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SOAC

STATE-OF-THE-ART CAR

ENGINEERING TESTS AT

DEPARTMENT OF TRANSPORTATION

HIGH SPEED GROUND TEST CENTER

FINAL TEST REPORT

VOLUME II. PERFORMANCE TEST

<DOT Logo>

JANUARY 1975

FINAL REPRT

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16. Abstract

This six-volume report presents the technical methodology, data samples, and results of tests conducted on the SOAC on the Rail Transit Test Track at the High Speed Ground Test Center in Pueblo, Colorado during the period April to July 1973. The UMTA-sponsored Urban Rail Supporting Technology Program, for which TSC is Systems Manager, emphasizes three major development task areas: facilities, technology and test program. Test program development comprises three sub-areas: vehicle testing, ways and structures testing and track geometry measurement. The objective of the SOAC program is to demonstrate the current state-of-the-art in rail rapid transit vehicle technology, with passenger convenience and operating efficiency as primary goals. The objectives of the Engineering Test program are to provide a set of SOAC engineering data and to further develop the methodology for providing transit vehicle comparisons. These objectives were met with the presentation of the test results in this report and the incorporation of refinement to the testing methodology into the General Vehicle Test Plan, GSP-064. In this series, Vol. I contains a description of the SOAC test program and vehicle, and a summary of the test results; Vol. II, Performance Test data; Vol. III, Ride Quality Test data; Vol. IV, Noise Test data; Vol. V, Structural, Voltage, and Radio Frequency Interference Test data; and Vol. VI a description of the Instrumentation System used for performance, ride quality and structural testing.

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Section 1

INTRODUCTION

This test report is presented in six volumes.

Volume I is a description of the program and a summary of the test results.

Volumes II through V are organized by technical disciplines as follows:

- Volume II Performance Tests
- Volume III Ride Quality Tests
- Volume IV Noise Tests
- Volume V Structural, Voltage, and Radio Frequency Interference Tests

Volume VI contains a description of the SOAC Instrumentation System used for Performance, Ride Quality, and Structural Testing.

Section 2

ACCELERATION TESTS

2.1 SUMMARY

Test Sequence

Table 2-1 presents a log of test runs and records obtained during acceleration testing.

Test Procedures

SOAC-P-2001-TT baseline procedure was used, with testing conducted at four controller inputs, three line voltages, and four car weights.

Objective

The objectives of the acceleration tests were: (1) to determine the SOAC acceleration characteristics, control response, line voltage, and load compensation effects throughout the operating range of the car; and (2) to provide baseline data on the SOAC operating on the Pueblo HSGTC oval for use during ACT-1 and subsequent rapid rail development programs.

Status

Data was recorded with both solid and resilient wheels. However, only the resilient wheel data is considered representative of specification car performance. All acceleration data has been reduced and is available in digitized, tabulated time-history format. Accelerometer "zero" shift and scatter (filtering) problems which occurred during resilient wheel tests necessitate caution in the use of digitized engineering data.

2.2 TEST DESCRIPTION

In general, acceleration testing consisted of accelerating the car to its maximum achievable speed on 4000 feet of level tangent track at various combinations of master controller inputs, car weights, and track voltage. During the acceleration

TABLE 2-1. SOAC ENGINEERING TEST RUN LOG

Type of Test: Acceleration
Type of Wheels: Solid Steel

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
5/3/73	096	435 450 455	1	Control response and car weight	1.0 0.75 0.75	80 80	90,000	2 (H-D)	fwd	600	Before propulsion modifications
5/8/73	099	1120 113[illegible]	1	Control response and car weight	0.75 0.75	 80	90,000	2	fwd	600	Before propulsion modifications
5/10/73	103	1105 1110	1	Voltage effects	1.0 1.0	80 80	105,000	2	fwd	650	Before propulsion modifications
5/10/73	104	250 258 305 310 315 320 330 335 350	1	Control response and car weight	1.0 0.875 0.875 0.75 0.75 0.75 0.75 0.625 0.625	90 71 80 56 66 70 72 34 39	105,000	2	fwd	600	Before propulsion modifications
5/10/73	104	417 420 430 435 440	1	Voltage effects	1.0 1.0 1.0 1.0 1.0	62 74 62 75 77	105,000	2	fwd	475	Before propulsion modifications
6/9/73	126	1120 1125 1131 1134 1145	1B	Control response and car weight	1.0 0.75 0.75 0.75 0.75	77 58 66 71 73	113,000	2	fwd	600	Before propulsion modifications

TABLE 2-1. SOAC ENGINEERING TEST RUN LOG (CONTINUED)

Type of Test: Acceleration
Type of Wheels: Resilient

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
7/14/73	142	1619	14	Control re-	1.0	76	105,000	2	fwd	600	After propulsion
		1628		sponse and	1.0	76		(H-D)	rev		modifications
		1637		car weight	0.875	74			fwd		
		1643			0.75	62					
		1648			0.75	74					
		1653			0.625	42					
		1700			0.625	49					
		1705			0.625	52					
7/16/73	143	1034	14	Voltage	1.0	79	105,000	2	fwd	630	After propulsion
		1055		effects	1.0	78					modifications
		1104			1.0	78					
		1127			1.0	67				500	
		1134			1.0	67				500	
		1142			1.0	78				500	
		1204			1.0	61				460	
		1211			1.0	72				460	
7/17/73	146	1537	14	Control re-	1.0	73	113,000	2	fwd	600	After propulsion
		1543		sponse and	0.75	62					modifications
		1550		car weight	0.75	74					
		1723			1.0	75					
7/18/73	148	1457	14	Car weight effects	1.0	69	130,000	2	fwd	600	After propulsion modifications
7/19/73	151	1405	14	Control re-	1.0	79	90,000	2	fwd	600	After propulsion
		1411		sponse and	1.0	78					modifications
		1417		car weight	0.75	62					
		1423			0.75	71					

various car and traction system parameters were recorded to determine the characteristics of system operation.

2.3 TEST INSTRUMENTATION

The following parameters were recorded on magnetic tape during the acceleration testing: Data Sheet 1 for solid wheels and Data Sheet 14 for resilient wheels. All Data Sheet 14 parameters were also recorded on the quick-look oscillographs during post-wheel-change tests. Data Sheet 1 is shown as Table 2-2; Data Sheet 14 as Table 2-3.

Two instrumentation setups were used to record data during the testing. The change in instrumentation coincides with the resilient wheel change. In general the pre-wheel-change data system consisted of the AiResearch R-32 NYCTA Energy Storage Car equipment, transducers, tape deck, and CEC recording oscillograph. The post-wheel-change system was designed for the SOAC and consisted of two tape decks, oscillographs, and separate signal conditioning for each type of test data required: performance, ride quality, or structures. Descriptions of parameters, sensors, and calibrations are contained in Volume VI of this report.

Distance data is obtained using the event marker which is triggered at the start and at 500-foot track markers. For time-speed-distance data, zero-time is based on first perceived car motion and not controller input. This technique is carried over from the acceptance test program and is not necessarily applicable to other vehicle test programs. Dead-time evaluations shown in this section are based on controller input time such that either zero-time reference may be used with the data.

The "quick-look" stripouts were used to validate instrumentation operation, define various time constants, define digitize times for various records, and provide a check on calibrated-digitized data.

Digitized data at one or two second intervals was obtained from the magnetic tape using a machine sampling rate of one per second and filtering on applicable parameters.

2.4 TEST PROCEDURES

The actual test procedures used during the SOAC testing are contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1). These procedures provided sufficient detailed directions and informal instructions to enable relatively inexperienced personnel to perform and validate the tests. The

TABLE 2-2. LABORATORY TAPE RECORDER DATA SHEET NO. 1

Test Title Performance

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/1/73 Test Eng ______ Tech RPM-DLB Tape Type & Size ______

Tape Recorder Model No. SABRE III Tape Recorder S/N ______ Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect		Remarks	Quick-Look Oscillograph
					Type	C.E.		
1	Line E	Volt/Div		±10.0 VDC	FM		+ 1000 VDC = +10.000 VDC	X
2	Line I	3000 AMP Hall		±10.0 VDC	FM		+ 2000 ADC = +10.000 VDC	
3	Long. Accel.	0.25G S/N 2807		± 5.0 VDC	FM		± 0.25G = ± 5.000 VDC	X
4	Speed #3 Axle			± 5.0 VDC	FM		80 MPH = +5.000 VDC	X
5	#1 Truck Arm E	Volt/Div		± 5.0 VDC	FM		+ 1000 VDC* = +5.000 VDC	
6	SYNC			± 5.0 VDC	FM			
7	#2 Truck Arm E	Volt/Div		± 5.0 VDC	FM		+ 1000 VDC* = +5.000 VDC	
8	#1 Truck Arm I	1000 AMP A-A-C S/N 32		± 5.0 VDC	FM		+ 1000 ADC = +5.000 VDC	X
9	#2 Truck Arm I	A-A-C S/N 31		± 5.0 VDC	FM		+ 1000 ADC = +5.000 VDC	
10	#1 Truck Field I	SOAC Monitor		± 5.0 VDC	FM		± 50 ADC = ± 5.000 VDC	
11	#2 Truck Field I	SOAC Monitor		± 5.0 VDC	FM		± 50 ADC = ± 5.000 VDC	
12	'P' Wire I			± 5.0 VDC	FM		+ 1.0 ADC = -5.000 VDC	X
13	Brake Press Axle #3	200 PSI Tabor Model 185		± 5.0 VDC	FM		100 PSI = +5.000 VDC	X
14	Event			± 5.0 VDC	FM		2 HZ Signal	X
Edge A					Dir.			
Edge B	Voice							

* Later changed to 1200 VDC on Data Sheet 1B

TABLE 2-3. LABORATORY TAPE RECORDER DATA SHEET NO. 14

Test Title Performance

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 7/14/73 Test Eng ____ Tech RPM-DLB Tape Type & Size 1-inch x 7200 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph Location
1	301 Long Accel	±0.25 G's		±5.0 VDC	FM	3.375 KC	± 0.25G's = ± 5.000 VDC	R/H
2	302 Line E	Volt/Div S/N D02		±5.0 VDC	FM	3.375 KC	Zero VDC = -5.00 VDC +1000 VDC = +5.00 VDC	L/H
3	303 Line I	3000 AMP Hall Device		±5.0 VDC	FM	3.375 KC	Zero ADC = -5.00 VDC + 2000 ADC +5.00 VDC	L/H
4	304 #1 Arm E	Volt/Div S/N 001		±5.0 VDC	FM	3.375 KC	+ 1200 VDC = 5.00 VDC	L/H
5	305 #1 Arm I	1000 AMP AM-A-C		±5.0 VDC	FM	3.375 KC	+ 1000 ADC = 5.00 VDC	R/H
6	306 #1 Field I	150 A S/N 57	3 Turns 50A =5.0 VDC x 1	±5.0 VDC	FM	3.375 KC	± 50 ADC = ±5.00 VDC	L/H
7	307 #2 Arm E	Volt/Div S/N 003		±5.0 VDC	FM	3.375 KC	+ 1200 VDC = 5.00 VDC	L/H
8	308 #2 Arm I	1000 AMP AM-A-C		±5.0 VDC	FM	3.375 KC	+ 1000 ADC = 5.00 VDC	R/H
9	309 #2 Field I	500A AM-A-C	5 Turns 50A =2.5 VDC x 2	±5.0 VDC	FM	3.375 KC	± 50 ADC = ± 5.00 VDC	L/H
10	310 P Wire I	1.0 AMP AM-A-C		±5.0 VDC	FM	3.375 KC	+ 1.0 ADC = 5.00 VDC	R/H
11	311 Analog Valve I	5.0 AMP AM-A-C		±5.0 VDC	FM	3.375 KC	5.0 ADC = 5.00 VDC	L/H
12	315 Speed	Monopole		±5.0 VDC	FM	3.375 KC	80 MPH = 626.5 HZ	R/H
13	318 Brake Press	Tabor 0-200 PSIG Mod 185		±5.0 VDC	FM	3.375 KC	100 PSIG = 5.00 VDC	R/H
14	Time Code	IRIG B		±5.0 VDC	FM	3.375 KC		Both (2)
Edge A							NOTE: D.S. #14 for Post-Wheel Change Data Only	
Edge B	Voice & Event				Dir			Both (2)

resulting baseline test procedures are contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2), Procedure SOAC-P-2001-TT.

I. Preliminary (pre-test)

A. Attach instrumentation or patch in desired parameters at storage or shop.

B. Add ballast weights to simulate desired car weight (AW________)

C. Check out and calibrate instrumentation.

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

E. Make up desired train consist.

F. Proceed to test zone.

G. Make inspection passes over test zone; check out vehicle and track.

H. Record ambient conditions as required.

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

II. Test Procedure (at test zone)

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

B. Start recording instrumentation.

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

D. Start timing devices and put event mark on recorders at time of control input or "first sensed car motion" as required by specific test program.

E. Accelerate vehicle at the fixed input command for the full 4000-foot test zone.

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

G. After passing Station 340, note car speed and stop recorders.

H. Stop vehicle and reposition for next test record.

Option (1)

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

A-1 Position car such that the speed attained in Item G can be obtained at Station 300. Identify test record.

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

C-1 Start recording instrumentation prior to entering test zone.

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

E-1 through H-1 Repeat Items E through H.

Option (2)

Repeat Items A through H-1 as required to provide sufficient confidence in recorded test data.

Option (3)

Repeat Items A through H-1 in reverse direction; Station 340 to Station 300, as required.

Option (4)

Repeat Items A through H-1 at the desired input command positions.

Option (5)

Repeat Items A through H-1 at the desired car weights.

Option (6)

Repeat Items A through H-1 at the desired line voltages.

Option (7)

Repeat Items A through H-1 with the desired train consists.

Using the generalized acceleration procedures the following conditions were tested:

- Controller Inputs (amperes)

  1.0, 0.875, 0.75, 0.625

- Track Voltages (volts)

  650, 600, 475

- Car Weights (pounds)

  90,000; 105,000; 113,000; 130,000

The car was accelerated at the desired conditions with fixed input command. If the 4000-foot test section was insufficient to attain maximum speed a second pass was made using a similar technique with car speed at the zero distance equal to car speed at the 4000-foot mark on the previous record.

2.5 TEST DATA

2.5.1 Test Data Reduction

As noted in the Test Run Log of Table 2-1, two sets of acceleration data were recorded during the test program. The test program calls for a comparison of performance between the solid steel wheels and the resilient-aluminum centered wheels. While no performance differences were expected (other than friction braking temperatures, etc.), a valid acceleration performance comparison is not possible based on the recorded test data. This problem is due to a change in the level of performance which occurred during the time when resilient wheels were being installed.

Prior to the wheel change a degradation in acceleration capability and unbalances in truck currents were noted on the digitized data as compared to Acceptance Test data. This problem was traced to an out-of-calibration and drifting armature current sensor which was prematurely restricting both "truck" and total armature current. During the wheel change, logic circuits were returned to AiResearch, Torrance, California for rework. Following the wheel change, car accelerations were found to be increased over both pre-wheel change and Acceptance Test levels. This performance change corresponds in time to the wheel change thus negating any attempts to determine wheel effects on acceleration. Figure 2-1 illustrates the pre- and post-wheel change levels of performance.

Two different data reduction sequences are shown on Figure 2-1 for the pre-wheel change data: 2-second and 1-second digitize times. These sequences were set up at different times but should have contained identical filtering equipment. The longitudinal accelerometer has a predominant 32 to 36 Hz frequency during acceleration at low levels or high-speed cruise. The large amount of scatter in the 1-second digitize time data suggests a filtering problem. This problem also occurs during much of the post-wheel change accelerations along with a second problem area, a zero shift as shown in Figure 2-1.

The above problem areas complicated the data reduction and analysis; however, a method was developed which provides reasonable accuracy:

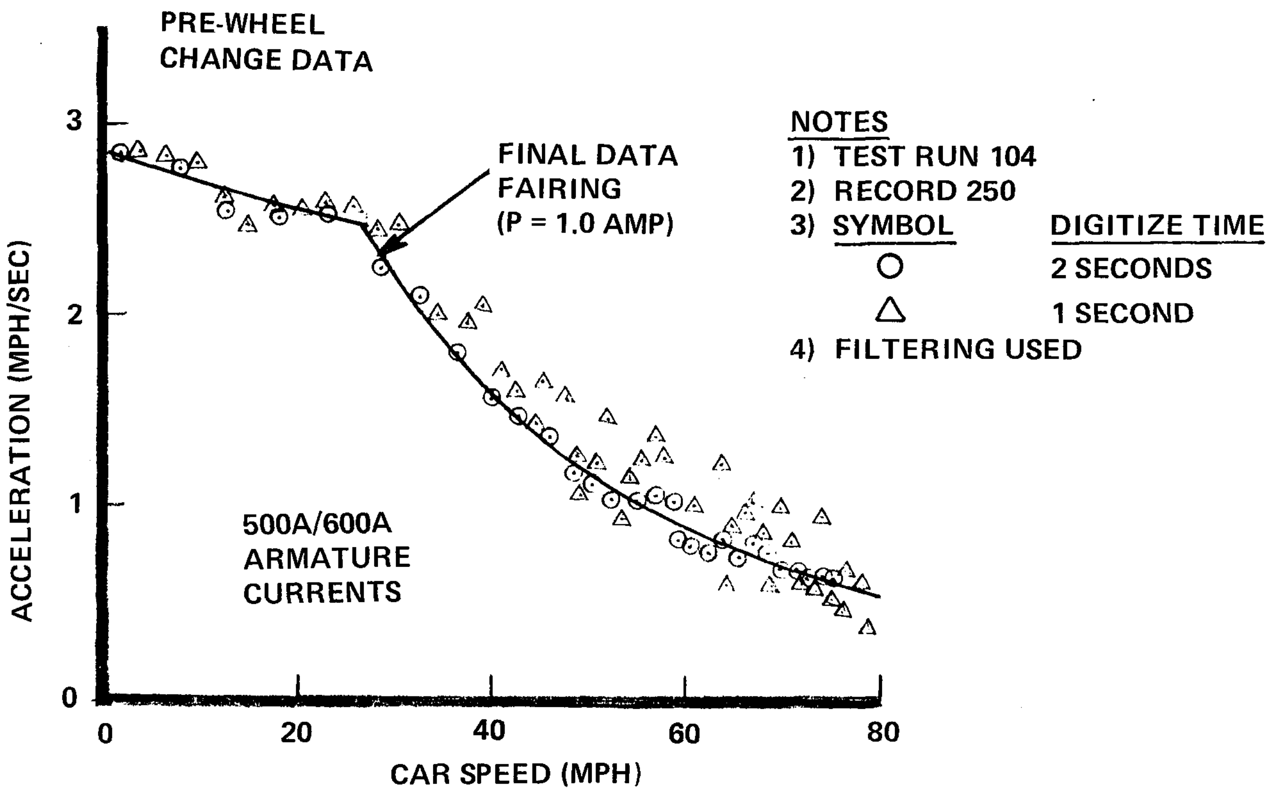
1. Digitized data (prior to initiating car acceleration) was examined to determine the magnitude of any zero-shift.

2. Acceleration-speed and speed-time profiles were plotted with the final data fairing based on the more valid of the two: "acceleration" at high rate and low speed, Δ speed/Δ time at higher speeds where accelerometer data is scattered.

The data contained in this section is based on the post-wheel change level of performance only. Samples of reduced data in standard output formats of digital time-history, analog time-history, and tabulated output are contained in this section, as well as preliminary analyses of the control, load weigh, and track voltage effects.

The data contained in this report are for single car operation. During the Acceptance Test Program it was found that the track voltage drop and power supply capability precluded accurate determination of two-car acceleration performance.

Figure 2-2 illustrates a typical two-car acceleration and the associated current and acceleration transients. The resulting reduced performance is not sufficient to provide a comparison to single car operation.



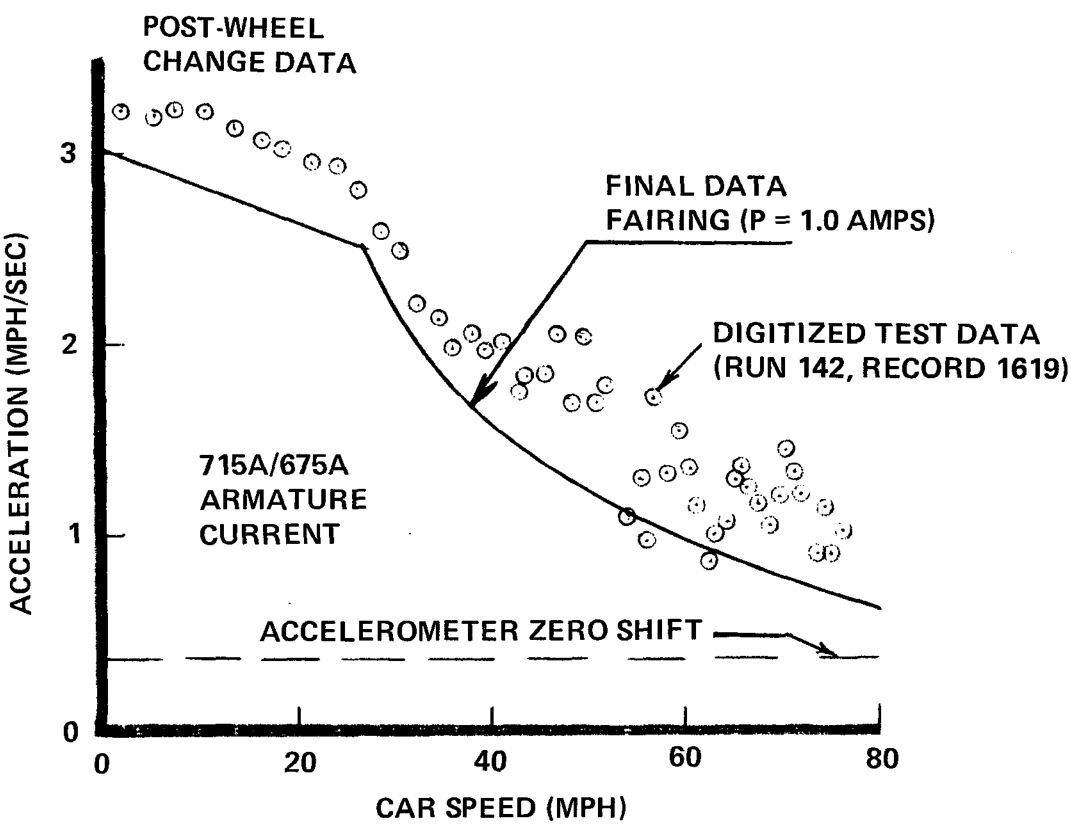


Figure 2–1. Performance Level and Data Reduction Problem Areas (105,000-Pound Car; Nominal 600 Volts

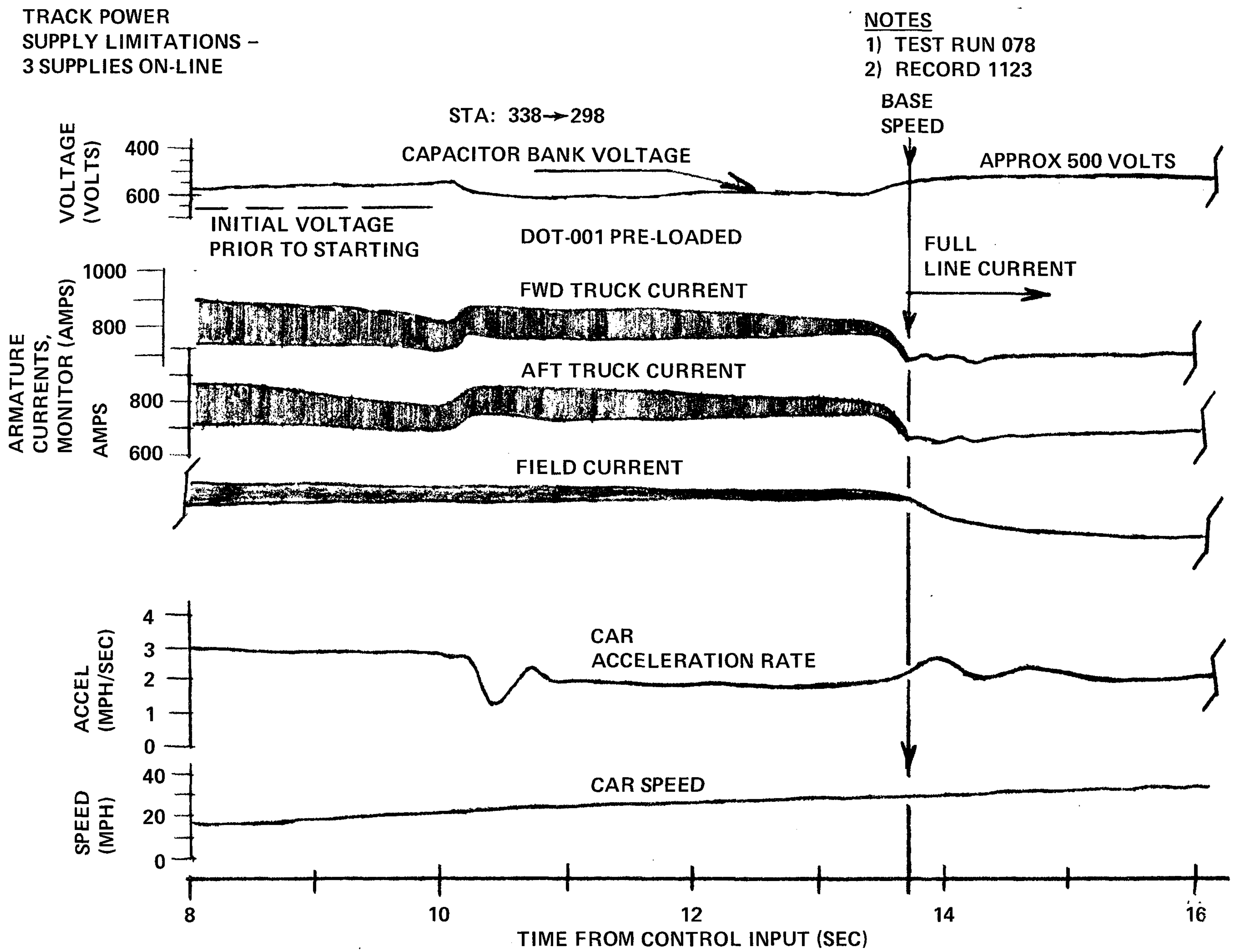


Figure 2–2. Two-Car Train Performance

2.5.2 Sample Data Output

Three types of standard data output are shown in the following tables and illustrations:

1. Table 2-4 shows a sample output of tabulated digitized data.

2. Figure 2-3 is a digital time-history of Table 2-4 data.

3. Figure 2-4 is an analog time-history tracing of the quick-look oscillograph data. Calibrations are available but are not shown on this figure.

A digitized, tabulated standard output is available for all valid acceleration test records. The following paragraphs and figures provide preliminary analyses of the standard outputs which provide a comparative base of SOAC acceleration performance and control characteristics.

2.5.3 Control Characteristics

Figure 2-5 presents a summary of SOAC acceleration data at four master controller inputs throughout the speed range of the car. A comparison of measured control linearity with design characteristics is contained in the upper part of Figure 2-5. The resulting time-speed-distance characteristics are shown in Figure 2-6 for the four controller inputs. The SOAC control system provides essentially proportional (i.e., proportional to 100 percent capability) acceleration control throughout the speed range.

Figure 2-7 illustrates the acceleration jerk rates and control dead-times for master controller step inputs of 1.0 and 0.75 amps. These data are based on overlays of the "quick-look" oscillograph strip-out with calibrations verified against the digitized standard output. For the 1.0-amp (full acceleration) input the total dead-time is 1.42 seconds and the jerk rate is 1.95 mph/sec^2.

2.5.4 Load Weight Compensation

The SOAC was tested at four car weights: 90,000-pound empty car to 130,000-pound crush load car. The design weight of the car is 105,000 pounds and this weight should correspond to maximum tractive effort from the propulsion system. Figure 2-8 presents the acceleration data at four weights and two controller inputs. As expected, the maximum acceleration rate is reduced in proportion to weights above 105,000 pounds while the acceleration rate at one-half full command is essentially consistent for all weights tested. The control linearity is

TABLE 2-4. TEST RECORD NO. 1619 (TEST RUN 142: ACCELERATION AT P = 1.0 AMP; 105,000-POUND CAR)

TEST RECORD NUMBER 1619

PAGE 1

SOAC DATA REDUCTION

TEST RUN 142

DATE 7/25/7

REQUEST NUMBER...60

	DIGITIZE TIME SEC	EVENT MARK ΔSEC	SPEED MPH	P-WIRE AMPS (ZERO SHIFT)	ACCEL MPH/SEC	LINE VOLT (NOM. 600V)	LINE AMPS	MOTOR NO.1 VOLTS	MOTOR NO.2 VOLTS	ARMATURE NO.1 AMPS	ARMATURE NO.2 AMPS	FIELD NO.1 AMPS	FIELD NO.2 AMPS
	0.		1.70	-0.005	0.37	695.	31.	-11.1	-11.1	-5.1	-4.9	-0.4	-3.1
T = 0 →	1.		-0.23	0.475	0.41	695.	31.	-11.4	-10.3	-4.8	-4.3	-0.5	-3.1
"INPUT"	2.		-0.25	0.976	0.36	693.	37.	-6.6	-3.2	106.3	110.5	14.7	9.9
FIRST MOTION →	3.	+.25	-0.21	0.975	1.64	687.	86.	16.1	20.3	470.1	463.3	31.5	28.3
	4.		1.96	0.977	3.24	659.	292.	75.7	80.3	804.4	780.1	39.8	38.5
	5.		5.18	0.977	3.21	646.	434.	130.8	137.5	806.3	774.0	39.8	38.3
	6.		7.54	0.977	3.23	631.	585.	187.3	195.0	796.0	766.4	40.0	38.0
	7.		10.43	0.976	3.23	617.	735.	241.9	251.1	783.2	754.5	40.1	37.7
	8.		13.56	0.977	3.13	605.	876.	298.1	307.8	770.8	733.9	40.0	37.6
	9.		16.36	0.977	3.09	594.	1015.	350.9	361.8	755.1	722.6	40.0	37.5
	10.		18.56	0.977	3.03	587.	1139.	404.2	415.6	737.0	710.2	40.1	37.2
	11.		21.58	0.977	2.96	580.	1266.	456.7	468.5	726.0	699.2	39.8	37.3
	12.		24.18	0.978	2.94	575.	1385.	507.7	521.8	715.1	691.0	39.9	37.0
	13.		26.43	0.976	2.84	575.	1414.	550.5	563.2	684.8	662.2	37.1	34.8
	14.		28.83	0.977	2.58	576.	1418.	551.5	564.3	690.8	663.1	30.0	26.4
	15.		30.76	0.976	2.50	575.	1434.	549.7	562.2	700.8	668.6	25.4	21.9
	16.		32.61	0.977	2.22	575.	1439.	550.7	563.2	701.0	670.6	22.1	19.2
	17.		34.85	0.976	2.16	577.	1440.	551.8	564.0	703.2	673.7	21.0	17.1
	18.		36.07	0.977	1.99	577.	1432.	553.6	565.3	707.0	676.4	19.8	15.2
500 ft—	19.	+.25	38.03	0.976	2.07	577.	1447.	552.3	565.3	707.7	674.4	18.9	14.3
	20.		39.61	0.978	1.99	579.	1441.	554.7	566.9	713.6	674.2	17.6	13.2
	21.		41.41	0.977	2.00	579.	1437.	554.4	567.2	713.9	670.6	17.2	11.9
700 ft—	22.	+.75	42.98	0.978	1.75	577.	1433.	553.1	565.8	706.5	671.5	16.7	11.5
	23.		43.87	0.977	1.83	578.	1444.	553.6	566.6	708.4	678.8	15.2	11.3
	24.		45.72	0.978	1.86	580.	1443.	555.7	568.7	712.0	676.6	15.5	10.0
	25.		47.05	0.977	2.06	581.	1447.	556.8	569.8	713.9	680.4	15.1	9.7
	26.		48.32	0.978	1.69	579.	1445.	554.9	568.2	715.5	677.3	13.8	9.7
1000 ft—	27.	+.25	49.74	0.977	2.04	580.	1450.	556.8	569.8	713.4	676.6	14.2	8.9
	28.		50.89	0.977	1.70	581.	1447.	557.3	570.6	715.1	677.5	14.0	8.6
	29.		52.05	0.978	1.78	582.	1448.	557.8	570.8	714.4	680.1	13.5	8.5
	30.		52.98	0.978	1.30	582.	1460.	557.8	570.3	715.8	679.0	12.7	8.3
	31.		54.09	0.978	1.12	584.	1454.	559.6	572.7	719.1	681.7	13.0	7.6
	32.		55.27	0.978	1.32	584.	1454.	558.9	571.9	716.5	682.1	12.9	7.3
1500 ft—	33.	+.5	56.07	0.979	0.97	584.	1451.	559.9	573.5	721.5	682.6	12.6	6.8
	34.		57.01	0.978	1.73	586.	1437.	561.7	573.7	716.5	684.3	12.0	6.7

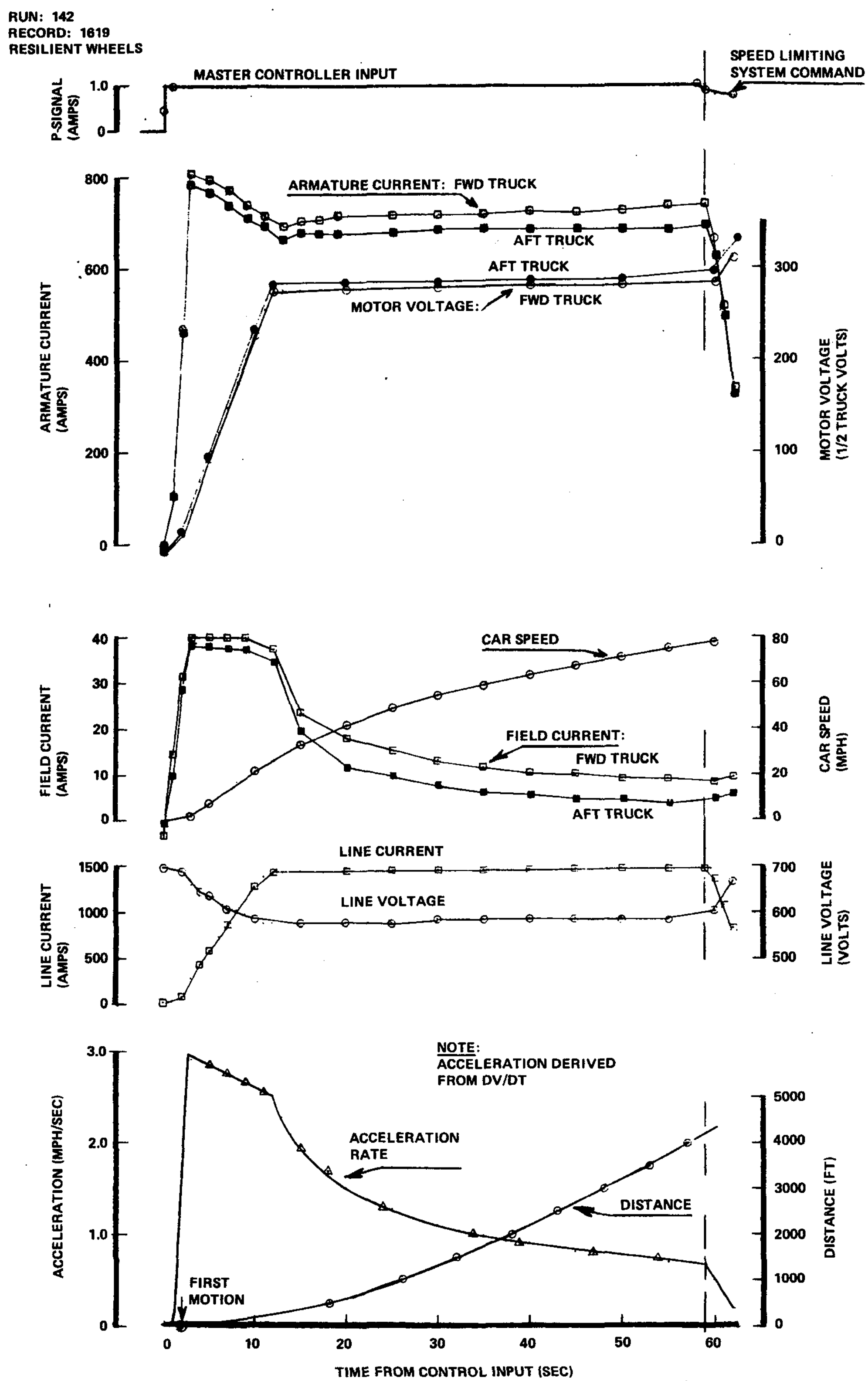


Figure 2–3. Typical Maximum Acceleration Digitized Data (105,000-Pound Car; Nominal 600 Volts)

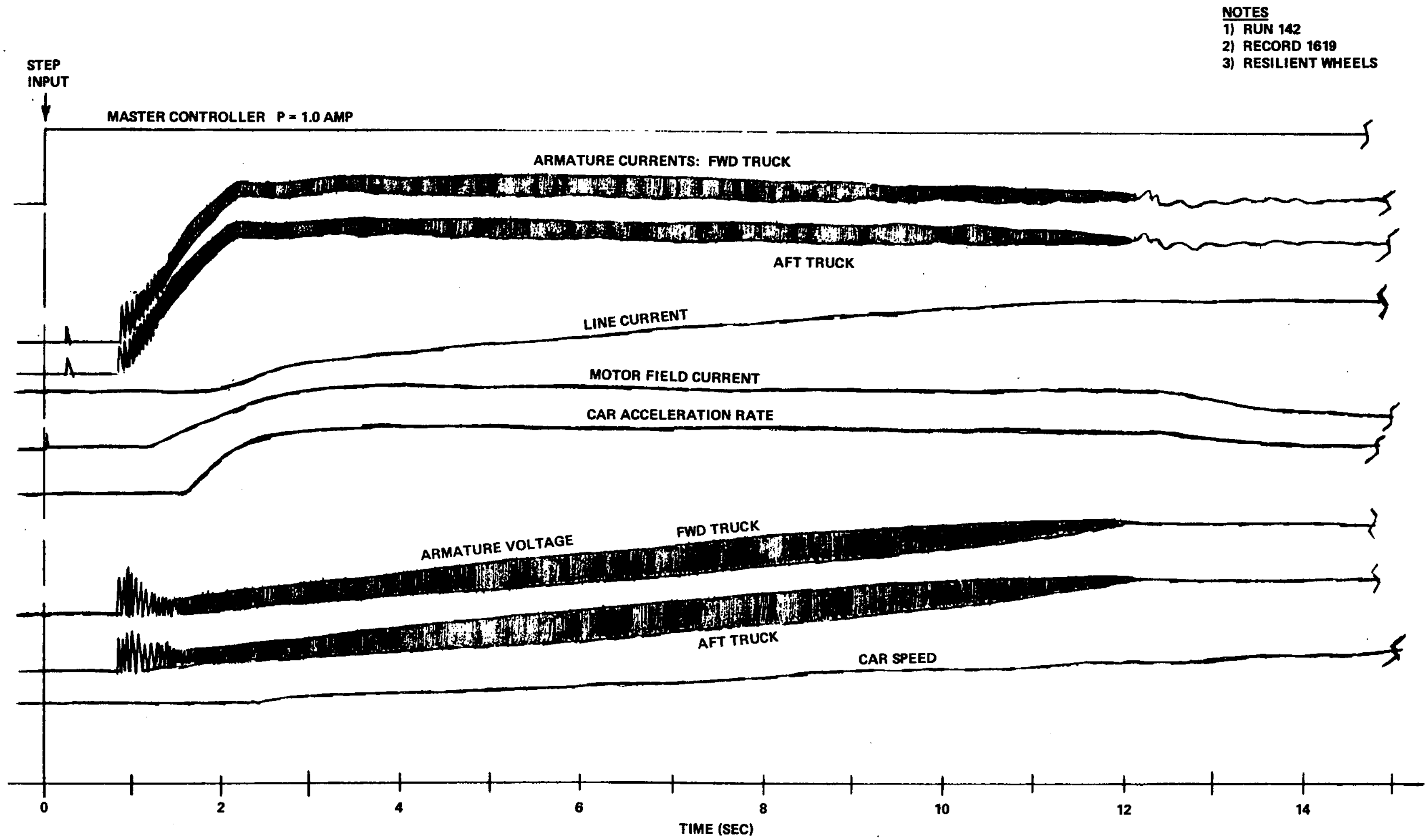
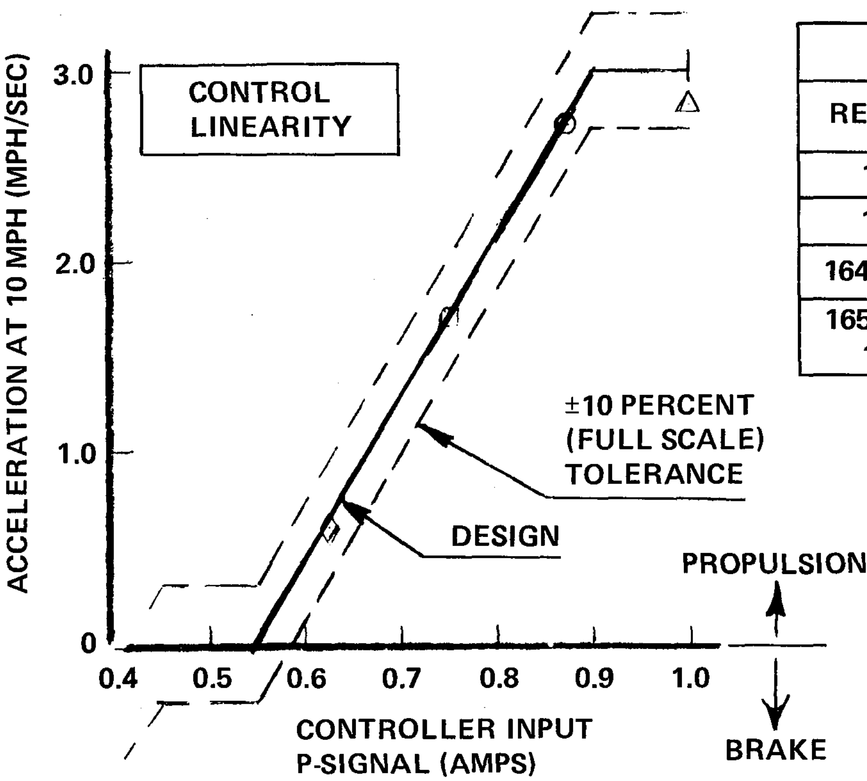
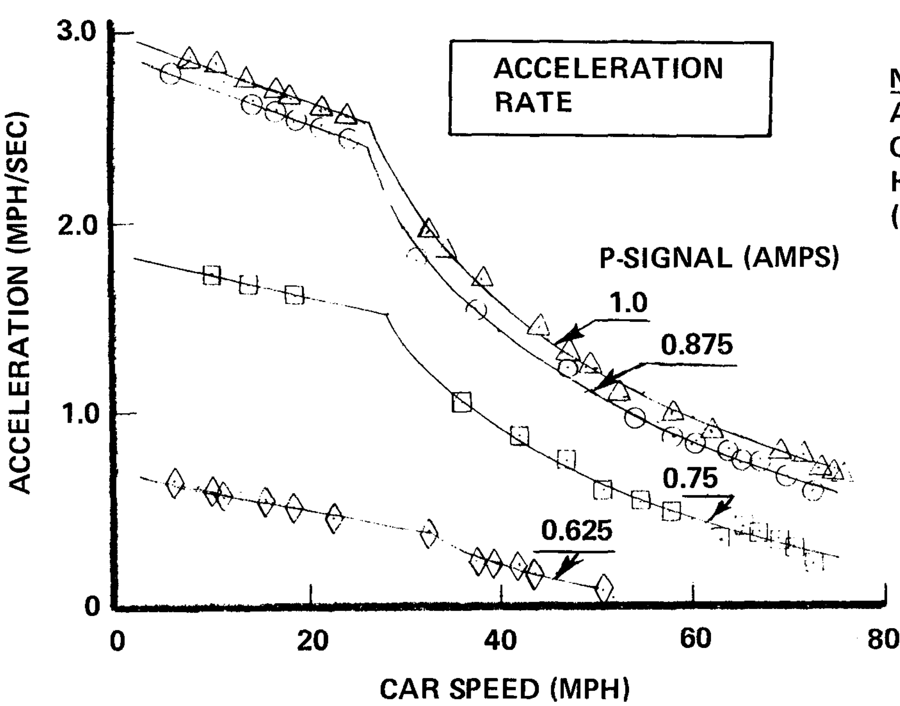


Figure 2–4. Time History of Typical Initial Acceleration (105,000-Pound Car; 600 Volts)



RUN 142		
RECORD	P-SIGNAL (AMPS)	SYMBOL
1619	1.0	△
1637	0.875	○
1643,1648	0.75	□
1653,1700 1705	0.625	◇



NOTE
ACCELERATION RATE OBTAINED FROM TIME HISTORY OF SPEED ($\Delta V/\Delta T$)

Figure 2–5. Acceleration Control Characteristics (105,000-Pound Car; Nominal 600 Volts)

RUN 142		
SYMBOL SPEED DIST	RECORD	P-SIGNAL
○ ●	1619	1.0
□ ■	1637	0.875
◇ ◆	1643 1648	0.75
△ ▲	1653 1700 1705	0.625

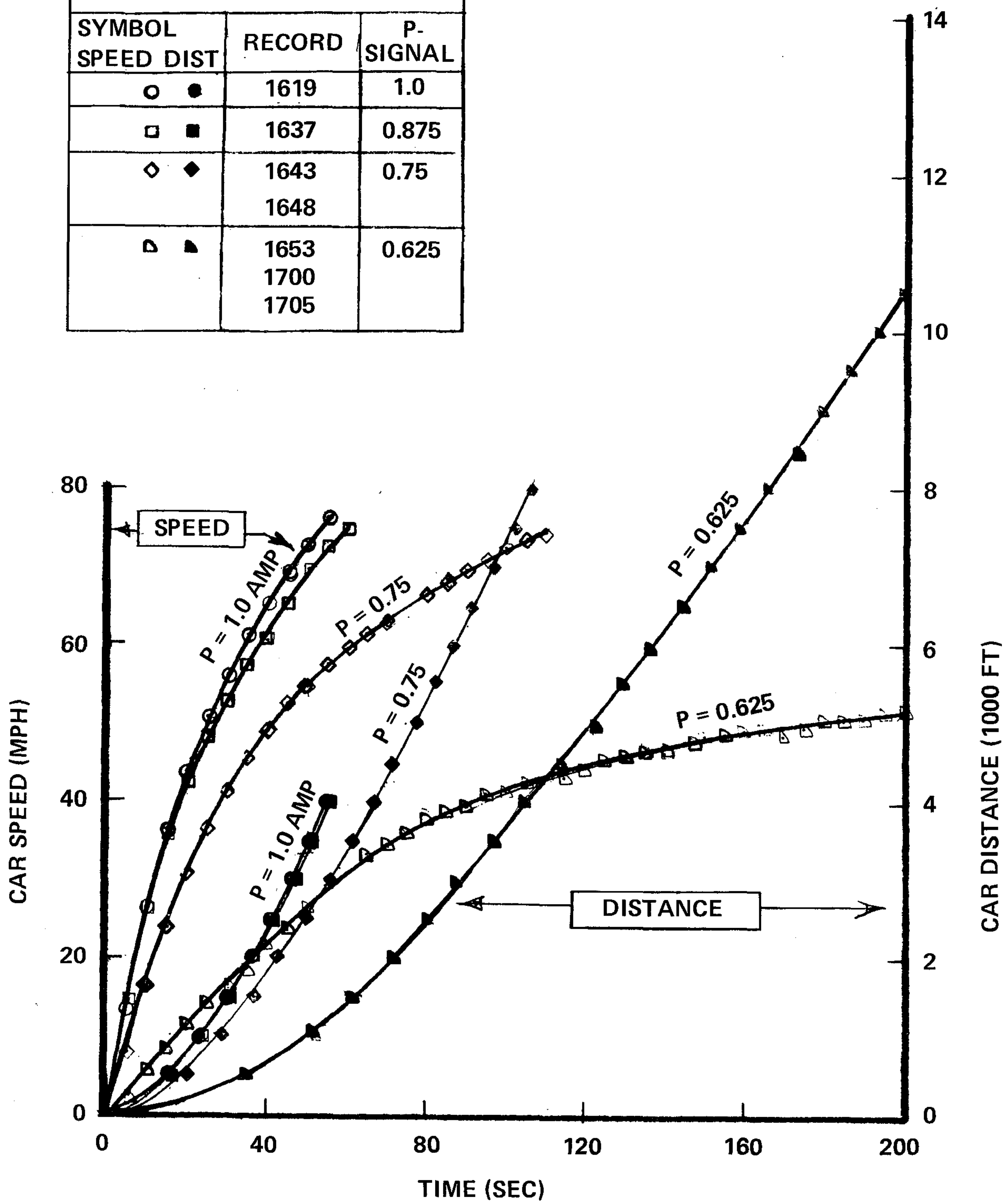


Figure 2–6. Time-, Distance-, and Speed-to-Accelerate Control Characteristics (105,000-Pound Car; Nominal 600 Volts)

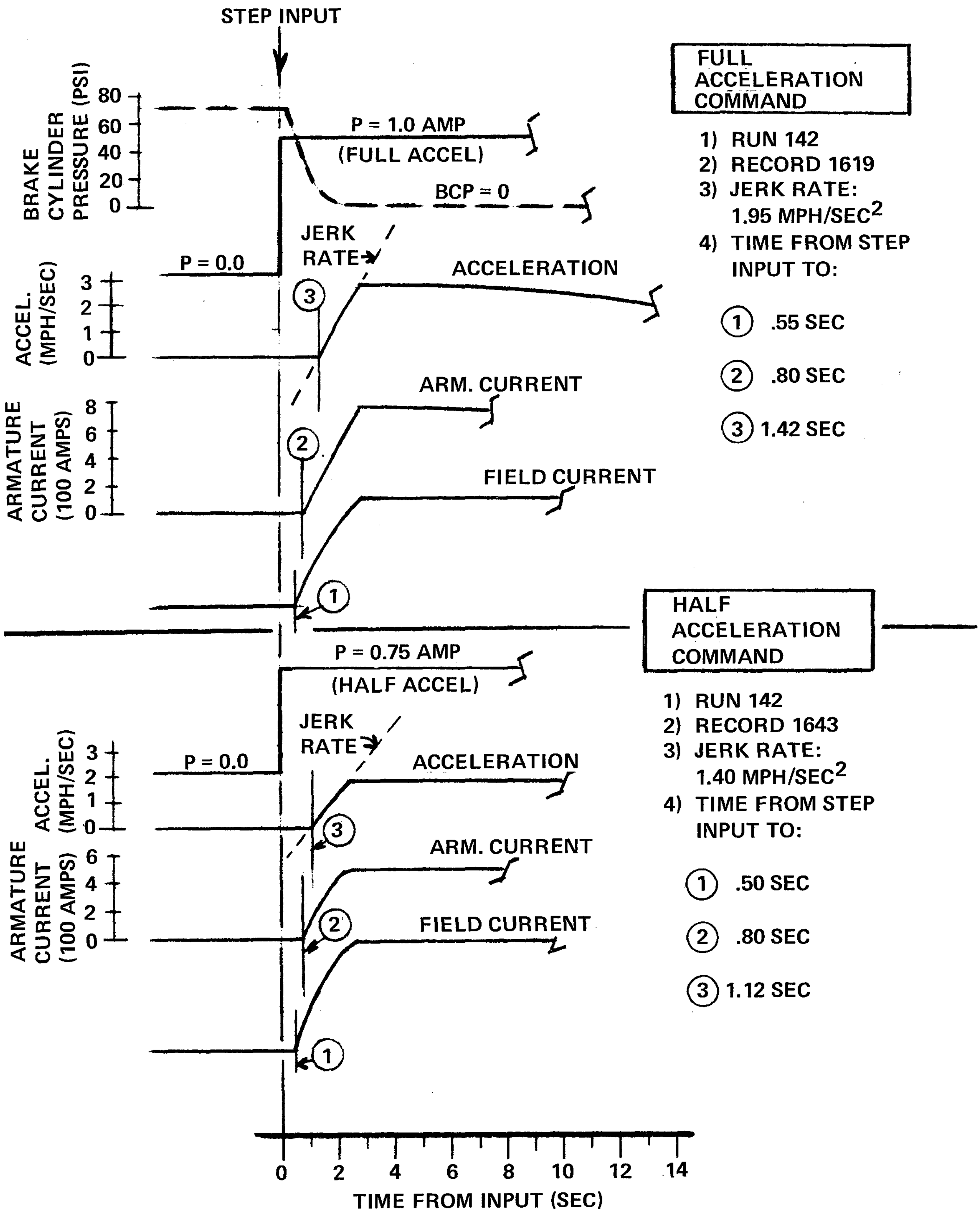


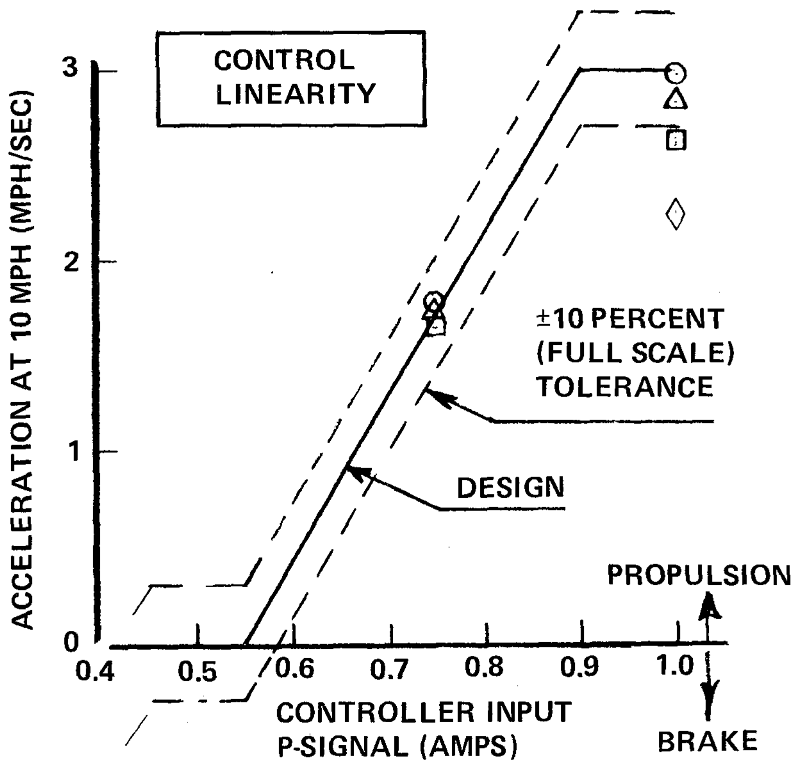
Figure 2—7. Acceleration Deadtime and Jerk Rates (105,000-Pound Car; 600 Volts)

shown in the upper part of Figure 2-8; time-speed-distance characteristics are shown on Figure 2-9 in standard output format.

2.5.5 Off-Nominal Track Voltage

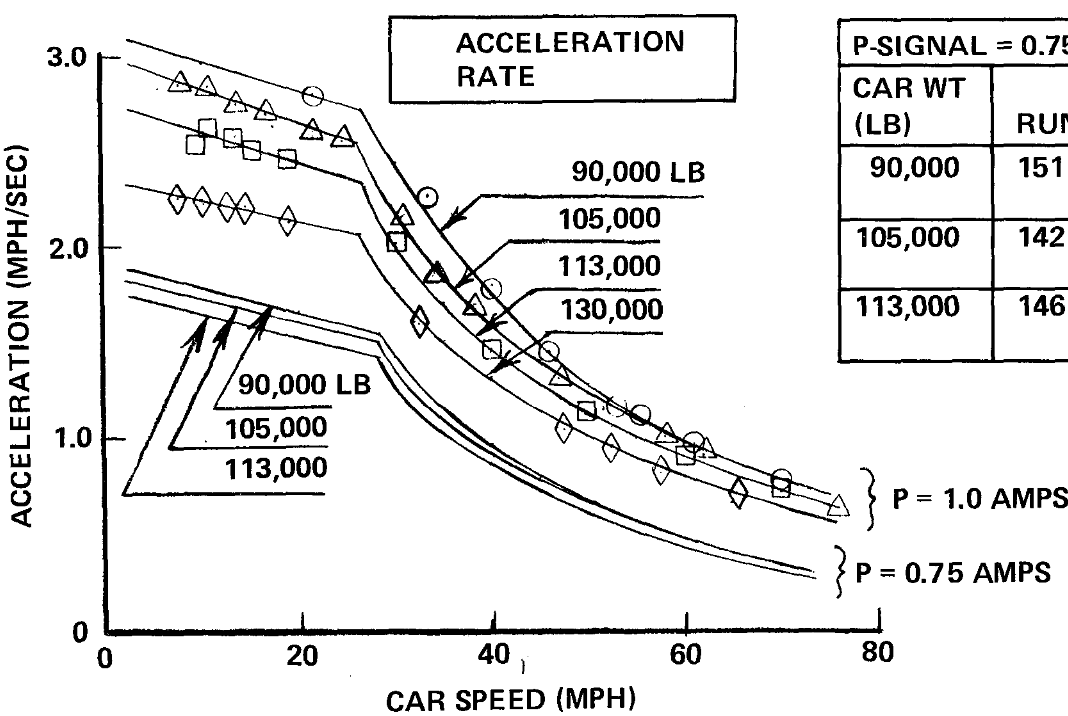
The SOAC was designed for a normal operating track voltage of 600 volts. The propulsion system's sensitivity to off-design voltages (above and below 600 volts) was tested at 105,000-pound car weight and nominal voltages of 650, 600, and 475 volts under full accelerating current demand. The Pueblo track power supplies and third rail resistance combined to provide a relatively soft system as illustrated in Figure 2-3. For example, line voltage drops from 698 volts at minimum load to 580 volts at full accelerating load (1450 amps). This is considered a "nominal 600 volts". The nominal 650-volt and 475-volt conditions were set at full accelerating current on the 4000-foot test section. The resulting acceleration data are shown in Figure 2-10 along with the actual voltage obtained during each record. Figure 2-11 illustrates the time-speed-distance characteristics associated with each voltage. The time-speed-distance data are useful in determining SOAC schedule service performance under adverse voltage conditions.

Track voltages less than nominal 450 volts could not be tested as the propulsion system is designed to shut down at voltages less than approximately 450 to 425 volts.



CAR WT (LB)	SYMBOL
90,000	○
105,000	△
113,000	□
130,000	◇

P-SIGNAL = 1.0 AMPS		
CAR WT (LB)	RUN	RECORD
90,000	151	1405
105,000	142	1619
113,000	146	1537
130,000	148	1457



P-SIGNAL = 0.75 AMPS		
CAR WT (LB)	RUN	RECORD
90,000	151	1417 1423
105,000	142	1643 1648
113,000	146	1543 1550

Figure 2-8. Acceleration Car Weight Effects.

CAR WEIGHT (LB)	RUN	RECORD	SYMBOL SPEED	DIST
90,000	151	1405	○	●
105,000	142	1619	△	▲
113,000	146	1537	□	■
130,000	148	1457	◇	◆

NOTE: P-SIGNAL = 1.0 AMPS

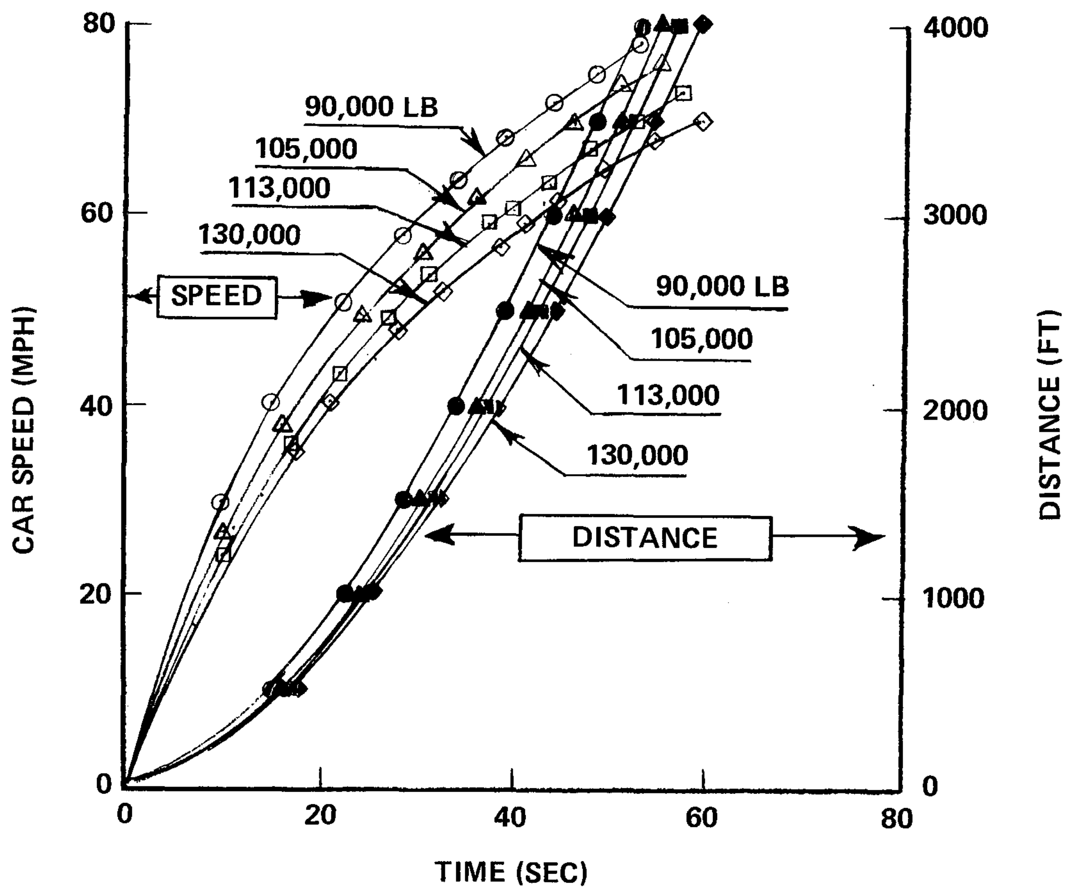


Figure 2–9. Time-, Distance-, and Speed-to-Accelerate Car Weight Effects

NOMINAL VOLTAGE	RUN	RECORD	WHEELS	SYMBOL	ACTUAL VOLTS*
650	103	1105	SOLID	□	650
	143	1104	RESILIENT	———	630
600	142	1619	RESILIENT	— — —	580
475	104	430,435 440	SOLID	△	475
	143	1204,1211	RESILIENT	———	460

*ABOVE 30 MPH

NOTE: P-SIGNAL = 1.0 AMPS

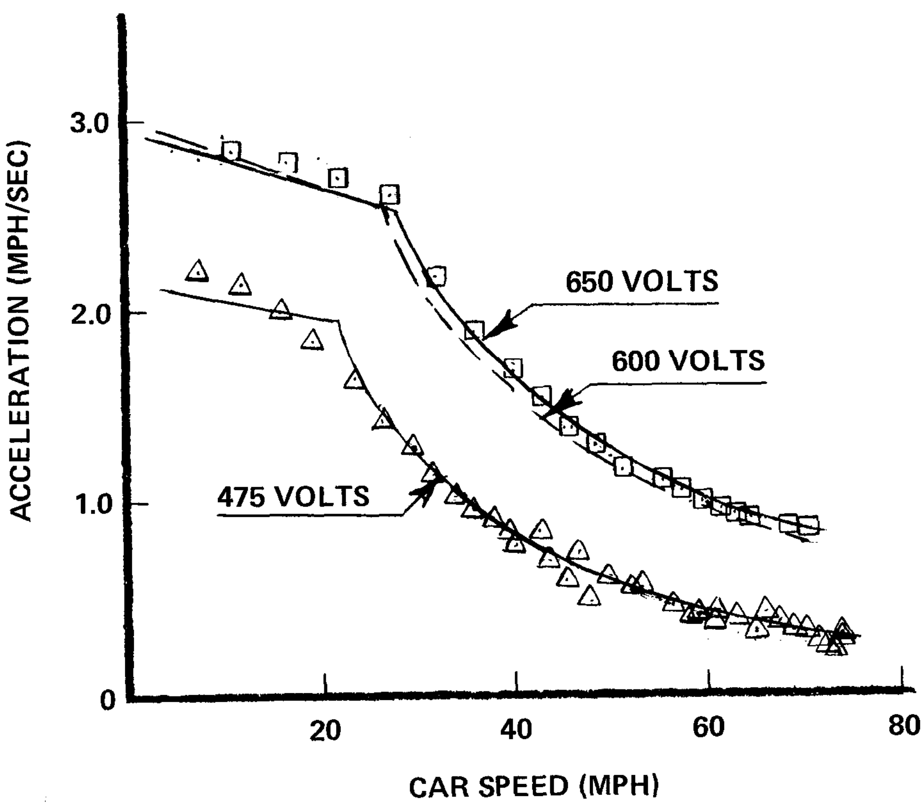


Figure 2–10. Acceleration at Off-Nominal Track Voltage (105,000-Pound Car).

VOLTAGE	RUN	RECORD	SYMBOL SPEED	SYMBOL DIST	ACTUAL VOLTS
650	143	1104	□	■	630
600	142	1619	○	●	580
475	143	1204 & 1211	△	▲	460

NOTE: P-SIGNAL = 1.0 AMPS

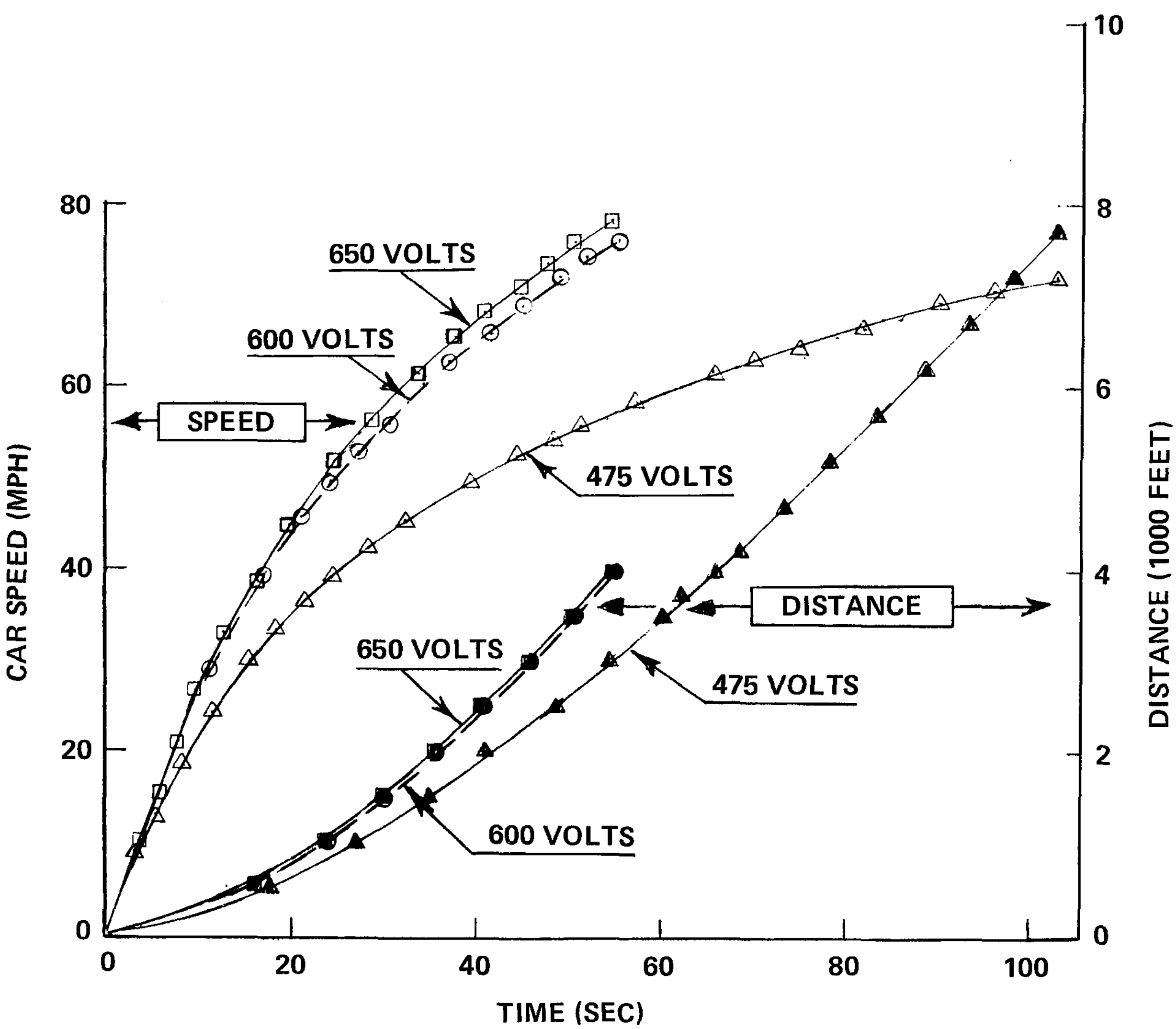


Figure 2–11. Time-, Distance-, and Speed-to-Accelerate at Off-Nominal Track Voltage (105,000-Pound Car)

Section 3

DECELERATION TESTS

3.1 SUMMARY

Test Sequence

Table 3-1 presents a log of test runs and records obtained during deceleration testing.

Test Procedures

SOAC-P-3001-TT (through 3004) baseline test procedures were used at four controller inputs, four car weights, three line voltages, and with four types of braking modes.

Objective

The objective of the deceleration testing was to determine the overall characteristics and stopping distances associated with the four SOAC braking modes (blended, dynamic only, service friction only, emergency friction) throughout the operating range of the car.

Status

All data shown on Table 3-1 have been reduced and are available in digitized, tabulated time-history format. The car performance level and data reduction problems noted in Section 2 also apply to deceleration testing, although to a lesser extent. Solid wheel data is used to define control response and weight effects for blended and dynamic braking only. Service friction and emergency braking data are based on resilient wheel testing due to improper brake pressure adjustments made during solid wheel tests (all 105,000-pound data is considered valid since this is the car's design weight and pressures were adjusted at this weight).

3.2 TEST DESCRIPTION

In general, the deceleration tests were performed by accelerating the car to the target test speed prior to entering the

TABLE 3-1. SOAC ENGINEERING TEST RUN LOG

Type of Test: Deceleration
Type of Wheels: Solid Steel

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
5/3/73	096	510 515 530 535	1	Blended braking	0. 0. 0. 0.	80 60 40 20	90,000	2	fwd	600	Prior to propulsion modifications
		540 542 544 546	1	Blended braking	0.25 0.25 0.25 0.25	80 60 40 20	90,000	2	fwd	600	Prior to propulsion modifications
5/8/73	099	1145 1155 1200 1205 1210	1&3	Service friction braking	0. 0. 0. 0. 0.	80 60 40 20 80	90,000	2	fwd	600	Prior to propulsion modifications Suspect friction BCP
5/8/73	100	155 200 205 210 215	3	Service friction braking	0.25 0.25 0.25 0.25 0.25	20 40 60 80 20	90,000	2	fwd	600	Prior to propulsion modifications Suspect friction BCP
5/9/73	102	205 210 220 225 230 235 240 245	1	Blended braking (fwd and rev)	0. 0. 0. 0. 0. 0. 0. 0.	80 60 40 20 80 60 40 20	105,000	2	fwd fwd fwd fwd rev rev rev rev	600	Prior to propulsion modifications
		325 330 335 345	1	Blended braking (control)	0.125 0.25 0.375 0.375	80 80 80 30	105,000	2	fwd	600	
5/9/73	102	350 355 400 405 415	1	Service friction braking (control)	0. 0.125 0.25 0.375 0.375	80 80 80 80 51	105,000	2	fwd	600	Prior to propulsion modifications
		425 430 435 440 445	1		0. 0.125 0.25 0.375 0.375	80 80 80 80 37	105,000	2	fwd	600	
5/10/73	103	1120	1	Blended braking	0.	80	105,000	2	fwd	650	Prior to propulsion modifications
5/10/73	104	500	1	Blended braking	0.	80	105,000	2	fwd	475	Prior to propulsion modifications

TABLE 3-1. SOAC ENGINEERING TEST RUN LOG (CONTINUED)

Type of Test: Deceleration
Type of Wheels: Solid Steel

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
6/9/73	126	645	3B	Dynamic only	0.	78	113,000	2	fwd	600	Prior to propulsion modifications
		700 705 720 730	3B	Blended braking	0. 0. 0. 0.	59 40 78 59	113,000	2	fwd	600	
		735 740 745	3B	Service friction braking	0. 0. 0.	78 59 40	113,000	2	fwd	600	Suspect friction BCP and hung-up brake
		750 755	3B	Blended friction	0.25 0.25	78 78					
6/11/73	127	1015 1035 1040 1045 1050 1055	2B	Emergency friction braking	N/A	20 20 40 40 59 59	130,000	2	fwd	600	Prior to propulsion modifications Suspect friction BCP and hung-up brake
6/11/73	127	1115 1135 1122 1130 1140 1145	2B	Emergency friction brake	N/A	20 20 40 40 59 59	130,000	2	rev	600	Prior to propulsion modifications Suspect friction BCP and hung-up brake

TABLE 3-1. SOAC ENGINEERING TEST RUN LOG (CONTINUED)

Type of Test: Deceleration
Type of Wheels: Resilient

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
7/16/73	144	1640	14	Blended braking	0.	78	105,000	2	fwd	600	After propulsion modifications
		1646			0.	59					
		1650			0.	41					
		1654			0.	40					
		1656			0.	21					
		1705	14		0.	78			rev	600	
		1713			0.	61					
		1719			0.	40					
		1720			0.	20					
		1722	14	Service friction braking	0.	20	105,000	2	rev	600	
		1724			0.	21			rev		
		1729			0.	41			rev		
		1732			0.	58			rev		
		1736			0.	79			rev		
		1741			0.	78			fwd		
		1746			0.	38			fwd		
		1835	14	Emergency friction braking	N/A	39	105,000	2	fwd	600	BCP set to 78 psi
		1841				20					
		1850				62					
		1855				78					
7/17/73	146	1644	14	Blended braking	0.	79	113,000	2	fwd	600	
		1648			0.	60					
		1654			0.	41					
		1657			0.	20					
		1734			0.25	79					
7/17/74	146	1611	14	Service friction braking	0.	80	113,000	2	fwd	600	After propulsion modifications
		1621			0.	41					
		1626			0.	20					
		1631			0.	60					
		1636			0.	77					
		1742			0.25	78					
		1753	14	Dynamic	0.	78	113,000	2	fwd	600	
		1702	14	Emergency friction braking	N/A	20	113,000	2	fwd	600	
		1704				40					
		1708				60					
		1714				80					
7/18/73	148	1345	14	Blended braking	0.	20	130,000	2	fwd	600	After propulsion modifications
		1351			0.	39			fwd		
		1355			0.	60			fwd		
		1403			0.	62			rev		
		1408			0.	42			rev		
		1411			0.	20			rev		
		1420	14	Service friction	0.	60	130,000	2	fwd		
		1427	14	Emergency friction braking	N/A	60			fwd		
		1432				40			fwd		
		1438				20			fwd		
		1452				61			rev		
7/19/73	151	1428	14	Service friction	0.	79	90,000	2	fwd	600	After propulsion modifications
		1436	14	Emergency friction	N/A	78	90,000	2	fwd		

Station 300 to Station 340 test zone. The brake systems were preset so that the proper combination of brakes could be applied by the motorman upon entering the test zone. At the beginning of the test zone, braking was commanded at the desired control input in a manner approaching a step input (release of controller handle for FULL SERVICE; rapid handle movements for less than full service; and EMERGENCY STOP pushbutton for emergency braking).

The four possible system combinations were set up as follows:

1. Blended Braking

   Normal operation with input by master controller at "brake" marker on the wayside.

2. Service Friction Braking Only

   Traction system dynamic brake "failed" prior to test zone by simulated traction motor cooling airflow loss with remote switch in cab. Friction brakes applied using master controller at "brake" marker.

3. Dynamic Braking Only

   Service friction brakes were cut out at each truck's analog valve prior to initiating testing. Emergency brake system remained operable. Dynamic brakes applied using master controller at "brake" marker.

4. Emergency Friction Braking

   Normal operation using EMERGENCY STOP pushbutton on motorman's console.

3.3 INSTRUMENTATION

The instrumentation parameters recorded during deceleration testing are shown on the following tables. The individual data sheets are applicable to the test runs specified in the Test Run Log, Table 3-1.

Data Sheet No.	Table
1	3-2
3 (3B)	3-3
2B	3-4
14	3-5

Time and distance to stop were recorded from hand-held stop watches and a surveyor's steel chain marked to 1/10 of a foot.

TABLE 3-2. LABORATORY TAPE RECORDER DATA SHEET NO. 1

Test Title Performance Test Type Deceleration

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/1/73 Test Eng ____ Tech RPM-DLB Tape Type & Size ____

Tape Recorder Model No. SABRE III Tape Recorder S/N ____ Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph
1	Line E	Volt/Div		±10.0VDC	FM	3.375 KC	+ 1000 VDC = + 10.000 VDC	X
2	Line I	3000 Amp Hall		±10.0VDC	FM	3.375 KC	+ 2000 ADC = + 10.000 VDC	
3	Long. Accel	0.25G S/N 2807		±5.0VDC	FM	3.375 KC	±0.25G = ± 5.000 VDC	X
4	Speed #3 Axle			±5.0VDC	FM	3.375 KC	80 MPH = + 5.000 VDC	X
5	#1 Truck Arm E	Volt/Div		±5.0VDC	FM	3.375 KC	+ 1000 VDC* = +5.000 VDC	
6	Sync			±5.0VDC	FM	3.375 KC		
7	#2 Truck Arm E	Volt/Div		±5.0VDC	FM	3.375 KC	+ 1000 VDC* = +5.000 VDC	
8	#1 Truck Arm I	1000 Amp A-A-C S/N 31		±5.0VDC	FM	3.375 KC	+ 1000 ADC = +5.000 VDC	X
9	#2 Truck Arm I	A-A-C S/N 31		±5.0VDC	FM	3.375 KC	+ 1000 ADC = + 5.000 VDC	
10	#1 Truck Field I	SOAC Monitor		±5.0VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
11	#2 Truck Field I	SOAC Monitor		±5.0VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
12	P Wire I			±5.0VDC	FM	3.375 KC	+ 1.0 ADC = 5.000 VDC	X
13	Brake Press Axle #3	200 PS Tabor Model 185		±5.0VDC	FM	3.375 KC	100 PSI = + 5.000 VDC	X
14	Event			±5.0VDC	FM	3.375 KC	2 HZ Signal	X
Edge A					Dir.			
Edge B	Voice							

* Later changed to 1200 volts DC on Data Sheet 1B

TABLE 3-3. LABORATORY TAPE RECORDER DATA SHEETS 3 AND 3B

Test Title Performance Test Type Deceleration

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/ /73 Test Eng ______ Tech RPM DLB Tape Type & Size 3M 7200 ft

Tape Recorder Model No. SABRE III Tape Recorder S/N 7267 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph
1	Line E	Volt/Div		10.0VDC	FM	3.375 KC	+ 1000 VDC = +10.000 VDC	X
2	Line I	3000 Amp Hall		10.0VDC	FM	3.375 KC	+ 2000 ADC = +10.000 VDC	
3	Long. Accel.	0.25G S/N 2807		5.0VDC	FM	3.375 KC	± 0.25G = ± 5.000 VDC	X
4	Speed #3 Axle			5.0VDC	FM	3.375 KC	80 MPH = +5.000 VDC	X
5	#1 Truck Arm E	Volt/Div		5.0VDC	FM	3.375 KC	+ 1000 VDC* = + 5.000 VDC	
6	Sync			5.0VDC	FM	3.375 KC		
7	Analog Valve I			5.0VDC	FM	3.375 KC	100% = -5.000 VDC	
8	#1 Truck Arm I			5.0VDC	FM	3.375 KC	1000 ADC = + 5.000 VDC	X
9	#2 Truck Arm I			5.0VDC	FM	3.375 KC	1000 ADC = + 5.000 VDC	
10	#1 Truck Field I	Monitor		5.0VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
11	#2 Truck Field I	Monitor		5.0VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
12	P-Wire I			5.0VDC	FM	3.375 KC	+ 1.0 ADC = -5.000 VDC	X
13	Brake Press Axle #1	200 PSI Tabor Model 185		5.0VDC	FM	3.375 KC	100 PSI = + 5.000 VDC	X
14	Event			5.0VDC	FM	3.375 KC	2 HZ/SEC Sig.	X
Edge A								
Edge B	Voice				Dir			

* Later changed to 1200 volts DC on Data Sheet No. 3B

TABLE 3-4. LABORATORY TAPE RECORDER DATA SHEET NO. 2B

Test Title Performance   Test Type Deceleration

Specimen P/N ______ Specimen S/N ______ Test Location Pueblo

Date 6/8/73 Test Eng ______ Tech RPM DLB   Tape Type & Size 3M 7200 ft

Tape Recorder Model No. 3614 SABRE III Tape Recorder S/N 7267   Tape Speed 1-7/8 IPS   Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph
1	Line E			10 VDC	FM	3.375 KHz	+ 1000 VDC = + 10.00 VDC	
2	Line I			10 VDC	FM	3.375 KHz	+ 2000 ADC = +10.00 VDC	
3	Long. Accel			5.0 VDC	FM	3.375 KHz	± 0.25G = ± 5.00 VDC	
4	Axle 3 Speed			5.0 VDC	FM	3.375 KHz	80 MPH = + 5.00 VDC	
5	Monitor Axle 4 Speed			5.0 VDC	FM	3.375 KHz	100 MPH = + 5.00 VDC	
6	Sync			5.0 VDC	FM	3.375 KHz		
7	Analog Valve I			5.0 VDC	FM	3.375 KHz	100% = -5.00 VDC	
8	#1 Truck Arm I			5.0 VDC	FM	3.375 KHz	1000 ADC = + 5.00 VDC	
9	#2 Truck Arm I			5.0 VDC	FM	3.375 KHz	1000 ADC = + 5.00 VDC	
10	Axle 1 Speed			5.0 VDC	FM	3.375 KHz	80 MPH = + 5.00 VDC	
11	Axle 2 Speed			5.0 VDC	FM	3.375 KHz	80 MPH = + 5.00 VDC	
12	P Wire I			5.0 VDC	FM	3.375 KHz	1.00 ADC = -5.00 VDC	
13	Brake Press Axle			5.0 VDC	FM	3.375 KHz	100 PSIG = + 5.00 VDC	
14	Event			5.0 VDC	FM	3.375 KHz	2 HZ Pulse with event	
Edge A	Voice				Dir			
Edge B					Dir			

TABLE 3-5. LABORATORY TAPE RECORDER DATA SHEET NO. 14

Test Title Performance Test Type Deceleration

Specimen P/N SOAC No. 2 Car Specimen S/N ____ Test Location Pueblo

Date 7/14/73 Test Eng ____ Tech RPM-DLB Tape Type & Size 1 in. x 7200 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph Location
1	301 Long Accel	±0.25G's		±5.00VDC	FM	3.375 KC	± 0.25G's = ± 5.00 VDC	R/H
2	302 Line E	Volt/Div. S/N 002		±5.00VDC	FM	3.375 KC	Zero VDC = -5.00 VDC + 1000 VDC = +5.00 VDC	L/H
3	303 Line I	3000 Amp Hall Device		±5.00VDC	FM	3.375 KC	Zero ADC = -5.00 VDC + 2000 ADC = +5.00 VDC	L/H
4	304 #1 Arm E	Volt/Div S/N 001		±5.00VDC	FM	3.375 KC	+ 1200 VDC = 5.00 VDC	L/H
5	305 #1 Arm I	1000 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+ 1000 ADC = 5.00 VDC	R/H
6	306 #1 Field I	150A S/N 57	3 Turns 50A=5.0 VDC x 1	±5.00VDC	FM	3.375 KC	± 50 ADC = ± 5.00 VDC	L/H
7	307 #2 Arm E	Volt/Div S/N 003		±5.00VDC	FM	3.375 KC	+ 1200 VDC = 5.00 VDC	L/H
8	308 #2 Arm I	1000 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+1000 ADC = 5.00 VDC	R/H
9	309 #2 Field I	500 A AM-A-C	5 Turns 50A=2.5 VDC x 2	±5.00VDC	FM	3.375 KC	± 50 ADC = ± 5.00 VDC	L/H
10	310 P Wire I	1.0 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+ 1.0 ADC = 5.00 VDC	R/H
11	311 Analog Valve I	5.0 Amp AM-A-C		±5.00VDC	FM	3.375 KC	5.0 ADC = 5.00 VDC	L/H
12	315 Speed	Monopole		±5.00VDC	FM	3.375 KC	80 MPH = 626.5 HZ	R/H
13	318 Brake Press	Tabor 0-200 PSIG Mod 185		±5.00VDC	FM	3.375 KC	100 PSIG = +5.00 VDC	R/H
14	Time Code	Irig B		±5.00VDC	FM	3.375 KC		Both (2)
Edge A							NOTE: D.S. #14 for Post-Wheel Change Data Only.	
Edge B	Voice & Event				Dir			Both (2)

Event marks on the tape were also used for time measurements.

The data reduction was carried out in a manner similar to acceleration testing previously defined in Section 2. Data was digitized at one or two-second intervals using filtering on applicable channels. Descriptions of parameters, sensors and calibrations are contained in Volume VI of this report.

3.4 TEST PROCEDURES

Test procedures used during the SOAC deceleration testing are contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1). In Section 2, these procedures provide sufficient information for car operation and setup for each brake system test. For baseline tests the SOAC procedures have been generalized and are contained in REVISED GENERAL VEHICLE TEST PLANS (Reference 2). The following procedures are applicable:

Type of Test	Procedure
Blended Braking	RB-P-3001-TT
Service Friction Only	RB-P-3002-TT
Dynamic Only	RB-P-3003-TT
Emergency	RB-P-3004-TT

The procedure for blended braking follows. Other braking procedures are found in Reference 2.

I. Preliminary (pre-test)

A. Attach instrumentation or patch in desired parameters at storage or shop.

B. Add ballast weights to simulate desired car weight (AW______).

C. Check out and calibrate instrumentation.

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

E. Make up desired train consist.

F. Proceed to test zone.

G. Make inspection passes over test zone. Check out vehicle and track.

H. Record ambient conditions as required.

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

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

II. Test Procedure (at test zone)

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

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

C. Identify test record and start recorders.

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

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

F. Decelerate car to full stop with master controller in the required input position.

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

H. Vehicle Stops: Stop timing devices, put event mark on recorders, stop recorders.

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

J. Reposition vehicle for next test record.

Option (1)

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

K. Repeat Items A through J with target entry speed as defined above.

Option (2)

Repeat Items A through K as required to provide sufficient confidence in data accuracy.

Option (3)

Repeat Items A through K such that target speeds of 80, 60, 40 and 20 mph are tested (as required).

Option (4)

Repeat Items A through K in the reverse car direction as required. Station 340 becomes the "brake" mark.

Option (5)

Repeat Items A through K at the desired input command positions.

Option (6)

Repeat Items A through K at the desired car weights.

Option (7)

Repeat Items A through K at the desired line voltages.

Option (8)

Repeat Items A through K with the desired train consists.

Option (9)

Repeat Items A through K with the desired brake blending ratios (dynamic/friction).

Option (10)

Repeat Items A through K with the desired line receptivity (regeneration "load") as applicable.

Using the preceding blended braking test procedure, the following blended braking combinations were tested:

Controller Inputs (amperes)

0.0, 0.125, 0.25, 0.375

Track Voltage Nominal (Volts)

650, 600, 475

Car Weights (pounds)

90,000; 105,000; 113,000; 130,000

Initial Speeds (mph)

80, 60, 40, 20

(Note: Not all tests were performed at all conditions.)

Service friction, dynamic, and emergency braking were tested within the above test conditions, using procedures similar to blended braking. See Test Run Log (Table 3-1) for exact conditions.

3.5 TEST DATA

3.5.1 Test Data Reduction

Two sets of deceleration data were recorded during the test program. As noted in Section 2, Acceleration, the combination of wheel change, car performance level change and data reduction problems (filtering and zero shift) precludes any valid comparisons between solid and resilient wheel deceleration performance. (No differences were expected using blended or dynamic braking only.)

Because of the filtering and zero shift problems found in the digitized resilient wheel test data, the solid wheel test data were used as the basis for control, weight and track voltage comparisons. The full-service deceleration rate differences between the two data sets are shown in Figure 3-3 at 105,000 pounds. This rate difference is 0.1 to 0.2 mphps and both data sets are within SOAC specification tolerances (3.0 mphps ±0.3 mphps). A more complete description of data reduction problems is contained in Section 2, Paragraph 2.5.1.

3.5.2 Sample Data Output

As with the acceleration data three types of standard outputs were used in the deceleration data reduction. Samples of these appear in the following illustrations and tables:

1. Table 3-6 shows a sample output of tabulated digitized data from resilient wheel tests.

2. Figure 3-1 is a digital time-history of Table 3-6 data.

TABLE 3-6. TEST RECORD NO. 1640 (RUN 144: BLENDED BRAKING STOP FROM 78 MPH; FULL-SERVICE RATE; 105,000-POUND CAR)

TEST RECORD NUMBER 1640

SOAC DATA REDUCTION — TEST RUN 144 — DATE 7/18/73

REQUEST NUMBER...47

"DIGITIZE"

TIME SEC	EVENT	SPEED MPH	P-WIRE AMPS	ACCEL MPH/SEC	LINE VOLT	LINE AMPS	MOTOR NO.1 VOLTS (TRUCK)	MOTOR NO.2 VOLTS (TRUCK)	ARMATURE NO.1 AMPS	ARMATURE NO.2 AMPS	FIELD NO.1 AMPS	FIELD NO.2 AMPS	ANALOG VALVE AMPS (NO. 1 TRUCK)	BRAKE PRESSURE PSI (NO. 1 TRUCK)
T = 0.	"BRAKE" +.75	78.16	0.749	0.41	638.	723.	622.1	627.5	333.2	323.5	9.6	7.3	-3.09	-1.5
1.		78.65	-0.005	0.55	658.	587.	648.1	658.4	238.6	235.5	9.0	7.8	-2.20	-1.5
2.		78.23	-0.015	0.09	733.	41.	184.7	64.9	-14.8	-7.4	0.2	0.8	-2.19	-1.6
3.		77.69	-0.015	-1.01	719.	41.	-483.2	-517.6	331.5	325.7	-10.2	-9.6	-1.47	14.9
4.		74.94	-0.016	-2.65	715.	42.	-1108.2	-1133.5	741.7	713.3	-26.6	-26.2	-2.21	7.2
5.		71.96	-0.015	-2.50	712.	34.	-1198.2	-1210.3	790.3	760.7	-30.8	-31.8	-2.19	0.7
6.		69.05	-0.015	-2.58	709.	41.	-1203.8	-1215.0	794.4	754.3	-33.9	-34.8	-2.19	0.8
7.		66.03	-0.015	-2.76	705.	54.	-1207.2	-1217.4	777.4	754.7	-37.8	-38.8	-2.19	0.9
8.		63.07	-0.015	-2.95	704.	52.	-1208.2	-1218.7	775.3	753.6	-43.1	-43.9	-2.19	0.9
9.		59.81	-0.015	-2.94	704.	52.	-1152.3	-1158.9	779.4	738.6	-42.1	-44.5	-2.19	0.9
10.		56.52	-0.015	-2.75	703.	54.	-1094.8	-1102.5	757.9	744.3	-43.4	-45.0	-2.19	0.9
11.		53.58	-0.015	-2.58	702.	50.	-1036.0	-1041.4	764.8	740.3	-42.5	-45.0	-2.19	0.9
12.		50.34	-0.015	-2.82	701.	53.	-972.9	-977.7	778.4	752.9	-43.5	-44.9	-2.19	0.9
13.		47.23	-0.014	-2.77	700.	49.	-909.4	-912.6	779.6	756.3	-43.6	-44.8	-2.18	1.0
14.		44.23	-0.014	-3.06	699.	52.	-846.4	-848.3	782.0	748.3	-43.4	-45.0	-2.18	1.0
15.		40.95	-0.014	-2.75	699.	54.	-784.4	-787.5	780.8	752.3	-43.6	-45.0	-2.19	0.9
16.		37.85	-0.013	-2.71	700.	54.	-721.4	-723.8	774.1	753.8	-43.4	-45.1	-2.18	1.0
17.		34.78	-0.014	-2.79	699.	54.	-659.4	-660.0	787.0	747.2	-43.5	-45.2	-2.18	1.0
18.		31.63	-0.013	-2.75	700.	52.	-598.0	-598.6	779.8	751.8	-43.5	-45.1	-2.18	1.0
19.		28.03	-0.014	-2.82	698.	53.	-535.2	-534.9	780.8	750.5	-43.5	-45.0	-2.18	1.1
20.		25.17	-0.013	-2.80	699.	54.	-473.5	-471.9	781.5	756.5	-43.6	-44.9	-2.16	1.1
21.		22.16	-0.013	-2.78	698.	53.	-413.6	-410.8	774.8	759.1	-43.6	-45.0	-2.18	1.0
22.		19.07	-0.013	-2.75	698.	54.	-350.9	-348.4	776.7	759.8	-43.5	-45.0	-2.18	1.1
23.		15.45	-0.014	-2.85	698.	53.	-289.7	-287.3	775.8	762.2	-42.7	-44.8	-2.18	0.9
24.		12.34	-0.012	-2.76	698.	54.	-225.9	-222.5	775.8	760.5	-43.6	-44.8	-2.17	1.2
25.		9.63	-0.013	-2.77	698.	53.	-164.7	-160.6	769.1	765.1	-43.8	-44.6	-2.18	1.0
26.		6.32	-0.012	-2.87	698.	55.	-99.3	-94.5	772.2	767.8	-43.8	-44.5	-2.17	1.1
27.		3.45	0.040	0.62	683.	624.	201.2	118.1	738.6	727.5	-41.9	-48.9	-1.65	-0.9
28.		0.67	-0.012	-0.92	698.	55.	-11.6	-8.2	201.5	201.8	-45.1	-45.9	-1.32	8.0
29.	+.0	0.38	-0.013	0.41	698.	56.	-8.2	-4.0	-11.7	-6.0	-45.3	-46.7	-0.82	53.8
30.	"STOP"	0.05	-0.012	0.37	698.	56.	-6.9	-3.2	-11.3	-4.9	-45.3	-46.7	-0.82	59.8
31.		0.05	-0.013	0.37	699.	41.	-8.2	-5.3	-11.5	-7.1	-1.9	-8.3	-0.75	61.3
32.		0.05	-0.012	0.37	700.	42.	-7.7	-4.3	-10.8	-5.8	-0.6	-1.3	-0.74	65.3

ZERO SHIFT (boxed ACCEL values 0.37 at 30.–32.)

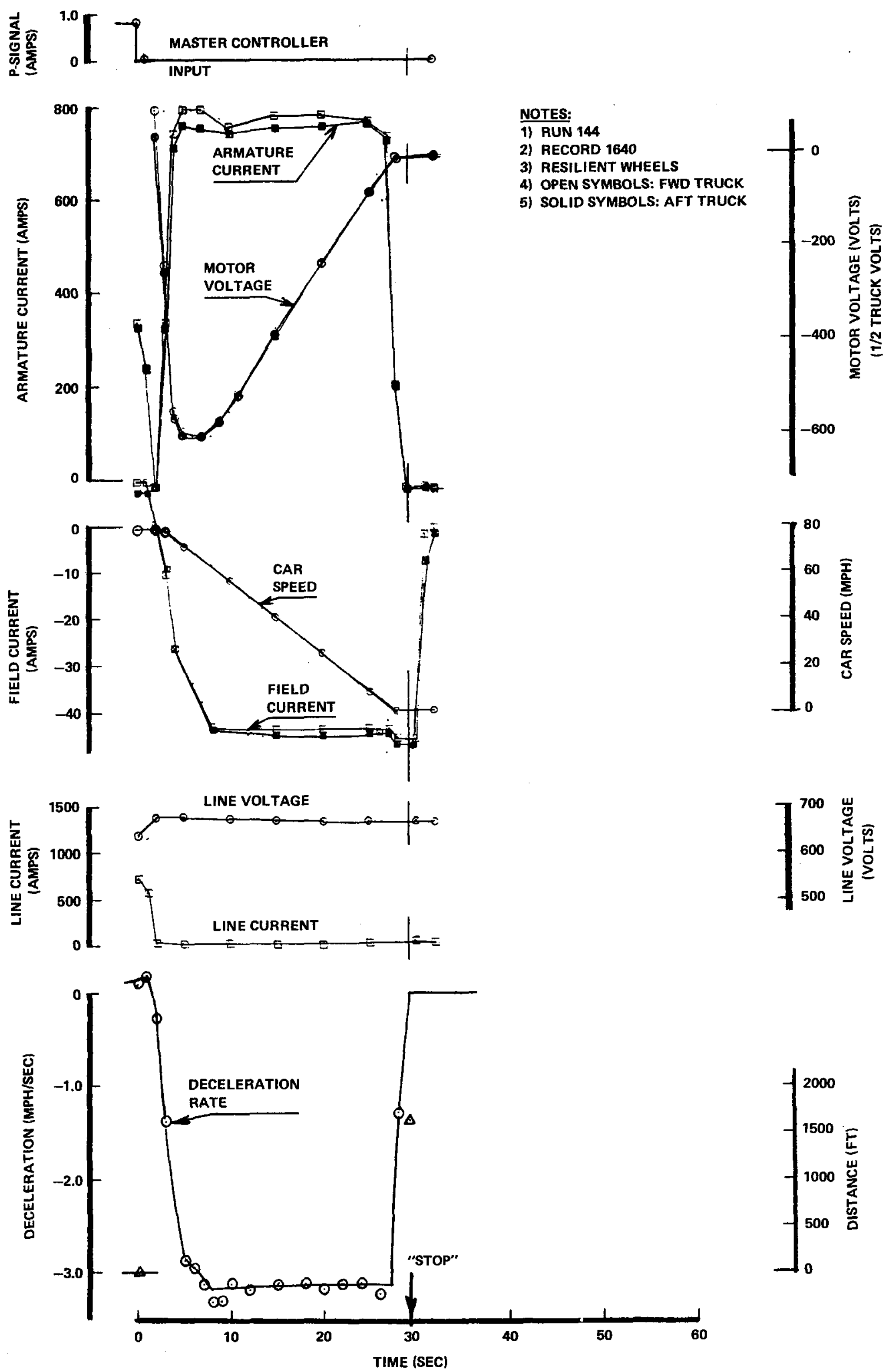


Figure 3–1. Typical Blended Deceleration Digitized Data (105,000-Pound Car).

3. Figure 3-2 is an analog time-history tracing of the quick-look oscillograph data. Calibrations are available but are not shown on this figure.

A digitized, tabulated standard output is available for all valid deceleration test records. The preliminary analyses of the standard outputs presented in the following paragraphs and figures provide a comparative base of SOAC deceleration performance and control for each brake system.

3.5.3 Blended Braking Control Characteristics

Figure 3-3 presents a summary of blended braking test data over the range of car speeds and controller inputs. This figure also shows the change in car performance experienced during the wheel change. As shown in the upper portion, the control linearity is well within the 10 percent (full-scale) tolerance band applied to the design characteristic. The slight downward curvature of the deceleration data is essentially due to the car's traction resistance as speed.

The reduced braking rate noted above 65 mph at full service brake command is due to the design voltage restrictions on the traction motors. Application of friction brake pressure during each stop was limited to 3 to 5 psi inshot pressure.

Brake blending upon initial "brake" command was verified as the brake pressure increased until the dynamic brake feedback showed sufficient brake effort to meet the entire command level (usually 1-2 seconds of increasing brake pressure). This initial blending action is mostly due to the dead-time associated with drive-dynamic brake transition, as shown in Figure 3-5.

Figure 3-4 presents time and distance to stop from speeds up to 80 mph at full service braking for both forward and reverse car directions. The differences in stopping distance associated with car direction may be attributed to commutator brush "seating" in the motors during several cycles of forward and reverse operation. The insert on Figure 3-4 shows time and distance to stop from 80 mph (corrected from 76-77 mph data) over the range of master controller inputs.

The baseline braking and control data previously shown will be of assistance in determining the SOAC's capabilities under automatic train operations and precision station stopping conditions.

Figure 3-5 illustrates the time delays and jerk limits associated with blended braking commands of 0.0 and 0.25 amps. For a full-service brake command (0.0 amp) the jerk rate is 2.66 mphps and the time for removal of tractive effort (jerk

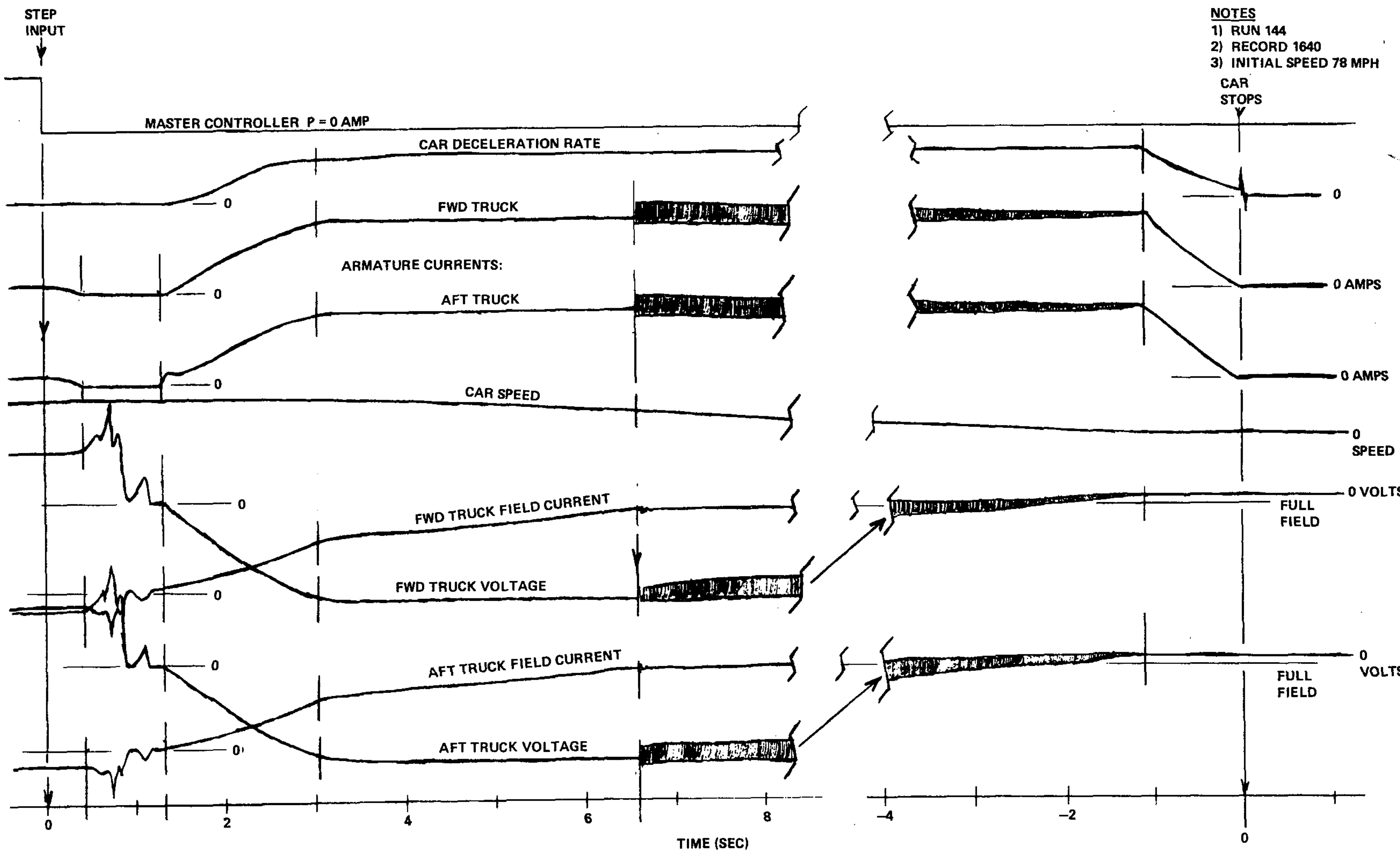


Figure 3–2. Time History of Typical Blended Braking

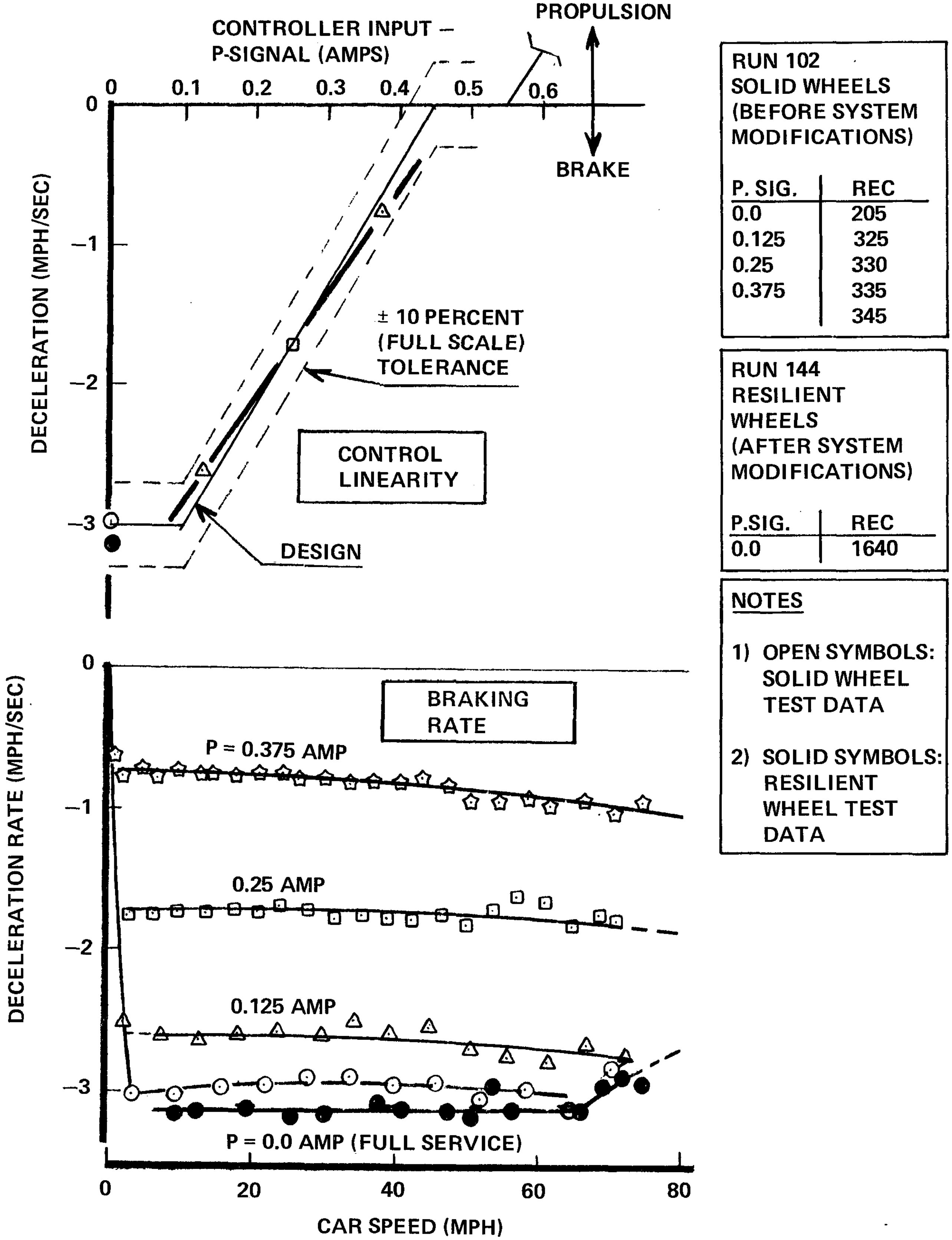


Figure 3–3. Blended Braking Control Characteristics (105,000-Pound Car)

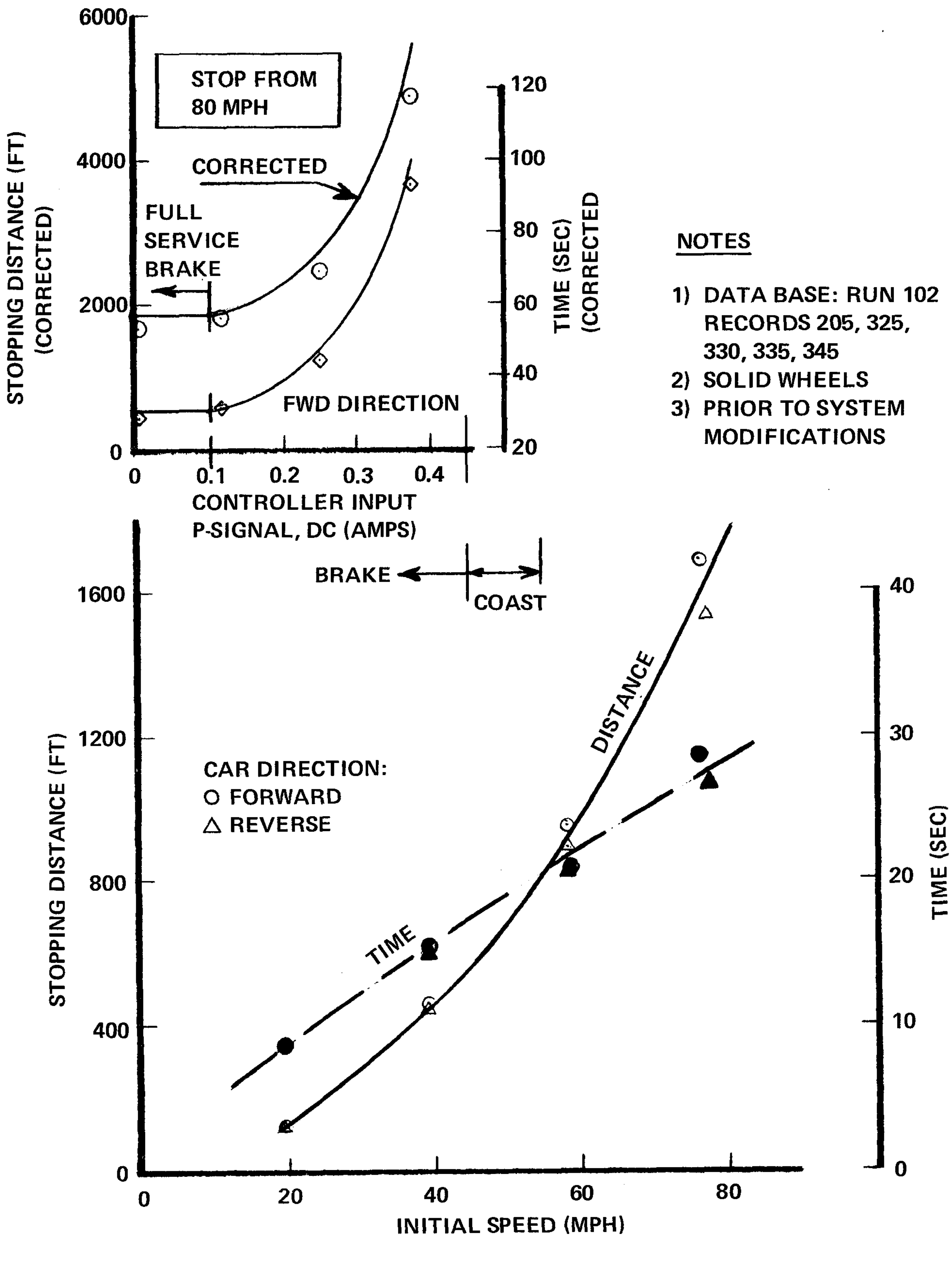


Figure 3–4. Blended Braking Stopping Distance (105,000-Pound Car)

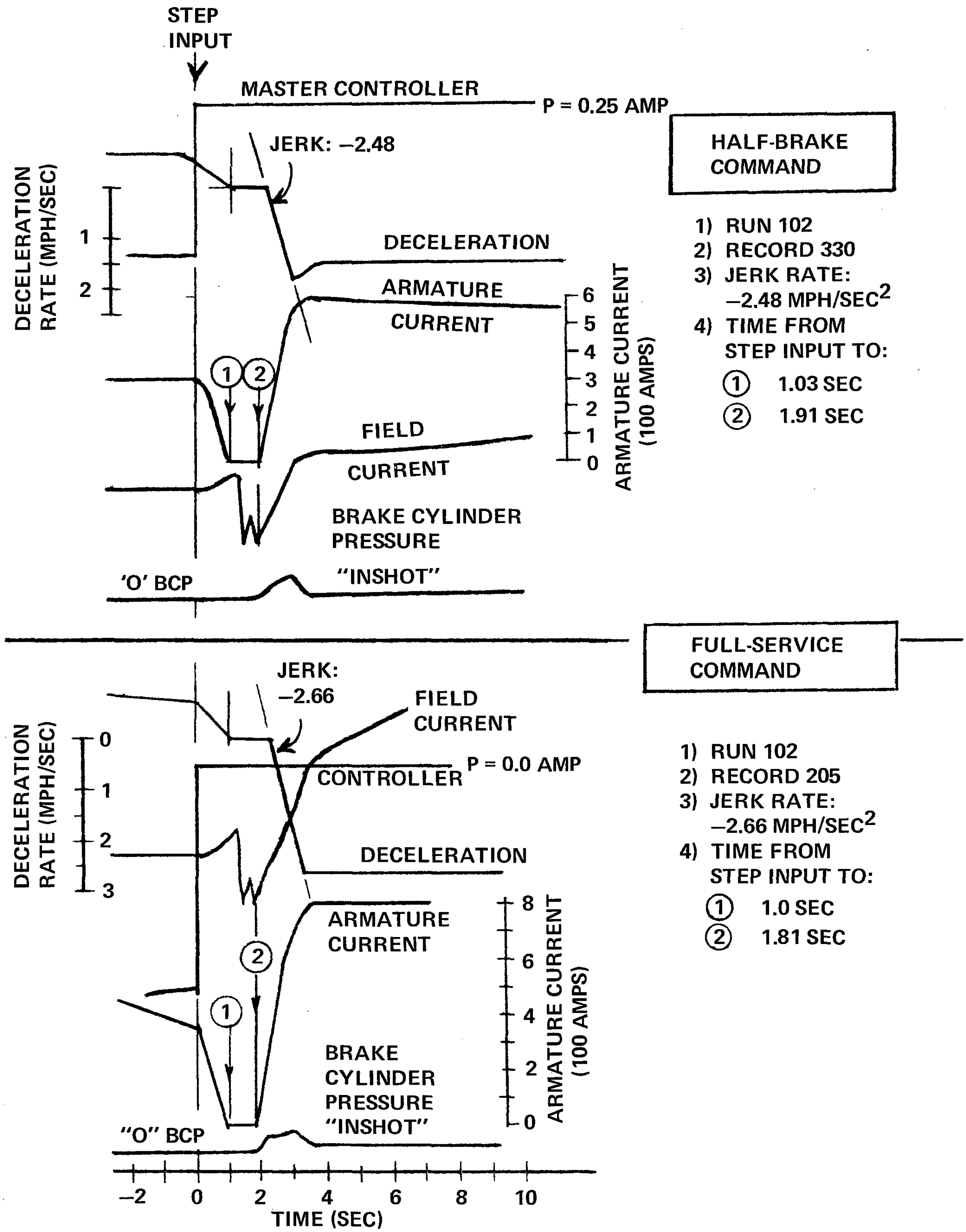


Figure 3–5. Blended Breaking Deadtime and Jerk Rate (105,000-Pound Car).

limiting) is 1.0 seconds with a 0.81 second control dead-time (i.e., point two less point one).

3.5.4 Blended Braking Load Weight Compensation

The effect of car weight on deceleration rate at two control inputs is shown in Figure 3-6. The resilient wheel data for 130,000 pounds is the only blended brake data available at this weight. As shown in the upper scale, the control characteristic is generally within the applicable 10 percent tolerance with the exception of the 130,000 pounds full-service data. It is apparent from this data that dynamic/friction brake blending did not occur during the stop; friction brake pressure remained at the 2-3 psi "inshot" level. The ratio of deceleration rates between the 113,000- and 130,000-pound tests is substantially in agreement with the car weight ratio. Brake blending upon total loss of dynamic brake effort was tested during the SOAC acceptance tests and was found to be functioning properly for total dynamic brake signal loss. The failure to provide partial blending at 130,000 pounds is not explained at this time. It should be noted that 113,000 pounds will be the maximum operational weight of the SOAC, and brake rates are within specifications at this weight.

Figure 3-7 presents stopping distances associated with several weights and control inputs. Testing at 130,000 pounds was restricted to a maximum speed of 60 mph. As shown in Figure 3-7 the blended braking stopping distance from 60 mph varies from 930 to 1160 feet over the total weight range of the car (90,000 to 130,000 pounds). This 230-foot (25 percent) variation is reduced to 110 feet (12 percent) if only weights up to 113,000 pounds are considered.

3.5.5 Blended Braking Line Voltage Effects

Testing for line voltage effects was conducted during the same test runs noted for acceleration performance in Section 2. Since the SOAC dynamic brake is only dependent on the line for field power and cooling power, no effects were expected. No-load (braking) voltages of 740, 690 and 540 volts were obtained during testing. The results are shown in Figure 3-8 for each voltage.

Similar voltage effect tests using a regenerative (blended) braking system could be used to determine the proper blending functions of such a system.

3.5.6 Service Friction Braking Control Characteristics

The service friction brake deceleration and control characteristics are shown in Figure 3-9 for a 105,000-pound car. The shape of the rate-speed curves generally conforms to existing

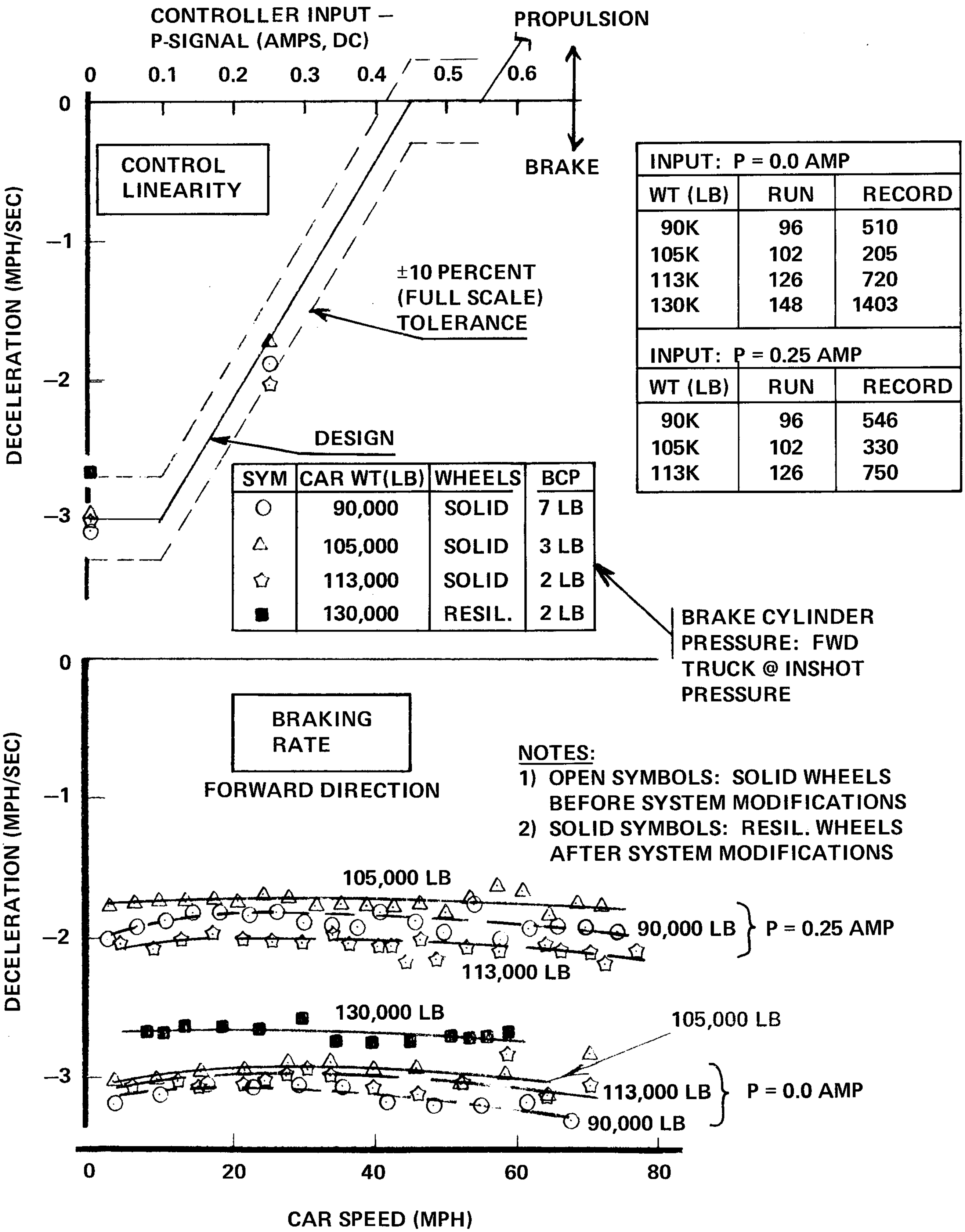


Figure 3–6. Blended Braking Load Weight Compensation

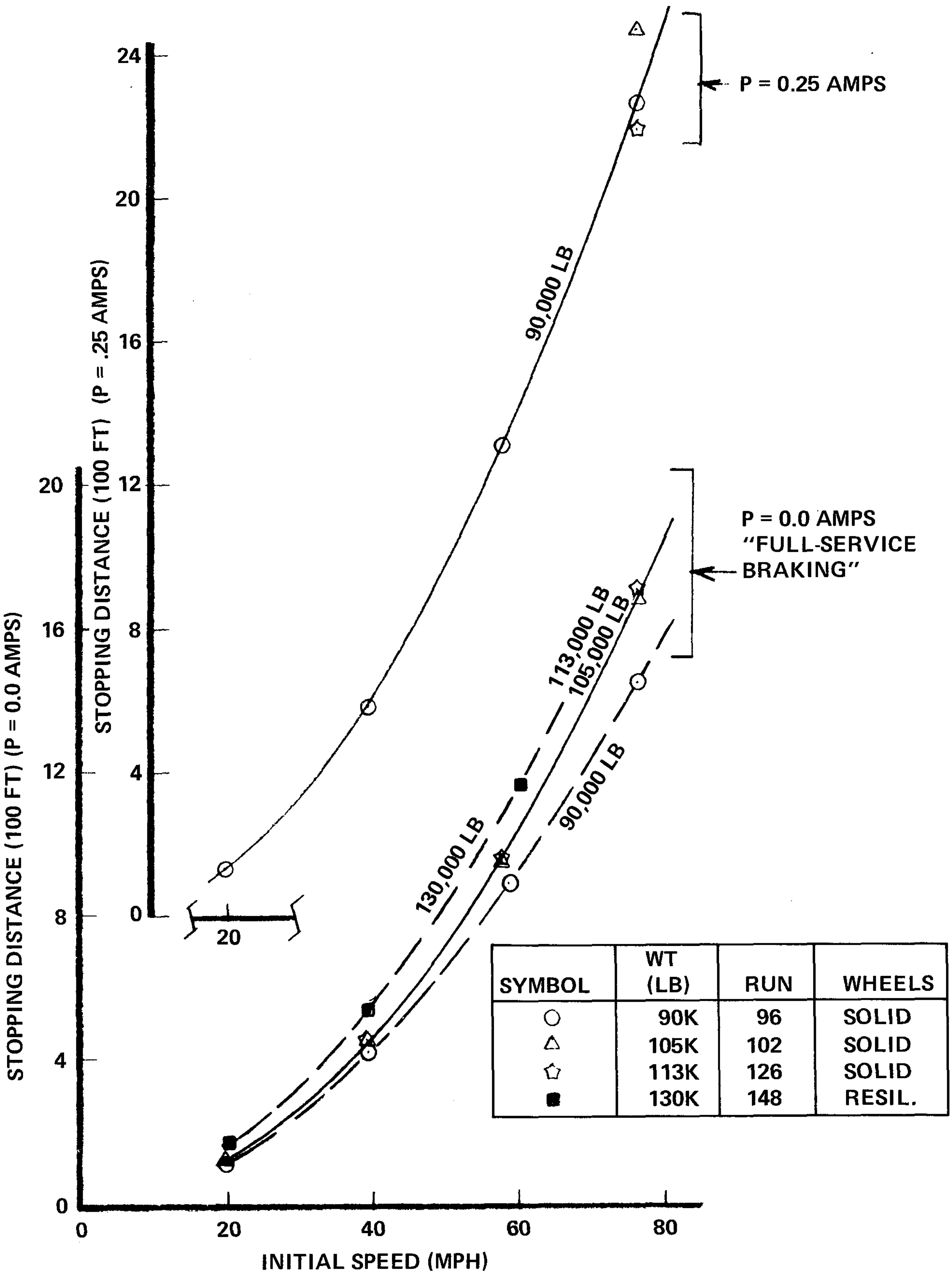


Figure 3–7. Effect of Car Weight on Blended Braking Stopping Distance in Forward Direction.

SYMBOL	RUN	RECORD	VOLTS*	WHEELS
○	102	205	600/690	SOLID
△	103	1120	650/740	SOLID
☆	104	500	475/540	SOLID

*600/690 DENOTES: NOM. VOLTS DURING ACCEL/NOM. VOLTS DURING BRAKING

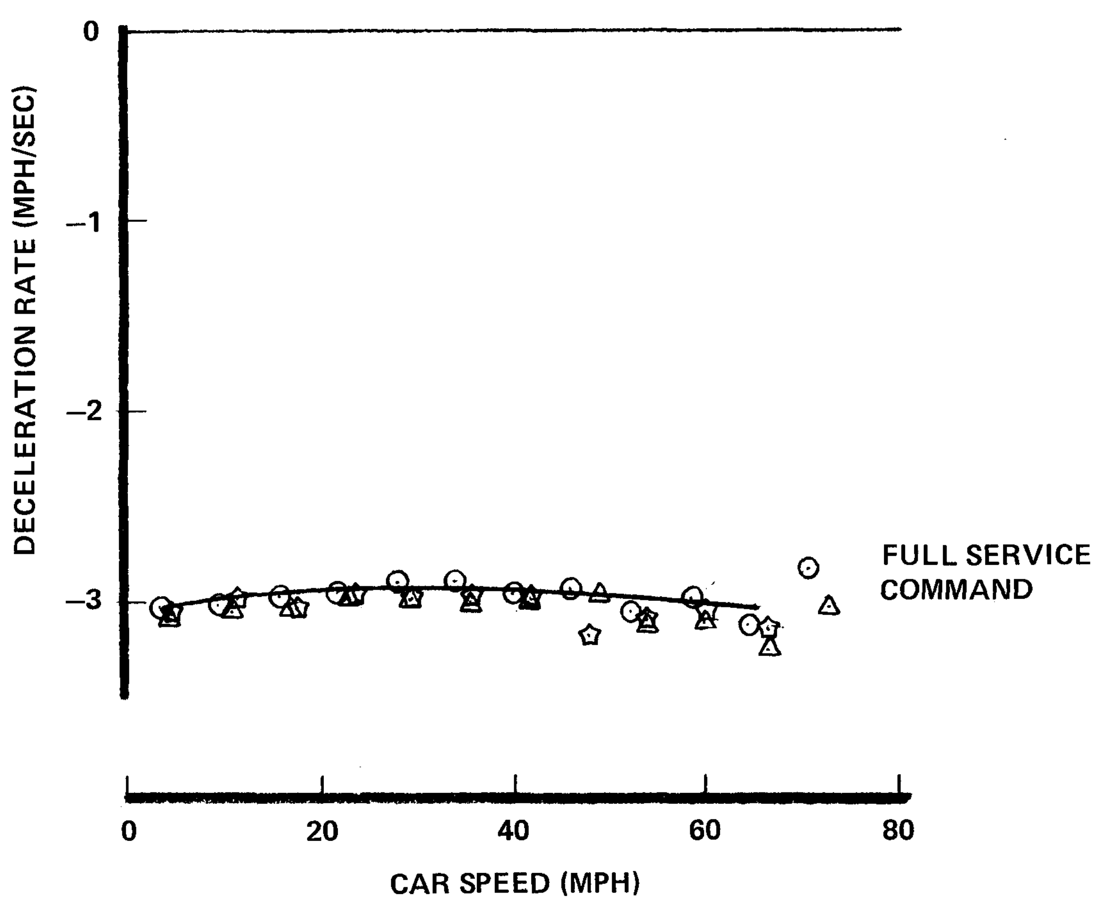
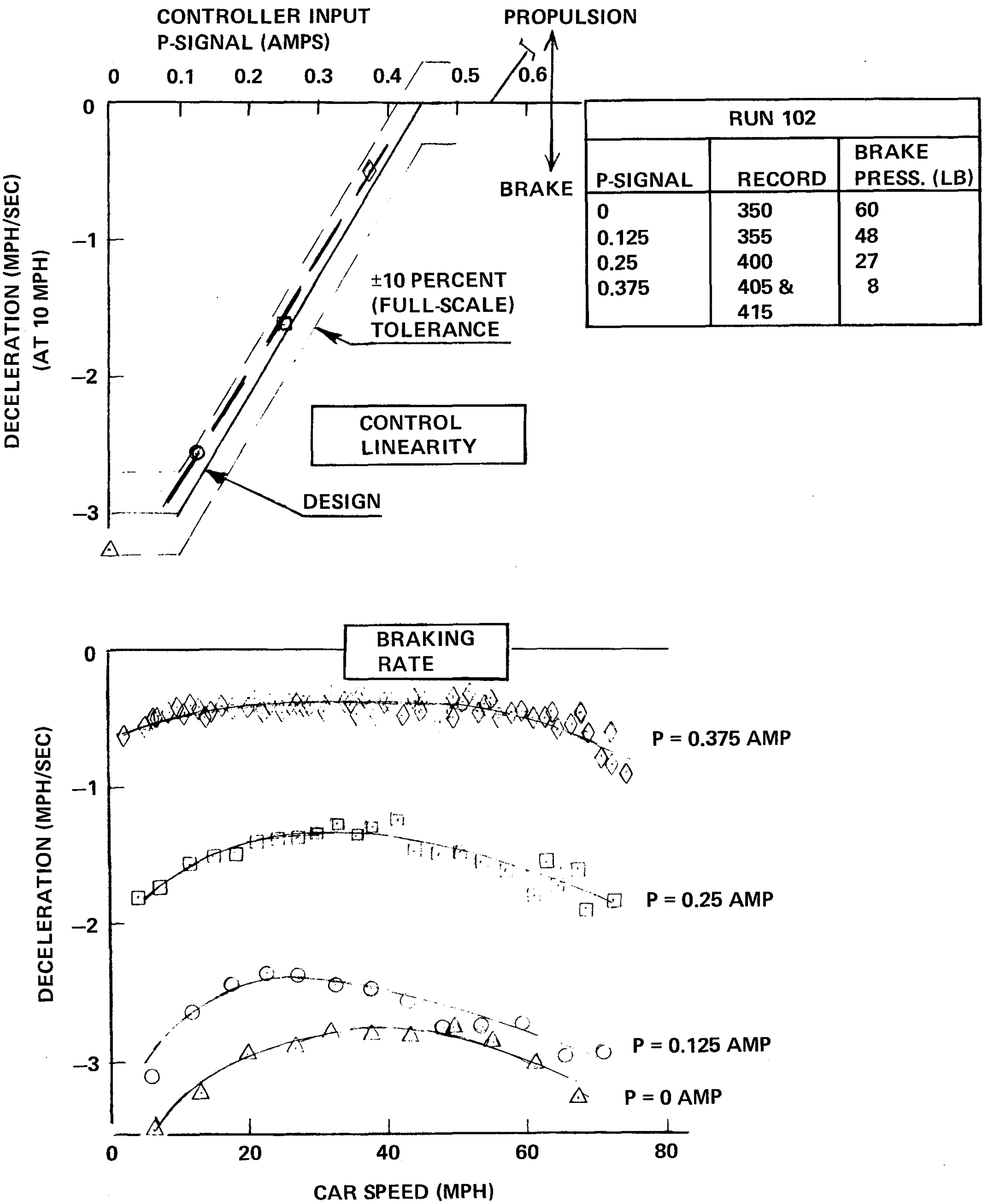


Figure 3–8. Deceleration of 105,000-Pound Car in Full-Service Braking at Off-Nominal Track Voltage



RUN 102		
P-SIGNAL	RECORD	BRAKE PRESS. (LB)
0	350	60
0.125	355	48
0.25	400	27
0.375	405 & 415	8

Figure 3–9. Friction Braking Only Control Characteristics (105,000-Pound Car)

Cobra (composition) shoe friction coefficient-speed trends. The friction brake control linearity is shown in the upper scale, based on a 10-mph car speed, and may be compared to the blended braking control characteristics of Figure 3-3. The data of Figure 3-10 are based on solid wheel tests since all four control inputs were checked at that time. The propulsion system modifications discussed for acceleration and blended braking tests do not apply to friction brake tests; however, it was determined that brake pressures were incorrect at weights other than 105,000 pounds during solid wheel tests. Therefore, solid wheel deceleration performance is shown at 105,000 pounds only in this report.

Figure 3-10 shows stopping times and distances associated with the control inputs of Figure 3-9. The data is corrected from test initial speeds of 77-78 mph to a true 80 mph. These distances may be compared to blended braking distances shown in Figure 3-4. For example, a controller input of 0.25 amp will result in a stopping distance from 80 mph of 2720 feet with blended brakes, and 2960 feet with service friction brakes only.

Figure 3-11 illustrates the friction brake system control characteristics during service brake application. As noted from this figure, the step controller input is modified by the system jerk limiting such that the analog valve current (command to truck brake cylinders) is a "ramp" input and jerk rate is limited to 2.4 mph/sec^2. The associated dead-time is 0.66 second at zero BCP command (approximately 2 amps analog valve current). Following this period "inshot" pressure starts to build in the brake cylinders and deceleration begins. The Figure 3-11 data, based on 90,000-pound car tests, also shows the relationship between brake pressure and car weight for load weight compensation.

3.5.7 Service Friction Braking Load Weight Compensation

The SOAC was tested at weights from 90,000 to 130,000 pounds at full and one-half service braking to determine the accuracy of the load weighing system. Figure 3-11 illustrates the trend of brake pressure to car weight. As previously mentioned a discrepancy in the setting of the brake pressures invalidated testing with solid wheels at weights other than 105,000 pounds. The solid and resilient wheel brake pressure readings (service brake) are summarized in Table 3-7.

The data basis for the load weight compensation tests is the resilient wheel data shown in Figure 3-12. Throughout the tests the brake pressure recorded on the forward truck varied from 2 to 3 psi at 105,000 pounds during successive applications following pressure adjustment.

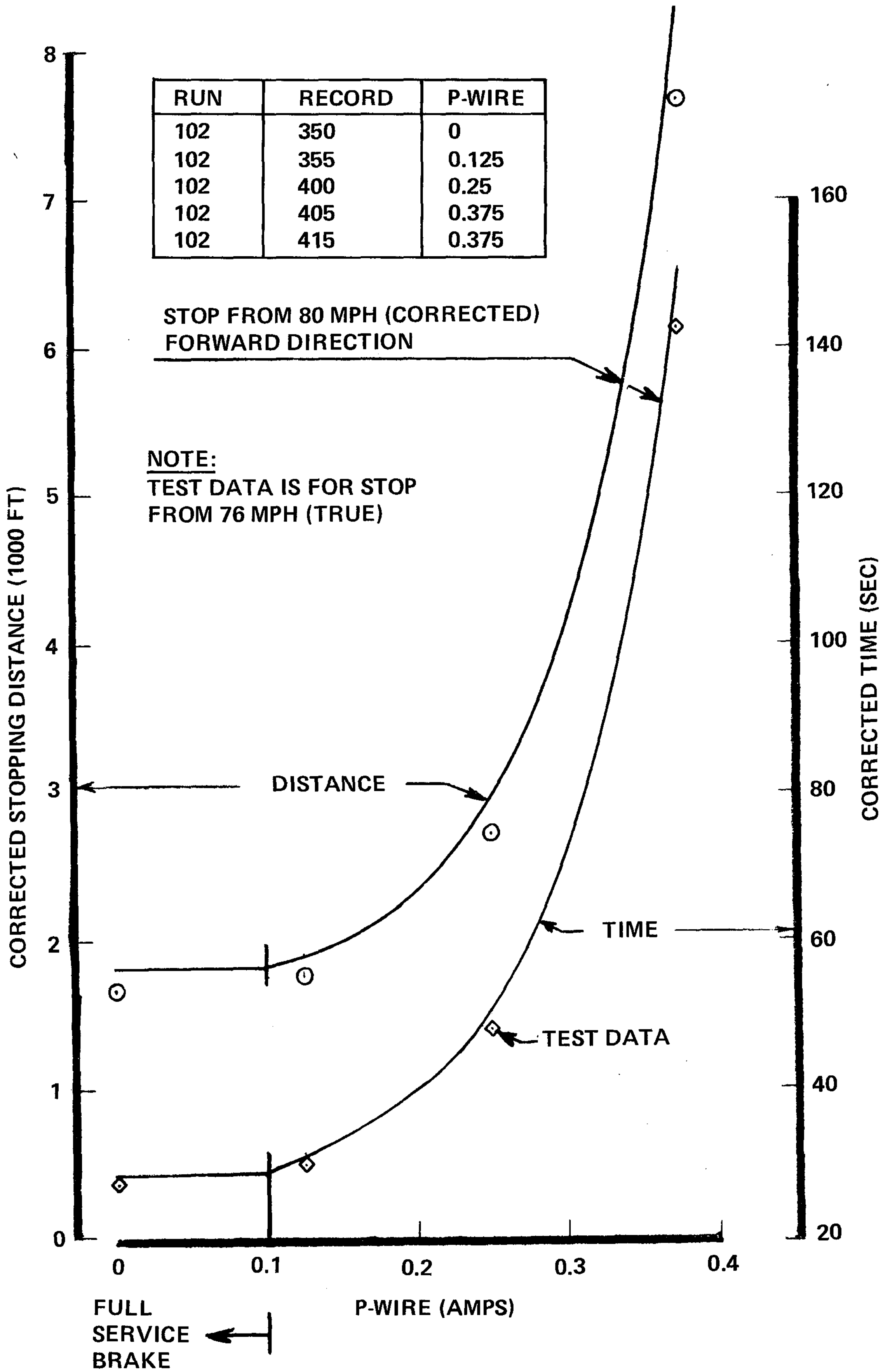


Figure 3–10. Friction Braking Stopping Distance (105,000-Pound Car)

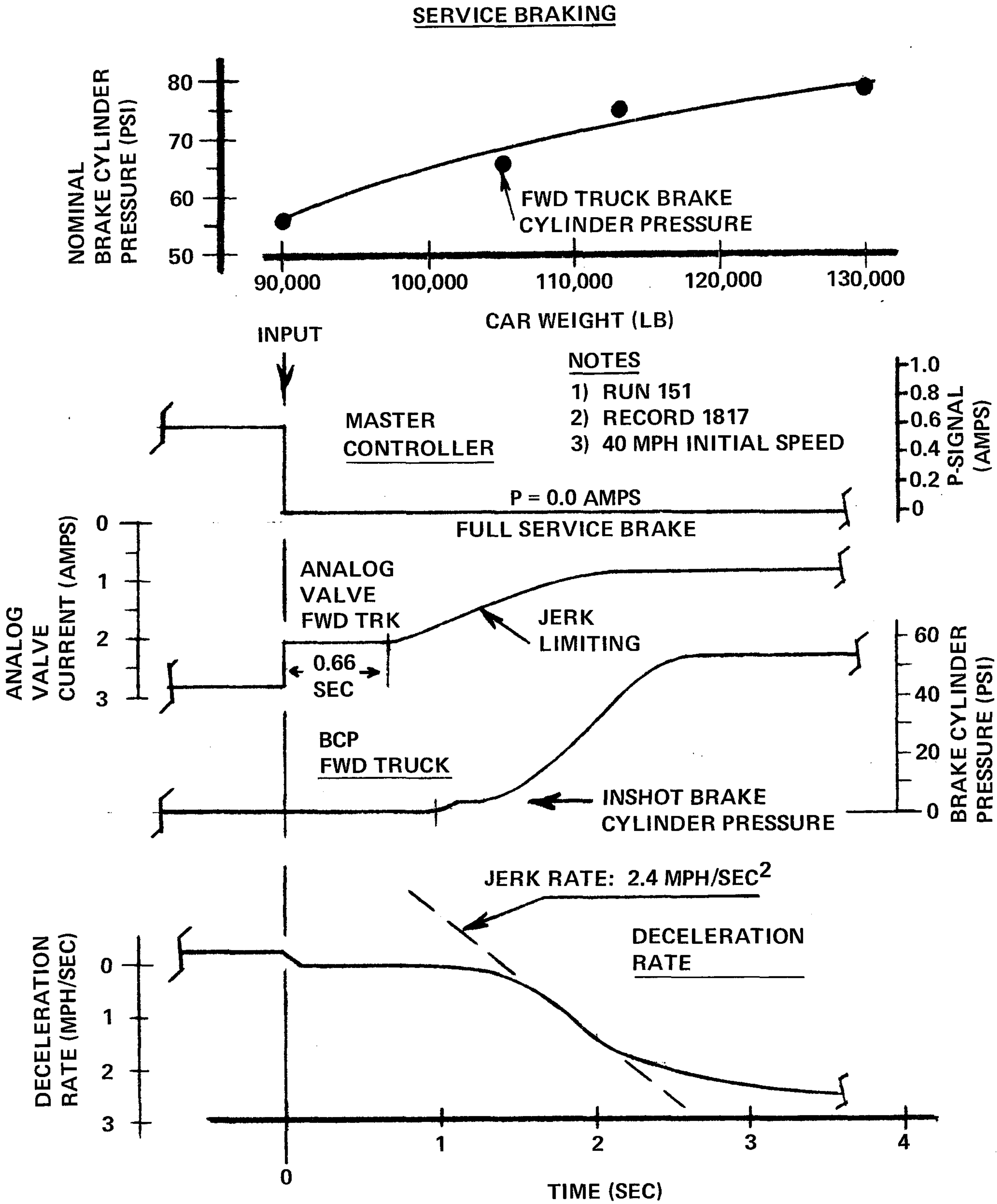
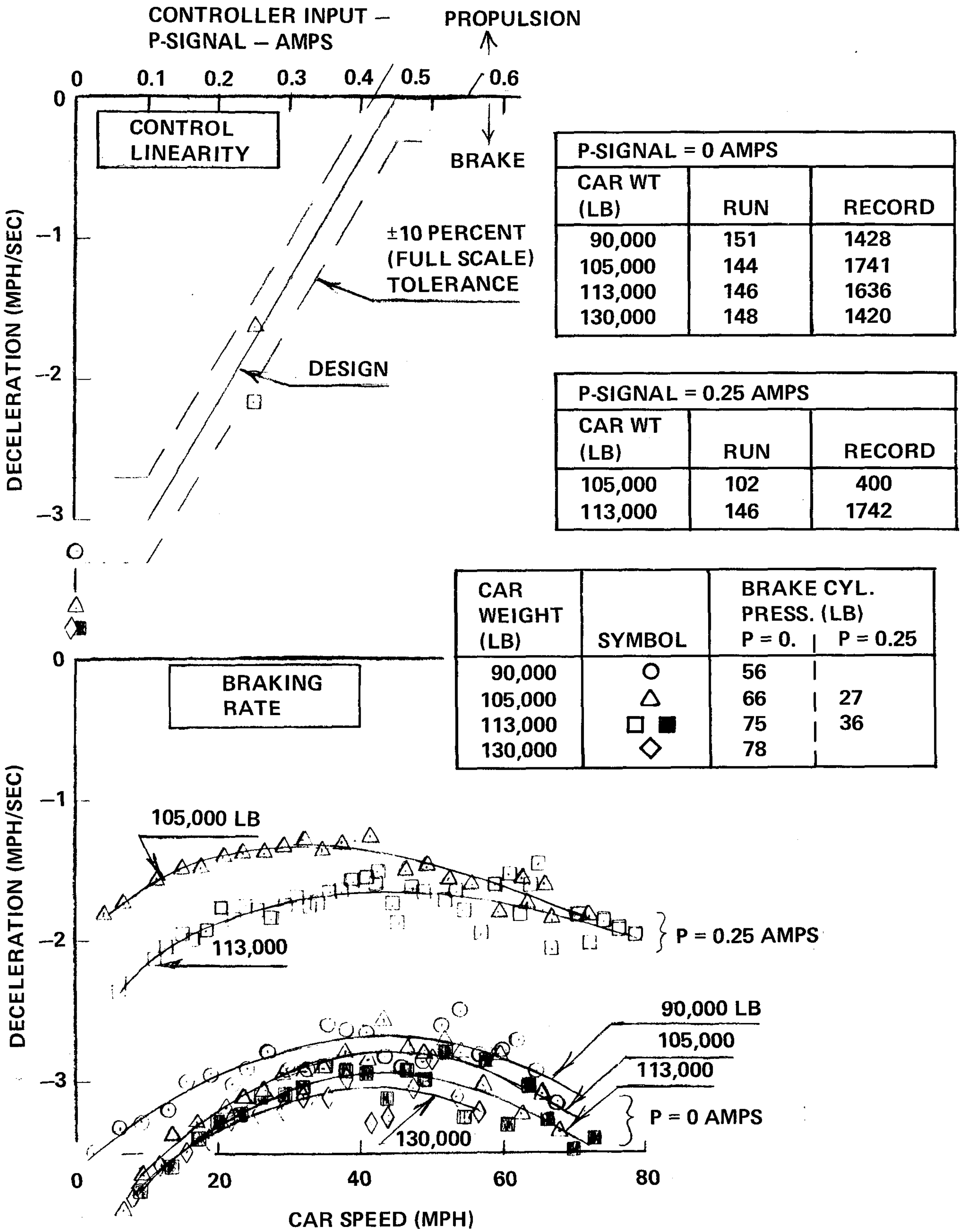


Figure 3–11. Friction Brake Pressure and Application Characteristics



P-SIGNAL = 0 AMPS		
CAR WT (LB)	RUN	RECORD
90,000	151	1428
105,000	144	1741
113,000	146	1636
130,000	148	1420

P-SIGNAL = 0.25 AMPS		
CAR WT (LB)	RUN	RECORD
105,000	102	400
113,000	146	1742

CAR WEIGHT (LB)	SYMBOL	BRAKE CYL. PRESS. (LB) P = 0.	P = 0.25
90,000	○	56	
105,000	△	66	27
113,000	□ ■	75	36
130,000	◇	78	

Figure 3–12. Friction-Braking-Only Load Weight Compensation

TABLE 3-7. HIGH-DENSITY SOAC BRAKE PRESSURES

Car Weight (lb)	Solid Wheels Fwd (psi)	Solid Wheels Aft (psi)	Resilient Wheels Fwd (psi)	Resilient Wheels Aft (psi)
90,000	50	-	55	58
105,000*	68	68	68	68
113,000	82	-	75	74
130,000	88	-	80	81

*Brakes set to 68 psi at 105,000 pounds.

Figure 3-12 presents a summary of the weight compensation data taken at four weights and two controller positions. The linearity of the control, expressed in the upper curve, is a cross-plot of deceleration rate at 10 mph (comparable to acceleration and blended deceleration data in Section 2 and paragraph 3.5.3).

Figure 3-13 summarizes full-service rate stopping distances at the four car weights. At 60 mph the difference in stopping distance over the range of car weight from 105,000 to 130,000 pounds is less than 70 feet (7 percent).

3.5.8 Dynamic Braking Only

The capability of the dynamic brake system (without service friction brake blending) was tested at the design weight of 105,000 pounds for the complete range of controller inputs. The service friction brakes were disabled prior to the tests, as noted in Paragraph 3.2. The SOAC dynamic brake is capable of bringing the car to a complete stop on level track from any speed and controller input.

Figure 3-14 illustrates the deceleration rate and control linearity of the dynamic brake. Solid wheel data is used to provide a comparison with blended braking as shown in Figure 3-3. The blended and "dynamic only" rates differ by the 6 to 8 psi of friction brake "inshot".

Stopping distances at four controller inputs are shown in Figure 3-15. The dynamic brake stopping distance from 80 mph is within 30 feet of either blended or service friction braking capability at full service rate.

NOTES
1) P = 0.0 AMPS
2) FULL SERVICE BRAKING

SYMBOL	CAR WT (LB)	RUN	WHEELS
△	90K	151	RESILIENT
○	105K	144	RESILIENT
□	113K	146	RESILIENT
△	130K	148	RESILIENT

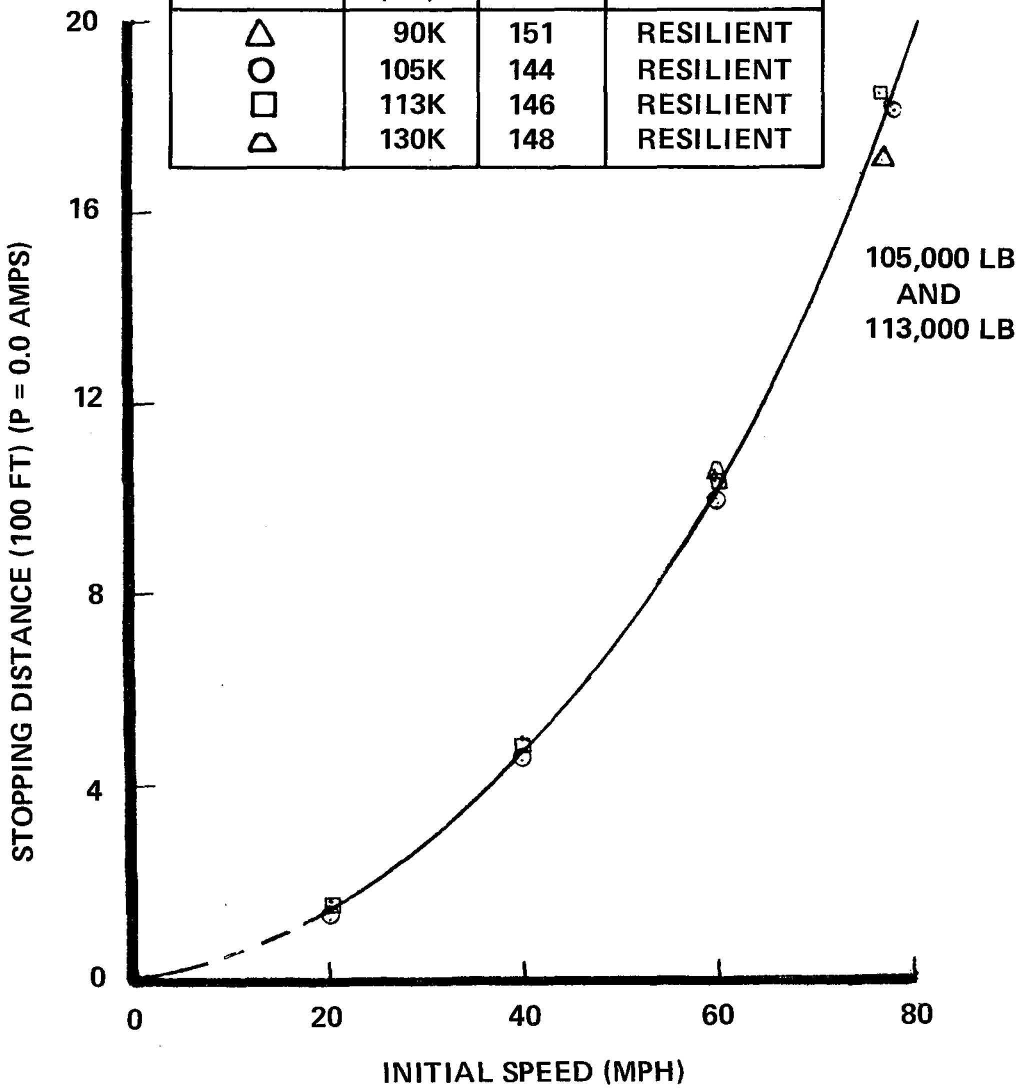


Figure 3–13. Effect of Car Weight on Friction-Braking Stopping Distance in Forward Direction

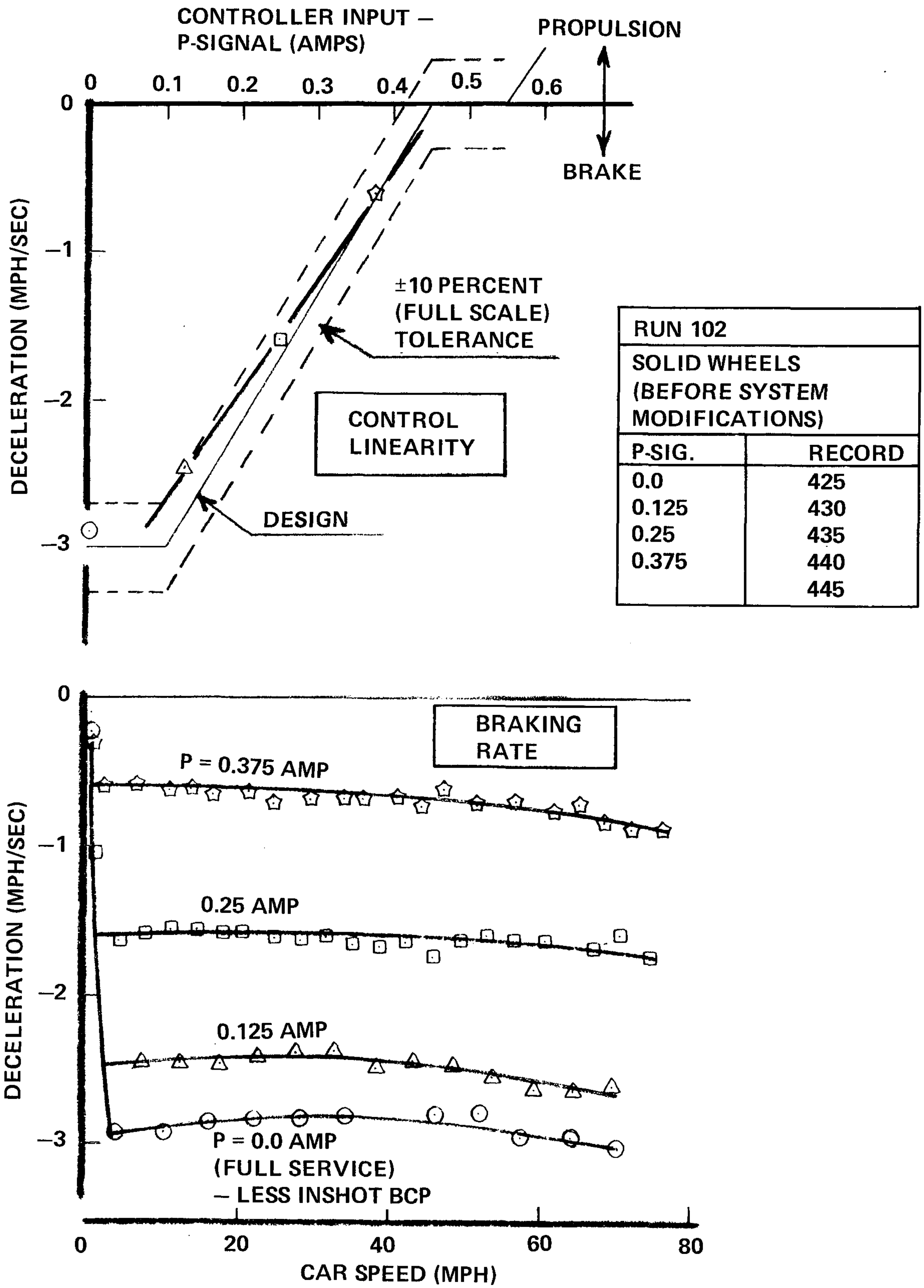


Figure 3–14. Dynamic Braking Only Control Characteristics (105,000-Pound Car)

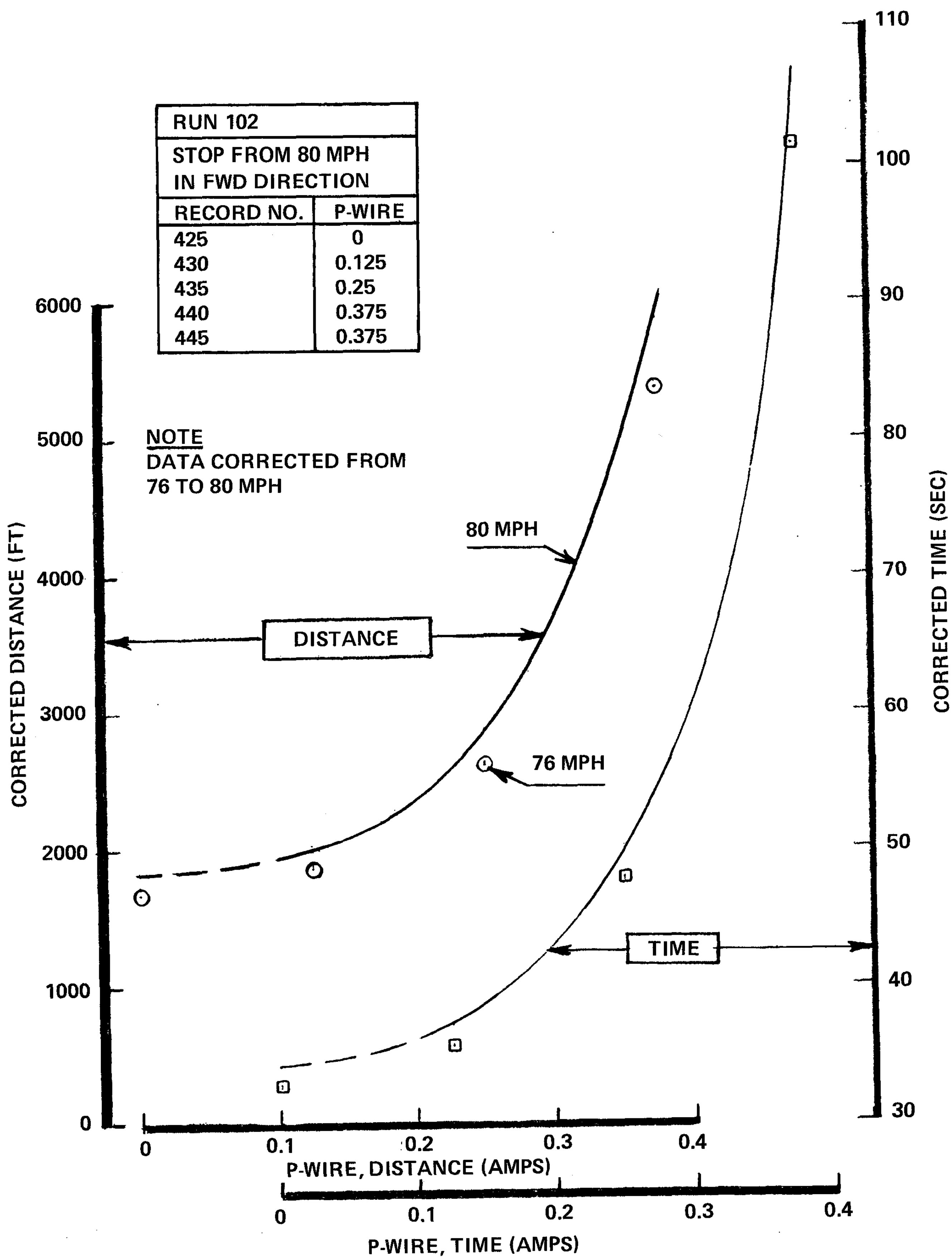


Figure 3—15. Dynamic Braking Stopping Distance

3.5.9 Emergency Friction Braking

Resilient wheel data is used to summarize the SOAC emergency braking capability since the complete car weight range was tested with these wheels. The brake pressures recorded during the test program are summarized in Table 3-8. (Also see Paragraph 3.5.7.)

TABLE 3-8. HIGH-DENSITY SOAC BRAKE PRESSURES

	Solid Wheels		Resilient Wheels	
Car Weight (lb)	Fwd (psi)	Aft (psi)	Fwd (psi)	Aft (psi)
90,000	N/A	-	68	71
105,000*	78	78	78	78
113,000	N/A	-	85	84
130,000	96	-	95	93

*Brakes set to 78 psi at 105,000 pounds

Figure 3-16 illustrates the braking rates throughout the car's weight range at speeds up to the 60 mph test limit. The SOAC specification tolerance band is shown for comparison. Wheel slides were not encountered during these (dry rail) tests.

The deceleration rate-speed characteristic generally follows the trend anticipated for the composition shoes.

Time and distance to stop with emergency brakes are shown in Figure 3-17. From an initial speed of 60 mph the 800 feet nominal stopping distance is 170 feet shorter than blended service braking (Figure 3-4).

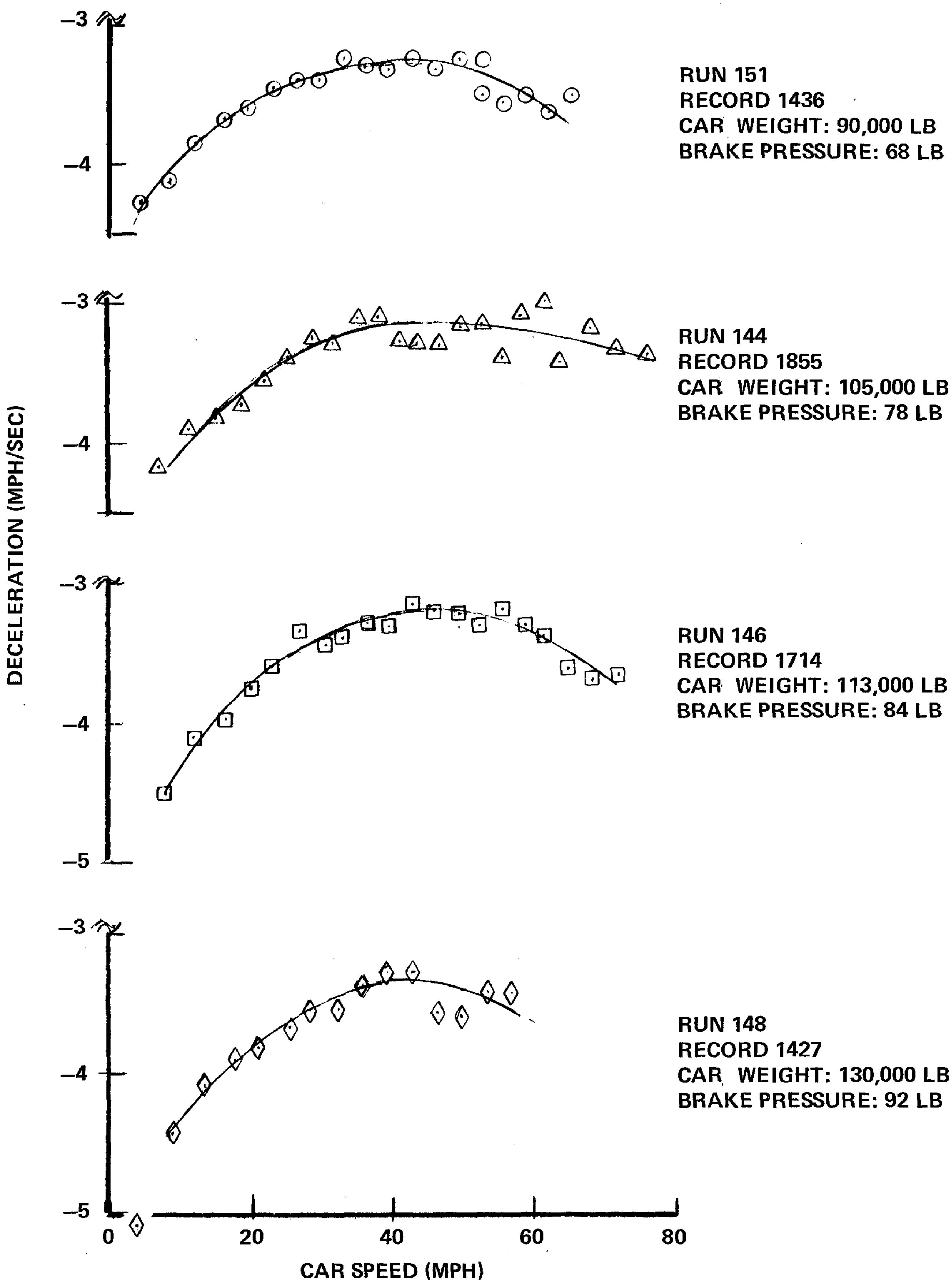


Figure 3–16. Emergency-Friction-Braking Load Weight Compensation

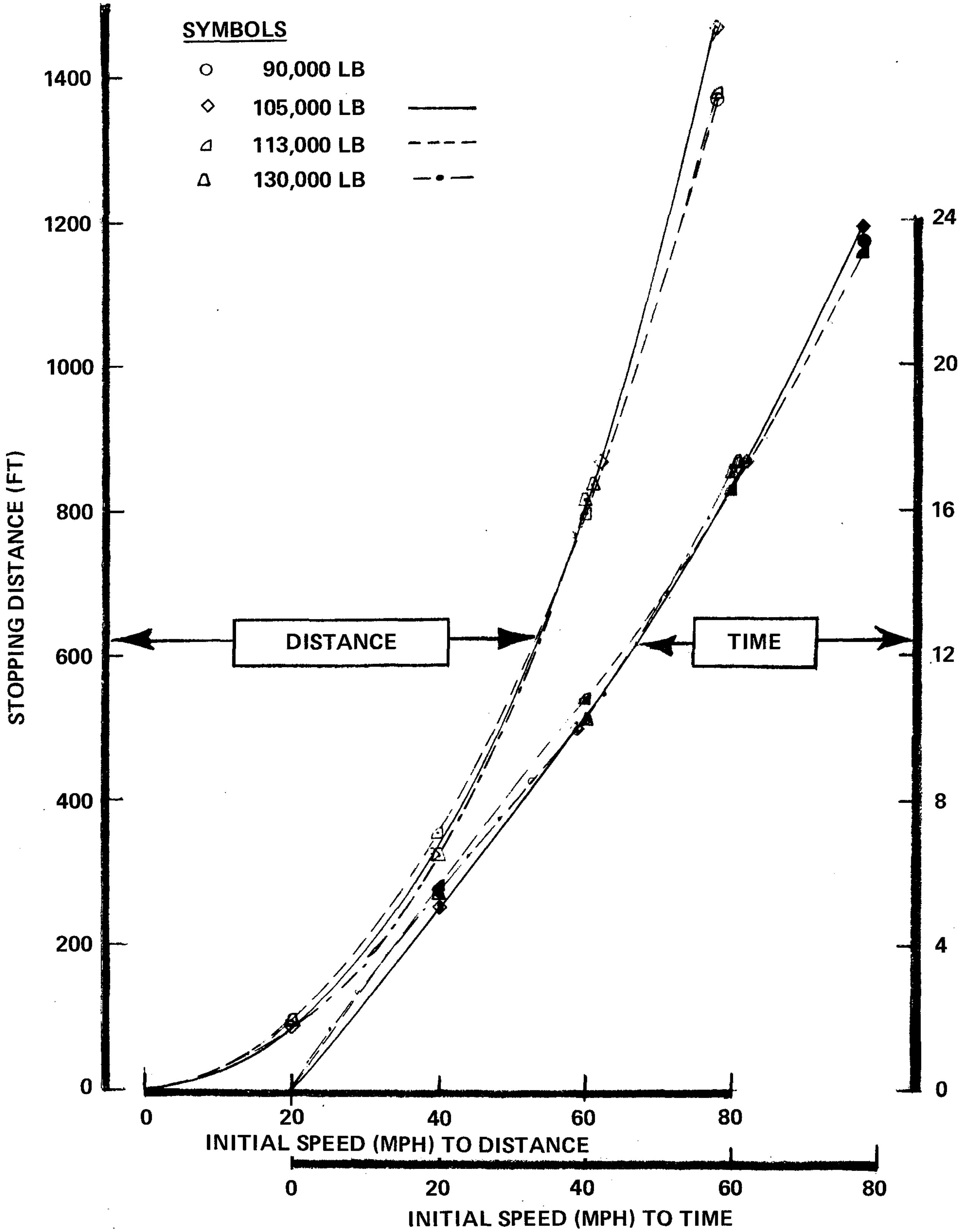


Figure 3—17. Emergency Braking Stopping Distance

Section 4

TRACTION RESISTANCE TESTS

4.1 SUMMARY

Test Sequence

- Single Car

  Test Run 102, records 455 through 522.

- Two-Car Train

  Test Run 121, records 1030 through 1145.

Test Procedure

SOAC-P-4001-TT baseline test procedure was used for single and two-car tests.

Objective

The objective of the traction resistance testing was to determine the traction resistance of the SOAC for use in analysis of wheel-rail adhesion factors and traction system propulsion and braking force characteristics.

Status

Single and two-car test data have been reduced. Train resistance versus car speed relationships have been developed. Although there is considerable data scatter for both tests, the SOAC appears to have a higher rolling resistance at low speed and a lower air resistance at high speed than previously estimated during the design phase. The single-car data are considered of prime importance since they are used in the single-car adhesion test data reduction. The two-car traction resistance test data do not appear to conform to the single-car data adjusted to a two-car consist using standard Davis methods.

Since the test data were acquired at the 4,900-foot test site altitude and will be applied to adhesion data taken at the same altitude, no attempt was made to correct for density altitude effects.

4.2 TEST DESCRIPTION

The traction resistance tests were performed by allowing the car to coast or "drift" through its speed range on level tangent track. Many passes were made over the Station 300 to Station 340 test zone to obtain 10 to 75 mph data in each direction. During the tests both the propulsion system (airflow loss) and service friction brake (analog valve) were cut out to ensure a true coasting mode.

4.3 INSTRUMENTATION

The instrumentation parameters recorded during the drift tests were similar to those recorded during other performance tests. Table 4-1 presents the parameters recorded on Data Sheets 1 and 1B. These tape-recorded parameters were then digitized at two-second intervals using filtering on the accelerometer channel. Event marks were put on the tape (and digital output) at 500-foot intervals as a distance reference.

4.4 TEST PROCEDURE

The test procedure employed during the SOAC drift tests is contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1). The procedure provides detailed instructions on car operation and data recording sufficiently specific for the SOAC test program. For baseline tests this procedure has been generalized and is contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2). The SOAC procedure, SOAC-P-4001-TT, is as follows:

Drift Test Procedure

I. Preliminary (pre-test)

  A. Attach instrumentation, or patch in desired parameters at storage or shop.

  B. Add ballast weights to simulate desired car weight (AW______).

  C. Check out and calibrate instrumentation.

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

  E. Make up desired train consist.

  F. Proceed to test zone.

TABLE 4-1. LABORATORY TAPE RECORDER DATA SHEET NO. 1

Test Title Performance Test Type Deceleration

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/1/73 Test Eng Tech RPM-DLB Tape Type & Size

Tape Recorder Model No. SABRE III Tape Recorder S/N Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph
1	Line E	Volt/Div		±10.0VDC	FM	3.375 KC	+ 1000 VDC = + 10.000 VDC	X
2	Line I	3000 Amp Hall		±10.0VDC	FM	3.375 KC	+ 2000 ADC = + 10.000 VDC	
3	Long. Accel	0.25G S/N 2807		±5.0 VDC	FM	3.375 KC	± 0.25G = ± 5.000 VDC	X
4	Speed #3 Axle			±5.0 VDC	FM	3.375 KC	80 MPH = + 5.000 VDC	X
5	#1 Truck Arm E	Volt/Div		±5.0 VDC	FM	3.375 KC	+ 1000 VDC* = + 5.000 VDC	
6	Sync			±5.0 VDC	FM	3.375 KC		
7	#2 Truck Arm E	Volt/Div		±5.0 VDC	FM	3.375 KC	+ 1000 VDC* = + 5.000 VDC	
8	#1 Truck Arm I	1000 Amp A-A-C S/N 32		±5.0 VDC	FM	3.375 KC	+ 1000 ADC = + 5.000 VDC	X
9	#2 Truck Arm I	A-A-C S/N 31		±5.0 VDC	FM	3.375 KC	+ 1000 ADC = + 5.000 VDC	
10	#1 Truck Field I	SOAC Monitor		±5.0 VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
11	#2 Truck Field I	SOAC Monitor		±5.0 VDC	FM	3.375 KC	± 50 ADC = ± 5.000 VDC	
12	P Wire I			±5.0 VDC	FM	3.375 KC	+ 1.0 ADC = - 5,000 VDC	X
13	Brake Press Axle #3	200 PSI Tabor Model 185		±5.0 VDC	FM	3.375 KC	100 PSI = + 5.000 VDC	X
14	Event			±5.0 VDC	FM	3.375 KC	2 Hz Signal	X
Edge A					Dir			
Edge B	Voice							

* Later changed to 1200 volts DC on Data Sheet 1B

G. Make inspection passes over test zone; check out vehicle and track.

H. Record ambient conditions as required:

Air Temperature: ___________

Wind Speed: ______________

Direction: _______________

I. Determine if ambient conditions are within the maximum allowables for the drift tests.

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

II. <u>Test Procedure (at test zone)</u>

A. The test zone is the 4000-foot level tangent track from Stations 300 to 340.

B. Approach test zone at maximum train speed in clockwise direction.

C. Start recorders, disable traction system, and obtain a true coasting mode with no airbrake "inshot". Leave master controller slightly above coast position in "power" mode.

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

E. Put event mark on recorders as each off-car distance reference is passed.

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

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

H. Repeat Items C through F for records in each car direction.

I. Repeat Items B through G, but with a test zone entry speed equal to the exit speed of Item F, less 5 mph (one record in each direction).

J. Repeat Item I until an exit car speed less than 10 mph in each direction is obtained.

Option (1)

Repeat Items A through J as required to provide sufficient confidence in data accuracy.

Option (2)

Repeat Items A through J at the desired car weights.

Option (3)

Repeat Items A through J with the desired train consists.

The SOAC was tested as a single car and in a two-car train at 105,000 pounds using the procedure described above.

4.5 TEST DATA

4.5.1 Test Data Reduction

Both single-car and two-car train drift tests were performed with the solid wheels. A time history of the 4000-foot test zone was recorded with 500-foot distance "EVENTS" marked on the tape. This time history was digitized at two second intervals and differential-speed/differential-time calculations were performed using faired speed-time plots. Prior to testing it was anticipated that the event marks would be printed at time of occurrence between the standard 2-second outputs and that time-distance calculations could also be made. This did not prove possible since the event marks are printed at the nearest 2-second interval as noted on Table 4-2. During later performance test data reduction, the event mark output was modified to indicate event time to the nearest quarter second; however, the drift test data were not reprocessed.

4.5.2 Sample Data Output

Table 4-2 illustrates a typical drift test digitized output. The train resistance calculations are based on speed-time plots obtained from this data.

A digitized, tabulated standard output is available for all valid drift test records. The following paragraphs detail the results of the drift tests; Tables 4-3 through 4-6 present the traction resistance calculations for the single- and two-car tests.

TABLE 4-2. TYPICAL DRIFT TEST DIGITIZED OUTPUT (TEST RECORD NO. 455: RUN 102; SINGLE CAR)

TEST RECORD NUMBER 455

SCAC DATA REDUCTION TEST RUN 102 DATE 5/9/73

SINGLE CAR

DISTANCE EVENT	TIME SECS	SPEED MPH	P-WIRE AMPS	ACCEL MPH/SEC	LINE VOLTS	LINE AMPS	ANALOG VALVE AMPS	BRAKE PRESSURE PSI
	0.0	74.61	-0.766	0.15	645.	642.	-1.59	0.6
	2.0	74.68	-0.770	0.31	643.	635.	-1.59	0.6
	4.0	74.56	-0.765	0.17	639.	634.	-1.58	0.6
	6.0	74.39	-0.725	0.15	639.	619.	-1.59	0.6
0 ft *	8.0	74.39	-0.655	-0.19	753.	23.	-0.15	0.7
	10.0	73.81	-0.700	-0.40	698.	53.	-0.16	0.6
	12.0	73.26	-0.677	-0.27	695.	45.	-0.16	0.6
*	14.0	72.70	-0.677	-0.19	685.	61.	-0.16	0.7
	16.0	72.25	-0.678	-0.16	685.	53.	-0.16	0.6
*	18.0	71.68	-0.678	-0.34	683.	49.	-0.16	0.6
	20.0	71.18	-0.678	-0.15	684.	50.	-0.16	0.6
*	22.0	70.62	-0.677	-0.16	678.	61.	-0.16	0.4
	24.0	70.07	-0.677	-0.23	681.	51.	-0.16	0.3
	26.0	69.66	-0.677	-0.28	680.	53.	-0.16	0.6
*	28.0	69.17	-0.677	-0.22	680.	47.	-0.15	0.6
	30.0	68.69	-0.677	-0.19	678.	56.	-0.15	0.6
*	32.0	68.27	-0.677	-0.15	681.	51.	-0.16	0.6
	34.0	67.74	-0.677	-0.16	681.	49.	-0.15	0.6
	36.0	67.28	-0.677	-0.20	678.	50.	-0.15	0.6
*	38.0	66.79	-0.677	-0.17	678.	46.	-0.15	0.6
	40.0	66.38	-0.677	-0.11	677.	60.	-0.15	0.6
*	42.0	65.92	-0.678	-0.13	676.	56.	-0.15	0.5
	44.0	65.41	-0.678	-0.12	676.	55.	-0.15	0.5
	46.0	64.95	-0.678	-0.13	678.	55.	-0.15	0.5
4000 ft * →	48.0	64.39	-0.536	-0.18	677.	56.	-0.15	0.5
	50.0	63.73	-0.369	-0.16	677.	54.	-0.03	0.4
	52.0	63.03	-0.553	-0.09	674.	56.	-0.14	0.4
	54.0	62.34	-0.596	-0.08	674.	55.	-0.14	0.5
	56.0	61.71	-0.640	-0.11	676.	54.	-2.28	0.4
	58.0	61.30	-0.535	0.08	650.	288.	-1.97	10.9
	60.0	71.27	-0.933	-0.51	589.	1287.	-1.45	0.6
	62.0	72.68	-0.929	-0.51	590.	1275.	-1.45	0.6

500-FT DISTANCE INTERVALS

PRINTOUT TO NEAREST 2 SECONDS

PROPULSION AND SERVICE FRICTION BRAKES CUT OUT.

NO GOOD FOR T-S-D CALCULATIONS

TIME-SPEED PLOTTED WITH DECELERATION RATE CALCULATED FROM FAIRING Δv/Δt.

TABLE 4-3. TRACTION RESISTANCE FOR 105,000-POUND SINGLE CAR IN FORWARD DIRECTION (RUN 102)

Record No.	Initial Speed V_o (mph)	Final Speed V_f (mph)	ΔV (mph)	ΔT (sec)	$\frac{\Delta V}{\Delta T}$ (mph/sec)	Average Speed V (mph)	Train Resistance ($\frac{mph}{sec}$ x 5137)*
455	74.39	71.68	2.71	10	0.271	73.0	1392
	71.68	69.17	2.51	10	0.251	70.4	1289
	69.17	66.79	2.36	10	0.236	67.9	1212
	66.79	64.39	2.4	10	0.24	65.6	1233
505	64.26	61.91	2.35	10	0.235	63.1	1207
	61.91	59.51	2.40	10	0.24	60.7	1233
	59.51	57.46	2.08	10	0.208	58.5	1068
	56.46	55.56	1.90	10	0.19	56.5	976
515	47.53	45.88	1.65	10	0.165	46.7	847
	45.88	44.37	1.51	10	0.151	45.1	776
	44.37	43.04	1.33	10	0.133	43.7	683
	43.04	41.44	1.60	10	0.16	42.2	821
	41.44	40.03	1.41	10	0.141	40.7	724
	40.03	38.77	1.26	10	0.126	39.4	647
520	29.59	28.45	1.14	10	0.114	29.0	586
	28.45	27.34	1.14	10	0.111	27.9	570
	27.34	26.35	.99	10	0.099	26.9	508
	26.35	25.4	.95	10	0.095	25.9	488
	25.4	24.37	1.0	10	0.1	24.9	514
520	24.37	23.35	1.02	10	0.102	23.8	524
	23.35	22.42	0.93	10	0.093	22.9	477
	22.42	21.54	0.88	10	0.088	22.0	452
	21.54	20.74	0.80	10	0.08	21.1	411
	20.74	19.86	0.88	10	0.088	20.3	452
	19.86	19.05	0.81	10	0.081	19.45	416

*Notes

1) Train Resistance = g's x (weight + equivalent weight)

2) $g's = \frac{mph/sec}{21.95}$

3) Equivalent weight = 7774 lb

4) $\frac{\text{weight + equivalent weight}}{21.95} = 5137$

TABLE 4-4. TRACTION RESISTANCE FOR 105,000-POUND SINGLE CAR IN REVERSE DIRECTION (RUN102)

Record No.	Initial Speed V_o (mph)	Final Speed V_f (mph)	ΔV (mph)	ΔT (sec)	$\frac{\Delta V}{\Delta T}$ (mph/sec)	Average Speed V (mph)	Train Resistance $(\frac{mph}{sec} \times 5137)$*
500	74.44	71.21	3.23	10	0.323	72.8	1659
	71.21	68.27	2.94	10	0.294	69.7	1510
	68.27	65.26	3.01	10	0.301	66.8	1546
	65.26	62.64	2.62	10	0.262	63.9	1345
510	61.76	59.03	2.73	10	0.273	60.4	1402
	59.03	56.75	2.28	10	0.228	57.9	1171
	56.75	54.21	2.54	10	0.254	55.5	1304
	54.21	51.76	2.45	10	0.245	53.0	1258
	51.76	50.38	1.38	6	0.23	51.1	1181
518	47.45	45.56	1.99	10	0.199	46.56	1022
	45.56	43.69	1.87	10	0.187	44.6	960
	43.69	41.79	1.9	10	0.190	42.7	976
	41.79	40.05	1.74	10	0.174	40.9	894
	40.05	38.47	1.58	10	0.158	39.2	811
	38.47	36.78	1.69	10	0.169	37.6	868
522	30.19	28.97	1.22	10	0.122	29.6	626
	28.97	27.65	1.32	10	0.132	28.3	678
	27.65	26.45	1.2	10	0.12	27.0	616
	26.45	25.32	1.13	10	0.113	25.9	580
	25.32	24.10	1.22	10	0.122	24.7	626
	24.10	22.92	1.18	10	0.118	23.5	606
	22.92	21.77	1.15	10	0.115	22.3	590
	21.77	20.79	0.98	10	0.098	21.3	503
	20.79	19.81	0.98	10	0.098	20.3	503
	19.81	18.86	0.95	10	0.095	19.3	488

*Notes

1) Train Resistance = g's x (weight + equivalent weight)

2) $g's = \frac{mph/sec}{21.95}$

3) Equivalent weight = 7774 lb

4) $\frac{\text{weight + equivalent weight}}{21.95} = 5137$

TABLE 4-5. TRACTION RESISTANCE FOR TWO-CAR TRAIN (105,000 POUNDS PER CAR) IN FORWARD DIRECTION (RUN 121)

Record No.	Initial Speed V_o (mph)	Final Speed V_f (mph)	ΔV (mph)	ΔT (sec)	$\frac{\Delta V}{\Delta T}$ (mph/sec)	Average Speed V (mph)	Train Resistance ($\frac{mph}{sec}$ x 5137)*
1035	71.3	67	4.3	20	0.215	69.1	1104
	69	64.96	4.0	20	0.2	67.0	1027
1045	61.8	58.1	3.7	20	0.185	59.9	950
	59.1	55.5	3.6	20	0.18	57.3	9247
1120	51.3	48.1	3.2	20	0.16	49.2	822
	48.1	45.2	2.9	20	0.145	46.6	745
	45.7	43.3	2.4	20	0.12	44.5	616
1130	43.3	41.8	1.5	10	0.15	43.0	770.6
	41.8	40.2	1.6	10	0.16	41.0	822.0
	40.7	38.0	2.7	20	0.135	39.3	693.5
	38.0	35.5	2.5	20	0.125	36.7	642.0
1140	33.5	31.0	2.5	20	0.125	32.3	642.0
	31.0	28.54	2.46	20	0.123	30.0	631.8
	29.2	26.9	2.3	20	0.115	28.0	590.8
	26.9	24.8	2.2	20	0.11	25.8	565
	24.7	22.6	2.1	20	0.105	23.6	539
1145	22.26	20	2.26	20	0.113	21.1	580
	21.8	19.5	2.3	20	0.115	20.6	590.8
	20.0	18.5	2.0	20	0.10	19.0	513.1
	18.5	16.4	2.0	20	0.105	17.5	539.0
	16.4	14.4	2.0	20	0.10	15.4	513.7
	14.4	12.5	1.9	20	0.095	13.4	488
	12.5	10.7	1.8	20	0.09	11.6	462

*Notes

1) Train Resistance = g's x (weight + equivalent weight)

2) $g's = \frac{mph/sec}{21.95}$

3) Equivalent weight = 7774 lb

4) $\frac{\text{weight + equivalent weight}}{21.95} = 5137$

TABLE 4-6. TRACTION RESISTANCE FOR TWO-CAR TRAIN (105,000 POUNDS PER CAR) IN REVERSE DIRECTION (RUN 121)

Record No.	Initial Speed V_o (mph)	Final Speed V_f (mph)	ΔV (mph)	ΔT (sec)	$\frac{\Delta V}{\Delta T}$ (mph/sec)	Average Speed V (mph)	Train Resistance ($\frac{mph}{sec}$ x 5137)*
1030	72.0	67	5.0	20	0.225	69	1156
1040	65.3	61.2	4.1	20	0.205	63	1053
	63.25	59.0	4.25	20	0.212	61.2	1089
	61.2	59.0	2.2	10	0.22	60.1	1130
	64.25	60.1	4.15	20	0.207	62.2	1063
1100	48.04	44.65	3.39	20	0.169	46.3	868
	44.65	41.85	2.8	20	0.14	43.3	719
	41.85	39.10	2.75	20	0.137	40.4	704
1110	39.7	36.9	2.8	20	0.14	37.3	719
	38.3	35.6	2.7	20	0.135	36.9	693
	38.6	33.0	2.6	20	0.13	34.3	668
	33.0	30.6	2.4	20	0.12	31.8	616
1125	34.7	32.3	2.4	20	0.12	33.5	621.0
	32.3	29.7	2.6	20	0.13	31.0	668.0
	33.6	30.9	2.7	20	0.135	32.2	693.0
	30.22	27.78	2.44	20	0.122	29.0	626.7
	27.78	25.4	2.38	20	0.119	26.6	611.0
	25.4	23.1	2.3	20	0.115	24.2	590.8
1135	21.5	19.2	2.3	20	0.115	20.3	591
	20.3	17.8	2.5	20	0.125	19.0	642
	19.2	16.6	2.6	20	0.13	17.9	668
	17.8	15.4	2.4	20	0.12	16.6	616
	15.4	13.1	2.3	20	0.115	14.4	591
	13.1	10.7	2.4	20	0.12	11.9	616
	10.5	8.4	2.3	20	0.115	9.6	591

*Notes

1) Train Resistance = g's x (weight + equivalent weight)

2) $g's = \frac{mph/sec}{21.95}$

3) Equivalent weight = 7774 lb

4) $\frac{\text{weight + equivalent weight}}{21.95} = 5137$

4.5.3 Single-Car Traction Resistance

Figure 4-1 presents traction resistance for a single car in both forward and reverse direction. The pre-test prediction was based on the Davis equation coefficients used during the design phase of the car:

$$TR = 1.3W + 29n + 0.045\ WV + (0.0024) + N - 1\ (0.00034)\ AV^2$$

where TR = Total resistance, pounds
W = Weight per train, tons
n = Number of axles per train
V = Train speed, mph
N = Number of cars in train
A = Frontal area of lead car = 115 square feet

The pre-test estimate of Figure 4-1 is based on the above equation. The test fairing was made using the basic form of the Davis equation to determine the shape. Since the forward and aft ends of the SOAC are dissimilar, the forward data was weighed somewhat more heavily in constructing the test fairing. The resulting fairing is essentially top-of-forward data scatter and bottom-of-reverse data scatter while still conforming to the Davis shape. Based on the data of Figure 4-1, the SOAC has a higher rolling resistance at low speed and a lower air resistance at high speed than predicted with the standard Davis equation.

The test fairing of Figure 4-1 was adjusted to a 90,000-pound car weight using standard Davis techniques (1.3W + 0.045 WV) for use in data reduction of adhesion tests. The scatter in Figure 4-1 is equivalent to a value of ±0.001 in the adhesion coefficients shown in Section 8. (±130 pounds TR at 40 mph = ±0.001g at 90,000-pound car weight).

The test fairing is based on the following modified Davis equation (for a single car weighing 105,000 pounds):

$$TR = \text{"300"} + 0.045\ WV + 0.0019\ AV^2$$

where "300" = $R_1W + R_2n$

R_1 and R_2 are the coefficients for journal resistance: 1.3 and 29, respectively, in the standard Davis equation. These coefficients total 184 pounds for the SOAC in the Davis equation compared to "300" pounds in the test data. The increased drag at low speed may be attributable to higher than anticipated bearing or gear drag.

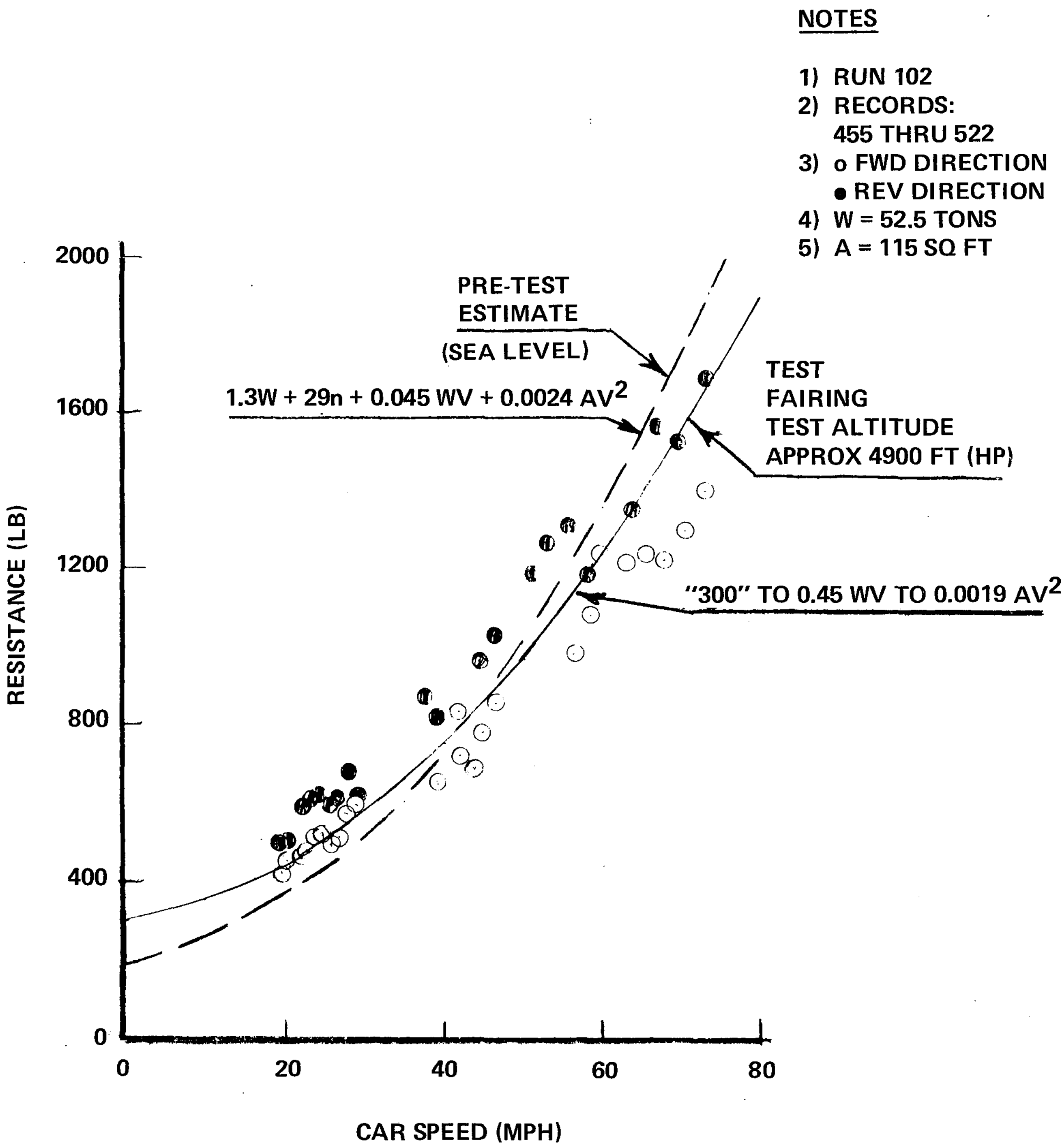


Figure 4—1. Traction Resistance (105,000-Pound Single Car)

4.5.4 Two-Car Traction Resistance

Figure 4-2 presents the results of the two-car train drift tests. The two-car test data has somewhat less scatter than the single-car data. The estimated fairing shown on the figure is based on the single-car test fairing (Figure 4-1) adjusted to a two-car consist using the basic Davis air resistance coefficient for trailing cars. The "estimated fairing" (per 105,000-pound car) is based on the following:

$$TR = 300. + 0.045\ WV + \frac{(0.0019 + 0.0034)}{2}\ AV^2$$

where W = weight per car, tons
(other symbols are as in paragraph 4.5.3)

The test fairing is based on the estimated two-car shape and the two-car test data. The two-car rolling resistance at low speed shows a higher resistance per car than either the standard Davis equation (184 pounds) or the single-car data (300 pounds). At high speed the test fairing approaches the estimated fairing.

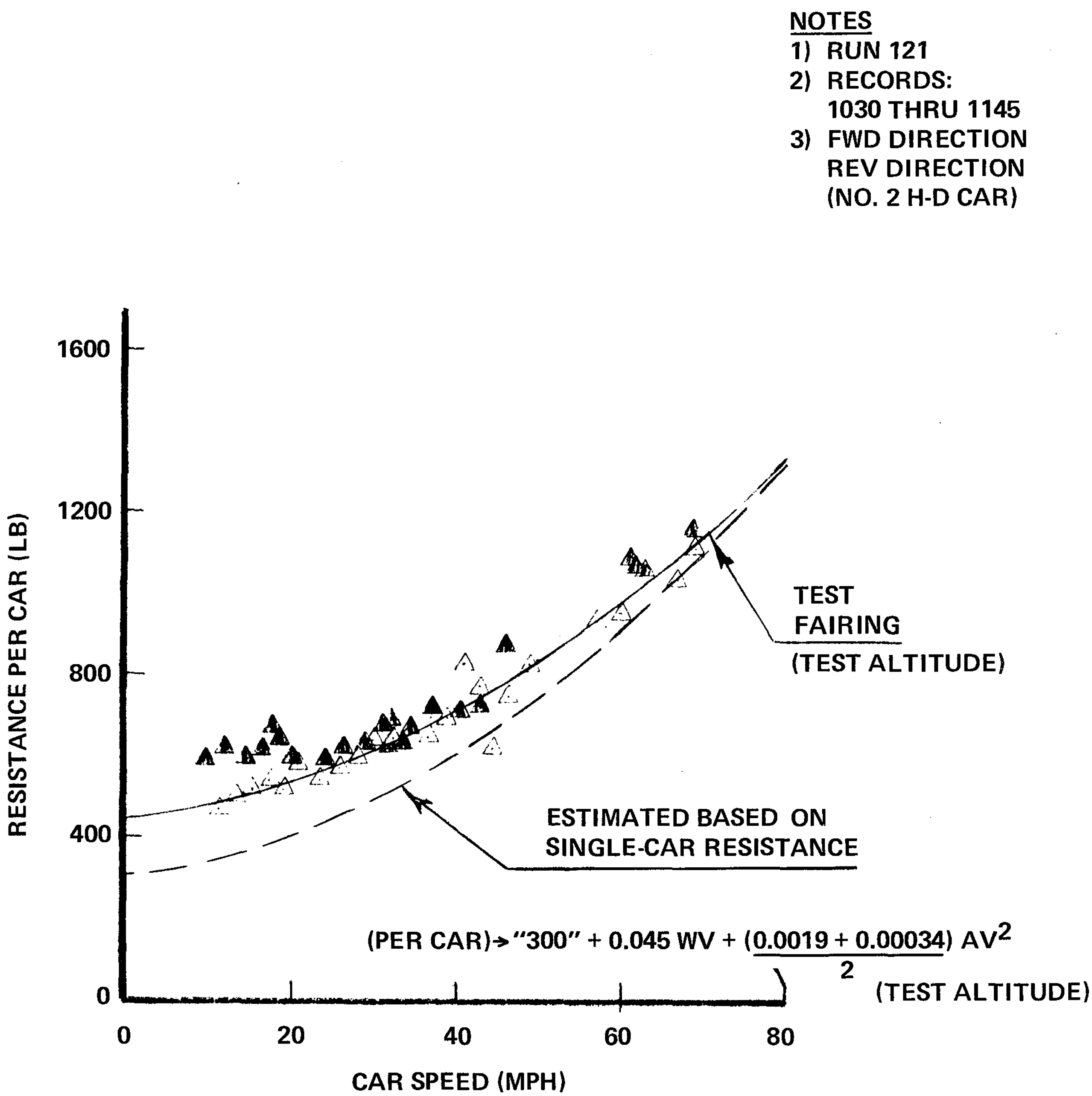


Figure 4—2. Traction Resistance (105,000-Pound Two-Car Train)

Section 5

FRICTION BRAKING DUTY CYCLE TESTS

5.1 SUMMARY

Test Sequence

Two duty cycles were tested with solid and resilient wheels at a single-car weight of 105,000 pounds, as follows:

Duty Cycle	Test Run	Record No.	Wheels
I (35 mph)	117	1255 (1-38)	Solid
II (50 mph)	117	307 (1-17)	Solid
I	141	1104 (1-37)	Resilient
II	142	1445 (1-17)	Resilient

Test Procedures

The SOAC-P-5001-TT procedure was used to perform the tests for two duty cycles. Cruise speeds of 35 and 50 mph were tested.

Objective

The objective of the friction brake duty cycle tests was to determine the thermal capacity of the SOAC tread brake system while operating on duty cycles similar to those anticipated during the SOAC demonstration, with the dynamic brake disabled. Cycle I simulates NYCTA 8th Avenue Express; Cycle II simulates the Cleveland Airport (CTS) route. Both solid and resilient wheels were tested to determine their capability and to define potential limitation for the demonstrations.

Status

The test data derived from the above four tests has been reduced and analysed to show tread temperature and deceleration rate effects on repetitive friction brake stops. The thermocouple data have been adjusted to account for the estimated response time. Deceleration rates from digitized tape data have been plotted for several stops during the duty cycles for both types of wheels.

Energy consumption was recorded during the duty cycles; the data has been reduced and is presented in Section 6.

5.2 TEST DESCRIPTION

In general, the duty cycle tests were performed by accelerating the car at full service rate to a target cruise speed. This speed was then maintained for a specified time. Following cruise time the propulsion system was disabled by simulating a propulsion system cooling airflow loss; full-service friction brake was applied; and the car was stopped. After a simulated station dwell of 30 seconds the above procedure was repeated in accordance with the specific duty cycle (I or II).

The recorders were left running throughout the test, brake shoe temperatures were recorded every 12 seconds, and wheel tread temperatures were recorded (manual thermocouple on aft left-hand wheel) every fourth stop.

5.3 INSTRUMENTATION

Test parameters recorded on tape during the duty cycle tests are presented in Tables 5-1 and 5-2, as follows:

Test Run	Data Sheet No.	Table
117	5	5-1
141	14	5-2
142	14	5-2

In addition brake shoe and wheel tread temperatures were recorded on a 12-point Leeds & Northrup Speedomax-H temperature recorder. With only two thermocouples in use, there is a 12-second interval between successive printouts of each thermocouple.

One thermocouple was embedded in the composition brake shoe approximately 0.4 to 0.5 inch from the surface during test run 117 and 0.2 to 0.25 inch from the surface during test runs 141 and 142 (due to brake wear). The second thermocouple was loosely attached outside the car and manually positioned on the wheel tread or rim during every fourth station stop. Two or three successive printouts of this thermocouple were obtained before continuing the test cycles.

TABLE 5-1. LABORATORY TAPE RECORDER DATA SHEET NO. 5

Test Title Performance Test Type Duty Cycles

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/31/73 Test Eng ______ Tech ______ Tape Type & Size 3M 7200 ft

Tape Recorder Model No. SANGAMO SABRE III Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect		Remarks	Quick-Look Oscillograph
					Type	C.E.		
1	Line E			±10.0VDC	FM	3.375 Hz	+ 1000 VDC = + 10.000 VDC	
2	Line I				FM	3.375 Hz	+ 2000 ADC = + 10.000 VDC	
3	Long. Accel			±5.0VDC	FM	3.375 Hz	± 0.25G = ± 5.000 VDC	X
4	Speed Axle #3			±5.0VDC	FM	3.375 Hz	80 MPH = + 5.000 VDC	X
5	#1 Truck Arm E			±5.0VDC	FM	3.375 Hz	+ 1200 VDC = + 5.000 VDC	
6	Sync			±5.0VDC	FM	3.375 Hz	Tape Sync	
7	Total Pwr			±5.0VDC	FM	3.375 Hz	1 Pulse/.1 KWH	X
8	#1 Truck Arm I			±5.0VDC	FM	3.375 Hz	+ 1000 ADC = + 5.000 VDC	X
9	#2 Truck Arm I			±5.0VDC	FM	3.375 Hz	+ 1000 ADC = + 5.000 VDC	X
10	#1 Truck Field I			±5.0VDC	FM	3.375 Hz	+ 50 ADC = ± 5.000 VDC	
11	#2 Truck Field I			±5.0VDC	FM	3.375 Hz	± 50 ADC = ± 5.000 VDC	
12	P Wire I			±5.0VDC	FM	3.375 Hz	+ 1.0 ADC = -5.000 VDC	X
13	Brake Press Axle #1			±5.0VDC	FM	3.375 Hz	100 PSI = + 5.000 VDC	X
14	Event			±5.0VDC	FM	3.375 Hz	2 Hz Signal	X
Edge A								
Edge B	Voice				Dir			

TABLE 5-2. LABORATORY TAPE RECORDER DATA SHEET NO. 14

Test Title Performance Test Type Duty Cycles

Specimen P/N SOAC No. 2 Car Specimen S/N ____ Test Location Pueblo

Date 7/14/73 Test Eng ____ Tech RPM-DLB Tape Type & Size 1 in. x 7200 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph Location
1	301 Long. Accel	±0.25G's		±5.00VDC	FM	3.375 KC	±0.25G's = ±5.00 VDC	R/H
2	302 Line E	Volt/Div S/N 002		±5.00VDC	FM	3.375 KC	Zero VDC = -5.00 VDC +1000 VDC = +5.00 VDC	L/H
3	303 Line I	3000 Amp Hall Device		±5.00VDC	FM	3.375 KC	Zero ADC = -5.00 VDC +2000 ADC = +5.00 VDC	L/H
4	304 #1 Arm E	Volt/Div S/N 001		±5.00VDC	FM	3.375 KC	+1200 VDC = 5.00 VDC	L/H
5	305 #1 Arm I	1000 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+1000 ADC = 5.00 VDC	R/H
6	306 #1 Field I	150A S/N 57	3 turns 50A=5.0 VDC x 1	±5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	L/H
7	307 #2 Arm E	Volt/Div S/N 003		±5.00VDC	FM	3.375 KC	+1200 VDC = 5.00 VDC	L/H
8	308 #2 Arm I	1000 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+1000 ADC = 5.00 VDC	R/H
9	309 #2 Field I	500A AM-A-C	5 turns 50A=2.5 VDC x 2	±5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	L/H
10	310 P Wire I	1.0 Amp AM-A-C		±5.00VDC	FM	3.375 KC	+1.0 ADC = 5.00	R/H
11	311 Analog Valve I	5.0 Amp AM-A-C		±5.00VDC	FM	3.375 KC	5.0 ADC = 5.00 VDC	L/H
12	315 Speed	Monopole		±5.00VDC	FM	3.375 KC	80 MPH = 626.5 Hz	R/H
13	318 Brake Press	Tabor 0-200 PSIG Mod 185		±5.00VDC	FM	3.375 KC	100 PSIG = +5.00 VDC	R/H
14	Time Code	IRIG B		±5.00VDC	FM	3.375 KC		Both (2)
Edge A							NOTE: D.S. #14 for post-wheel change data only	
Edge B	Voice & Event				Dir			Both (2)

5.4 TEST PROCEDURES

Duty cycle test procedures for Cycles I and II are contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1). The procedures detail the specific speed, time, and dwell requirements as well as SOAC operating instructions and data recording techniques.

For baseline tests these SOAC procedures have been generalized into one procedure contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2). The procedure, RB-P-5001-TT, is as follows:

Duty Cycles Friction Braking Procedure

I. Preliminary (pre-test)

  A. Attach instrumentation, or patch in desired parameters at storage or shop.

  B. Add ballast weights to simulate desired car weight (AW______).

  C. Check out and calibrate instrumentation.

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

  E. Make up desired train consist.

  F. Proceed to test zone.

  G. Make inspection passes over test zone; check out vehicle and track.

  H. Record ambient conditions as required.

  I. Adjust car such that the dynamic brake can be disabled on each start-stop cycle.

II. Test Procedure (at test zone)

  A. Position car at defined track location for testing in the defined car direction.

  B. Start recorders, identify records, record track station number.

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

D. Maintain the target cruise speed for the specified time period.

E. At end of cruise time, disable dynamic brake and apply full-service friction braking.

F. Bring car to complete stop and simulate a station dwell of the desired length.

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

H. Repeat Items C through G until the specified number of start-stop cycles have been completed. Record completed laps of the test oval, total elapsed time from the start (Item C), and the track station at which the test was completed.

Option (1)

Repeat Items A through H at the specified cruise speeds and cruise times.

Option (2)

Repeat Items A through H at the specified car weights.

Option (3)

Repeat Items A through H with the specified wheel or brake configuration (i.e., type of brake or level of blended brake).

Option (4)

Repeat Items A through H at the specified brake rate command.

During the SOAC Duty Cycle tests, the above procedure was used in the following combinations:

Test Item	Duty Cycle I	Duty Cycle II
No. of start-stops	37	17
Cruise speed, mph	35	50
Cruise time, seconds	45	55
Average distance per cycle, miles	0.55	1.05

The testing was accomplished with both solid and resilient wheels with a single car at 105,000 pounds in the clockwise track direction.

5.5 TEST DATA

5.5.1 Test Data Reduction

The measured tread temperatures were corrected to an ambient temperature of 100°F on a one-to-one basis using the pre-test measured ambient temperature. The test thermocouple values were also corrected according to the analysis procedure outlined below. Deceleration rates for the various stops were obtained from digitized tape data corrected for any zero shifts (as noted in Section 3). The plotted data of Figures 5-5 and 5-6 are representative of level track brake rates since the car-mounted accelerometer data was utilized (not $\Delta V/\Delta t$) and grade effects are cancelled out by using the level track reference as the "zero".

Thermocouple Data Analysis

As previously noted in Paragraph 5.3, the temperature monitoring system used (a Leeds & Northrup Multipoint Chart Recorder with chromel-alumel thermocouples) has a capability of monitoring 12 channels in series by switching from one channel to the next. A 6-second interval occurs between data point recordings for each channel. When only two channels are used the recorder alternates between them, giving 12 seconds between consecutive points on one thermocouple.

The thermocouples were not factory manufactured; the Garrett Instrumentation Group welded a 1/16-inch lead on the tip of chromel-alumel leads. These thermocouples were sufficient for measuring slow changing temperatures.

Following the test procedure of Paragraph 5.4, the wheel tread temperatures were measured at every fourth stop by a test crew member who exited from the rear of the car, took the remote thermocouple taped to the car body, and manually held it on the wheel tread. Initially this thermocouple was at nearly ambient temperature (approximately 70°F) while wheel tread temperatures were up to 300°F. Because time lag had been noted on early stops, the thermocouple was held on the tread for from two to three 12-second cycles of the recorder (see Figures 5-1 and 5-2 for sample data outputs).

Since a large amount of scatter was noted in the data during preliminary analyses, a decision was made to try to correlate the continuously measured brake shoe temperatures with the scattered tread temperatures. Although brake shoe wear

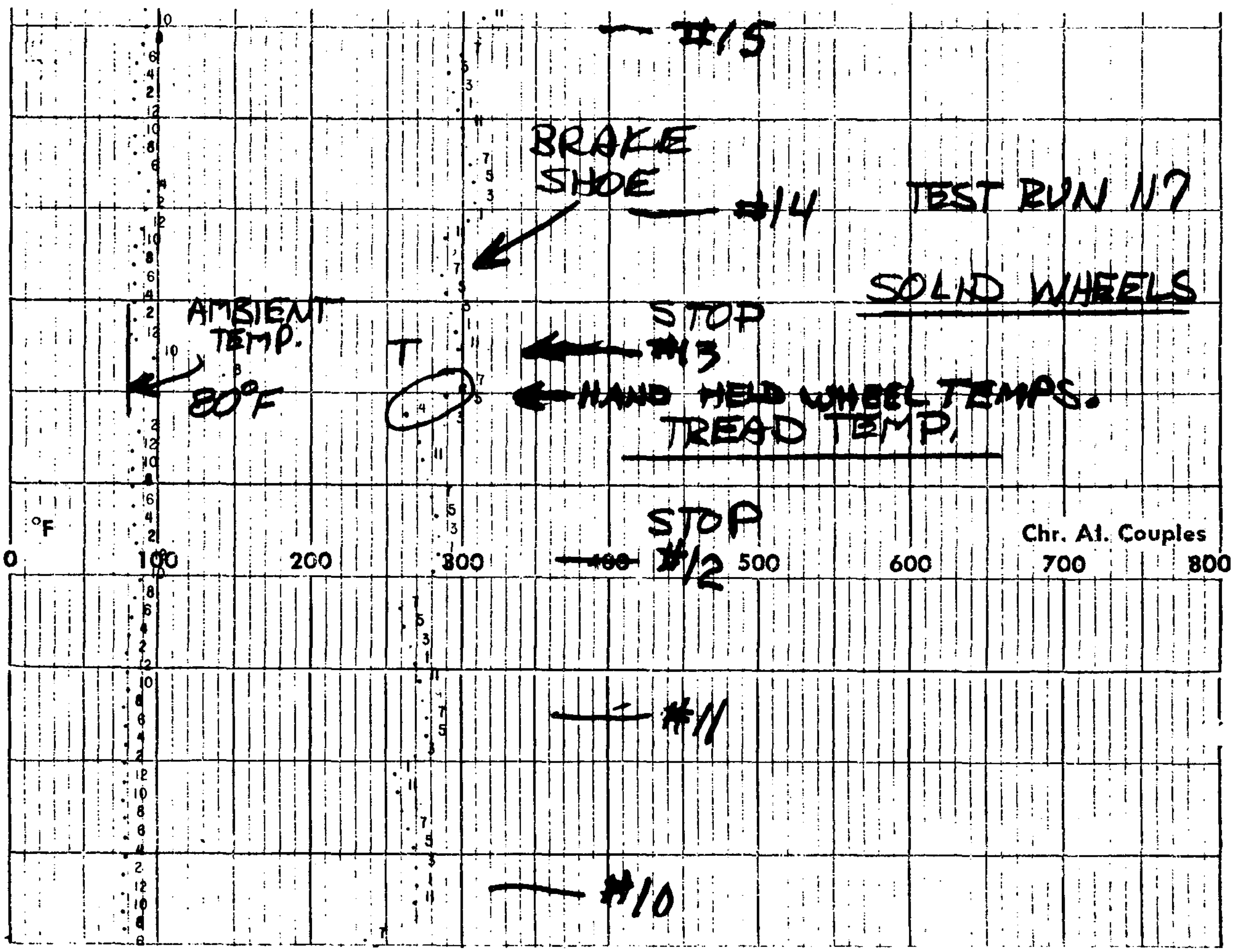


Figure 5–1. Sample Temperature Monitor Data Output (Test Run 117, Solid Wheels)

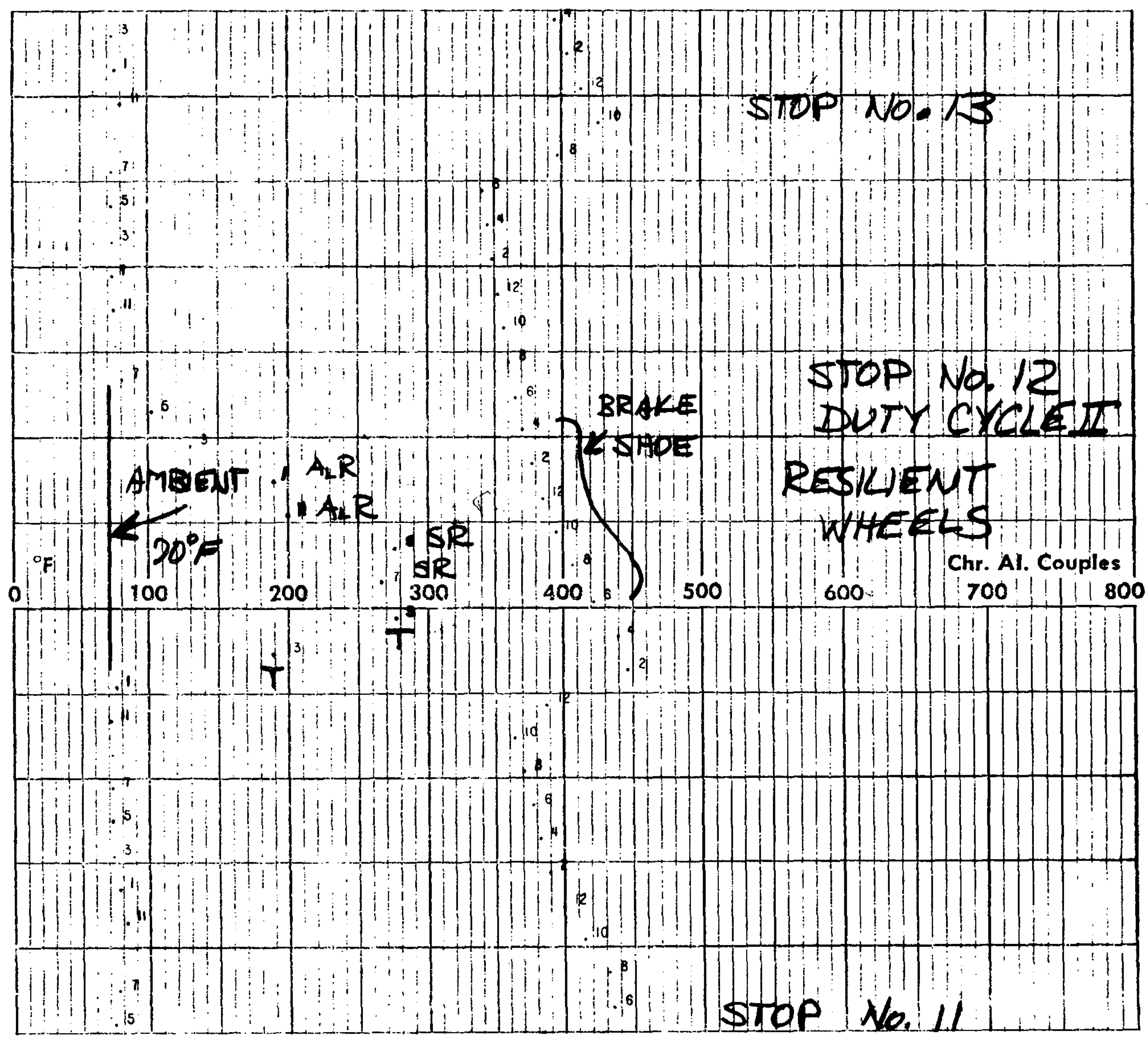


Figure 5–2. Sample Temperature Monitor Data Output (Test Run 142, Resilient Wheels)

increased between solid and resilient wheel tests, the measured value of shoe temperature (i.e., thermocouple nearer to point of peak shoe/tread temperature) the trend of the ratio of shoe temperature to stop number provided a useful baseline.

It was recognized that errors could have been introduced into the wheel tread temperature readings in any of the following ways:

1. Response time of the thermocouple: Theoretically, it could have responded slowly enough so that it never reached the actual wheel tread temperature in the 6 to 12 seconds it was applied to the tread. Some effort was made to determine this response time, but it was not successful.

2. The technique of applying the thermocouple to the tread: Two individuals performed this function, each probably in a different manner. The temperature reached by the thermocouple could have been affected by the point where applied on the tread, the pressure of contact, or any sliding of the thermocouple on the tread. One test crew member noticed some of these variations which could not be avoided.

3. "Movement" of the thermocouple in the brake shoe: It was suggested that the apparent non-correlation of the resilient wheel temperatures to brake shoe temperatures could be due to the fact that the brake shoe thermocouple was closer to the tread. The brake shoes have worn considerably since the steel wheel tests, and the thermocouple could be closer to the tread and therefore responding more to peak tread temperatures.

   In order to perform the correlation, a simple linear regression was made of the brake shoe maximum temperature and the measured wheel tread temperatures. Initially, all of the test points measured during the steel wheel test were used as the data set. Statistically, this is a large sample and bad data could therefore be identified; the correlation coefficient (a "goodness" figure) equals 0.945 (1.0 is perfect). Other statistical quantities indicate that there is good correlation. In addition, certain data points were identified as being in suspected error, notably the 8th stop in Duty Cycle II. When this one point is eliminated from the data, a correlation coefficient of 0.974 results. With the elimination of three additional suspected points, the correlation coefficient becomes 0.994. All of the suspected data points may derive from the second suggested error mechanism.

This correlation prompted a check of the resilient wheel tests. All of the measured wheel tread temperatures and maximum brake shoe temperatures were used to run the same type linear regression. The raw data (total of 16 points) produced a correlation coefficient of 0.917, and again there were other statistical indications of a good correlation. Elimination of the three worst points produced a correlation coefficient of 0.980; elimination of 6 worst points produced 0.994. Since the statistical evidence shows there was good correlation between brake shoe temperature and wheel tread temperature, this information was used to correct the inconsistencies of the test data. Consequently, the results shown in Figures 5-3 and 5-4 should be used as the wheel tread temperature profiles.

5.5.2 Sample Data Output

Sample temperature recorder strip-charts for solid and resilient wheel Duty Cycle II tests are shown in Figures 5-1 and 5-2, respectively. The manually held tread thermocouple temperataure lag is noted on these figures.

The deceleration rate data shown in Figures 5-4 and 5-6 are based on digitized listings similar to those shown in Sections 2 and 3.

5.5.3 Duty Cycle I Results

Duty Cycle I was designed to simulate operation on the NYCTA 8th Avenue Express, on the 207th Street to Lefferts Boulevard Route; Table 5-3 compares the actual and tested routes.

Figure 5-3 presents the results of Duty Cycle I testing with both types of wheels and also contains the raw brake shoe data. Based on the corrected data, the resilient wheels can be expected to average about 25 to 50°F above solid steel wheels. It should be noted, however, that the tested duty cycles do not represent a normal service condition since the dynamic brake will absorb most of the car's energy in service use.

The tread (bulk) temperatures measured on the SOAC resilient wheels are considerably below temperatures measured on the resilient wheels during dynamometer testing of 50 consecutive stops from 80 mph (6 minutes apart) with a simulated 140,000-pound car: 540°F tread bulk and 410°F rim bulk. The limiting temperature criteria is a differential bulk temperature of 100°F between the tread and rim. The maximum differential measured during the Duty Cycle I resilient wheel tests was approximately 15°F.

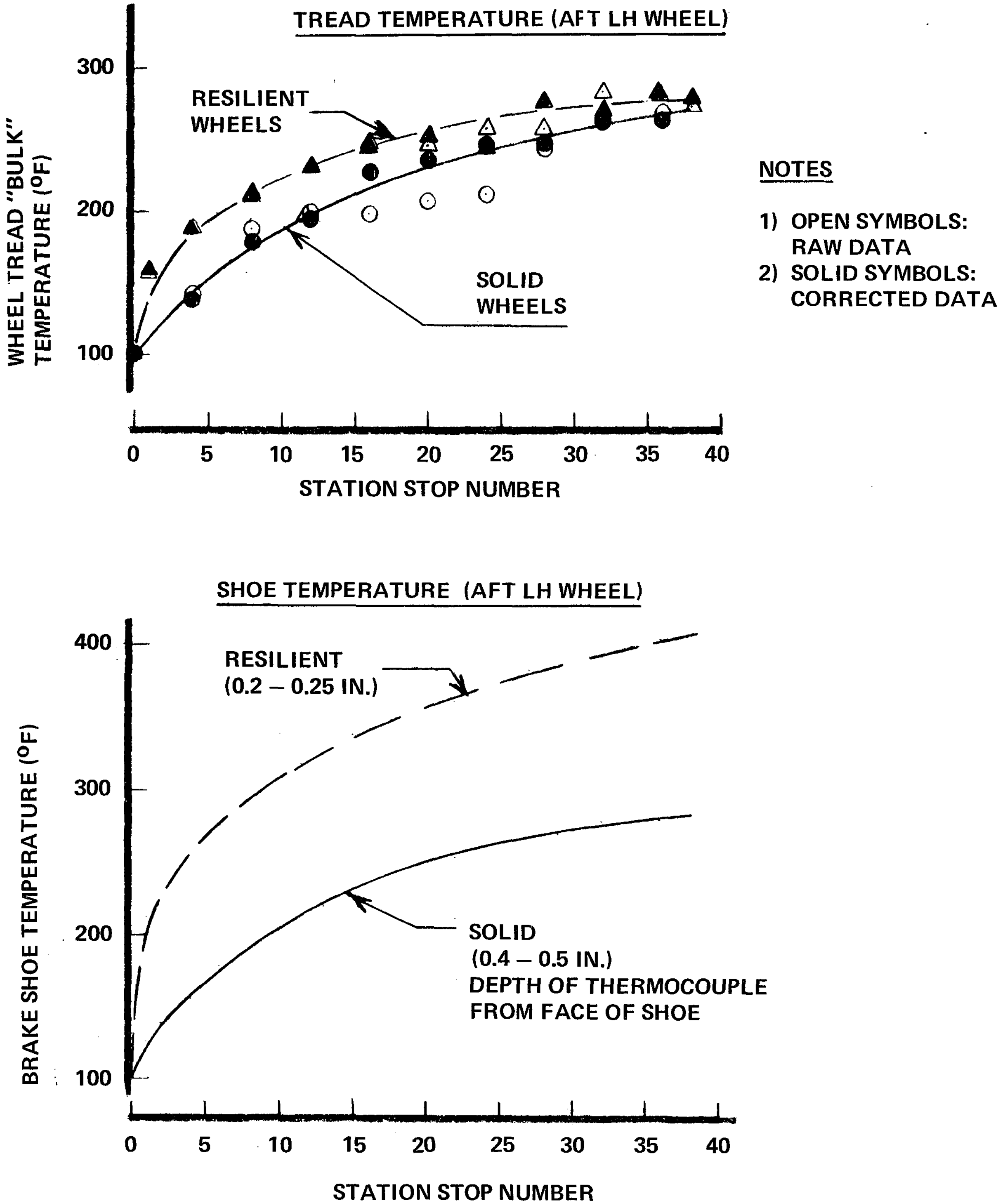


Figure 5–3. Duty Cycle I Tread and Shoe Temperature (105,000-Pound Car, Service Friction Braking Only)

TABLE 5-3. DUTY CYCLE I (NYCTA ROUTE)

Route	NYCTA (8th Ave. Express)	Pueblo Duty Cycle I
Distance, miles	22.5	21.8*
Scheduled time, minutes	68	65*
No. of start-stop cycles	38	38
Stops per mile	1.69	1.74
Maximum speed, mph	35 (est, avg)	35 (actual)
Schedule speed, mph	19.8	20.1*
Measured maximum tread bulk temperatuares, °F		
Solid	N/A	264°
Resilient	N/A	282°

*Solid wheels; Test Run 117.

Figure 5-4 presents deceleration rates recorded during several stops for Duty Cycle I. The increased deceleration rate noted between the solid and resilient wheel data may be attributed to the 6 to 7 psi increase in brake cylinder pressure.

A further complication in the test data for resilient wheels was that a front right-hand brake was not making proper contact with the tread, thereby increasing the energy absorbed by the remaining seven shoes. The brake pressures were adjusted to the nominal 68 psi prior to performing Duty Cycle II; deceleration rates show better correlation for that data (Figure 5-6).

Within the temperature range shown in Figure 5-4, the Cobra composition shoes show a random variation of about 0.3 mphps at 20 mph over the 34 stops for either type of wheel.

5.5.4 Duty Cycle II Results

Duty Cycle II was designed to simulate operation on the Cleveland Transit System (CTS) Windermere Airport Route; Table 5-4 compares the actual and tested routes.

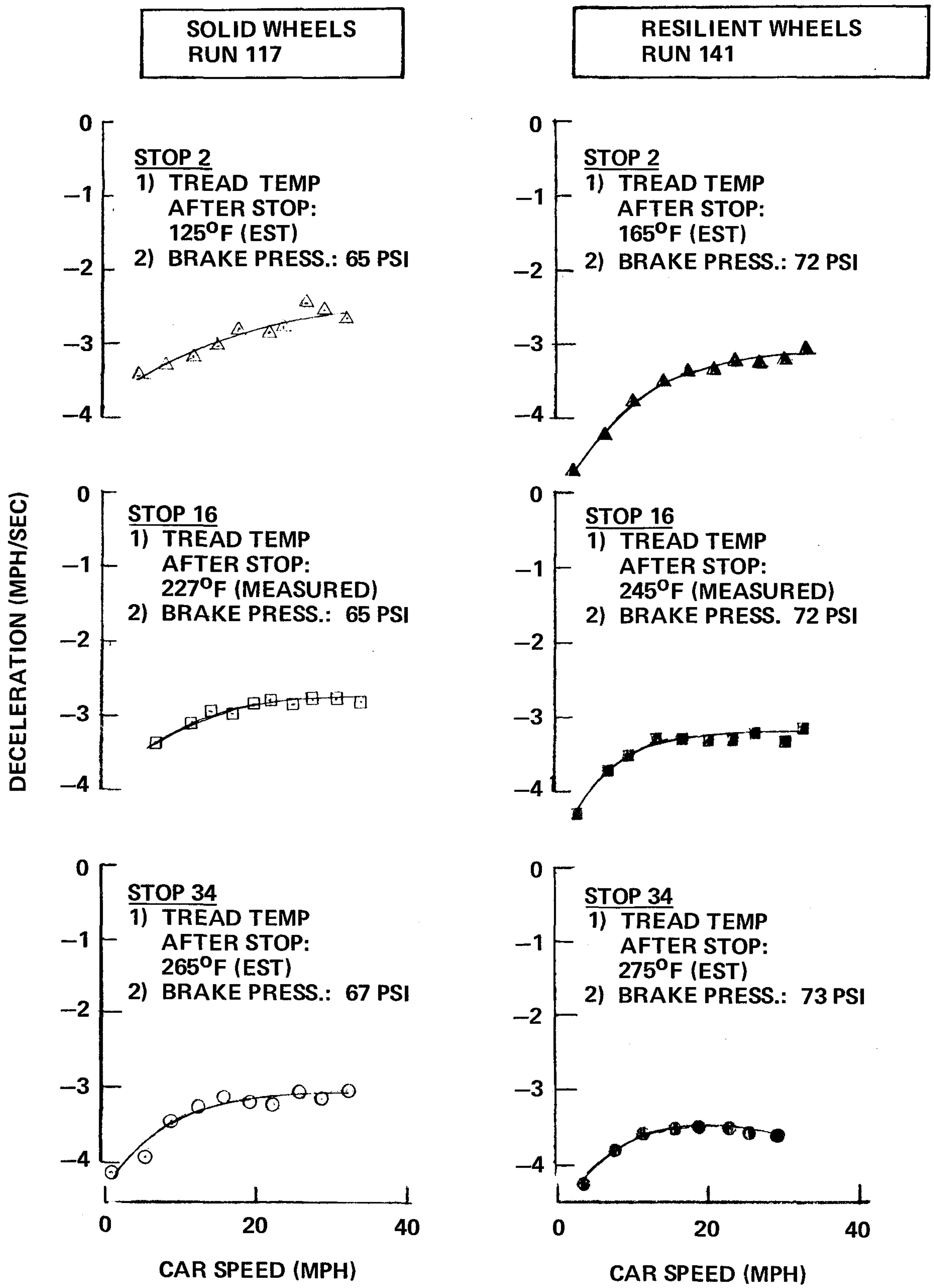


Figure 5–4. Duty Cycle I Friction Braking Deceleration (105,000-Pound Car Braking from 35 MPH)

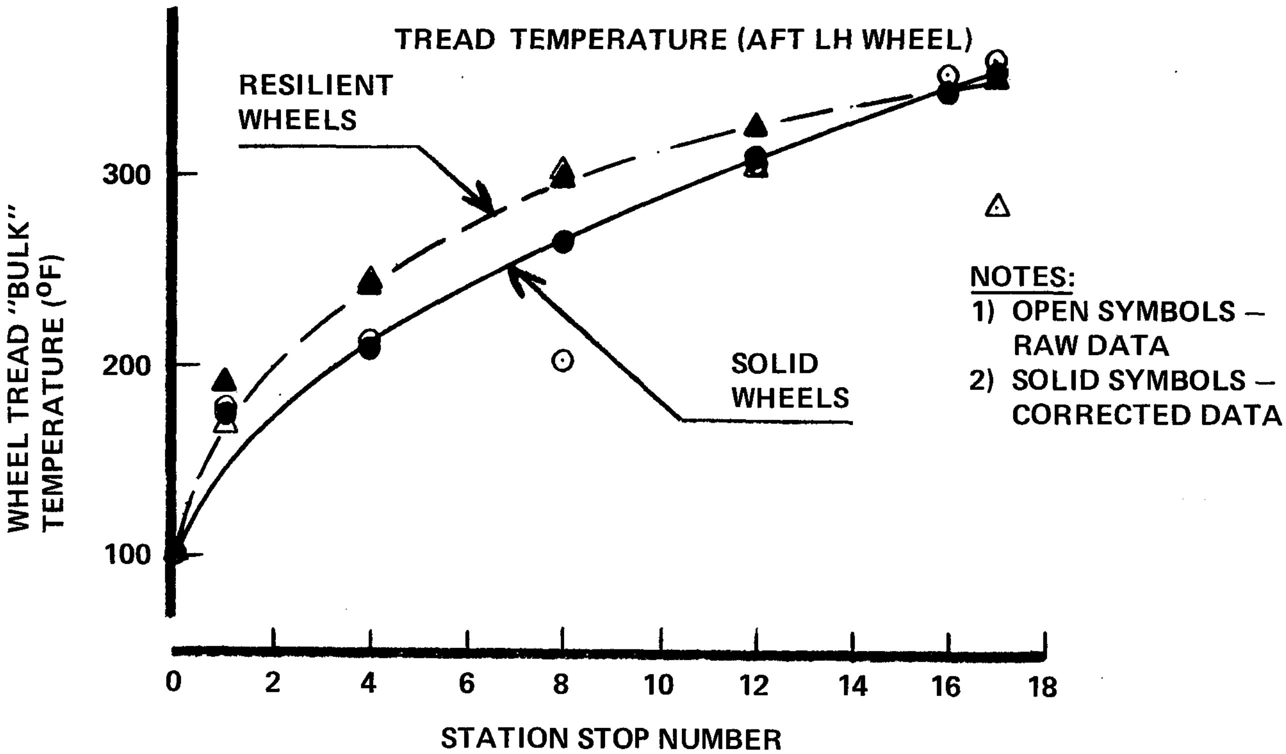
TABLE 5-4. DUTY CYCLE II (CLEVELAND)

Route	Cleveland (CTS) Airport Route	Pueblo Duty Cycle II
Distance, miles	19.0	17.9*
Scheduled time, minutes	36	38*
No. of start-stop cycles	17	17
Stops per mile	0.9	0.95
Maximum speed, mph	52 (est, avg)	50 (actual)
Schedule speed, mph	31.6 (est)	28.2*
Measured maximum tread bulk temperatures, °F		
Solid	N/A	350°
Resilient	N/A	350°

*Solid wheels; Test Run 117.

Figure 5-5 presents the results of Duty Cycle II testing with both solid and resilient wheels, and also contains the raw brake shoe data. Based on the corrected data, the resilient wheels can be expected to average 30 to 35°F above the solid wheels. As previously noted, these temperatures are considerably below the maximum bulk temperatures recorded on resilient wheels during dynamometer testing. The maximum bulk temperature differential, tread to rim, recorded during Duty Cycle II testing with resilient wheels was 30°F.

Figure 5-6 illustrates the deceleration rates recorded during the tests. At 30 mph, the variation in rate over the 17 stops is about 0.3 mphps for solid wheels and 0.5 mphps for the resilient wheels. Also note that the characteristic increase in deceleration rate at low speed is diminished by about 1 mphps as the brakes are heated. Figure 5-6 provides a valid rate comparison between wheel types since brake pressures were essentially constant for the six stops shown.



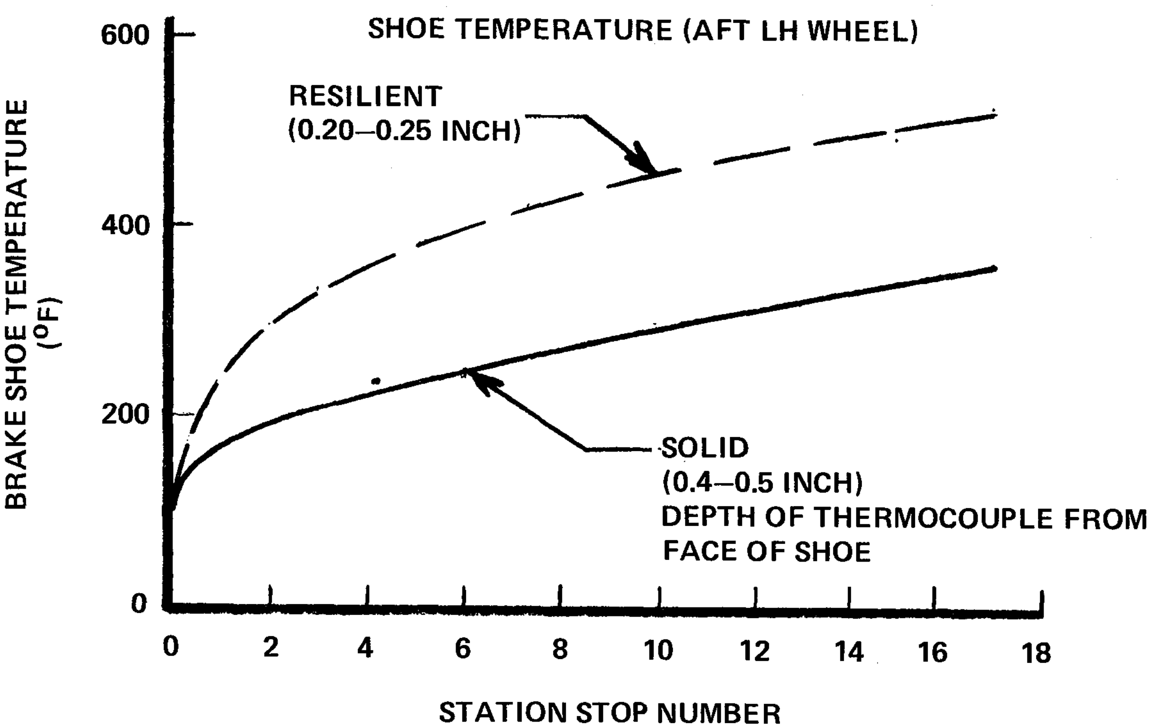


Figure 5–5. Duty Cycle II Tread and Shoe Temperatures (105,000-Pound Car)

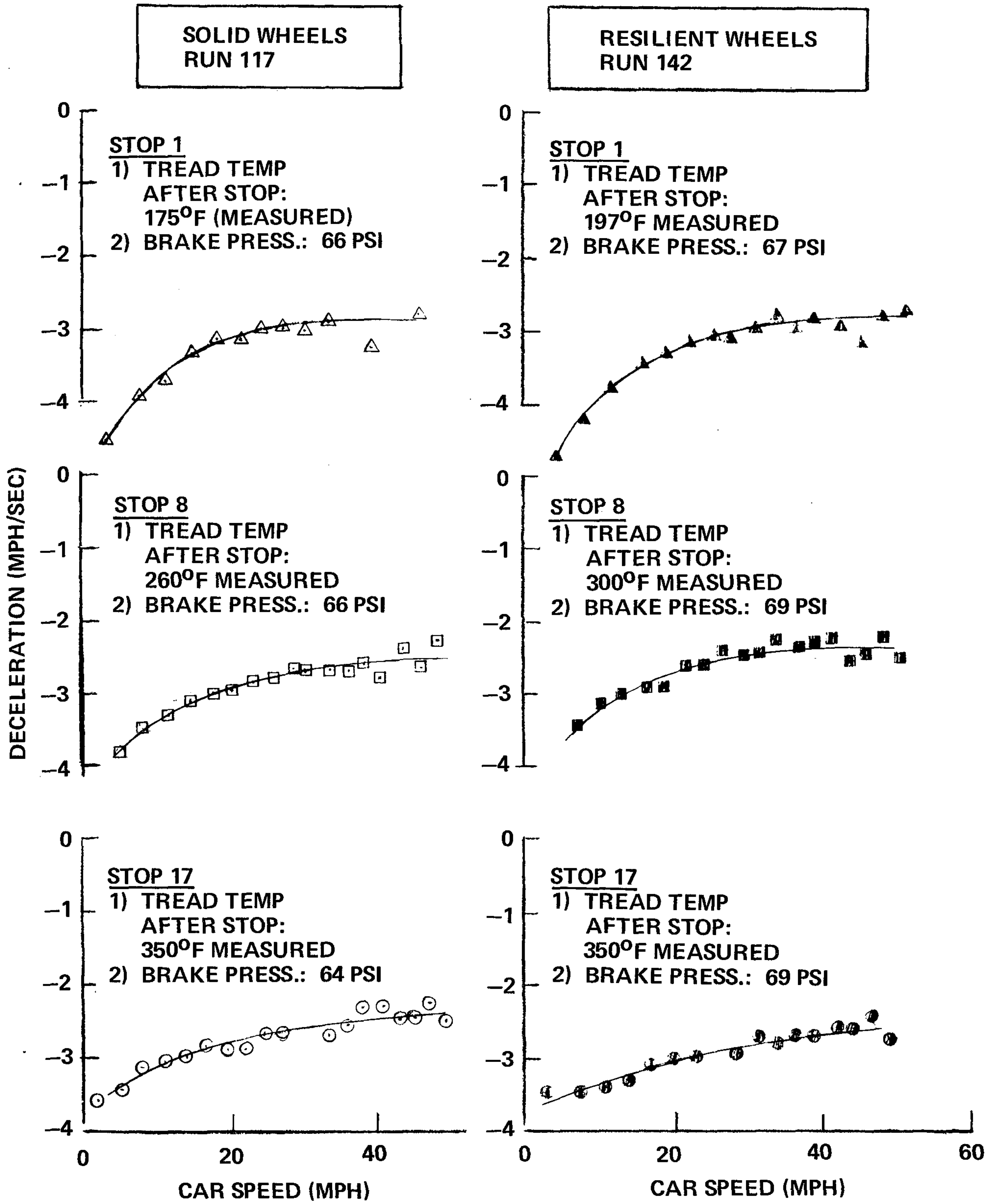


Figure 5–6. Duty Cycle II Friction Braking Deceleration Rates (105,000-Pound Car Braking from 50 MPH)

Section 6

POWER CONSUMPTION AND UNDERCAR EQUIPMENT TEMPERATURE TESTS DURING SIMULATED TRANSIT OPERATION

6.1 SUMMARY

Test Sequence

Table 6-1 presents a run log of Power Consumption Testing.

Procedures

SOAC-PC-5011-TT procedure was used for testing on the Synthetic Transit Route; SOAC-P-5001-TT procedure was used to obtain energy consumed during the friction brake duty cycles described in Section 6.

Objective

The objective of the power consumption testing was to determine the SOAC's energy consumption and schedule speed on the Synthetic Transit Route developed for the ACT-1 Program. The test results will provide a baseline for both the SOAC and the route (as laid-out at Pueblo). The overall efficiency of the traction system will be estimated from this data.

Status

Test data were obtained from two round trips of the 9.25-mile synthetic route for a single car weighing 105,000 pounds. In addition the energy consumed during the friction brake duty cycles was recorded and has been reduced for both solid and resilient wheel testing. Data reduction consisted of off-car machine combination and summation of the car's input voltage and current.

Undercar equipment temperatures were also recorded during the synthetic route tests. The data were recorded on the 12-channel recorder and peak temperatures were corrected to an ambient temperature of 125°F, the design goal of the SOAC.

TABLE 6-1. SOAC ENGINEERING TEST RUN LOG

Type of Test: Energy Consumption
Type of Wheels: Solid and Resilient

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
5/31/73	117	1255	5	Duty Cycle I	1.0 to 0.0	35	105,000	2 (H-D)	fwd	600	Solid wheels
5/31/73	117	307	5	Duty Cycle II	1.0 to 0.0	50	105,000	2 (H-D)	fwd	600	Solid wheels
7/14/73	141	1104	14	Duty Cycle I	1.0 to 0.0	35	105,000	2	fwd	600	Resilient wheels
7/14/73	142	1445	14	Duty Cycle II	1.0 to 0.0	50	105,000	2	fwd	600	Resilient wheels
7/18/73	149	1712	15	ACT-1 Route (CW)	1.0 to 0.0	Var. 80	105,000	2	fwd	600	Resilient wheels, wet rails, slip-slides
		1741		ACT-1 Route (CCW)					rev		
7/20/73	153	1359	15	ACT-1 Route (CW)	1.0 to 0.0	Var. 80	105,000	2	fwd	600	Resilient wheels, dry rails
		1438		ACT-1 Route (CCW)					rev		

6.2 TEST DESCRIPTION

Energy Consumption Testing was accomplished by operating the car in simulated schedule service over a defined series of station stops at various maximum speeds. Service maximum accelerations and decelerations were employed. For a single car of 105,000 pounds, data from three types of routes were recorded using two test methods:

Method I

a. Specified station locations

b. Various maximum speeds between stations

c. Complete round trip of this simulated route (ACT-1 Synthetic Transit Route)

Method II

a. Station locations not specified

b. Acceleration, cruise speed, cruise time specified with repetitive operation, i.e., average station spacing.

c. One-way operation only

d. Two route structures tested, Duty Cycles I and II.

e. Blended braking not used

6.3 INSTRUMENTATION

The instrumentation parameters recorded during energy consumption testing consisted of the basic performance parameters plus one channel combining line volts, line amps, and time with a digital counter (0.1 kw-hr) as quick-look readout. Since some errors were made in the wiring of this counter, the final data were obtained by a machine integration technique at the AiResearch Torrance (California) facility.

Applicable Data Sheet identification is contained in Table 6-1; data sheets are located as follows:

Data Sheet No.	Table No.
5	5-1 (Section 5)
14	5-2 (Section 5)
15	6-2

6.4 TEST PROCEDURE

The test procedure used to perform the energy consumption tests on the ACT-1 Synthetic Transit Route is contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1), along with a detailed description of the route and car operating instructions. Test procedure for car operation during the friction brake duty cycles is contained in Section 5 of this report.

For baseline testing the SOAC procedures have been generalized and are contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2). The baseline procedures are: RB-PC-5011-TT, Energy Consumption (Synthetic Route); and RB-P-5001-TT, Duty Cycles I and II.

Power Consumption Procedure RB-PC-5011-TT

I. Preliminary (pre-test)

A. Attach instrumentation or patch-in desired parameters at storage or shop.

B. Add ballast weights to simulate desired car weight (AW __)

C. Check out and calibrate instrumentation

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

E. Lay out simulated route: station locations and "brake" application markers

F. Make up desired train consist

G. Proceed to test zone

H. Make inspection passes over test zone; check out vehicle and track.

TABLE 6-2. LABORATORY TAPE RECORDER DATA SHEET NO. 15

Test Title Energy Consumption Test Type Energy Consumption

Specimen P/N SOAC NO. 2 Car Specimen S/N ______ Test Location Pueblo

Date 7/18/73 Test Eng ______ Tech RPM-DLB Tape Type & Size 1 in. x 7200 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph Location
1	Long. Accel 301			5.00VDC	FM	3.375 KC	±0.25G's = ±5.00VDC	R/H
2	Line E 302			10.00 VDC	FM	3.375 KC	Zero VDC = Zero VDC +1000 VDC = -10.00VDC	L/H
3	Line I 303			10.00 VDC	FM	3.375 KC	Zero Amps DC = Zero VDC +2000 Amps DC = -10.00 VDC	L/H
4	#1 Arm E 304			5.00VDC	FM	3.375 KC	1200 VDC = 5.00 VDC	L/H
5	#1 Arm I 305			5.00VDC	FM	3.375 KC	1000 ADC = 5.00 VDC	R/H
6	#1 Fld I 306			5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	L/H
7	#2 Arm E 307			5.00VDC	FM	3.375 KC	±1200 VDC = ±5.00 VDC	L/H
8	#2 Arm I 308			5.00VDC	FM	3.375 KC	+1000 ADC = +5.00 VDC	R/H
9	#2 Fld I 309			5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	L/H
10	P Wire I 310			5.00VDC	FM	3.375 KC	+1.0 ADC = +5.00 VDC	R/H
11	Total Pwr Consumption 317			5.00VDC	FM	3.375 KC	1.0 Pulse/0.1 KW	L/H
12	Speed 315			5.00VDC	FM	3.375 KC	80 MPH = 626.5 Hz	R/H
13	Brake Press 318			5.00VDC	FM	3.375 KC	100 PSIG = +5.00 VDC	R/H
14	Time Code	IRIG B		5.00VDC	FM	3.375 KC		Both (2)
Edge A								
Edge B	Voice & Event				Dir			Both (2)

I. Record ambient conditions as required

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

II. <u>Test Procedures (at test zone)</u>

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

B. Position car at the first simulated station, identify records, set counters to zero, start recorders.

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

D. As car attains the required cruise speed, decrease power and maintain cruise speed.

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

F. Bring car to a complete stop within one car length of the "station" marker using motorman's controller as required.

G. Simulate station dwell of the required time.

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

I. Repeat Items D through H until a complete trip of the specified route has been made in the clockwise direction.

J. Repeat Items B through I with car operating in the counterclockwise direction (to provide for a complete round trip).

OPTION (1)

Repeat Items A through J at the required car weights.

OPTION (2)

Repeat Items A through J at the required combinations of regenerative/dynamic braking.

OPTION (3)

Repeat Items A through J with the desired regenerative "load".

OPTION (4)

Repeat Items A through J at the desired line voltage.

OPTION (5)

Repeat Items A through J with the desired train consists.

The SOAC was tested on the 9.25-mile ACT-1 Synthetic Route in both directions as a single car weighing 105,000 pounds.

6.5 TEST DATA

6.5.1 Test Data Reduction

The test data reduction consisted of a machine combination of line volts, line amps, and time over the test route. Quick-look counter data was found to be in error due to wiring problems and final data are based on playback of the tape (at AiResearch, Torrance, California) with machine analysis at that point. Auxiliary power load was determined by digital print out of line volts and amps during station dwell and by manually timing the quick-look counters (error corrected) during a station stop.

6.5.2 Sample Data Output

A sample standard output tabulation by station is shown in Table 6-3 for the ACT-1 Synthetic Route (Run 153). Digital outputs for auxiliary load may be found in Sections 3 and 4.

Complete energy consumption on all tests is summarized in the following paragraphs.

TABLE 6-3. SOAC DATA REDUCTION: REQUEST NUMBER 59, REVISION I (RUN 153)

Record 1359 Station	Kw-hr	Record 1438 Station	Kw-hr
A-		O-	
B-	9.1	N-	13.5
C-	9.9	M-	4.5
D-	6.2	L-	6.2
E-	8.9	K-	3.7
F-	6.2	J-	12.9
G-	4.1	I-	15.1
H-	4.1	H-	5.5
I-	6.9	G-	3.9
J-	17.3	F-	3.9
K-	16.5	E-	6.3
L-	4.5	D-	9.4
M-	6.9	C-	6.3
N-	4.3	B-	13.2
O-	11.0	A-	9.6
Total	115.9 kw-hr (clockwise)	Total	114.0 kw-hr (counterclockwise)

Notes: (1) This data processed from voltage and current signals recorded on tape.

(2) Average auxiliary power was approximately 34 kw (included in tabulated data).

6.5.3 Schedule Speed and Energy Consumption on ACT-1 Synthetic Transit Route

Figure 6-1 defines the 9.25-mile route layout on the Pueblo oval. This figure locates the stations and defines the maximum speeds between stations. The results of the round-trip testing conducted on this route are summarized in Table 6-4 for the two test runs conducted. Test run 153 is considered the primary data since this test was conducted on dry rails at maximum car performance. Test run 149, conducted on wet rails, resulted in numerous slips and slides. As noted on Table 6-4 the overall round-trip energy consumption for a single car at 105,000 pounds is 229.9 kw-hr or 12.43 kw-hr per car mile.

6.5.4 Energy Consumption During Friction Brake Duty Cycles

Energy consumption during the friction braking cycles was recorded and processed as noted in Paragraph 6.5.1. Tables 6-5 and 6-6 summarize the results for Duty Cycles I and II, respectively, for both solid and resilient wheel testing. Wheel type was not expected to influence the test results; however, the car performance was increased during the wheel change. Both schedule speeds and energy consumption per car mile are increased as a result. (See Section 5 for description of each Duty Cycle and its relation to New York and Cleveland transit routes.)

Based on the available data, the SOAC energy consumption is expected to average 6.7 kw-hr per car mile on short station (0.6-mile) routes and 6.6 kw-hr per car mile on longer station (1.1-mile) routes. Schedule speeds would be 21 mph and 30 mph, respectively, with station stops of 30 seconds.

6.5.5 Equipment Temperatures on Synthetic Route

Air temperatures within several equipment enclosures under the car were measured during test tuns 149 and 153. The thermocouple general location and "Stamp Number" on the recorder are shown in Table 6-7. A sample data output is shown in Figure 6-2.

Data reduction consisted of determining the peak parameter temperatures and adjusting to an ambient of 125°F based on the test measured ambient (one-to-one basis). Table 6-8 summarizes these adjusted equipment temperatures for the two test runs. The data are based on a round trip for each test run; 40 minutes for each round trip. The performance level of the car during the synthetic route tests approximates the one-hour rating of the traction system.

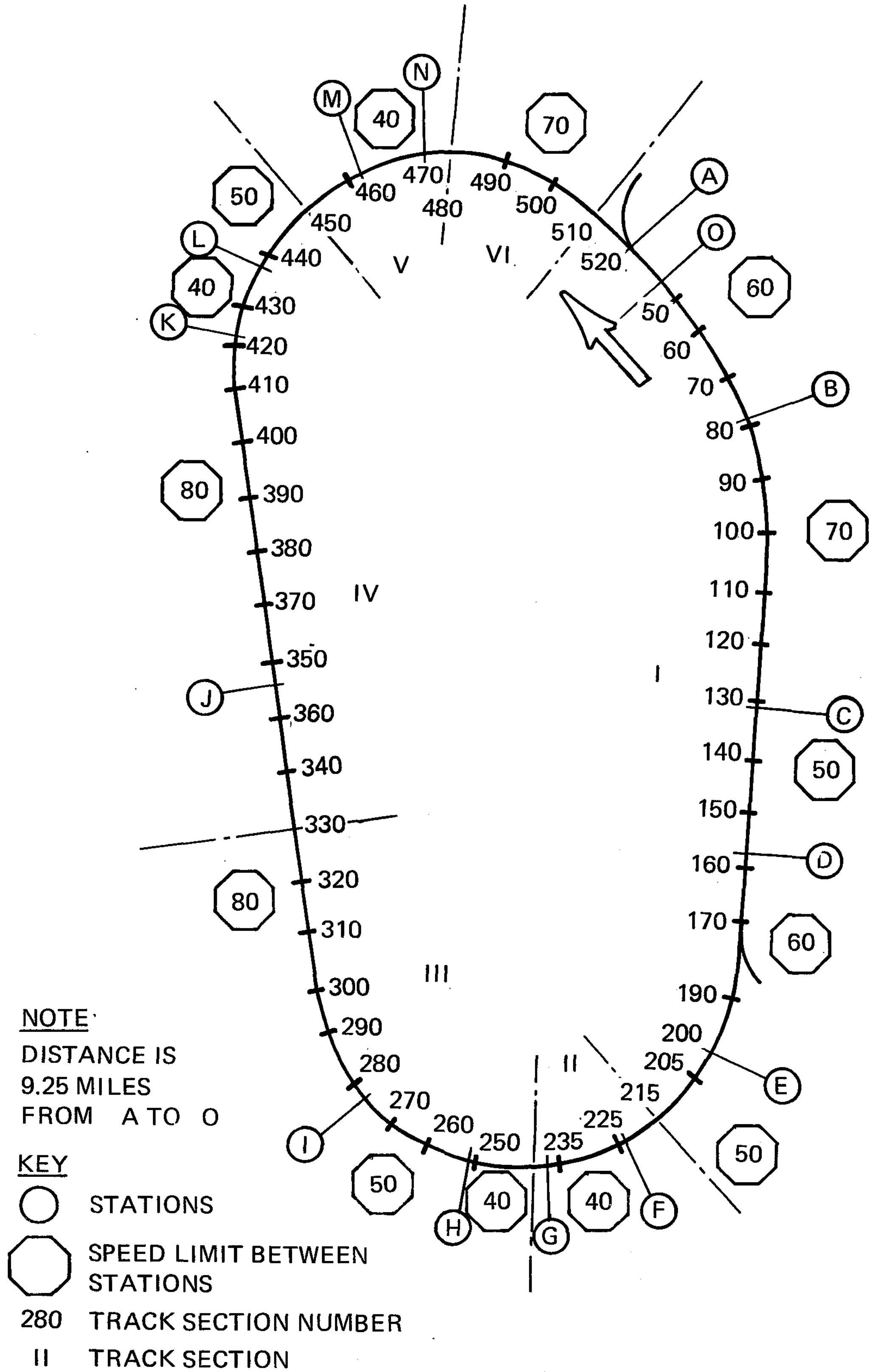


Figure 6–1. ACT-1 Synthetic Transit Route

TABLE 6-4. SUMMARY OF SOAC ENERGY CONSUMPTION ON ACT-1 SYNTHETIC TRANSIT ROUTE (RUN 153)

Station (Two Directions)	Maximum Speed (mph)	Distance (miles)	Two-Directional Energy (kw-hr*) Total	Per Car-Mile
A to B	60	0.75	9.35	12.47
B to C	70	1.00	11.55	11.55
C to D	50	0.50	6.25	12.50
E to E	60	0.75	9.15	12.20
E to F	50	0.50	6.25	12.50
F to G	40	0.25	4.00	16.00
G to H	40	0.25	4.00	16.00
H to I	50	0.50	6.20	12.40
I to J	80	1.50	16.20	10.80
J to K	80	1.25	14.70	11.76
K to L	40	0.25	4.10	16.40
L to M	50	0.50	6.55	13.10
M to N	40	0.25	4.40	17.60
N to O	70	1.00	12.25	12.25
			x(2)	
	18.5-Mile Total		229.9	12.43
Schedule Speed:	27.8 mph			
DATA FROM TEST RUN 149 (Numerous spin/slides on wet rails)				
	18.5-Mile Total		235.1	12.71
Schedule Speed:	27.3 mph			

*Includes 34 kw auxiliary power

TABLE 6-5. SUMMARY OF ENERGY CONSUMPTION DURING DUTY CYCLE I[1] (105,000-POUND CAR)

Test Item	Test Run 117 (Solid Wheels)	Test Run 141 (Resilient Wheels)
Distance, miles	21.85	24.68
Time, minutes	65.0	68.2
No. of stops	38	38
Station spacing, miles	0.58	0.65
Maximum speed, mph	35	35
Schedule speed, mph	20.2	21.7
Total energy, kw-hr	142.1	170.0
Energy consumption, (3) kw-hr/car-mile	6.50	6.89
Average auxiliary power, kw	34[2]	34[2]

Notes:

(1) Duty Cycle I simulates duty cycle on NYCTA 8th Avenue Express

(2) Average of data from Run 116 and Run 149

(3) Includes auxiliary power

TABLE 6-6. SUMMARY OF ENERGY CONSUMPTION DURING DUTY CYCLE II[1] (105,000-POUND CAR)

Test Run	Test Run 117 (Solid Wheels)	Test Run 142 (Resilient Wheels)
Distance, miles	17.97	19.50
Time, minutes	38	37.3
No. of stops	17	17
Station spacing, miles	1.06	1.15
Maximum speed, mph	50	50
Schedule speed, mph	28.4	31.4
Total energy, kw-hr	123.5	122.4
Energy consumption, kw-hr/car-mile	6.87	6.28
Average auxiliary power, kw	34[2]	34[2]

Notes:

(1) Duty Cycle II simulates duty cycle on Cleveland's Windermere to Airport Route

(2) Average of data from Run 116 and Run 149

TABLE 6-7. THERMOCOUPLE AND RECORDER STAMP NUMBERS

Parameter	Thermocouple No.	Recorder Stamp No.
Traction Motor No. 3, Frame	T1	1
Air Conditioner, Condenser, Input Air	T2	2
Chopper Box, Outlet Air	T3	3
Propulsion Blower, Outlet Air	T4	4
Brake Grid, Air	T5	5
PCU, Interior Air	T7	6
Motor Smoothing Reactor	T8	7
Chopper Box, Interior Air	T9	8
PPCU, Interior Air	T11	9
APCU, Interior Air	T12	10
Motor Alternator, Outlet Air	T13	11
Traction Motor, Outlet Air	T14	12

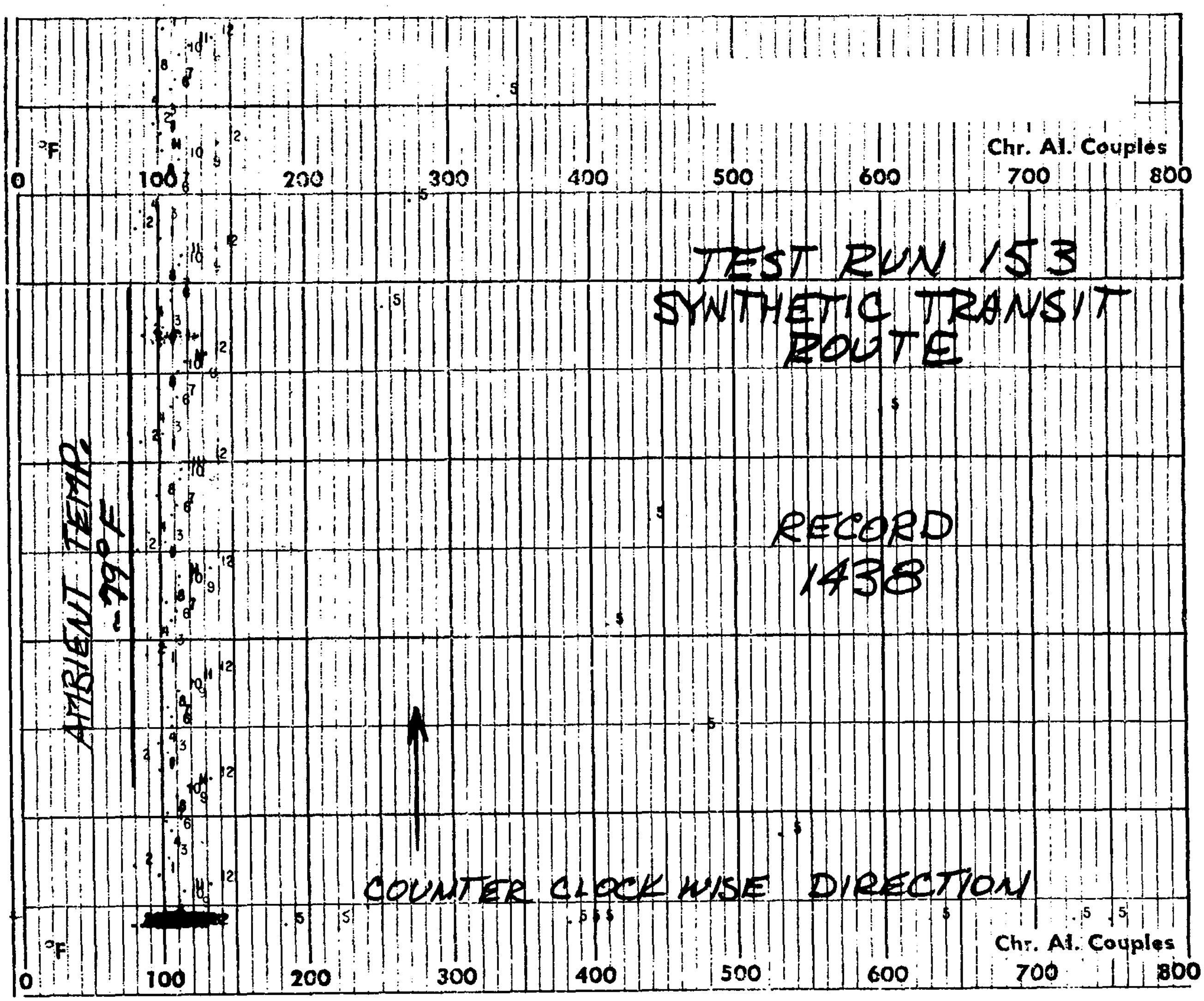


Figure 6–2. Synthetic Transit Route Sample Data Output (Test Run 153)

TABLE 6-8. SUMMARY OF UNDERCAR EQUIPMENT TEMPERATURES ON SYNTHETIC TRANSIT ROUTE (105,000-POUND CAR ADJUSTED TO 125°F AMBIENT SOAC DESIGN GOAL)

Parameter	No.	Peak Temperature (°F) Run 149	Peak Temperature (°F) Run 153
Propulsion blower, Outlet air	4	135	146
Chopper box, Interior air	8	141	150
Chopper box, Outlet air	3	142	148
Traction motor, Outlet air	12	183	182
Traction motor, No. 3 frame	1	151	151
PCU, Interior air	6	147	156
PPCU, Interior air	9	178	177
APCU, Interior air	10	155	165
Motor smoothing reactor	7	167	166
Brake grid air	5	820*	850*
Motor-alternator, Outlet air	11	169	168
Air conditioner, Condenser, Input air	2	162	157
Test ambient air		75	79

Notes

(1) Performance level - duty cycle: 1-hour rating
(2) PCU = Power control unit
(3) PPCU = Propulsion power control unit
(4) APCU = Auxiliary power control unit

* Peak recorded temperature during brake applications.

Section 7

SPIN/SLIDE PROTECTION SYSTEM TESTS

7.1 SUMMARY

Test Sequence

Table 7-1 presents a summary of test runs with both solid and resilient wheels for single car tests at 90,000-pound car weights.

Test Procedures

SOAC-P-2001-TT procedure was used for acceleration testing; SOAC-P-3011-TT for deceleration testing. Procedures were used throughout the speed range during testing with blended, dynamic, or service friction braking only.

Objective

The objective of the spin/slide protection system testing was to determine the efficiency of the SOAC spin/slide protection system throughout the speed range of the car in both drive and brake modes on wetted rail. An additional objective was to define a specific data acquisition and analysis technique to standardize the calculation of efficiency.

Status

Data was recorded with both solid and resilient wheels. Sample digital and analog time history standard outputs are contained in this part for three combinations of brake systems and for acceleration on wetted rails. The efficiencies of the spin/slide systems have been calculated and summarized over the speed range from 10 to 80 mph. Methodology for calculating efficiency is detailed in the text. Difficulty in obtaining consistent wetted rail adhesion limits precludes a valid comparison between the solid and resilient wheel tests. (Only subtle variations in wheel deceleration/reacceleration were anticipated). Variations in wet rail adhesion are explained in Section 8.

TABLE 7-1. SOAC ENGINEERING TEST RUN LOG

Type of Test: Spin-Slide Performance
Type of Wheels: Solid

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
5/4/73	097	1120 1130 1135 1140	2	Decel., blended brakes	0.0	40 60 80 20	90,000	2 (H-D)	fwd	600	Tests are on wetted rails
		1145 1150 1155 1200	2	Decel., service friction brakes	0.0	20 40 60 80	90,000	2 (H-D)	fwd	600	Tests are on wetted rails
5/4/73	098	205 207 211 215	2	Decel., dynamic brakes only	0.0	20 40 60 80	90,000	2	fwd	600	Tests are on wetted rails
		245 250	2	Accel.	1.0	0 to 80	90,000	2	fwd	600	Tests are on wetted rails

TABLE 7-1. SOAC ENGINEERING TEST RUN LOG (CONTINUED)

Type of Test: Spin--Slide Performance
Type of Wheels: Resilient

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
7/19/73	151	1732 1734 1738 1741 1753 1800	16	Decel., blended brakes	0.0	21 39 41 60 60 80	90,000	2 (H-D)	fwd	600	Tests are on wetted rails
		1804 1809 1817 1821 1827 1842 1845	16	Decel., Service friction brakes	0.0	60 60 40 40 60 78 60	90,000	2 (H-D)	fwd	600	Tests are on wetted rails
		1707	16	Accel.	11.0		90,000	2 (H-D)	fwd	600	Tests are on wetted rails

7.2 TEST DESCRIPTION

The spin/slide tests were conducted on the level tangent track from Station 300 to 340. Deceleration testing was accomplished by wetting the rails with an onboard spray rig (see Para 8.5.3), commanding full-service braking at the target speed, and allowing the car to decelerate with sliding wheels under control of the spin/slide systems. Acceleration testing was conducted in the speed range up to 35 mph by accelerating the car at full service rate on the wetted rails, allowing the spin/slide system to function. The following tests were performed:

- Deceleration with blended braking, dynamic braking only, and service friction braking only.
- Acceleration up to base speed at full tractive effort.

7.3 INSTRUMENTATION

The instrumentation parameters recorded during spin/slide testing were similar to the basic performance parameters with all four axle speeds recorded in place of certain parameters. Tables 7-2 and 7-3 present the data sheets used during solid and resilient wheel testing, respectively. The four axle speeds were used to determine the presence of spins/slides and the accelerometer peaks were used to define "available" adhesion levels.

7.4 TEST PROCEDURES

Two basic test procedures were utilized during the SOAC testing: acceleration and deceleration. The actual procedures are contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1). For baseline tests these procedures have been generalized and are contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2). These procedures are as follows: RB-P-2011-TT, acceleration; and RB-P-3011-TT, deceleration.

The latter procedure is contained in the following paragraphs.

I. Preliminary (pre-test)

A. Attach instrumentation or patch in desired parameters at storage or shop.

B. Add ballast weights to simulate desired car weight (AW ___).

TABLE 7-2. LABORATORY TAPE RECORDER DATA SHEET NO. 2

Test Title Performance Test Type Spin Slide

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/4/73 Test Eng ____ Tech RPM-DLB Tape Type & Size 1 in. x 7000 ft 3M

Tape Recorder Model No. SABRE III Tape Recorder S/N ____ Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph
1	Line E			10.0VDC	FM		1000 VDC = 10.000 VDC	
2	Line I			10.0VDC	FM		2000 ADC = 10.000 VDC	
3	Long Accel			5.0VDC	FM		±0.25G's = +5.000 VDC	X
4	Axle #3 Speed			5.0VDC	FM		80 MPH = ±5.000 VDC	X
5	#2 Trk Arm I			5.0VDC	FM		+1000 ADC = +5.000 VDC	
6	Sync Sig			5.0VDC	FM			
7	Axle #1 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
8	#1 Trk Arm. I			5.0VDC	FM		+1000 ADC = +5.000 VDC	
9	Analog Valve I			5.0VDC	FM		100% = (-)5.000 VDC	
10	Monitor Axle #4 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
11	Axle #2 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
12	P Wire I			5.0VDC	FM		+1.00 Amp DC = -5.000 VDC	X
13	Brake Press Axle #1			5.0VDC	FM		100 PSIG = +5.000 VDC	X
14	Event			5.0VDC	FM		2 Hz Signal with Neg Event Pulse	X
Edge A								
Edge B	Voice				Dir			

TABLE 7-3. LABORATORY TAPE RECORDER DATA SHEET NO. 16

Test Title Performance Slip-Slide Test Type Spin-Slide

Specimen P/N SOAC No. 2 Car Specimen S/N ______ Test Location Pueblo

Date 7/19/73 Test Eng ______ Tech RPM-DLB Tape Type & Size 1 in. x 7700 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect Type	Record Elect C.E.	Remarks	Quick-Look Oscillograph Location
1	301 Long Accel			±5.00 VDC	FM	3.375 KC	±0.25G = ±5.00 VDC	Both
2	303 Line I			±5.00 VDC	FM	3.375 KC	Zero VDC = +5.00VDC +1000 VDC = -5.00 VDC	
3	305 #1 Arm I			±5.00 VDC	FM	3.375 KC	+1000 ADC = +5.00 VDC	LH
4	306 #1 Field I			±5.00 VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	LH
5	308 #2 Arm I			±5.00 VDC	FM	3.375 KC	+1000 ADC = +5.00 VDC	LH
6	309 #2 Field I			±5.00 VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	LH
7	310 P Wire I			±5.00 VDC	FM	3.375 KC	+1.0 ADC = +5.00 VDC	LH
8	311 Analog Valve I			±5.00 VDC	FM	3.375 KC	+5.0 ADC = -5.00 VDC	
9	313 #1 Speed			±5.00 VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
10	314 #2 Speed			+5.00 VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
11	315 #3 Speed			±5.00 VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
12	316 #4 Speed			±5.00 VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
13	318 Brake Press			±5.00 VDC	FM	3.375 KC	100 PSIG = +5.00 VDC	RH
14	Time Code	IRIG B		±5.00 VDC	FM	3.375 KC		Both
Edge A								
Edge B	Voice & Event				Dir			Both

C. Check out and calibrate instrumentation.

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

E. Install rail spray apparatus on forward truck, forward axle.

F. Fill spray reservoir with desired mixture (water + ____).

G. Make up desired train consist.

H. Proceed to test zone.

I. Make inspection passes over test zone; check out vehicle and track.

J. Record ambient conditions as required.

K. Make several low speed passes over test zone to fully wet the rails.

L. Ensure that the proper combination of brake systems can be selected during the test.

M. Assure functioning of spin/slide systems.

II. Test Procedure (at test zone)

A. The test zone is the 4000 feet of level tangent track from Station 300 to Station 340. The car will be operated in the forward direction with the spray apparatus on the leading axle.

B. Approach test zone in car's forward direction at a car speed of 20 mph.

C. Start recorders, identify records, set up proper brake system combination, start rail sprayers.

D. When in the test zone apply full-service blended braking by decreasing the master controller command. (Note: Increase brake rate gradually to avoid any excessive wheel slides).

E. Maintain the brake command for 10 to 20 cycles of the spin/slide system (20 to 30 seconds) as applicable to the test car speed.

F. Following these cycles, reduce the command below the slide level and bring the car to stop; stop recorders; stop rail sprayers.

G. Repeat Items B through F at initial speeds of 40, 60, and 80 mph, or at maximum car speed so that the full range of operational speeds is tested.

Option (1)

Repeat Items A through G using service friction braking only; disable dynamic brake prior to Item D.

Option (2)

Repeat Items A through G at the desired rail conditions: clean-wet, oiled-wet, dry, sanded, etc.

Option (3)

Repeat Items A through G using dynamic braking only (disable service friction brakes, retain emergency brakes).

Option (4)

Repeat Items A through G with the desired brake configuration; however, determine the stopping time and distance from the initial speed by initiating full-service-brake command (Item D) at Station 300 (clockwise) and bring car to a complete stop. Measure time and distance to stop.

During the SOAC test program the complete speed range of the car from 20 to 80 mph was tested using three combinations of braking: blended, dynamic only, and friction only. Both solid and resilient wheels were tested.

7.5 TEST DATA

7.5.1 Data Reduction

The data reduction used both digitized time histories at 0.25-second intervals and analog time histories. The analog "strip-outs" were used to locate the areas of the record which were suitable for efficiency calculations, i.e., continuous spin/slide system activity. The digitized data was then used to obtain a calibrated time history of axle speeds and peak deceleration (adhesion).

Spin/slide system efficiency was then calculated from the digital time-history using the following technique:

a. Average "available deceleration rate" was determined from a time-average of the maximum deceleration rate during periods of minimum or no-wheel slides.

b. The "actual deceleration rate" was determined from the axle speed time histories. An attempt was made to locate areas on the speed traces which correspond to no-slides (i.e., true car speed).

c. Both a 4-second time interval and the complete 10 to 20-second test record were used to calculate the efficiency:

$$\text{Efficiency} = \frac{\text{"Actual" Deceleration}}{\text{"Available" Deceleration}}$$

The traction resistance of the car was not factored out of the test data since this force contributes equally to both the numerator and denominator of the above equation as applied to the test data.

7.5.2 Sample Data Output

The tabulated digitized time histories are similar to the standard outputs shown in Sections 2 and 3. The following paragraphs present sample digital and analog time history plots for each type of system tested. Back-up data for efficiency calculations are shown on the digital plots. Table 7-4 summarizes the overall efficiencies of the three combinations tested.

7.5.3 Blended-Braking Tests

Figure 7-1 presents a sample digital time-history for a brake application at 60 mph. Figure 7-2 is an analog time-history of the same test record. Figure 7-1 was used to estimate the average "available" deceleration and the "actual" deceleration for the efficiency calculation. As noted, the average efficiency is 77.7 percent with a variation between 82 and 71.4 percent during the sequence.

Tables 7-5 through 7-8 present a summary of efficiencies for the three brake combinations tested at four initial speeds. For blended braking the average efficiency from 80 to 10 mph is 78.5 percent using both solid and resilient wheel data. Differences in the level of "available" deceleration from test to test appear to affect the calculated efficiencies, precluding any meaningful comparison of wheel effects. Only slight effects were anticipated from inertial variation.

TABLE 7-4. SUMMARY OF WHEEL SPIN-SLIDE SYSTEM EFFICIENCIES*

Braking Mode (80 to 10 mph speed range):

• Blended braking	78.5%
• Service friction braking	63.4%
• Dynamic braking only	77.4%

Accelerating Mode (0 to 35 mph speed range):

• Full power acceleration	82% (solid wheels)

$$\text{Efficiency} = \frac{\text{"Actual" Deceleration Rate}}{\text{Average "Available" Deceleration Rate}}$$

* Based on both solid and resilient wheel data.

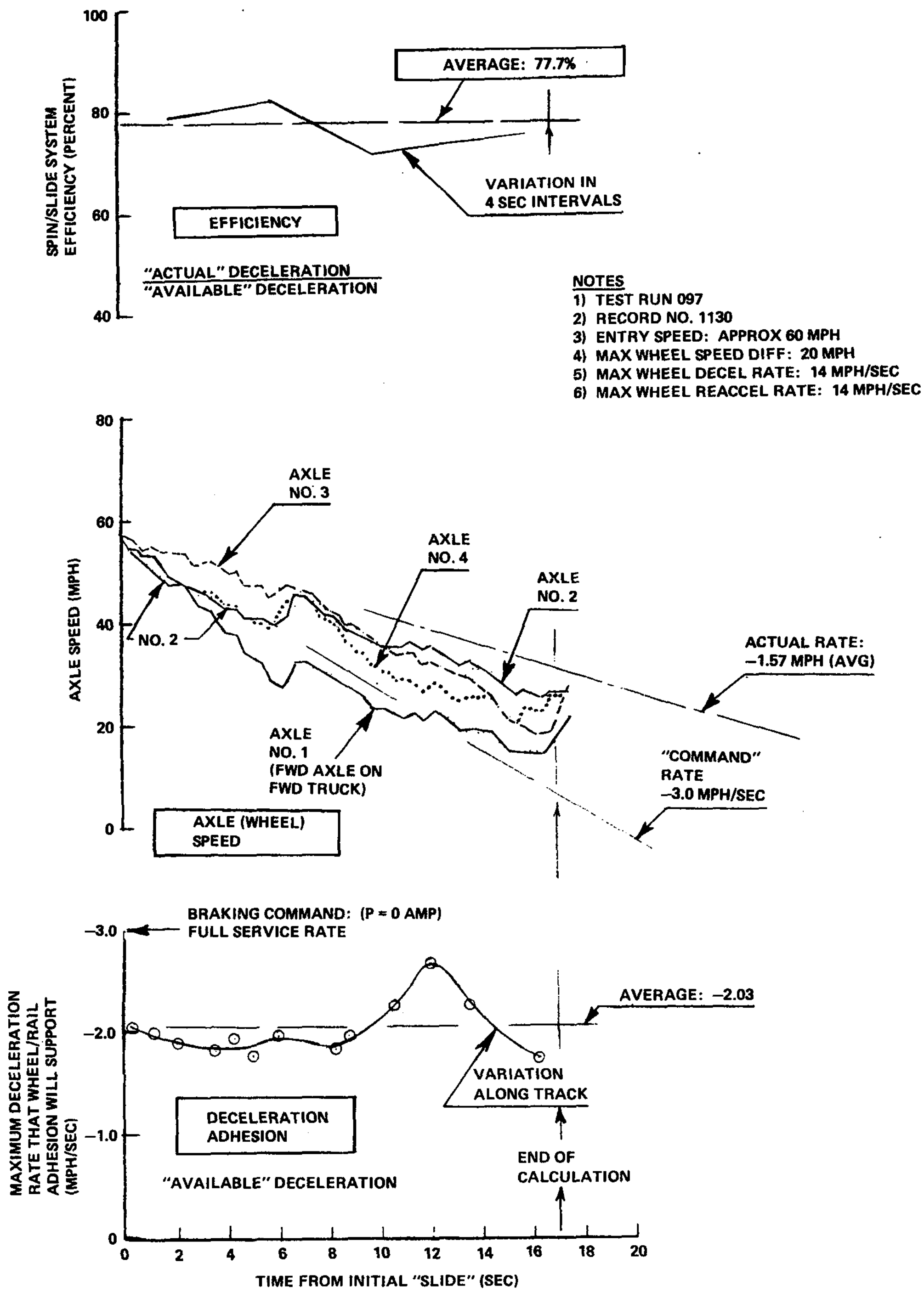


Figure 7–1. Spin-Slide System Efficiency of 90,000-Pound High-Density Car During Deceleration with Blended Service Brakes on Wetted Rails

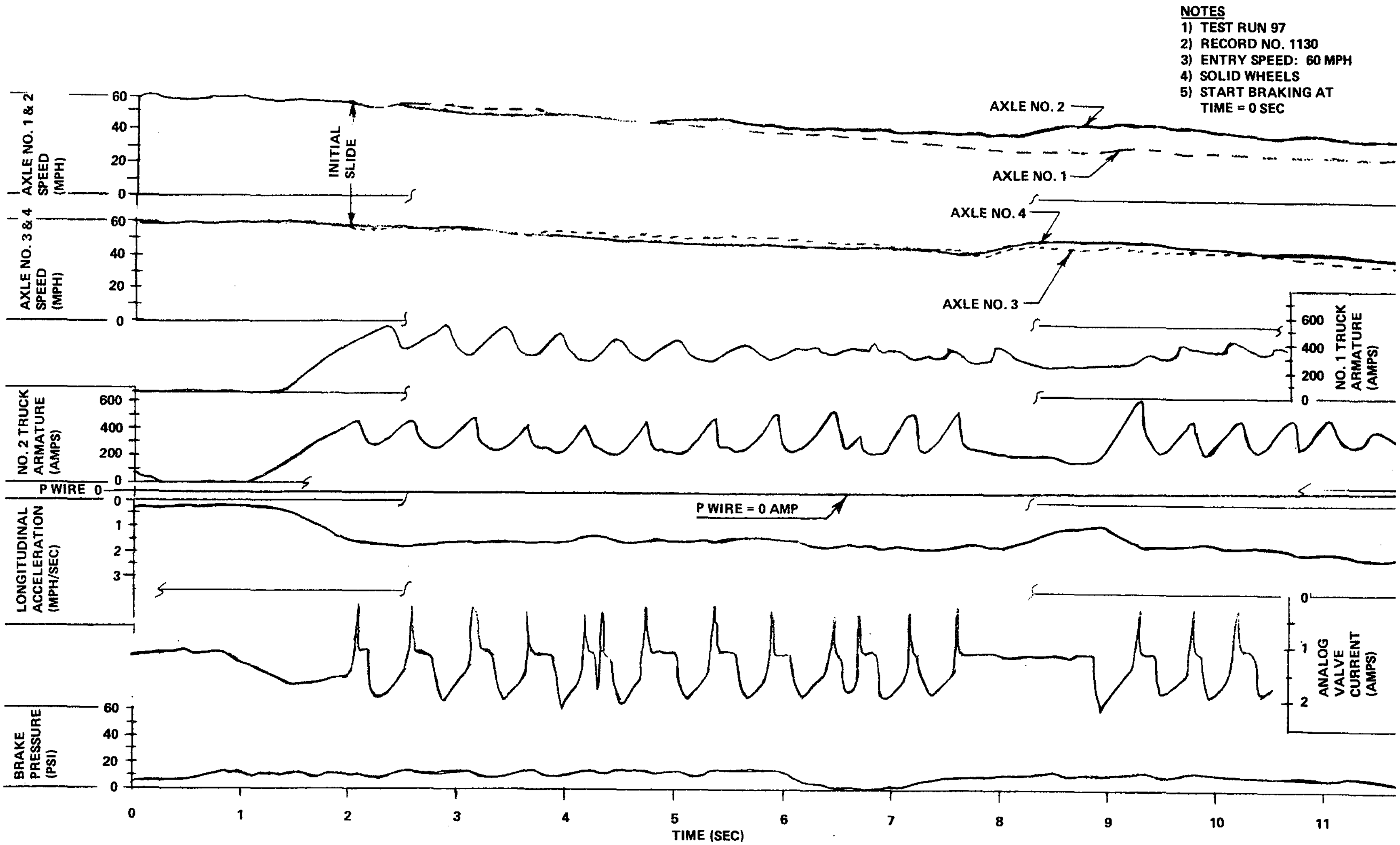


Figure 7–2. Deceleration of 90,000-Pound High-Density Car with Blended Brakes on Wetted Rails

TABLE 7-5. SPIN-SLIDE EFFICIENCY CALCULATIONS (80 MPH INITIAL SPEED)

Test Item	Brake System				
	Blended Brakes		Service Friction Brakes		Dynamic Brake Only
	Solid Wheels	Resil. Wheels	Solid Wheels	Resil. Wheels	Solid Wheels
Test run	97	151	97	151	98
Test record	1135	1800	1200	1842	215
Initial speed, mph	75	80 (approx)	78 (approx)	77	76
Average speed, mph	55	-	62	46	58
"Actual" deceleration rate, mphps	1.59	-	1.41	1.86	1.33
Average "available" decel. rate, mphps	2.13	-	2.33	2.86	1.84
Efficiency, percent	74.6	No valid slide	60.5	65.0	72.9
Number of spin-slide cycles	11	-	11	21	35
Duration of above cycles, sec	26	-	24	40	28
Type of wheel slides involved (R=random; S=sync.)	S-2* & R	-	R	S-2*	R

* Note

S-2 denotes two axles of one truck in synchronous slide.

TABLE 7-6. SPIN-SLIDE EFFICIENCY CALCULATIONS
(60 MPH INITIAL SPEED)

Test Item	Brake System: Blended Brakes, Solid Wheels	Blended Brakes, Resil. Wheels	Service Friction Brakes, Solid Wheels	Service Friction Brakes, Resil. Wheels	Dynamic Brake Only, Solid Wheels
Test run	97	151	97	151	98
Test record	1130	1741	1155	1804	211
Initial speed, mph	57	60	55	59	57
Average speed, mph	40	43	42	41	44
"Actual" deceleration rate, mphps	1.57	1.92	1.525	1.69	1.45
Average "available" decel. rate, mphps	2.03	2.43	2.17	2.85	1.94
Efficiency, percent	77.7	79.0	70.0	59.0	75.0
Number of spin-slide cycles	26	38	9	14	21
Duration of above cycles, sec	17	29	22	35	17
Type of wheel slides involved (R=random; S=sync.)	R	R	S-2* & S-4	R & S-2*	R

* Note

S-2 denotes two axles of one truck in synchronous slide.

TABLE 7-7. SPIN-SLIDE EFFICIENCY CALCULATIONS
(40 MPH INITIAL SPEED)

Test Item	Brake System: Blended Brakes, Solid Wheels	Blended Brakes, Resil. Wheels	Service Friction Brakes, Solid Wheels	Service Friction Brakes, Resil. Wheels	Dynamic Brake Only, Solid Wheels
Test run	97	151	97	151	98
Test record	1120	1738	1150	1817	207
Initial speed, mph	38	42	38	37	38
Average speed, mph	22	33	30	24	26
"Actual" deceleration rate, mphps	2.118	2.07	1.74	1.33	1.64
Average "available" decel. rate, mphps	2.56	2.45	2.43	2.32	2.017
Efficiency, percent	82.7	84.5	7.15	57.5	81.6
Number of spin-slide cycles	18	9	7	11	16
Duration of above cycles, sec	16	10	15	26	16
Type of wheel slides involved (R=random; S=sync.)	S-3*	S-4	S-4	S-4	S-3* & R

* Note

S-3 denotes three axles in synchronous slide.

TABLE 7-8. SPIN-SLIDE EFFICIENCY CALCULATIONS (20 MPH INITIAL SPEED)

Test Item	Brake System				
	Blended Brakes		Service Friction Brake		Dynamic Brake Only
	Solid Wheels	Resil. Wheels	Solid Wheels	Resil. Wheels	Solid Wheels
Test run	97	151	97	Not Done	98
Test record	1140	1732	1145	-	205
Initial speed, mph	18	19	17	-	19
Average speed, mph	10	15	13	-	14
"Actual" deceleration rate, mphps	1.49	2.13	1.3	-	2.12
Average "available" decel. rate, mphps	2.11	2.64	2.15	-	2.64
Efficiency, percent	70.5	80.7	60.6	-	80.3
Number of spin-slide cycles	9	11	4	-	5
Duration of above cycles, sec	8	10	7	-	6
Type of wheel slides involved (R=random; S=sync.)	S-4* & R	S-4*	S-2	-	S-4*

* Note

S-4 denotes four axles in synchronous slide.

7.5.4 Service-Friction-Braking Tests

Figures 7-3 and 7-4 present sample digital and analog time-histories respectively of a friction brake application at 60 mph. Note that the average "available" deceleration of Figure 7-3 is somewhat greater than Figure 7-1 (-2.17 vs -2.03 mphps) while the "actual" deceleration is somewhat less (-1.525 vs -1.57 mphps). Also note that the characteristic of the slides is different between blended and friction braking. For example, in Figure 7-1 the quick response of the dynamic brake results in some sliding motion of all axles at all times but still yields a high (77.7 percent) efficiency. The slower response of the friction brake results in the slides being corrected (longer brake "off" time) which leads to a lower average efficiency (70 percent).

Using the summaries of Tables 7-5 through 7-8, the average friction brake efficiency is 63.4 percent compared to the 78.5 percent efficiency of the blended brake system.

7.5.5 Dynamic-Braking-Only Tests

Figure 7-5 presents a sample digital time history and efficiency calculation for tests employing the dynamic brake only. As noted, the average efficiency for this 60 mph initial speed is 75 percent while the overall efficiency from 80 to 10 mph is 77.4 percent, in comparison to 78.5 percent for blended and 63.4 percent for friction only.

7.5.6 Acceleration Tests

The efficiency of the spin/slide system in acceleration was tested by commanding full acceleration rate (p = 1.0 amp) on wetted rails. Figures 7-6 and 7-7 present sample digital and analog time-histories of the test data. The calculated efficiency was 82 percent for speeds up to 32 mph during continuous wheel slip cycles.

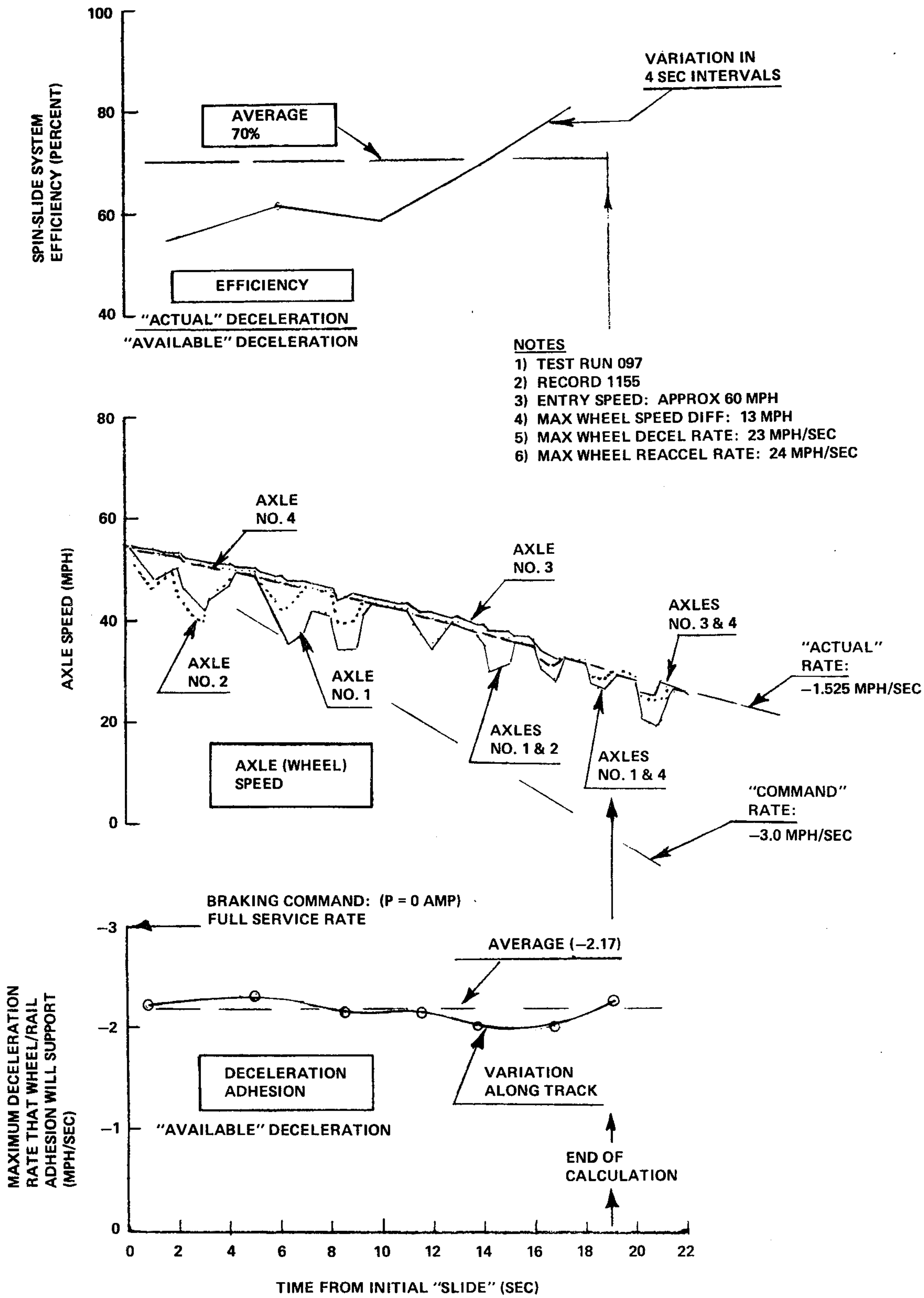


Figure 7—3. Spin-Slide System Efficiency of 90,000-Pound High-Density Car During Deceleration with Friction Brakes Only on Wetted Rails

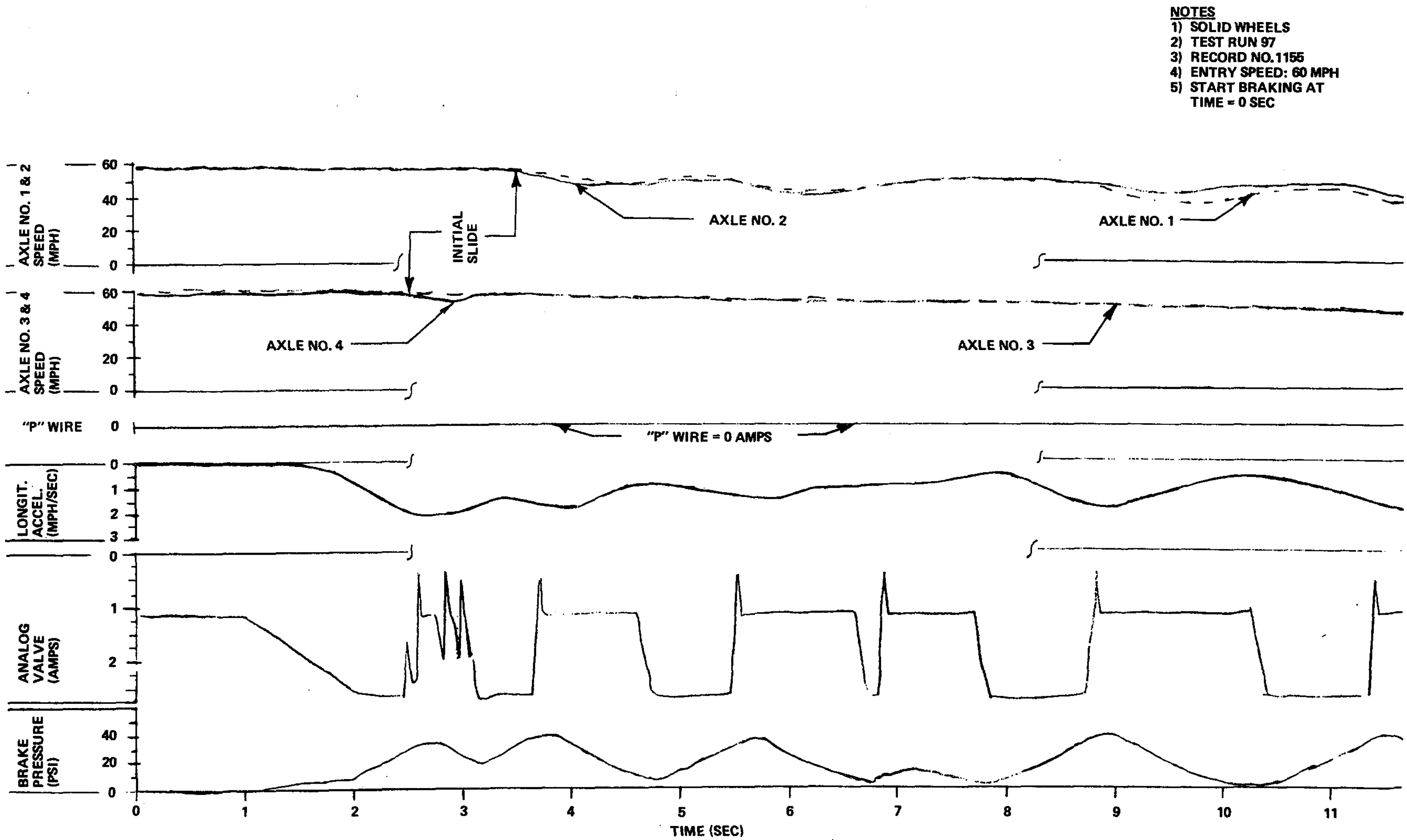


Figure 7–4. Deceleration of 90,000-Pound High-Density Car with Friction Brakes Only on Wetted Rails

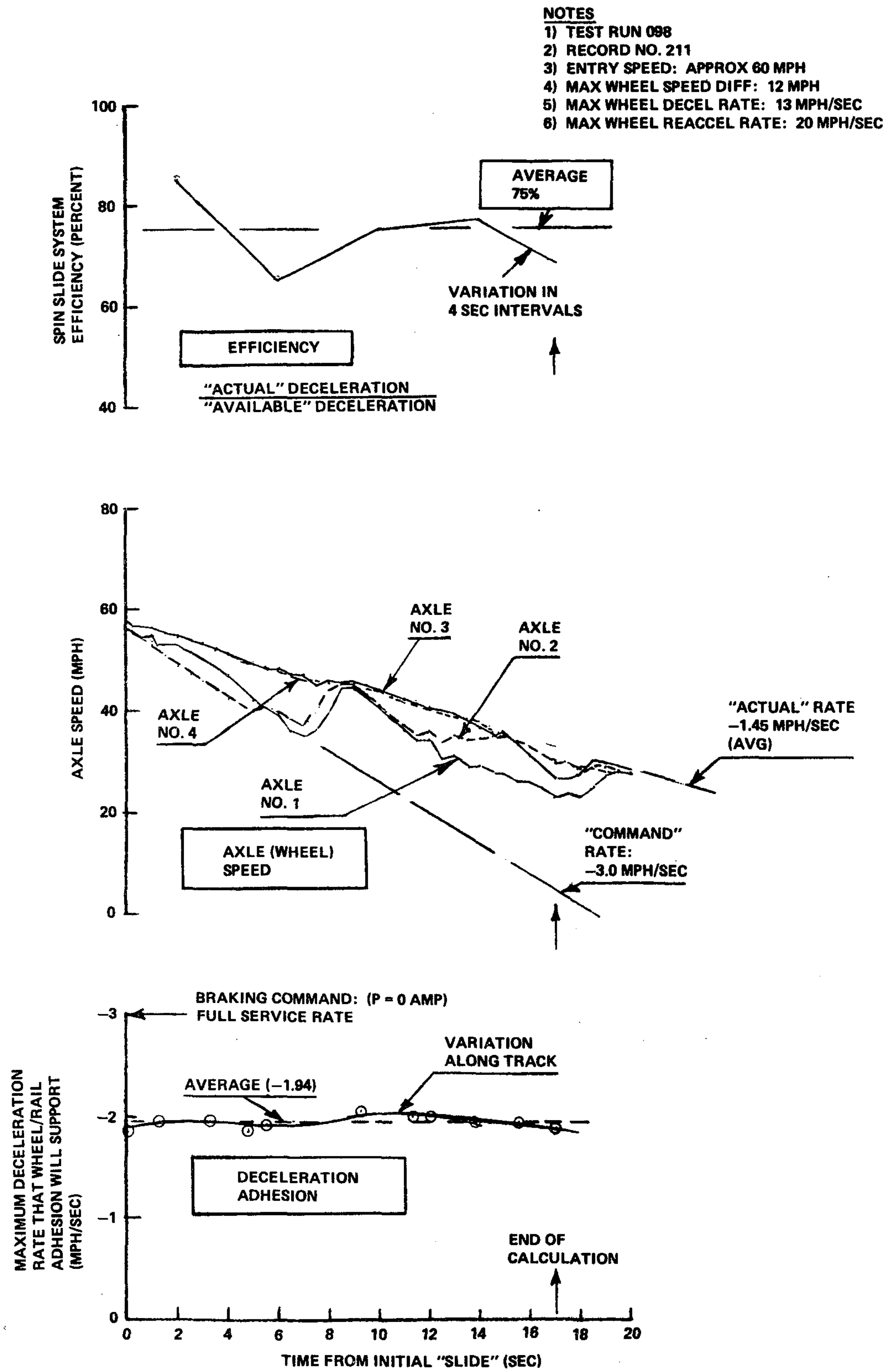


Figure 7–5. Spin-Slide System Efficiency of 90,000-Pound High-Density Car During Deceleration with Dynamic Brakes on Wetted Rails

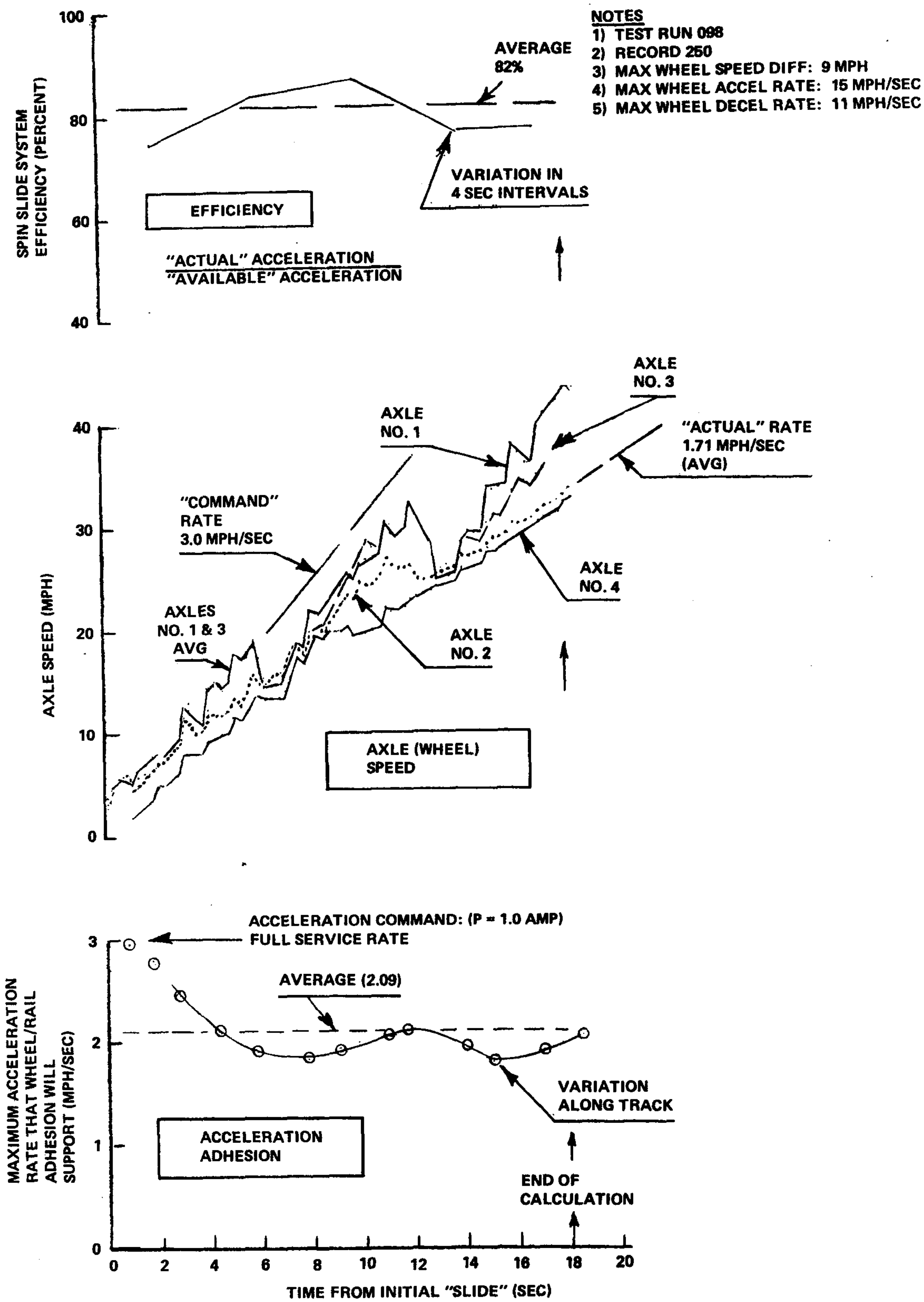


Figure 7–6. Spin-Slide System Efficiency of 90,000-Pound High-Density Car During Acceleration on Wetted Rails

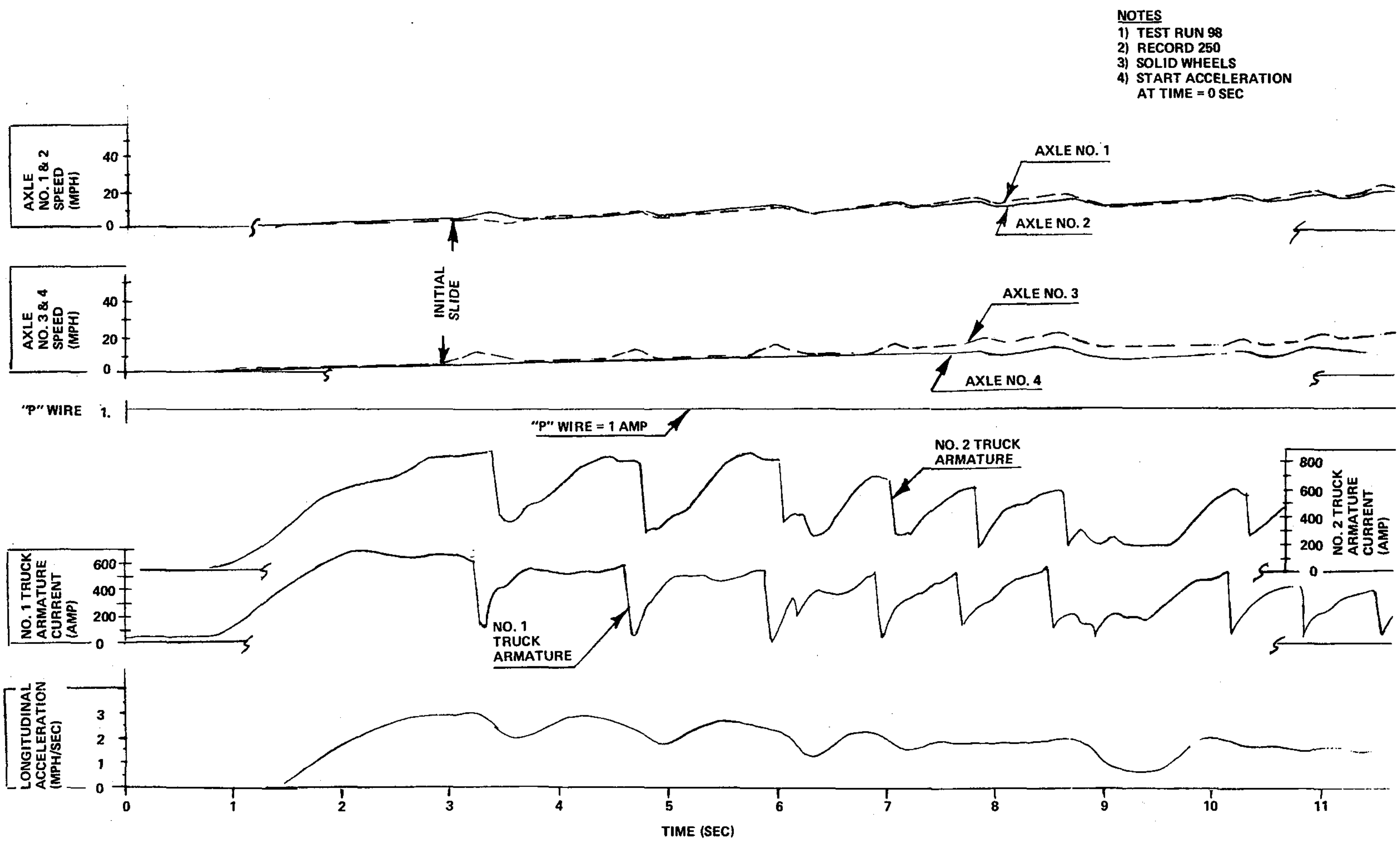


Figure 7–7. Acceleration of 90,000-Pound High-Density Car on Wetted Rails

Section 8

ADHESION TESTS

8.1 SUMMARY

Test Sequence

Table 8-1 presents a test run log of adhesion tests on wetted and dry rails with both solid and resilient wheels.

Test Procedures

SOAC-A-3021-TT test procedure was utilized during the test program to obtain adhesion data in the braking mode.

Objective

The objectives of the adhesion tests were to determine the dry and wetted rail adhesion factors for use in spin-slide system detailed performance analyses and to determine the wetted rail adhesion factor associated with the wetting solution used during spin-slide tests.

Status

Test data were obtained for wetted rails with both solid and resilient wheels at empty car weights (90,000 pounds). Data from all tests has been reduced and combined with the traction resistance data of Section 4 to define the wheel-rail adhesion factors throughout the speed range from 10 to 75 mph. Due to problems associated with the rail wetting apparatus and wetting solutions, two levels of adhesion are apparent during the tests. These two levels were also noted during the spin-slide systems tests of Section 7.

The determination of dry rail adhesion factors was not satisfactorily accomplished since brake pressure could not be raised to a sufficient level to slide the wheels repeatedly.

TABLE 8-1. SOAC ENGINEERING TEST RUN LOG

Type of Test: Adhesion
Type of Wheels: Solid and Resilient

Date	Run No.	Record No.	Data Sheet No.	Type of Test	P-Sig.	Max or Initial Speed (mph)	Car Weight (lb)	Car No.	Dir.	Line Volts	Notes
5/8/73	100	245 255 300 305 310	2	Adhesion, wet rails	Var.	20 40 60 80 20	90,000	2 (H-D)	fwd	600	Solid wheels
6/11/73	128	516 520 410 417 420 425	2B	Adhesion, dry rails	Var.	78 59 20 40 59 80	90,000	2 (H-D)	fwd	600	Solid wheels, inconclusive data
7/19/73	151	1626 1631 1648 1653	16	Adhesion, wet rails	Var.	40 60 79 20	90,000	2 (H-D)	fwd	600	Resilient wheels, incomplete wetting

8.2 TEST DESCRIPTION

Adhesion testing in the deceleration mode was conducted on the level tangent track using the service friction brakes on the front truck only; aft truck friction brakes and the complete dynamic brake were disabled prior to testing. In addition, for dry rail testing the normal full-service brake pressure for the test weight (56 psi at 90,000 pounds) was increased to 95 psi in an unsuccessful attempt to induce wheel slides.

Rails were wetted using a spray apparatus attached in front of the leading axle. A solution of water and a wetting agent was used. Prior to initiating testing, several passes over the test zone were made to fully wet the rails.

During actual testing the master controller was operated to slowly increase brake pressure and induce a slide. Several cycles of slide-roll were obtained in this manner.

8.3 INSTRUMENTATION

The test instrumentation used during adhesion testing was similar to that used in spin-slide tests. Tables 8-2 and 8-3 are the data sheets used during the solid and resilient wheel tests.

8.4 TEST PROCEDURE

The adhesion test procedure employed during the SOAC tests is contained in SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES (Reference 1) and contains sufficient instructions to operate the car and determine the validity of the data. For baseline testing this procedure has been generalized and is contained in the revised GENERAL VEHICLE TEST PLAN (Reference 2). The baseline procedure, RB-A-3021-TT, is as follows:

I. Preliminary (pre-test)

A. Attach instrumentation or patch in desired parameters at storage or shop.

B. Add ballast weights to simulate desired car weight (AW __).

C. Check out and calibrate instrumentation.

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

E. Attach rail wetting apparatus to front axle of leading truck.

TABLE 8-2. LABORATORY TAPE RECORDER DATA SHEET NO. 2

Test Title Performance Test Type Adhesion

Specimen P/N SOAC Specimen S/N No. 2 Car Test Location Pueblo

Date 5/4/73 Test Eng Tech RPM-DLB Tape Type & Size 1 in. x 7000 ft 3M

Tape Recorder Model No. SABRE III Tape Recorder S/N Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect		Remarks	Quick-Look Oscillograph
					Type	C.E.		
1	Line E			10.0VDC	FM		1000 VDC = 10.000 VDC	
2	Line I			10.0VDC	FM		2000 ADC = 10.000 VDC	
3	Long. Accel			5.0VDC	FM		±0.25G's = ±5.000 VDC	X
4	Axle #3 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
5	#2 Trk Arm I			5.0VDC	FM		+1000 ADC = +5.000 VDC	
6	Sync Sig			5.0VDC	FM			
7	Axle #1 Speed			5.0VDC	FM		80 MPH = +5.00 VDC	X
8	#1 Trk Arm I			5.0VDC	FM		+1000 ADC = +5.000 VDC	
9	Analog Valve I			5.0VDC	FM		100% = (-)5.000 VDC	
10	Monitor Axle #4 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
11	Axle #2 Speed			5.0VDC	FM		80 MPH = +5.000 VDC	X
12	P Wire I			5.0VDC	FM		+1.00 Amp DC = -5.000 VDC	X
13	Axle #1 Brake Press			5.0VDC	FM		100 PSIG = +5.000 VDC	X
14	Event			5.0VDC	FM		2 Hz Signal with Neg Event Pulse	X
Edge A								
Edge B	Voice				Dir			

TABLE 8-3. LABORATORY TAPE RECORDER DATA SHEET NO. 16

Test Title Performance Slip-Slide Test Type Adhesion

Specimen P/N SOAC NO. 2 Car Specimen S/N ____ Test Location Pueblo

Date 7/19/73 Test Eng ____ Tech RPM-DLB Tape Type & Size 1 in. x 7200 ft 3M

Tape Recorder Model No. 3614 Tape Recorder S/N 7291 Tape Speed 1-7/8 IPS Record Mode FM

Chan No.	Parameter Description	Transducer Type & S/N	Sig Cond Gain or Atten	Tape FS Level	Record Elect		Remarks	Quick-Look Oscillograph Location
					Type	C.E.		
1	301 Long. Accel			±5.00VDC	FM	3.375 KC	±0.25G = ±5.00 VDC	Both
2	303 Line I			±5.00VDC	FM	3.375 KC	Zero VDC = +5.00 VDC +1000 VDC = -5.00 VDC	
3	305 #1 Arm I			±5.00VDC	FM	3.375 KC	+1000 ADC = +5.00 VDC	LH
4	306 #1 Field I			±5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	LH
5	308 #2 Arm I			±5.00VDC	FM	3.375 KC	+1000 ADC = +5.00 VDC	LH
6	309 #2 Field I			±5.00VDC	FM	3.375 KC	±50 ADC = ±5.00 VDC	LH
7	310 P Wire I			±5.00VDC	FM	3.375 KC	+1.0 ADC = +5.00 VDC	LH
8	311 Analog Valve I			±5.00VDC	FM	3.375 KC	+5.0 ADC = -5.00 VDC	
9	313 #1 Speed			±5.00VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
10	314 #2 Speed			±5.00VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
11	315 #3 Speed			±5.00VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
12	316 #4 Speed			±5.00VDC	FM	3.375 KC	80 MPH = +5.00 VDC	RH
13	318 Brake Press			±5.00VDC	FM	3.375 KC	100 PSIG = +5.00 VDC	RH
14	Time Code	IRIG B		±5.00VDC	FM	3.375 KC		Both
Edge A								
Edge B	Voice & Event				Dir			Both

F. Provide desired mixture of rail wetting fluid (water + _____).

G. Cut out service friction brakes on aft truck. (Ensure full emergency brake capability for both trucks).

H. Provide for cut-out of full dynamic brake system during test runs. (Disable at shop or provide for cut-out during car operation.)

I. Make up desired train consist.

J. Proceed to test zone.

K. Make inspection passes over test zone; check out vehicle and track.

L. Record ambient conditions as required.

M. Make several passes over test zone with sprayers activated to thoroughly wet the rails.

N. Ensure proper functioning of all brake control and slide protection systems.

II. Test Procedure (at test zone)

A. The test zone is the 4000 feet of level tangent track from Station 300 to Station 340. The car will be tested in the forward direction with rail sprayers on the leading axle.

B. Approach test zone in forward direction at an initial speed of 20 mph.

C. Start recorders, identify records, start rail sprayers.

D. When car is within test zone, transition to brake mode, disable dynamic brake as applicable.

E. Increase brake command slowly (increase BCP) until forward truck wheel slide is induced. Difference in axle speeds between forward truck and non-braked aft truck will provide slide indication. Onboard spin-slide monitors may also detect the axle speed difference.

F. When slide occurs reduce brake command (and BCP) until slide is corrected and all axle speeds become equal.

G. Repeat Items E and F for several slide-roll cycles. Monitor friction brake temperatures as applicable.

H. Following desired number of cycles, decrease brake command to a non-sliding level; stop rail sprayers; stop recorders; stop car. Monitor brake temperatures

I. Allow brakes to cool to acceptable temperatures and position car for the next test run in the same, forward direction.

J. Repeat Items B through I for initial speeds of 40, 60, 80 mph or the maximum car speed.

Option (1)

Repeat Items B through J as required with the desired rail conditions: dry, clean-wet, etc.

Option (2)

Repeat Items B through J as required to provide sufficient data accuracy.

Option (3)

Repeat Items B through J at the desired car weights.

8.5 TEST DATA

8.5.1 Sample Data Output

Figure 8-1 presents a sample analog time-history standard output from adhesion tests. The key data points are noted on this figure for the determination of maximum adhesion (deceleration rate) prior to wheel slips.

8.5.2 Data Reduction

The following paragraphs detail the method used to develop adhesion factors from the test measured parameters. The traction resistance developed in Section 4 is also used in the calculated data results.

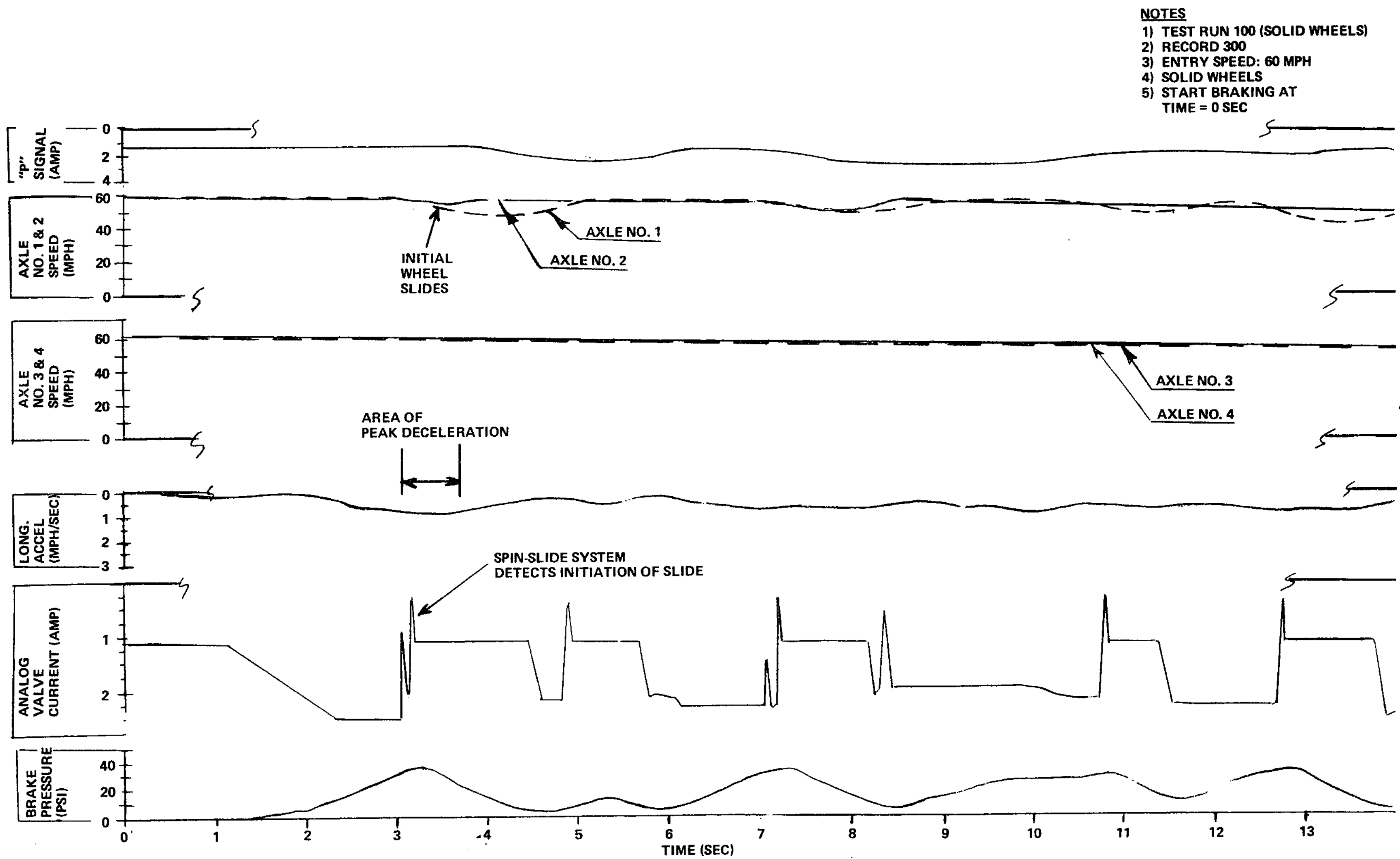


Figure 8–1. Adhesion of 90,000-Pound Car on Wetted Rails During Deceleration with Friction Brakes Only (Friction Braking on Aft Truck Cut Out for Adhesion Tests)

The asterisk-marked deceleration rates of Tables 8-3 and 8-4 were read manually from the oscillograph traces of car deceleration. The manual readings were necessary for Run 151 because of the large amount of scatter in acceleration and deceleration rates in all of the testing with resilient wheels.

Manual readings for deceleration rates for Run 100 were compared with the data computer printouts as a check that peak deceleration rates were being obtained. Discrepancies between manual and printout rates were caused by a 0.25-second minimum digitizing time interval inherent in the existing Garrett data reduction system. Manual deceleration rates were used when the scatter between manual and printout rates was large, since it is possible the rate could have peaked at a time other than 0.25-second digitizing interval.

8.5.3 Discussion of Test Results

Figure 8-2 summarizes the results of the adhesion tests. Tables 8-4 and 8-5 present the backup calculations based on the preceding Sample Calculation technique.

Two clearly defined levels of adhesion are defined by the fairings through the test data points. The wetting of the rails was accomplished by attaching a pump to a 50-gallon drum on board the car and pumping water through two garden hoses fitted with spray nozzle attachments. The hoses were attached so that the nozzle attachment would spray water over each rail in front of the forward wheel. The two levels of adhesion performance were obtained as a result of the manner in which a wetting agent was added to the water.

The wetting agent, which was used to decrease the rail adhesion, is manufactured by the Amway Corp. and distributed under the trade name Liquid Organic Concentrate (LOC). A basic ingredient in LOC is a coconut oil base. During the adhesion testing with solid wheels (Run 100), three pints of LOC were poured into the 50-gallon drum and then approximately 50 gallons of water were added. This procedure resulted in the lower level of adhesion since the LOC was thoroughly mixed with the water. However, preparation of the wetting mixture in this manner caused a large amount of foaming. Therefore, during the testing with resilient wheels (Run 151), the LOC was added after the 50-gallon drum was filled with water, in an attempt to prevent foaming. The preparation of the wetting mixture in this manner resulted in a higher level of adhesion since emulsification of the LOC was not achieved. The result was the higher level of adhesion noted on Table 8-2.

TEST RUN 100 (SOLID WHEELS)		
RECORD	ENTRY SPEED (MPH)	SYMBOL
245	20	▲
255	40	■
300	60	●
305	80	♦

TEST RUN 151 (RESILIENT WHEELS)		
RECORD	ENTRY SPEED (MPH)	SYMBOL
1653	20	△
1626	40	□
1631	60	○
1648	80	◊

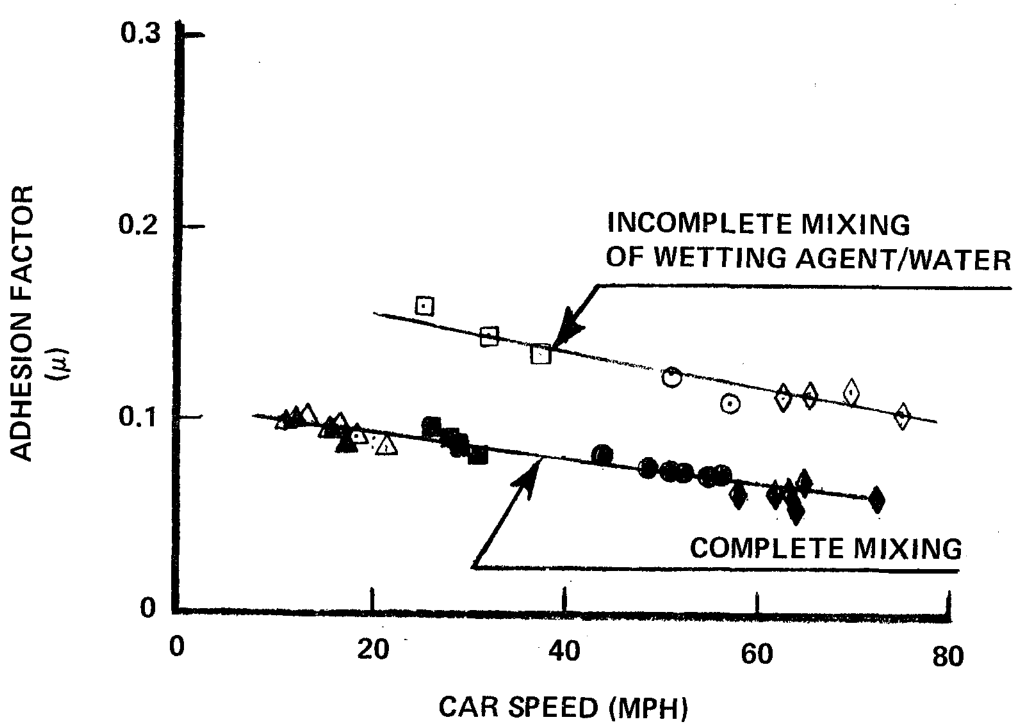


Figure 8–2. Adhesion of 90,000-Pound High-Density Car on Wetted Rails

TABLE 8-4. CALCULATION OF ADHESION FACTOR (SOLID WHEELS, 90,000-POUND CAR, WETTED RAILS)

Run No.	Record No.	Time (Sec)	Decel. (mphps)	Car Speed V_o (mph)	Traction Resistance (mphps)	Decel. Traction Resistance (mphps)	Braking Effort (Lb) (Decel.-Tr.) x 4454.4	Adhesion Factor (μ) = BE/Nf (N_f=45,000)
		1			2		3	4
100	245	7.5	0.94	17.3	0.088	0.852	3795	0.084
		9.25	1.02	15.5	0.083	0.937	4173	0.0927
		13.25	1.06	12.0	0.078	0.982	4374	0.0972
		14.75	1.06	11.2	0.077	0.983	4379	0.0973
100	255	15.5	0.92	31	0.123	0.799	3559	0.079
		18.5	0.95	29	0.117	0.833	3710	0.0824
		19.5	1.01	28	0.115	0.895	3987	0.0885
		22.25	1.08*	25.8	0.108	0.978	4356	0.0968
100	300	6.75	0.98*	56.6	0.245	0.735	3274	0.073
		9.5	0.95*	54.8	0.239	0.712	3167	0.0704
		12.75	0.98*	52.5	0.223	0.757	3372	0.0749
		14.25	0.96*	51	0.215	0.745	3318	0.073
		17.5	0.96*	49	0.203	0.757	3372	0.0749
		23.0	1.01*	44	0.177	0.833	3710	0.0824
100	305	8.5	0.98	72.6	0.355	0.625	2784	0.0618
		18.0	0.98	64.8	0.30	0.68	3029	0.0673
		18.75	0.99	64.4	0.29	0.70	3118	0.0692
		19.25	0.86	63.9	0.295	0.575	2561	0.0569
		19.75	0.95	63.5	0.292	0.666	2966	0.0659
		27.75	0.89	58.2	0.257	0.633	2819	0.0626

* See Sample Calculation, Table 8-6, for notes.

TABLE 8-5. CALCULATION OF ADHESION FACTOR
(RESILIENT WHEELS, 90,000-POUND CAR, WETTED RAILS)

Run No.	Record No.	Time (Sec) 1	Decel. (mphps)	Car Speed V_o (mph)	Traction Resistance (mphps) 2	Decel. Traction Resistance (mphps)	Braking Effort (Lb) (Decel.-Tr.) x 4454.4 3	Adhesion Factor (μ) $= BE/N_f$ (N_f=45,000) 4
151	1653	5.0	0.96*	21.6	0.098	0.862	3840	0.085
		8.0	0.96*	20.0	0.093	0.867	3861	0.085
		11.25	1.01*	18.3	0.09	0.917	4084	0.090
		16.0	1.01*	15.5	0.085	0.925	4120	0.091
		20.25	1.01*	13.1	0.080	0.93	4142	0.097
		24.25	1.01*	10.7	0.077	0.933	4156	0.092
151	1626	9.75	1.51*	37.2	0.145	1.365	6075	0.135
		23.0	1.72*	24.8	0.105	1.615	7198	0.160
		15.0	1.58*	31.8	0.125	1.455	6481	0.144
151	1631	9.25	1.37*	57.3	0.25	1.12	4988	0.110
		15.0	1.48*	51.0	0.215	1.265	5635	0.125
151	1648	8.0	1.45*	75	0.375	1.075	4788	0.106
		14.0	1.53*	69.5	0.335	1.20	5345	0.118
		18.75	1.48*	65	0.30	1.18	5256	0.116
		21.5	1.46*	62.5	0.285	1.15	5123	0.113

* See Sample Calculation, Table 8-6, for notes.

TABLE 8-6. SAMPLE CALCULATION FOR ADHESION FACTOR, μ (90,000-POUND CAR, WETTED RAILS)

The sample calculations presented below outline the procedure used to obtain the coefficient factor, μ. The sample calculation of μ provides for a car speed of 54.8 mph to illustrate the method. However, the calculations of the adhesion factors in Figure 8-2 is based on a fairing of traction resistance through points calculated for 0, 20, 40, 60 and 80 mph. For ease of calculation the sample calculation is presented for Run 100, Record 300. (Note: Time coincides with SOAC data reduction computer printouts. There is no correction to time = 0 for start of braking.)

SAMPLE CALCULATIONS:

1. Traction Resistance

$$\text{Traction Resistance}\left(\frac{\text{mph}}{\text{sec}}\right) = \left[\frac{\text{train resistance}}{\text{car weight} + 7774}\right] \times 21.95$$

where 7774 = The equivalent weight for SOAC cars (motor rotor weight and inertia from Garrett).

21.95 = Conversion factor, longitudinal acceleration (g's) to mphps

Train resistance was obtained from the SOAC drift tests (Run 102, Records 455 through 522) for a car weight of 105,000 pounds. To obtain traction resistance for a car weight of 90,000 pounds, the following equation was used:

$$\text{Traction Resistance at 90,000 lb}\left(\frac{\text{mph}}{\text{sec}}\right) \text{ for } V_o =$$

$$\left[\frac{\underset{\text{(at 105,000 lb and } V_o\text{)}}{\text{Train Resistance}} - \underset{\text{(at } V_o\text{)}}{\Delta\ \text{Train Resistance}}}{\text{Car Weight} + 7774}\right] \times 21.95$$

where train resistance for 105,000 pounds at V_o is obtained from Figure 4-1 and V_o is the specific car speed for which the adhesion factor, μ, is calculated.

TABLE 8-6. Continued

The Δ train resistance for any car weight utilizes the Davis Equation (Reference 3).

$$1.3W + 29n + .045WV + 0.0019 \ AV^2$$

The air resistance for a single SOAC car is obtained from the term:

$$0.0019 \ AV^2$$

The mechanical resistance is obtained from the journal resistance and flange resistance:

$$1.3W + 29n + 0.045WV$$

where W = car weight in tons
n = number of axles per car
A = frontal area, 115 quare foot for SOAC
V = car speed, mph

The only terms affecting the traction resistance for identical cars with car weight variance are:

$$1.3W + .045WV$$

Δ Train resistance for 90,000 pounds at V_o is obtained as follows:

$$\left[(1.3)\left(\frac{105,000}{2,000}\right) + (0.045)\left(\frac{105,000}{2,000}\right)(V_o)\right] -$$

$$\left[(1.3)\left(\frac{90,000}{2,000}\right) + (.045)\left(\frac{90,000}{2,000}\right)(V_o)\right]$$

For V_o = 54.8 mph the above equation yields a Δ train resistance of 28 pounds and from Figure 4-1 the train resistance for 105,000 pounds at 54.8 mph is 1093 pounds utilizing these inputs in the equation for "traction resistance" for 90,000 pounds

$$\left[\frac{1093 - 28}{90,000 + 7774}\right] 21.95 = 0.239 \ \frac{mph}{sec}$$

2. Braking Effort

$$= \left[\text{Deceleration-Traction Resistance} \right] \left[\frac{\text{Car Weight} + 7774}{21.95} \right]$$

For V_o = 54.8 mph

$$\left[.95 - .239 \right] \left[\frac{90{,}000 + 7774}{21.95} \right] = 3167 \text{ Lb.}$$

3. Adhesion Factor, μ

$$\text{Adhesion Factor, } \mu = \frac{\text{Braking Effort}}{N_f}$$

where N_f is the normal force of the car weight acting on the front truck. For 90,000 pounds N_f is 45,000 pounds and for $V_o = 54.8$ $\mu = \frac{3167}{45{,}000} = 0.0704$

The adhesion testing for Run 151, Record 1653 (resilient wheels) was performed with a setting mixture prepared in the same manner as in testing with solid wheels, Run 100. The three pints poured into the drum prior to the addition of water provided test data points that fit in with the lower level of adhesion.

REFERENCES

1. SOAC ENGINEERING TEST PROGRAM TEST PROCEDURES, D174-10023-1, Boeing Vertol Company, Philadelphia, Pa., July 1973.

2. GENERAL VEHICLE TEST PLANS, GSP 064, Transportation Systems Center, Cambridge, Mass.

3. Davis, W. J., THE TRACTIVE RESISTANCE OF ELECTRIC LOCOMOTIVES AND CARS, General Electric Review, Volume XXIX, No. 10, October 1926, pp. 685-707.