45 seconds 50 mph for 55 seconds
(2)	Car weight	AW2 or AW3
(3)	Brake type	Solid and resilient wheels
(5)	Brake blending	Blended and Friction only

6.1.3 STATUS

The energy storage cars successfully completed the friction brake duty cycle tests as prescribed by the conditions specified in paragraph 6.1.2. Refer to test log runs 77 and 81 presented in Volume I, Appendix C of this report.

6.2 PROCEDURES

The following test procedures are included as part of the ESC-P-5001-TT Test Set. These procedures were used, unless otherwise noted in paragraph 6.3, for the energy storage car friction brake duty cycle tests.

6.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop

(b) Add Ballast weights to simulate desired car weight

(c) Check out and calibrate instrumentation

(d) Photograph instrumentation (location of transducers/sensors, etc.)

(e) Make-up desired train consist

(f) Proceed to test zone

(g) Make inspection passes over test zone; check out vehicle and track.

(h) Record ambient conditions as required

(i) Adjust car such that the dynamic brake can be disabled on each start/stop cycle.

6.2.2 TEST PROCEDURE

(a) Position car at defined track location for testing in the defined car direction.

(b) Start recorders, identify records, record track station number.

(c) Accelerate car at full service rate to the target speed. Put event mark on recorders and record time-of-day as the controller is moved to full power.

(d) Maintain the target cruise speed for the specified time period.

(e) At end of cruise time, disable dynamic brake and apply full service friction braking.

(f) Bring car to complete stop and simulate a station dwell of the desired length.

(g) Record completed cycle number and off-car temperatures as required (Note: any increased station dwell during off-car measurements should be subtracted from succeeding station stops).

(h) Repeat steps c through g until the specified number of start/stop cycles have been completed. Record completed laps of the test oval, total elapsed time from the start (step c) and the track station at which the test was completed.

Option 1 Repeat steps a through h at the specified cruise speeds and cruise times.

Option 2 Repeat steps a through h at the specified car weights.

Option 3 Repeat steps a through h with the specified wheel or brake configuration. (Type of brake or level of blended brake.)

Option 4 Repeat steps a through h at the specified brake rate command.

Option 5 Repeat steps a through h with the desired level of dynamic brake blending.

6.3 TEST DESCRIPTION AND RESULTS

The energy storage car (ESC) friction brake duty cycle tests were conducted in accordance with AiResearch Document 74-10441 as defined in paragraph 6.3.1 and in compliance with GSP-064 Test Set ESC-P-5001-TT, described in paragraphs 6.1.1 and 6.1.2.

6.3.1 DESCRIPTION

The ESC friction brake duty cycle tests were performed on a level tangent track at the AW2 car weight to test the thermal capacity of the friction brake system on a simulated service run. The following parameters were recorded for this test using the test procedure described in paragraph 6-2:

(a) Acceleration

(b) Speed

(c) Distance

(d) Car command signal

(e) Brake pressure

(f) Brake shoe temperature

(g) Wheel rim temperature

The wheel rim temperatures were taken at each stop. This was accomplished by pressing a portable sensor against the wheel on its normal line of contact with the rail within 10 seconds after stopping.

During the braking interval, flywheel energy storage is disabled for the test and the electrical system, as shown in figure 6-2, is dormant. The car command signal is derived from the contacts of the air brake rate sensor and merely shows the relative air pressure level in the brake cylinder line.

6.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of the instrumentation related to the friction brake duty cycle tests is shown in figure 1-5. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

6.3.3 RESULTS

Representative samples of the ESC friction brake duty cycle test results are presented in figures 6-1 and 6-2. The level of brake shoe and wheel rim temperatures recorded at the various stops is shown in figure 6-1 and time histories of the parameters listed in paragraph 6.3.1 are shown in figure 6-2.

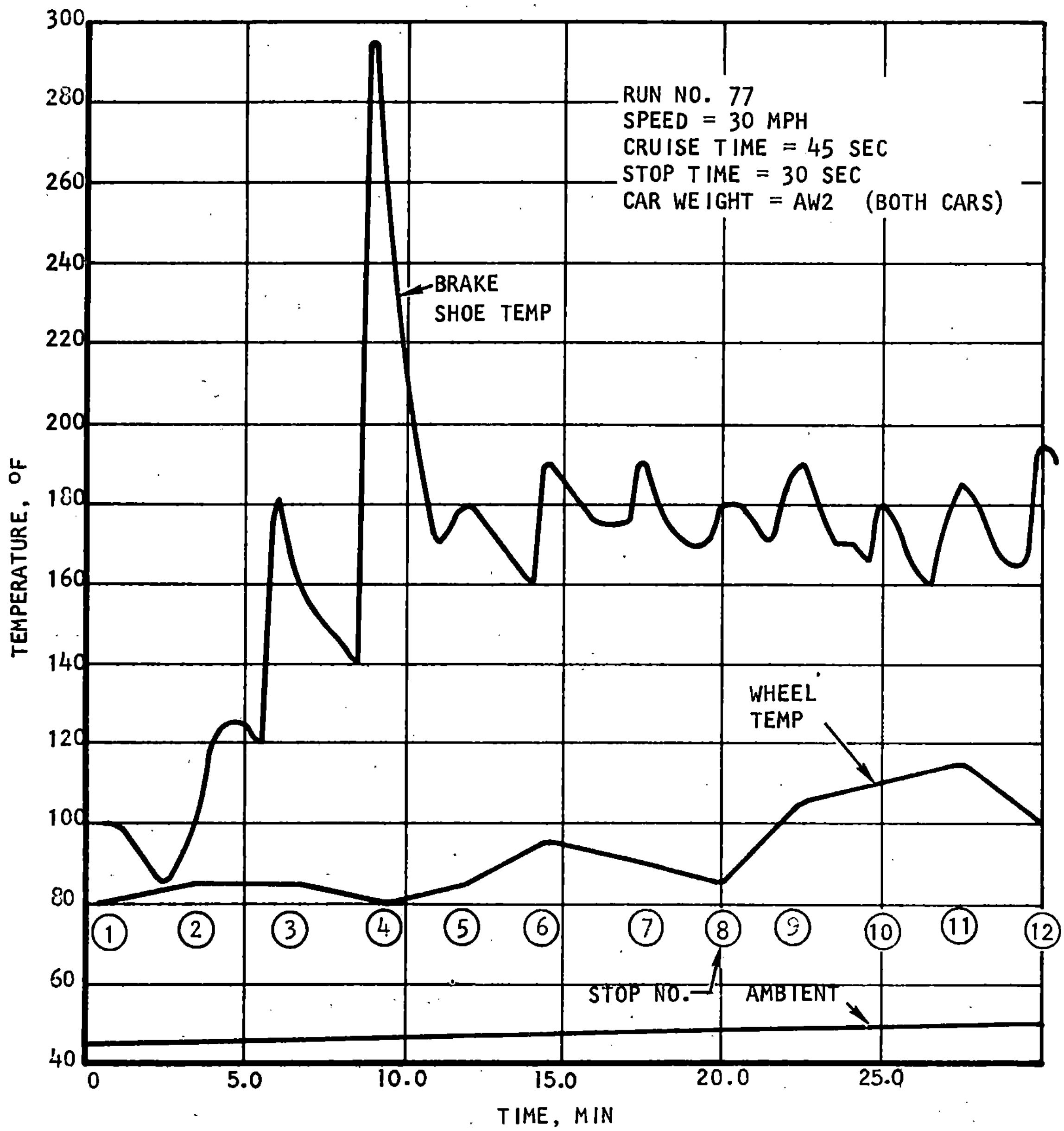


Figure 6-1. Friction Brake Duty Cycle - Temperature vs Time (Sheet 1)

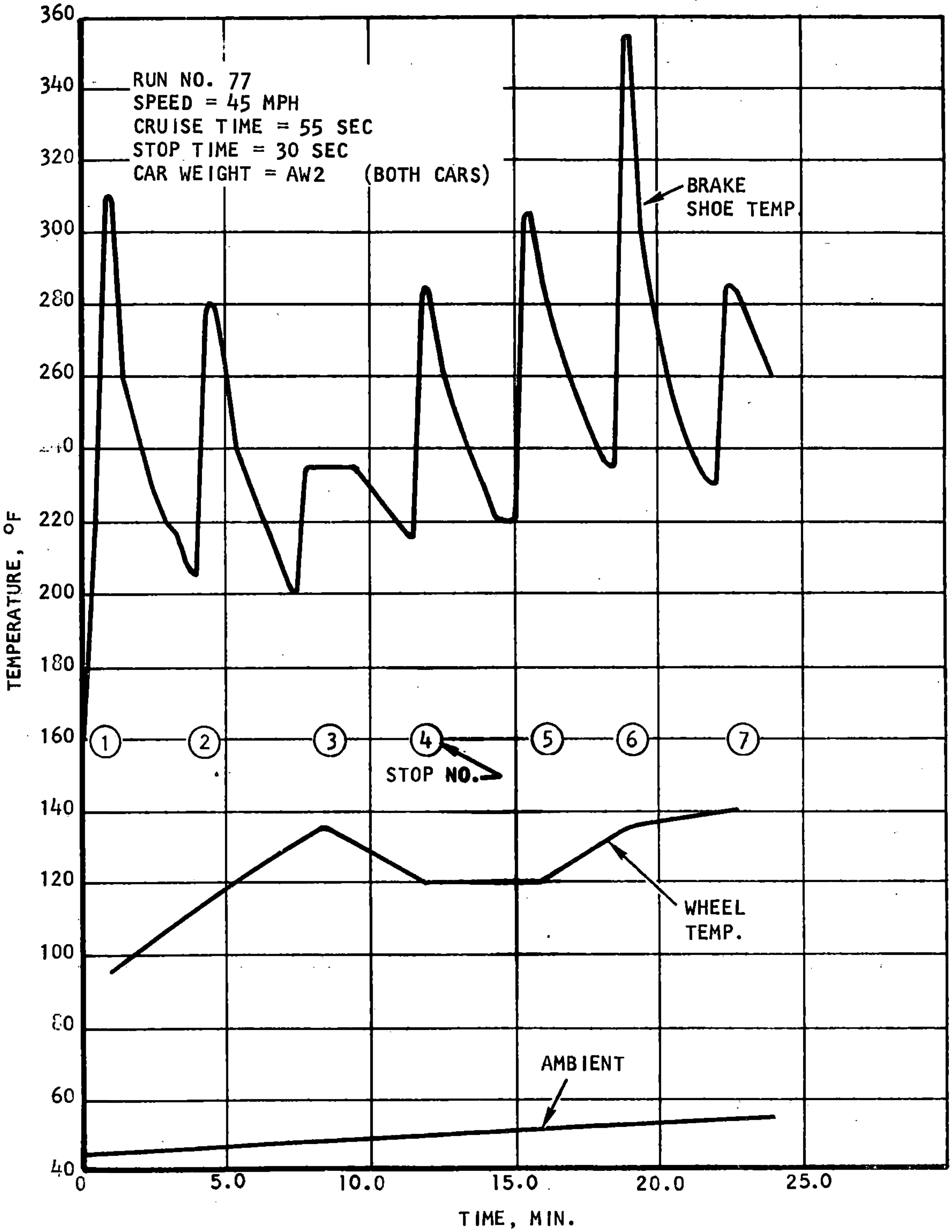


Figure 6-1. Friction Brake Duty Cycle - Temperature vs Time (Sheet 2)

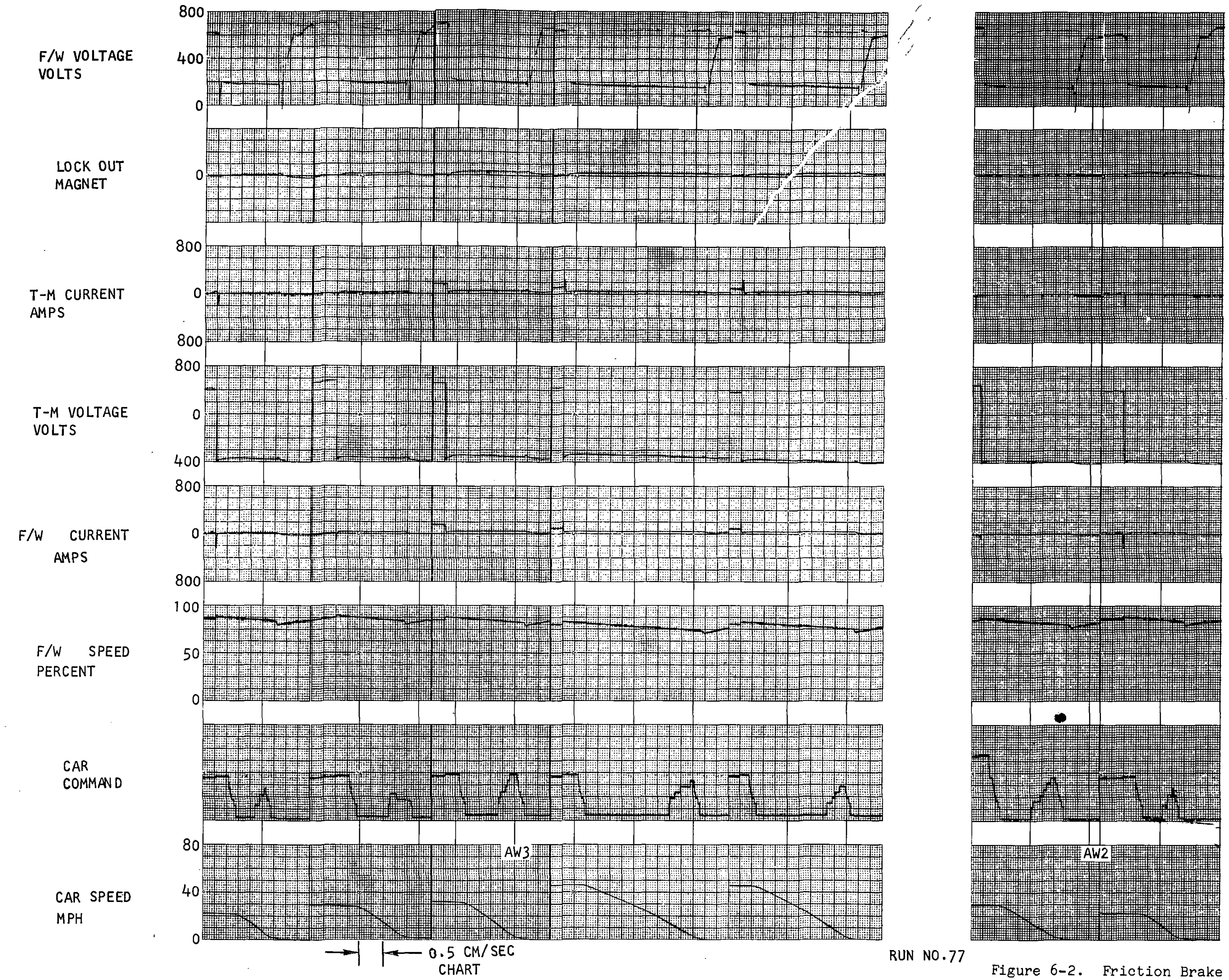


Figure 6-2. Friction Brake Duty Cycle Tests

SECTION 7

7. POWER CONSUMPTION (ESP-PC-5011-TT)

7.1 SUMMARY

The power consumption test for the energy storage cars was conducted in compliance with Test Set Number ESC-PC-5011-TT of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 7.1.1 through 7.2.2. Refer to paragraph 7.3 for a description of the test, instrumentation used, and for the test results.

7.1.1 TEST OBJECTIVE

To determine the power consumption of the test vehicle while operating on a sample service route at a defined level of schedule performance. The tests will provide a measure of car schedule performance, power consumption (regeneration), and overall traction system efficiency.

7.1.2 TEST DESCRIPTION

The cars will be operated over a simulated route with stops at specified stations. Normal service performance will be used. Power consumed by the traction and auxiliaries will be measured for each stop and the round-trip.

Procedure Options	Prime Variable	Test Conditions
(1)	Car weight	AW2
(2)	Regeneration	100 percent and zero
(3)	Regenerative load	100 percent and 50 percent
(4)	Line voltage	Min., 600, and max. volts
(5)	Train consists	Single car and 4-car train

7.1.3 STATUS

The energy storage cars successfully completed the power consumption tests as prescribed by the conditions specified in paragraph 7.1.2. Refer to test log runs 35 through 48 presented in Volume I, Appendix C of this report.

7.2 PROCEDURES

The following test procedures are included as part of the ESC-PC-5011-TT Test Set. These procedures were used, unless otherwise noted in paragraph 7.3, for the energy storage car power consumption tests.

7.2.1 PRETEST PROCEDURE

(a) Attach instrumentation or patch-in desired parameters at storage or shop.

(b) Add ballast weights to simulate desired car weight

(c) Check out and calibrate instrumentation

(d) Photograph instrumentation (Location of transducers/sensors etc.).

(e) Layout simulated route: Station locations and "brake" application markers.

(f) Make up desired train consist

(g) Proceed to test zone

(h) Make inspection passes over test zone; check out vehicle and track.

(i) Record ambient conditions as required

(j) Energize the normal auxiliary power load of the car, including traction system auxiliary equipment. Measure line power drawn for each or all auxiliaries with car at full stop.

7.2.2 TEST PROCEDURE

(a) The test zone is the complete transit oval or designated sections with station locations specifically marked.

(b) Position car at the first simulate dstation, identify records, "zero" counters, start recorders.

(c) Accelerate car in the clockwise direction at full service rate. Start timing devices, put event mark on recorders.

(d) As car attains the required cruise speed, decrease power and maintain cruise speed.

(e) Apply full service (blended) braking at the "brake" marker for the next station.

(f) Bring car to a complete stop within one car length of the "station" marker using motorman`s controller as required.

(g) Simulate station dwell of the required time.

(h) At end of station dwell, accelerate the car at full service rate, put event mark on recorders, record elapsed time and watt-hours energy consumed (quick-look counter).

(i) Repeat steps d through h until a complete trip of the specified route has been made in the clockwise direction

(j) Repeat steps b through i with car car operating in the counter-clockwise direction. (Will provide for a complete round-trip.)

Option 1 Repeat steps a through j at the required car weights.

Option 2 Repeat steps a through j at the required combinations of regenerative/dynamic braking.

Option 3 Repeat steps a through j with the desired regenerative "load".

Option 4 Repeat steps a through j at the desired line voltage.

Option 5 Repeat steps a through j with the desired train consists.

7.3 TEST DESCRIPTION AND RESULTS

The energy storage car (ESC) power consumption tests were conducted in accordance with AiResearch Document 73-9373 as defined in paragraph 7.3.1 and in compliance with GSP-064 Test Set ESC-PC-5011-TT, described in paragraphs 7.1.1 and 7.1.2.

7.3.1 DESCRIPTION

The ECS power consumption tests were performed to determine power consumption of the energy storage cars as a function of station spacing, car weight and speed limit. Prior to performing the tests, identifying markers were placed at 2000, 3000 and 5000 foot increments around the complete circumference of the track. The test runs listed in Table 7-1 were then conducted according to the operating rules listed below:

(a) All station stops were 30 seconds with doors opening after cars stopped

(b) Parallel mode was used for acceleration away from station

(c) Full service braking used on approach to the station stop

(d) Tests run for car weights of AW0 and AW3

The following parameters were recorded either manually or by recorders at each station stop using test procedures described in paragraph 7-2:

(a) Acceleration

(b) Car speed

(c) Flywheel speed

(d) Distance

(e) Car command signal

(f) Third rail voltage

(g) Third rail current (each car)

Table 7-1. Power Consumption Test Summary

Run	Station Spacing (feet)	No. of Laps	Speed Limit (mph)
1	2000	1	15
2	2000	1	30
3	2000	1	45
4	3000	1	15
5	3000	1	30
6	3000	1	45
7	5000	2	45
8	5000	2	*
9	10000	2	45
10	10000	2	*

Note: *Accelerate to 45 mph, brake to 15 mph, accelerate to 30 mph, and then complete the run.

The RMS current levels for the traction motor and the flywheel motor were reduced by numerical integration from the station-to-station run over level tangent track. A representative segment from the 3000 foot duty cycle runs was selected as typical and several system parameters were extracted from the recorded data and plotted. These are shown in figures 2-8 and 2-9 for acceleration data and figures 3-6 and 3-7 for deceleration data.

The armature currents shown are for one truck and its associated flywheel. The third rail current shown on the plot is distributed approximately one half to each truck. Consequently, the traction motor current should be the algebraic sum of the flywheel motor current plus one half the third rail current. Examination of the plots indicate that the calibration for the traction motor and flywheel motor are in good agreement where third rail current is near zero. It appears that the third rail current calibration is about 8 percent high (comparing third rail and traction motor current where flywheel current equals zero) but is within the band of accuracy expected if one assumes an average unbalance between the two trucks of ±3 percent.

The RMS values of the traction and flywheel motor armature currents is shown in Table 7-2. These data are calculated by numerical integration using the plots in figures 2-8, 2-9 and figures 3-6, 3-7, based on the following equation

$$I_{rms} = \sqrt{\frac{\Sigma(y^2 \cdot \Delta t)}{\Sigma \Delta t}}$$

Table 7-2. Calculated RMS Armature Currents

Time	Traction Motor	Flywheel Motor
82 sec (run time)	293 amps	257 amps
112 sec (run + 30 sec stop)	251 amps	220 amps

Note: CW on level tangent 3000 ft, 2 car train AW3
FW Speed 94 percent max, 77.5 percent min
Max car speed 37 mph
Run #78/1317

The values in table 7-2 are related to a 3000 foot distance between stations. A good approximation for shorter runs can be made using the 3000 foot duty cycle data illustrated in the plots of figure 6-2. A reconstructed 1000 foot run with 30 second station stops works out to 305 amps RMS for the traction motor. The motor design ratings are 360 amps and 430 amps respectively for the traction motor and the flywheel motor.

7.3.2 INSTRUMENTATION

Block diagrams of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of the instrumentation related to the ESC power consumption tests is shown in figure 1-6. Information concerning instrumentation for overall data acquisition for the energy storage car tests is described in Volume I of this report.

7.3.3 RESULTS

Results of the power consumption test are shown in table 7-3 and figures 7-1 and 7-2. Some inconsistency can be noted, particularly in the 15 mph maximum speed runs, for power consumption and average speeds. These are attributed to motorman proficiency in the early tests (AWO) in holding speed and stopping on the station marked.

Figure 7-3 shows a typical 3000 foot run over level tangent track and flywheel speed versus car speed is shown in figure 7-4.

The system component temperatures shown in figure 7-5 are for a 15 mph maximum speed run with 2000 foot station stops. The second test, started after a short pause, were run out and return over the same length of track but were not complete laps. The highest temperatures recorded for flywheel motor B was 170°F in the acceleration tests which were run at higher maximum (up to 45 mph) speeds.

Table 7-3. Power Consumption Test Results

			AWO							
			CW			CCW			Average	
No.	Distance, ft	Car Speed, mph	2 Cars KWR/Lap	KWR/CM	Minutes Per Lap	2 Cars KWR/Lap	KWR/CM	Min /Lap	KWR/CM	Car Speed, mph
1	2000	15	89.3	4.9	47.0	95.3	5.24	49.0	5.1	11.4
2	2000	30	65.4	3.59	32.5	75.9	4.17	33.0	3.9	16.6
3	2000	45	71.3	3.91	--	61.4	3.37	--	3.6	--
4	3000	15	94.6	5.2	49.0	100.0	5.49	49.0	5.3	11.2
5	3000	30	64.8	3.55	28.4	67.0	3.68	28.35	3.6	19.25
6	3000	45	69.5	3.81	28.0	66.8	3.67	28.0	3.7	19.5
7	5000	45	58.8	3.23	21.0	61.1	3.35	20.5	3.3	26.2
8	5000	45-15-30	65.4	3.59	27.4	71.5	3.93	26.75	3.8	20.15
9	10,000	45	41.5	2.28	16.6	41.9	2.30	16.5	2.3	33.0
10	10,000	45-15-30	54.0	2.96	20.75	56.9	3.13	19.6	3.0	27.0

			AW3							
			CW			CCW			Average	
No.	Distance, ft	Car Speed, mph	2 Cars KWR/Lap	KWR/CM	Min /Lap	2 Cars KWR/Lap	KWR/CM	Min /Lap	KWR/CM	Car Speed, mph
1	2000	15	70.7	3.89	48.9	76.5	4.2	45.4	4.0	11.6
2	2000	30	99.2	5.45	35.5	90.1	5.0	37.3	5.2	15.9
3	2000	45	99.0	5.44	36.7	94.8	5.21	37.3	5.3	14.75
4	3000	15	78.5	4.31	47.0	71.0	3.9	42.5	4.1	12.2
5	3000	30	83.5	4.58	31.5	82.4	4.52	32.0	4.5	17.2
6	3000	45	83.7	4.6	28.9	82.5	4.53	30.0	4.6	18.5
7	5000	45	63.3	3.47	23.6	63.0	3.46	23.75	3.5	23.0
8	5000	45-15-30	68.1	3.73	27.5	71.1	3.9	26.5	3.8	20.2
9	10,000	45	52.3	2.87	19.25	49.8	2.74	18.85	2.8	28.6
10	10,000	45-15-30	73.5	4.03	23.0	73.3	4.02	22.8	4.0	23.8

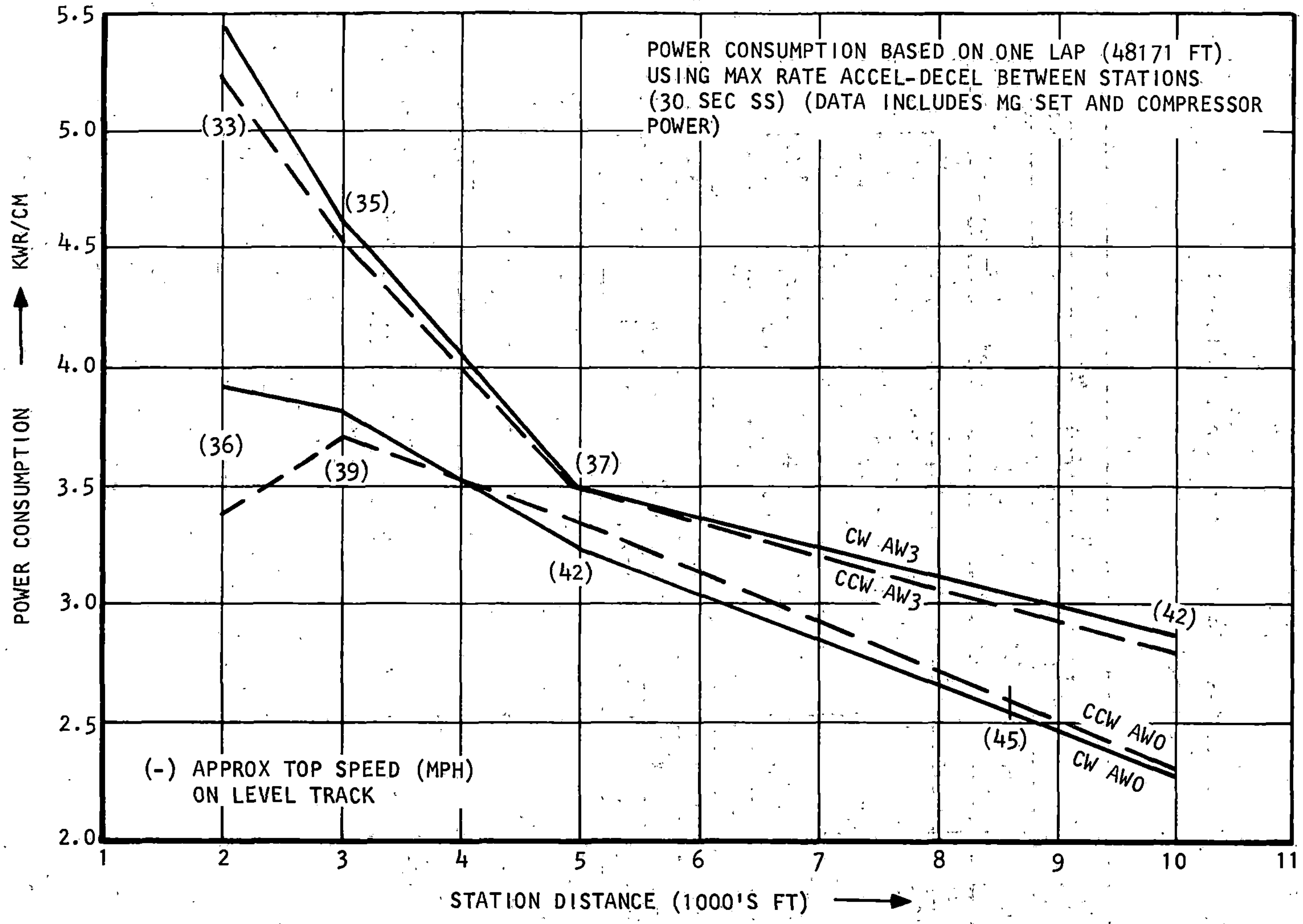


Figure 7-1. Power Consumption Tests

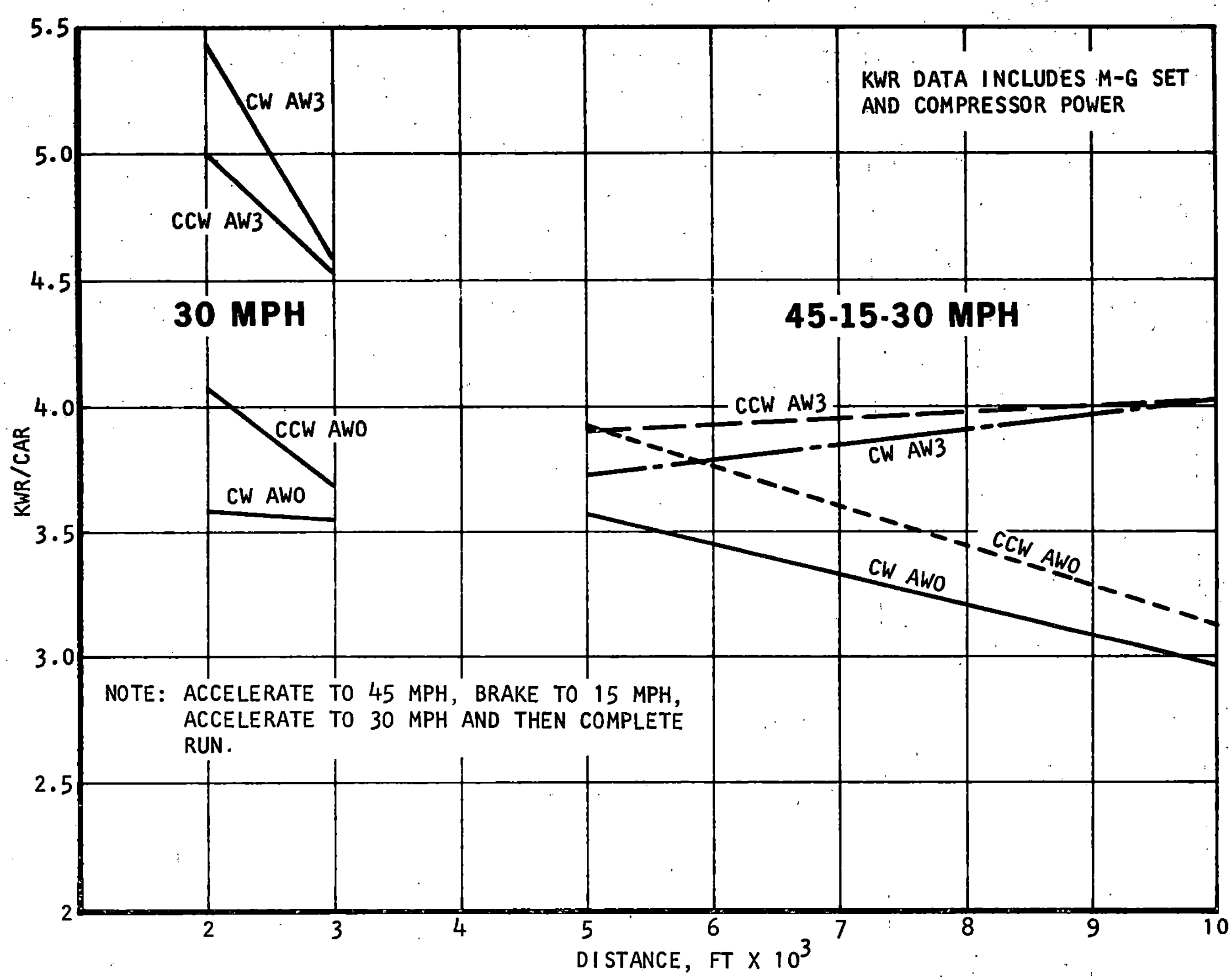


Figure 7-2. Power Consumption vs Distance

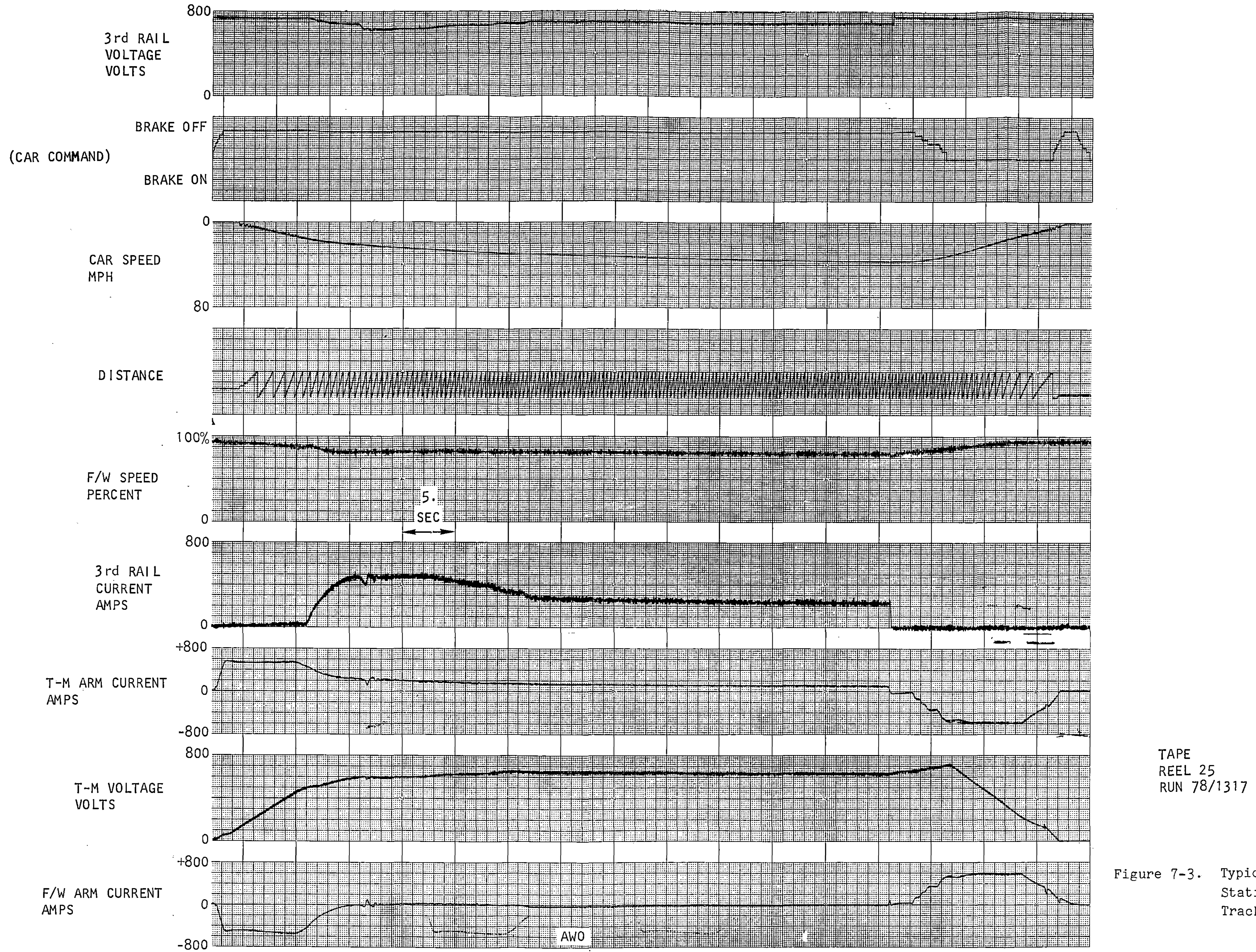


Figure 7-3. Typical 3000 foot Station-to-Station Run on Level Tangent Track

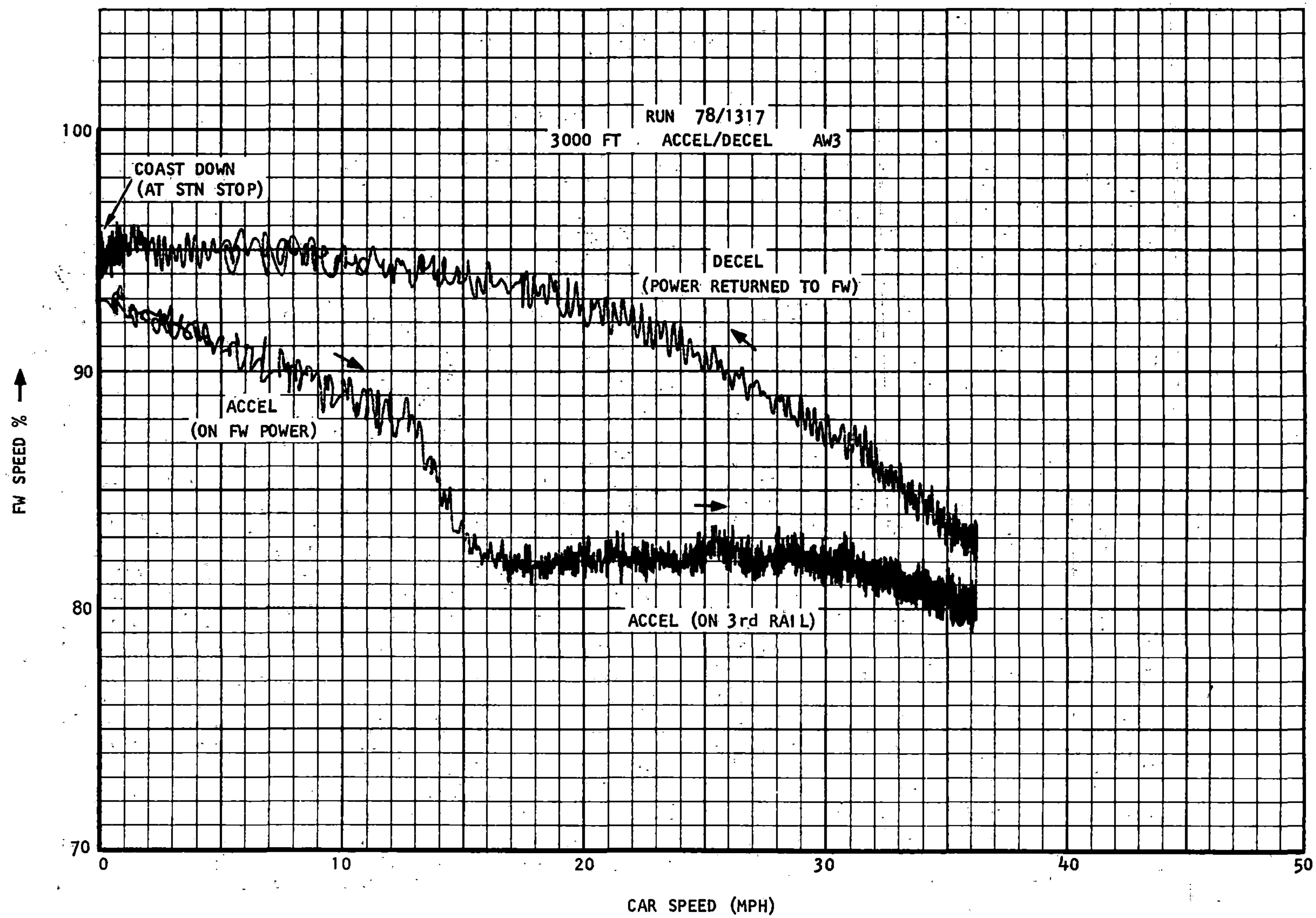


Figure 7-4. Flywheel Speed vs Car Speed

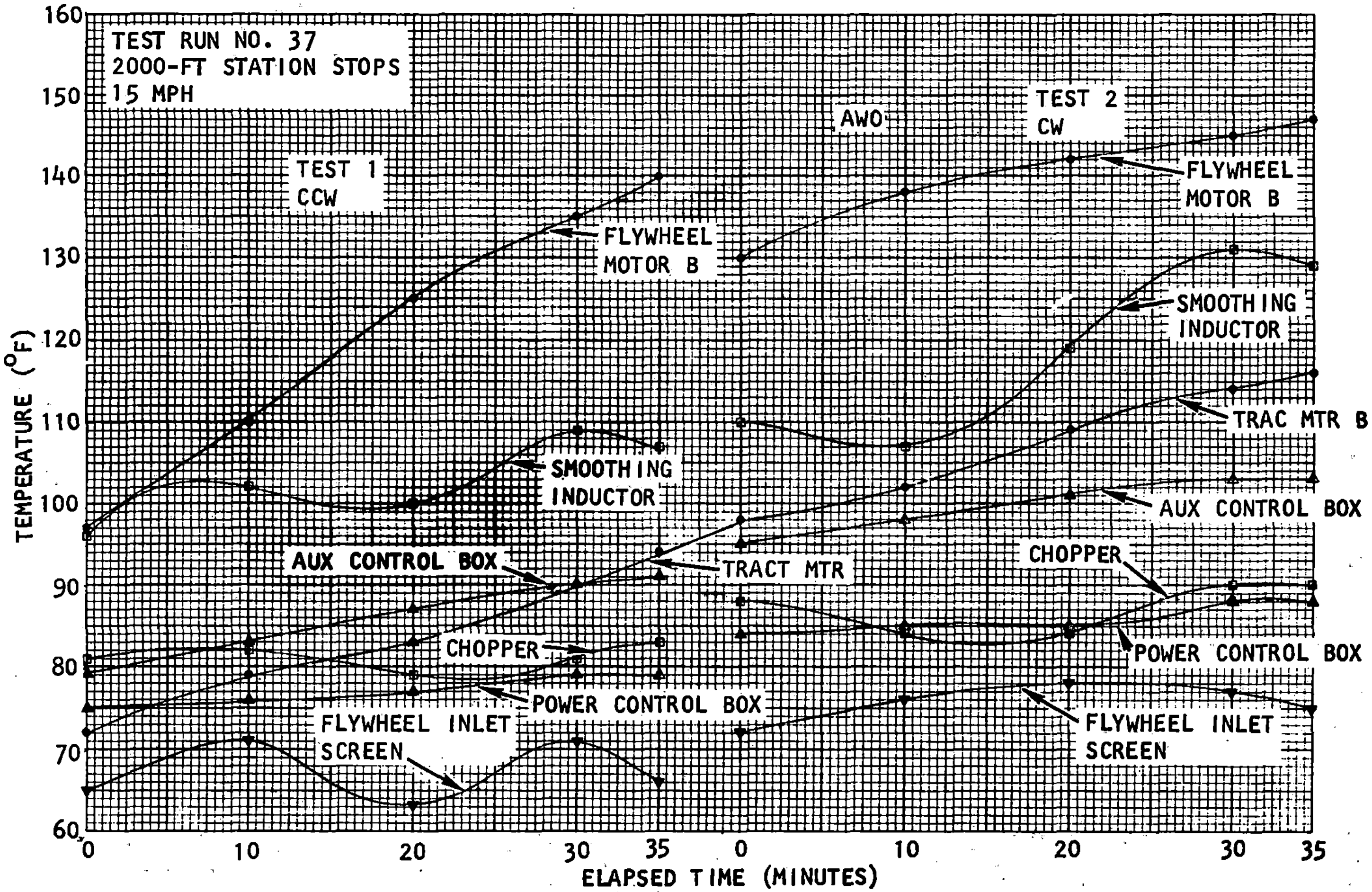


Figure 7-5. Power Consumption - Temperature vs Time

8. RADIO FREQUENCY INTERFERENCE (ESP-PSI-6001-TT)

8.1 SUMMARY

The radio frequency interference test for the energy storage cars was conducted in compliance with Test Set Number ESC-PSI-6001-TT) of the TSC General Vehicle Test Plan, GSP-064. Requirements and procedures covered by this test set are defined in paragraphs 8.1.1 through 8.2.2. Refer to paragraph 8.3 for a description of the test, instrumentation used, and for the test results.

8.1.1 TEST OBJECTIVE

To determine levels of broadband radiated electromagnetic emmission from the test vehicle to the wayside.

8.1.2 TEST DESCRIPTION

This test is to be performed with test vehicle passing by a wayside station under each of the following conditions:

(a) Acceleration above and below base speed

(b) Constant speed

(c) Braking

8.1.3 STATUS

The energy storage cars successfully completed the radio frequency interference tests as prescribed by the conditions specified in paragraph 8.1.2. Refer to test log runs 80 through 82 presented in Volume I, Appendix C of this report.

8.2 PROCEDURES

The following test procedures are included as part of the ESC-PSI-6001-TT Test Set. These procedures were used, unless otherwise noted in paragraph 8.3, for the energy storage car radio frequency interference tests.

8.2.1 PRETEST PROCEDURE

(a) Identify model and serial numbers of each component of radio frequency interference measurement system.

CAUTION

> Test frequencies with high ambient electromagnetic noise level (such as broadcast frequency of local station) are to be avoided.

(b) Set up radio frequency interference measurement system inside and near midpoint of test vehicle. With all test vehicle systems and third rail power deenergized, scan complete test frequency range and select four discrete test frequencies per decade, at which electric field intensity is to be measured throughout wayside test program. Measure and record electric field intensity at each test frequency.

(c) Repeat frequency scan after all test vehicle systems have been energized, in order to identify any emission frequencies (noise peaks) associated with test vehicle systems. Add any such frequencies to list of test frequencies. Measure and record electric field intensity at each test frequency.

(d) Set up radio frequency interference measurement system with antenna tripod located 100 feet from track centerline. With all test vehicle systems and third rail power deenergized, measure and record electric field intensity at each test frequency.

8.2.2 TEST PROCEDURE

(a) Select three test vehicle speeds representative of normal operating speed range.

CAUTION

> For tests performed with test vehicle passing by wayside test station at constant speed, absence of acceleration or braking is more important than accurate nominal test velocity.

(b) At each test frequency, measure and record electric field intensity level with test vehicle passing by wayside test station at each selected constant speed.

(c) At each test frequency, measure and record electric field intensity level while test vehicle passes by wayside test station accelerating, above base speed, at maximum rate. With test vehicle accelerating, below base speed, at maximum rate, repeat measurements at some test frequencies (at least one frequency per decade).

(d) At each test frequency, measure and record electric field intensity level while test vehicle passes by wayside test station decelerating at maximum rate.

8.3 TEST DESCRIPTION AND RESULTS

Tne energy storage car (ESC) radio frequency interference tests were conducted in accordance with AiResearch Document 74-10441 as defined in paragraph 8.3.1 and in compliance with GSP-064 Test Set ESC-PSI-6000-TT, described in paragraphs 8.1.1 and 8.1.2.

8.3.1 DESCRIPTION

Measurements to determine levels of broadband radiated electromagnetic emmissions from the energy storage cars were taken using a radio interference field intensity meter and an antenna located either on board, at approximately the mid-point of the vehicle, or outside, 100 feet from the track centerline.

The following parameters were recorded for each of the measurements using the test procedures described in paragraph 8.2:

(a) Interior scan

(b) Exterior scan

(c) Constant speed (20, 30 and 40 mph)

(d) Acceleration above base rate

(e) Acceleration below base rate

(f) Deceleration (service brake)

8.3.2 INSTRUMENTATION

Block diagrams, of the data acquisition system and the data recovery system are provided in figures 1-1 and 1-2. Details of the instrumentation related to the ESC radio frequency interference tests are shown in figures 1-7 (internal) and 1-8 (external). Information concerning instrumentation for overall data acquisition for energy storage car tests is described in Volume I of this report.

8.3.3 RESULTS

Representative samples of the ESC radio frequency interference test results for measurements of the ambient and frequency scan tests, constant speed, acceleration and deceleration tests are shown in figures 8-1 through 8-9.

The interior ambient test was conducted in accordance with procedure described in step b of paragraph 8.2.2 with antenna aboard and all vehicle systems deenergized. For the frequency scan test, all systems were energized for the test.

The interior ambient test was performed with antenna aboard and all vehicle systems deenergized; see figure 8-1 for results. All systems were energized for the frequency scan test, results are shown in figure 8-2. For the exterior ambient test, the antenna was located 100 feet from the track centerline and all systems deenergized; results are shown in figure 8-3.

Constant speed tests were performed at 12, 18, and 40 mph with the antenna located 100 feet from the track. Constant speed test results are shown in figures 8-4 through 8-6.

Test results of the acceleration tests, with vehicle accelerating at maximum rates both below and above base speed are shown in figures 8-7 and 8-8.

The deceleration test was performed with the vehicle decelerating at maximum rate. Test results are shown in figure 8-9.

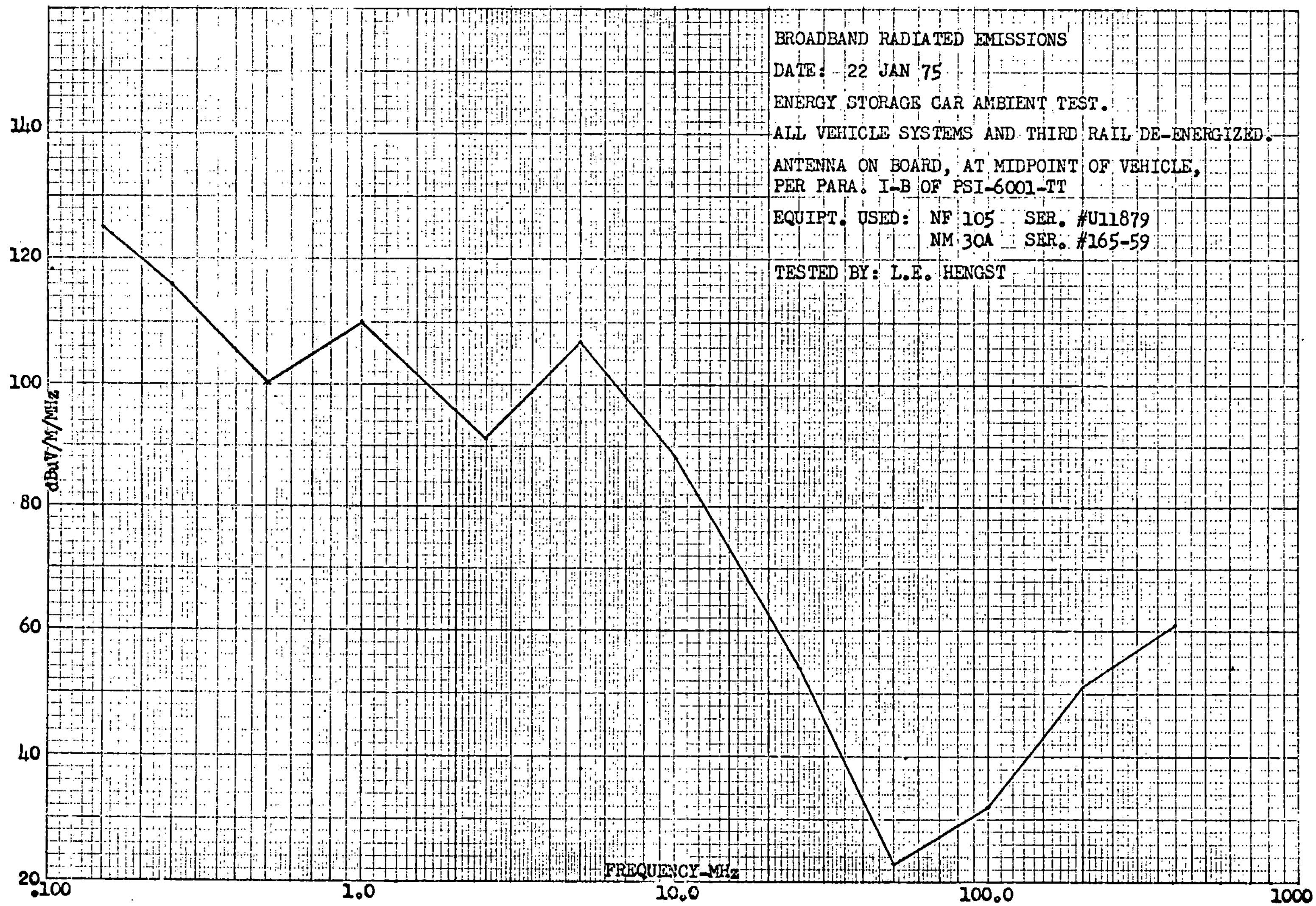


Figure 8-1. Ambient Test - Interior

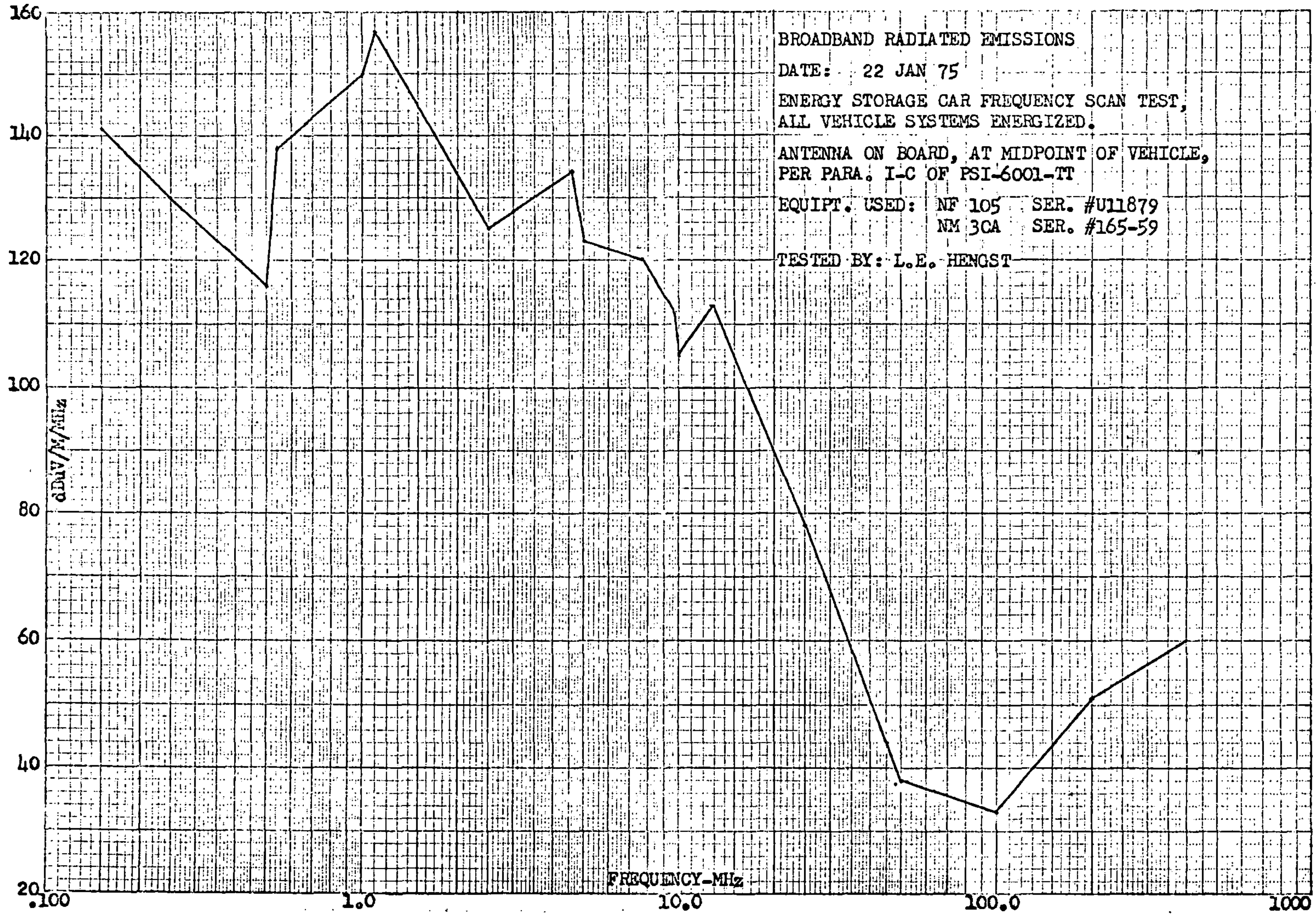


Figure 8-2. Frequency Scan Test

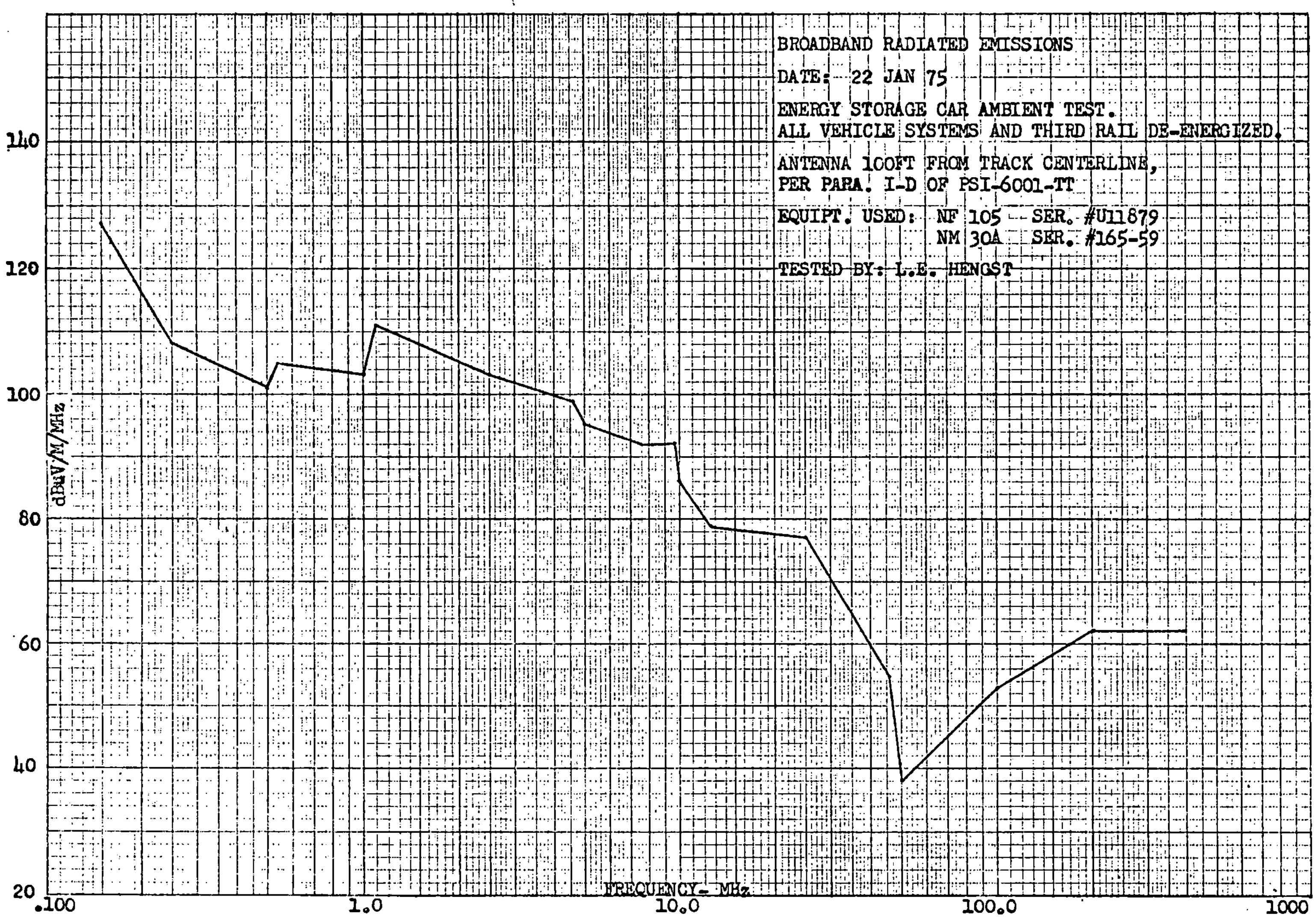


Figure 8-3. Ambient Test - Exterior

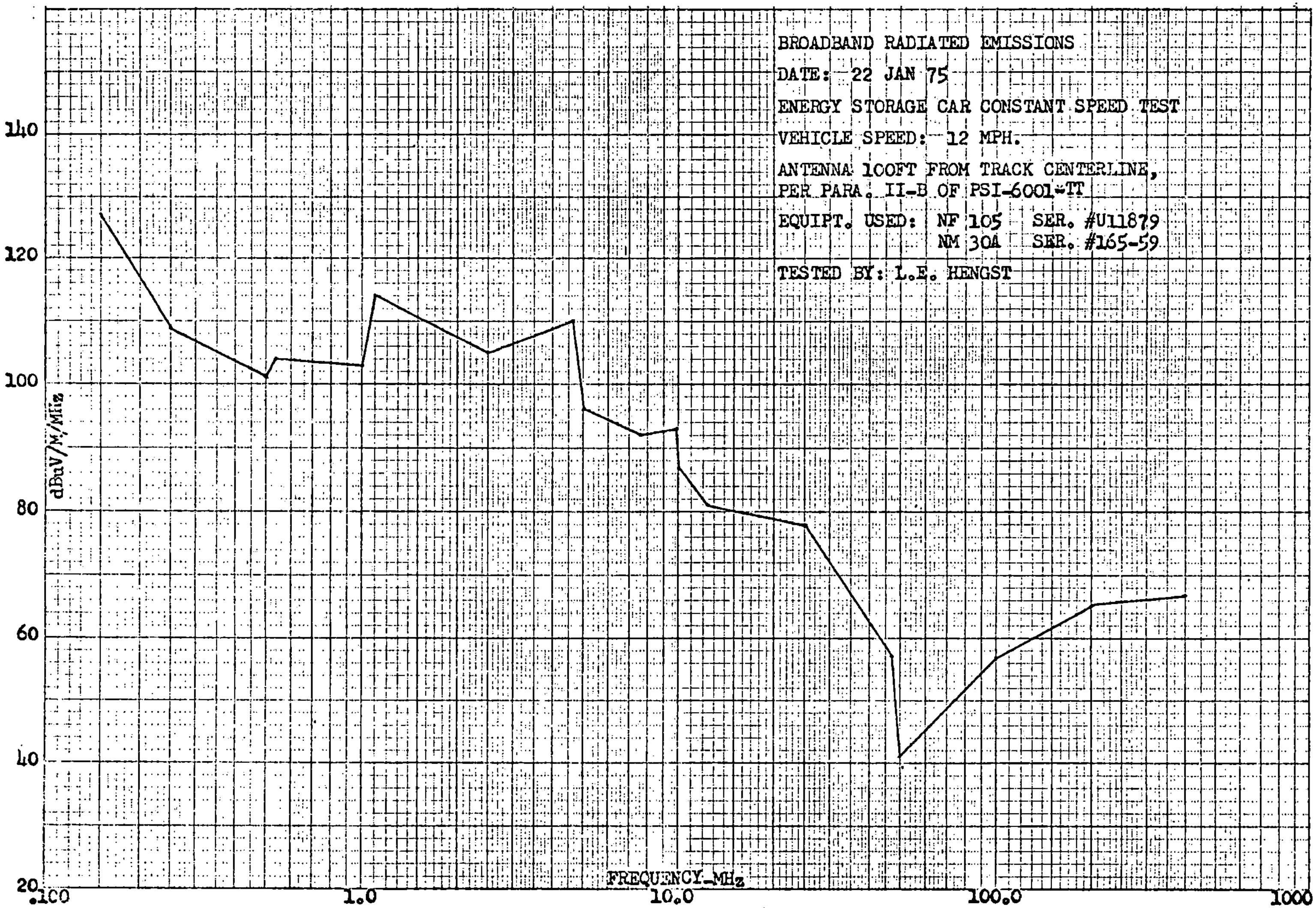


Figure 8-4. Constant Speed Test - 12 MPH

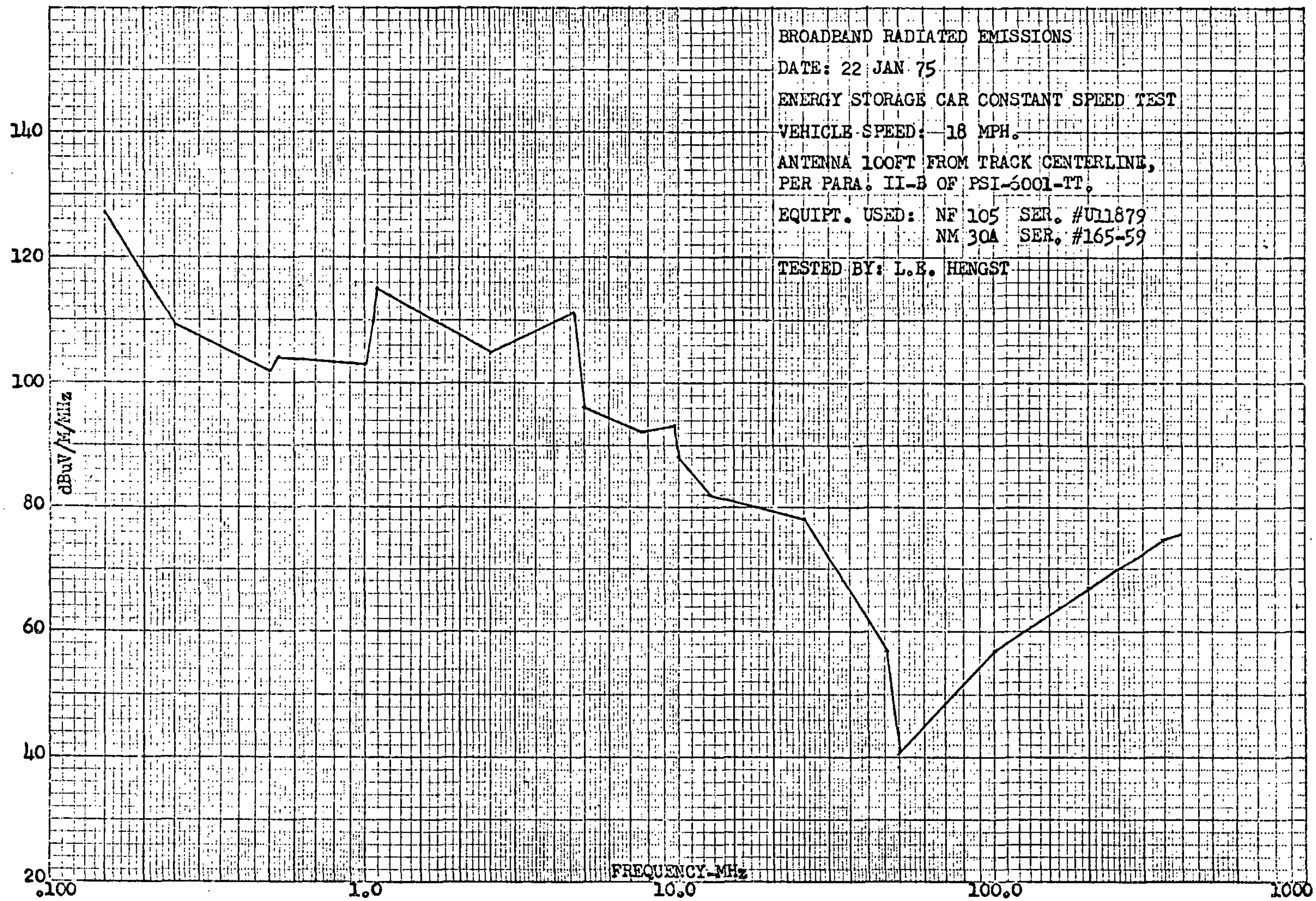


Figure 8-5. Constant Speed Test - 18 MPH

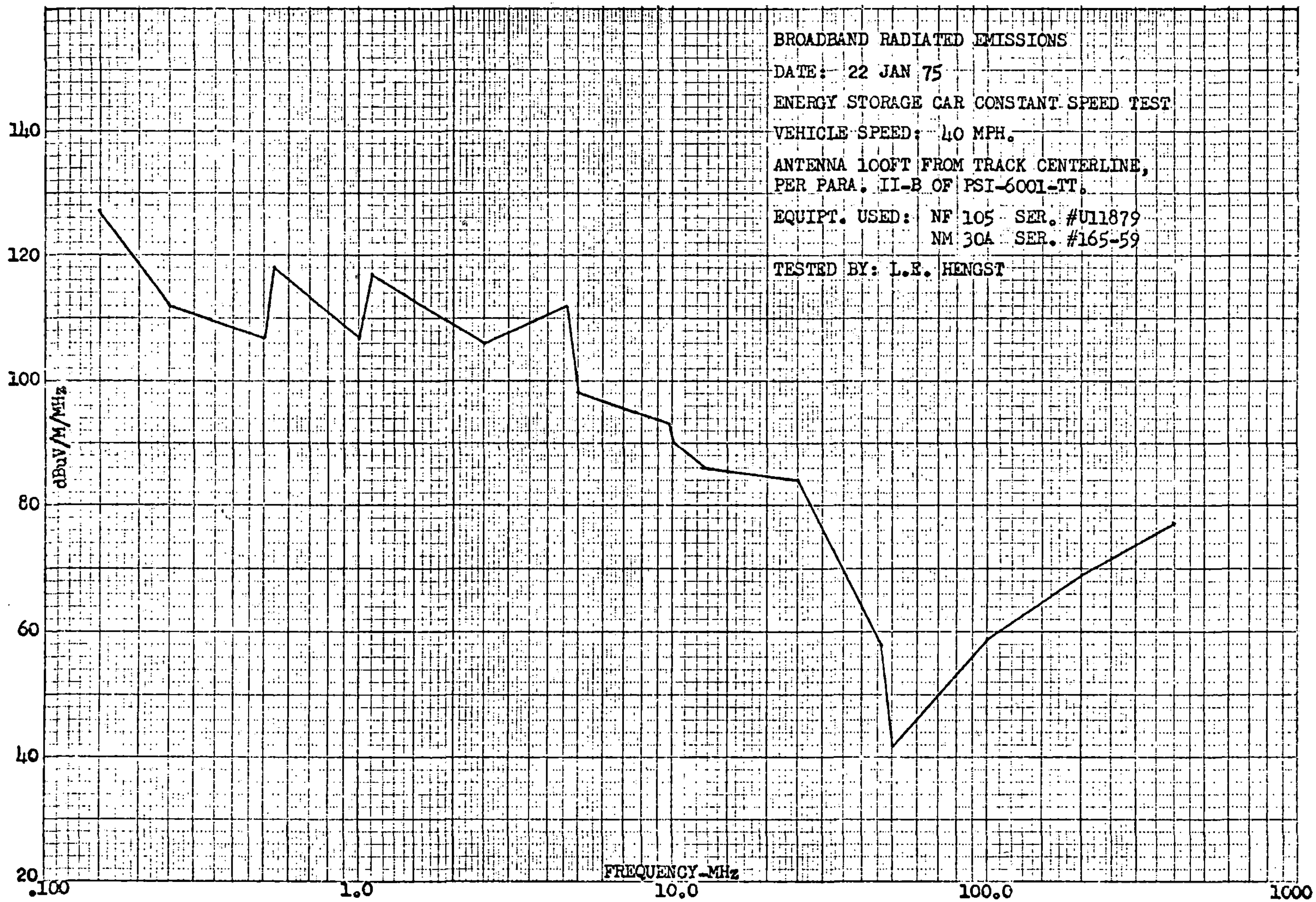


Figure 8-6. Constant Speed Test - 40 MPH

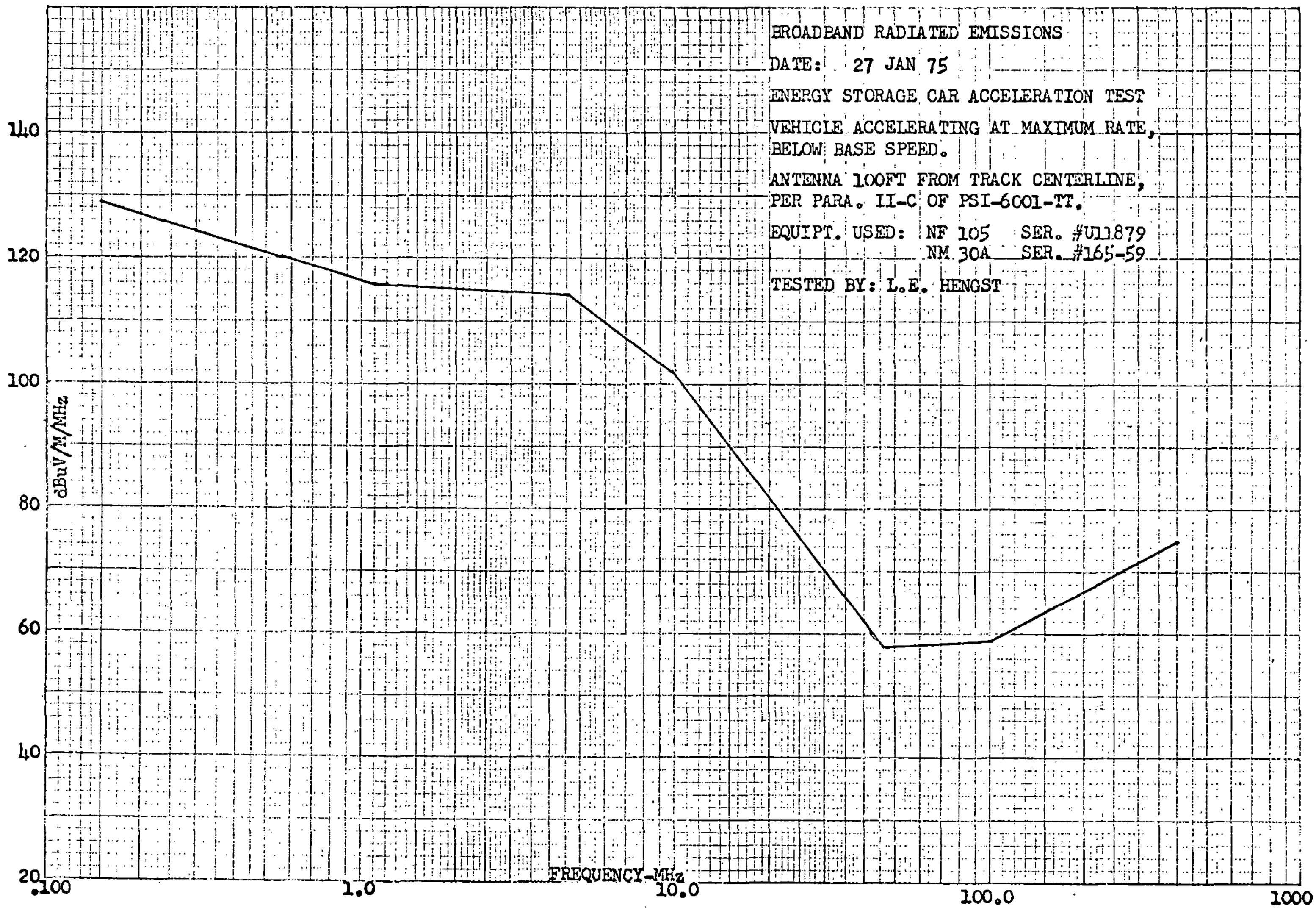


Figure 8-7. Acceleration Test - Below Base Speed

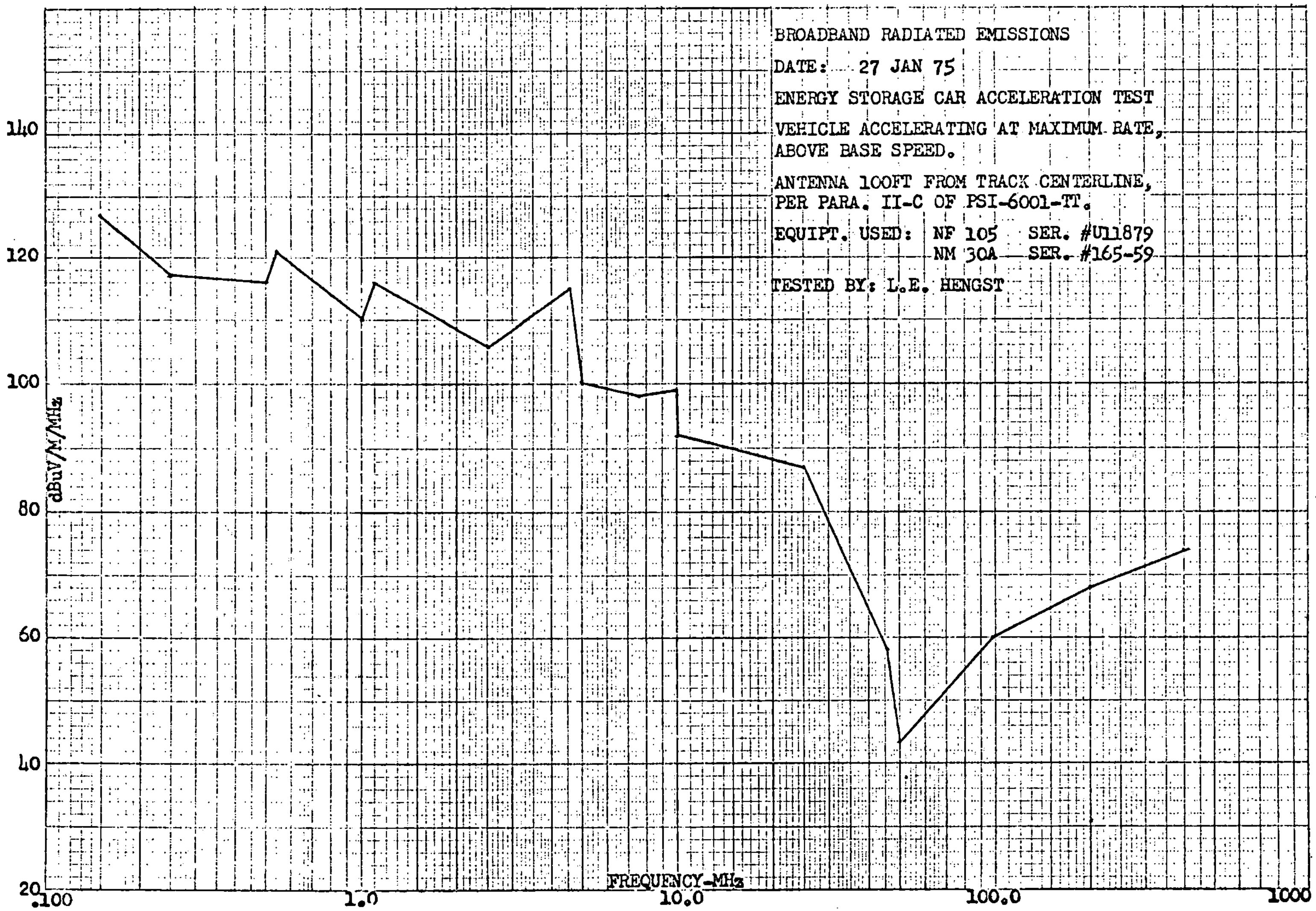


Figure 8-8. Acceleration Test - Above Base Speed

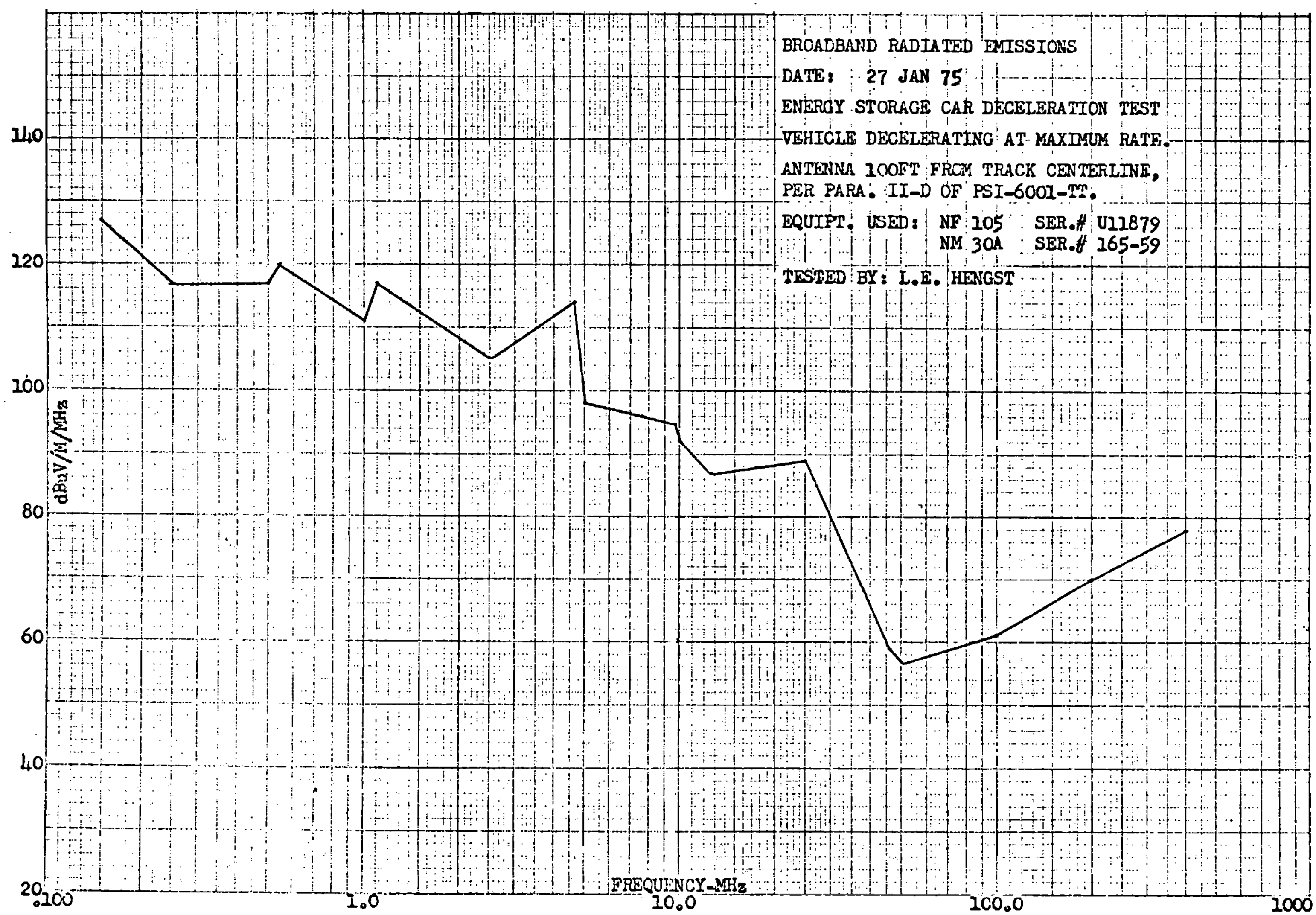


Figure 8-9. Deceleration Test

9. GLOSSARY

Ampl vs Freq plot	Log-log plot or semi-log plot of data
AW0	Vehicle empty weight
AW2	Vehicle empty weight plus full load
AW3	Vehicle empty weight plus crush load
CB	Carbody
DOT	Department of Transportation
ESC	Energy storage car
ESS	Energy storage system
FWD	Forward
F.S.	Full scale
F/W	Flywheel
H.P.	Hewlett Packard
MTA	Metropolitan Transportation Agency
NA	Not applicable
NYCTA	New York City Transit Authority
PAR	Parallel
QSD	Quick shutdown
REV	Reverse
RQD	Required
SER	Series
SW	Switch
TSC	Transportation Systems Center
TTC	Transportation Test Center
T/M	Traction motor
UMTA	Urban Mass Transportation Administration
X-Y Plot	Graphical data presentation obtained by running analog magnetic tape into an X-Y plotter with minimum filtering.

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