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WMATA RAPID TRANSIT VEHICLE ENGINEERING TESTS

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Transportation Test Center
Pueblo, Colorado 81001

MAY 1979
FINAL REPORT

Prepared for

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16. Abstract

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PREFACE

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The Urban Rail Supporting Technology Program of the Transportation Systems Center (TSC), in accordance with project plan agreements with the Office of Rail and Construction Technology in the Urban Mass Transportation Administration, Office of Technology Development and Deployment, has been conducting research, development, and evaluative testing efforts directed toward the introduction of improved technology and more effective use of available technology in the specification, design, and production of cost-effective urban rail vehicles. As a part of its testing program, a standard "General Vehicle Test Plan" has been developed for the evaluation of urban rail vehicles. The event of the WMATA vehicle and its test program at the Transportation Test Center provided an opportunity to exercise the GVTP and also to gather and analyze useful data on the WMATA vehicle.

The program was managed by the DOT, Federal Railroad Administration, Test Operations Division at the TTC, with general support and data analysis and processing provided by Dynalectron Corporation, the Operations and Maintenance Contractor at the TTC. Test conduct and instrumentation functions were carried out by ENSCO, Incorporated, Dynalectron's subcontractor for Instrumentation and Test Support.

It is not the purpose of this report to make comprehensive evaluations with other transit vehicles except for direct numerical comparisons. It is solely to gather, record, and analyze data pertinent to transit vehicle performance and characteristics in an accelerated and significant manner, in reference to standardized testing procedures and conditions; and to make such results available to the transit industry for both managerial and engineering purposes. Subsequent efforts will lead to comparative evaluations of performance of various transit vehicles.

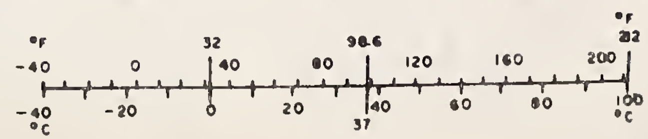
METRIC CONVERSION FACTORS

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



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ACRONYM LIST

ACT-1	Advanced Concept Train-1
ALD	Automatic Location Detector
CTA	Chicago Transit Authority
CTS	Cleveland Transit System
DOT	Department of Transportation
EMF	Electromotive Force
GVTP	General Vehicle Test Plan
NYCTA	New York City Transit Authority
PSD	Power Spectral Density
R&D	Research and Development
RMS	Root Mean Square
TSC	Transportation Systems Center
TTC	Transportation Test Center
TTT	Transit Test Track
UMTA	Urban Mass Transportation Administration
URST	Urban Rail Supporting Technology
WMATA	Washington Metropolitan Area Transit Authority

1.0 GENERAL PROGRAM DESCRIPTION

1.1 INTRODUCTION.

This report presents the results of a series of engineering tests carried out on the Washington Metropolitan Area Transit Authority (WMATA) rapid transit cars from September 1976 to August 1977, at the Department of Transportation (DOT), Transportation Test Center (TTC) Pueblo, Colorado. The test program was sponsored by the Office of Rail and Construction Technology in the Urban Mass Transportation Administration (UMTA), Office of Technology Development and Deployment, with the Transportation Systems Center (TSC) as program directors. TSC supported UMTA by providing systems management for the Urban Rail Supporting Technology (URST) Program in the design, construction, and operation of UMTA test facilities, the analysis and testing of vehicles and components, and the development of key technological data. In response to these tasks, TSC has been instrumental in preparing standardized test procedures, the "General Vehicle Test Plan" (GVTP) for the evaluation of rail transit vehicles, using the TTC 9.1 mile (14.6 km) Transit Test Track (TTT) with the objective of providing a common baseline for the comparative evaluation of rapid transit vehicles and vehicle systems. The test program reported herein was conducted in accordance with the guidelines of the GVTP.

1.2 THE GENERAL VEHICLE TEST PLAN.

The General Vehicle Test Plan (GVTP) for Urban Rail Transit Cars, Report No. UMTA-MA-06-0025-74-14, provides a standardized system for testing, documenting, and utilizing data in the testing of urban rail transit cars. The purpose of the GVTP is to evaluate the total vehicle performance on a standardized data base, to provide technical information for:

- The qualitative analysis of competitive vehicle systems,
- Identifying technical areas where research and development activity is desirable,
- Defining system improvement achieved by research and development (R & D) effort, and
- Maintaining a data bank for transit properties and vehicle manufacturers planning and developing new transit systems.

The GVTP details test procedures in eight vehicle test categories:

- Performance (Propulsion, Control, Braking),
- Power Consumption,
- Adhesion,
- Noise,
- Ride Roughness,
- Power System Interactions (Radio Frequency Interference),
- Structural Dynamics, and
- Simulated Revenue Service.

1.3 THE WMATA RAPID TRANSIT CAR.

This section presents a general description of the WMATA Rapid Transit Car (figure 1-1) with information pertaining to: Car Specifications, Car Body, Trucks and Suspension, Traction Motors and Transmissions, Braking System, and Propulsion and Control System.

1.3.1 Car Specifications.

Car Length	75 ft (22.86 m)
Car Width	10 ft 1-3/4 in (3 092 mm)
Car Height	10 ft 10 in (3 302 mm) from top of rail
Empty Weight	A-car 72,000 lbs (32 658 kg) B-car 72,000 lbs (32 658 kg)
Seated Passenger Load	80 persons
Full Passenger Load	175 persons
Crush Passenger Load	220 persons
Maximum Speed	75 mi/h (120.7 km/h)
Maximum Acceleration	3 mi/h/s (4.8 km/h/s)
Train Consist	One pair minimum, to four pairs maximum

Text continues on page 4

FIGURE 1-1. WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY (WMATA) RAPID TRANSIT CARS AT THE TRANSPORTATION TEST CENTER.

1.3.2 Car Body.

The car body is of aluminum unibody construction featuring a main underframe of aluminum beams and intercostals attached to the car body side sills; the end underframes incorporating the bolsters, draft sills, and anti-climbers are steel weldments. The body side walls and roof exterior panels are brush-finished aluminum extrusions riveted together and to vertical frames; there are two extruded aluminum collision posts at the sides of the end door openings, connected by a horizontal member to aluminum corner posts to form a crash attenuation structure. The cab ends are formed from fiber-glass reinforced plastic; doors are of aluminum skin-honeycomb composite construction.

1.3.3 Trucks and Suspension.

The trucks are of the high speed, parallel-drive type. The trucks are of three-piece construction, comprising a steel bolster and two cast steel sideframes. Cylindrical rubber sleeves between the journal bearings and the side frames provide bearing resiliency. The truck bolsters are supported on two air springs per truck with load-weigh compensation incorporated to provide a constant floor height of 40 inches (1.02 m) above the rail. Three adjustable hydraulic shock absorbers per truck are factory preset to provide ride damping and control; rubber bump pads provide lateral constraint. The truck-car body longitudinal relationship is maintained by two radius rods connecting the truck bolster to the sideframe.

1.3.4 Traction Motors and Transmissions.

Two traction motors (rated at 175 hp at 2,450 rpm) (130.5 kW) are suspended from rubber cushioned hangers on each truck. They are 4-pole DC, series wound motors, and each pair is connected in series. They are resiliently mounted to two parallel-type, double reduction gear box units with an overall reduction ratio of 5.44:1. Misalinement between motor and gearbox is accommodated by a gear-type misalinement coupling. Twenty-eight inch (711 mm) wheels are used.

1.3.5 Braking System.

Under normal operation, the major braking effort is provided by the dynamic braking capability of the vehicle propulsion system with supplemental braking effort provided by friction brakes. Friction braking is blended with dynamic braking electronically by a brake control system to maintain a constant deceleration rate. In practice, the friction brakes "fill" the transition from a power to a brake mode, and take over the braking effort with the dropout of dynamic braking at low speed. In the event of failure of the dynamic braking system, full service braking effort can be maintained by the friction brake system.

Friction braking is provided by an electronically controlled, hydraulically operated system on each car which actuates a disc brake mounted externally at each wheel.

Emergency braking is provided by the friction brake system only, and is air-initiated from a train-lined brake pipe. A spin/slide control system provides protection against excessive spinning or sliding of the wheels during either propulsion or braking; this system does not function during emergency braking.

1.3.6 Propulsion and Control System.

The propulsion and control system follows conventional transit car practice: an electro-pneumatic power cam controller, responding to command signals from the operator's master controller or from an Automatic Train Control, is used to switch permutations of three basic types of traction motor current control, i.e., series resistor banks, series to series-parallel connection of pairs of traction motors, and three stages of field shunting. A second resistor bank and cam controller is used to control dynamic braking by varying the amount of resistance across the traction motors in the braking mode, to maintain constant back electromotive force (EMF), and therefore constant braking rate.

Logic circuits in the propulsion and control system provide compensation for vehicle weight, to provide constant acceleration and deceleration rates regardless of passenger load, and spin-slide, and jerk limit protection.

1.4 THE TRANSIT TEST TRACK.

The WMATA general vehicle tests were carried out on the TTT at the TTC. The TTT is a 9.1 mile (14.6 km) oval incorporating six different types of track construction, representative of new construction used in operating transit system properties. The TTT features a perturbed section of track, typical grade crossings and switches, and a 4,000 ft (1 219 m) level tangent section which was used for all performance testing.

Track orientation and plan are shown in figure 1-2, and the track profile is shown in figure 1-3. Table 1-1 shows the characteristics of each of the six different track sections.

Text continues on page 9

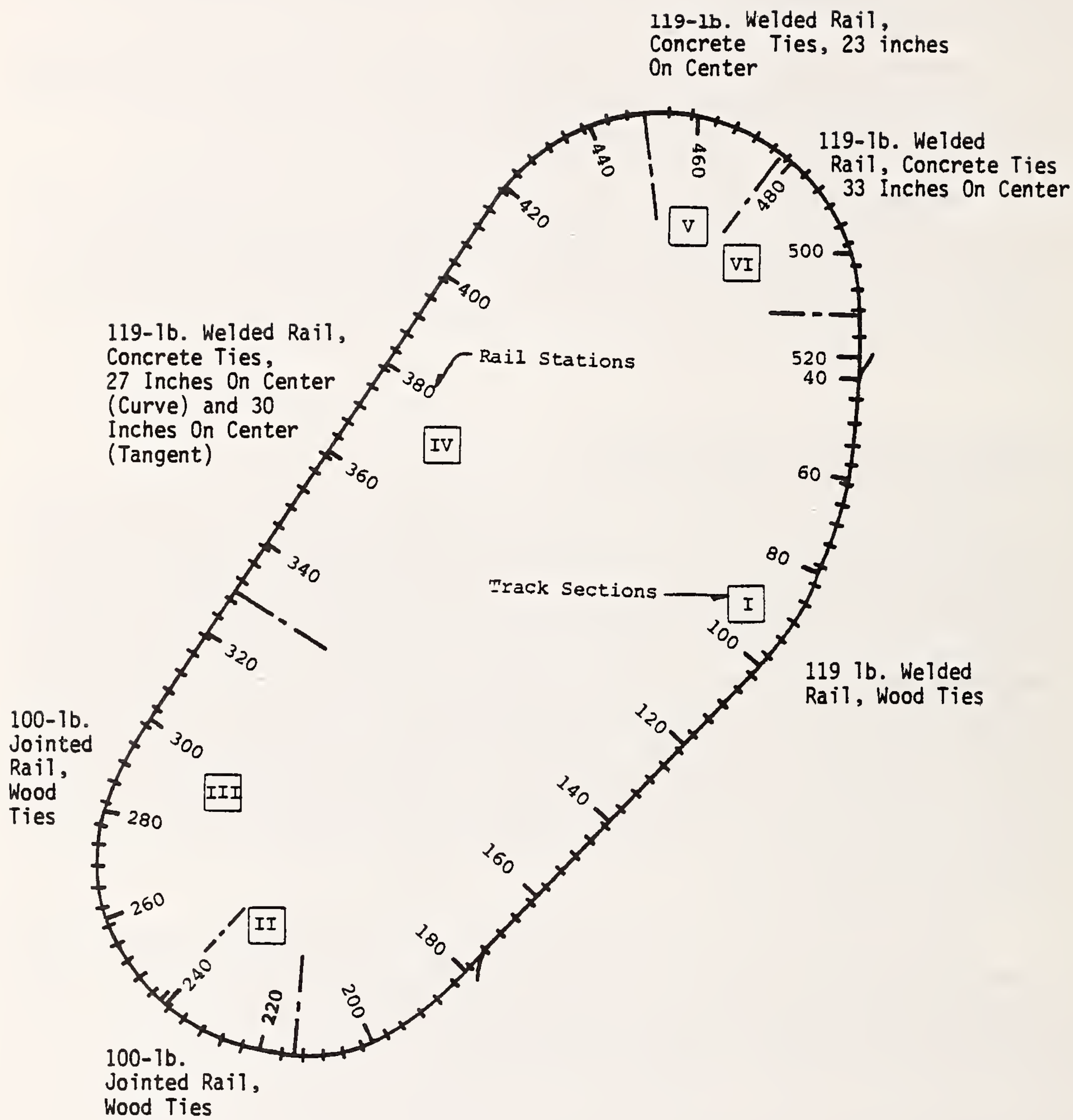

FIGURE 1-2. TTC TRANSIT TEST TRACK.

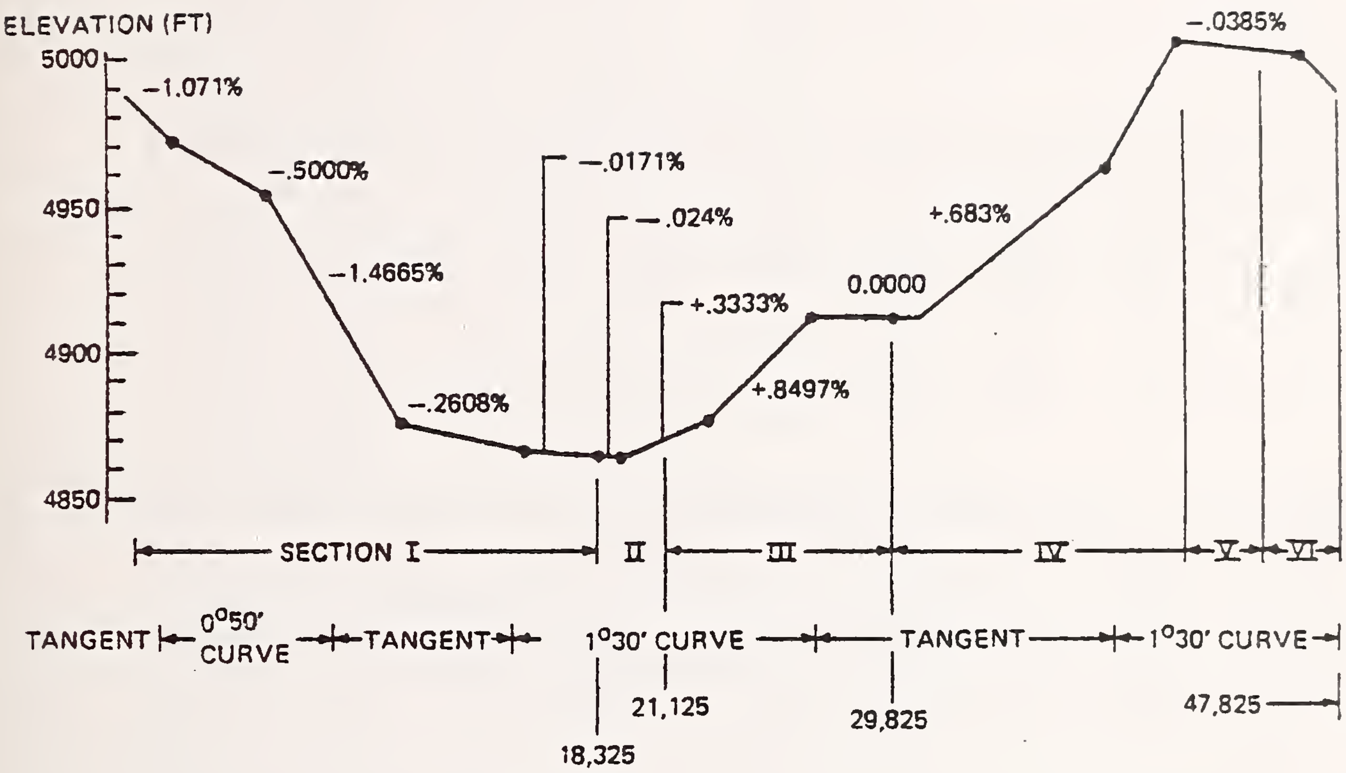

FIGURE 1-3. TRANSIT TEST TRACK PROFILE SHOWING GRADES.

TABLE 1-1. SUMMARY OF TTC TRANSIT TEST TRACK CONFIGURATION.

Section	Location (Sta to Sta)	Alinement	Trackage	Fastener	Rail
I	0 - 174	Tangent and 0° 50' curve	Wooden ties 24" on center	Spike	119 lb/yd Welded
	174 - 210	1° 30' curve	Wooden ties 23" on center		
II	210 - 235	1° 30' curve	Wooden ties 23" on center	Spike	100 lb/yd Welded
III	235 - 290	1° 30' curve	Wooden ties 23" on center	Spike	100 lb/yd Jointed
	290 - 325	Tangent	Wooden ties 24" on center		
IV	325 - 405	Tangent	Concrete ties 30" on center	Spring clip	119 lb/yd Welded
	405 - 440	1° 30'	Concrete ties 27" on center		
V	440 - 470	1° 30'	Concrete ties 24" on center	Spring clip	119 lb/yd Welded
VI	470 - 500	1° 30'	Concrete ties 33" on center	Spring clip	119 lb/yd Welded

Note: All Trackage On Stone Ballast.

A perturbed section of track is in the TTT test configuration between rail stations 118 and 140. The perturbations were made to the outer rail only, in profile and alinement; wavelength varied between 14 ft and 56 ft (4.27 and 17 m). Table 1-2 details the amplitude and waveforms of the perturbations.

The level tangent section of track between rail stations 300 and 340 was used for all performance brake and acceleration runs and for train resistance tests. The track is designed for sustained 80 mi/h (129 km/h) vehicle operation with the exception of the perturbed track section, which was subject to a 45 mi/h (72.4 km/h) speed limit.

Vehicle location on the track was determined by means of a series of station markers posted at 1,000 ft (304.8 m) intervals. These were supplemented with an Automatic Location Detector (ALD) system; the ALD system consists of an active vehicle-mounted inductive probe that detects the presence of metal along the centerline of the track, together with a series of metal targets positioned between the running rails at each rail station.

1.4.1 Third Rail.

The third rail was constructed to New York City Transit Authority (NYCTA) specifications; it was necessary to mount the WMATA car third rail current collectors on 1-1/2" (38.1 mm) wooden spacers in order to make the vehicle compatible with the TTT third rail configuration.

1.4.2 Power Source.

The power source for the WMATA test program was the Chicago Transit Authority (CTA) rectifier station, a unit purchased from the CTA and recommissioned at TTC. Nominal line voltage was set at 760 VDC, with a current limitation of 7,500 amps for two hours. The rectifier station line voltage can be preset from 600 to 780 VDC.

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TABLE 1-2. TRANSIT TEST TRACK PERTURBATIONS, RAIL STATIONS 118 TO 140.

PROFILE					ALINEMENT		
STA 118	STA 120	STA 122	STA 124	STA 126	STA 136	STA 138	STA 140
1.5"	.375"	.375"	.75"	1.5"	.75"	.375"	.75"
1.481" ± 1 tie	.305" ± 1 tie	.3565" ± 1 tie	.713" ± 1 tie	1.426" ± 1 tie	.741" ± 1 tie	.305" ± 1 tie	.713" ± 1 tie
1.425" ± 2 ties	.146" ± 2 ties	.3045" ± 2 ties	.609" ± 2 ties	1.218" ± 2 ties	.7125" ± 2 ties	.146" ± 2 ties	.609" ± 2 ties
1.336" ± 3 ties	.018" ± 3 ties	.229" ± 3 ties	.458" ± 3 ties	.916" ± 3 ties	.668" ± 3 ties	.018" ± 3 ties	.458" ± 3 ties
1.218" ± 4 ties	0 ± 4 ties	.146" ± 4 ties	.292" ± 4 ties	.584" ± 4 ties	.609" ± 4 ties	0" ± 4 ties	.292" ± 4 ties
1.075" ± 5 ties		.0705" ± 5 ties	.141" ± 5 ties	.282" ± 5 ties	.5375" ± 5 ties		.141" ± 5 ties
.917" ± 6 ties		.0185" ± 6 ties	.037" ± 6 ties	.074" ± 6 ties	.4585" ± 6 ties		.037" ± 6 ties
.75" ± 7 ties		0 ± 7 ties	0 ± 7 ties	0 ± 7 ties	.375" ± 7 ties		0 ± 7 ties
.583" ± 8 ties					.2916' ± 8 ties		
.425" ± 9 ties					.2125' ± 9 ties		
.282" ± 10 ties					.141" ± 10 ties		
.164" ± 11 ties					.082" ± 11 ties		
.074" ± 12 ties					.037" ± 12 ties		
.019" ± 13 ties					.01" ± 13 ties		
0 ± 14 ties					0 ± 14 ties		
WAVE LENGTH 56'	14'	28'	28'	28'	56'	14'	28'

PROFILE = Outer rail
ALINEMENT = Outer rail perturbed toward outside of oval
Perturbations are symmetrical around station number

2.0 TEST DESCRIPTION

2.1 INTRODUCTION.

Two pairs of WMATA rapid transit cars (1104/1105 and 1108/1109) were tested during the period September 1976 to August 1977. Three major test objectives were accomplished during that time period:

- A vehicle engineering acceptance test was conducted by Rohr Industries, the manufacturer, to demonstrate compliance with the vehicle specification,

- An extended mileage endurance test program was carried out using a simulated WMATA revenue service profile; the program was structured to obtain accelerated information on the vehicle's extended performance under revenue service conditions, and addressed problems such as brake pad optimization for wear and squeal properties, and

- A General Vehicle Test Program; this was an engineering test program conducted to the guidelines of the "General Vehicle Test Plan (GVTP) for Urban Rail Transit Vehicles", Report No. UMTA-MA-06-0025-75-14.

This report details the results of tests carried out to meet the last objective, the General Vehicle Test Program.

The GVTP defines test procedures, required instrumentation, final data output format, and required preliminary analysis for nine categories previously mentioned; however, no structural dynamics testing was planned or carried out.

2.2 GENERAL VEHICLE TEST SET.

The basic unit of the GVTP is a test set. A specific test, figure 2-1 for example, is related to one of the test and evaluation categories and contains a title, operating procedures, and requirements for instrumentation and preliminary analysis of data. The test set specifies and controls those elements of testing that must be consistent from test to test, and yet provides for sufficient flexibility to allow adaption for different vehicles. From this common base, data can be gathered to allow the comparative evaluation of rapid transit vehicles; from this evaluation, gains in transit vehicle technology may be assessed.

The GVTP test set contains a unique test set number which identifies:

Text continues on page 13

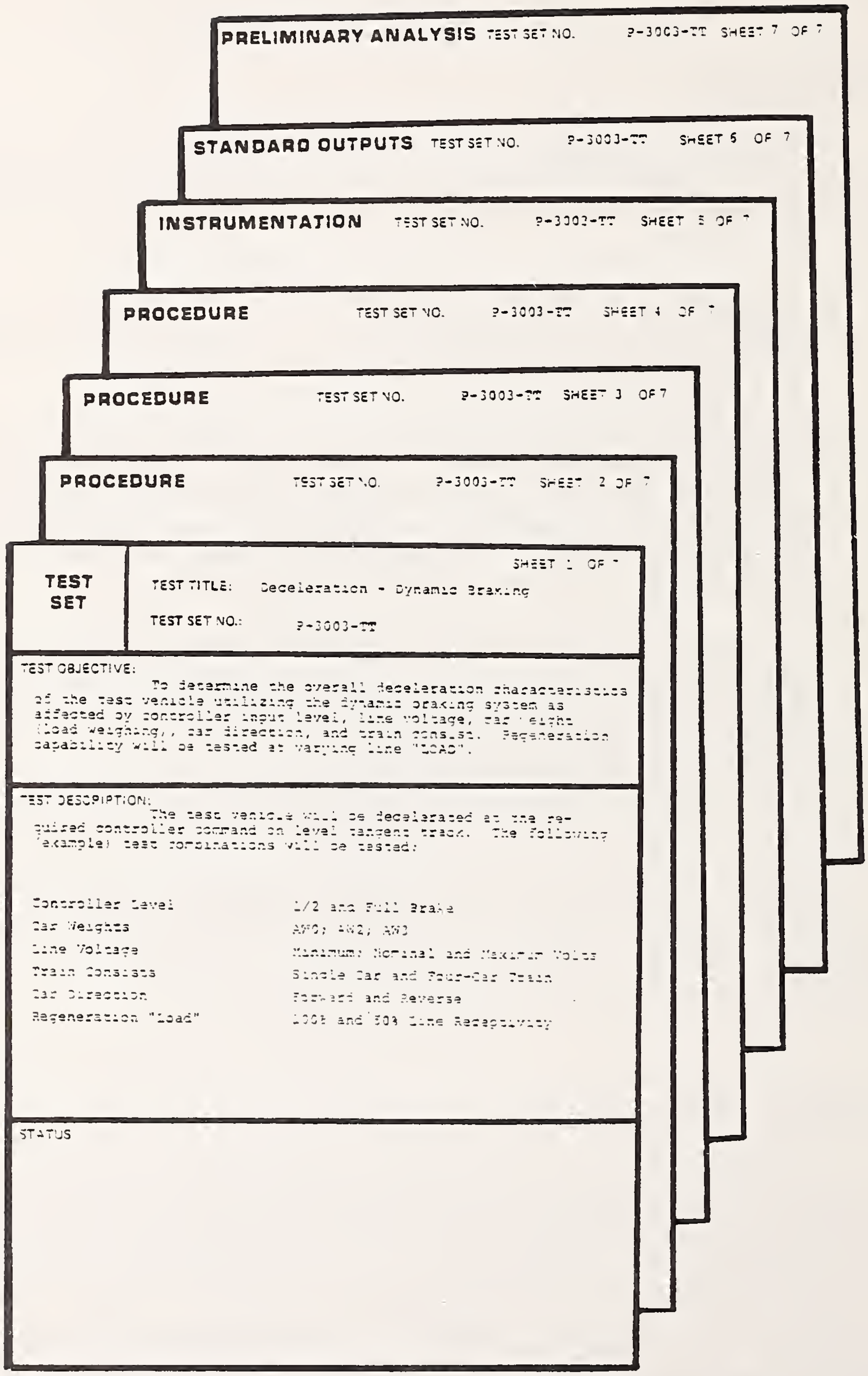

FIGURE 2-1. SAMPLE OF A GENERAL VEHICLE TEST SET.

- o The type of vehicle,
- o The evaluation category,
- o The testing procedure category, and
- o The test location.

The first page of a test set also contains a test objective and test description for the specific vehicle, figure 2-1, sheet 1. The second part, figure 2-1, sheets 2 through 5, contains the detailed step-by-step instructions for set-up and conducting the test. Sheets 6 and 7, figure 2-1, describes the data reduction and analysis through standard output codes defined in the GVTP.

2.3 BASELINE TEST PLAN.

A Baseline Test Plan, comprising a number of test sets in each category of vehicle evaluation, has been defined in the GVTP to present a consistent test program for quantifying the operational characteristics of a typical rapid transit vehicle. The Baseline Test Plan is shown in table 2-1.

2.4 THE WMATA TEST PROGRAM.

2.4.1 Exceptions to the Baseline Test Plan.

The WMATA test program followed the general guidelines of the Baseline Test Plan, but with some exceptions which are explained below.

Consist: Testing was limited to a two-car married pair with the exception of Train Resistance evaluation (P-4001-TT, Drift Test) and Wayside Noise evaluation (PN-1001-TT, Speed Effect, Wayside) test sets which were carried out with a four-car consist, in addition to the two-car configuration.

Control Level: The WMATA master controller has five levels of service brake application (B1 through B5) and five levels of power application (P1 through P5). The vehicle was tested at each control level. The GVTP calls for a percentage of total controller movement as in a fully proportional response system.

Input Voltage: Nominal line voltage was set at 760 VDC with the vehicle stationary and auxiliaries running. This is in excess of the 700 VDC nominal property line voltage, but was required to minimize voltage drop under acceleration, caused by the

Text continues on page 15

TABLE 2-1. BASELINE TEST PLAN.

TEST SET	TITLE	VEHICLE WEIGHTS	CONSISTS	SPD. MPH	CONTROL LEVEL	INPUT VOLT.	REMARKS	TEST REC.
P-2001-TT	Acceleration	AW0,AW2,AW3	Single & Train		1.0 & .75	600(1)	(1) Do 450 & 700 VDC with Single	24
P-3001-TT	Deceleration-Blended Braking	AW0,AW2,AW3	Single & Train	(2)	0.0 & .25	600(1)	(2) 15,25,35,50 mph	48
P-3002-TT	Deceleration-Service Friction	AW0,AW2,AW3	Single & Train	(2)	0.0 & .25	600		48
P-3003-TT	Deceleration-Dynamic	AW0,AW2,AW3	Single & Train	(2)	0.0 & .25	600		48
P-3004-TT	Deceleration-Emergency	AW0,AW2,AW3	Single & Train	(2)	-	-		24
P-4001-TT	Drift Test	AW0,AW2	Single & Train			600		4
P-5001-TT	Duty Cycle-Friction Brake	AW2	Single			600	Repeat for Two Cycles	2
P-2011-TT	Spin/Slide-Acceleration	AW0	Single			600		1
P-3011-TT	Spin/Slide-Deceleration	AW0	Single			600	Repeat for Brake Modes	3
PC-5011-TT	Power Consumption	AW2	Single & Train			600		2
A-3021-TT	Adhesion	AW0	Single			600		1
CN-0001-TT	Equipment Noise Survey	AW0						1
CN-1001-TT	Speed Effect-Wayside	AW0,AW3	Single & Train	(2)		600		16
CN-1201-TT	Screech Loop-Wayside	AW0,AW3	Single			600		1
PN-1001-TT	Speed Effect-On Car	AW0,AW3	Single	(2)		600	Four Interior Locations	32
PN-1101-TT	Track Type Effect-On Car	AW0	Single	35		600		1
PN-1201-TT	Screech Loop-On Car	AW0,AW3	Single			600		2
PN-1301-TT	Interior Survey	AW0	Single	35		600		1
PN-2001-TT	Acceleration-On Car	AW0,AW3	Single			600		2
PN-3001-TT	Deceleration-On Car	AW0,AW3	Single			600	Repeat for Brake Modes	8
R-0001-XX	Dynamic Shake-Vertical	AW0,AW2,AW3	Single				Min. of 4 Interior Locations	12
R-0002-XX	Dynamic Shake-Lateral	AW0,AW2,AW3	Single				Min. of 4 Interior Locations	12
R-0003-XX	Dynamic Shake-Longitudinal	AW0,AW2,AW3	Single				Min. of 4 Interior Locations	12
R-3001-TT	Deceleration	AW0,AW2,AW3	Single			600	Repeat for Brake Modes	
R-0010-TT	Component Induced Vibration	AW0	Single			600		1
R-2001-TT	Acceleration	AW0,AW2,AW3	Single			600		3
R-1101-TT	Worst Speeds	AW0,AW2,AW3	Single	(2)		600		12
RS-5001-TT	Simulated Revenue Service	AW2	Single & Train			600		2
PSI-6001-TT	Radio Frequency Interference	AW0	Single & Train	(2)		600		8
S-1001-TT	Constant Speed	AW0,AW2,AW3	Single	(2)		600		12
S-2001-TT	Acceleration	AW0,AW2,AW3	Single			600		3
S-3001-TT	Deceleration	AW0,AW2,AW3	Single			600	Repeat for Brake Modes	12

AW0 = Vehicle Empty Weight
AW1 = Vehicle Empty Weight plus Normal Load
AW2 = Vehicle Empty Weight plus Full Load
AW3 = Vehicle Empty Weight plus Crush Load

"soft" characteristics of the TTC power system. Some of the noise survey data from CN-0001-TT (Interior Survey) may be pessimistic because the higher-than-normal voltage with the vehicle at rest caused an overspeed of the vehicle auxiliaries.

Dynamic Shake Test. Test sets R-0001-XX and R-0003-XX, (dynamic shake tests of the car body in the vertical, lateral and longitudinal modes) were not attempted. As a result, no information is available on car body natural frequences and mode shapes, and it was not possible to interpret the structural vibration contribution to ride roughness.

2.4.2 Vehicle Test Weights.

The WMATA cars were tested at three weights, AWO, AW2, and AW3, representing empty weight, full passenger load, and crush passenger load, respectively:

Weight Code	Nominal Weight	Passenger Load	Actual Weight (Test)* Car #1104	Actual Weight (Test)* Car #1105
AWO	72,000 lb (32 658 kg)	Empty	72,130 lb (32 717 kg)	74,060 lb (33 592 kg)
AW2	72,000 lb (32 658 kg)	Full	96,400 lb (43 726 kg)	95,800 lb (43 453 kg)
	+24,000 lb (10 886 kg)			
=	96,000 lb (43 545 kg)			
AW3	72,000 lb (32 658 kg)	Crush	104,760 lb (47 518 kg)	105,340 lb (47 781 kg)
	+33,000 lb (14 968 kg)			
=	105,000 lb. (47 627 kg)			

* Actual weight includes instrumentation and the data aquisition system but excludes test crew weight; the average test crew weight was 1,280 pounds (580.6 kg).

2.5 TEST PROGRAM SUMMARY DESCRIPTION.

A summary description of each test performed on the WMATA cars, with brief descriptions of the test objectives and variables follows, together with a discussion of the test results. Data plots illustrating the points raised in discussion are attached to each test subsection. Test procedures used were those documented in the "General Vehicle Test Plan".

2.5.1 Acceleration (Test Set No. P-2001-TT)

Objective: To determine the overall acceleration and propulsion control characteristics of the test vehicle as affected by master controller input, line voltage, car weight (load-weigh compensation), direction of travel, and train consist.

Test Description: The WMATA test vehicle was accelerated on level tangent track at a series of required controller commands. The following combinations of variables were tested:

Prime Variable	Test Conditions
Controller Level	Controller positions P1 through P5
Line Voltage	760 VDC nominal, under "no-load" conditions (vehicle auxiliaries operating). 695 VDC and 710 VDC at AW2 weight only
Car Weight	AW0, AW2, and AW3
Car Direction	Forward and Reverse
Train Consist	2-car train

Test Results: Figures 2-2, 2-3, and 2-4 illustrate the acceleration and control characteristics of the WMATA rapid transit cars at AW2 vehicle weight, and are typical of the test results gathered at other weights. Plots are presented of speed versus acceleration, speed versus elapsed time, and time versus distance for master controller power positions P1 through P5. Acceleration characteristics with increasing vehicle weight are shown in Figures 2-5, 2-6, and 2-7 for a P5 master controller position, demonstrating that the vehicle has adequate load-weigh response.

The TTT power supply (CTA rectifier station) was found to be a relatively "soft" system; typically, maximum acceleration runs would reduce the line voltage from 760 VDC to approximately 600-630 VDC depending on vehicle weight and location on the track. Off-nominal line voltage acceleration tests were attempted at no-load line voltages of 695 and 710 VDC; below 695 VDC the line voltage would drop under maximum acceleration power demand, until low voltage protection relays on the vehicle would

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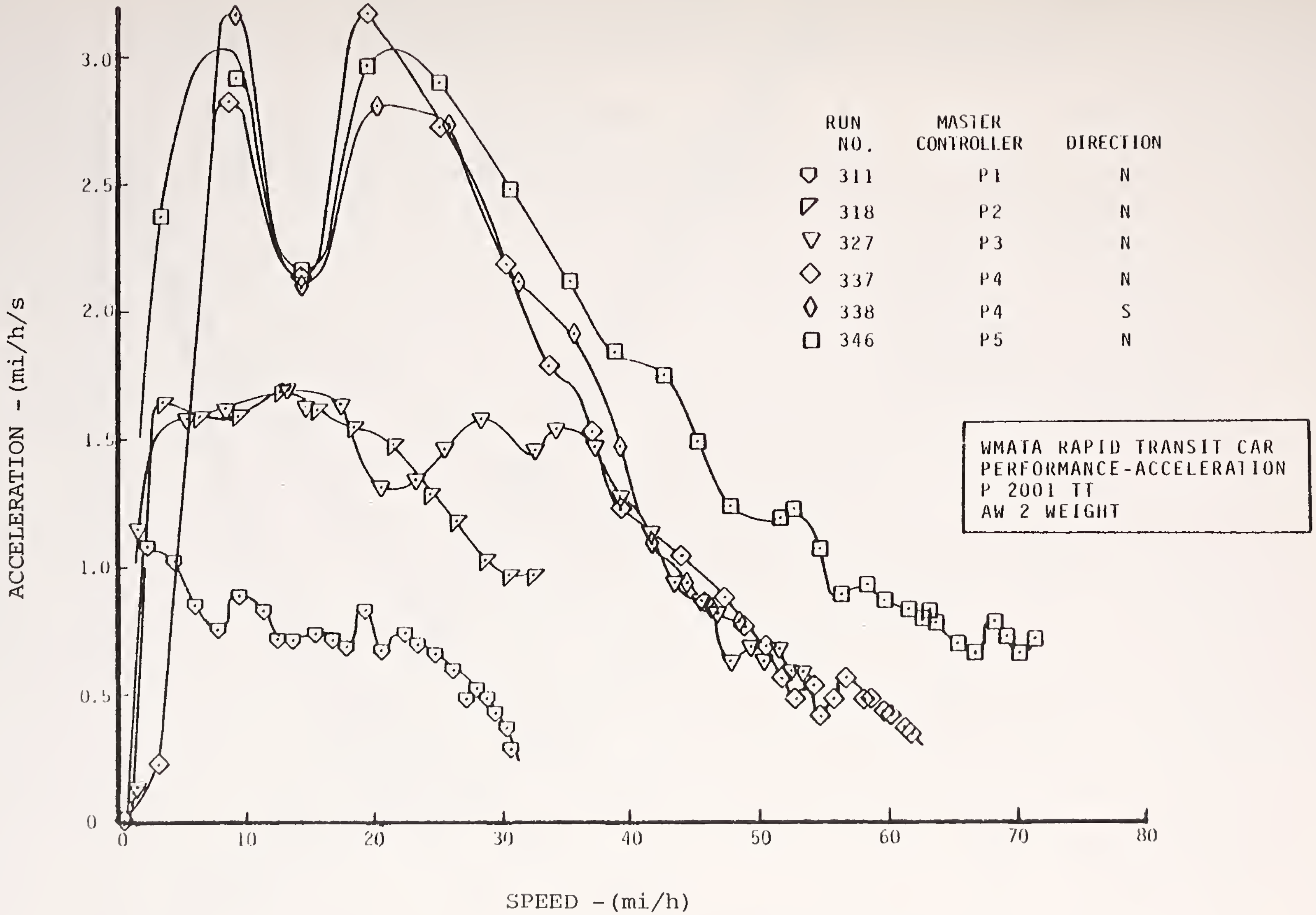

FIGURE 2-2. PERFORMANCE ACCELERATION - SPEED vs. ACCELERATION, EFFECT OF MASTER CONTROLLER POSITION.

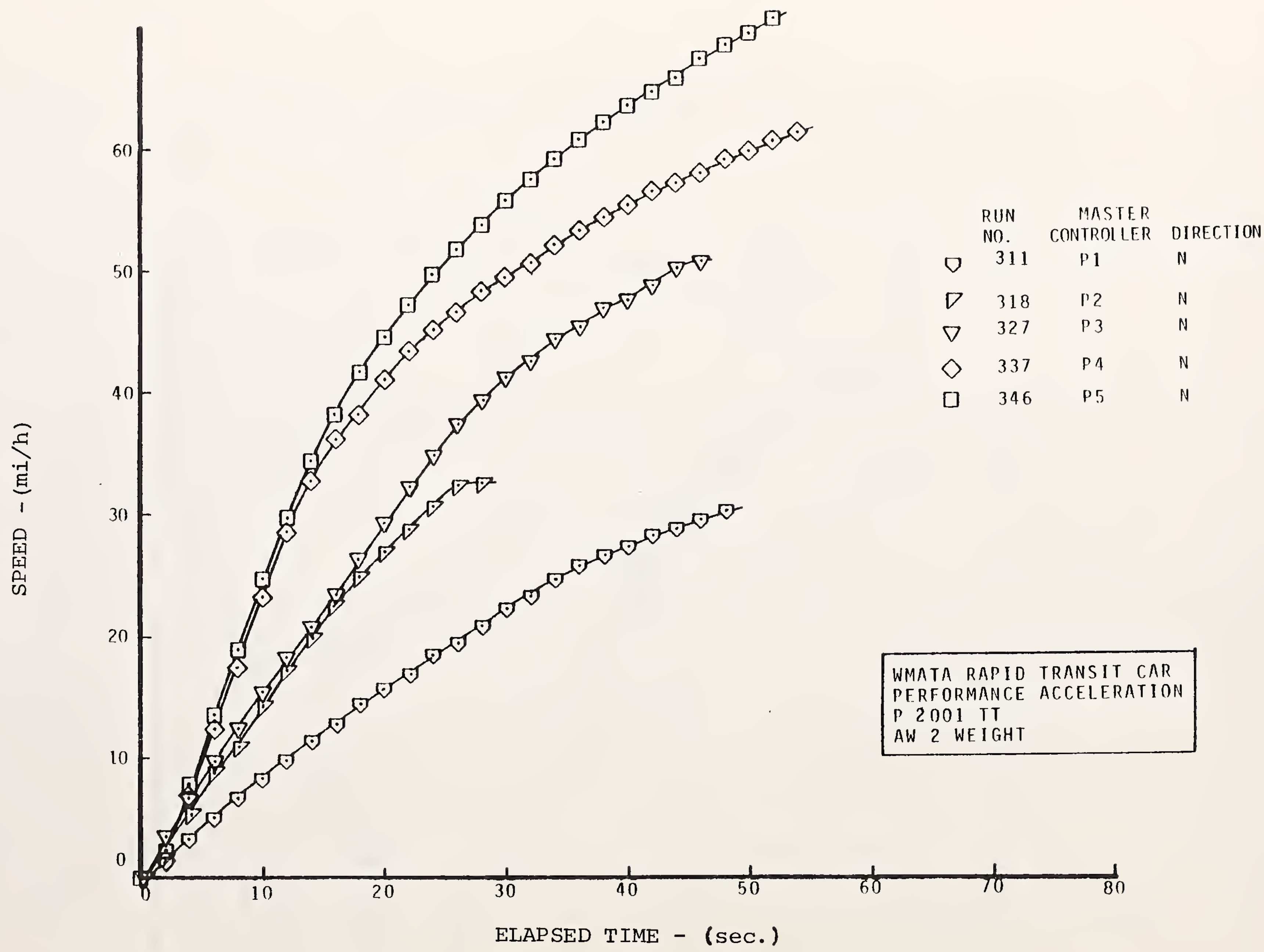

FIGURE 2-3. PERFORMANCE ACCELERATION - SPEED vs. ELAPSED TIME, EFFECT OF MASTER CONTROLLER POSITION.

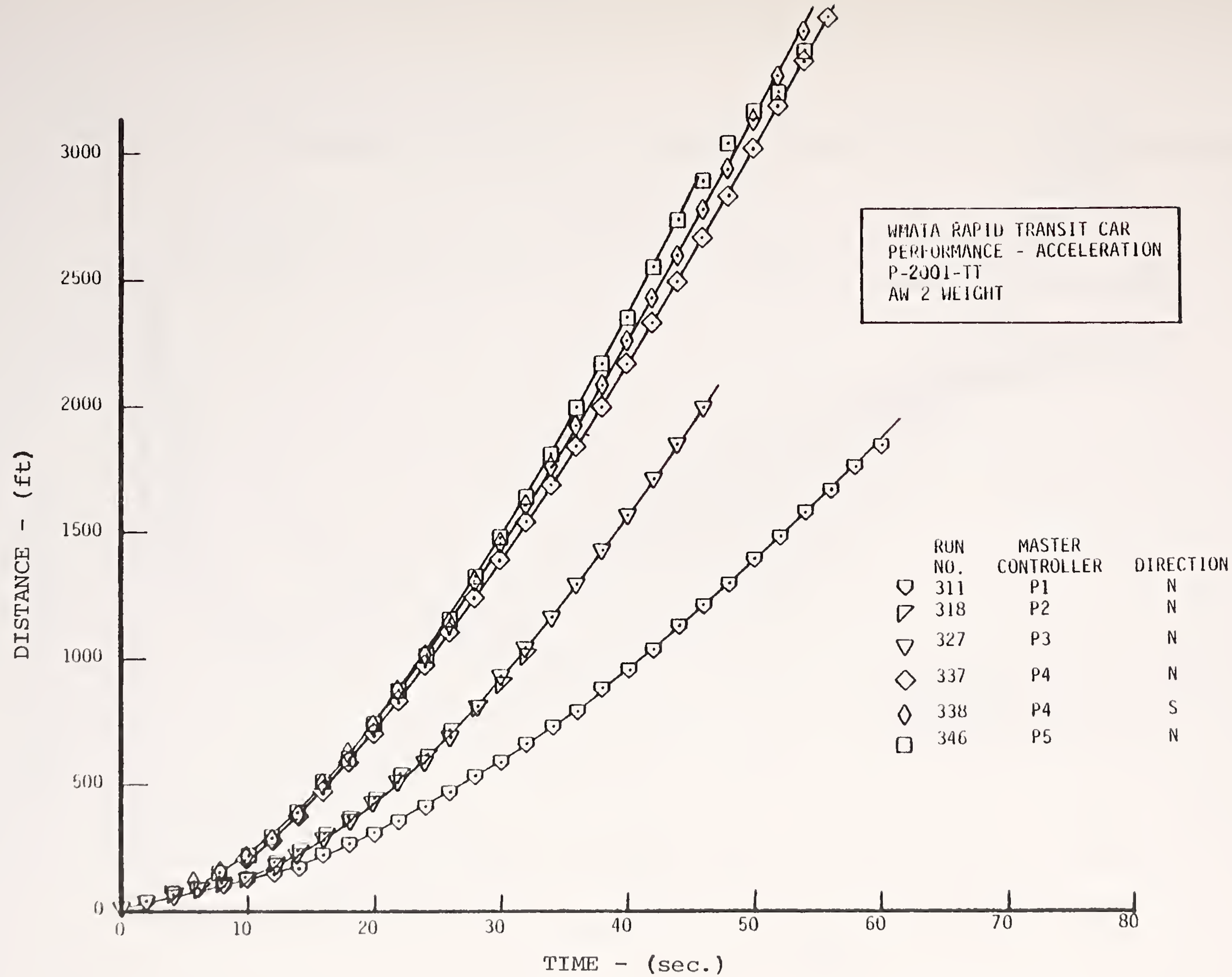

FIGURE 2-4. PERFORMANCE ACCELERATION - TIME vs. DISTANCE, EFFECT OF MASTER CONTROLLER POSITION.

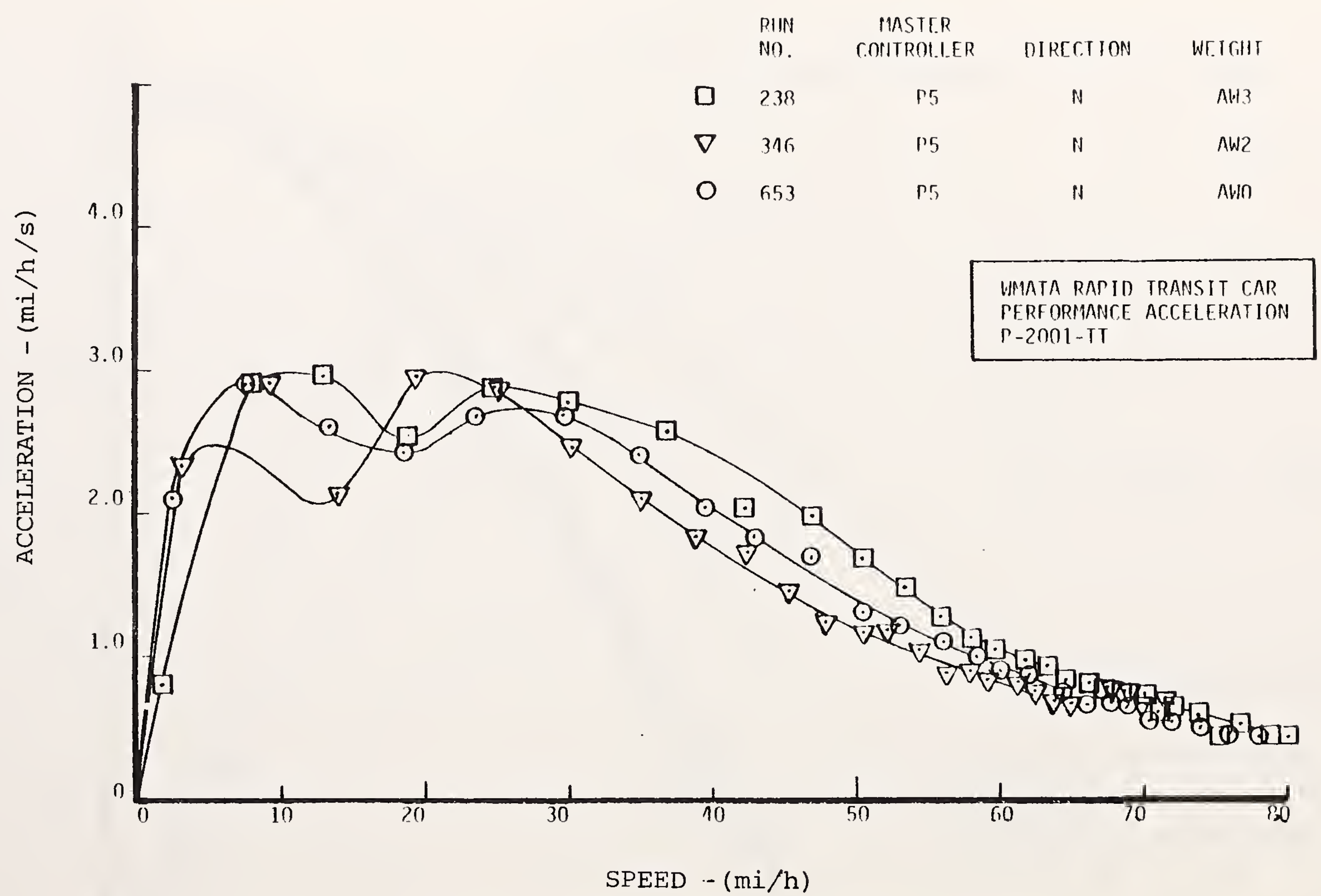

FIGURE 2-5. PERFORMANCE ACCELERATION - LOAD-WEIGH COMPARISON, SPEED vs. ACCELERATION.

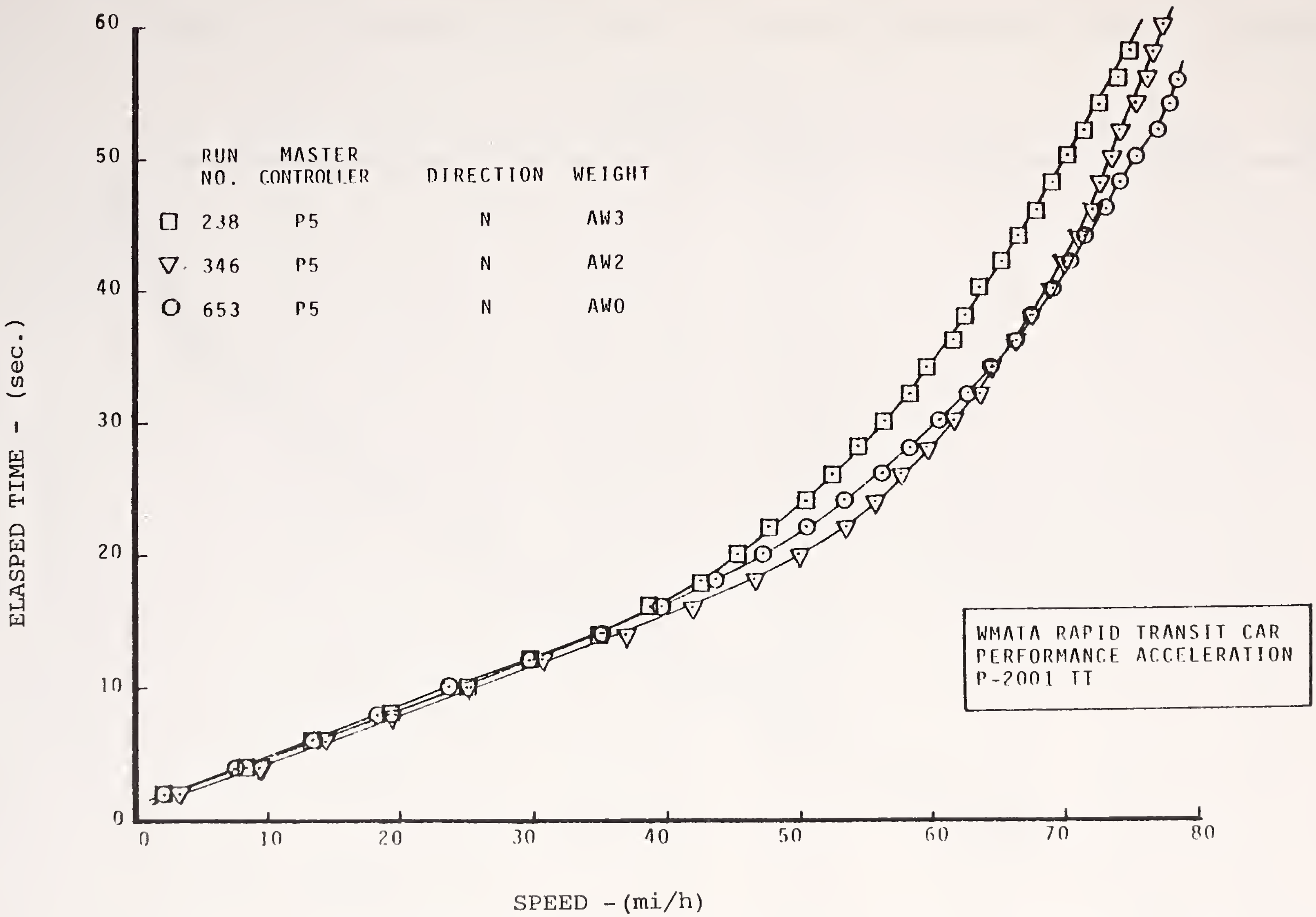

FIGURE 2-6. PERFORMANCE ACCELERATION - LOAD-WEIGH COMPARISON, SPEED vs. ELAPSED TIME.

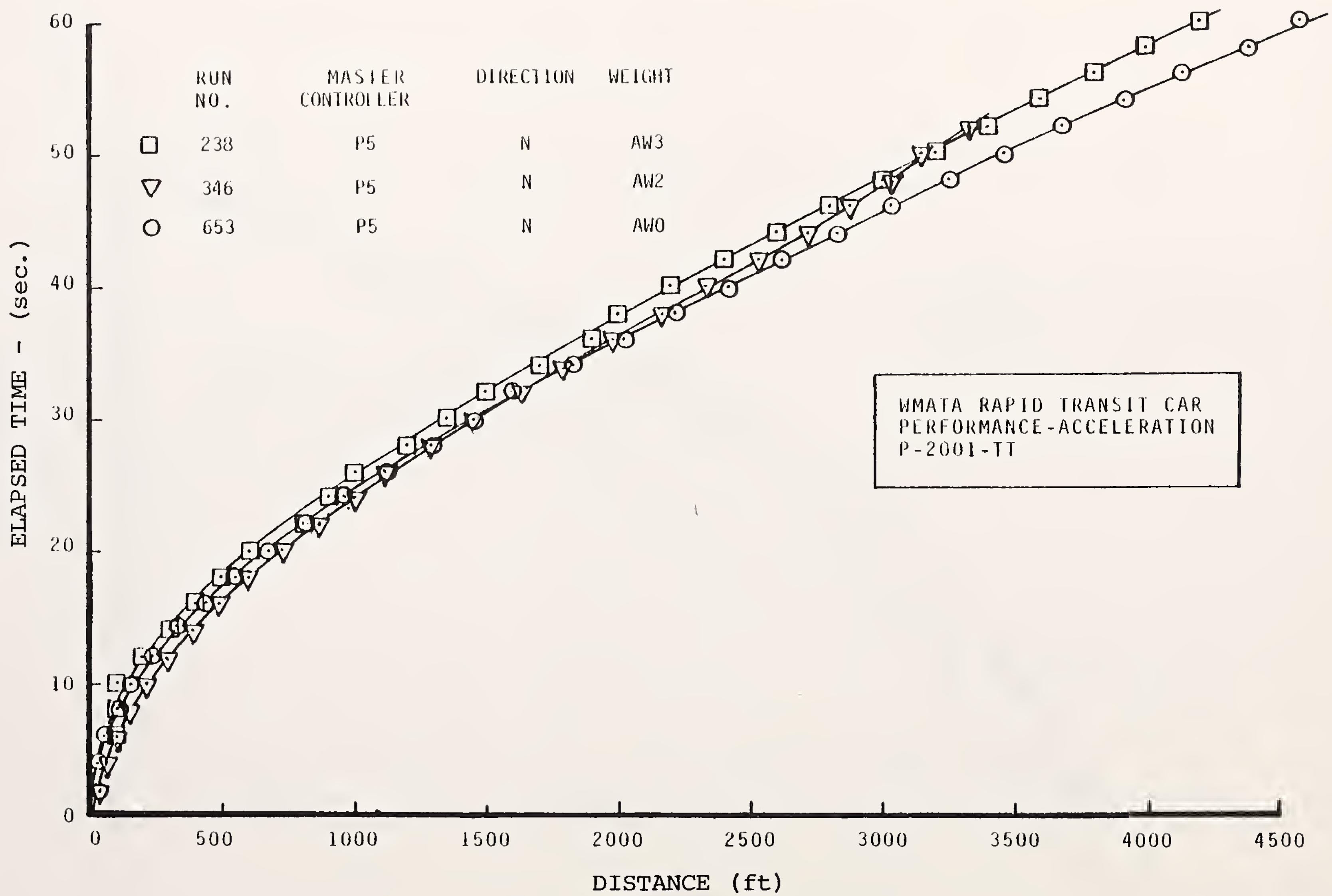

FIGURE 2-7. PERFORMANCE ACCELERATION - LOAD-WEIGH COMPARISON, TIME vs. DISTANCE.

momentarily de-energize the propulsion system. As a result, only a limited line voltage variation could be tested; due to this and the "soft" nature of the power system, no clear acceleration and control characteristic trends with line voltage could be defined.

Variations in vehicle acceleration levels due to forward and reverse travel were not found to be significant. Because the car could not be turned for each reverse run, any discernible changes in acceleration levels between forward and reverse travel data are more likely to be due to external ambient conditions, for example, wind speed and direction, than to differences in the vehicle propulsion system.

The effect of train consist on acceleration was not examined. The WMATA rapid transit cars were tested only in a two-car married pair consist comprising cars 1104 and 1105.

2.5.2 Deceleration: Blended Braking (Test Set No. P-3001-TT), Friction-Only Braking (Test Set No. P-3002-TT), Dynamic-Only Braking (Test Set No. P-3003-TT); Emergency Braking (Test Set No. P-3004 -TT).

Objective: To determine the overall control characteristics, deceleration rates, and stopping distances associated with four braking modes (blended, friction-only, dynamic-only, and emergency braking) as affected by controller input level, line voltage, car weight (load-weigh), car direction of travel, and train consist.

Test Description: The WMATA test vehicle was decelerated at the required controller command level on level tangent track at brake entry speeds from 30 to 75 mi/h (48 to 120.7 km/h) for blended, friction-only, and dynamic-only brake modes. The emergency braking mode was tested at brake entry speeds from 20 to 75 mi/h (32 to 120.7 km/h); braking was initiated by releasing the motorman's "dead-man" handle. The following combinations of variables were tested:

Prime Variable	Test Conditions
Controller Level	B1 through B5 and Emergency
Car Weight	AW0, AW2, and AW3
Line Voltage	760 VDC nominal, under "no-load" conditions (vehicle auxiliaries operating); 695 VDC and 710 VDC at AW2 weight only
Train Consist	2-car train

Prime Variable	Test Conditions
Car Direction	Forward and Reverse

Test Results: Plots of deceleration rate versus vehicle speed for each braking mode at AW2 vehicle weight, i.e blended braking, emergency braking, friction-only braking, and dynamic-only braking are presented in figures 2-8 through 2-11. Blended, friction-only, and dynamic-only braking modes are presented for each master controller position, B1 through B5, and for entry speeds from 30 to 75 mi/h (48 to 120.7 km/h). Emergency braking plots are presented from 20 to 75 mi/h (32 to 120.7 km/h). The general trends of these plots are characteristic of the data obtained at all vehicle weights.

Figures 2-12 through 2-14 illustrate the stopping distance and elapsed time to stop for blended braking at B5, B4, and B3 master controller positions at the AW2 vehicle weight, plotted versus initial vehicle speed. The plots were obtained by cross-plotting data from a series of test runs made at various initial speeds so that each test point represented a separate brake application. Time and distance were computed from first application of the brakes rather than first movement of the master controller; therefore, system response times are not included. Some zero errors are evident in the speed/time to stop plots, probably as a result of the 2-second time interval of the engineering unit listing, which could give a maximum 4-second error between the first indication of brake application and change in vehicle speed. The deceleration rate plot presented in figure 2-15 and the speed/time and speed/distance plots presented in figures 2-16 and 2-17 illustrate the effect of vehicle load-weigh compensation, by comparing three blended brake runs at the B5 brake master controller setting. The plots show minimal differences in the deceleration rates and time/distances with increasing vehicle weight, indicating satisfactory load-weigh response.

2.5.3 Drift Test: Traction Resistance (Test Set No. P-4001-TT):

Objective: To determine the train resistance of the WMATA rapid transit cars for use in the analysis of adhesion test data, to check the coefficient used to calculate the design performance of the vehicle. The data would be used as a baseline for analysis of the vehicle tractive and braking effort values.

Test Description: Drift tests were carried out over level tangent track between track stations 300 and 340, at AW2 vehicle weight for a two- and four-car consist. Tests were conducted under conditions of minimal wind, (headwind less than 5 mi/h (8 km/h) and cross-wind less than 10 mi/h (16 km/h) to minimize errors in the vehicle deceleration rates. As a further safe-

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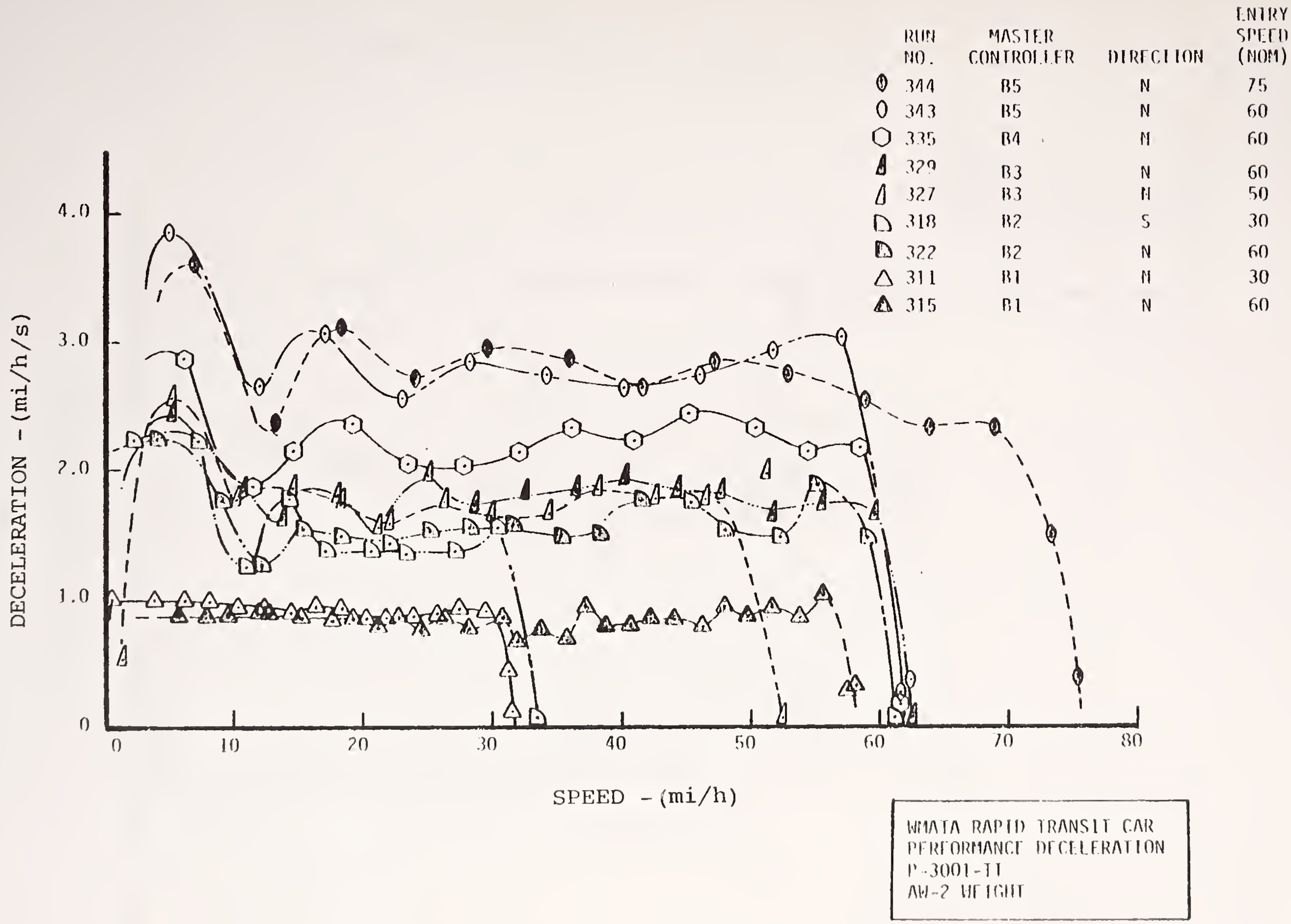

FIGURE 2-8. PERFORMANCE DECELERATION - BLENDED BRAKING, DECELERATION vs. SPEED.

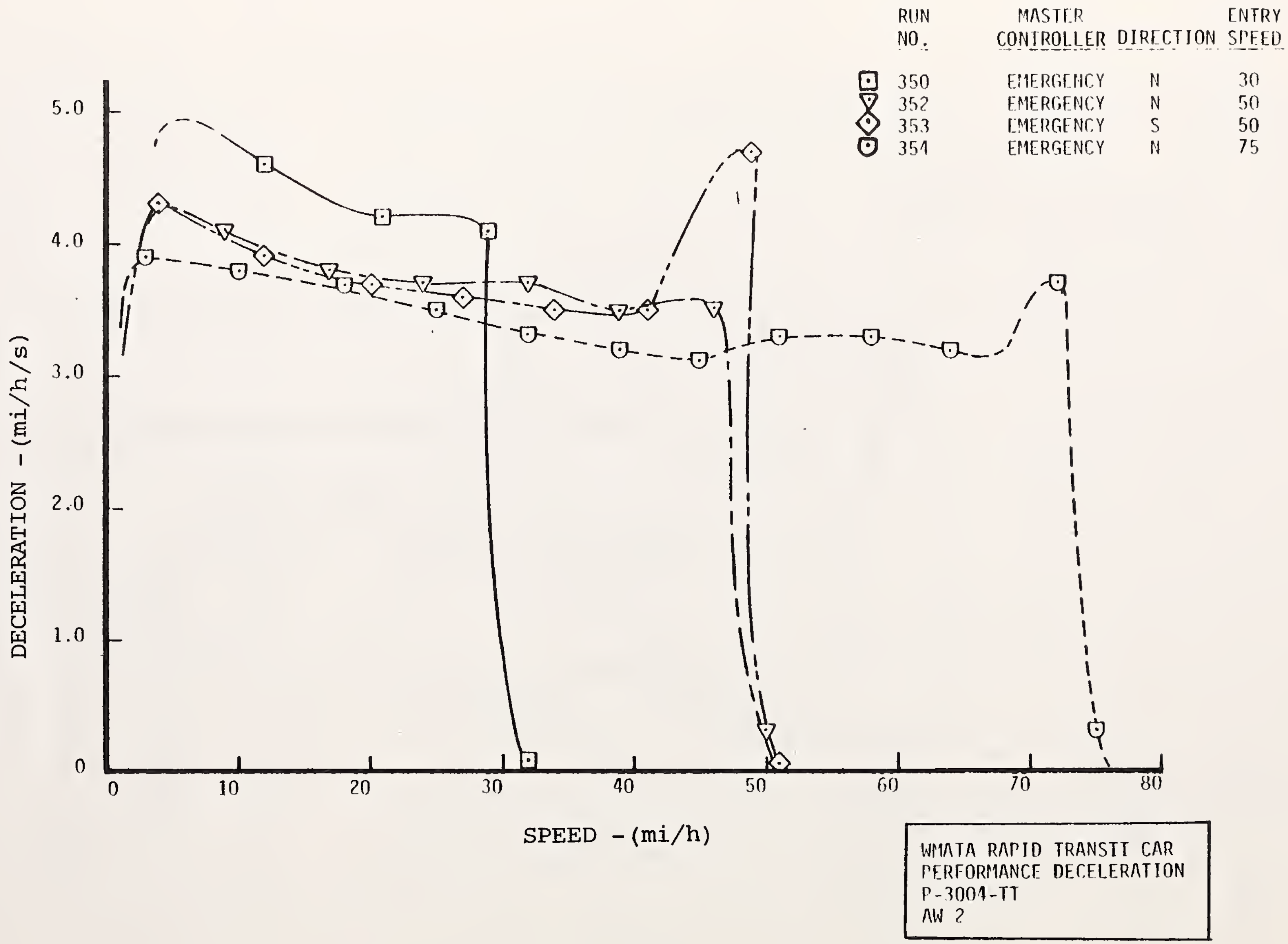

FIGURE 2-9. PERFORMANCE DECELERATION - EMERGENCY BRAKING, DECELERATION vs. SPEED.

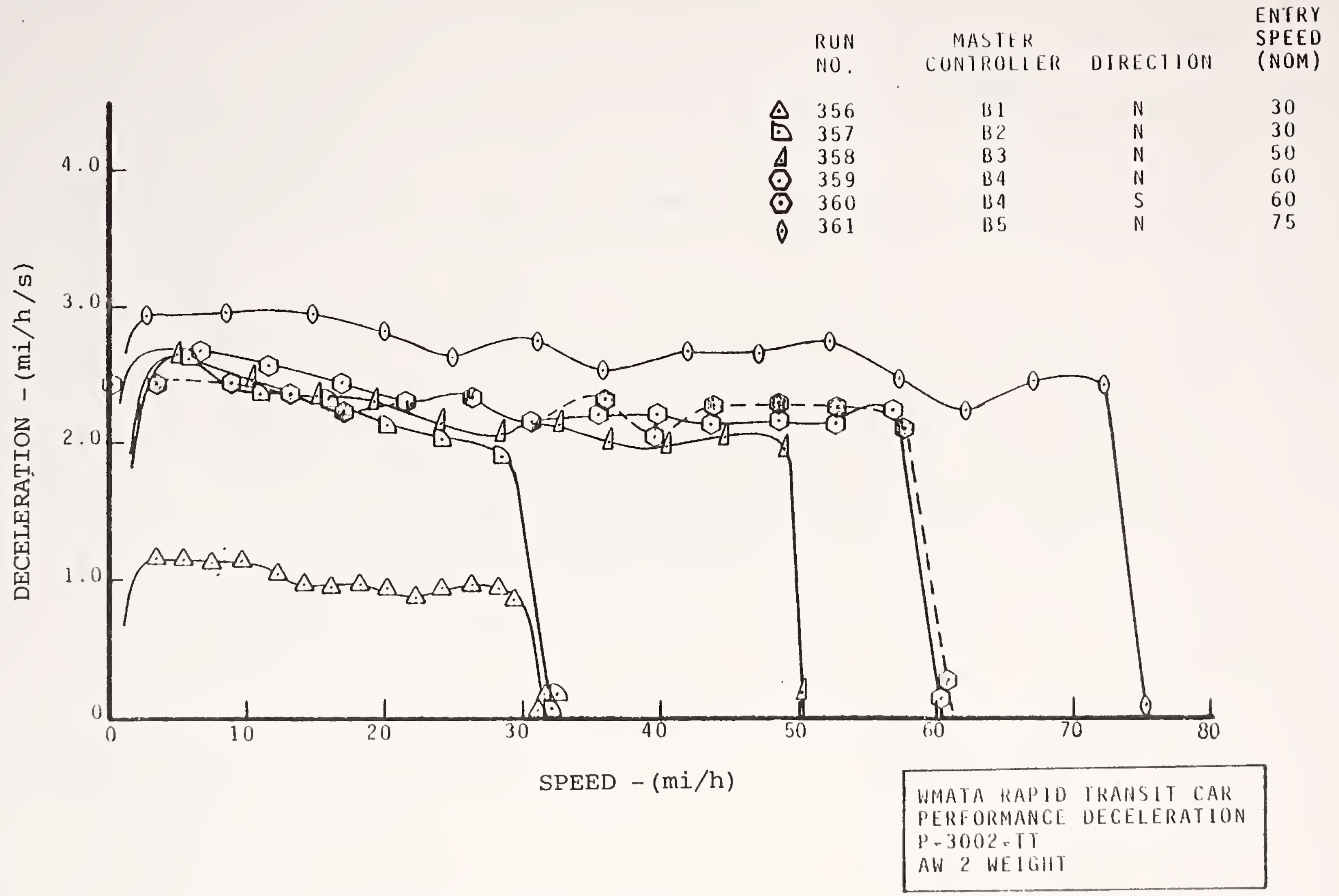

FIGURE 2-10. PERFORMANCE DECELERATION - FRICTION-ONLY BRAKING, DECELERATION vs. SPEED.

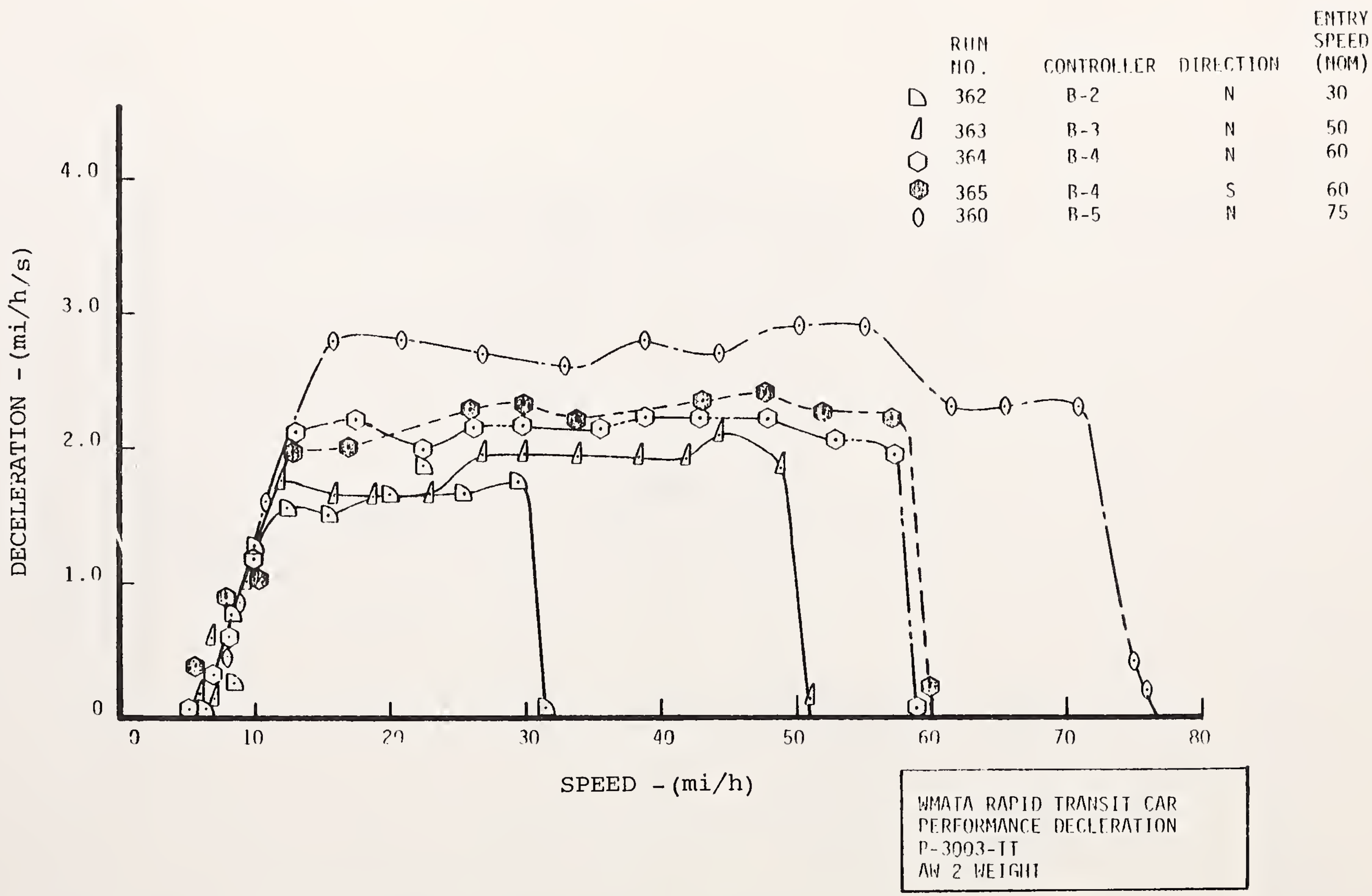

FIGURE 2-11. PERFORMANCE DECELERATION - DYNAMIC-ONLY BRAKING, DECELERATION vs. SPEED.

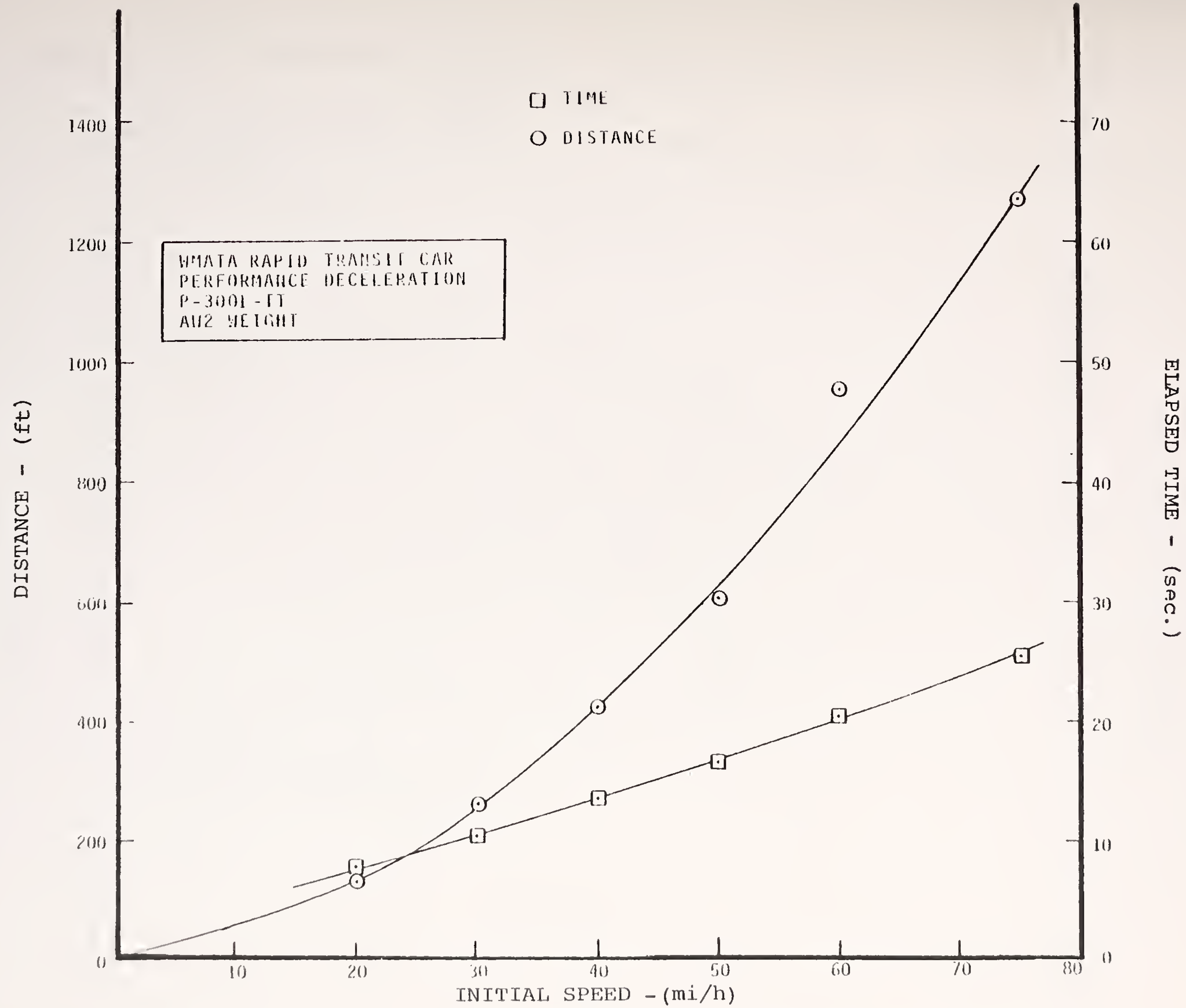

FIGURE 2-12. PERFORMANCE DECELERATION - BRAKE 5 RATE, DISTANCE vs. INITIAL SPEED.

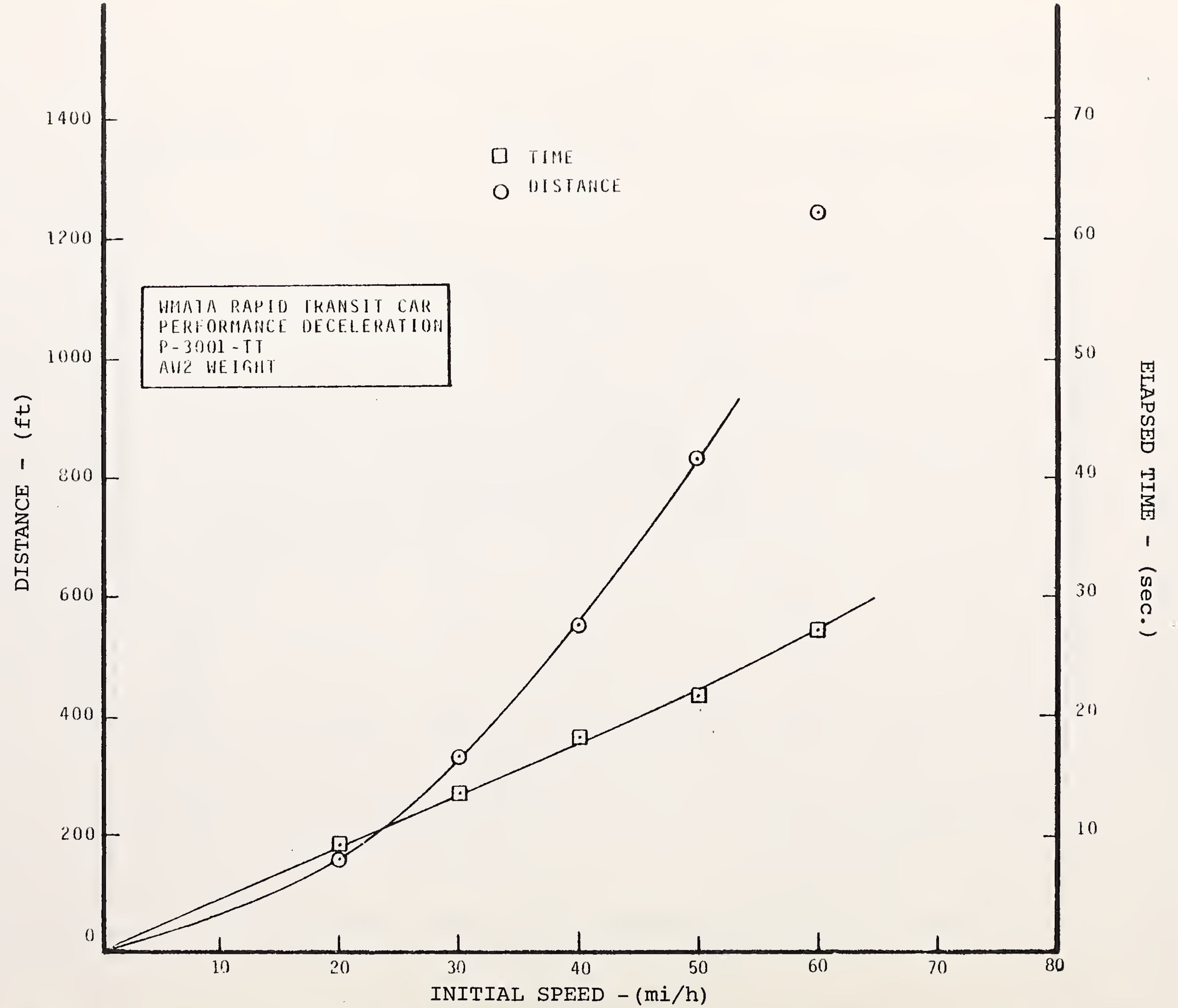

FIGURE 2-13. PERFORMANCE DECELERATION - BRAKE 4 RATE, DISTANCE vs. INITIAL SPEED.

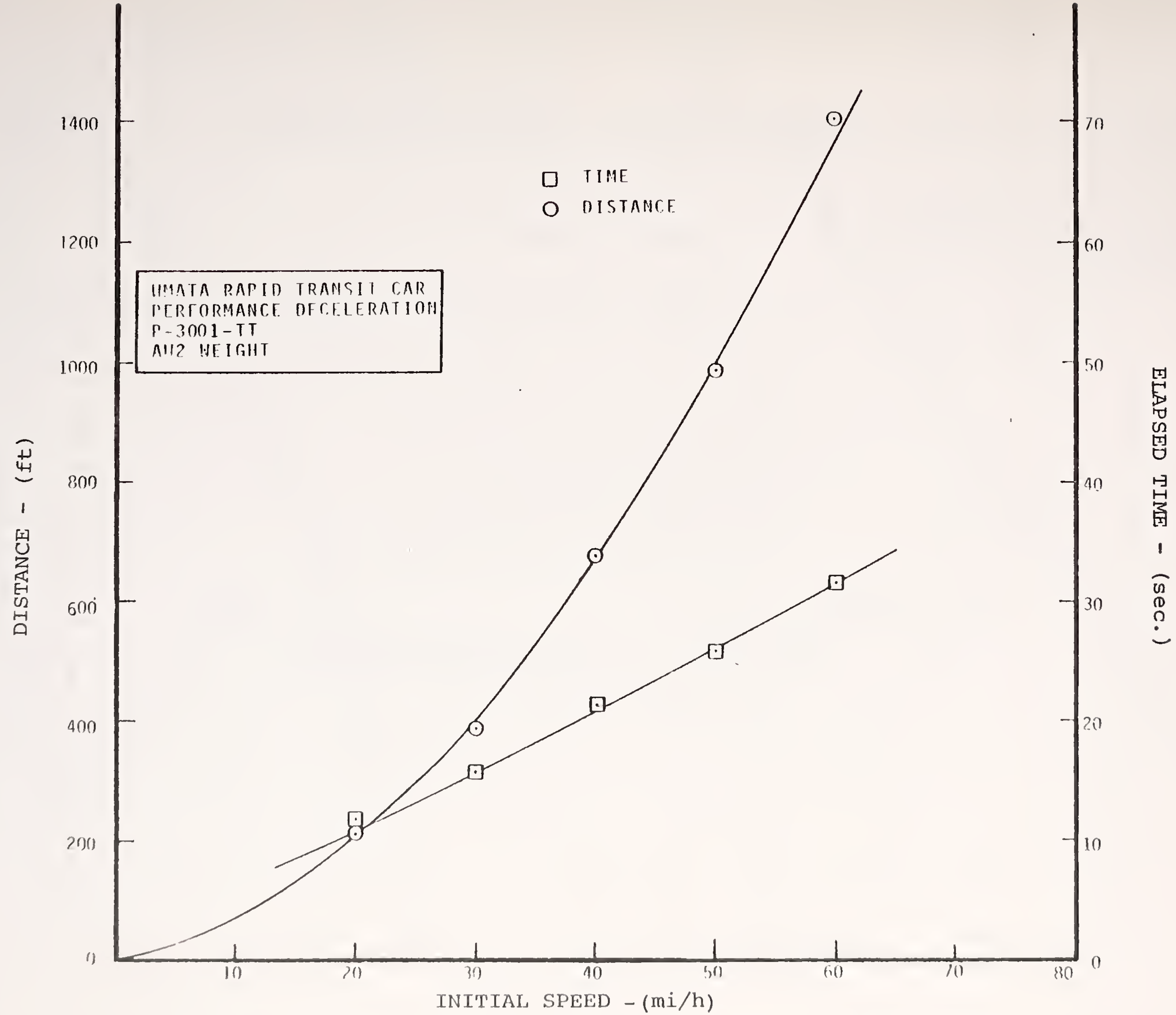

FIGURE 2-14. PERFORMANCE DECELERATION - BRAKE 3 RATE, DISTANCE vs. INITIAL SPEED.

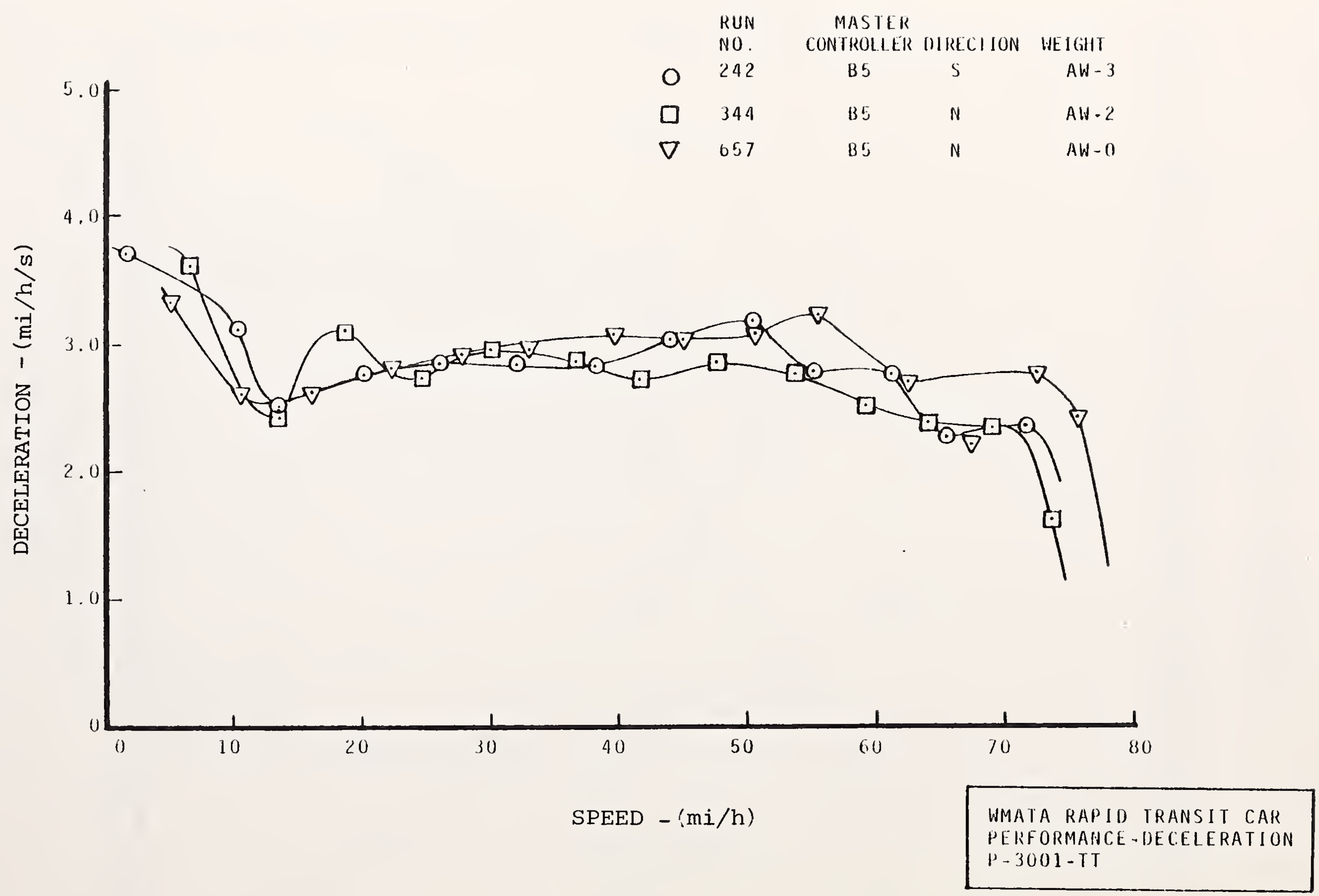

FIGURE 2-15. PERFORMANCE DECELERATION - LOAD-WEIGH COMPARISON, DECELERATION vs. SPEED.

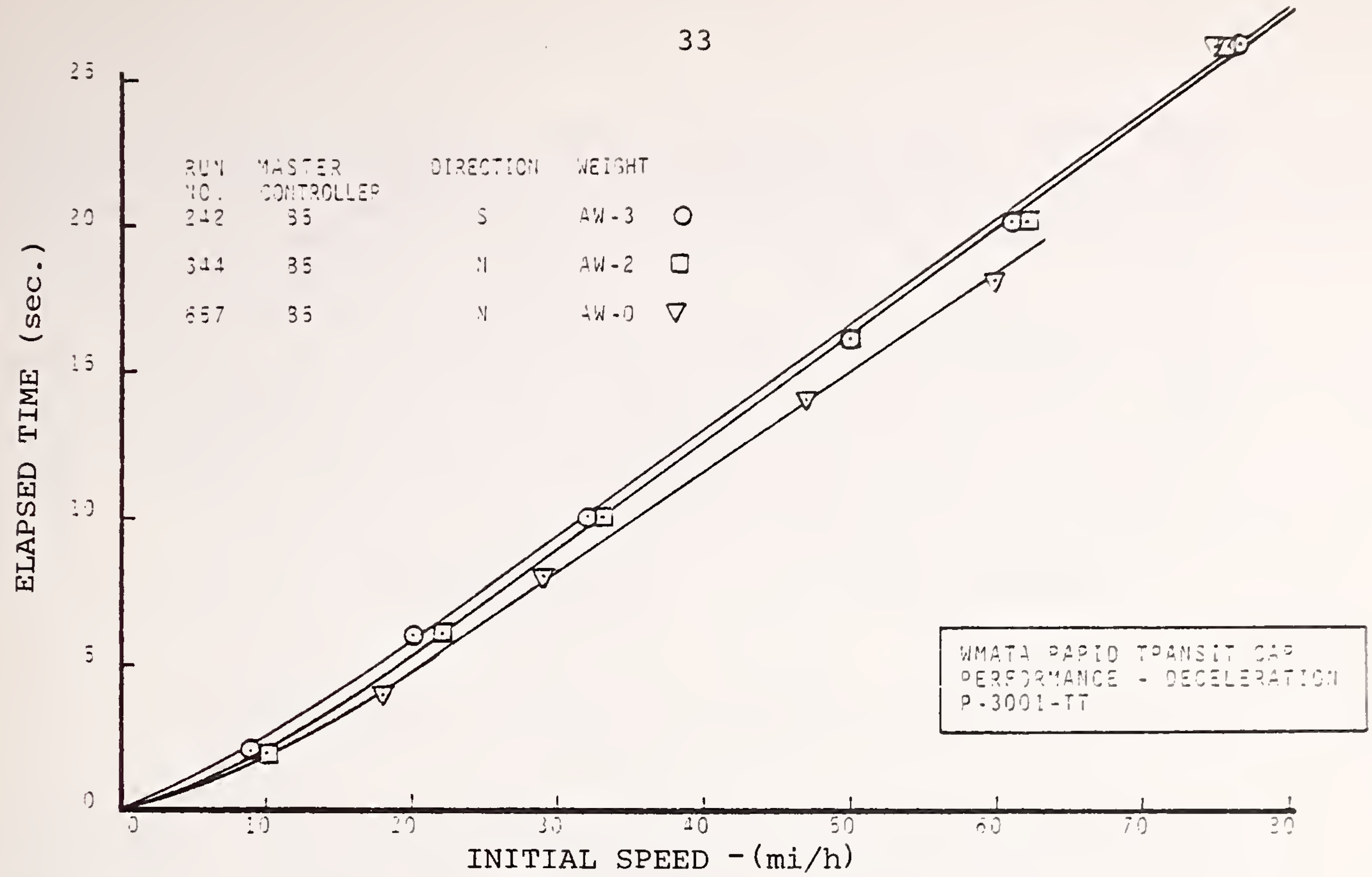

FIGURE 2-16. PERFORMANCE DECELERATION -LOAD-WEIGH COMPARISON, SPEED vs. TIME.

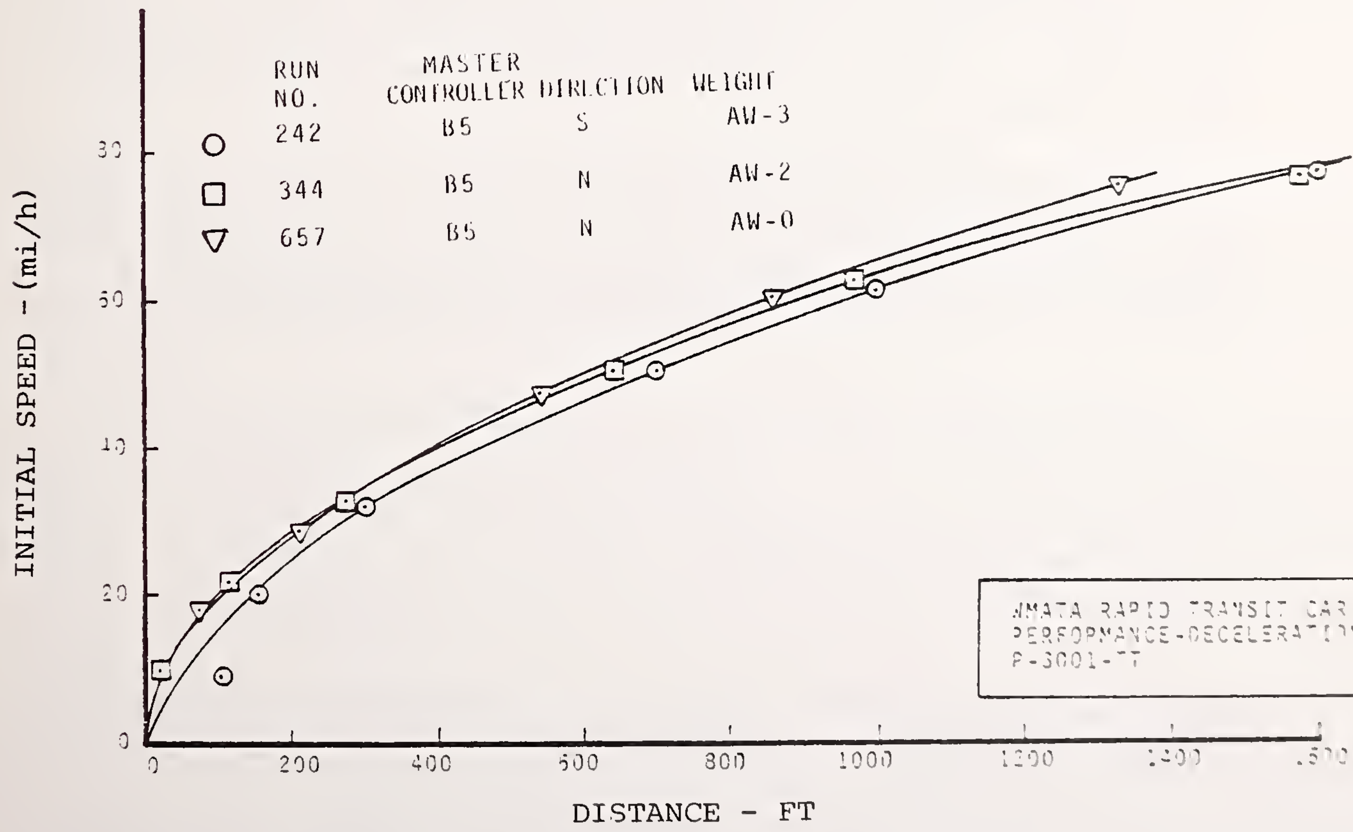

FIGURE 2-17. PERFORMANCE DECELERATION -LOAD-WEIGH COMPARISON, DISTANCE vs. SPEED.

guard, tests were conducted in both northbound and southbound directions. To obtain true "coast" conditions, dynamic braking was disabled during the test to eliminate small residual motor currents otherwise present in "coast". Due to the limited length of level tangent track numerous runs were required so that the speed range could be covered in each direction. On each successive run, the consist entered the level tangent test zone at a speed equal to the exit speed of the previous run, and the master controller was moved to a "coast" position just prior to entry. Initial entry speed was 75 mi/h (120.7 km/h). The following combinations of variables were tested:

Prime Variable	Test Conditions
Car Weight	AW2 only
Train Consist	2-car and 4-car train

Analysis Procedure: The desired approach was to determine deceleration over each 10-second interval and then to obtain the bi-directional mean by averaging the values spanning the same velocity ranges in opposite directions. The values of deceleration derived could then be multiplied by the equivalent mass of the consist to obtain the train resistance.

The actual procedure differed in the method of bi-directional correction and in the use of equivalent mass. Obtaining a bi-directional mean for each deceleration pair was found impractical because of the different numbers of data points encountered in each direction (resulting from slightly different rates of deceleration).

Also, considerable jitter in deceleration values required some method of smoothing to take advantage of the consecutive nature of the data. Consequently, a least squares approach was adopted to fit each directional set independently to the equation:

$$A = A_o + A_1 V + A_2 V^2$$

Where:

A = Acceleration, mi/h/s

V = Velocity, mi/h

Subsequently, the coefficients A_0, A_1, and A_2 were averaged to obtain bi-directionally corrected data.

This approach had two additional advantages. The coefficients derived had direct correspondence to those used in common train resistance formulas, which permitted comparison of WMATA with other empirically derived coefficients of rolling friction, viscous friction, and aerodynamic drag. Also, these coefficients allowed direct determination of external resistance in the evaluation of traction and spin/slide data without the need of a conversion table.

A second departure from the GVTP-suggested method of analysis resulted from the lack of information regarding equivalent mass. The true mass of the vehicle was used which did not include the additional inertia of rotating machinery. However, given the value of the equivalent mass, the coefficients presented here can be corrected by multiplying each by EM/6300 slugs where EM is the correct total equivalent mass of the consist in slugs.

Test Results: Tables 2-2 and 2-3 summarize each set of data. The bidirectional averaged coefficients are as follows:

Coefficient	2-Car	SOAC Comparison
A_0	.041	.051
A_1	.00071	.00125
A_2	.000024	.000024

SOAC coefficients, derived during the process of validating the drift procedure, are included here because of availability. There is no intent to compare the two systems competitively.

2.5.4 Duty Cycle: Friction Brakes (Test Set No. P-5001-TT).

Objective: To determine the thermal capacity of the vehicle friction brake system while operating on duty cycles similar to those anticipated in revenue service.

Test Description: Duty cycle testing was carried out to subject the WMATA car friction brakes to the repeated applications that would be experienced during a revenue service run. Tests were conducted on a two-car consist at AW2 vehicle weight; dynamic braking was disabled. B-5 controller position was used for all brake applications. Three types of revenue service runs were simulated:

a. Accelerate to 35 mi/h (56 km/h), maintain speed for 45 seconds and then brake to a full stop. Following a 30-second station stop, repeat the cycle. Thirty cycles were made, simulating an NYCTA 8th Avenue express revenue run.

b. Accelerate to 50 mi/h (80 km/h), maintain speed for 55 seconds and then brake to a full stop. Following a 30-second station stop, repeat the cycle. Sixteen cycles were

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TABLE 2-2. TABULATED DATA - DRIFT TESTS (NORTHBOUND).
2-Car Consist

INITIAL VELOCITY (VO) (mi/h)	FINAL VELOCITY (VF) (mi/h)	DELTA VELOCITY (DV) (mi/h)	AVERAGE VELOCITY (mi/h)	DELTA TIME (sec)	ACCEL. (mi/h/s)	RESIST. (lbs)
61.7	60.0	1.70	60.9	10.0	0.17	1002.6
60.0	58.3	1.70	59.2	10.0	0.17	1008.6
58.3	56.7	1.60	57.5	10.0	0.17	990.6
56.7	55.0	1.70	55.9	10.0	0.17	1020.6
55.0	53.5	1.50	54.3	10.0	0.15	888.6
53.5	52.1	1.40	52.8	10.0	0.14	828.5
52.1	50.6	1.50	51.4	10.0	0.15	912.6
50.6	49.4	1.20	50.0	10.0	0.12	720.4
49.4	48.0	1.40	48.7	10.0	0.14	852.5
46.3	44.9	1.40	45.6	10.0	0.14	852.5
44.9	44.0	0.90	44.5	10.0	0.09	540.3
44.0	42.5	1.50	43.3	10.0	0.15	882.5
42.5	41.5	1.00	42.0	10.0	0.10	612.4
38.8	38.0	0.80	38.4	10.0	0.09	516.3
38.0	37.0	1.00	37.5	10.0	0.10	576.4
37.0	36.0	1.00	36.5	10.0	0.10	582.4
36.0	35.0	1.00	35.5	10.0	0.11	678.4
32.0	31.1	0.90	31.6	10.0	0.09	540.3
31.1	30.3	0.80	30.7	10.0	0.08	480.3
30.3	29.4	0.90	29.9	10.0	0.09	552.3
29.4	28.7	0.70	29.1	10.0	0.07	432.3
28.7	27.7	1.00	28.2	10.0	0.10	600.4
25.7	25.1	0.60	25.4	10.0	0.07	402.3
25.1	24.2	0.90	24.7	10.0	0.08	504.3
24.2	23.5	0.70	23.9	10.0	0.08	450.3
23.5	22.9	0.60	23.2	10.0	0.06	366.2
22.9	22.2	0.70	22.6	10.0	0.06	378.2
22.2	21.6	0.60	21.9	10.0	0.07	402.3
16.9	16.4	0.50	16.7	10.0	0.05	300.2
16.4	15.8	0.60	16.1	10.0	0.06	336.2
15.8	15.2	0.60	15.5	10.0	0.06	348.2
15.2	14.6	0.60	14.9	10.0	0.06	360.2
14.6	14.0	0.60	14.3	10.0	0.07	408.3
14.0	13.6	0.40	13.8	10.0	0.04	210.1
13.6	13.0	0.60	13.3	10.0	0.06	372.2
13.0	12.6	0.40	12.8	10.0	0.04	264.2

ACCELERATION COEFFICIENTS OF RESISTANCE
A0 = 0.0344
A1 = 0.00105
A2 = 0.0000202

MASS IS 6003.72678 SLUGS.

TABLE 2-3. TABULATED DATA - DRIFT TESTS (SOUTHBOUND).
2-Car Consist

INITIAL VELOCITY (VO) (mi/h)	FINAL VELOCTIY (VF) (mi/h)	DELTA VELOCITY (DV) (mi/h)	AVERAGE VELOCITY (mi/h)	DELTA TIME (sec)	ACCEL. (mi/h/s)	RESIST. (lbs)
65.9	63.9	2.00	64.9	10.0	0.20	1200.7
63.9	62.0	1.90	63.0	10.0	0.19	1152.7
62.0	60.1	1.90	61.1	10.0	0.19	1164.7
60.1	58.3	1.80	59.2	10.0	0.18	1080.7
58.9	58.3	0.60	58.6	10.0	0.06	354.2
58.3	56.6	1.70	57.5	10.0	0.18	1056.7
56.6	54.9	1.70	55.8	10.0	0.17	1014.6
54.9	53.3	1.60	54.1	10.0	0.16	960.6
53.3	51.5	1.80	52.4	10.0	0.18	1062.7
51.5	50.0	1.50	50.8	10.0	0.15	900.6
49.9	48.2	1.70	49.1	10.0	0.18	1056.7
48.2	46.7	1.50	47.5	10.0	0.15	918.6
46.7	45.2	1.50	46.0	10.0	0.14	864.5
45.2	44.1	1.10	44.7	10.0	0.12	696.3
44.1	43.6	0.50	43.9	10.0	0.05	300.2
43.5	42.0	1.50	42.8	10.0	0.16	936.6
42.0	41.1	0.90	41.6	10.0	0.08	492.3
41.1	40.2	0.90	40.7	10.0	0.09	564.4
40.2	39.0	1.20	39.6	10.0	0.12	714.4
39.0	38.1	0.90	38.6	10.0	0.10	576.4
38.1	36.7	1.40	37.4	10.0	0.13	804.5
36.7	35.6	1.10	36.2	10.0	0.11	672.4
35.6	34.9	0.70	34.3	10.0	0.07	408.3
34.9	33.9	1.00	33.6	10.0	0.11	654.4
33.9	33.1	0.80	33.5	10.0	0.08	474.3
33.1	32.1	1.00	32.6	10.0	0.09	552.3
32.1	31.3	0.80	31.7	10.0	0.08	480.3
31.3	30.5	0.80	30.9	10.0	0.08	504.3
30.5	29.6	0.90	30.1	10.0	0.09	540.3
29.6	28.8	0.80	29.2	10.0	0.08	486.3
28.8	28.0	0.80	28.4	10.0	0.08	462.3
28.0	27.1	0.90	27.6	10.0	0.09	528.3
27.1	26.3	0.80	26.7	10.0	0.08	504.3
26.3	25.6	0.70	26.0	10.0	0.07	426.3
25.6	24.6	1.00	25.1	10.0	0.09	552.3
24.6	24.1	0.50	24.4	10.0	0.06	342.2
23.9	23.3	0.60	23.6	10.0	0.07	396.2
23.3	22.4	0.90	22.9	10.0	0.09	528.3
22.4	21.8	0.60	22.1	10.0	0.06	336.2
21.8	21.1	0.70	21.5	10.0	0.08	450.3
21.1	20.3	0.80	20.7	10.0	0.08	450.3
20.3	19.6	0.70	20.0	10.0	0.07	426.3
19.6	19.0	0.06	19.3	10.0	0.06	360.2
19.0	18.3	0.70	18.7	10.0	0.08	468.3

ACCELERATION COEFFICIENTS OF RESISTANCE
AO = 0.0488
A1 = 0.00038
A2 = 0.0000285

MASS IS 6003.72678 SLUGS.

made, simulating Cleveland Transit System's (CTS) Cleveland airport route.

c. A 30-minute run with eighteen 15-second station stops at various speeds which simulated a Washington Metropolitan Area Transit Authority revenue run representing WMATA routes from Grosvenor to Metro Center and Silver Spring to Metro Center. The run is detailed in table 2-4 and was used for power consumption studies.

Chromel-Constantan thermocouples were attached to the right-hand disk brake pad of the A-truck on WMATA car 1105, to measure both pad and disk temperatures. The pad temperature thermocouple was bonded into a blind hole drilled radially in the pad, and the disk temperature thermocouple was bonded into a similar hole exposed to the face of the brake disk; this represents a compromise since the thermocouple was not in direct contact with the disk. The temperatures from both sources were monitored continuously on an analog strip chart and were recorded on magnetic tape. The following combinations of variables were tested:

Prime Variable	Test Conditions
Cruise Speed and Time	(1) 35 mi/h (56 km/h) for 45 seconds
	(2) 50 mi/h (80 km/h) for 55 seconds
	(3) WMATA revenue profile
Car Weight	AW2
Braking Mode	Friction only, dynamic braking disabled

Test Results: Figures 2-18, and 2-19 A and B present brake temperature data from runs 462, 463, and 464, which were made to the three revenue profiles described above. The plots show disk and pad temperatures for each station stop on the respective profile. In each case the temperature data was read at the end of the station stop immediately prior to acceleration of the car on the next profile leg.

Peak temperatures were recorded on the WMATA revenue profile for the brake disk (474°F (245.6°C) at the sixteenth station stop). The other two profiles required lower energy absorbtion from the braking system, which was reflected in the brake temperature profiles for runs 463 and 464. Peak rotating disk temperatures were 326°F (163°C) for the NYCTA profile and 388°F (198°C) for the CTS profile.

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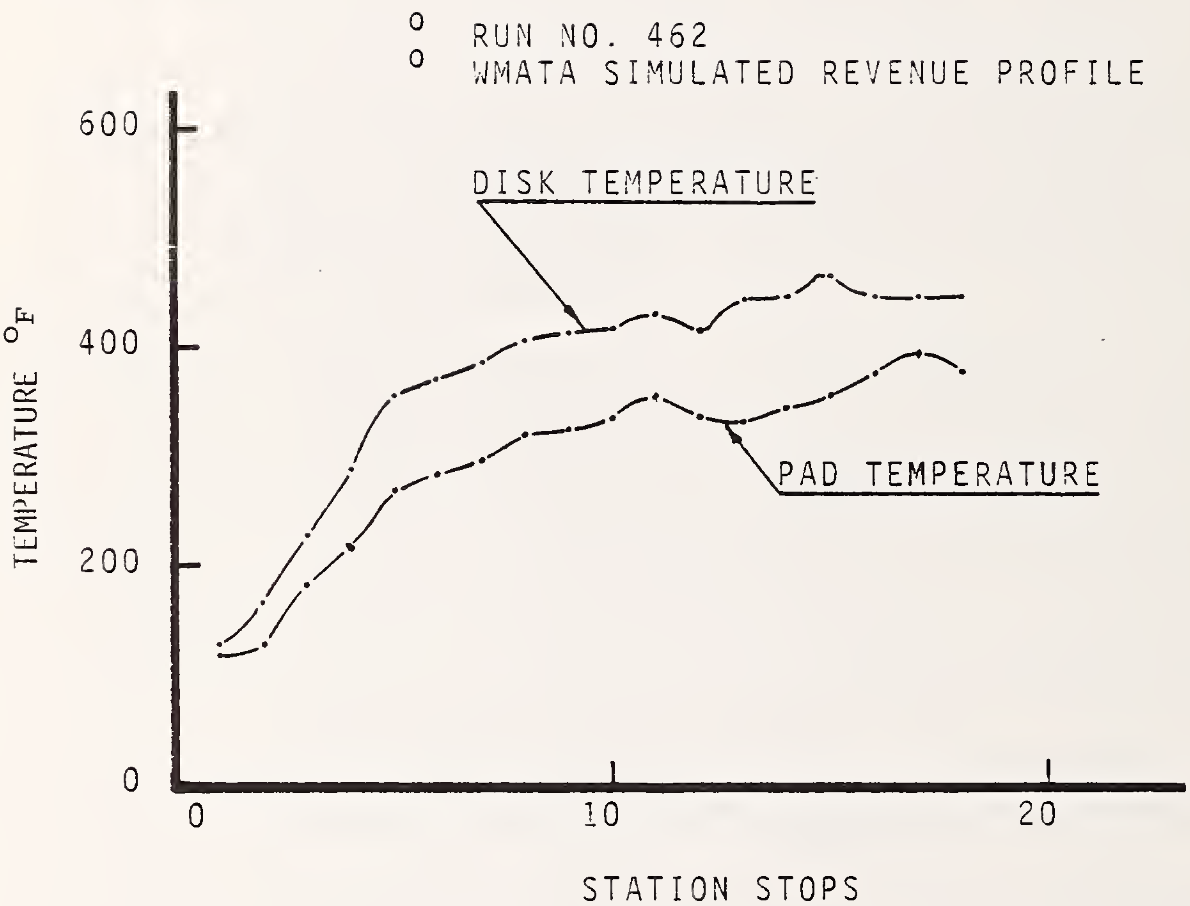
TABLE 2-4. WMATA SIMULATED LINE PROFILE.

GROSVENOR TO METRO CENTER, SILVER SPRING TO METRO CENTER

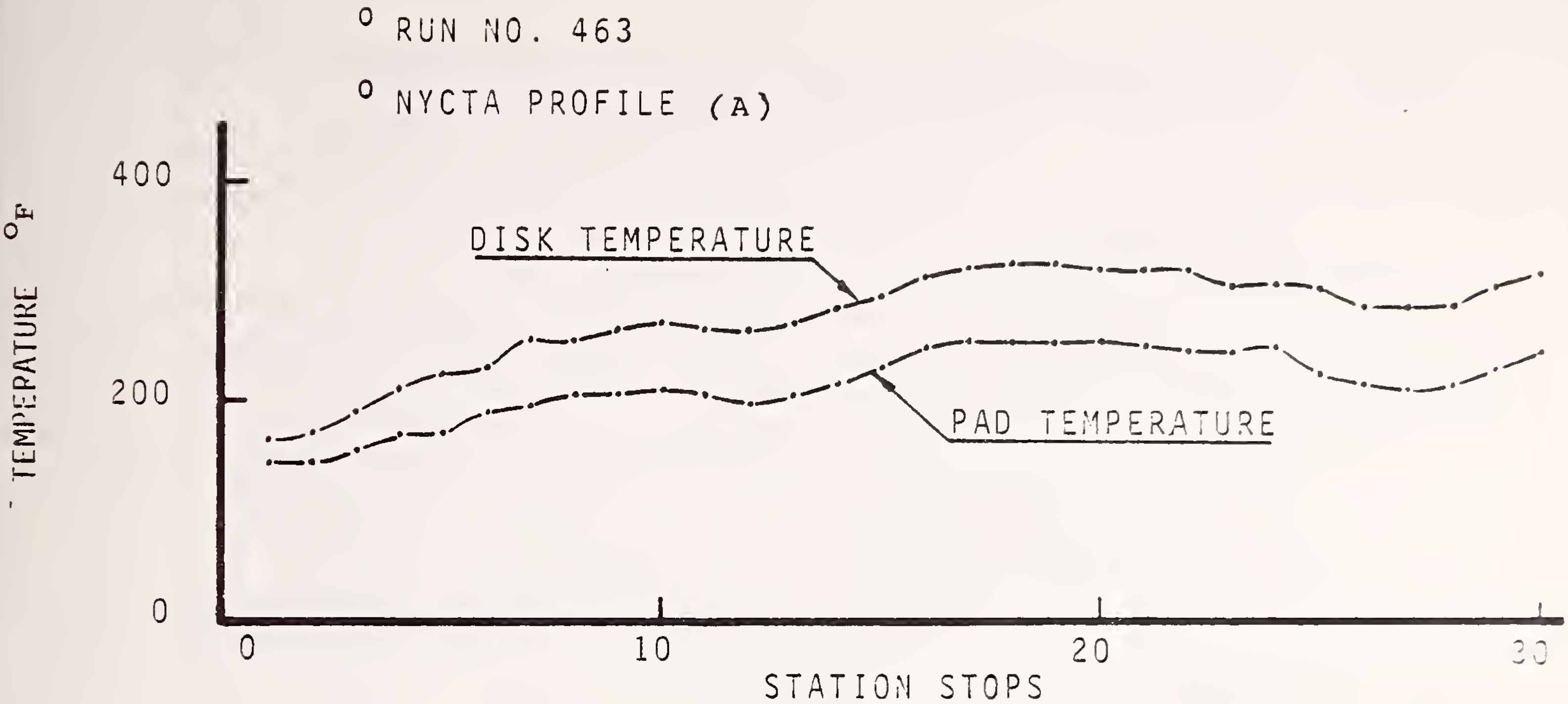
TIME AT START	START STATION	DIRECTION	PS ACCEL. TO:	CHANGE TO NEXT SPEED AT TIME:	NEXT SPEED	CHANGE TO NEXT SPEED AT TIME:	NEXT SPEED	CHANGE AT	NEXT SPEED
0	30	N	70	1.05	60	1.36	0		
2.19	38.7	S	70	3.26	50	3.46	0		
4.24	30.9	N	75	5.42	0				
6.32	39.1	S	60	7.16	50	7.30	0		
8.08	34.2	N	40	8.37	60	9.07	40	9.50	0
10.24	41.0	S	50	10.58	0				
11.36	38.4	S	60	12.20	0				
13.03	34.2	N	70	14.06	0				
14.54	40.08	S	50	15.30	0				
16.08	37.9	S	50	17.01	0				
17.40	33.3	N	75	19.22	0				
20.13	44.3	S	75	21.48	0				
22.39	33.7	N	70	23.49	55	24.0	0		
24.40	41.1	S	60	25.31	55	25.36	0		
26.14	36.0	S	75	27.23	65	27.53	0		
28.38	25.9	N	40	29.07	45	29.16	40	29.34	0
30.07	29.3	N	45	30.34	0				
31.10	31.0	N	40	31.33	0				

WMATA RAPID TRANSIT CAR
PERFORMANCE-DUTY CYCLES
P-5001-TT



- o 2-CAR TRAIN, AW2 WEIGHT
- o FRICTION-ONLY BRAKING
- o WEATHER: 70 °F TEMP.
  22 MPH/360° WIND
- o BRAKE TEMPERATURE CAR 1105, 'A' TRUCK,
  NO. 2 AXLE

FIGURE 2-18. DUTY CYCLE - TEMPERATURE vs. STATION STOPS.



- o 2-CAR TRAIN, AW2 WEIGHT
- o FRICTION-ONLY BRAKING
- o WEATHER: 70 °F TEMP.
  22 MPH/360° WIND
- o BRAKE TEMPERATURE CAR 1105,
  'A' TRUCK, NO. 2 AXLE

WMATA RAPID TRANSIT CAR
PERFORMANCE-DUTY CYCLES
P-5001-TT

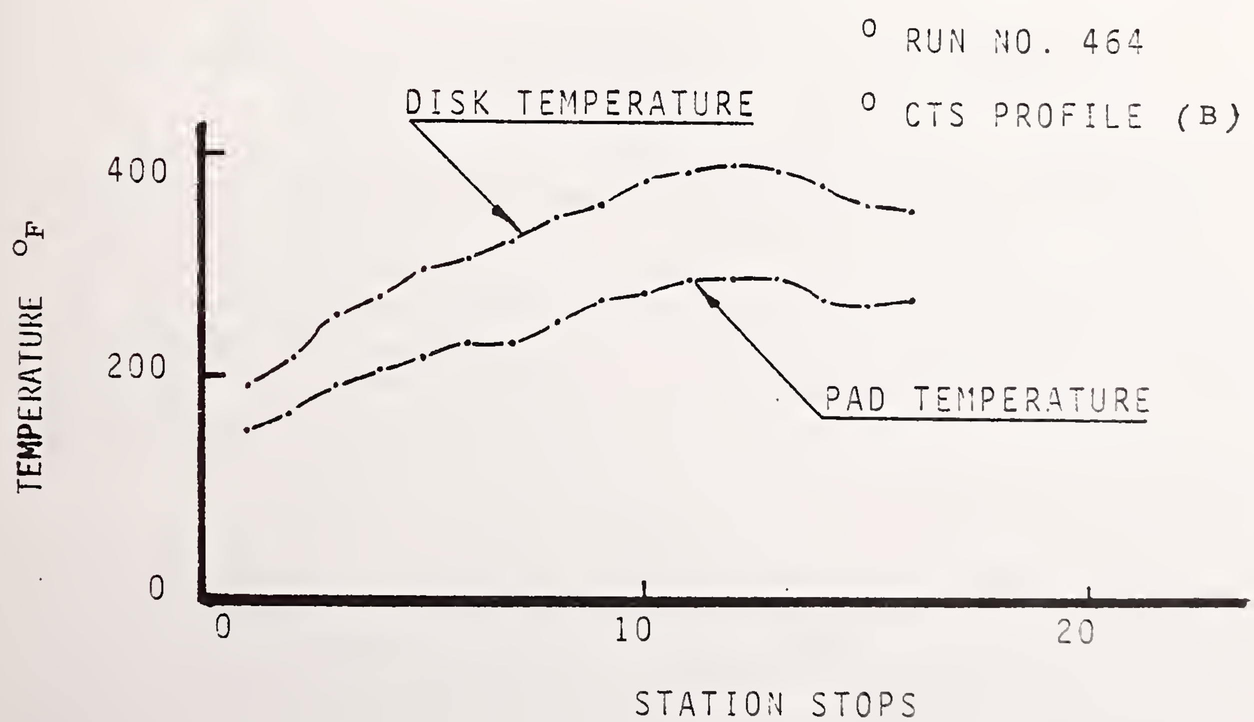


FIGURE 2-19. DUTY CYCLE - TEMPERATURE vs. STATION STOPS.

2.5.5 Spin/Slide Acceleration (Test Set No. P-2011-TT), Spin/Slide Deceleration (Test Set No. P-3011-TT).

Objective: To determine the efficiency of the spin/slide protection system during braking and acceleration throughout the speed range of the vehicle.

A spray rig, comprising a hydraulic pump, storage tank, and flexible hose was mounted in the lead car (car 1104) and connected to two spray nozzles mounted ahead of the lead axle of the "A" truck, spraying directly on the rail head. A soap solution of liquid soap and water in an approximate 10% solution was used to wet the rail. The rail was wetted prior to each test run by backing the test vehicle at approximately 10 mi/h (16 km/h) over the section of rail designated for the test with the spray rig operating. With the rail "conditioned" in this manner, acceleration and braking runs were made through this section of track.

A timing device in the WMATA transit car propulsion logic, which disengaged the spin/slide protection system after three seconds of continuous spins or slides on any axle, was not used for the test. The following combinations of variables were tested:

Prime Variable	Test Condition
Rail Condition	Wetted rail, liquid soap and water 10% solution
Brake Mode	Blended and friction-only brake modes

Test Results: The spin/slide program was attempted during hot, dry weather conditions which made adequate wetting of the rail extremely difficult; drying of the soap solution was almost immediate due to the rail temperature. Spins and slides could not be induced by rail conditioning alone, as described above, and it was found necessary to spray the soap solution on the test run, with the result that only the wheels on the lead axle were lubricated directly; each successive wheel passage removed some of the soap solution. Only one or two tests showed significant slippage of each of the first four axles.

Under these conditions, the approach to data analysis proposed in the "General Vehicle Test Plan, Appendix C", is inappropriate. The GVTP approach assumes that each axle will be limited to the maximum adhesion derived from the adhesion test. This was not so, because the cleaning effect of each successive wheelset removed the soap solution, so that each succeeding wheel experienced a higher coefficient of friction. Efficiency was defined as actual deceleration, divided by "available" deceleration as defined by the adhesion test. Given the increased traction of succeeding wheel sets due to decreased soap solution, it is likely that the GVTP procedure resulted in apparent efficiencies greater than 100%.

A second approach has been used (State-of-the-Art Car Engineering Tests, Report No. UMTA-MA-06-0025-75-1) in instances where occasional peak accelerations from the longitudinal accelerometer can be attributed to momentary nonslip conditions of all axles. These momentary peaks can be considered maximum adhesion points. The total tractive efficiency can then be determined by dividing the average acceleration experienced by the peak values. For the WMATA spin/slide tests, it was not known for any test that all eight axles were slipping, and the amount of traction experienced by the nonslipping wheels cannot be estimated. Furthermore, it is unlikely that all eight axles were periodically slipping; test data are needed which correspond to maximum adhesion for all wheels. Using this method will assuredly produce a efficiency less than 100%, but nevertheless one which is misleadingly high. Consequently, this approach is also considered inappropriate for WMATA.

The authors conclude that the aforementioned problems, of determining available adhesion at each wheelset and of obtaining synchronous wheel spins or slides on all wheelsets, make GVTP procedures for determining the efficiency of spin/slide protection systems impracticable.

2.5.6 Power Consumption (Test Set No. PC-5011-TT).

Objective: To determine the power consumption of the WMATA rapid transit cars while operating on a simulated service route at a defined level of schedule performance.

Test Description: Power consumption tests were made for a two-car consist at two vehicle weights, AW2 and AW3. The cars were operated over simulated revenue profiles, making scheduled starts, stops, and station dwells, and maintaining predetermined block speeds between stations.

Power consumption measurements were made using two watthour meters designed and constructed at TTC; each watt-hour meter gave a digital display of power consumption for individual cars of a married pair. A functional description of the meter is given in section 3.3, "Power Consumption Watt-Hour Meter". Cumulative power consumption in kilowatt-hours was recorded at the end of each station stop throughout each test run.

Tests were conducted for two simulated revenue service profiles representing, (a) the WMATA revenue profile as detailed in table 2-4, above, and (b) the Advanced Concept Train-1 (ACT-1) Synthetic Transit Route, illustrated in figure 2-20.

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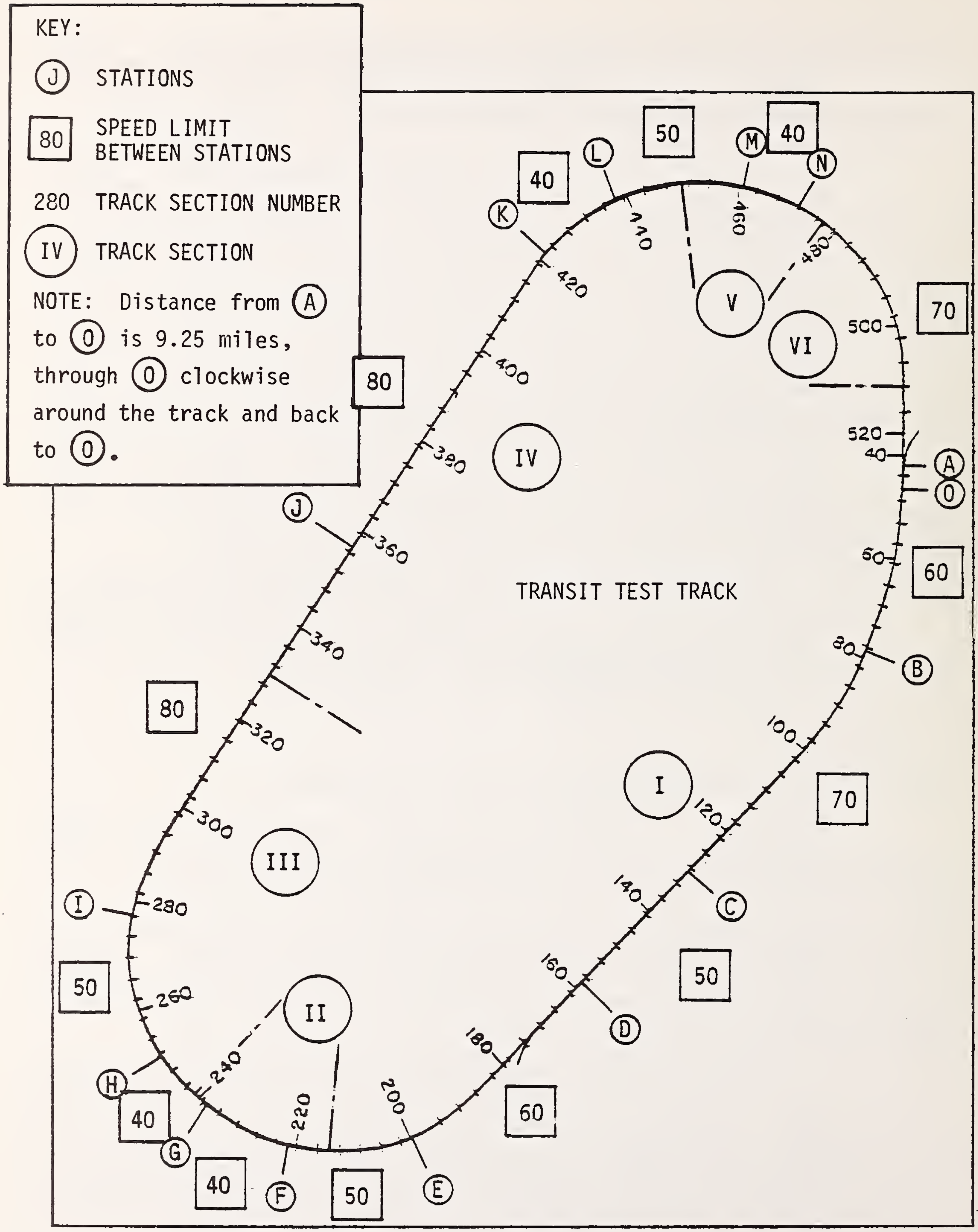

FIGURE 2-20. ACT-1 SYNTHETIC TRANSIT ROUTE.

The WMATA simulated line profile represents a theoretical profile assembled from Grosvenor to Metro Center and Silver Spring to Metro Center routes, modified slightly for use on the TTT. This profile is basically a set of 18 runs with theoretical station stops. Station stops may have varied slightly from profile to profile as the runs were made using a stop watch to key the events shown in figure 2-20.

The ACT-1 synthetic transit route is a theoretical profile designed to make the best use of the TTT as a tool for comparative evaluation of transit vehicles. The runs conducted to this profile were made in a slightly different manner from those conducted to the WMATA profile, in that the actual station stops and block maximum speeds were maintained as accurately as possible, with no target times for each block. All profiles were made using P5 acceleration and B4 master controller levels.

In addition to the GVT power consumption tests detailed above, a power consumption test program was conducted on cars 1104, 1105, 1108, and 1109 during the period from January to August 1977. A study of 60 power consumption runs was made as part of the performance evaluation and reliability testing (reference, section 2.1). Those data have been used in this report to add statistical depth to GVTP data, to gain information representative of year-round performance, and to study the effect of operation at lower acceleration rates (P3 and P2 controller settings). The following combinations of variables were tested:

Prime Variable	Test Conditions
Car Weight	AW2 and AW3
Acceleration Rate	Master controller P5, P3, and P2
Simulated Route	WMATA simulated revenue profile ACT-1 synthetic transit route

Test Results: Table 2-5 presents typical data for a WMATA simulated line profile power consumption run at AW3 vehicle weight. Incremental kilowatt-hour values for each car of the married pair are tabulated for each station stop for the Grosvenor/Metro Center, Silver Spring/Metro Center simulated profile run, assuming that the station stops used at TTC were identical. Each incremental value includes kilowatt-hour per car-mile values which are presented for the total run by averaging power consumed for the two-car train. Since the consist is a "married" pair, not all auxiliary equipment is common to each individual car.

Figures 2-21 and 2-22 illustrate the trends of power consumption with vehicle weight, and with reduced power accelerations using P3 and P2 master controller positions respectively. The data were obtained from the WMATA power consumption study.

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TABLE 2-5. SUMMARY OF CAR ENERGY CONSUMPTION.

RUN: 274 WEIGHT: AW3

SIMULATED LINE PROFILE RUN

	ACCELERATE TO AND MAINTAIN	FOR A TOTAL TIME OF	REDUCE TO AND MAINTAIN	FOR A TOTAL TIME OF	CUMULATIVE TIME OF	CUMULATIVE POWER CONSUMPTION A KW-HR CAR 1104	CUMULATIVE POWER CONSUMPTION B KW-HR CAR 1105	DISTANCE MILES
Grosvenor	70	65.2			1:05.2			
			60	31.2	1:36.4			
Medical Center			0	42.6	2:19.0	13.4	12.8	1.63
	70	67.0			3:26.0			
			50	20.2	3:46.2			
Bethesda			0	37.8	4:24.0	23.5	23.1	3.06
	75	78.0			5:42.0			
Friendship Hts.			0	50.8	6:32.8	37.4	37.3	4.59
	60	44.0			7:16.8			
			50	13.8	7:30.6			
Tenley Circle			0	37.8	8:08.4	45.4	45.3	5.50
	40	29.0			8:37.4			
	60	30.0			9:07.4			
			40	43.4	9:50.8			
Van Ness			0	33.2	10:24.0	56.0	56.7	6.75
	50	34.3			10:58.6			
Cleveland Pk.			0	38.5	11:36.8	61.6	62.0	7.26
	60	44.0			12:20.8			
Zoological Pk.			0	42.6	13:03.4	69.3	69.5	8.03
	70	63.0			14:06.4			
Dupont Circle			0	47.8	14:54.2	81.6	82.4	9.19
	50	36.0			15:30.2			
Farragut North			0	37.8	16:08.0	86.8	88.1	9.72
	50	53.2			17:01.2			
Arrive Metro Ctr.			0	39.6	17:40.8	92.9	94.2	10.49
Silver Spring	75	102.1			19:22.9			
Takoma			0	50.7	20:13.6	110.4	111.7	12.51
	75	95.0			21:48.6			
Fort Totten			0	50.8	22:39.4	121.7	123.3	14.46
	70	70.0			23:49.4			
			55	10.8	24:00.2			
Brookland			0	40.2	24:40.4	134.8	136.2	15.80
	60	51.0			25:31.4			
			55	4.7	25:36.1			
Rhode Island Ave.			0	38.1	26:14.1	142.0	144.0	16.71
	75	69.0			27:23.2			
			65	29.8	27:53.0			
Union Station			0	45.2	28:38.2	155.9	157.4	18.64
	40	29.0			29:07.2			
	45	9.0			29:16.2			
			40	18.4	29:34.6			
Judiciary Square			0	33.2	30:07.8	162.3	163.9	19.24
	45	27.0			30:34.8			
Gallery Place			0	35.6	31:10.4	167.0	169.0	19.58
	40	23.0			31:33.4			
Arrive Metro Ctr.			0	18.2	31:51.6	171.2	173.3	19.73
		1018.8 seconds		892.8 seconds				

NOTE: 15 seconds dwell time at each station included: each power consumption value includes power consumed during the station stop.

TOTAL TRIP TIME: 31.86 minutes
AVERAGE SPEED: 37.16 mph

TOTAL POWER CONSUMED: 344.5 KW-HR
TOTAL DISTANCE: 19.73 miles
POWER CONSUMED PER CAR-MILE: $\frac{344.5}{2 \times 19.73}$

= 8.73 KW-HR/CAR-MILE

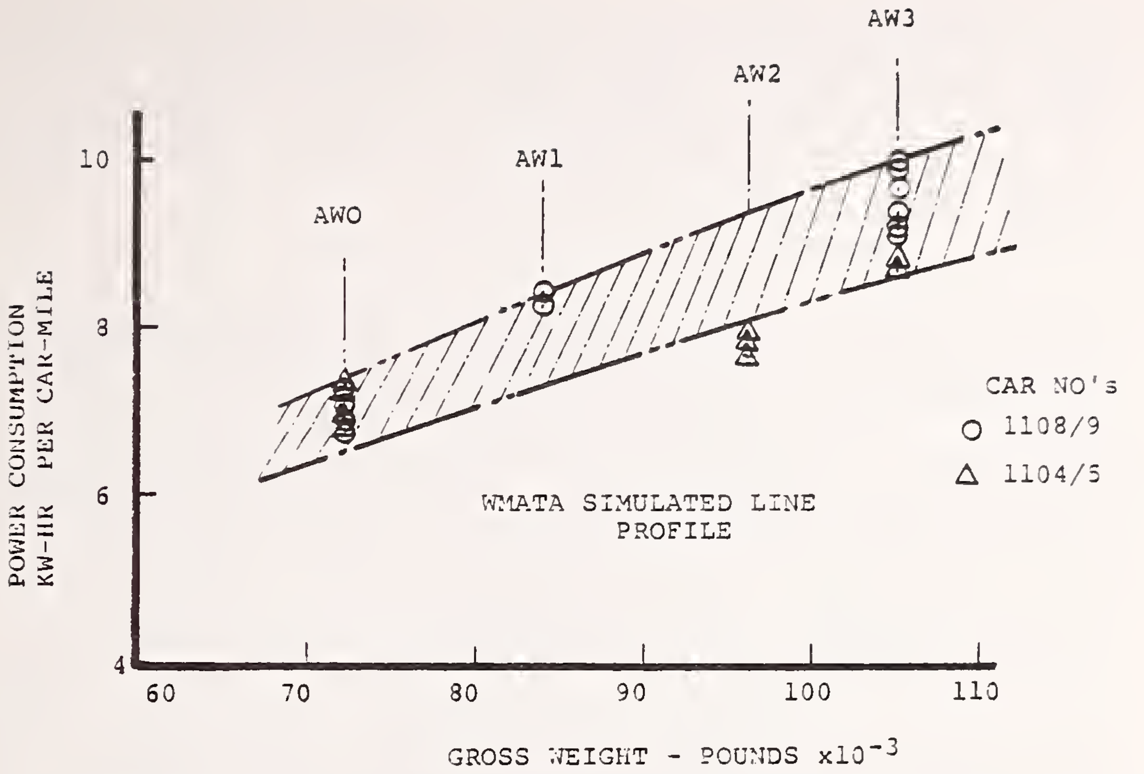

FIGURE 2-21. POWER CONSUMPTION - TREND WITH CAR WEIGHT.

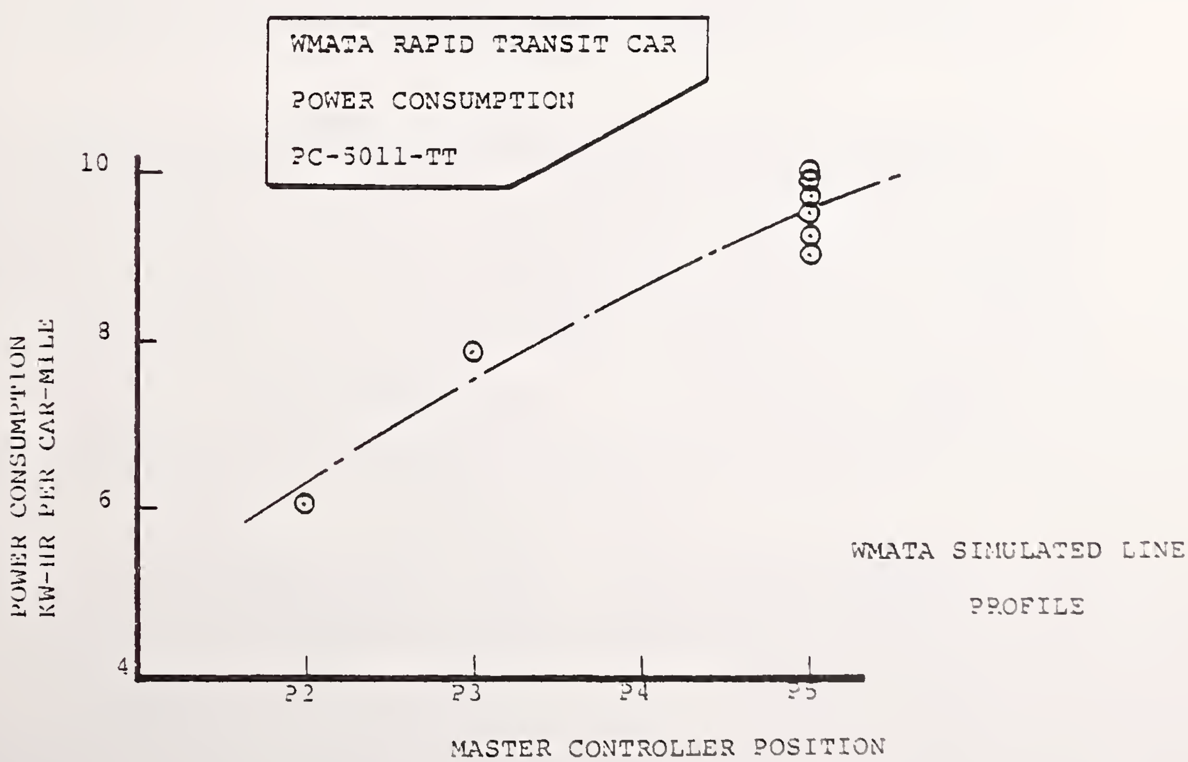

FIGURE 2-22. POWER CONSUMPTION - TREND WITH MASTER CONTROLLER DEMAND.

The plots show a variance between the power consumed for the 1104/1105 pair of cars and the 1108/1109 pair; the 1108/1109 pair always required more power than the 1104/1105 pair. A careful check and recalibration of voltage and current sensors was carried out on both cars but no reason could be found for the variation between vehicles.

2.5.7 Equipment Noise Survey: Wayside (Test Set No. CN-0001-TT), Effect of Car Speed on Wayside Noise Levels (Test Set No. CN-1001-TT).

Objective: To determine the contribution of auxiliary equipment noise to total static vehicle signature, and to determine the wayside noise levels during vehicle pass-by at constant speed.

Test Description: Noise measurements were made at a wayside station adjacent to rail station 340, 50 feet (15 m) from the centerline of the track on the outside of the TTT oval. The track at this station is level tangent, welded 119 lb/yd rail (59 kg/m) on concrete ties at 30" centers (762 mm); the microphones were located approximately at the level of the car floor. Wayside noise levels were recorded with a tape recorder at 7-1/2"/s tape speed using a dB A-weighting scale. Additional noise levels were recorded manually by using a hand-held noise level meter set to a dB A-weighting slow scale.

A stationary wayside survey was carried out on the two-car train at AW0 vehicle weight; noise levels were recorded while the vehicle's hydraulic power unit and air compressor cycled on and off. The passenger doors were also cycled and noise levels recorded.

The effect of vehicle speed on wayside noise levels was investigated by making a series of runs with a two- and four-car train at AW0 vehicle weight, and a two-car train at AW3 vehicle weight at constant passby speed. Data were recorded for speed increments of 15, 30, 45, 60 and 75 mph (24, 48, 72, 96, and 120 km/h). The following combinations of variables were tested:

Prime Variables	Test Conditions
Car Speed	Stationary and five selected speeds
Car Weight	AW0 (2-and 4-car train) AW3 (2-car train)
Train Consist	2-car and 4-car train

Test Results: The test results presented here are from the hand-held meter; the tape-recorded data will be the subject of an in-depth analysis, and will be published as a future TTC technical report.

A wayside survey with the two-car stationary consist gave peak noise levels of 61 dBA with all auxiliary systems operating and 55 dBA with hydraulic power unit shutdown. Ambient noise level was 36 dBA and the wind velocity was zero.

Figure 2-23 illustrates the typical noise levels at 50 ft (15 m) from track centerline, due to a train passing at speeds from 15 to 75 mi/h (24 to 120 km/h). Ambient wind conditions were marginal for two of the tests, 6 mi/h (9.6 km/h) for the two-car, AW3 test and 10-15 mi/h (16-24 km/h) for the four-car, AW0 test. The 2-4 dB change in noise level data between runs is thought to be more clearly attributable to the wind speed and direction effects than to vehicle configuration; note that 150° wind direction blew generally from the noise station toward the rail and a 270° wind direction blew generally from the rail toward the wind measurement station, which correlated with the observed changes in noise level.

2.5.8 Interior Noise: Effect of Speed (Test Set No.PN-1001-TT), Effect of Track Type (Test Set No., PN-1101-TT), Interior Survey (Test Set No. PN-1301-TT), Acceleration (Test Set No. PN-2011-TT), Deceleration (Test Set No. PN-3011-TT).

Objective: To evaluate the interior acoustic characteristics of the WMATA rapid transit cars, by sampling noise data at a number of locations representative of seated and standing passengers; specifically, to investigate the effect of speed, track type, interior location, and vehicle acceleration and deceleration on noise levels experienced by the vehicle passengers.

Test Description: The five test sets described here have been grouped together because of their similar objectives and instrumentation, and the fact that they were conducted concurrently.

Interior noise measurement testing was conducted in WMATA rapid transit car 1104, which was used exclusively because it was fully equipped with seats and was most representative of a vehicle in revenue service. The five microphone positions, illustrated in figure 2-24, were chosen to represent the ear level of standing and seated passengers in typical positions throughout the length of the car.

Interior noise level data were recorded with a tape recorder at 7-1/2"/s tape speed using a dB A-weighting scale. Additional average noise levels were estimated and recorded manually by using a handheld noise meter set to a dB A-weighting slow scale.

The following tests were conducted:

a. Noise measurements were made at each microphone location, over a range of speeds from 15 to 75 mi/h (24 to 120 km/h),

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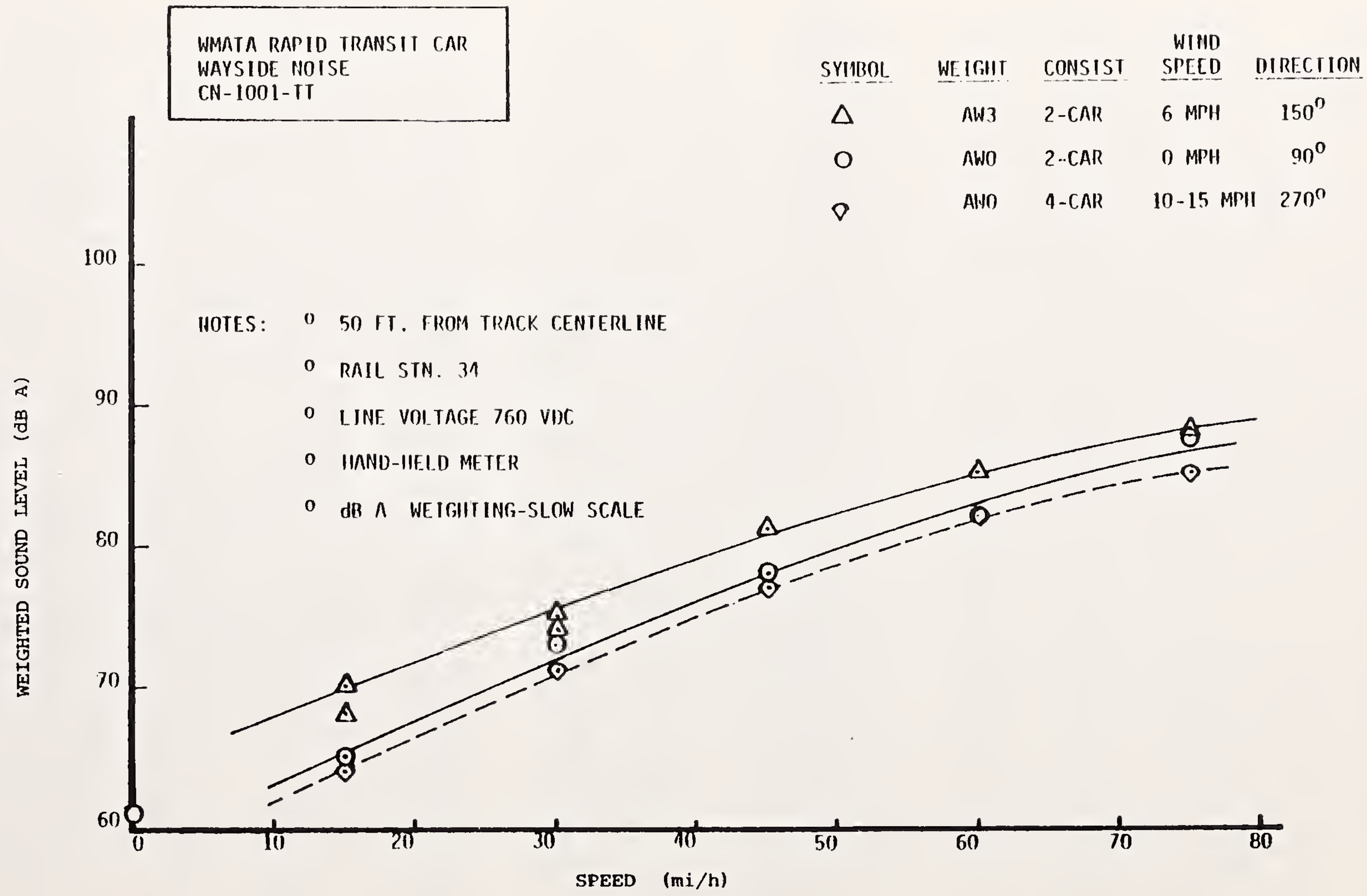

FIGURE 2-23. WAYSIDE NOISE LEVELS.

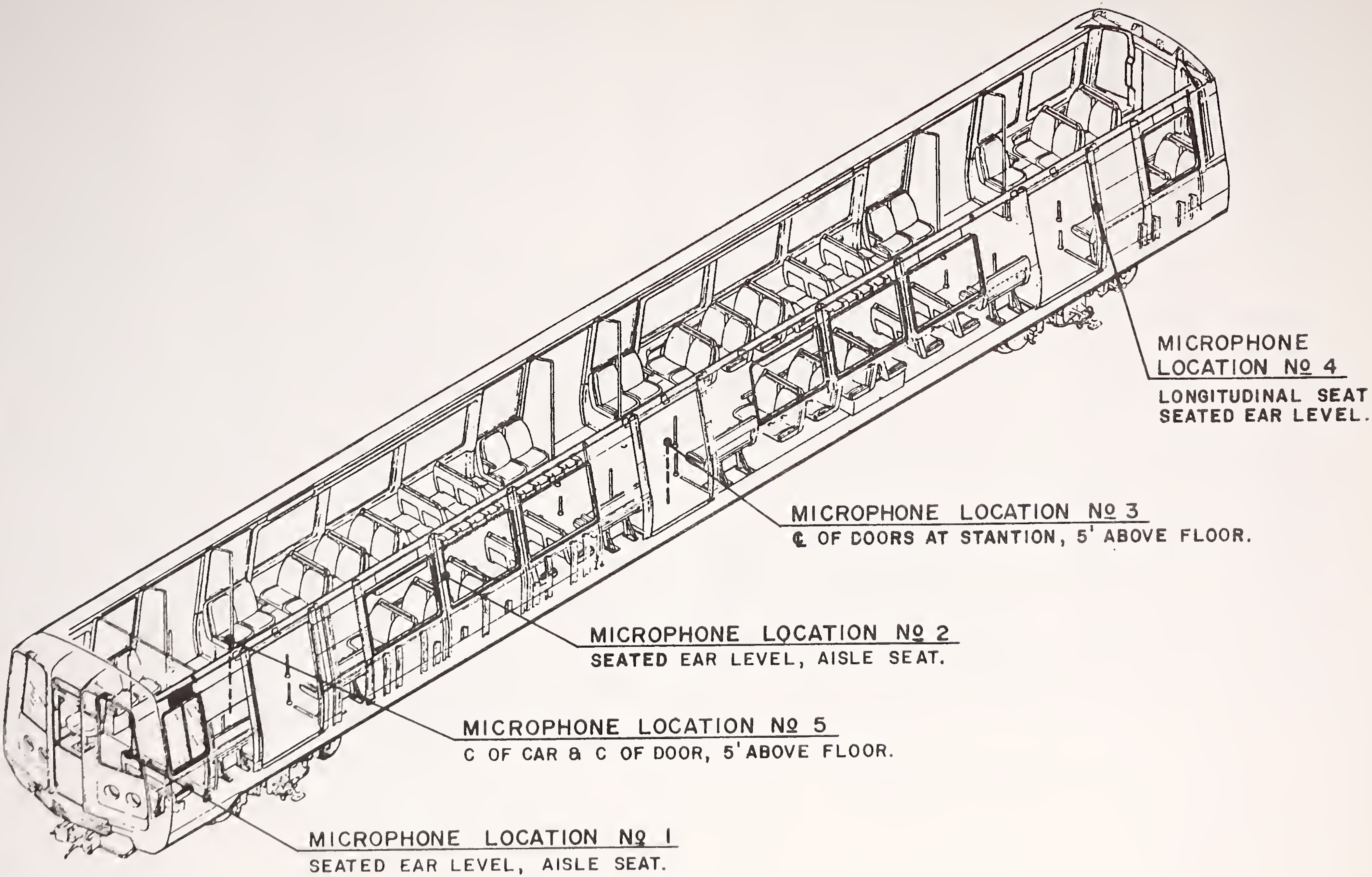

FIGURE 2-24. MICROPHONE LOCATIONS CAR NO. 1104.

on tangent track with welded rail and concrete ties. These tests accomplished the goals of the "Effect of Speed" and "Interior Survey" GVTP test sets, and were conducted at AW0 and AW3 weights.

b. A survey of the entire Transit Test Track was made at 50 mi/h (80 km/h), recording noise levels at microphone positions #4 and #5 for each typical section of track and for switches, grade crossings, and track perturbations. Two vehicle weights, AW0 and AW3, were tested. These tests met the requirements of the "Effect of Track Type" test set.

c. Acceleration and braking test runs were made from rest to 75 and 75 mi/h (120 km/h) to a full stop respectively, using P5 master controller position for acceleration and B5 master controller position for brake application; blended and friction-only brake modes were tested. The tests were made on tangent track with welded rail and concrete ties, at two vehicle weights, AW0 and AW3. Data was recorded at microphone locations #1 and #2. These tests met the objectives of the "Acceleration" and "Deceleration" test sets. The following combinations of variables were tested:

Prime Variables	Test Condition
Car Speed	15, 30, 45, 60, and 75 mi/h (24,48,72,96, and 120 km/h)
Car Weight	AW0 and AW3
Track Type	Six track sections comprising the TTT
Interior Location	Five microphone locations

Test Results: The test data presented here were recorded using the hand-held meter; the tape-recorded data will be the subject of a later in-depth analysis. Figures 2-25 and 2-26 illustrate the trends of interior noise levels with speed on tangent welded track with concrete ties at two vehicle weights, AW0 and AW3. The interior noise levels vary from 60-65 dBA at 15 mi/h (24 km/h), to 65-70 dBA at 75 mi/h (120 km/h) and are sensitive to microphone location. The noisiest passenger locations in the car are adjacent to the operator's cab and at longitudinal seats located at either end of the car, over the trucks.

Table 2-6 shows the results of a survey of the TTT conducted at steady 50 mi/h (80 km/h), with the hand-held noise meter located at microphone locations #4 and #5, respectively (i.e., two of the less favorable set locations). Noise levels were estimated from the noise meter as the train traversed the various sections of track. General noise levels were in the range 71 to 75 dBA with momentary peaks at switches and cross-

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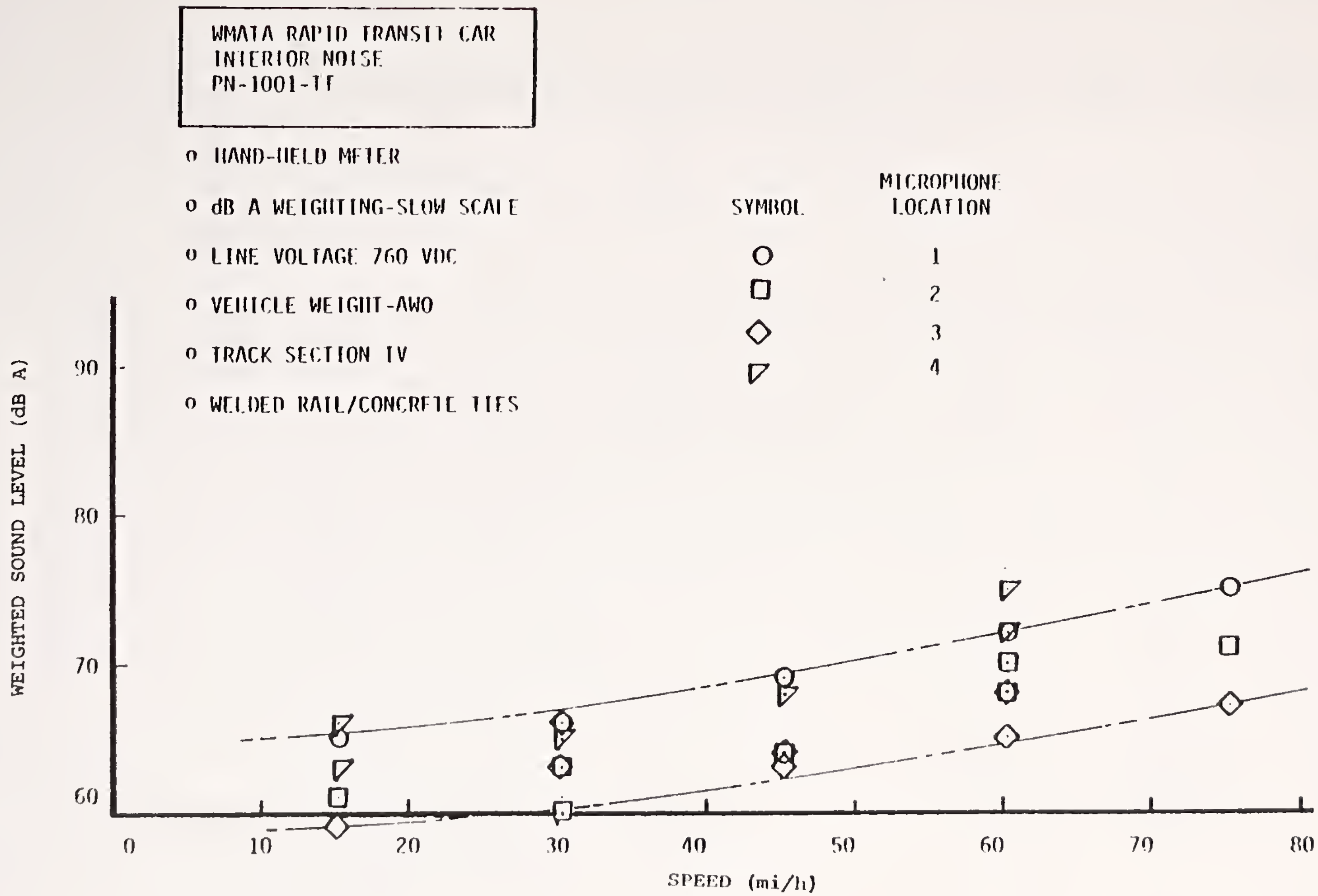

FIGURE 2-25. INTERIOR NOISE LEVELS - EFFECT OF SPEED, AWO WEIGHT.

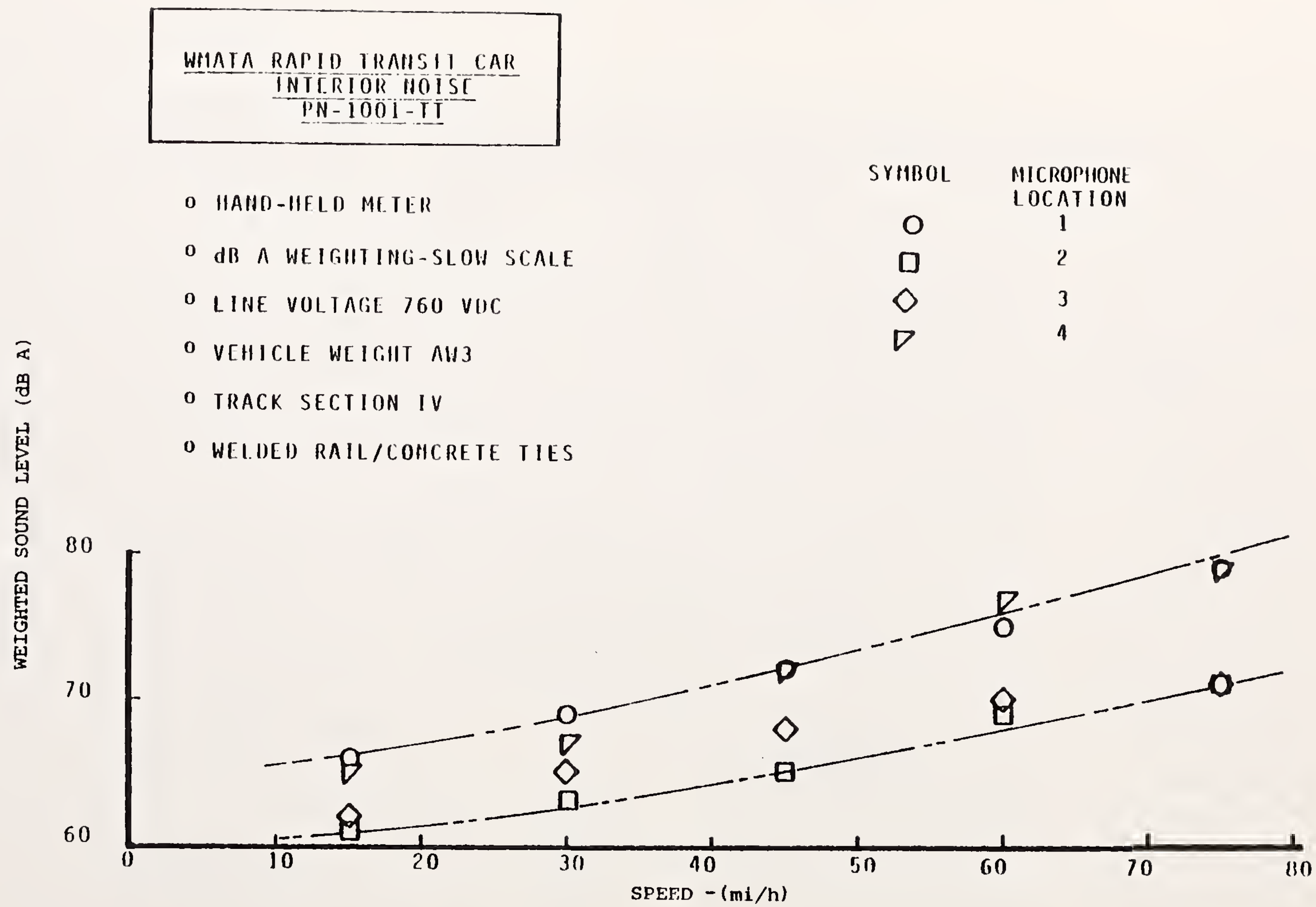

FIGURE 2-26. INTERIOR NOISE LEVELS - EFFECT OF SPEED, AW3 WEIGHT.

TABLE 2-6. INTERIOR NOISE - EFFECT OF TRACK SECTION.

EFFECT OF TRACK SECTION, PN-1101-TT

- o VEHICLE WEIGHT AWO
- o " SPEED 50 MPH
- o " DIRECTION CLOCKWISE
- o HAND-HELD METER
- o dBA SLOW SCALE

RAIL STATION	TRACK SECTION	TRACK TYPE	ALINEMENT	NOISE LEVEL dBA	
				RUN 723	RUN 724 *
31	III	100 LB/YD JOINTED RAIL, WOODEN TIES	TANGENT	73	74
38	IV	119 LB/YD WELDED RAIL, CONCRETE TIES	TANGENT	71	72
44	IV	119 LB/YD WELDED RAIL, CONCRETE TIES	1° 30' CURVE	75	74
NORTH TRANSIT SWITCH	I	119 LB/YD WELDED RAIL, WOODEN TIES	TANGENT	74	77
NORTH TRANSIT CROSSING	I	119 LB/YD WELDED RAIL, WOODEN TIES	TANGENT	83	77
POWER SPUR	I	119 LB/YD WELDED RAIL, WOODEN TIES	TANGENT	77	76
SOUTH TRANSIT SWITCH	I	119 LB/YD WELDED RAIL, WOODED TIES	TANGENT	82	78
SOUTH TRANSIT CROSSING	I	119 LB/YD WELDED RAIL, WOODED TIES	1° 30' CURVE	75	74
24	II	100 LB/YD WELDED RAIL, WOODEN TIES	1° 30' CURVE	72	73

* RUN 723 = MICROPHONE LOCATION #4, 724 = LOCATION #5.

ings. The worst recorded noise level was a momentary 77-83 dBA when traversing the North Transit grade crossing.

Noise levels under acceleration were typically 75 dBA for microphone location #1, and 71 dBA for location #2, regardless of vehicle weight. Blended braking noise levels were also 75 dBA and 71 dBA respectively at locations #1 and #2 with no variation due to vehicle weight. Friction-only brake noise levels were similar to blended brake modes at AW3 vehicle weight for microphone locations #1 and #2, but were substantially higher, 84 and 82 dBA respectively, at AW0 vehicle weight because of protracted brake squeal.

2.5.9 Ride Roughness: Component Induced Vibration (Test Set No. R-0010-TT), Worst Speeds (Test Set No. R-1101-TT), Acceleration (Test Set No. R-2001-TT), Deceleration (Test Set No. R-3001-TT)

Objectives: To define the ride quality characteristics of the WMATA rapid transit car and to determine the effects of weight, speed, type of track, acceleration, and deceleration on ride quality. To determine the vibration levels due to operation of the vehicles' auxiliary equipment.

Test Description: The ride quality evaluation program consisted of four separate sequences of tests designed to isolate possible contributors to vibrations that affect passengers. The tests, although identified by different GVTP test set numbers, have been grouped together here because of their common objectives, instrumentation, and data analysis techniques.

WMATA car 1104 was instrumented for ride quality testing. Lateral and vertical accelerometers were mounted on the front truck, the forward car body, and the mid-car body. For component vibration, a supplemental probe was added to measure vibration resulting from the train-line air compressor located in car 1105.

The prime sensor data used in the ride quality analysis presented here was taken from the forward car body lateral and mid-car vertical accelerometers; both were mounted on the car centerline. The mid-car lateral accelerometer, and the mid-car vertical accelerometer located on the left-hand side were used to determine the sensitivity of ride quality to location. All car body sensors were mounted on ballasted frames with adjustable, pointed feet which penetrated the floor carpet and provided a solid, grounded base for the accelerometers.

Truck accelerometer data was recorded for the determination of stimulus vibration, if objectionable levels of car vibration were encountered; to date, it has not been necessary to reduce these data.

The test program was carried out at three vehicle weights, AW0, AW2, and AW3, and two vehicle configurations, with and without 1/8" shims (3 mm) under the lateral bumpers. The bumpers are conical, progressive-rate rubber bump stops mounted between the bolster and the truck frame, on each side of the truck. They provide lateral snubbing of excessive truck/bolster lateral motion.

In order to meet the component induced vibration test objectives, the two-car train (cars 1104 and 1105) was positioned on tangent track, with welded rail and concrete ties. The vehicle's auxiliary systems, i.e., its motor generator set, the environmental blower, the train-line air compressor, and the air-conditioning compressor were operated both separately and together while vibration surveys were made of the vehicle floor in the areas of the respective systems.

"Worst speed" ride roughness test objectives were met by operating the train on all sections of the TTT at constant speed increments from 15 to 75 mi/h (24 to 120 km/h). The tests provided information on the effect of speed and type of track, and also operation of the train through grade crossings and switches typical of those in use throughout the transit properties.

Ride roughness acceleration and deceleration test objectives were met by making acceleration and blended braking runs on tangent, welded rail, concrete tie track. Acceleration runs were made from a standing start to 75 mi/h (120 km/h) at P5 master controller demand (i.e., maximum acceleration) and deceleration runs were made from 75 mi/h (120 km/h) to a full stop at B5 master controller demand (full service braking).

The following combinations of variables were tested:

Prime Variables	Test Condition
Car Weight	AW0, AW2, AW3
Speed	15, 30, 45, 60, and 75 mi/h (24, 48, 72, 96, and 120 km/h)
Track	TTT Track Sections I through VI

Analysis Procedure: A brief description of the techniques used to process the ride roughness data follows, as an understanding of the techniques is required by the reader to comprehend the following ride roughness data plots.

Unfiltered accelerometer data was recorded on magnetic tape with timing, track section markers, and car speed. Subsequently the vibration data was processed through analog filters and root mean square (RMS) conversion devices to provide ride quality time histories, figure 2-27. The filters used approximated the human factor transfer functions specified in the GVTP figures 2-28 and 2-29, for vertical ride roughness and horizontal ride roughness respectively, but differed sufficiently over some frequencies to require critical examination. A full description of the ride roughness filter networks used for data analysis and a critique of their performance is contained in section 5.

As a parallel processing activity, magnetic tapes were digitized by computer. The digital tapes were used to generate calibrated vibration time histories and power spectral densities (PSD's) as required. The PSD's were used to perform accurate filtering in the frequency domain and for precise RMS determination. The PSD filtering operation was a manual entry task; as such, the process was used judiciously for a limited number of cases. Consequently, the RMS values which appear on the filtered PSD plots do not necessarily correspond to the RMS values on the parametric ride quality plots, which were obtained from the less precise analog filter.

<u>Test Results</u>: Test results are summarized below.

<u>Component Induced Vibration Data</u>.

Vibration levels perceptible to human beings were insignificant for the stationary test program with the exception of operation of the train-line air compressor. Ride quality filtered levels did not increase over background with the turning on of the motor/generator set or cycling of the hydraulic power unit. Lateral ride roughness remained at less than 0.002 g singular and vertical ride roughness at less than 0.001 g.

The addition of an overhead environmental blower increased vertical ride roughness to 0.007 g, but did not affect the lateral measurement. The further addition of an air conditioner compressor increased vertical roughness slightly to 0.011 g, but again did not affect lateral ride quality.

Operation of the train-line air compressor was monitored by a special probe in the otherwise uninstrumented "A" car. This test resulted in a vertical ride roughness measurement of 0.025 g. This moderate level is comparable to constant speed ride quality at 75 mi/h (120 km/h), but may not be representative of levels measured in seats displaced any distance from the probe location. Conceivably, the probe could have been measuring a highly localized phenomena on the floor structure immediately above the compressor.

<u>Worst Speeds/Track Type Data</u>.

Figures 2-30 through 2-41 are plots of RMS-averaged, ride roughness weighted data from the car body vertical and lateral

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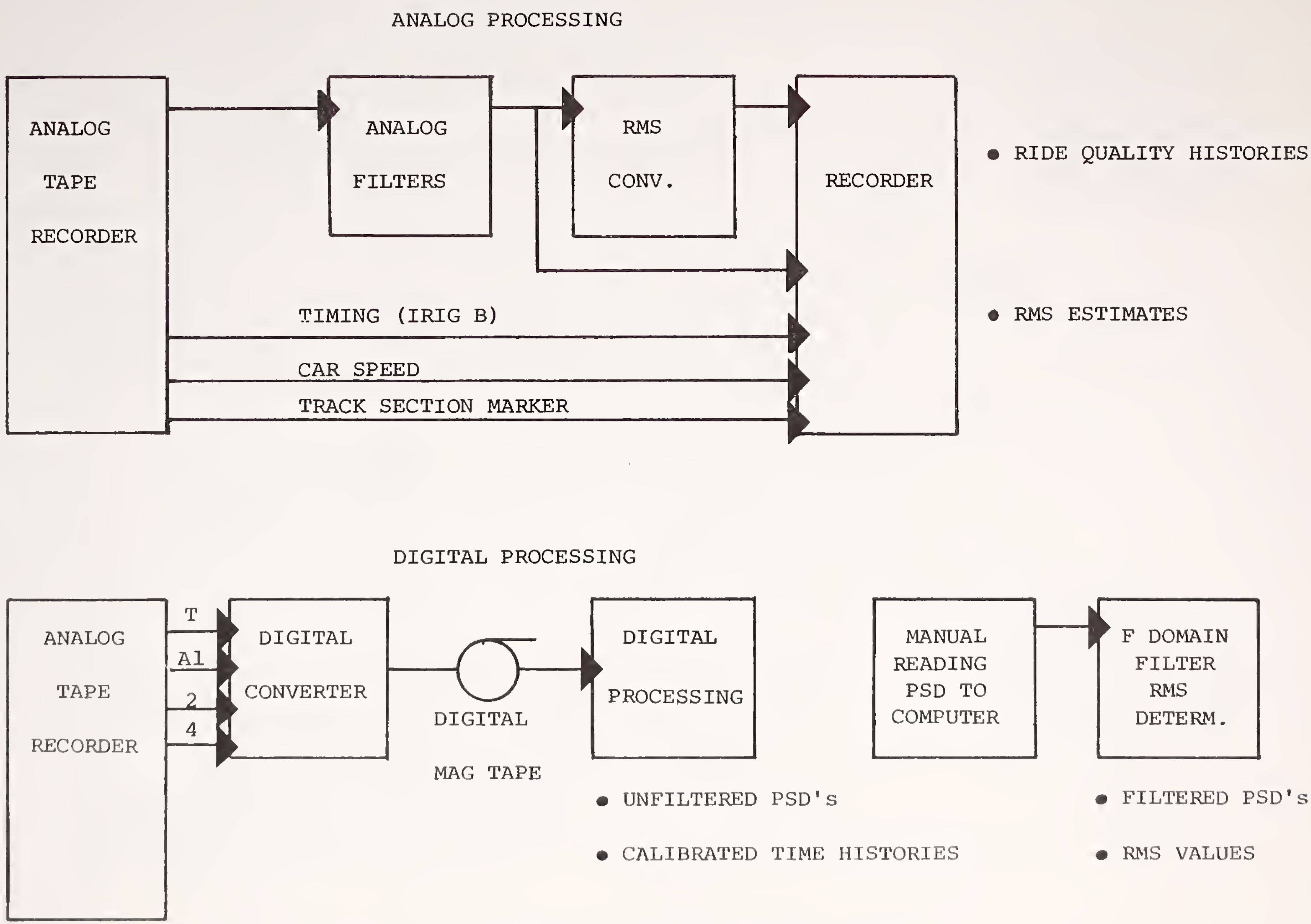


FIGURE 2-27. RIDE QUALITY DATA PROCESSING SCHEMATIC.

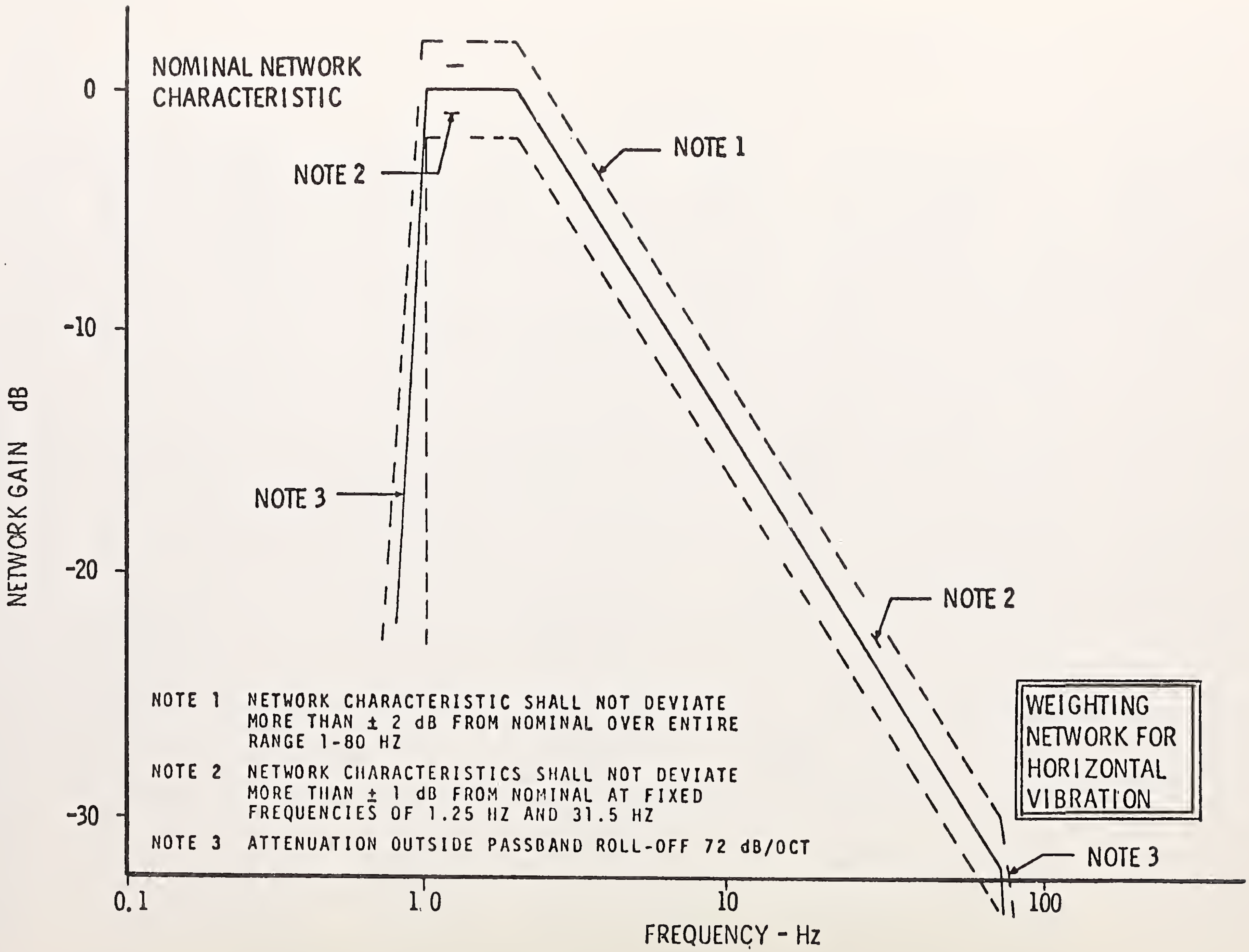


FIGURE 2-28. GVTP LATERAL RIDE QUALITY FILTER.

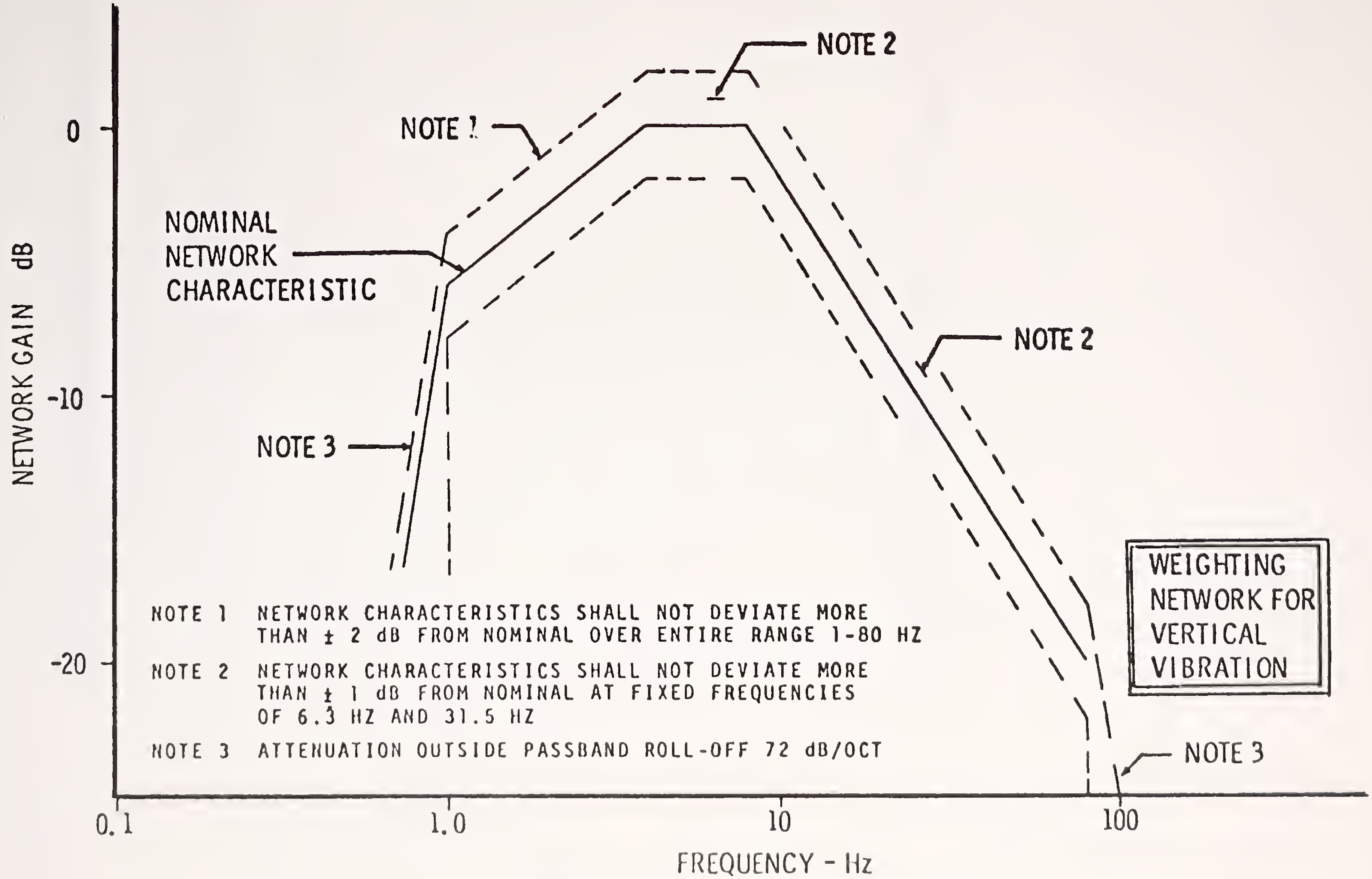
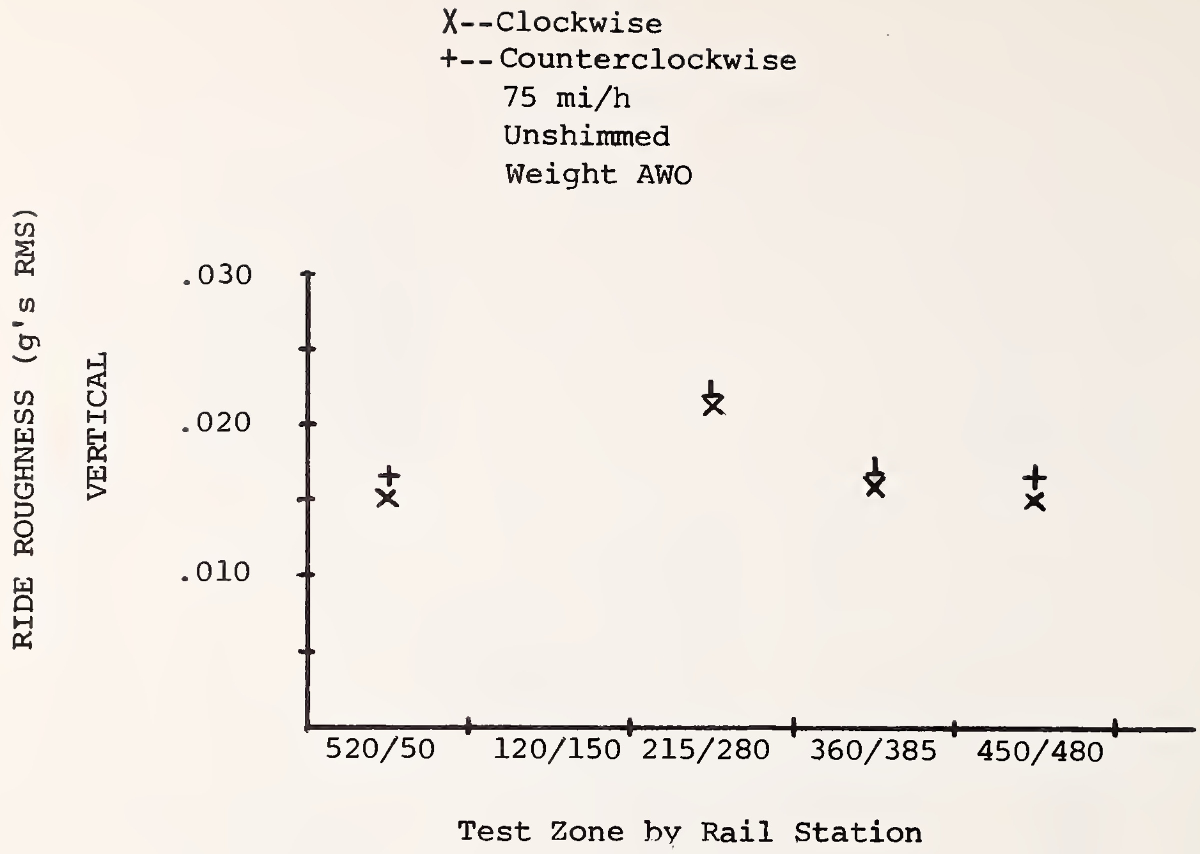


FIGURE 2-29. GVTP VERTICAL RIDE QUALITY FILTER.



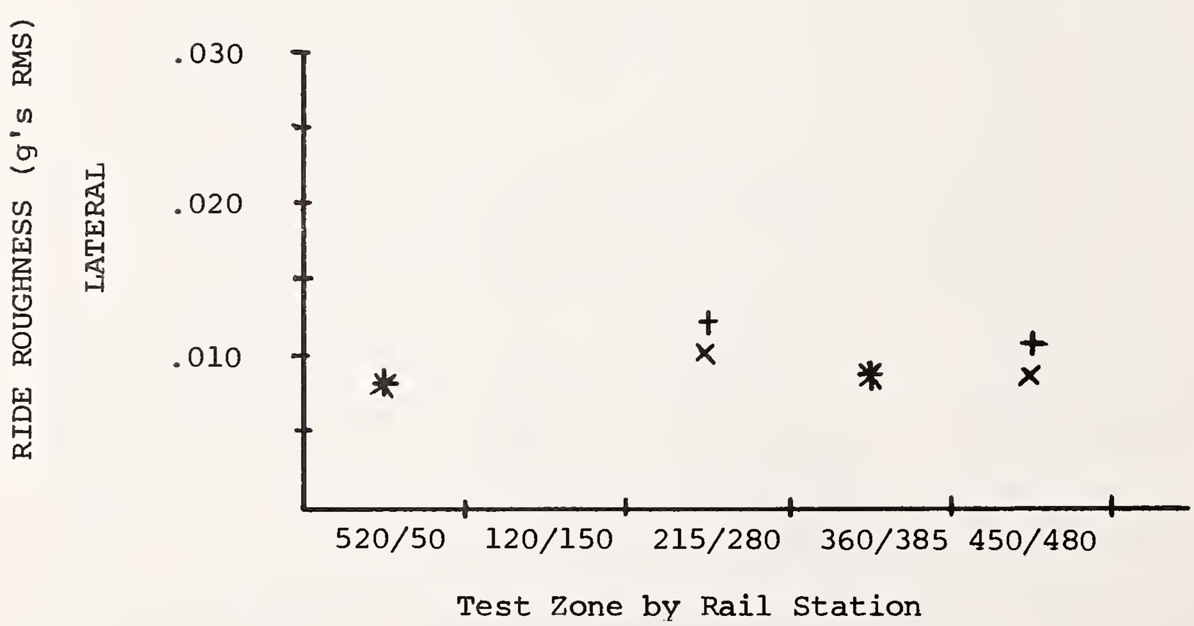
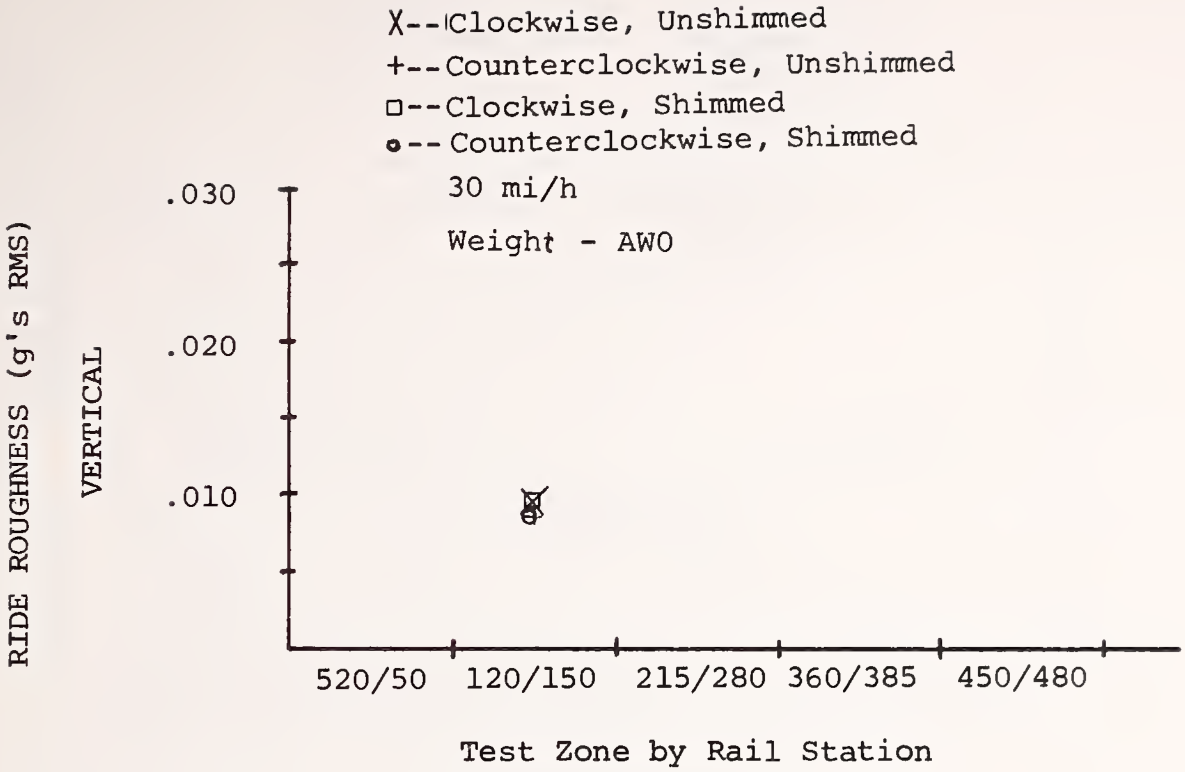


FIGURE 2-30. RIDE ROUGHNESS vs. TEST ZONES, A.



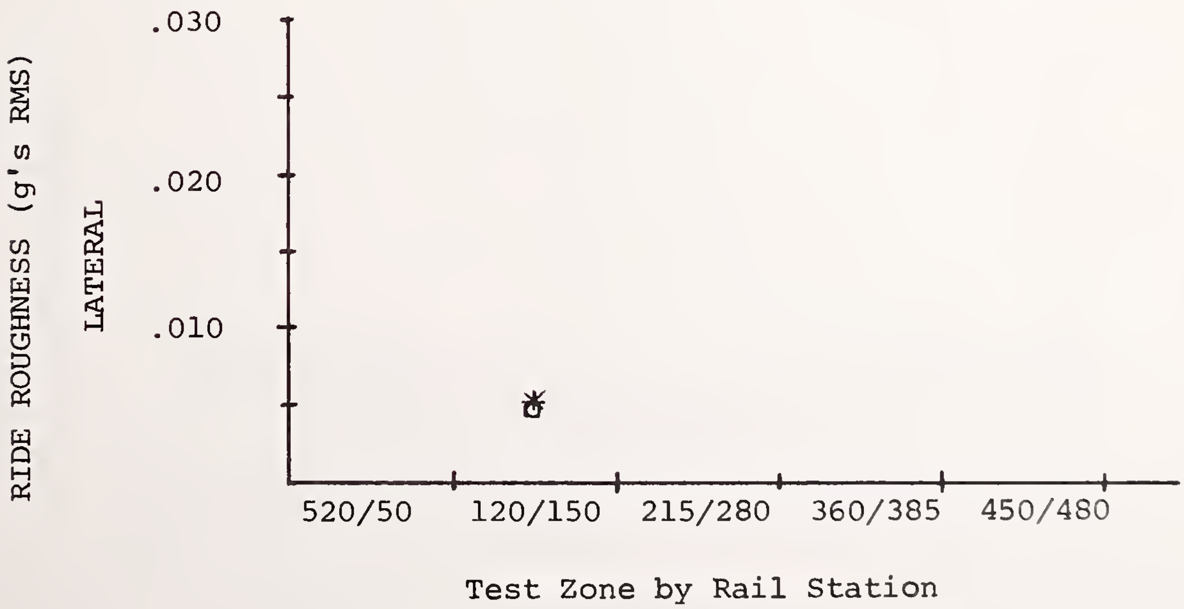
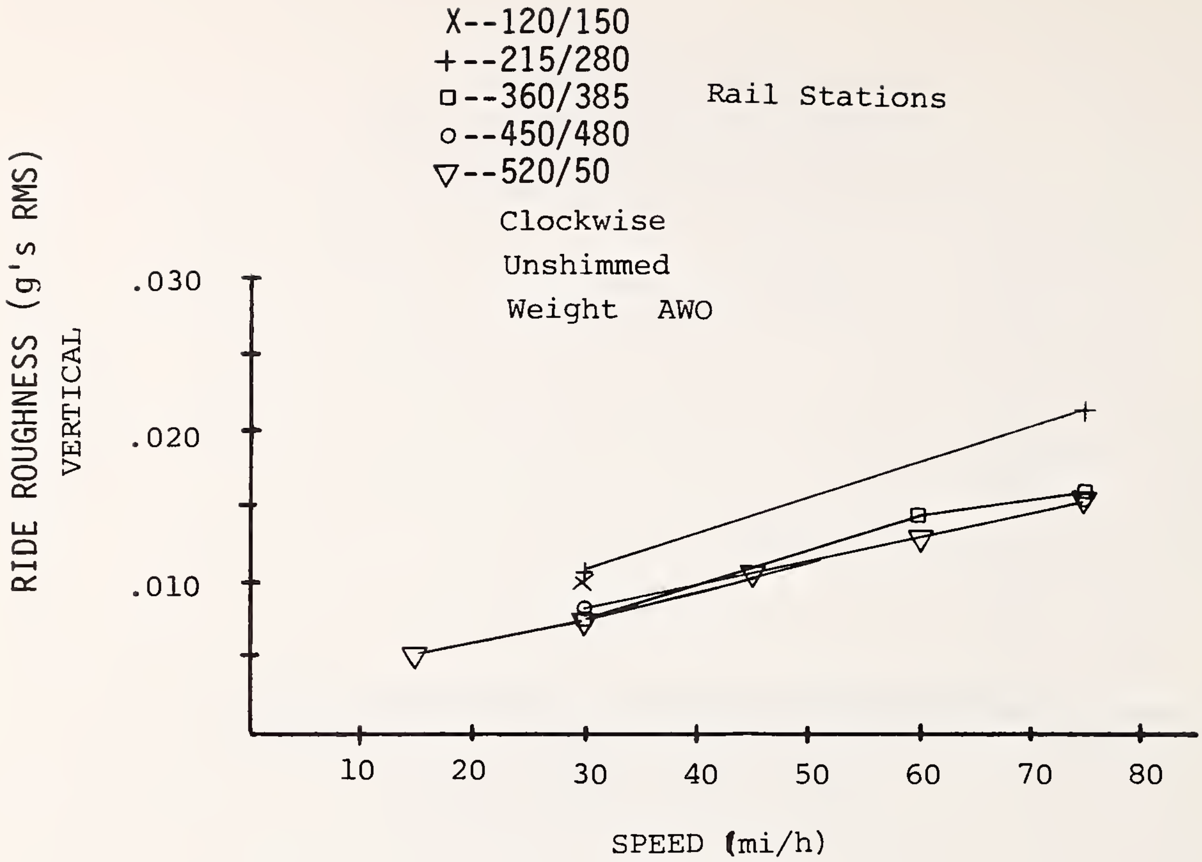


FIGURE 2-31. RIDE ROUGHNESS vs. TEST ZONES, B.



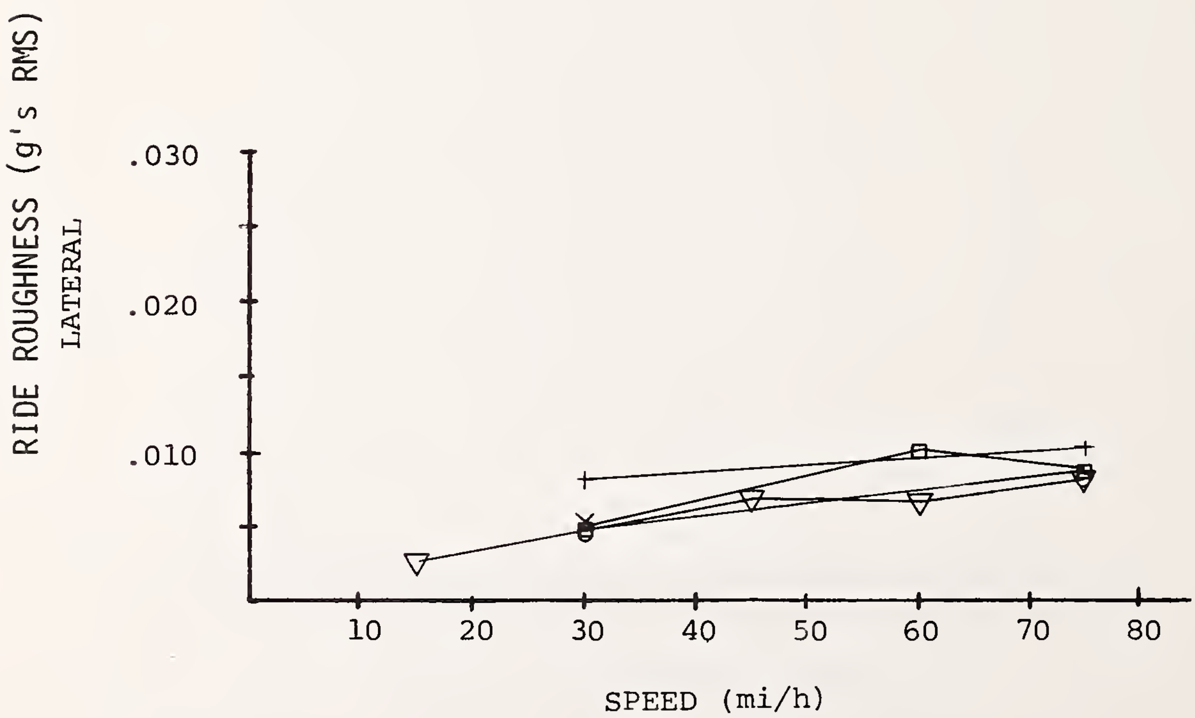
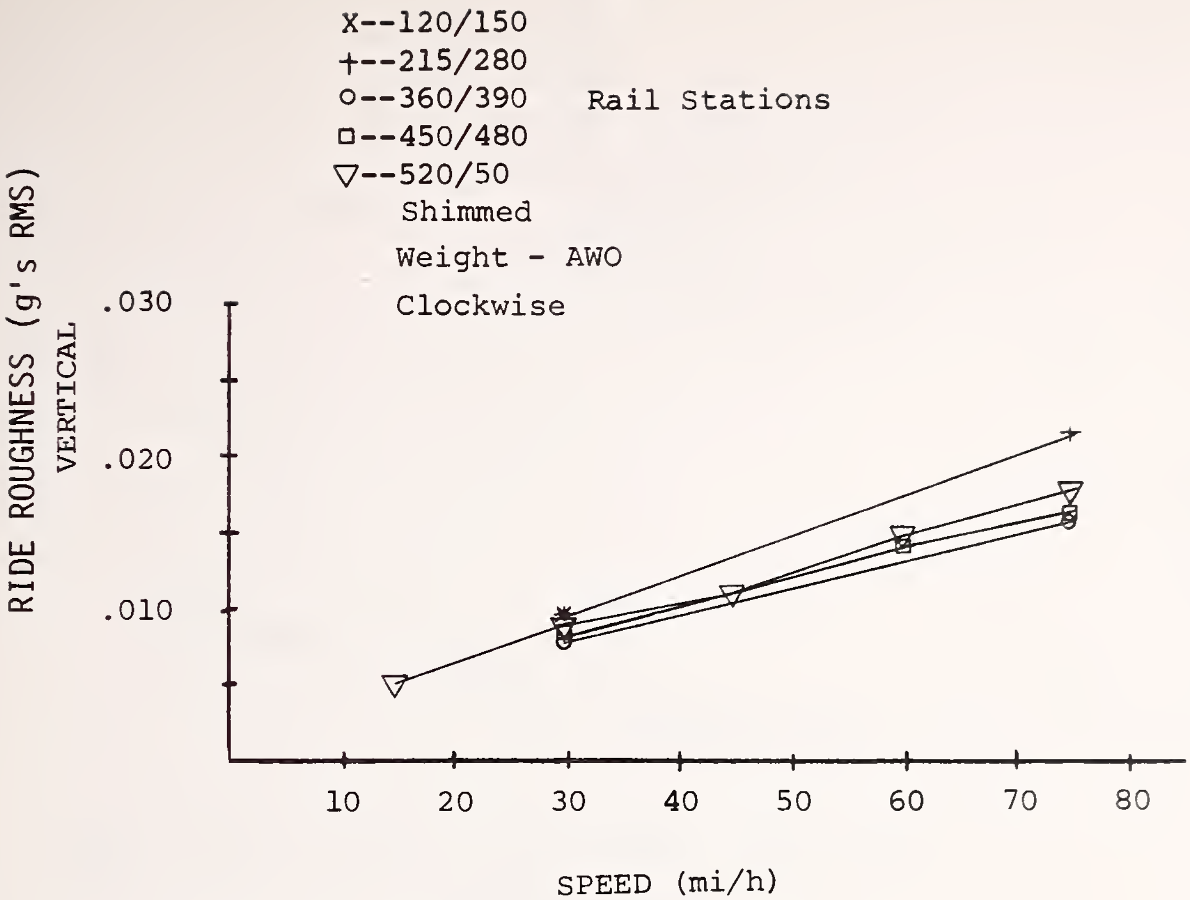


FIGURE 2-32. RIDE ROUGHNESS vs. SPEED, A.



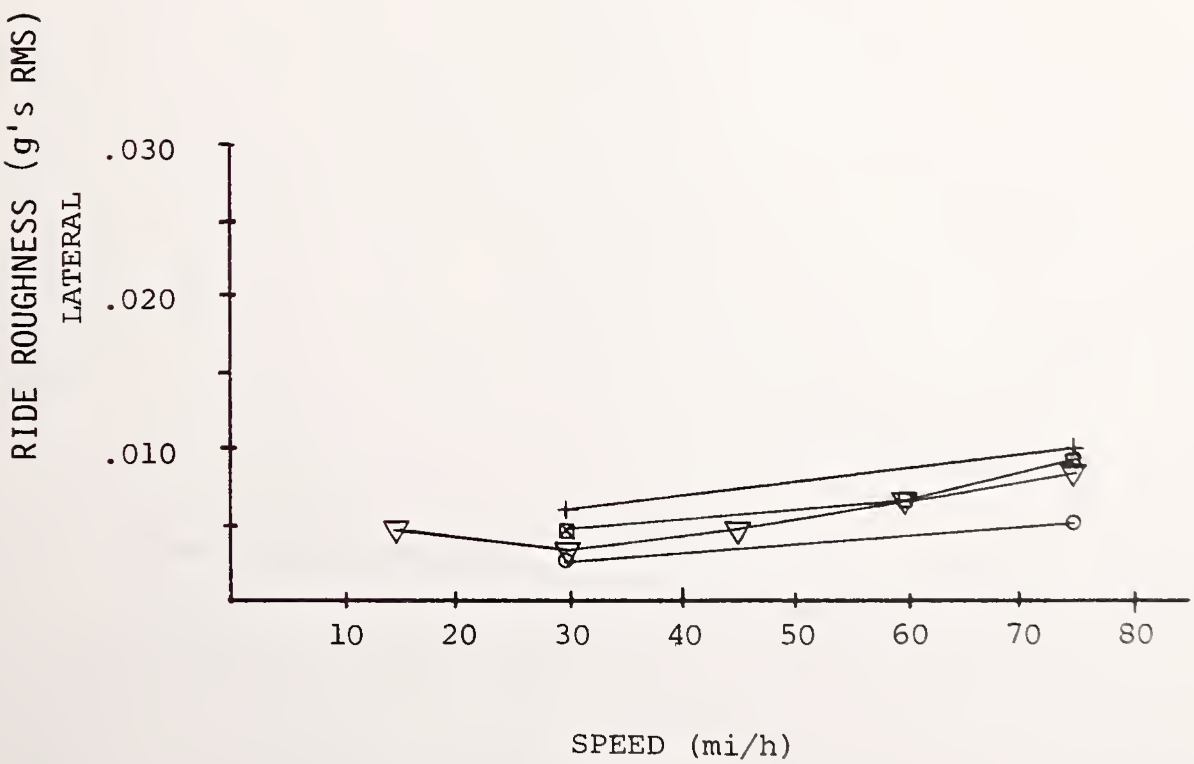


FIGURE 2-33 RIDE ROUGHNESS vs. SPEED, B.

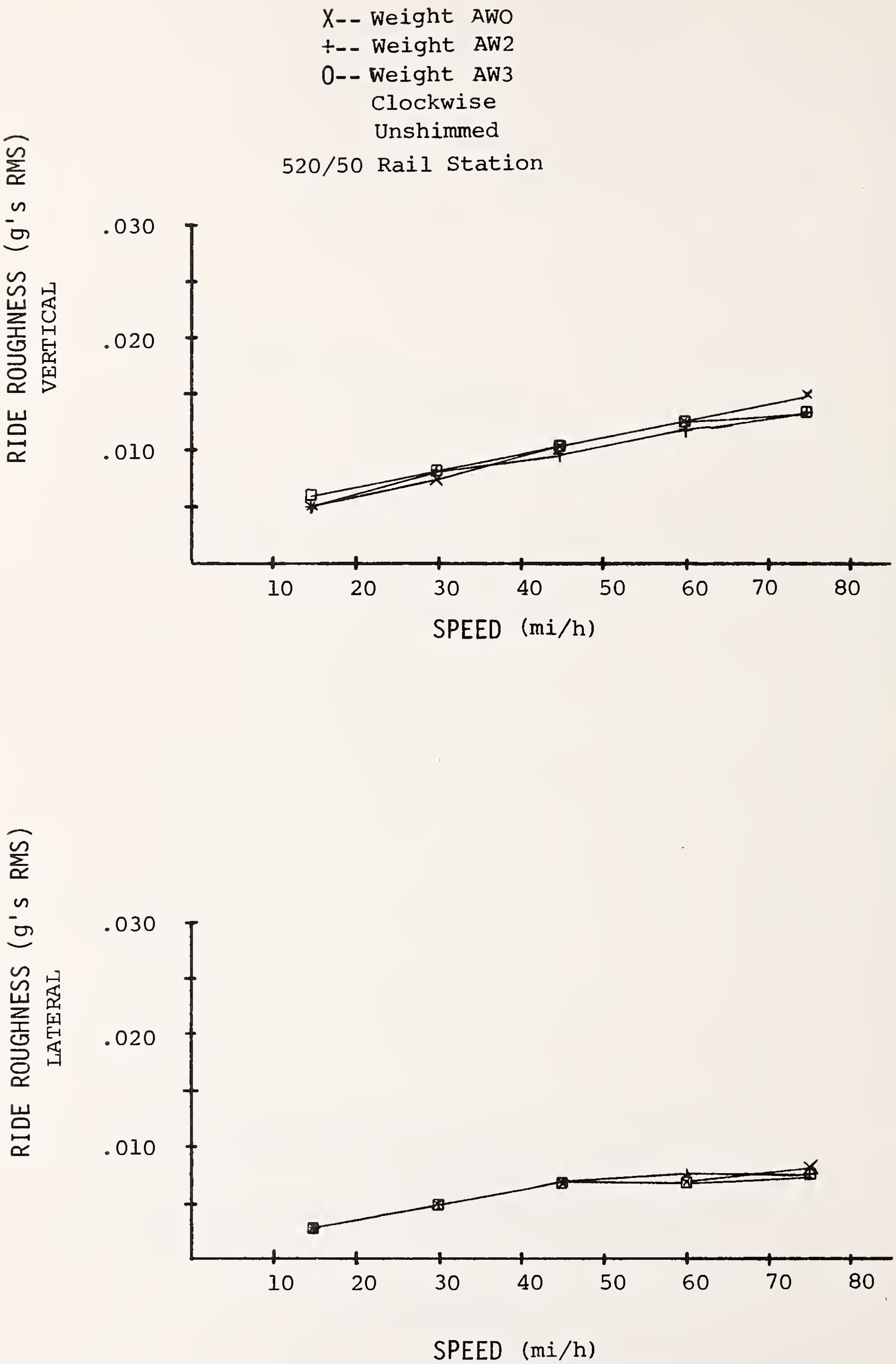


FIGURE 2-34. RIDE ROUGHNESS vs. SPEED, C.

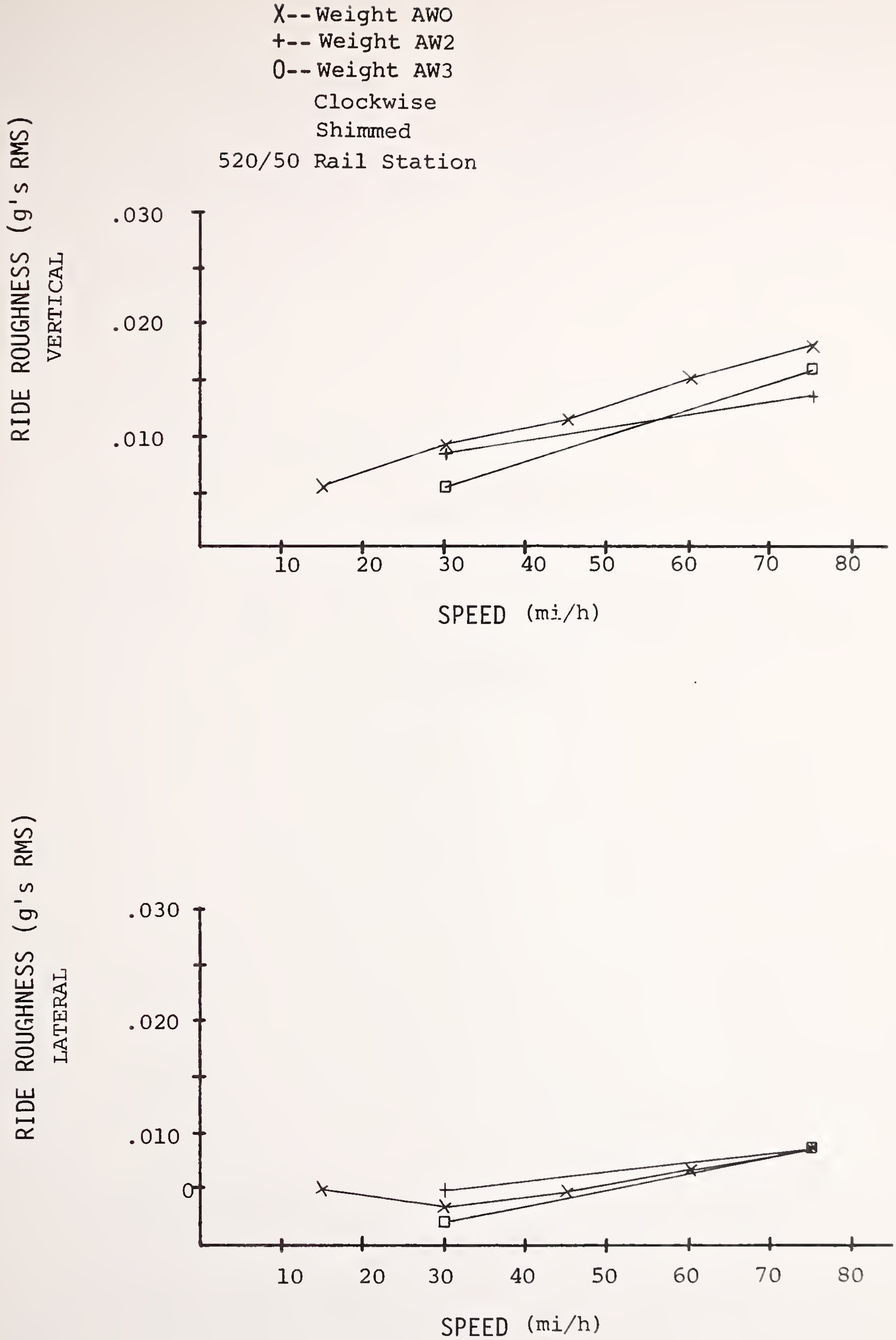


FIGURE 2-35. RIDE ROUGHNESS vs. SPEED, D.

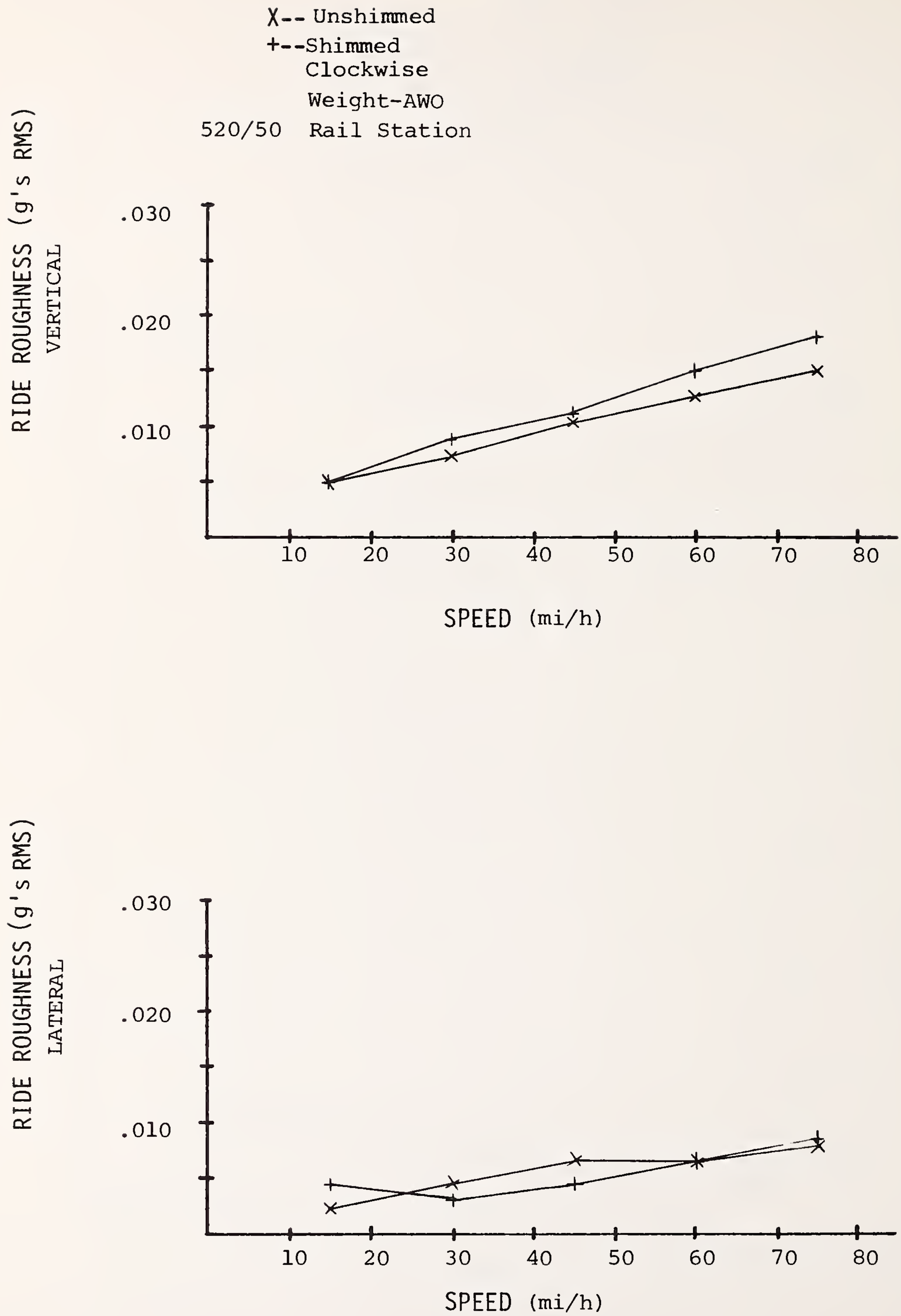


FIGURE 2-36. RIDE ROUGHNESS vs. SPEED, E.

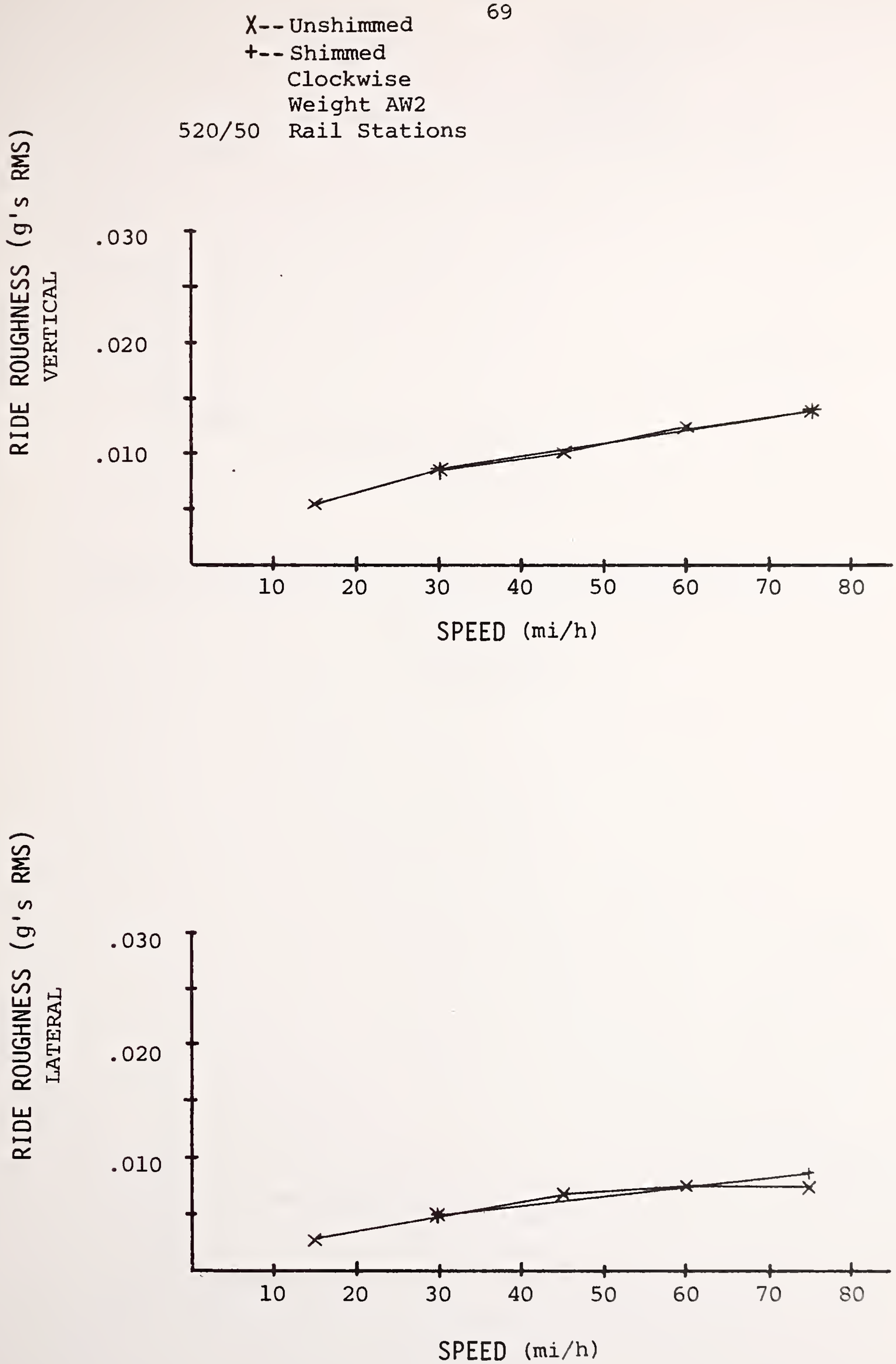
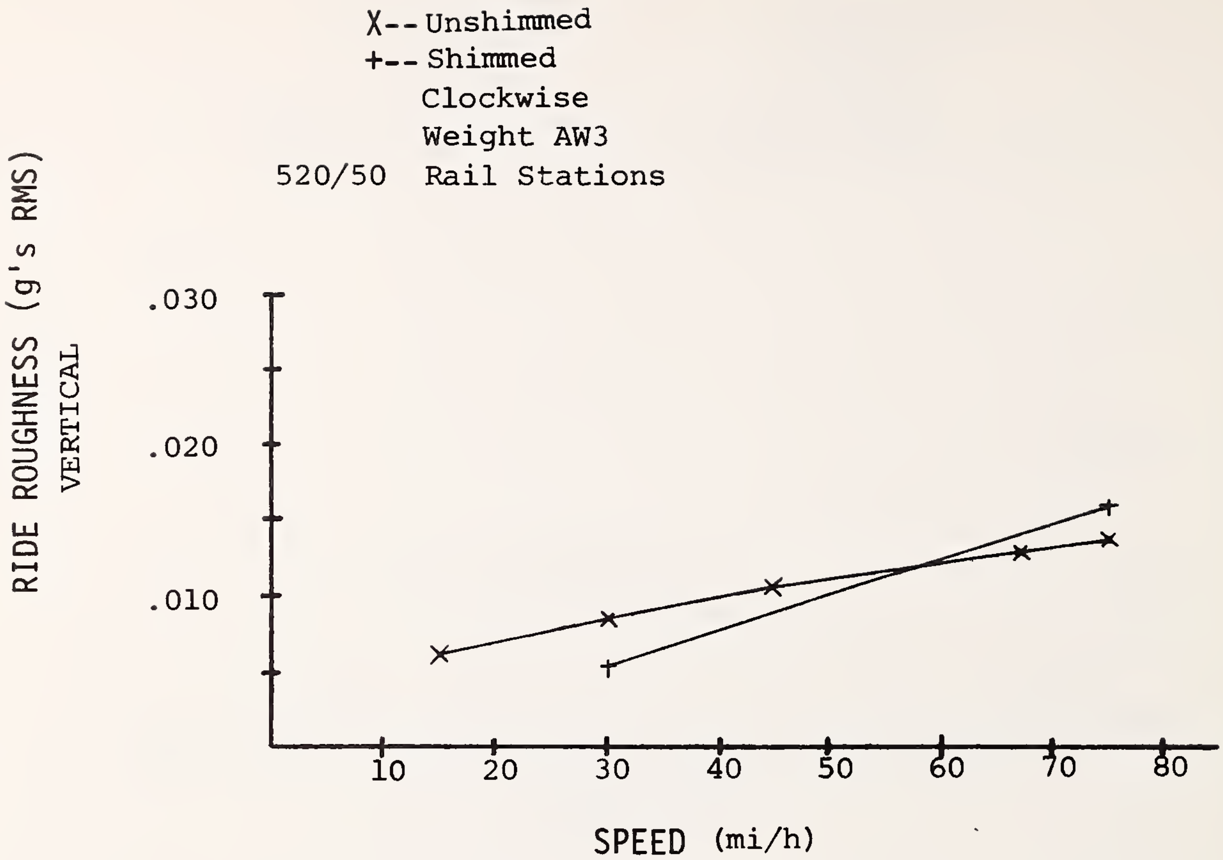


FIGURE 2-37. RIDE ROUGHNESS vs. SPEED, F.



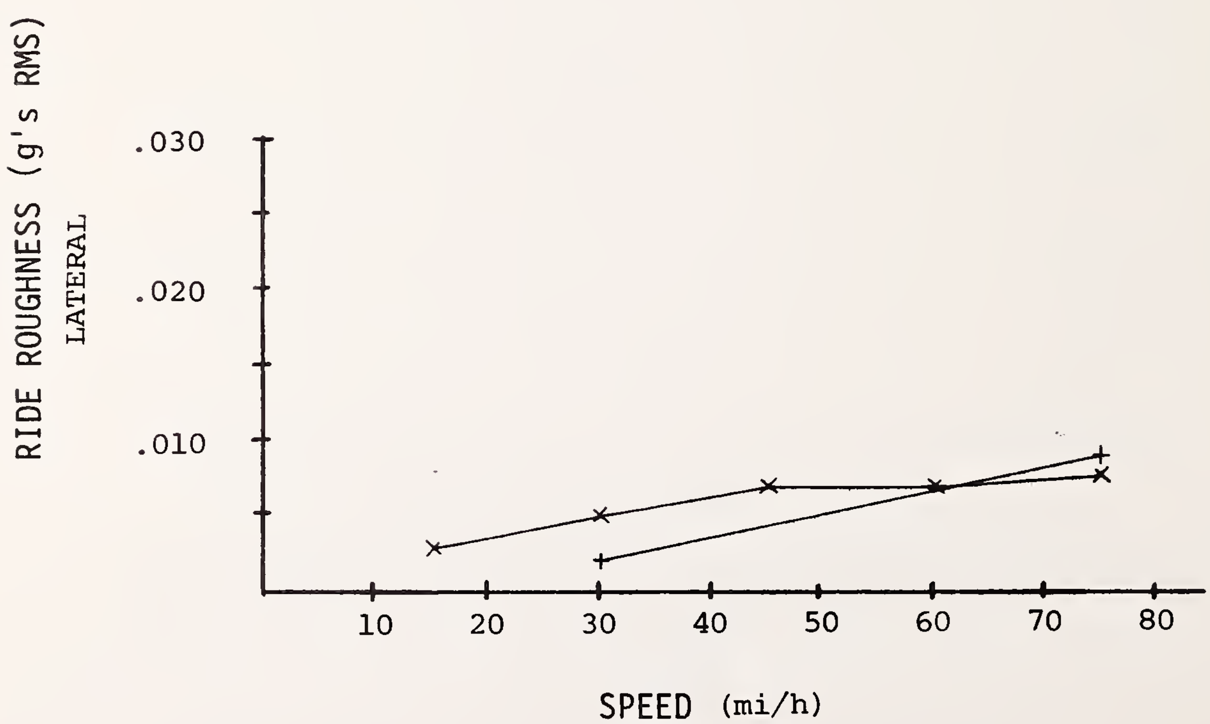
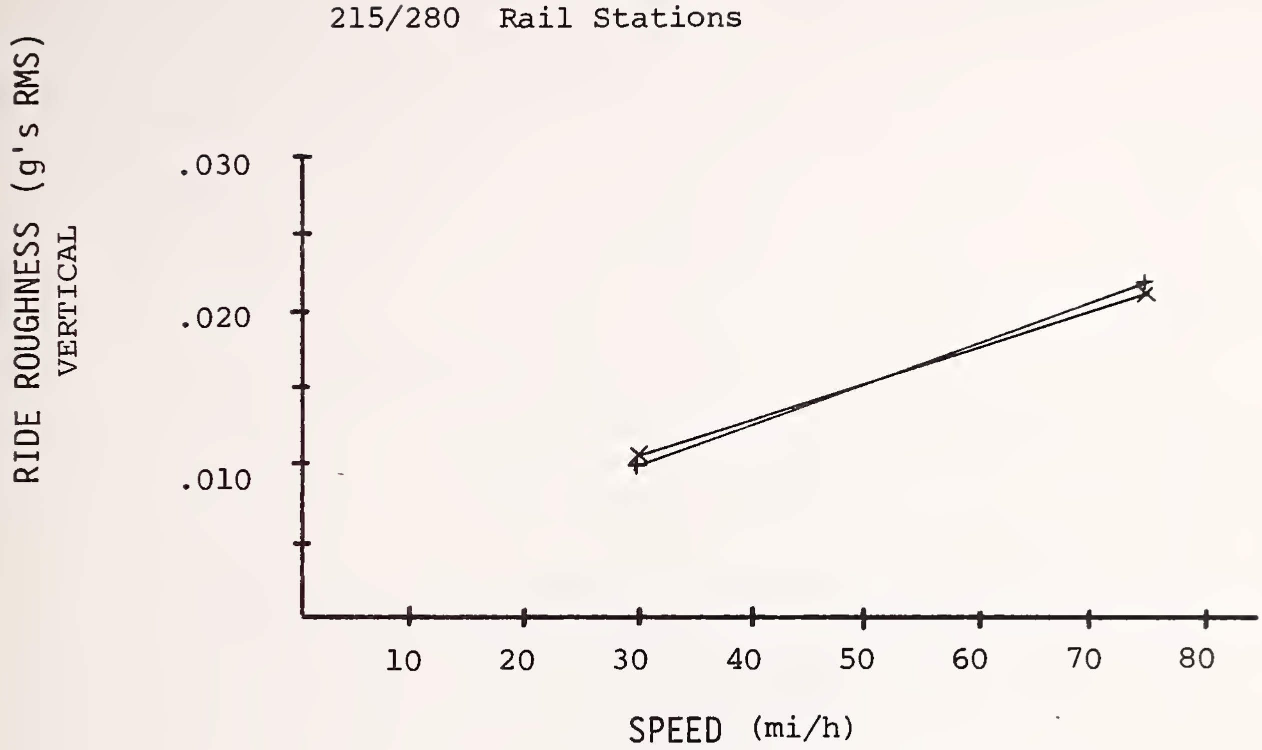


FIGURE 2-38. RIDE ROUGHNESS vs. SPEED, G.

X-- Unshimmed
+--Shimmed
Clockwise
Weight AWO
215/280 Rail Stations



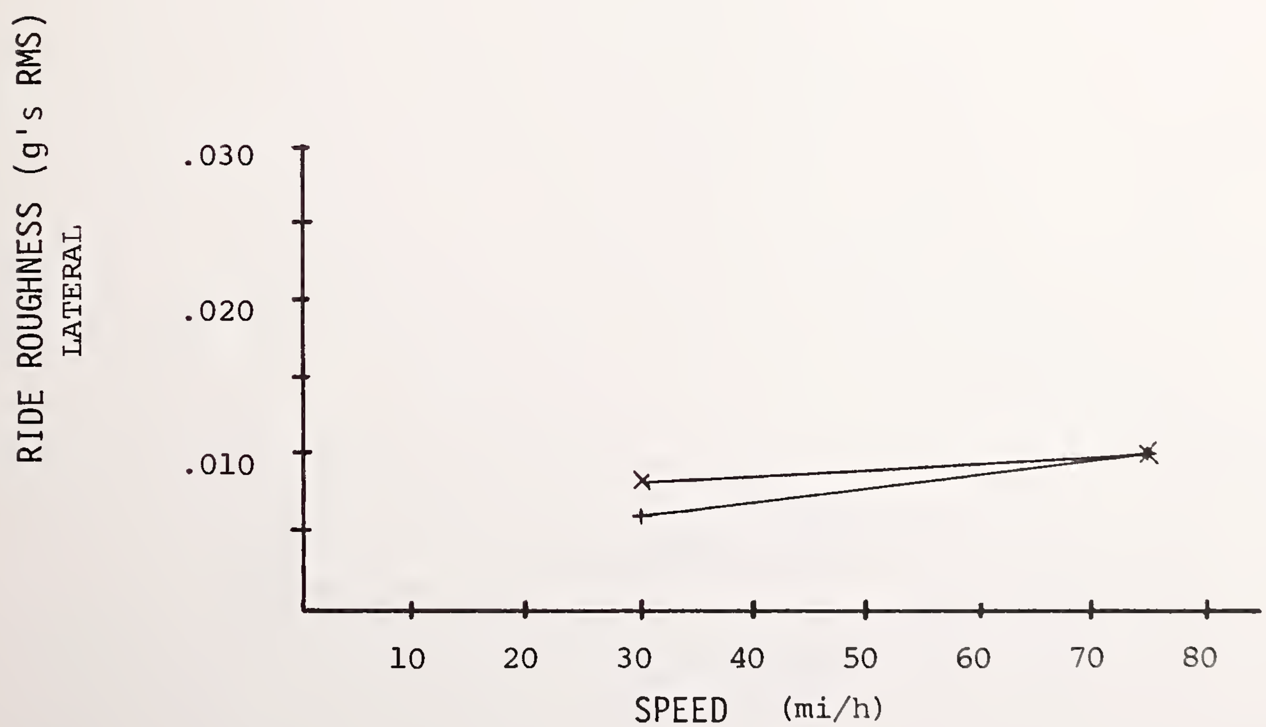


FIGURE 2-39. RIDE ROUGHNESS vs. SPEED, H.

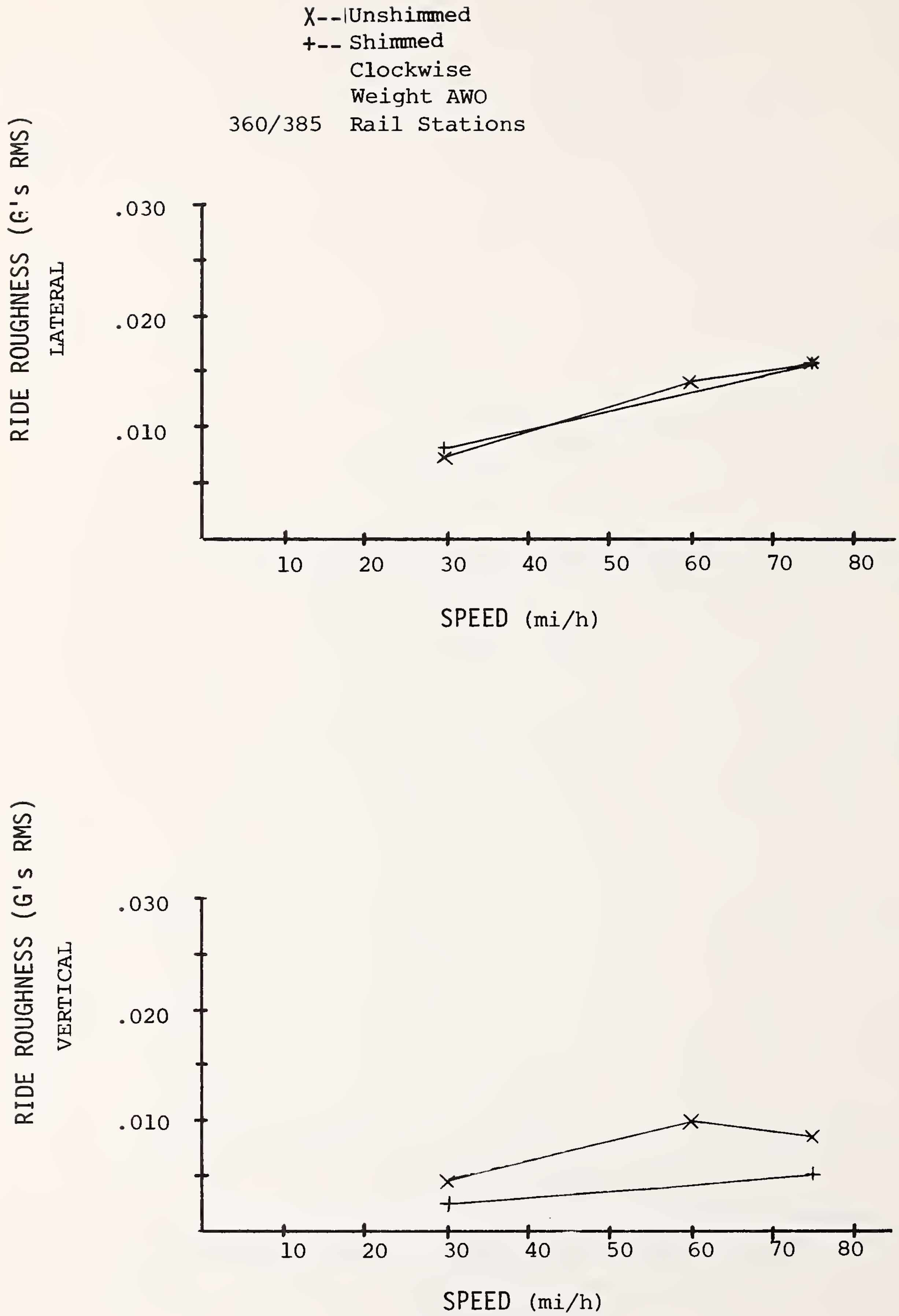
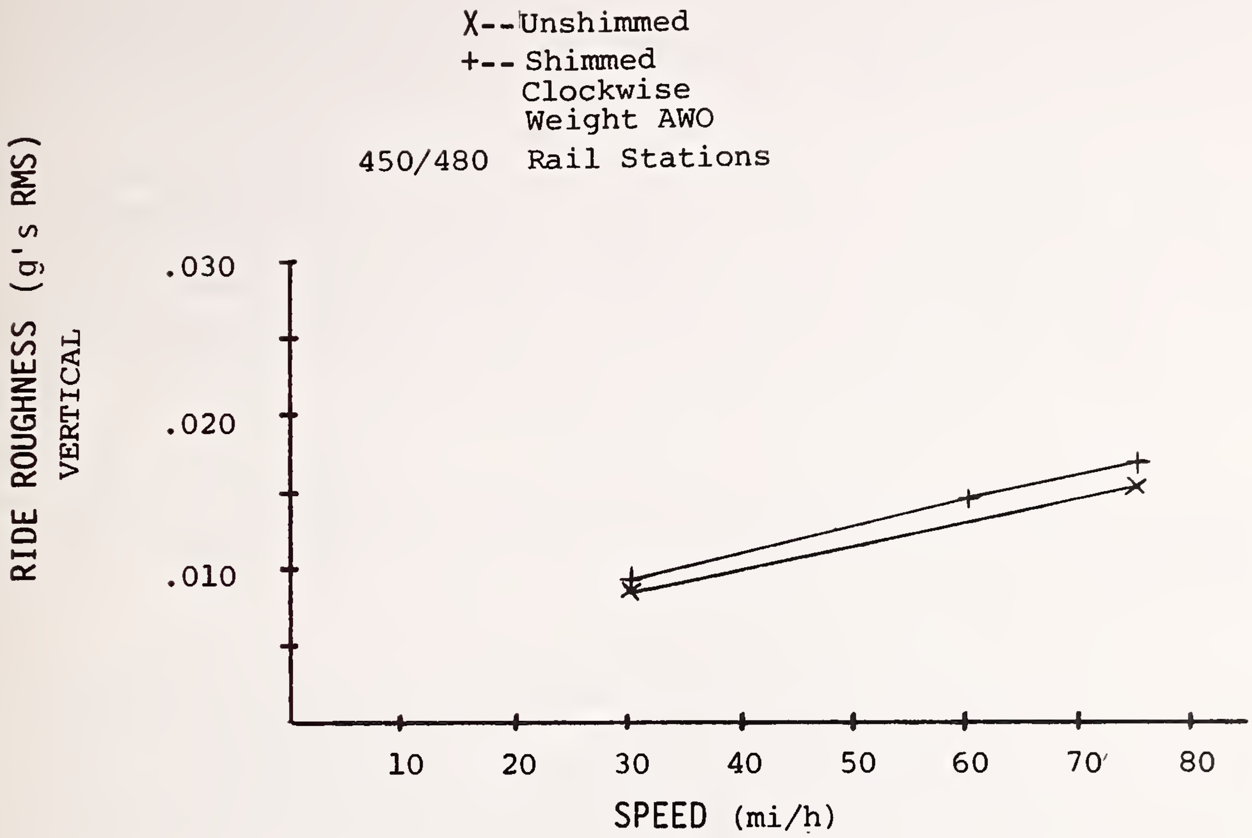


FIGURE 2-40. RIDE ROUGHNESS vs. SPEED, I.



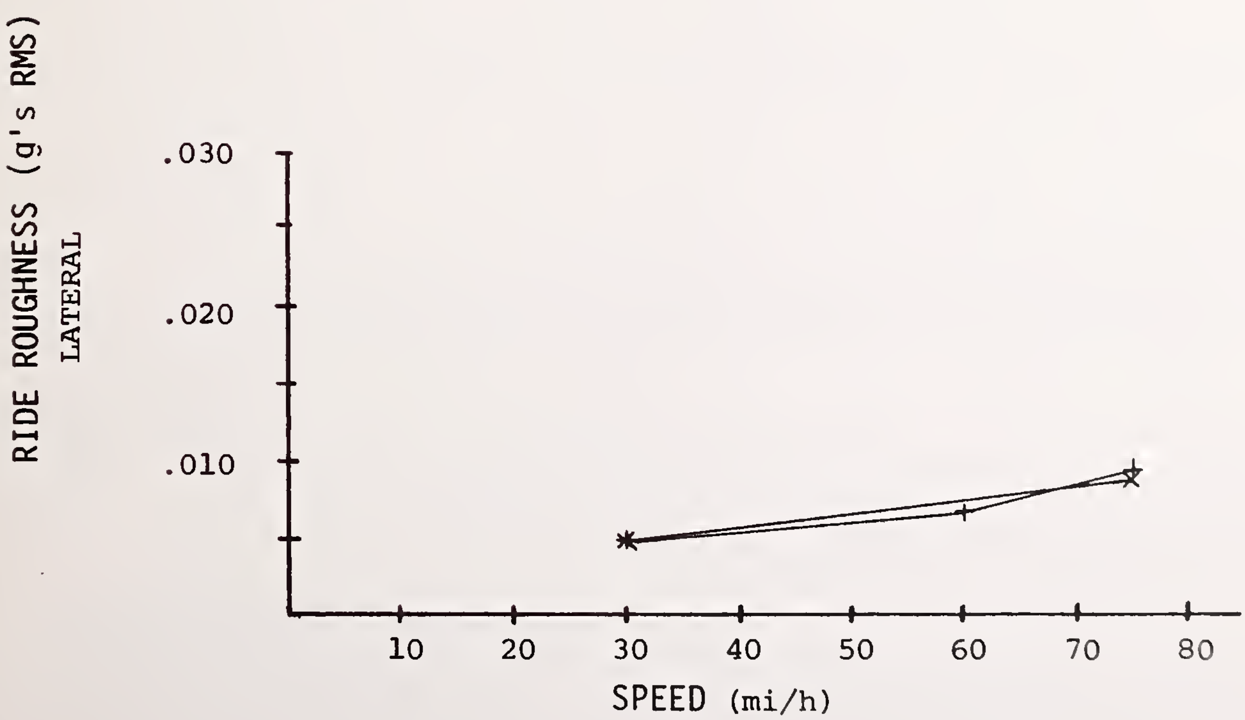


FIGURE 2-41. RIDE ROUGHNESS vs. SPEED, J.

accelerometers, and illustrate the effects of track section, speed, direction, vehicle weight, and shimmed/unshimmed lateral bumpers on ride quality.

A comparison of direction, figure 2-30, above, shows a slightly improved ride at 75 mi/h (120 km/h) in the clockwise direction. However, this is more likely attributable to small differences in start and stop times of RMS evaluations than any real difference in track characteristics. The same comparison at 30 mi/h (48 km/h) shows no difference in the track between track station markers 120 and 150, figure 2-31.

Different track sections did exhibit variations in ride quality, figures 2-32 and 2-33, with track between stations 215 to 280 giving the roughest ride and stations 450 to 480 the smoothest.

Car weight had slight, if any, effect upon ride roughness, figures 2-34 and 2-35, based upon comparisons made for data from rail stations 520 through 50. There is some indication that the lighter AW0 weight exhibited a rougher vertical ride over the entire frequency range with shims under the lateral bump stops, although no rational explanation can be made. In any case, differences appear to be slight.

Figures 2-36 through 2-38 illustrate the effect of lateral bumper shims for the track from rail stations 520 to 50; this track section includes a switch and a grade crossing, and could conceivably produce the largest lateral excitation. Differences between shimmed and unshimmed data are, however, minor, with the most significant change at AW3 vehicle weight. An improvement of approximately 0.002 g RMS is shown for shimmed bumpers at 30-45 mi/h (48-72 km/h). Figures 2-39 through 2-41 examine the effect of shims on other track sections, again showing no clearly defined trends.

The relatively large differences in lateral ride roughness evident in figure 2-40 for the track between rail stations 360 and 385 (tangent track), are considered to be due to low amplitude body motion, and as such, carry little weight in evaluating the effect of shims under the lateral bumpers.

<u>Acceleration/Deceleration Data</u>.

Figure 2-42 shows a typical time history for the forward vertical and lateral vehicle body accelerometers during an acceleration from rest to 75 mi/h (120 km/h) at P5 master controller position, followed by a deceleration from 75 mi/h (120 km/h) to a full stop at B5 master controller position; the run was made in a northbound direction. Vertical and lateral accelerometer outputs are shown scaled, unfiltered, processed through the vertical and horizontal ride roughness filter networks and RMS to DC converter respectively. Transient vertical

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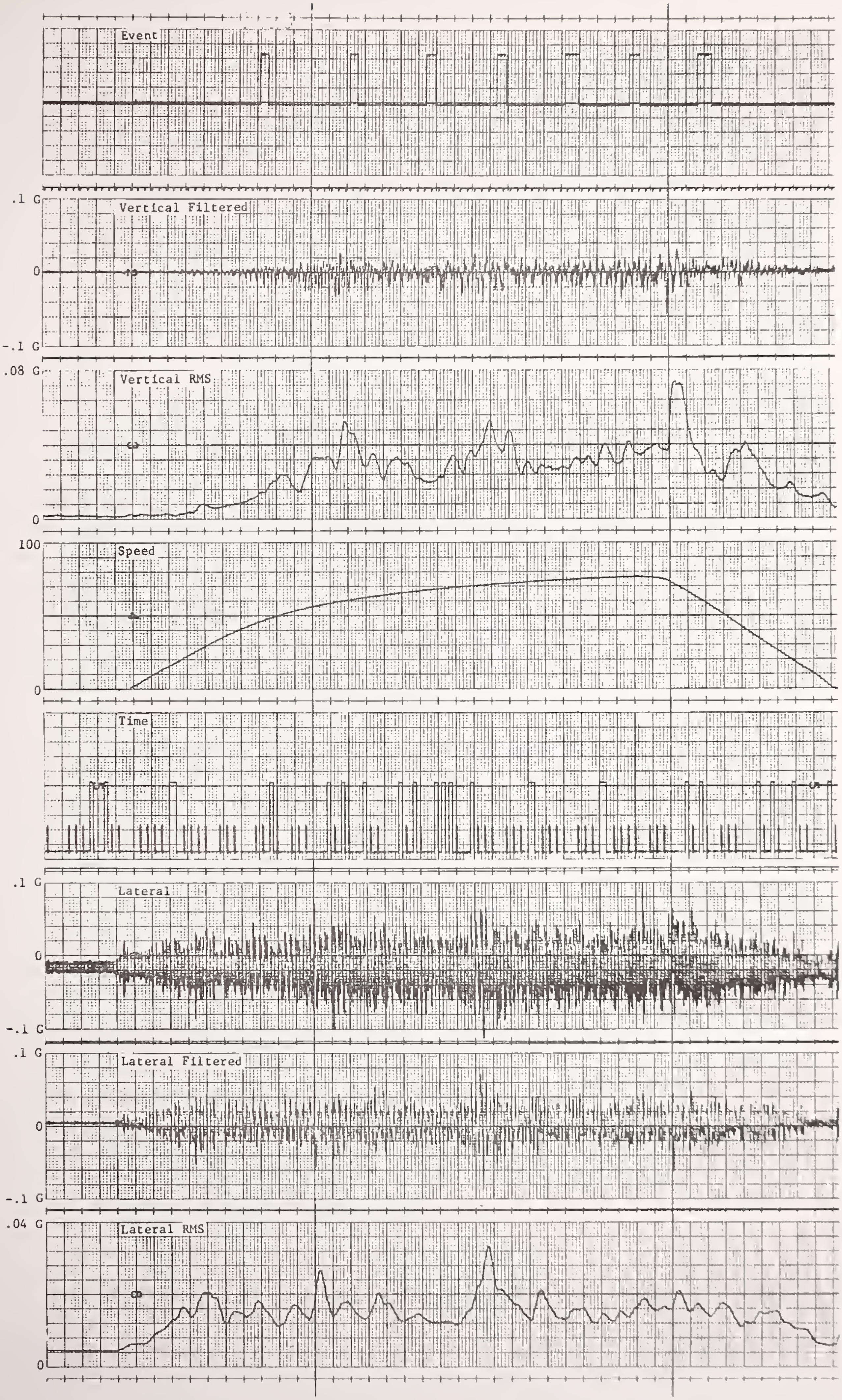

FIGURE 2-42. ACCELERATION/DECELERATION RMS HISTORY, RUN 440.

and lateral acceleration peaks are apparent at approximately 60 to 70 mi/h (96 to 112 km/h) under acceleration, with a further vertical peak at 70 mi/h (112 km/h) under braking. However, without a comprehensive track geometry characterization of the track over the section used for the run, it is not possible to determine if the transients are car or track induced.

2.5.10 Simulated Revenue Service (Test Set No. RS-5001-TT).

Objective: To determine the dynamic response of the test vehicle while operating on a sample service route at a defined level of schedule performance. To provide a measure of track conditions, riding comfort, and noise levels.

Test Description: A two-car train was operated at AW2 vehicle weight over two simulated revenue profiles, the WMATA profile and the ACT-1 profile, as used for the power consumption test objectives and described in table 2-4 and figure 2-20 (above) respectively. Continuous data were recorded from a series of car body and truck mounted accelerometers configured as for the ride roughness tests described in 2.5.9. Continuous accelerometer data were recorded throughout the simulated revenue service runs.

The following combinations of variables were tested:

Prime Variable	Test Conditions
Car Weight	AW2
Braking	Normal service B4, B5
Train Consist	2-car
Route	(1) WMATA revenue profile
	(2) ACT-1 synthetic transit route

Test Results: Analog and digital tape records of the simulated revenue service runs are available at the TTC and can be processed, following appropriate approvals, for any interested party. Because of the magnitude of the task, no attempt has been made to analyze and include the data in this report.

2.5.11 Radio Frequency Interference (Test Set No. PSI-6001-TT).

Objective: To determine the levels of broad band radiated electro-magnetic emission from the test vehicle to the wayside.

<u>Test Description</u>: Electrical field intensity measurements were made for a two-car train comprising WMATA rapid transit cars 1104 and 1105, at AW0 vehicle weight. Test runs were made by driving the train past a stationary field intensity meter at constant speeds up to 75 mi/h (120 km/h), and under acceleration and braking.

The field measurement station was located at station 340, 100 ft (30 m) from the track centerline on the inside of the TTT loop. The center of the antenna was located approximately 5-6 ft (1.5-1.8 m) above ground level and 10 ft (3 m) above the rail. A radio frequency interferance (RFI) meter with a discone antenna was used to scan field intensity in the range 30 to 200 MHz. Readings were not taken below 30 MHz because a low-noise power source was not available.

<u>Test Results</u>: Tabulated values of radiated electro-magnetic emissions over the frequency range 30 to 200 MHz for a range of car pass-by speeds are presented in table 2-7. Figure 2-43 illustrates the general trend of electro-magnetic emissions, which appear to be independent of speed or mode of operation.

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TABLE 2-7. RADIO FREQUENCY INTERFERENCE TEST RESULTS.

FREQ. (MHz)	POLARITY	CAR SPEED (mi/h)	CORRECTED READING (dB)
30	VERTICAL	40	49
30	VERTICAL	50	54
30	HORIZONTAL	15	39
55	VERTICAL	60-75	48
55	HORIZONTAL	60-75	38
55	VERTICAL	30-0	43
75	VERTICAL	50	40
75	HORIZONTAL	50	25
105	VERTICAL	30-10	28
105	VERTICAL	60	33
105	HORIZONTAL	60	28
150	VERTICAL	50	29
150	HORIZONTAL	60	29
175	VERTICAL	75	27
190	VERTICAL	75	36
200	VERTICAL	60	33
200	HORIZONTAL	60	34

- WMATA Rapid Transit Cars 1104 & 1105.
- 2-Car Train at AWO Vehicle Weight.
- Field Intensity Measurements at

  Rail Stn. 34

  100 Ft. from Track Centerline.

- Discone Antenna.
- RFI Meter (At .05 second peak).
- Antenna Corrections applied.

WMATA RAPID TRANSIT CAR
RADIO FREQUENCY INTERFERENCE
PSI-6001-TT
VEHICLE WEIGHT AWO
CONSIST 2-CAR

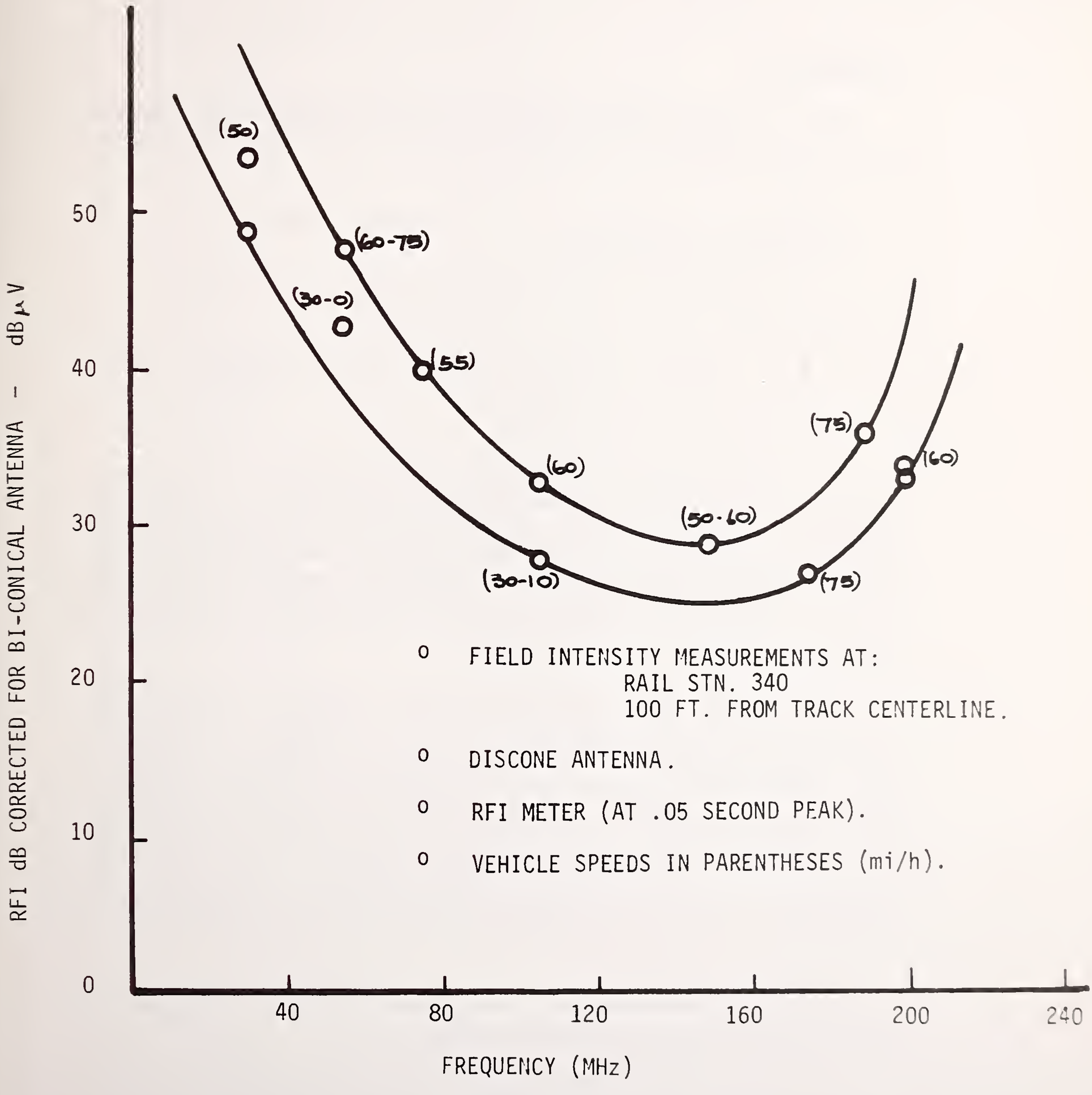

FIGURE 2-43. RADIO FREQUENCY INTERFERENCE vs. FREQUENCY.

3.0 DATA ACQUISITION AND INSTRUMENTATION DESCRIPTION

This section describes the data acquisition system used to gather GVTP data for the WMATA test program and the instrumentation sensors used for each test objective.

3.1 INTRODUCTION.

The instrumentation requirements of the WMATA rapid transit car GVTP program were divided into four basic groups according to the type of test to be performed:

- o Performance (Acceleration, Deceleration, Power Consumption, Adhesion).
- o Vehicle Dynamics (Ride Roughness, Simulated Revenue Service).
- o Noise (Community or Wayside Noise, Interior Noise).
- o Radio Frequency Interference.

Performance and vehicle dynamics test phases were carried out using a series of car-mounted sensors detailed in tables 3-1 through 3-8. The data was acquired by an onboard analog data acquisition system. The system included signal conditioners, filters, and two 14-track tape recorders. Details concerning the data acquisition systems can be obtained from the TTC if they are required for understanding of the data accuracy and characteristics.

Noise tests were conducted using a hand-held sound level recorder and two microphones to record the data; the recorder was a battery operated, portable unit. In addition, two portable sound level meters with microphones were used for surveying the test areas, and as a backup to the tape-recorded data. The taped data were recorded at 7-1/2"/s tape speed using a dB scale with A-weighting. The hand-held meters were set to a dB scale with A-weighting and slow response. Radio frequency interference tests were conducted using a discone antenna and a RFI meter.

3.2 ONBOARD ANALOG DATA ACQUISITION SYSTEM.

An analog data system capable of recording data from 24 discrete sensors was assembled from inhouse components for the performance and ride quality test phases. The system was structured to acquire data in seven categories: reference data (speed,

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TABLE 3-1. INSTRUMENTATION SENSOR LISTING - PERFORMANCE, DRIFT, POWER CONSUMPTION, A.

TEST SET NO.s P-2001-TT, P-3001,2,3,4-TT, P-4001-TT, PC-5011-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE A					
1	SYNC	-----	0000	------------------	--------	--------
2	Distance	D/A	1421	Pulse from Speed Sensor	1 pulse/ 10 Ft.	20 Hz
3	Vehicle Acceleration	AP/A	2001	Servo Accelerometer	± 5 mphps	10 Hz
4	Line Voltage	LVD/A	1101	Resistive Divider	0-1000 VDC	200 Hz
5	Line Current 'B' Car	LCD/A	1105	Transductor	0-2000 A	200 Hz
6	Motor Current 'B' Car, Front	MACD/AF	1106	Transductor	0-1000 A	200 Hz
7	Motor Current 'B' Car, Rear	MACD/AR	1007	Transductor	0-1000 A	200 Hz
8	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
9	Brake Cyl. Press. 'B' Car, Front	BCP/AF	1203	Strain Gage Transducer	0-1000 psi	50 Hz
10	Brake Cyl. Press. 'B' Car, Rear	BCP/AR	1204	Strain Gage Transducer	0-1000 psi	50 Hz
11	Brake Temperature, Rotating	BT/A	3202	Chromel Constantan T/C	0-1000 °F	1 Hz
12	Brake Temperature, Stationary	BT/B	3201	Chromel Constantan T/C	0-1000 °F	1 Hz
13	Controller Setting	CS/A	1301	Composite Signal	--------	10 Hz
14	Trig 'B' Time Code	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-2. INSTRUMENTATION SENSOR LISTING - PERFORMANCE, DRIFT, POWER CONSUMPTION, B.

TEST SET NO.s P-2001-TT, P-3001,2,3,4-TT, P-4001-TT, PC-5011-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE B					
1	SYNC	-----	0000	------------------	--------	--------
2	Line Current 'A' Car	LCD/A	1102	Transductor	0-2000 A	200 Hz
3	Line Current 'B' Car	LCD/A	1105	Transductor	0-2000 A	200 Hz
4	Line Voltage	LVD/A	1101	Resistive Divider	0-1000 V	200 Hz
5	Motor Current 'A' Car, Front	MACD/AF	1103	Transductor	0-1000 A	200 Hz
6	Motor Current 'A' Car, Rear	MACD/AR	1104	Transductor	0-1000 A	200 Hz
7	Brake Cyl. Press. 'A' Car, Front	BCP/AF	1201	Strain Gage Transducer	0-1000 psi	50 Hz
8	Brake Cyl. Press. 'A' Car, Rear	BCP/AR	1202	Strain Gage Transducer	0-1000 psi	50 Hz
9	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
10	Distance	D/A	1421	Pulse from Speed Sensor	1 pulse/ 10 Ft.	20 Hz
11	Event	ET/A1	1422	------------------	--------	--------
12						
13						
14	Irig 'B' Time	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-3. INSTRUMENTATION SENSOR LISTING - 2-CAR DRIFT.

TEST SET NO.s P-4001-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	<u>TAPE A</u>					
1	SYNC	-----	0000	------------------	--------	--------
2	Distance	D/A	1421	Pulse Derived from Speed	1 pulse/ 10 Ft.	20 Hz
3	Vehicle Acceleration	AP/A	2001	Servo Accelerometer	± 5 mphps	10 Hz
4	Motor Current 'B' Car, Front	MACD/AF	1106	Transductor	0-1000 A	200 Hz
5	Motor Current 'B' Car, Rear	MACD/AR	1107	Transductor	0-1000 A	200 Hz
6	Brake Cyl. Press. 'B' Car, Front	BCP/AF	1203	Strain Gage Transducer	0-1000 psi	50 Hz
7	Brake Cyl. Press. 'B' Car, Rear	BCP/AR	1204	Strain Gage Transducer	0-1000 psi	50 Hz
8	Motor Current 'A' Car, Front	MACD/AF	1103	Transductor	0-1000 A	200 Hz
9	Motor Current 'A' Car, Rear	MACD/AR	1104	Transductor	0-1000 A	200 Hz
10	Brake Cyl. Press. 'A' Car, Rear	BCP/AR	1202	Strain Gage Transducer	0-1000 psi	50 Hz
11	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
12	Event	ET/A1	1422	------------------	--------	--------
13	Controller Setting	CS/A	1301	Composite Signal	--------	10 Hz
14	Irig 'B' Time Code	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-4. INSTRUMENTATION SENSOR LISTING - SPIN/SLIDE, ACCELERATION/DECELERATION, ADHESION, A.

TEST SET NO.s P-2011-TT, P-3011-TT, A-3021-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE A					
1	SYNC	-----	0000	------------------	--------	--------
2	Line Current 'A' Car	LCD/A	1102	Transductor	0-2000 A	200 Hz
3	Line Current 'B' Car	LCD/A	1105	Transductor	0-2000 A	200 Hz
4	Line Voltage	LVD/A	1101	Resistive Divider	0-1000 VDC	200 Hz
5	Distance	D/A	1421	Pulse from Speed Sensor	1 pulse/ 10 Ft.	20 Hz
6	Motor Current 'A' Car, Front	MACD/AF	1103	Transductor	0-1000 A	200 Hz
7	Motor Current 'A' Car, Rear	MACD/AR	1104	Transductor	0-1000 A	200 Hz
8	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
9	Brake Cyl. Press. 'A' Car, Front	BCF/AF	1201	Strain Gage Transducer	0-1000 psi	50 Hz
10	Brake Cyl. Press. 'A' Car, Rear	BCF/AF	1202	Strain Gage Transducer	0-1000 psi	50 Hz
11	Brake Temperature, Stationary	BT/B	3201	Chromel Constantan T/C	0-1000 °F	1 Hz
12	Vehicle Acceleration	AP/A	2001	Servo Accelerometer	± 5 mphps	10 Hz
13	Event	ET/A1	1422	------------------	--------	--------
14	Irig 'B' Time Code	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-5. INSTRUMENTATION SENSOR LISTING - SPIN/SLIDE, ACCELERATION/DECELERATION, ADHESION, B.

TEST SET NO.s P-2011-TT, P-3011-TT, A-3021-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE B					
1	SYNC	-----	0000	------------------	--------	--------
2	Vehicle Acceleration	AP/A	2001	Servo Accelerometer	± 5 mphps	10 Hz
3	Line Current 'B' Car	LCD/A	1105	Transductor	0-2000 A	200 Hz
4	Motor Current 'B' Car, Front	MACD/AF	1106	Transductor	0-1000 A	200 Hz
5	Motor Current 'B' Car, Rear	MACD/AR	1107	Transductor	0-1000 A	200 Hz
6	Brake Cyl. Press. 'B' Car, Front	BCP/AF	1203	Strain Gage Transducer	0-1000 psi	50 Hz
7	Brake Cyl. Press. 'B' Car, Rear	BCP/AR	1204	Strain Gage Transducer	0-1000 psi	50 Hz
8	Controller Setting	CS/A	1301	Composite Signal	--------	10 Hz
9	Brake Temperature, Rotating	BT/A	3202	Chromel Constantan T/C	0-1000 °F	1 Hz
10	Axle Speed #2	VS/A2	1402	Proximity Sensor	0-100 mph	10 Hz
11	Axle Speed #1	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
12	Axle Speed #3	VS/A3	1403	Proximity Sensor	0-100 mph	10 Hz
13	Axle Speed #4	VS/A4	1404	Proximity Sensor	0-100 mph	10 Hz
14	Trig 'B' Time	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-6. INSTRUMENTATION SENSOR LISTING - DUTY CYCLES, FRICTION BRAKE.

TEST SET NO.s P-5001-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE A					
1	SYNC	-----	0000	------------------	--------	--------
2	Line Voltage	LVD/A	1101	Resistive Divider	0-1000 VDC	200 Hz
3	Line Current 'A' Car	LCD/A	1102	Transductor	0-2000 A	200 Hz
4	Line Current 'B' Car	LCD/A	1105	Transductor	0-2000 A	200 Hz
5	Vehicle Acceleration	AP/A	2001	Servo Accelerometer	± 5 mphps	10 Hz
6	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
7	Distance	D/A	1421	Pulse from Speed Sensor	1 pulse/ 10 Ft.	20 Hz
8	Motor Current 'B' Car, Rear	MACD/AR	1107	Transductor	0-1000 A	200 Hz
9	Brake Temperature, Rotating	BT/A	3202	Chromel Constantan T/C	0-1000 °F	1 Hz
10	Brake Temperature, Stationary	BT/B	3201	Chromel Constantan T/C	0-1000 °F	1 Hz
11	Brake Cyl. Press. 'B' Car, Rear	BCP/AR	1204	Strain Gage Transducer	0-1000 psi	50 Hz
12	Controller Setting	CS/A	1301	Composite Signal	--------	10 Hz
13	Event	ET/A1	1422	------------------	--------	--------
14	Irig 'B' Time	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-7. INSTRUMENTATION SENSOR LISTING - RIDE QUALITY.

TEST SET NO.s R-0010-TT, R-2001-TT, R-3001-TT, R-1101-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE A					
1	SYNC	-----	0000	------------------	--------	--------
2	Accel. Fwd. Car Floor Centerline Vert.	AC/A1	2101	Servo Accelerometer	± 2g	100 Hz
3	Accel. Fwd. Car Floor Centerline Lat.	AC/A2	2102	Servo Accelerometer	± .5g	100 Hz
4	Accel. Fwd. Car Floor Centerline Long.	AC/A3	2103	Servo Accelerometer	± .5g	100 Hz
5	Accel. Mid Car Floor Centerline Vert.	AC/A4	2104	Servo Accelerometer	± 1g	100 Hz
6	Accel. Mid Car Floor Centerline Lat.	AC/A5	2105	Servo Accelerometer	± .5g	100 Hz
7	Accel. Mid Car Floor Left Vert.	AC/A6	2106	Servo Accelerometer	± 1g	100 Hz
8	Lead Axle Right Journal Vertical	AJ/A1	2201	Piezo Accelerometer	± 30g	100 Hz
9	Lead Axle Right Journal Lateral	AJ/A2	2202	Piezo Accelerometer	± 10g	100 Hz
10	Lead Axle Left Journal Vertical	AJ/A3	2203	Piezo Accelerometer	± 30g	100 Hz
11	Event	ET/A1	1422	------------------	--------	--------
12	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
13						
14	Trig 'B' Time	T/A	1411	Time Code Generator	--------	1000 Hz

TABLE 3-8. INSTRUMENTATION SENSOR LISTING - SIMULATED REVENUE SERVICE.

TEST SET NO.s RS-5001-TT

CHANNEL NO.	PARAMETER	STANDARD OUTPUT NAME	MEASUREMENT NUMBER	SENSOR TYPE	MEASUREMENT RANGE	FREQUENCY
	TAPE A					
1	SYNC	-----	0000	------------------	--------	--------
2	Lead Axle Right Journal Vertical	AJ/A1	2201	Piezo Accelerometer	± 30g	100 Hz
3	Lead Axle Right Journal Lateral	AJ/A2	2202	Piezo Accelerometer	± 10g	100 Hz
4	Lead Axle Left Journal Vertical	AJ/A3	2203	Piezo Accelerometer	± 30g	100 Hz
5	Accel. Fwd. Car Floor Centerline Vert.	AC/A1	2101	Servo Accelerometer	± 2g	100 Hz
6	Accel. Fwd. Car Floor Centerline Lat.	AC/A2	2102	Servo Accelerometer	± 5g	100 Hz
7	Accel. Fwd. Car Floor Centerline Long.	AC/A3	2103	Servo Accelerometer	± 5g	100 Hz
8	Accel. Mid Car Floor Centerline Vert.	AC/A4	2104	Servo Accelerometer	± 2g	100 Hz
9	Accel. Mid Car Floor Centerline Lat.	AC/A5	2105	Servo Accelerometer	± 5g	100 Hz
10	Pitch	AC/A2	2302	Angular Accelerometer	± 2 rad/sec	5 Hz
11	Roll	AC/A1	2301	Angular Accelerometer	± 1 rad/sec	5 Hz
12	Yaw	AC/A1	2303	Angular Accelerometer	± 2 rad/sec	5 Hz
13	Speed	VS/A1	1401	Proximity Sensor	0-100 mph	10 Hz
14	Trig 'B' Time	T/A	1411	Time Code Generator	--------	1000 Hz

time, distance), current, voltage, acceleration, pressure, temperature, and material strain. Test data were conditioned by signal conditioners and filtered by a bank of filters. The data were recorded on one of two FM tape recorders, and critical data channels were displayed on an 8-channel chart recorder for test monitoring purposes.

3.3 POWER CONSUMPTION WATT-HOUR METER.

Power consumption data were acquired during the test program by means of a unique watt-hour meter chassis, designed and constructed at the TTC. The chassis used an analog multiplier to produce an output from scaled voltage inputs of line voltage and current sensors proportional to instantaneous power consumption. The output of the multiplier was integrated with respect to time by an integrating voltage-frequency converter. This device produced a pulse frequency proportional to applied voltage. Each pulse represented an increment of energy, the sum of which represented total energy. The output from the frequency converter was then conditioned in a divider/counter driver circuit, using three scalable counters and a mono-stable multi-vibrator. They acted as a pulse stretcher to increase the pulse width to the 20 millisecond minimum required to drive a mechanical counter. Output from the divider/counter driver circuitry was then used to drive a six-digit mechanical counter (one for each car of a married pair), which totalized power consumption over the duration of a test run.

A functional description of the system, together with a circuit diagram of the watt/hour meter chassis, can be found under references 2 and 3 respectively.

4.0 DATA MANAGEMENT AND DOCUMENTATION

Over 700 test runs were made to achieve the objectives of the General Vehicle Test Plan for the WMATA rapid transit cars. An important factor, therefore, in the presentation of the WMATA data, is the adequate documentation of test run log and data logging procedures to allow a potential user easy access to the raw data in his field of interest.

This section describes the methods used to document test runs, weather conditions, vehicle weight, and other significant test factors, and to document sensor sensitivities, channel assignments, and analog tape data content.

4.1 DAILY TEST RUN LOGS.

Test run log sheets were completed for each daily test objective throughout the test program. Sample log sheets are illustrated in figure 4-1. These sheets identified the test program, the GVTP test set numbers, date of test, vehicle consist and weight, time, voltage, weather conditions, and any other notes pertinent to the test. Each test run was identified by a consecutive run number. Test direction of travel, master controller position, speed, track station number (where relevant) and time of day were logged for each run. The test run log sheets are kept on file at the TTC.

A run log summary, tables 4-1 through 4-8, has been prepared from the daily log sheets. These allow the data user to correlate the GVTP test set of interest with the run numbers identifying tests to meet the objectives of that test set, and with the reference numbers of raw data magnetic tape.

4.2 DATA ACQUISITION LOG SHEET AND TAPE LOG.

The prime purpose of the data acquisition log and the tape log sheet was to maintain an accurate record of the content of the analog raw data tapes. Examples of the two log sheets are illustrated in figure 4-2. The data acquisition log sheet was a precise account of the instrumentation sensors in use for any given test series and their channel assignment on the data tape. Detailed for each channel are the measurement name, type of transducer, transducer sensitivity, system sensitivity, filtering applied, tape calibration, equivalent engineering values, etc. The log was updated during the test program for each instrumentation change and a notation made to indicate the test runs for which that log sheet was valid. A copy of the data acquisition log sheet was made for each day's testing and was attached to the tape log for that day.

Text continues on page 101

TEST RUN LOG CONTINUATION SHEET

SHT. ___ OF ___

TEST PROGRAM ________________ DATE ________________

RUN NO	DIR	CONTROLLER		SPEED	TRACK STN. NO.		TIME	REMARKS
		PWR	BRK	MPH	START	STOP		

TEST RUN LOG SHEET SHT. 1 OF ___

TEST PROGRAM ________________ DATE ________________

TEST SET NO's ________________ TEST OBJECTIVES:

VEHICLE CONSIST (CLOCKWISE ORDER) ____________

VEHICLE WEIGHT ____________

LINE VOLTAGE ____________

TEST CREW NUMBER ____________

TEST CREW WT. (EST.) ____________

WEATHER ________ TEMP ______ F. WIND DIR ______ VELOCITY ______

RUN NO	DIR	CONTROLLER		SPEED MPH	TRACK STN. NO.		TIME	REMARKS
		PWR	BRK		START	STOP		

FIGURE 4-1. TEST RUN LOG SHEETS.

TABLE 4-1. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM
TEST & RUN NUMBER CROSS-REFERENCE, A.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
R-1101-TT	Ride Roughness - Worst Speeds	AWO	2-Car	15,30,45 60,75	-	STN 120-150	1-6	2001	5/2,5/3
						215-280	7-16	2002	
						360-385	17-22	2002	
						450-480	23-28	2002	
						520-50	29-38	2002	
						330-360	55-74	2002	
"	"	AWO	2-Car	"	-	Plus 1/8" WMATA Shims Under Lateral Bumpers			7/1/77
						STN 120-150	570-575	2007	
						220-280	576-585	2007	
						360-390	586-591	2007	
						450-480	592-597	2007	
						520-50	598-607	2007	
						330-360	618-637	2007	
"	"	AWO	2-Car	"	-	STN 120-150	101-106	2003	5/13/77
						210-280	107-116	2003	
						360-390	117-122	2003	
						450-480	123-128	2003	
						520-60	129-138	2003	
						340-360	141-160	2003	

TABLE 4-2. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM
TEST & RUN NUMBER CROSS-REFERENCE, B.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
R-1101-TT	Ride Roughness - Worst Speeds	AW2	2-Car	15,30,45, 60,75	-	Plus 1/8" WMATA Shims Under Lateral Bumpers			
						STN 120-150	394-399	2006	6/24/77
						210-280	400-409	2006	
						360-390	410-415	2006	
						450-480	416-421	2006	
						520-60	422-431	2006	
						340-360	442-461	2006	
"	"	AW3	2-car	"	-	STN 120-150	161-166	2003	5/17/77
						215-280	167-176	2003	
						360-385	177-182	2003	
						450-480	183-188	2003	
						520-50	189-198	2003	
						330-360	209-228	2003	
"	"	"	"	"	-	Plus 1/8" WMATA Shims Under Lateral Bumpers			6/29/77
						STN 120-150	465-470	2007	
						210-280	471-480	2007	
						360-390	481-486	2007	
						450-480	487-492	2007	
						520-60	493-502	2007	
						340-360	513-522	2007	
							525-534	2007	

TABLE 4-3. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM TEST & RUN NUMBER CROSS-REFERENCE, C.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
R-2001-TT	Ride Roughness - Acceleration	AW0	2-Car	30,50,60, 75	P1-P5	Concrete Tie & Welded Rail, L.Tan. Combined with Brake Runs.	39-48	2002	5/3/77
"	"	AW0	2-Car	"	"	" Plus 1/8" Shims Under Lateral Bumpers	608-617	2007	7/1/77
"	"	AW2	2-Car	75	P5	Concrete Tie, etc.	139,140	2003	5/13/77
"	"	AW2	2-Car	30,50,60, 75	P1-P5	Plus 1/8" Shims	432-441	2006	6/24/77
"	"	AW3	2-Car	"	"		199-208	2003	5/17/77
"	"	AW3	2-Car	"	"	Plus 1/8" Shims	503-512	2007	6/29/77
R-3001-TT	Ride Roughness - Deceleration	AW0	2-Car	30,50,60 75	B1-B5	Combined with Accel. Runs	39-48	2002	5/3/77
"	"	"	"	"	"	Plus 1/8" Shims	608-617	2007	7/1/77
"	"	AW2	"	75	B5		139,140	2003	5/13/77
"	"	"	"	30,50,60 75	B1-B5	Plus 1/8" Shims	432-441	2006	6/24/77
"	"	AW3	2-Car	"	"		199-208	2003	5/17/77
"	"	AW3	2-Car	"	"	Plus 1/8" Shims	503-512	2007	6/29/77

TABLE 4-4. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM
TEST & RUN NUMBER CROSS-REFERENCE, D.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
R-0010-TT	Ride Roughness Component Induced Vibration	AW0	2-Car	0	-	Data for: M-G Set, Hydraulic Pump, Air Comp, A/C Comp. Environmental Blower	49-54	2002	5/3/77
RS-5001-TT	Simulated Rev.	AW2	2-Car	Vary	P5,B4	WMATA Profile	307	2005	6/3/77
	Service	"	"	"	P5,B5	ACT-1 Profile	308	2005	6/3/77
P-2001-TT	Acceleration	AW0	2-Car	30,50,60, 75	P1-P5	Combined with Deceleration	645-654		7/5/77
"	"	AW2	2-Car	"	P1	"	310-312	2005	6/9/77
					P2		318,319	2005	
					P3		327,328	2005	
					P4		337,338	2005	
					P5		346,347	2005	
"	"	"	"	"	P1-P5	Line Voltage 695 vdc	368-371	2006	6/13/77
							374,375	2006	
"	"	"	"	"	P1-P5	Line Voltage 710 vdc	381-384	2006	6/13/77
							387,388	2006	
"	"	"	"	"	P1-P5	Combined with Deceleration	229-238	2004	5/27/77

TABLE 4-5. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM
TEST & RUN NUMBER CROSS-REFERENCE, E.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
P-3001-TT	Deceleration Blended Brake	AW0	2-Car	30,50,60, 75	B1-B5	Combined with Acceleration	645-650 655-658		7/5/77
"	"	AW2	2-Car	20,30,40, 50	B1		310-316	2005	6/9/77
				60,75	B2		317-323	2005	
				"	B3		324-330	2005	
				"	B4		331-336, 367	2005	
				"	B5		339-345	2005	
"	"	AW2	2-Car	30,50,60, 75	B1-B5	695 vdc	368-373	2006	61/3/77
"	"	"	"	"	"	710 vdc	381-386	2006	6/13/77
"	"	AW3	2-Car	"	"		229-234 239-242	2004 2004	5/27/77 5/27/77
P-3002-TT	Deceleration	AW0	2-Car	30,50,60, 75	B1-B5		665-674		7/5/77
"	Service Friction	AW2	"	"	"		356-361	2005	6/9/77
"	"	AW3	"	"	"		255-264	2004	5/27/77
P-3003-TT	Deceleration	AW0	2-Car	30,50,60, 75	B2-B5		675-682		7/5/77
"	Dynamic	AW2	"	"	"		362-366	2005	6/9/77
"	"	"	"	"	"	695 vdc	376-380	2006	6/13/77
"	"	"	"	"	"	710 vdc	389-393	2006	6/13/77
"	"	AW3	"	"	"		265-272	2004	5/27/77

TABLE 4-6. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM
TEST & RUN NUMBER CROSS-REFERENCE, F.

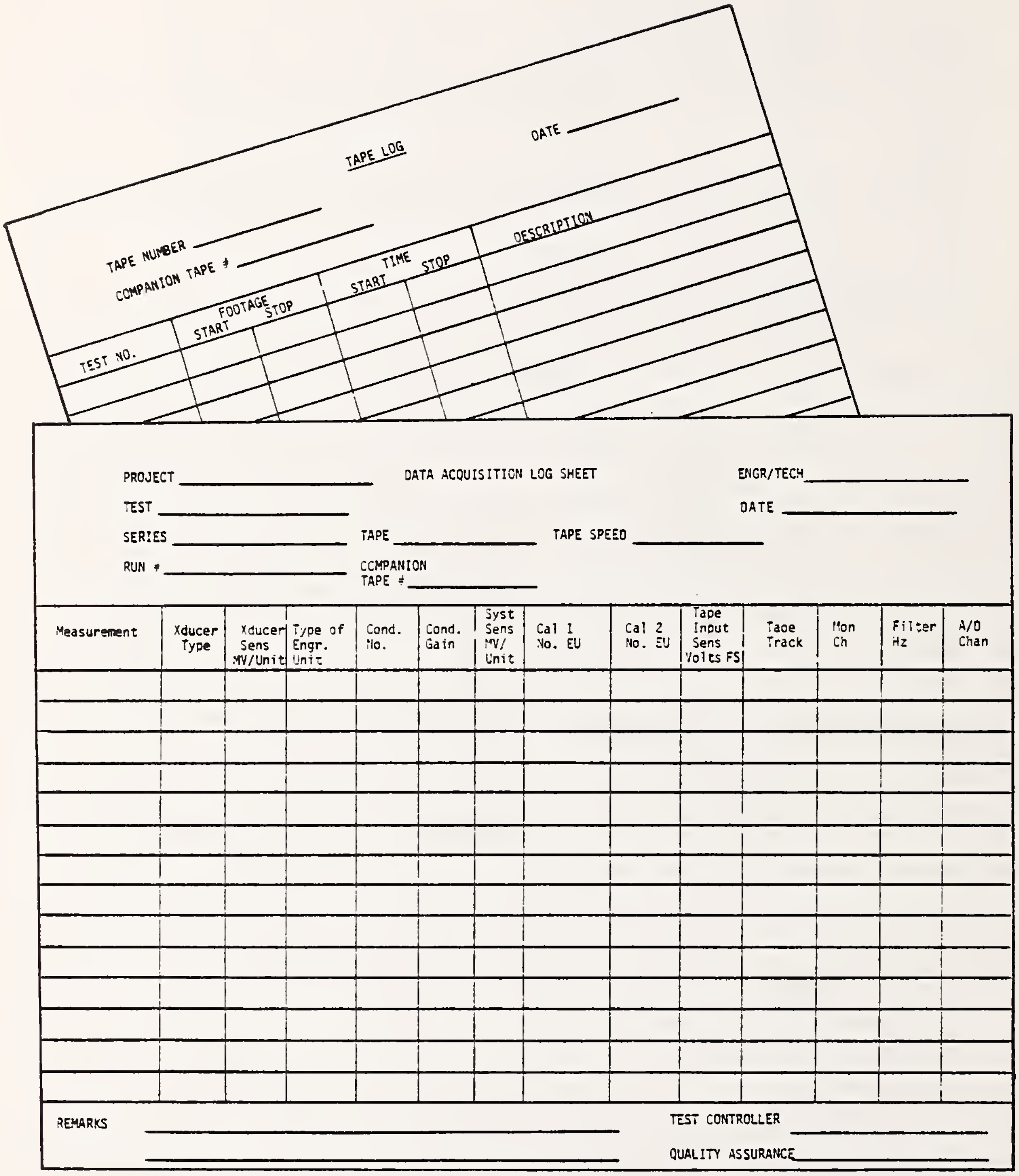
TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
P-3004-TT	Deceleration Emergency	AW0	2-Car	20,30,40, 50,60,75	Emerg.	Release Deadman	659-664 683-688		7/5/77
"	"	AW2	2-Car	20,30,50, 75	"	"	348-355	2005	6/9/77
"	"	AW3	2-Car	20,30,40, 50,60,75	"	"	243-254	2004	5/27/77
P-4002-TT	Drift Test	AW2	2-Car	75 entry	CST	Dynamic BR. Cut-Out	279-296	2005	6/3/77
"	"	"	"	45 entry	CST	"	748-755		7/26/77
"	"	"	4-Car	75 entry	CST	"	732-747		7/26/77
	Speed Calibration	AW2	2-Car	15,30,45, 60,75		Speed Calc. From E.T. between 2-STNS.	297-306	2005	6/3/77
P-5001-TT	Duty Cycles	AW2	2-Car	Vary	P5,B5	WMATA Profile	462	2006	6/28/77
"	Friction Brake	"	2-Car	35	P5,B5	NYCTA Profile	463	2006	6/2877
"	"	"	"	50	P5,B5	CTS Profile	464	2006	6/28/77
P-2011-TT	Spin/Slide Acceleration	AW0	2-Car	0-50	P5	STN 33-South	725-727		7/19/77
P-3011-TT	Spin/Slide Deceleration	AW0	2-Car		B3-B5	Blended Brake	728-731		7/19/77
"	"	AW0	2-Car	20,40,60, 75	B5	Blended Brake	756-761		8/4/77
"	"	"	"	"	"	Friction Only BR.	762-766		8/4/77
A-3021-TT	Adhesion	AW0	2-Car	20,40	B1,B2	Front Truck Only	767-771		8/4/77

TABLE 4-7. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM TEST & RUN NUMBER CROSS-REFERENCE, G.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
PC-5011-TT	Power Consump-tion	AW2	2-Car	Vary	P5,B4	WMATA Profile	276-278	2004	6/2/77
"	"	AW2	"	"	P5,B5	ACT-1 Profile	309	2005	6/6/77
"	"	AW3	"	"	P5,B4	WMATA Profile	273-275	2004	5/31/77
CN-0001-TT	Equipment	AW0	2-Car	0	-	Wayside Survey	695-696		7/6/77
"	Noise Survey	"	4-Car	0	-	" "	701		8/4/77
CN-1001-TT	Wayside Noise -Speed Effect	AW0	2-Car	15,30,45, 60,75	-	50' from Track Centerline	689-694		7/6/77
"	"	"	4-Car	"	-	"	696-700		8/4/77
"	"	"	"	-	P5	Acceleration	702		8/47/7
"	"	"	"	-	B4	Deceleration	703		8/4/77
"	"	AW3	2-Car	15,30,45, 60,75	-	50' From Track Centerline	563-569		6/30/77
PN-1001-TT	Noise-Speed Effect on Car	AW0	2-Car	15,30,45, 60,75	-	4-Microphone Locations	75-94 697-716		7/6/77
"	"	AW3	"	"		"	535-554		6/30/77
PN-1101-TT	Noise-Track	AW0	2-Car	50	-	Continuous Lap	95,96		5/10/77
"	Type Effect on	"	"	"	-	"	723,724		7/6/77
"	"	"	4-Car	"	-	"	704		8/47/7
PN-1301-TT	Noise-Interior Survey	-	-	-	-	-	-	-	8/4/77

TABLE 4-8. WMATA TRANSIT CAR GENERAL VEHICLE TEST PROGRAM TEST & RUN NUMBER CROSS-REFERENCE, H.

TEST SET	TITLE	WEIGHT	CONSIST	SPEED	CONTROL LEVEL	COMMENTS	RUN NO'S	TAPE NO.	TEST DATE
PN-2001-TT	Noise-Accel N.	AW0	2-Car	0-75	P5		97,99		5/10/77
"	On Car	"	"	"	P5		717,719		7/6/77
"	"	AW3	"	"	"		555,557		6/30/77
PN-3001-TT	Noise-Decel N.	AW0	2-Car	75-0	B5	Blended Brake	100		5/10/77
"	On Car	"	"	"	"	Blended Brake	718,720		7/6/77
"	"	"	"	"	"	Friction Brake	721,722		7/6/77
"	"	AW3	"	"	"	Blended Brake	555,557		6/30/77
"	"	"	"	"	"	"	559		6/30/77
						Friction Brake	560-562		6/30/77



TAPE LOG

TAPE NUMBER ______ DATE ______

COMPANION TAPE # ______

TEST NO.	FOOTAGE START	FOOTAGE STOP	TIME START	TIME STOP	DESCRIPTION

DATA ACQUISITION LOG SHEET

PROJECT ______ ENGR/TECH ______

TEST ______ DATE ______

SERIES ______ TAPE ______ TAPE SPEED ______

RUN # ______ COMPANION TAPE # ______

Measurement	Xducer Type	Xducer Sens MV/Unit	Type of Engr. Unit	Cond. No.	Cond. Gain	Syst Sens MV/ Unit	Cal 1 No. EU	Cal 2 No. EU	Tape Input Sens Volts FS	Tape Track	Mon Ch	Filter Hz	A/D Chan

REMARKS ______ TEST CONTROLLER ______

QUALITY ASSURANCE ______

FIGURE 4-2. DATA ACQUISITION LOG SHEET AND TAPE LOG, The tape log was an account of the content of each raw data tape in terms of the test run numbers on the tape and their location. During the test program a log was maintained of each test run number, the start and stop of the test run in tape footage, and the start and stop times from the time code generator display on the data system console. A standard time code (IRIG B) format was maintained on channel #14 of both tape recorders throughout the test program. Correlation of this time code with the noted time of day values in the tape log, taken from the same time code generator's display, gave a precise location of each test run on a data tape during post-test data analysis.

5.0 DATA PROCESSING TECHNIQUES

This section describes the data processing techniques used for performance and ride roughness data processing.

5.1 PERFORMANCE DATA REDUCTION.

5.1.1 Engineering Unit Listings.

Magnetic tapes with raw performance test data were played back on a tape recorder and input to the TTC computer, where they were digitized at 40 samples/second. Time history plots were made of all calibration steps on the data tape from the digitized values; these values were compared to known calibration voltage steps and sensor sensitivities to verify the calibration constants determined by the computer. The digitized data tapes were then processed on the computer to obtain engineering unit listings for each test run. The listings were, in general, made at two-second intervals throughout a test run, although this was modified to suit individual test requirements.

5.1.2 Temperature Data.

Brake disc and pad temperature data were recorded for a series of duty cycle-friction brake tests, each involving a run of 30 minutes or more. Due to the length of the run and the format of existing digital software, duty cycle tests were not suited to digital processing; these runs were therefore stripped out on a chart recorder from the magnetic data tapes, with scaled values of engineering units for each channel full scale deflection. Brake thermocouple outputs in millivolts were read for each data point and converted to temperature in degrees Fahrenheit using conversion tables.

5.2 RIDE QUALITY DATA REDUCTION.

5.2.1 Ride Roughness - Vertical and Horizontal (Analog Evaluation).

The standards set forth in the International Standards Organization (ISO) report TC 108, "Guide to the Evaluation of the Human Body Response to Whole Body Acceleration" provide an internationally accepted method for evaluating human response to vibration in the 1 to 80 Hz frequency ranges. The weighting networks defined in the "guide" for vertical and horizontal vibrations have been adopted by the GVTP for weighting ride quality data; figures 2-28 and 2-29, above, detail the desired frequency versus attenuation characteristics. Note that the networks for vertical and horizontal ride characteristics differ, to correspond to different sensitivities of human exposure in each axis. Motion sickness (frequencies in the 0.1 to 1.0 Hz range) or high frequency vibrations in excess of 80 Hz are not accounted for by the networks.

"Ride roughness" data processing, as established in GVTP, is a technique by which ride quality accelerometer data can be weighted to enhance the frequency range which most affects the human body. This is done by modifying the accelerometer output through the frequency attenuation networks described above. From this weighted output, an RMS-averaged ride roughness "figure of merit" can be obtained to express the ride comfort experienced by a passenger for each set of test conditions.

The WMATA ride quality data were processed using analog techniques to obtain ride roughness-filtered data. Ride quality tapes were played back on a tape recorder through filters. The filter characteristics approximated the weighting characteristics illustrated in figures 2-28 and 2-29, but differed sufficiently over some frequencies (particularly in the 1-2 Hz range) to require critical examination. A comparison of the filter characteristics compared to the desired characteristics is shown in figures 5-1 and 5-2. The filtered data were converted to RMS values using a true RMS-to-DC converter; an averaging time constant of 10 seconds was used. Instantaneous RMS values were recorded on a recorder together with raw and filtered data for each channel, track location, and IRIG time code. RMS values for each track section were then obtained from the chart recorder and mathematically averaged to derive one ride roughness number for the track section.

5.2.2 Ride Roughness - Digital Data Evaluation.

Magnetic tapes of raw, unfiltered data on ride quality were played back on a tape recorder and input to the TTC computer, where they were digitized at 400 samples/second. The digital tapes were used to generate calibrated vibration time histories and PSD's of unfiltered accelerometer data to determine significant frequency content. Additional digital data processing was accomplished on a remote computer using manual data entry from the remote computer terminal at TTC. Digital filtering techniques were used to apply the ride roughness weighting characteristics to PSD data. Because of the problems of manual data entry, this process was used for a limited number of cases to obtain accurate filtered/unfiltered data comparisons.

Text continues on page 106

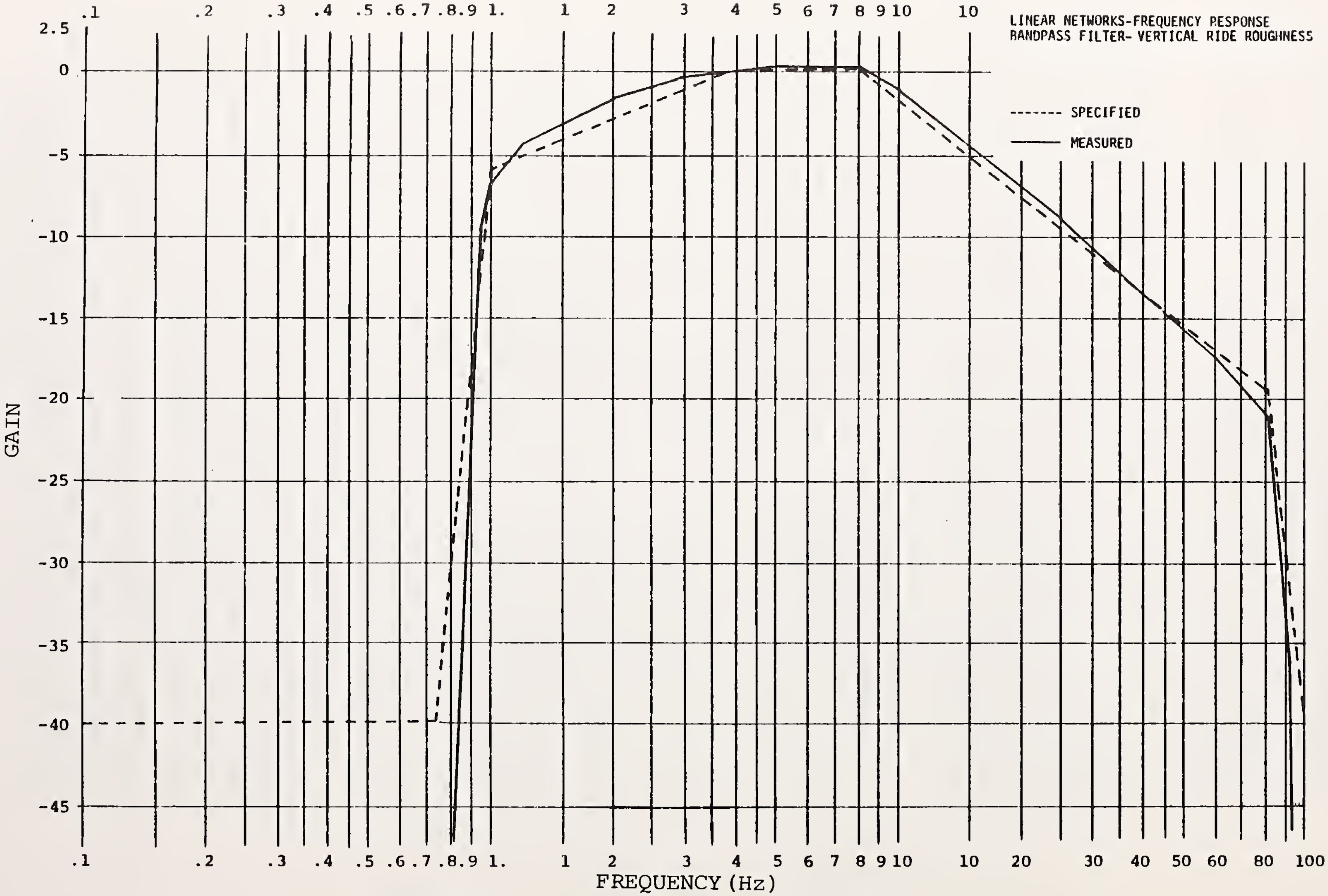


FIGURE 5-1. VERTICAL RIDE ROUGHNESS.

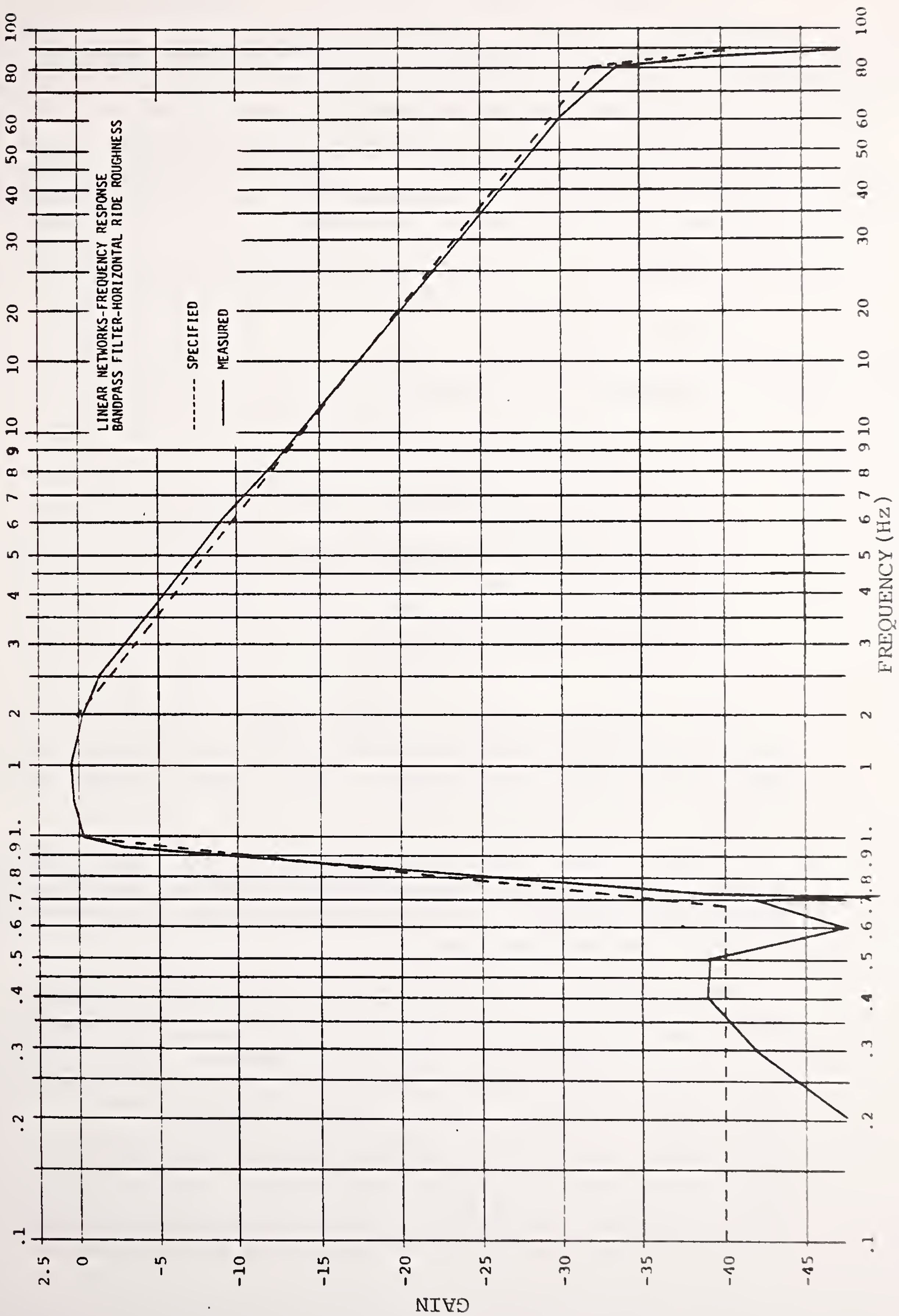


FIGURE 5-2. HORIZONTAL RIDE ROUGHNESS.

6.0 SUMMARY AND CONCLUSIONS

The purpose of this report is to present the results of a test program conducted at the Transportation Test Center (TTC) and carried out on examples of the Washington Metropolitan Area Transit Authority (WMATA) rapid transit cars. Analyzed and summarized data are found in this report, together with general descriptions of the test equipment and procedures. Such information is presented in the categories and format called for in the General Vehicle Test Plan (GVTP). The program addressed the following seven categories of transit vehicle evaluation:

- Performance (Acceleration, Deceleration, Drift, etc.),
- Power Consumption,
- Spin/Slide Protection,
- Noise (Wayside and Interior),
- Ride Roughness (Component Induced Vibration),
- Power System Interactions (Radio Frequency Interference), and
- Simulated Revenue Service.

Two married pairs of WMATA rapid transit cars (serial numbers 1104 and 1105, 1108 and 1109) were tested on the 9.1 mile (14.6 km) oval Transit Test Track during the period September 1976 to August 1977.

Among other results derived from the test program, the vehicles demonstrated braking characteristics conforming to the design specification, with good load-weigh response within the limits of the test envelope.

The measured acceleration characteristics demonstrated, within test limits, performance conforming to the design specification and adequate load-weigh response. Power consumption values varied from 6 kW-hr per car-mile to 10 kW-hr per car-mile depending on passenger load, as described in the text. Interior noise levels varied from 60-65 dBA at 15 mi/h (24 km/h) to 65-70 dBA at 75 mi/h (120 km/h) with momentary higher transients when negotiating grade crossings and switches. Wayside noise, under test conditions, ranged from dBA readings in the sixties at low speeds to values as high as the eighties at high speeds.

The test program pointed out some deficiencies in GVTP procedures, notably those to determine spin/slide protection system efficiencies. This procedure is impractical as currently defined and should be revised.

7.0 LIST OF REFERENCES

1. "General Vehicle Test Plan (GVTP) for Urban Rail Transit Cars," Report No. UMTA-MA-06-0025-75-14, April 1977, U.S. Department of Transportation/Urban Mass Transportation Administration.

2. "Functional Description of the Watt-Hour Meter", Transportation Test Center Memorandum IE/DG/76-10 of 11/23/76.

3. Transportation Test Center Drawing Number SK-RDL-4255 of 1/4/77.

4. International Standards Organization, "Guide to the Evaluation of the Human Body Response to Whole Body Acceleration" TC-108.

APPENDIX

REPORT OF INVENTIONS

After a diligent review of the work performed under this contract, it was determined that no innovation, discovery, improvement, or invention was made. The purpose of the effort was to test the WMATA vehicle in accord with the General Vehicle Test Plan to characterize the vehicle.

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