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REPORT NO. UMTA-MA-06-0025-78-5

TRANSIT CAR PERFORMANCE COMPARISON
State-of-the-Art Car vs. PATCO Transit Car, NYCTA R-46, MBTA Silverbirds

Boeing Vertol Company
Surface Transportation Systems
P.O. Box 16858
Philadelphia PA 19142

FEBRUARY 1978

FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
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16. Abstract

Following completion of the SOAC Property testing, Contract DOT-TSC-580 was extended for the purpose of gathering comparative test data on existing in-service transit cars. The three transit cars selected for testing were the PATCO transit car, the NYCTA R-46 transit car, and the MBTA Silverbird transit car. These cars were instrumented and then run in simulated revenue service while data was gathered. The results of these tests are reported in this document in a comparative format with the SOAC data recorded at each of the properties. The SOAC was found to be superior to all three of these existing transit cars in the area of noise reduction. The SOAC ride quality is better than the R-46 and the Silverbird, but not as good as the PATCO transit car. The SOAC propulsion system was inefficient while operating on the New York and Boston route structures, and only marginally better than the PATCO transit car in Philadelphia.

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PREFACE

Following completion of the SOAC Property testing, Contract DOT-TSC-580 was extended for the purpose of gathering comparative test data on existing in-service transit cars. The three transit cars selected for testing were the PATCO transit car, the NYCTA R-46 transit car, and the MBTA Silverbird transit car. These cars were instrumented, and then run in simulated revenue service while test data was gathered.

The three Garrett AiResearch technicians responsible for the recording of the data in each of the cities were Robert Paxton (MBTA and NYCTA), Gary Sessions (MBTA and PATCO) and Robert McCommon (PATCO and NYCTA). Coordination of their efforts and of the data reduction at Garrett AiResearch was accomplished by Andrew Tebelak. A sincere thank you to these four men for their contribution to the test program.

A thank you is also extended to the engineering managers at the three properties who gave their support to the test program. They were Jason Baker of MBTA, Ed O'Grady of NYCTA, and Robert Johnston of PATCO.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

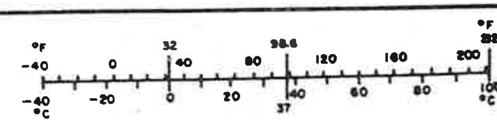


TABLE OF CONTENTS

Section Page

1. INTRODUCTION. 1–1

1.1 CONTRACT DOT-10007. 1–1

1.2 CONTRACT DOT-TSC-580. 1–1

1.3 DATA ACQUISITION – THREE TRAINS IN SERVICE 1–1

2. TRANSIT VEHICLE AND PROPERTY DESCRIPTION. 2–1

2.1 STATE-OF-THE-ART CAR 2–1

2.1.1 SOAC History 2–1
2.1.2 General. 2–1
2.1.3 SOAC Propulsion System. 2–1
2.1.4 SOAC Car Braking System 2–5
2.1.5 SOAC Trucks and Suspension 2–5
2.1.6 SOAC Wheels 2–5

2.2 PORT AUTHORITY TRANSIT COMPANY. 2–5

2.2.1 Lindenwold High Speed Line 2–5
2.2.2 PATCO Transit Car Description 2–6
2.2.3 PATCO Propulsion and Braking System 2–6

2.3 NEW YORK CITY TRANSIT AUTHORITY 2–6

2.3.1 NYCTA Description. 2–6
2.3.2 NYCTA R-46 Description. 2–12
2.3.3 NYCTA R-46 Propulsion and Braking System 2–12

2.4 MASSACHUSETTS BAY TRANSIT AUTHORITY. 2–12

2.4.1 MBTA Property Description. 2–12
2.4.2 MBTA Silverbird Transit Cars 2–12
2.4.3 MBTA Silverbird Propulsion and Braking System. 2–12

3. INSTRUMENTATION SYSTEM 3–1

3.1 GENERAL 3–1

3.2 RIDE QUALITY 3–1

3.2.1 Linear Car Body Motions 3–1
3.2.2 Rotational Car Body Motions 3–1
3.2.3 Linear Motion of the Wheel/Axle. 3–4

Section		Page
3.3	POWER CONSUMPTION	3–4
	3.3.1 Current Measurement	3–4
	3.3.2 Voltage Measurement	3–4
	3.3.3 Power Consumption Measurement	3–5
	3.3.4 Driver's Command	3–5
	3.3.5 Car Speed and Distance	3–5
	3.3.6 Car Acceleration	3–5
3.4	NOISE	3–5
	3.4.1 Interior Noise	3–6
	3.4.2 Exterior Noise	3–6
4.	TEST EQUIPMENT INSTALLATION	4–1
4.1	RIDE QUALITY	4–1
	4.1.1 Interior Sensors	4–1
	4.1.2 Exterior Sensors	4–1
4.2	NOISE	4–1
4.3	POWER CONSUMPTION	4–6
	4.3.1 Voltages	4–6
	4.3.2 Car Speed and Distance	4–6
	4.3.3 Car Acceleration	4–6
	4.3.4 Current Measurement	4–6
	4.3.5 Driver's Command	4–9
5.	TEST PROCEDURE	5–1
5.1	DETAILED TEST LOG	5–1
5.2	TEST CREW AND JOB DESCRIPTIONS	5–1
	5.2.1 Motorman	5–1
	5.2.2 Conductor	5–1
	5.2.3 Property Liaison Person	5–1
	5.2.4 Test Engineer	5–2
	5.2.5 Instrumentation Technician	5–2
5.3	TEST PROCEDURE	5–2
6.	DATA REDUCTION	6–1
6.1	GENERAL	6–1

Section Page

6.2 STATION SUMMARIES 6–1
6.2.1 Station Name 6–1
6.2.2 Distance 6–1
6.2.3 Block Time 6–1
6.2.4 Station Stop Time 6–3
6.2.5 Maximum Speed 6–3
6.2.6 Power Consumption. 6–3
6.2.7 Armature Current. 6–3

6.3 FREQUENCY DISTRIBUTION 6–3

6.4 TABULAR COMPARISONS 6–4
6.4.1 Cumulative Percentile 6–4
6.4.2 Maximum Value 6–4
6.4.3 Equivalent Sound Level 6–4
6.4.4 Weighted Averages 6–5
6.4.5 Total Distance 6–5
6.4.6 Average Block Distance 6–5
6.4.7 Total Run Time 6–5
6.4.8 Average Block Time. 6–5
6.4.9 Average Station Stop 6–6
6.4.10 Average Block Speed 6–6
6.4.11 Maximum Speed 6–6
6.4.12 Average Maximum Speed. 6–6
6.4.13 Total Kilowatt-Hours 6–6
6.4.14 Average Kilowatt-Hours 6–6
6.4.15 Average Kilowatt-Hours Per Mile 6–6
6.4.16 Average Armature Current 6–7

7. TEST RESULTS 7–1

7.1 INTRODUCTION 7–1

7.2 PATCO TRANSIT CAR VERSUS SOAC. 7–1
7.2.1 Summary 7–1
7.2.2 Noise 7–1
7.2.3 Ride Quality. 7–1
7.2.4 Power Consumption. 7–7

7.3 NYCTA R-46 VERSUS SOAC. 7–7
7.3.1 Summary 7–7
7.3.2 Noise 7–7
7.3.3 Ride Quality. 7–14
7.3.4 Power Consumption. 7–14

Section | Page

7.4 MBTA SILVERBIRD VERSUS SOAC 7–22
7.4.1 Summary 7–22
7.4.2 Noise 7–22
7.4.3 Ride Quality 7–22
7.4.4 Power Consumption 7–29

7.5 BEST AVAILABLE RIDE 7–29

7.6 ACOUSTIC COMPARISONS 7–29

7.7 POWER CONSUMPTION EFFICIENCY 7–29

8. CONCLUSIONS 8–1

8.1 SOAC 8–1

8.2 THREE TRAINS IN SERVICE 8–1

9. LIST OF REFERENCES 9–1

APPENDIX A. NYCTA R-46 TEST LOG A–1

APPENDIX B. DATTIS DATA REDUCTION PROGRAMS B–1

APPENDIX C. REPORT OF INVENTIONS C–1

LIST OF FIGURES

Number		Page
2–1	State-Of-The-Art Car	2–2
2–2	SOAC Performance and Design Characteristics	2–3
2–3	SOAC Operating Profile	2–4
2–4	Lindenwold High Speed Line	2–7
2–5	PATCO Transit Car	2–8
2–6	NYCTA Test Routes	2–10
2–7	NYCTA R-46 Transit Car	2–11
2–8	MBTA South Shore "Red" Line	2–13
2–9	MBTA Silverbird Transit Car	2–14
3–1	SOAC Instrumentation System	3–2
3–2	SOAC Instrumentation Console	3–3
4–1	Boston Silverbird Mid-Car Instrumentation	4–2
4–2	Boston Silverbird Forward Car Instrumentation	4–3
4–3	NYCTA R-46 Gearbox Mounted Accelerometers	4–4
4–4	PATCO Gearbox Mounted Accelerometers	4–4
4–5	Silverbird Gearbox Mounted Accelerometers	4–5
4–6	Voltage Divider Boxes and Isolation Amplifiers	4–7
4–7	Modification to TSC Isolation Amplifiers	4–8
4–8	Silverbird "Driver's Command" Installation	4–10
7–1	PATCO Ride Quality and Noise Data Summary	7–2
7–2	Station Summary for PATCO Transit Car Test	7–3

Number Page

7–3 Interior Noise Level Comparison – SOAC Versus PATCO 7–4

7–4 Noise Level Comparison 7–4

7–5 Longitudinal Ride Quality Comparison – SOAC Versus PATCO 7–5

7–6 Forward Car Lateral Ride Quality Comparison – SOAC Versus PATCO 7–5

7–7 Mid-Car Lateral Ride Quality Comparison – SOAC Versus PATCO 7–6

7–8 Forward Car Vertical Ride Quality Comparison – PATCO Versus SOAC 7–8

7–9 Mid-Car Vertical Ride Quality Comparison – PATCO Versus SOAC 7–9

7–10 PATCO Pitch Data 7–9

7–11 PATCO Roll Data 7–10

7–12 PATCO Yaw Data 7–10

7–13 Train Speed Comparison – PATCO Versus SOAC 7–11

7–14 Transit Car Acceleration Comparison – SOAC Versus PATCO 7–11

7–15 Interior Noise Level Comparison – SOAC Versus R-46 7–13

7–16 Noise Level Comparison – NYCTA "A" Line 7–15

7–17 Longitudinal Ride Quality Comparison – SOAC Versus NYCTA R-46 7–15

7–18 Forward Car Lateral Ride Quality Comparison – SOAC Versus NYCTA R-46 . 7–16

7–19 Mid-Car Lateral Ride Quality Comparison – SOAC Versus NYCTA R-46 . . . 7–16

7–20 Forward Car Vertical Ride Quality Comparison – SOAC Versus NYCTA R-46 . 7–17

7–21 Mid-Car Vertical Ride Quality Comparison – SOAC Versus NYCTA R-46 . . . 7–17

7–22 NYCTA R-46 Roll Data 7–18

7–23 NYCTA R-46 Pitch Data 7–18

7–24 NYCTA R-46 Yaw Data 7–19

7–25 Station Summary for R-46 on NYCTA "A" Line 7–20

Number		Page
7–26	Transit Car Speed Comparison – SOAC Versus NYCTA R-46	7–21
7–27	Transit Car Acceleration Comparison – SOAC Versus NYCTA R-46	7–21
7–28	Interior Noise Level Comparison – SOAC Versus Silverbird	7–24
7–29	Noise Level Comparison	7–24
7–30	Longitudinal Ride Quality Comparison – SOAC Versus Silverbird	7–25
7–31	Forward Car Lateral Ride Quality Comparison – SOAC Versus Silverbird	7–25
7–32	Mid-Car Lateral Ride Quality Comparison – SOAC Versus Silverbird	7–26
7–33	Mid-Car Vertical Ride Quality Comparison – SOAC Versus Silverbird	7–26
7–34	Forward Car Vertical Ride Quality Comparison – SOAC Versus Silverbird	7–27
7–35	MBTA Silverbird Roll Data	7–27
7–36	MBTA Silverbird Pitch Data	7–28
7–37	MBTA Silverbird Yaw Data	7–28
7–38	MBTA Station Summary	7–30
7–39	Transit Car Acceleration Comparison – SOAC Versus Silverbird Transit Car	7–31
7–40	Speed Distribution Comparison – SOAC Versus Silverbird	7–31
7–41	Ride Quality Comparison – Weighted Averages	7–32
7–42	Roll, Pitch, Yaw Comparison	7–33
7–43	Noise Level Comparisons	7–33
7–44	Power Consumption Summary Table	7–35
7–45	Power Consumption Efficiency	7–36

LIST OF TABLES

Table		Page
6–1	Correction of Distance Data	6–2
7–1	NYCTA R-46 Ride Quality and Noise Summary	7–12
7–2	Summary of R-46 Test on 'A' Line Southbound	7–13
7–3	MBTA Ride Quality and Noise Survey	7–23

1. INTRODUCTION

1.1 CONTRACT DOT-10007

The Rail Programs Branch of the Urban Mass Transportation Administration (UMTA), Office of Research and Development, is conducting programs to improve urban rail transportation systems. One of these is the Urban Rapid Rail Vehicle and Systems Program (Contract DOT-UT-10007). Boeing Vertol Company, Surface Transportation Systems, is acting as systems manager for UMTA on this program. The first phase of this contract authorized the design, development, and demonstration of two State-of-the-Art Cars (SOAC). The primary objective of the SOAC train was to demonstrate at existing transit properties the then-available technology in rail rapid transit car design.

1.2 CONTRACT DOT-TSC-580

The Transportation Systems Center (TSC) is UMTA's systems manager for the Urban Rail Supporting Technology Program. This program provides UMTA with test facility development, vehicle test and evaluation, technology development and application engineering. As part of its test and evaluation task, TSC awarded Boeing Vertol a contract to perform Engineering Testing on the SOAC train (Contract DOT-TSC-580). The initial phase of this test consisted of a series of discrete tests performed at the Transportation Test Center on the Transit Test Track. These tests provided detailed data on the operating envelope of the SOAC. The second phase of the SOAC test program consisted of defining the operation and response of the vehicle in simulated revenue service at six transit properties. The six properties tested during this phase were the New York Transit Authority, Massachusetts Bay Transportation Authority, Southeastern Pennsylvania Transportation Authority, Port Authority Transportation Company, Chicago Transit Authority, and Cleveland Transit System.

1.3 DATA ACQUISITION – THREE TRAINS IN SERVICE

Following the transit property demonstration phase, it became apparent that comparative data on existing transit vehicles was required in order to properly evaluate the SOAC's "current technology" subsystems. To obtain this additional data, TSC extended the TSC-580 contract to create the Data Acquisition – Three Trains in Service (DATTIS) Program. The goal of this test program was to record comparative noise, ride quality, and power consumption on three existing trains in simulated revenue service and present it in a comparative format with the data recorded on the SOAC train under the same conditions. The three trains selected were the NYCTA R-46, the PATCO transit car, and the MBTA Silverbird transit car. The DATTIS phase of the SOAC program is reported by this document.

2. TRANSIT VEHICLE AND PROPERTY DESCRIPTION

2.1 STATE-OF-THE-ART CAR

2.1.1 SOAC History

Following selection by Boeing Vertol Company and UMTA, the St. Louis Car Division of General Steel Industries built and delivered two SOAC cars to the Transportation Test Center (TTC) in September 1972 for developmental and acceptance testing. Following an extensive adjustment and development program, the two SOAC cars completed acceptance testing in April 1973. The SOAC cars (Figure 2-1) demonstrated the state-of-the-art in rapid rail car design. The primary goal in the SOAC design was to provide a passenger with quiet, comfortable and appealing transportation using existing technology. A detailed description of the SOAC and its subsystems may be found in the SOAC (State-of-the-Art Car) Development Program Report, Volume 1, Design, Fabrication and Test, UMTA-IT-06-0026-74-1, April 1974.

2.1.2 General

The SOAC exterior features a smooth, brush-finished stainless steel body with molded fiberglass ends. The basic car structure is of all steel welded construction. Each car is 75 ft. long and 9.75 ft. wide, with a truck center distance of 54 ft. Car height may be varied by shimming the position of the air bellows. Each car weighs 89,000 lbs. There are four 50-inch wide double sliding passenger doors on each side of the car. The performance and design characteristics are shown in Figure 2-2. The operating curve which was used in generating these design requirements is shown in Figure 2-3.

The vehicles utilize two types of interiors. The vehicle referred to as SOAC No. 1 features "low density" seating; it contains 62 cushioned, upholstered seats in four different arrangements. SOAC No. 2 contains 72 molded fiberglass seats with padded cushions and more standee space, designed for "high density" operation. Both SOAC cars are carpeted and each is equipped with two 8-ton air conditioners.

2.1.3 SOAC Propulsion System

The propulsion system consists of traction motors, gearboxes, high and low voltage power supplies, and the control systems necessary to provide operations in both driving and braking modes. There are two motors per truck which are connected electrically in series. The two truck assemblies are connected electrically in parallel. The motors are fully compensated DC, with separately excited fields, each motor having a continuous rating of 175 hp at 1560 rpm (460 amps). Control of the traction motors is by force commutated DC-DC chopper in the armature circuit and by AC-DC phase-delay rectifiers (thyristors) in the separate field circuits. AC power is supplied by the auxiliary power motor-alternator set. DC power to the armatures is supplied by the third rail shoes (or pantograph) through the input inductor-filter capacitor. Control subsystems provide for load-weight, jerk rate, and wheel spin/slide compensation, as well as dynamic-friction brake blending. The SOAC gearbox is a double-reduction parallel drive unit using helical gears. The overall gear ratio is 4.781 to 1. A magnetic pickup is provided in each gearbox to supply information for the car speedometer and spin/slide detection systems. An input reactor operates in conjunction with input filter capacitors to limit

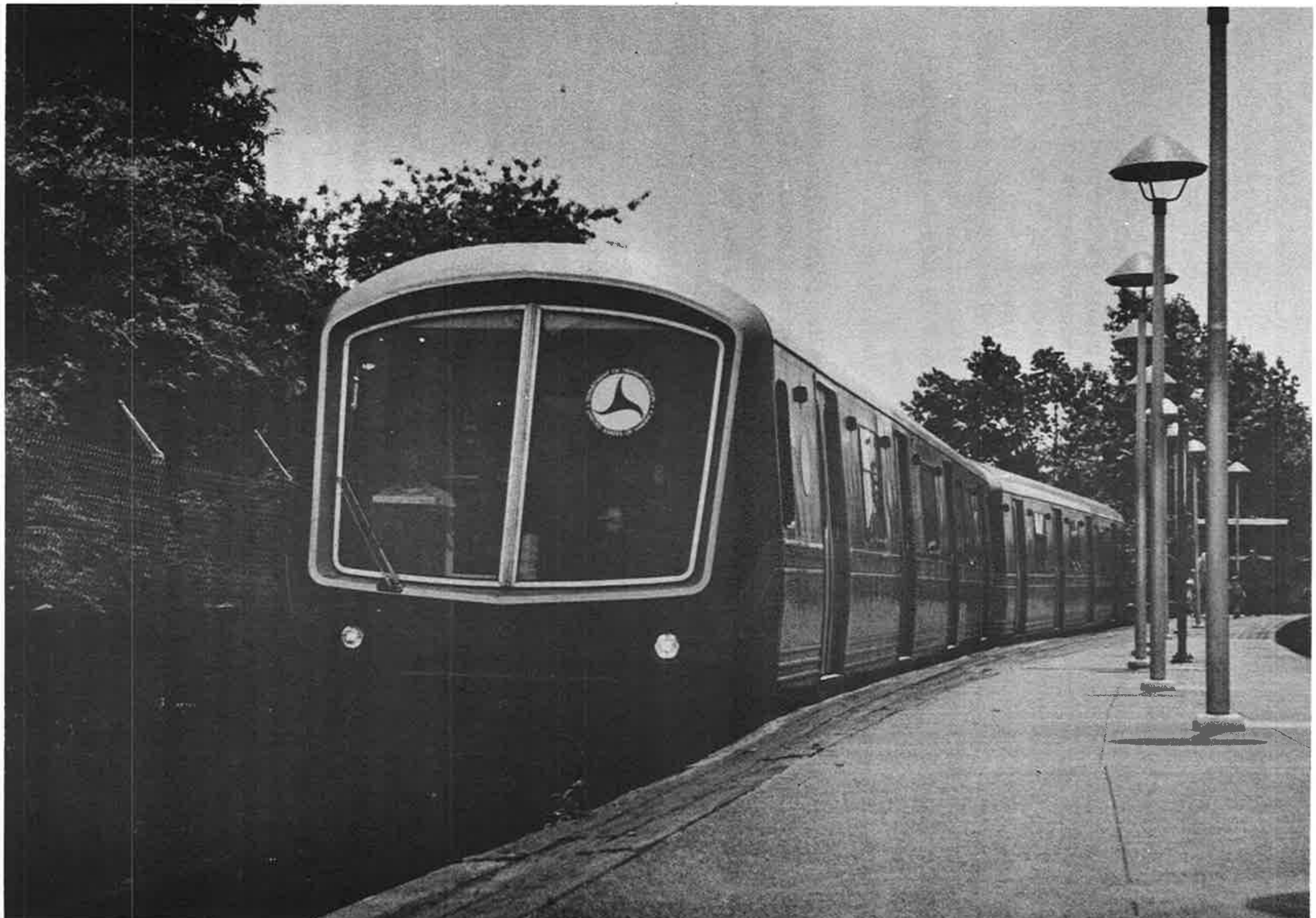
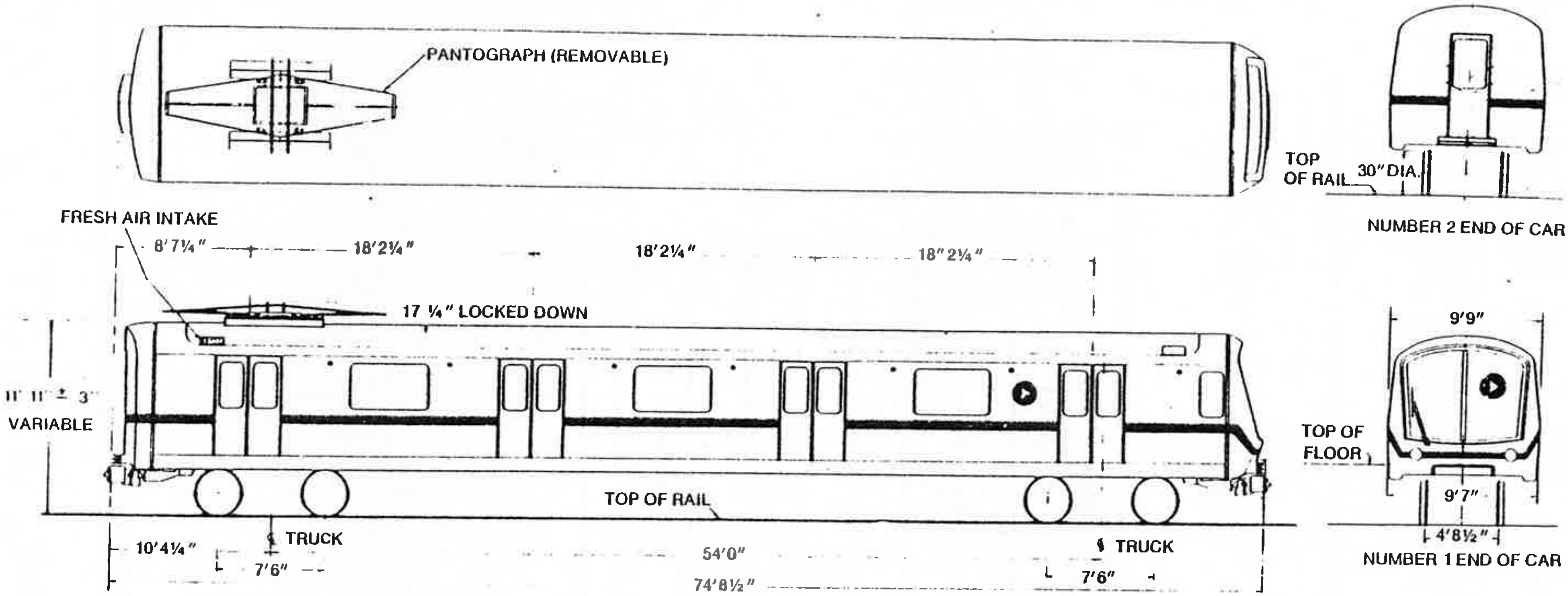


FIGURE 2–1. STATE-OF-THE-ART CAR.



Length	75 Feet
Width	9.75 Feet
Minimum Track Curve Radius	145 Feet
Speed	80 MPH
Acceleration, initial	3.0 MPH/Sec.
Jerk Rate	2.5 MPH/Sec.^{2}
Power	600 VDC Nominal
Noise Level, interior.	spec 75 dBA @ 50 MPH actual 63 dBA @ 50 MPH
Noise Level, 50 ft wayside	78 dBA @ 50 MPH actual 73 dBA @ 50 MPH

Passenger Capacity (No. 1 car)	
Seated	62
Nominal	100
Maximum	220
Passenger Capacity (No. 2 car)	
Seated	72
Nominal	100
Maximum	300

FIGURE 2–2. SOAC PERFORMANCE AND DESIGN CHARACTERISTICS.

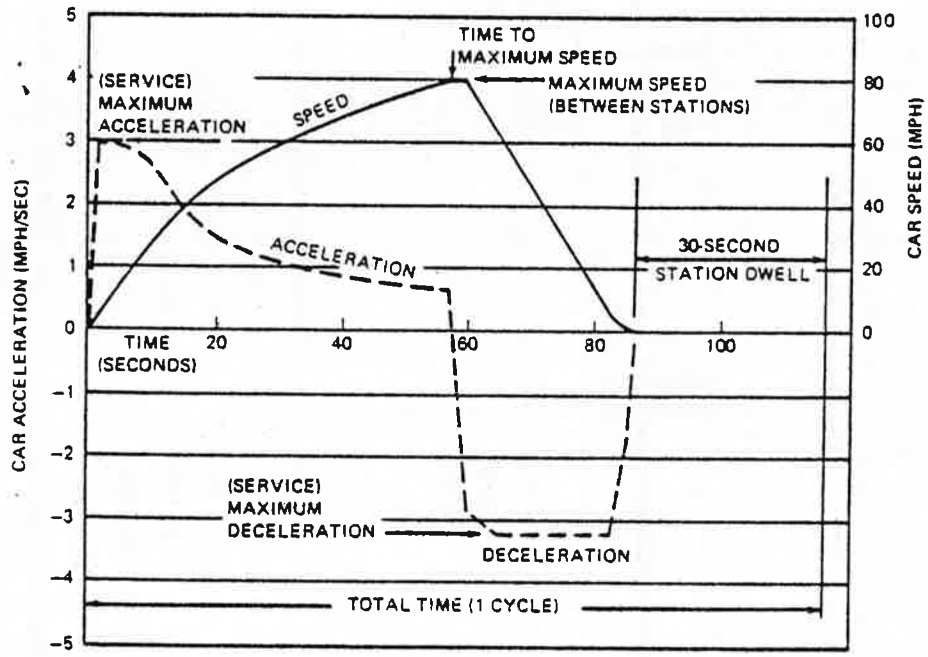


FIGURE 2–3. SOAC OPERATING PROFILE.

voltage and current transients through the chopper and low voltage power supply. Two brake resistor grids are mounted on the SOAC to provide the electrical load for the traction generators during dynamic braking. The control of tractive and braking effort is achieved using a tractive effort program which accepts input commands and controls the motor torque developed to the desired values. Closed-loop control of motor armature current is the primary method utilized. The command is modified by car weight as sensed by air suspension pressure. Jerk rate limiting and spin/slide protection are provided by monitoring the time rate of change of each of the four axle speedometers and altering the tractive effort command when the 2.5 mph/sec-sec limit is exceeded.

2.1.4 SOAC Car Braking System

The major braking effort is provided by the dynamic braking capability of the SOAC propulsion system. Under normal operation this system alone will bring the SOAC to a complete stop. The friction brake system will hold the SOAC on a slope and will blend with the dynamic system or provide full service braking under adverse operating conditions. The system is comprised of truck mounted air actuated cylinders which apply Cobra composition shoes to the wheel (eight cylinders per car); two analog brake units which accomplish load weigh compensation, and separate emergency and service brake functions.

2.1.5 SOAC Trucks and Suspension

The truck and suspension system is designed for improved ride quality and reduced noise. The truck has a 7.5 ft. wheel base for standard gauge track with inside wheel-axle bearing supports. Assembled weight of the cast-alloy, nickel steel truck is 14,500 lbs. The truck frame is isolated from the axles by rubber chevron primary springs. Air bellows control car body leveling and provide car body-to-truck isolation. Rubber bumpers are used to limit the deflection. Variable dampers are provided for all axes and can be adjusted during test to optimize ride quality.

2.1.6 SOAC Wheels

Model MB12511 Retreadable Acoustaflex Wheels manufactured by the Standard Steel Company were used during the SOAC program. This wheel has an aluminum hub, a steel rim, and a steel (tread-flange) tire. A layer of silicone rubber is bonded between the rim and the hub sections. These sections are connected by a multi-point shunt for electrical continuity. The wheel is 30 inches in diameter with a 1:20 tread contour per NYCTA 703-3001. When the condemning limit diameter of 28 inches has been reached, the steel (tread-flange) tire can be removed from the rim and a replacement installed by shrink fitting. The primary benefit of the resilient wheels is a significant reduction in the squeal that occurs when cars negotiate low radius curves. Some reduction of the higher frequency vibrations induced by the wheel/rail interface, as well as some reduction of the wheel/rail roar and impact noises, is an additional benefit.

2.2 PORT AUTHORITY TRANSIT COMPANY

2.2.1 Lindenwold High Speed Line

The PATCO Lindenwold High Speed Line is 14.1 miles long with 11 stations. The scheduled service time for the route is 22.5 minutes. The route originates in Lindenwold, New Jersey, and runs elevated and at grade level westward to Ferry Avenue. At Ferry Avenue the line goes underground beneath Camden, New Jersey and resurfaces at the Benjamin Franklin Bridge to cross the Delaware River into Philadelphia. The Pennsylvania portion of the Lindenwold line is all subway with the termination point being 15th and Locust Streets. The surface and elevated sections of the route in New Jersey have an operating speed of 75 mph. A map of the system is shown in Figure 2-4.

2.2.2 PATCO Transit Car Descriptions

The PATCO transit cars were manufactured by The Budd Company in 1967. The 75 cars include 25 single cars and 25 married pairs. This allows train consists of 1 to 8 cars, depending upon line load requirements. The PATCO transit car is 67.5 ft. long, 10 ft. 1.5 in. wide, and 12 ft. 4 in. high. The truck center distance is 47.5 ft. and each has a wheel base of 7.5 ft. for standard gauge track. The single cars weigh 79,500 lbs. each, while the married cars are lighter at 74,800 lbs. each. Each of the married cars seat 80 people and can carry 150 during rush hour conditions. The single cars seat 72 and can carry 142 passengers during rush hour. The seating is arranged in a 2-2 transverse pattern throughout the car. Seats are of a moderate bucket design, thickly padded, and covered by luxury vinyl. The married cars each have 2 double sliding doors per side, and the single cars 2 double doors per side plus a single door near the cab. The PATCO car body is an integrated body/frame design of stainless steel. The truck is a Budd Pioneer inside-bearing frame. Suspension consists of airsprings with vertical and lateral shock absorbers. Wheels are tapered with a 28 inch nominal diameter. Each PATCO transit car carries a 10-ton air conditioner. Power is supplied to the car by 650 vdc third rail. The PATCO train is normally run on Automatic Train Operation (ATO), with the driver initiating the start from each station. The ATO accelerates the car and maintains its speed between stations. A station stopping circuit automatically overrides the ATO and stops the train in the stations. A photograph of the train is shown in Figure 2-5.

2.2.3 PATCO Propulsion and Braking System

Four General Electric 1255-A1 motors power each PATCO transit car. The continuous rating for these motors is 160 hp. The motor's output is transmitted to the axle via a double reduction parallel drive gearbox. The propulsion system provides an initial acceleration rate of 3.0 mphps and a top speed of 85 mph. The General Electric SCM cam controller provides the dynamic braking to very low speeds for the PATCO car. At the lower speeds the WABCO RT-5 tread brake system stops and holds the train. The braking system provides an initial brake rate of 2.5 mphps at 75 mph, which is increased with decreasing speed to 3.0 mphps at 50 mph. The emergency capability of the system is 3.2 mphps. The PATCO propulsion system provides slip/slide control for adverse weather operation.

2.3 NEW YORK CITY TRANSIT AUTHORITY

2.3.1 NYCTA Description

The NYCTA manages 725 miles of rapid-transit railroad comprising over 250 route miles. This system is the result of growth and consolidation of four different operating agencies (the IRT, BMT, IND, and portions of the LIRR). Almost 4 million riders use the 476 stations daily. There are 7,200 cars of 20 different types. The Authority employs over

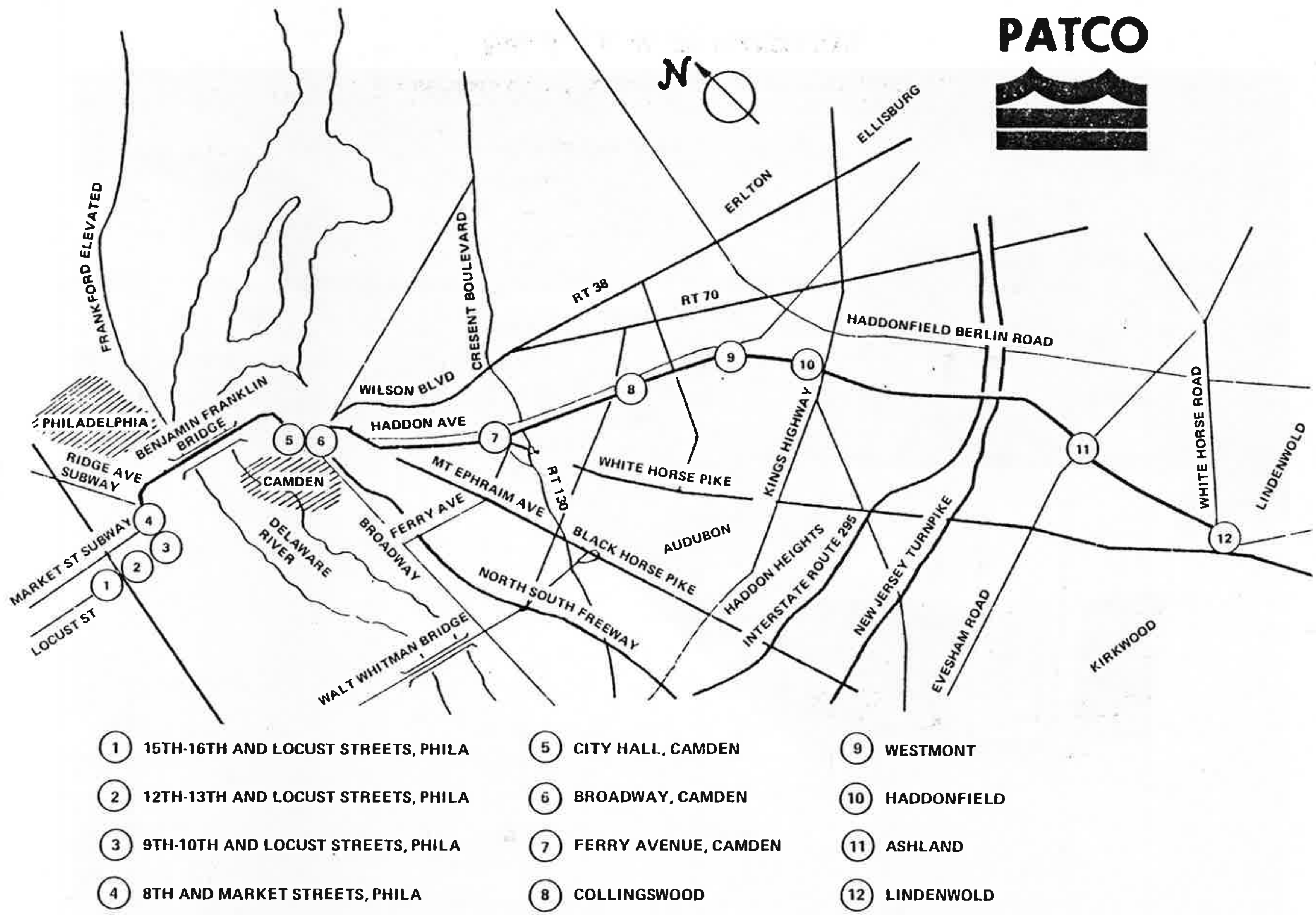


FIGURE 2–4. LINDENWOLD HIGH SPEED LINE.

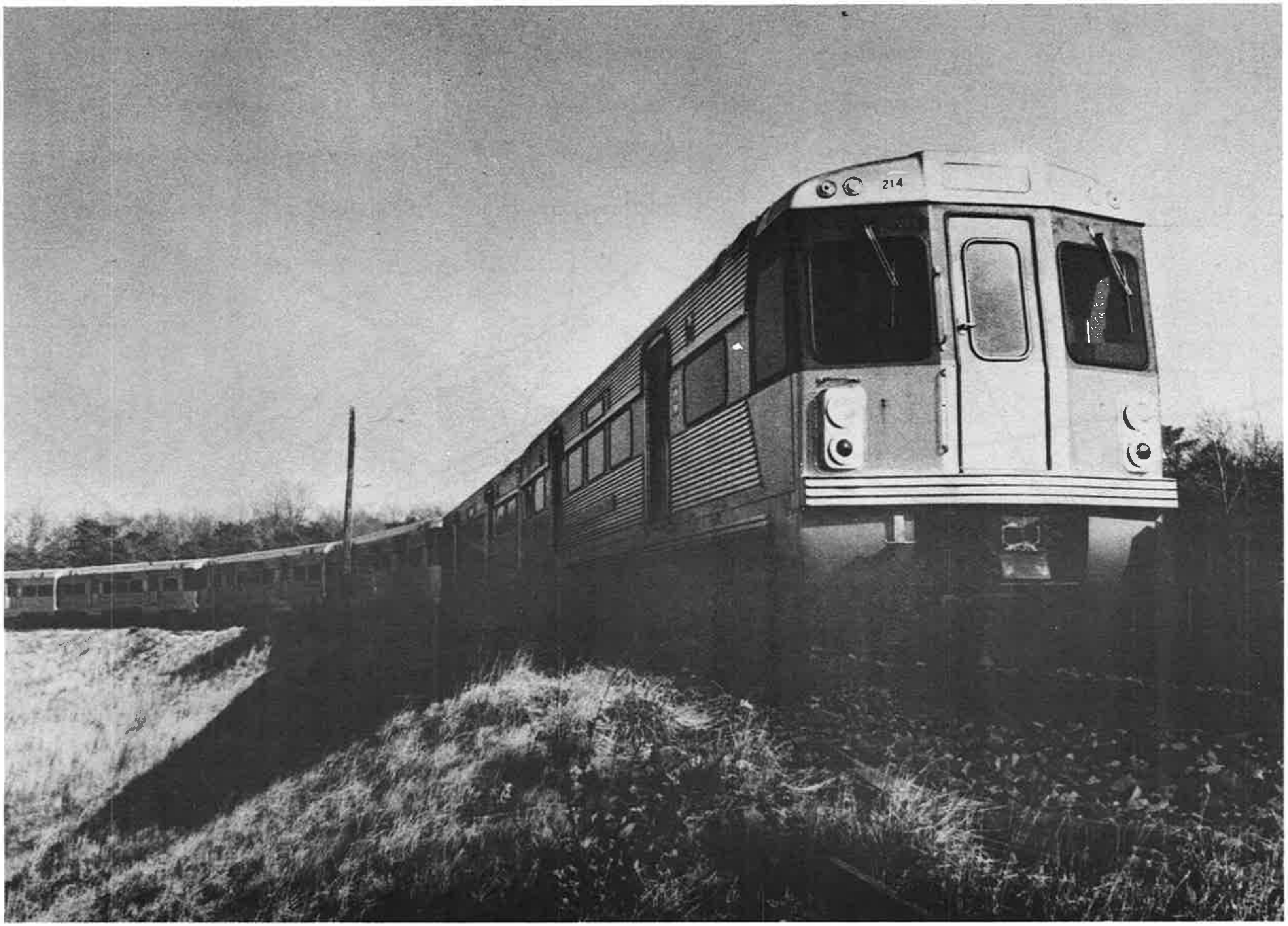


FIGURE 2–5. PATCO TRANSIT CAR.

30,000 people, and has an operating budget in excess of one billion dollars. NYCTA is clearly one of the largest rapid transit systems in the world.

The SOAC and the R-46 were tested on 3 IND lines and 1 BMT route in simulated revenue service. A sketch showing these routes is in Figure 2-6. The 1 BMT route run was the "N" line, the Broadway Express. The "N" line starts from 57th and 7th Avenue in mid-Manhattan and proceeds south as a subway under Manhattan. The line emerges from the ground to cross the Manhattan Bridge and goes underground again for the DeKalb Avenue Station. After DeKalb Avenue the line becomes elevated and runs south across Brooklyn through the NYCTA Coney Island Maintenance Yard and terminates at Stillwell Avenue. This route is 15.4 miles long with a scheduled run time of 49 minutes. The three IND lines run were the "A", "D", and "E". The "A" line, or 8th Avenue Express, runs underground in express service from 207th Street south through Manhattan, traverses the East River by tunnel, and remains underground past Grant Avenue. The "A" line then runs open-cut through Hudson Street to the terminal point of the line at Lefferts Boulevard. The "A" line is 23.6 miles long with a scheduled run time of 76 minutes. The "D" line, or 6th Avenue Express, operates from 205th Street as a subway down 8th Avenue to 53rd Street. The "D" line turns east at 53rd Street and then south again to Washington Square. The line surfaces to cross the East River via the Manhattan Bridge and then goes underground again between DeKalb Avenue and Prospect Park. Between Prospect Park and Newkirk the "D" line is open-cut, and from Newkirk to Stillwell Avenue the line is elevated. The total "D" line distance is 25.8 miles and is scheduled for 79 minutes run time. Only that portion of the "E" line from 179th Street to Hudson Terminal was used during the SOAC and R-46 tests. The "E" line, or 8th Avenue Express, runs underground its entire length starting at 179th Street in Queens, New York. The line runs west into Manhattan, then turns south under 8th Avenue and terminates at Chambers Street-Hudson Terminal. The "E" line route is 16.2 miles long with a scheduled run time of 44 minutes.

2.3.2 NYCTA R-46 Description

The NYCTA R-46 transit cars are manufactured by Pullman-Standard Company. The total order is for 754 cars, half "A" cars and half "B", with delivery started in 1976. The normal train consist is A-B-B-A, with 8 and 12-car trains used during peak load conditions. The R-46 is 75 ft. long, 10 ft. wide, and 12 ft. 1.5-inch from rail to roof. The trucks are 54 ft. on center and each truck has a wheel base of 82 in. The "A" cars weigh 89,000 lbs., and "B" cars 85,500. The R-46 "A" car seats 70, and can transport 300 people during rush conditions. The "B" car has 6 additional seats, and carries the same number during rush conditions. Seats are arranged laterally and longitudinally in the R-46, similar to the arrangement in the SOAC No. 2 car. Seats are formed fiberglass buckets with no inserts. The R-46 has four double sliding doors per car side. The R-46 car body is primarily constructed of stainless steel with an alloy steel body bolster. The truck frame is an articulated, outboard bearing design by Rockwell. Secondary suspension consists of airsprings and hydraulic shock absorbers. R-46 wheels have a taper of 1:20 and a nominal diameter of 34 inches. The R-46 carries two 10-ton air conditioners on each car. The R-46 ATO and ATC (currently inactive) were provided by WABCO. Power for the car is by overrunning third rail shoes at 600 vdc. A photograph of the car is shown in Figure 2-7.

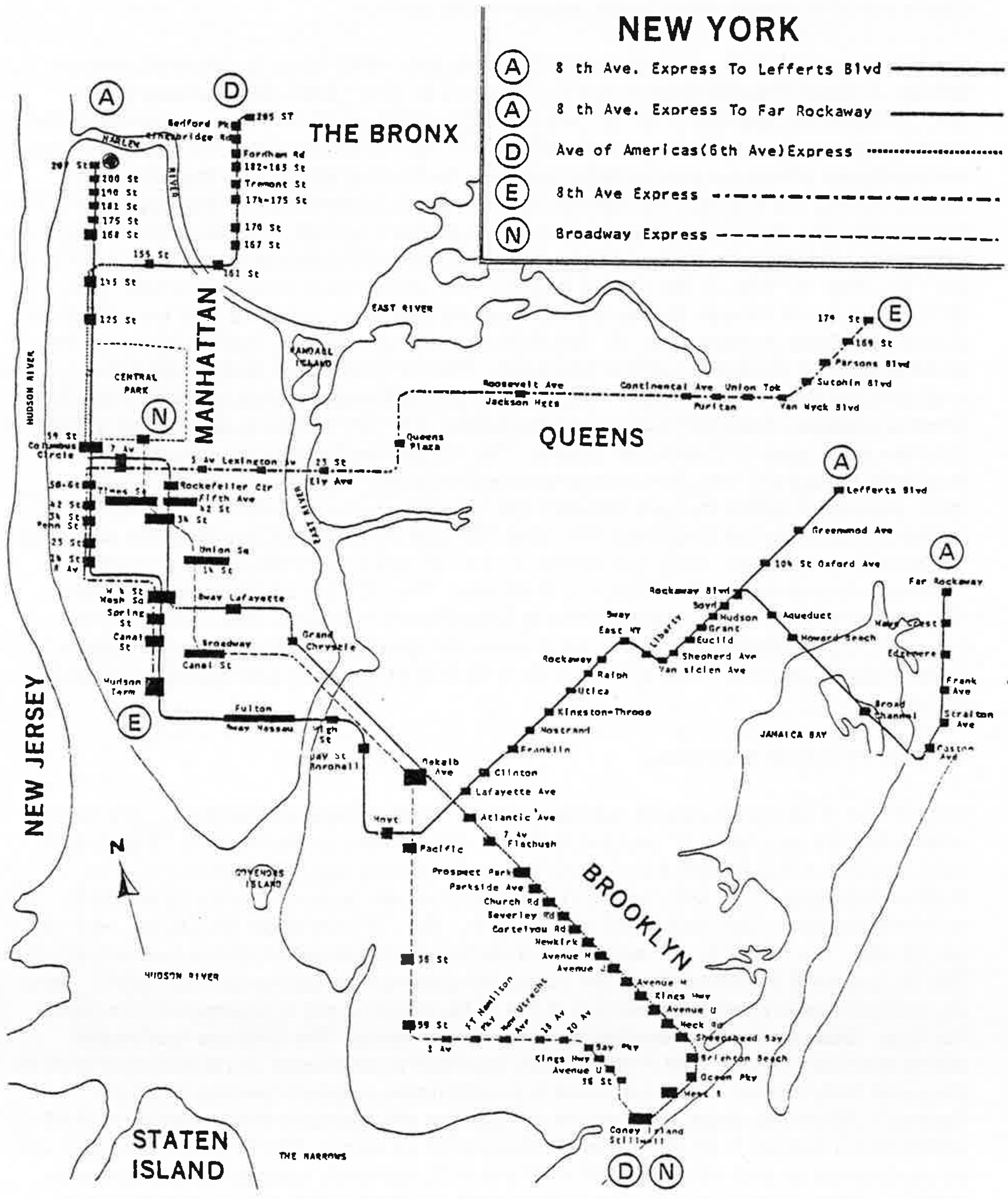


FIGURE 2–6. NYCTA TEST ROUTES.

FIGURE 2–7. NYCTA R-46 TRANSIT CAR.

2.3.3 NYCTA R-46 Propulsion and Braking System

Four General Electric motors power each car. Each of these motors has a continuous rating of 115 hp. The gearing between the motors and the axles is a single reduction, parallel drive gearbox. These motors and the General Electric cam controller provide an acceleration rate of 2.5 mphps and a top speed of 80 mph. The motors are also the primary braking system, providing dynamic braking to very low speeds. At the low speeds the Westcode tread brake system stops and holds the car. The normal service brake rate is 3.1 mphps, and the emergency capability is 3.2 mphps.

2.4 MASSACHUSETTS BAY TRANSIT AUTHORITY

2.4.1 MBTA Property Description

Testing in Boston was conducted on the South Shore (Cambridge-Dorchester) Red Line of the MBTA rapid rail system. A sketch of the system is shown in Figure 2-8. This line runs underground in Cambridge starting at Harvard Square and going to Kendall Square. Leaving Kendall Square the Red Line rises to the surface to cross the Charles River via the Longfellow Bridge and then enters the elevated Charles Station. The line becomes subway again under Boston and returns to grade level south of Broadway Station. The remainder of the route is at grade level. The route is split south of the Andrew Station with one portion of the line continuing to Ashmont and the other to Quincy Center. The service on the Harvard-Ashmont route is 9 miles long with 14 stations and has a scheduled run time of 22 minutes. The Harvard-Quincy Center route is 11.8 miles long, 12 stations, and has a scheduled run time of 23 minutes.

2.4.2 MBTA Silverbird Transit Cars

The MBTA Silverbird transit cars were manufactured by Pullman-Standard Company in 1969. The 76 cars consist of 24 single cars and 26 married pairs. Trains consist of 1 to 8 cars. The Silverbird car is 69 ft. 9.75 inches long, 10 ft. wide, and 12 ft. 4 inches high. The truck centers are 51 ft. apart, and the truck wheel base is 6 ft. 10 inches. Car weight is approximately 61,000 lbs. Single cars seat 60 and carry 228 during rush conditions. The married cars seat 64 and carry 239 passengers during peak load conditions. Seating is primarily 2-2 laterally, with longitudinal seating provided adjacent to the doors. The seats are a pedestal design, covered with vinyl upholstery. Each car has three double sliding doors per car side. The Silverbird car body is constructured of aluminum, except for the LAHT bolster-draft sill. The truck is a General 70 type featuring inboard bearings. Secondary suspension is air/coil springs with lateral and vertical motion controlled by hydraulic absorbers. Wheels have a tapered tread with a 28-inch nominal diameter. Each Silverbird transit car carries a 12-ton air conditioner. Power is supplied to the car via a 600 vdc third rail. The Silverbird married pairs share a single battery, air compressor, and motor generator. A photograph of the car is shown in Figure 2-9.

2.4.3 MBTA Silverbird Propulsion and Braking System

The Silverbird propulsion system was provided by Westinghouse Electric Company. Four 1460-A motors power each car with a combined continuous horsepower rating of 400 hp.

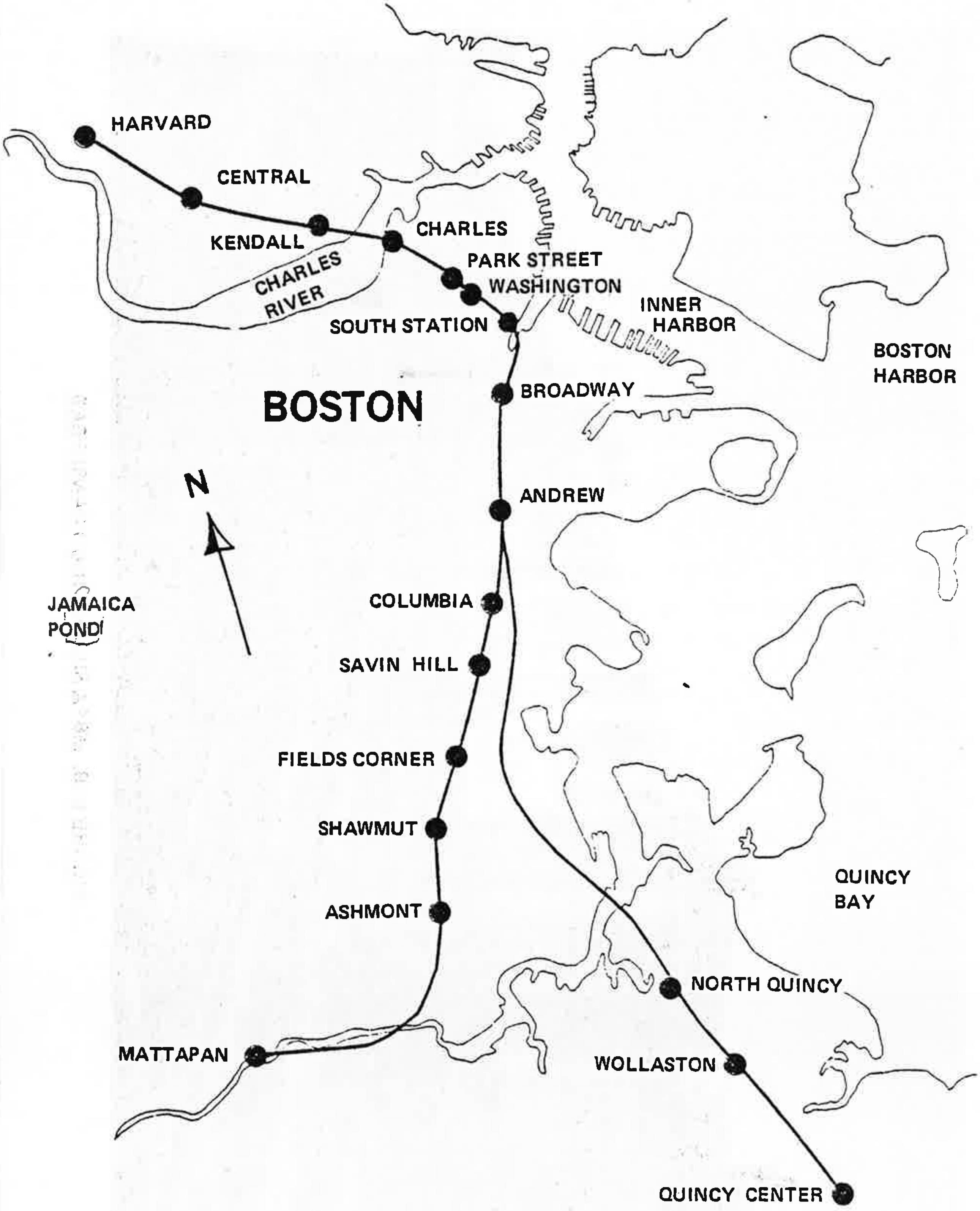


FIGURE 2–8. MBTA SOUTH SHORE "RED" LINE.

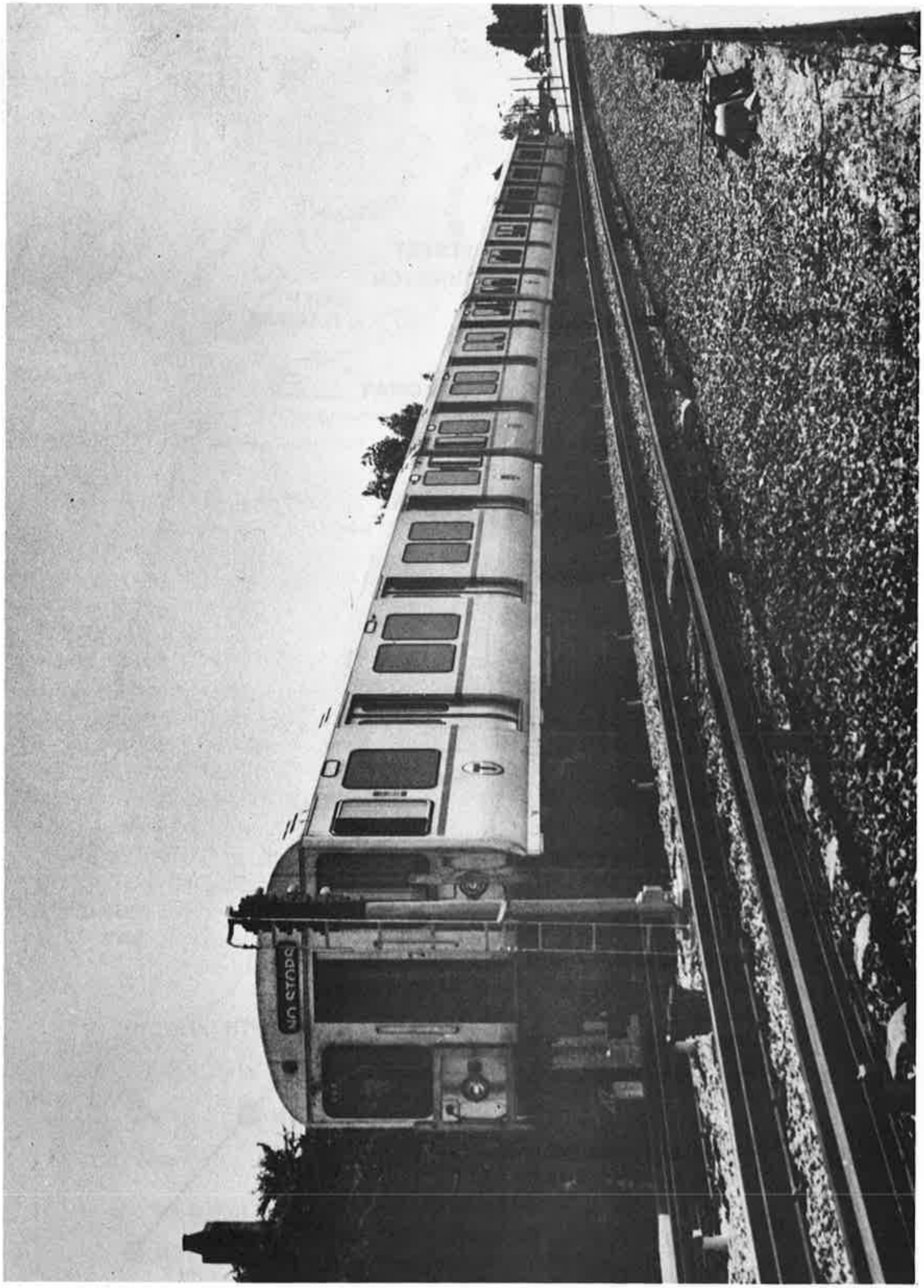


FIGURE 2–9. MBTA SILVERBIRD TRANSIT CAR.

The gearbox is a Westinghouse Tracpak featuring a parallel-drive, double-reduction gear arrangement. The Westinghouse cam controller and motors provide an initial acceleration rate of 2.5 mphps and a maximum speed of 70 mph. The primary braking system is the cam controlled dynamic braking. At 15 mph the friction braking is provided by a WABCO RT-2 tread brake system. The braking system provides a service brake rate of 2.75 mphps, and an emergency rate of 3.25 mphps.

3. INSTRUMENTATION SYSTEM

3.1 GENERAL

The SOAC Instrumentation System was used throughout the SOAC test program. This system is described in detail in reference 1. The electrical signals from the vehicle-mounted transducers are conducted by cables to a patch panel in the rear of the instrumentation console. The console contains two Sangamo Sabre III magnetic tape recorders, two Honeywell light beam oscillographs, a time code generator, and 65 signal conditioning cards and power supplies. Any 28 selected test parameters can be recorded on tape at one time, while only 12 parameters are normally displayed on the oscillographs at one time. In addition to the 28 recorded parameters, wheel speeds may be displayed directly on the oscillographs and power consumption visually displayed on a mechanical counter. The time code generator provides signals that are recorded on both tape and oscillograph. The oscillographs provide real time data reduction capability while the recorded data is stored for analysis at a later date. A schematic of the instrumentation system is shown in Figure 3-1, and a photograph of the console in Figure 3-2.

3.2 RIDE QUALITY

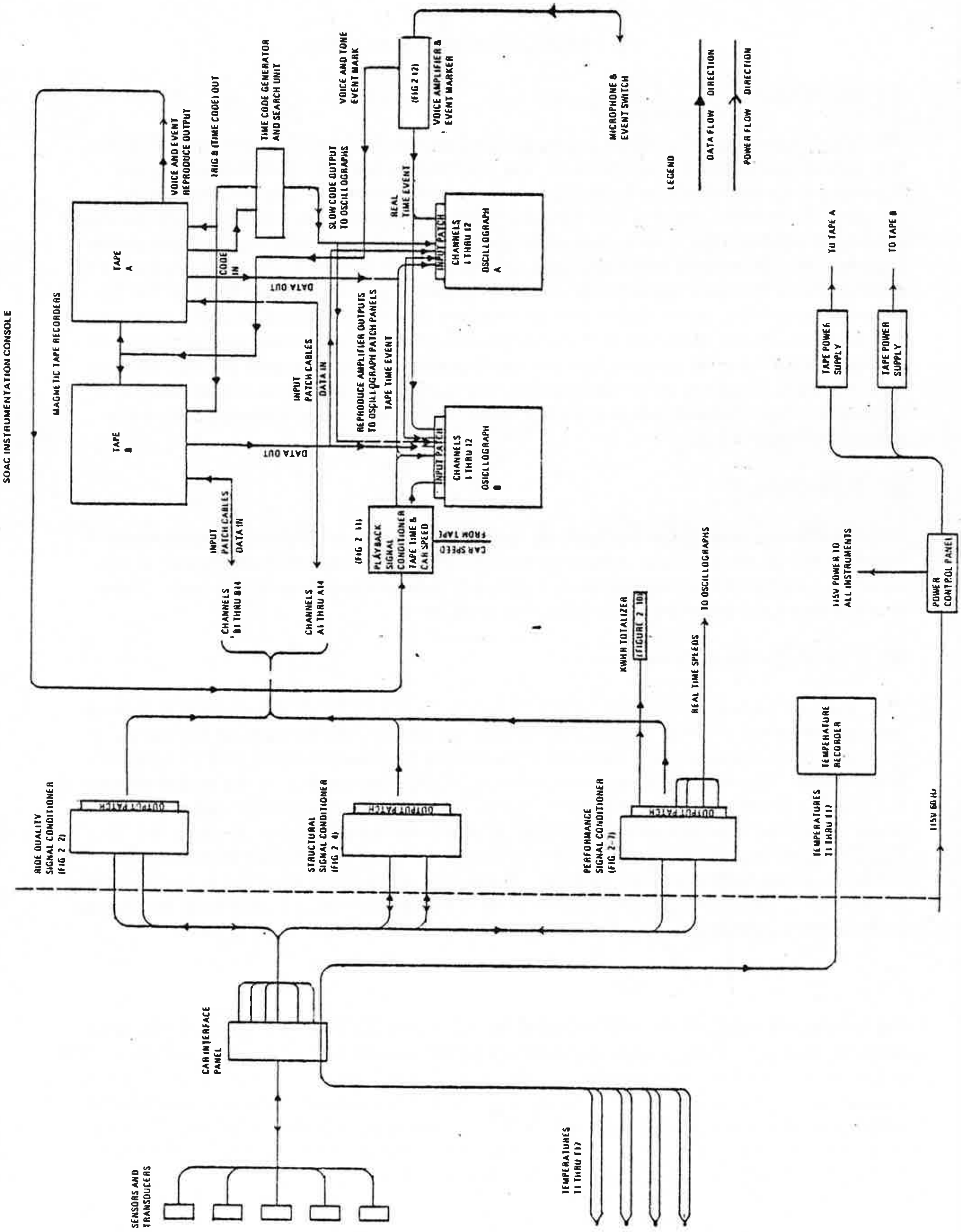
Ride quality instrumentation involved the measurement of three different types of motion: linear motion of the car body, rotational motion of the car body, and linear motion of the axles. For each of these measurements, a different type of accelerometer was used. These accelerometers are described in the following paragraphs.

3.2.1 Linear Car Body Motions

Five linear car body motions were measured during the DATTIS test effort: mid-car vertical, mid-car horizontal, mid-car longitudinal, forward car vertical, and forward car horizontal. All five of the parameters were measured by Schaevitz Engineering Model LSB-2 Linear Accelerometers. The range of the accelerometers is ± 2.0g. The linearity of the accelerometers is ± 0.05% full scale with a hysteresis of ± 0.02% full scale. The frequency response of the sensor is 0-20 Hz, the resolution is 0.0005% full scale, and the calibration accuracy is 0.1%. The Garrett AiResearch Corporation designed signal conditioning provides sensor power, buffering, offset adjustment, and balance. The output of the signal conditioner has an overall accuracy of ± 1.0%. The calibration method for the accelerometer is a centrifuge, and voltage substitution is used to adjust and calibrate the signal conditioning.

3.2.2 Rotational Car Body Motion

The three rotational car body motions recorded during the DATTIS test were roll rate, pitch rate, and yaw rate. These angular accelerations were measured with Statham Model AA-17-300 angular strain gage type accelerometers. The range of 2 of these units was ± 1.5 radian/sec/sec and the third ± 3.0 radian;sec;sec. The nonlinearity and hysteresis of these accelerometers is specified as less than ± 2% full scale, and each has a frequency response of 0-4 Hz. The SOAC signal conditioning provides sensor power, buffering, gain and offset adjustment, and balance. This signal conditioning is rated at an overall accuracy of ± 1.0%.



SOAC INSTRUMENTATION CONSOLE
MAGNETIC TAPE RECORDERS
TAPE A
TAPE B
VOICE AND EVENT REPRODUCE OUTPUT
TRIG B (TIME CODE) OUT
TIME CODE GENERATOR AND SEARCH UNIT
SLOW CODE OUTPUT TO OSCILLOGRAPHS
VOICE AND TONE EVENT MARK
(FIG 2 12)
VOICE AMPLIFIER & EVENT MARKER
MICROPHONE & EVENT SWITCH
LEGEND
DATA FLOW DIRECTION
POWER FLOW DIRECTION
REAL TIME EVENT
CODE IN
DATA OUT
INPUT PATCH
CHANNELS 1 THRU 12 OSCILLOGRAPH A
CHANNELS 1 THRU 12 OSCILLOGRAPH B
INPUT PATCH CABLES DATA IN
REPRODUCE AMPLIFIER OUTPUTS TO OSCILLOGRAPH PATCH PANELS
TAPE TIME EVENT
(FIG 2 11)
PLAYBACK SIGNAL CONDITIONER TAPE TIME & CAR SPEED
CAR SPEED FROM TAPE
CHANNELS B1 THRU B14
CHANNELS A1 THRU A14
TO TAPE A
TO TAPE B
TAPE POWER SUPPLY
115V POWER TO ALL INSTRUMENTS
POWER CONTROL PANEL
KWHR TOTALIZER
(FIGURE 2 10)
REAL TIME SPEEDS
TO OSCILLOGRAPHS
TEMPERATURE RECORDER
TEMPERATURES T1 THRU T17
115V 60 Hz
RIDE QUALITY SIGNAL CONDITIONER (FIG 2 2)
STRUCTURAL SIGNAL CONDITIONER (FIG 2 4)
PERFORMANCE SIGNAL CONDITIONER (FIG 2-7)
OUTPUT PATCH
CAR INTERFACE PANEL
SENSORS AND TRANSDUCERS

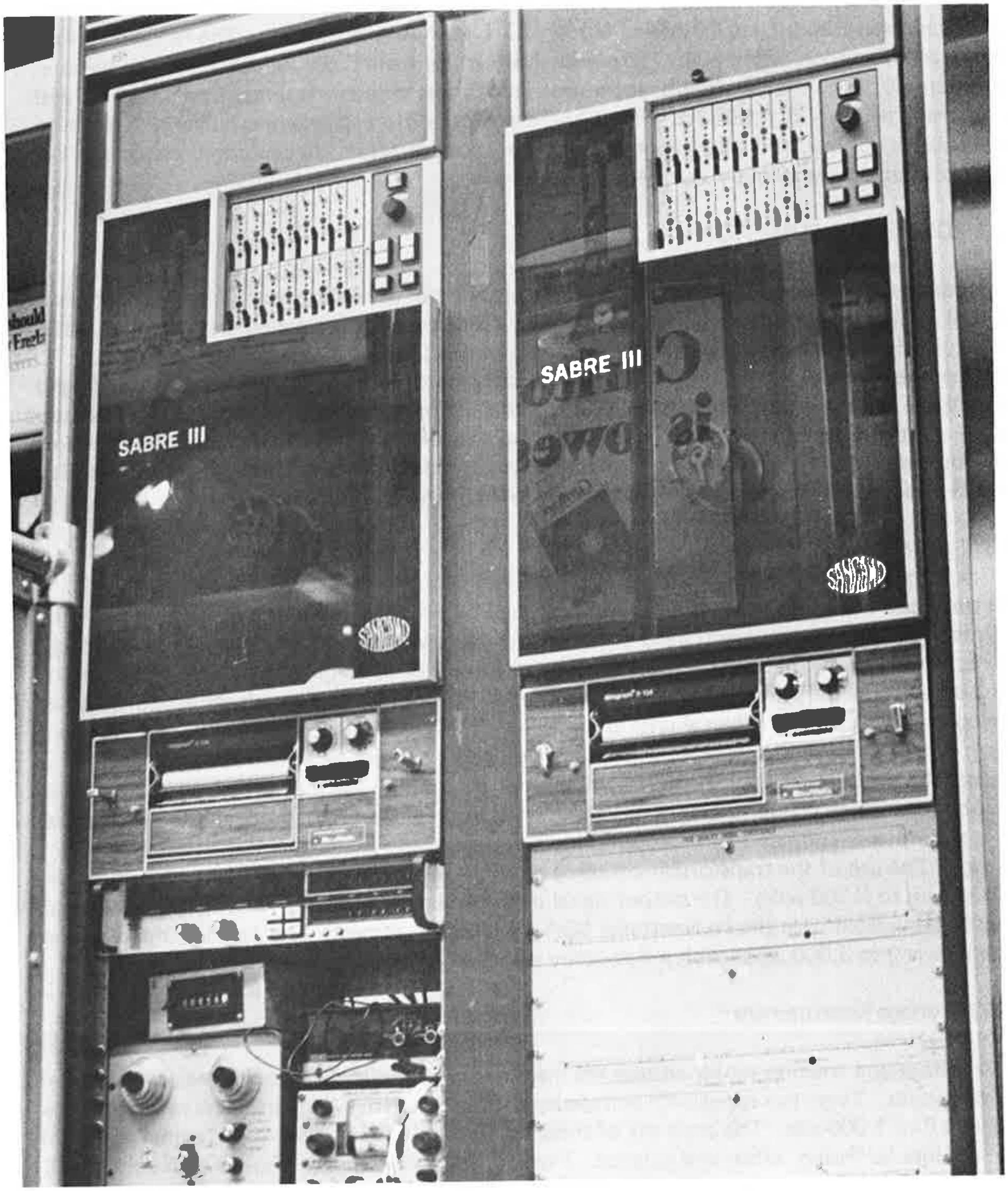


FIGURE 3–2. SOAC INSTRUMENTATION CONSOLE.

3.2.3 Linear Motion of the Wheel/Axle

The vertical and lateral motion of one wheel/axle, and the vertical motion of a second wheel/axle were measured by Setra Systems Model 117 Linear Accelerometers. The range of these three accelerometers was ± 50g. The nonlinearity is less than ± .5% full scale and the hysteresis less than ± 0.1% full scale. Frequency response for these accelerometers is 0 to 1,000 Hz with a natural frequency of 1,600 Hz. The SOAC signal conditioning provides buffering, offset and balance control, and gain adjustment. These accelerometers are calibrated on a centrifuge, and the recording system by voltage substitution.

3.3 POWER CONSUMPTION

The power consumption analysis requires measurement of several interactive test conditions, as well as the actual third rail consumed power. Three currents are measured: traction motor armature current, traction motor field current, and third rail total line current. The two voltages measured are third rail voltage and traction motor voltage. The third rail current and voltage are instantaneously multiplied and recorded as power consumption. The driver's input to the control system is measured by a linear displacement transducer. Car speed and distance are obtained from a magnetic pick-up installed in a traction motor gearbox. The car's acceleration is measured by a linear accelerometer mounted in the interior of the car.

3.3.1 Current Measurement

All three current measurements were accomplished by precision calibrated low value current shunts. These shunts are electrically connected in series with a resistor load when measuring the current through that load. By measuring the voltage drop across this resistor, the current can be determined by Ohm's Law. By proper amplification, an analog voltage proportional to the current is provided. When shunts are installed in 600 volt lines, direct connection of the shunt signal to conventional ground reference equipment would be hazardous. For this reason, the signal is pre-conditioned in an Isolation Amplifier. Each amplifier channel contains a modulator which converts the shunt voltage level into an equivalent frequency. This frequency is transformer coupled to a demodulator which reconverts the frequency into the signal voltage. The use of the transformer coupling provides adequate insulation for common mode voltages up to 5,000 volts. The output signal of the Isolation Amplifier, now ground referenced, may be connected with the conventional SOAC system equipment. The range of the isolation amplifier is 0 to 3,000 amps with a frequency response from DC to 1,000 Hz.

3.3.2 Voltage Measurement

Line voltage and traction motor voltage are measured by Garrett AiResearch designed voltage/divider boxes. These boxes measure voltage by precision resistive dividers. The range of these boxes is 0 to 1,000 vdc. The accuracy of these devices are ± 0.5%. The SOAC signal conditioning provides buffering, offset and balance. The primary calibration method is high voltage DC power supply in conjunction with a precision digital voltmeter. The recording system is calibrated by voltage substitution.

3.3.3 Power Consumption Measurement

The power consumption is recorded on magnetic tape and displayed on a mechanical counter. The power consumption, measured in kilowatt-hours, is obtained by multiplying the instantaneous values of line current and line voltage together. The SOAC signal conditioning provides for the multiplication of the output of line voltage and line current, buffering, offset, and balance adjustment. The accuracy of this measurement is ± 5.0%. The primary calibration method is to accurately measure the line voltage by digital voltmeter, the line current with a shunt, and then use a wattmeter and countertimer to check the kilowatt-hour meter. Secondary calibration is done by voltage substitution and counter-timer.

3.3.4 Driver's Command

The driver's command to the propulsion system can seriously affect the performance of an infinitely adjustable propulsion system. However, the cam control cars have a notched controller which allows only a small number of input commands to the propulsion system. To measure the driver's input command, a linear displacement transducer was connected to the control handle. The displacement pot was always calibrated in place, which results in a ± 1% accuracy. The SOAC signal conditioning provides sensor power, buffering, offset and balance adjustment.

3.3.5 Car Speed and Distance

Car speed and distance were measured by recording the pulses from a monopole magnetic pickup in the gearbox of each railcar. This monopole provides a pulse for each gear tooth that passes it. By knowing the gear ratio and the wheel diameter the car speed can be found from the frequency of the pulses, and the distance from the sum of the pulses. The SOAC signal conditioning provides buffering, offset, and balance adjustment. The accuracy of this signal conditioning is ± 1 count on frequency, and ± 1.0% on DC analog signal.

3.3.6 Car Acceleration

Car acceleration is measured with a linear servo accelerometer. The sensor used was a Schaevitz Engineering Model LSCO-0.25. The range of the sensor is ± 5.4 mphps and its linearity is ± 0.02% full scale. The hysteresis is negligible and frequency response 0-16 Hz. The resolution is 0.0001% full scale and calibration accuracy is 0.5%. The SOAC signal conditioning provides sensor power, buffering, offset and balance adjustment. The primary calibration process is a precision ground wedge (output versus angle). The recording system is calibrated by voltage substitution.

3.4 NOISE

Two noise measurements were made during DATTIS testing: interior noise and exterior noise. The interior noise measurements were recorded continuously for end-to-end runs on each line. The recorder was started at the beginning of each run and operated continuously until the car arrived at the opposite terminal. Measurements were made in a car in which there were no test personnel or passengers, although the doors were cycled normally at each station stop. The exterior noise was taken at the outside edge of the carbody near the center of the rear truck.

3.4.1 Interior Noise

Interior noise level was measured using a Bruel & Kjaer (B&K) Model 2206 Impulse Precision Sound Level meter. This meter features A, B, and C weighting networks. The range of measurement on the A-scale is 39 to 140 dB, on the B-scale 43 to 140 dB, and on the C-scale 51 to 140 dB. It is designed to meet all current standards set by the IEC for both Precision Sound Level meters and Impulse Sound Level Meters. Distortion is less than 1% for the full scale meter. Garrett AiResearch modified the unit to allow the meter output to be recorded on the SOAC instrumentation system. Calibration of the meter and recording system was made by using a B&K Sound Level Calibrator Type 4230. This calibrator produces a 94 dB-100 Hz signal which is recorded using each of the meter's scales.

3.4.2 Exterior Noise

Exterior noise was measured by a B&K Model 2209 Impulse Precision Sound Level meter. The Model 2209 is a compact, portable instrument for precision sound and vibration measurement. It is designed to meet all current standards set by the IEC for both Precision Sound Level meters and Impulse Sound Level meters. The 2209 is designed so that in the impulse mode, its response characteristics to short duration sounds approximate the response of the human ear. Thus, it effectively measures the subjective loudness of short duration sound as heard by the human ear. The 2209 is capable of measurements over a wide frequency and dynamic range. Built into the instrument are the A, B, and C frequency weighting networks plus the D weighting network for aircraft noise measurement. The DC output of the 2209 was then recorded on the SOAC Sabre III tape recorders. Calibration of the meter and recording system was made by using a B&K Sound Level Calibrator Type 4230. This calibrator produces a 94 dB-1,000 Hz signal which is recorded using each of the meter's scales.

4. TEST EQUIPMENT INSTALLATION

4.1 RIDE QUALITY

The ride quality instrumentation is broken into two groups for installation purposes: interior and exterior sensors. The interior sensors were mounted the same way in all three trains, and were equivalent to the SOAC installation for comparison purposes. The exterior sensors were mounted also in all three trains in the same manner, but because of different mechanical arrangements of the train components, the data from these exterior sensors is not readily comparable between the three trains and the SOAC.

4.1.1 Interior Sensors

The three angular accelerometers were mounted on a triaxial mounting plate to measure roll, pitch, and yaw. This plate was then placed in the center of the car, as shown in the Boston Silverbird installation in Figure 4-1. Three 2g linear accelerometers were mounted on a triaxial accelerometer mount to measure vertical, longitudinal and lateral vibration loads. This triaxial accelerometer mount was then mated to a mounting plate and placed at the center of the car (the Silverbird installation is shown in Figure 4-1). A second mounting plate and triaxial accelerometer mount was placed in the forward part of the car over the center of the truck. Two 2g accelerometers were placed on it, as shown in Figure 4-2, to measure the forward car vertical and lateral motions.

4.1.2 Exterior Sensors

The intent of measuring journal box accelerations was to demonstrate that the test vehicles had been subjected to the same rail roughness environment as had the SOAC during its previous test. However, because the test vehicles were the property of the transit systems and because of the severe time restrictions that occurred during the test, it was not possible to locate the accelerometers in a position in each of the trains that would be equivalent to the SOAC. During the first Engineering survey, the mounting location shown on Figure 4-3 was selected for the NYCTA R-46. Following TTC concurrence, a similar gearbox location was selected on the PATCO and Silverbird transit cars. The PATCO arrangement is shown in Figure 4-4, and the Silverbird installation shown in the photograph in Figure 4-5. The SOAC installation is shown in Appendix B of Reference 1. In each case, a vertical and lateral accelerometer were mounted on one side of the car, and a vertical on the other.

4.2 NOISE

The interior noise was measured in the second car of the two-car test train in each case. The B&K Model 2206 was mounted on the top of a seat back of a laterally mounted seat. In each case the seat selected was an aisle seat immediatley forward of the rear door in the empty test car. This location was maintained throughout the DATTIS test. This door location is representative of a typical seat within the test car, but it should be noted that it is compared with a mid-car location in the state-of-the-art car which is the quietest seat location for that vehicle. On the same car, seat locations near doors or over trucks are generally 2-4 dBA noisier than mid-car locations. No exterior noise was recorded during the SOAC property test.

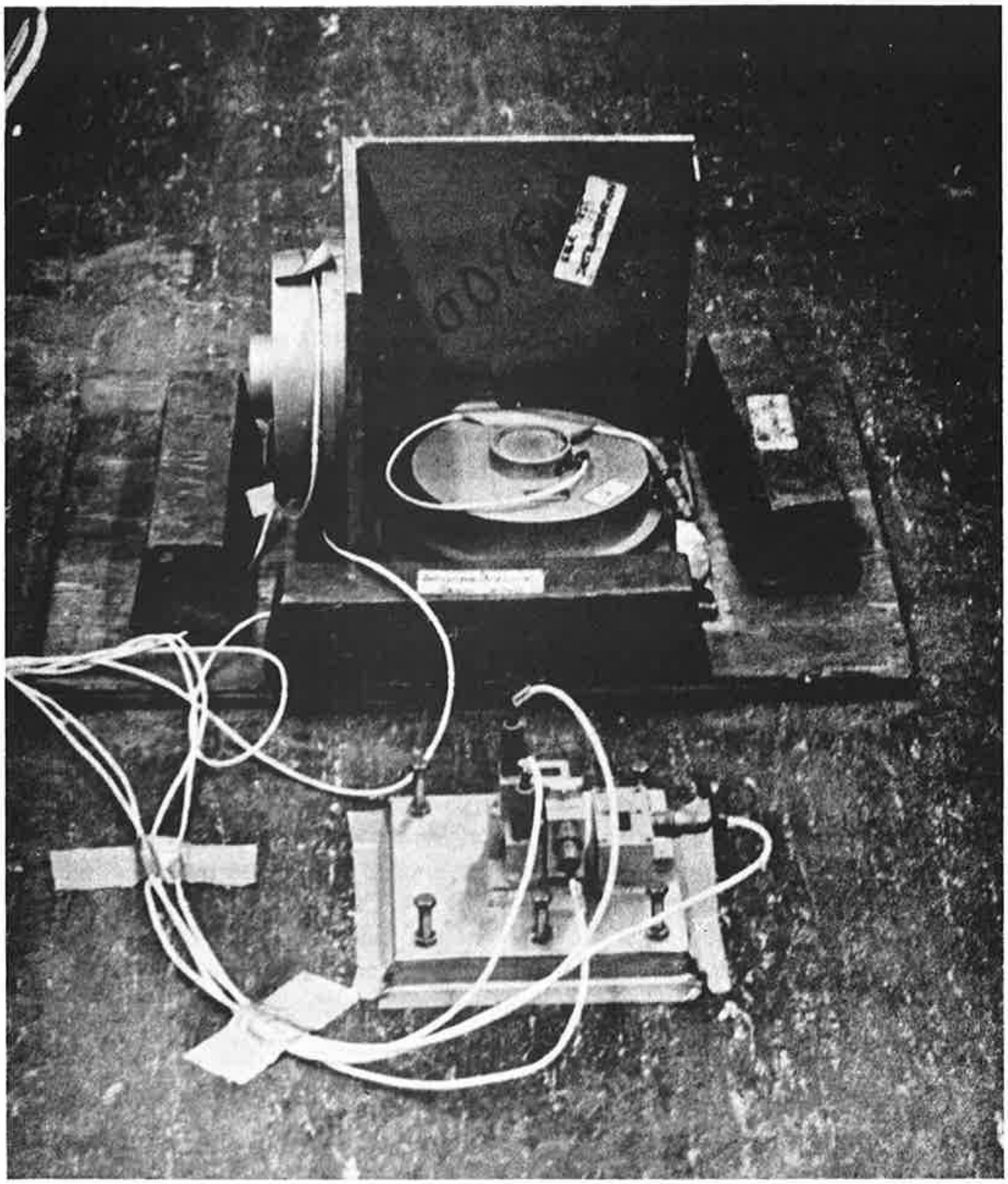


FIGURE 4–1. BOSTON SILVERBIRD MID-CAR INSTRUMENTATION.

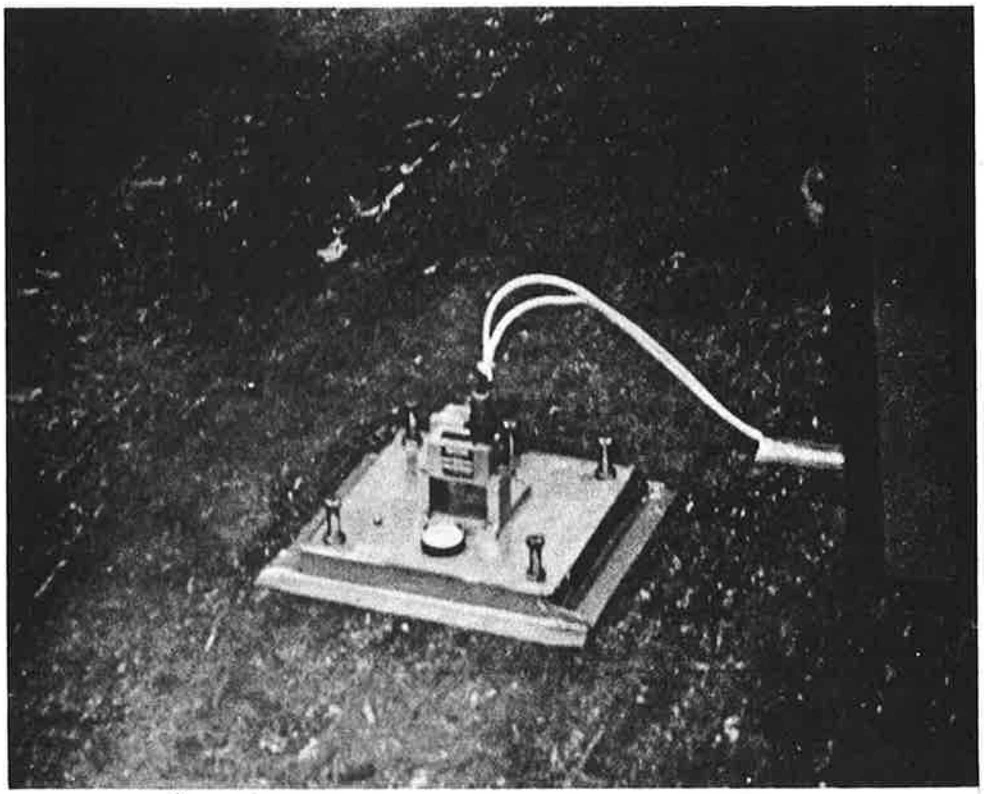


FIGURE 4–2. BOSTON SILVERBIRD FORWARD CAR INSTRUMENTATION.

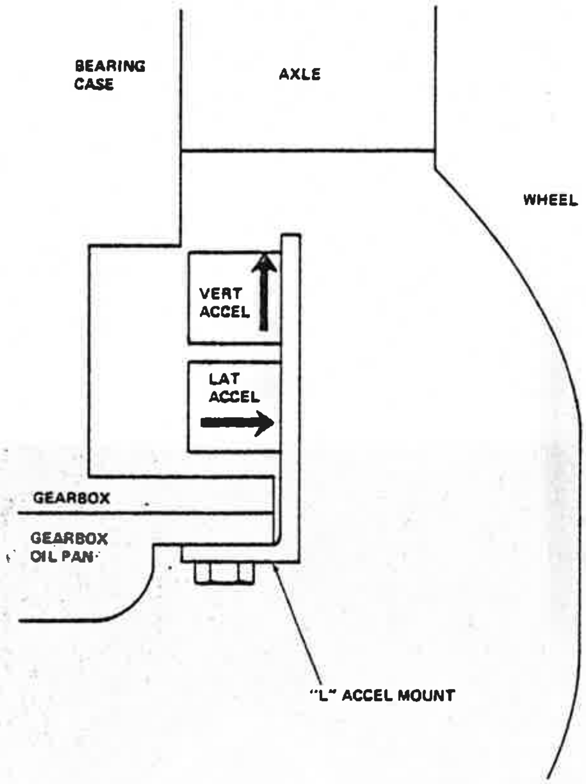


FIGURE 4–3. NYCTA R-46 GEARBOX MOUNTED ACCELEROMETERS.

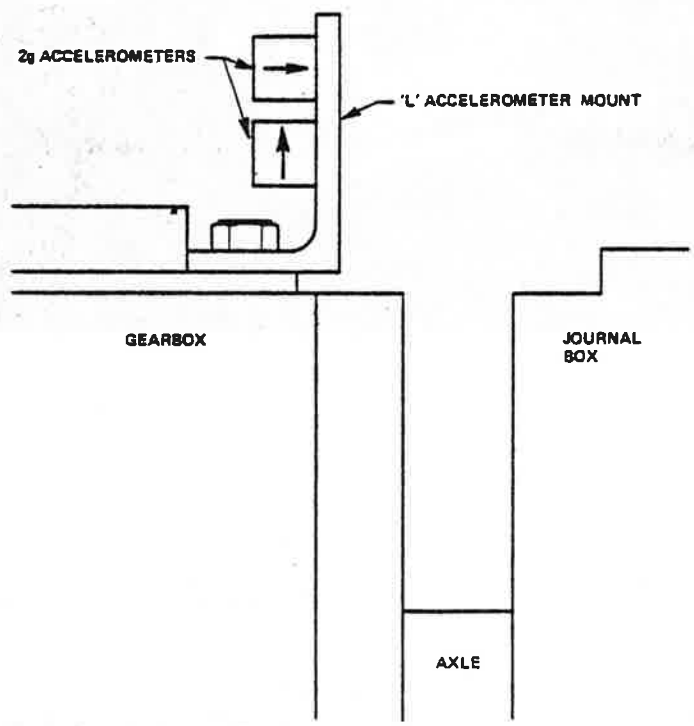


FIGURE 4–4. PATCO GEARBOX MOUNTED ACCELEROMETERS.

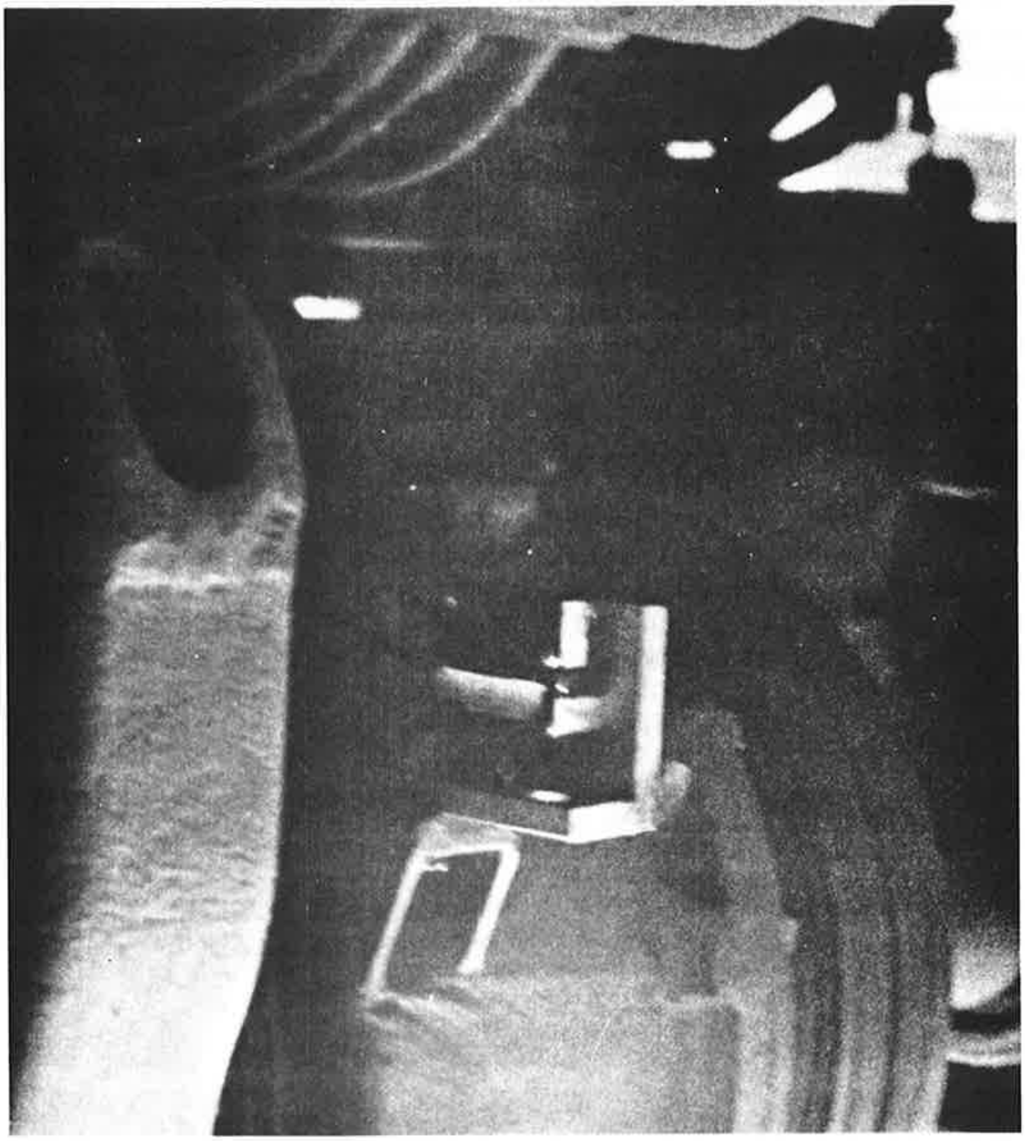


FIGURE 4–5. SILVERBIRD GEARBOX MOUNTED ACCELEROMETERS.

During DATTIS testing exterior noise was recorded at the lower edge of the car body adjacent to the center of the rear truck. This position was maintained throughout the DATTIS testing and allows direct comparison of the respective noise environments of the three trains.

4.3 POWER CONSUMPTION

Measurement of voltages, car speed and distance, and car acceleration during DATTIS testing was identical to the methods used during the SOAC testing. Measurement of currents was changed for greater accuracy by switching from Hall transducers to current shunts and isolation amplifiers. The cam control propulsion system also required a change in the method of measuring driver's command.

4.3.1 Voltages

Voltage dividers are shown in Figure 4-6. The high side of the line voltage measurement was always taken from the current shunt inserted at the knife switch for measurement of line current. The low side of the voltage measurement was car body ground. The armature voltage measurement was made from the armature current shunt to the armature return line in the cam controller box.

4.3.2 Car Speed and Distance

During the first test, the PATCO transit car, an attempt was made to use the pulse output of the ATO package for speed and distance measurement. However, different electrical ground references caused noise problems which could not be resolved. A monopole pick-up was removed from the PATCO stores and inserted in one of the alternate transducer locations on the gearbox. This dedicated monopole provided the pulse required for speed and distance measurement at PATCO. On the R-46 and the Silverbird, a "T" was inserted in the train's speed measurement circuit at the monopole. This arrangement provided trouble-free measurement of the speed and distance.

4.3.3 Car Acceleration

The accelerometer used for measuring car acceleration is mounted adjacent to the triaxial mounting pad on the mounting plate in the center of the car. This arrangement is shown in Figure 4-1.

4.3.4 Current Measurement

The current isolation/amplifier used throughout DATTIS testing is the TSC Model ISO-1 shown in Figure 4-6. Only three of the amplifier's five channels were used, and each of these was modified according to the diagram shown in Figure 4-7 to increase the output. In New York, 2 Janco 1000 amp current shunts were installed at the control box disconnect to measure field and armature shunts. A 2000 amp shunt was installed at the input to the third rail knife switch box to measure R-46 line current. PATCO officials refused to allow any installation of shunts for the measurement of field or armature current. However, the General Electric shunt used for propulsion control was available and used for the recording of PATCO

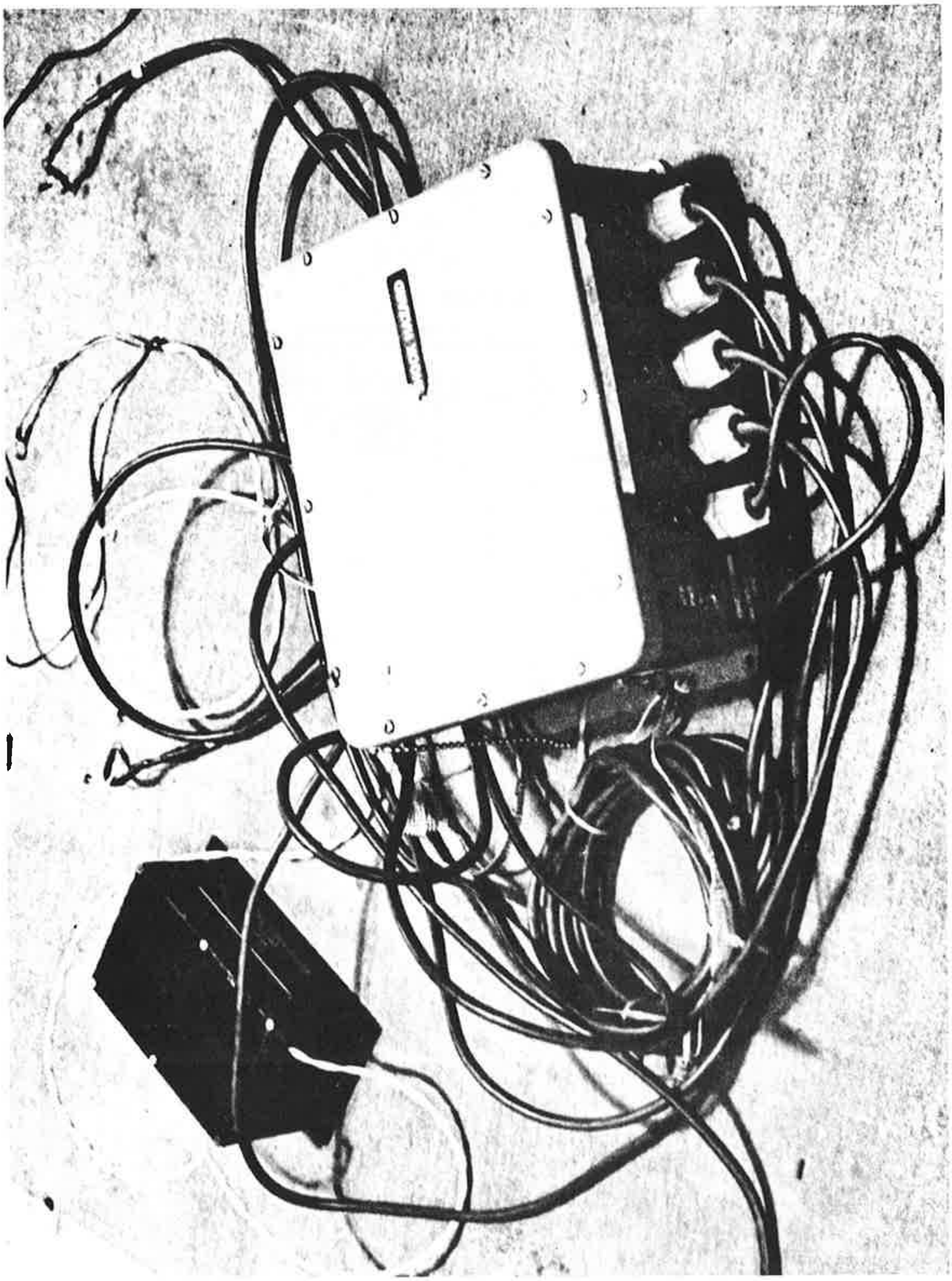


FIGURE 4–6. VOLTAGE DIVIDER BOX AND ISOLATION AMPLIFIER.

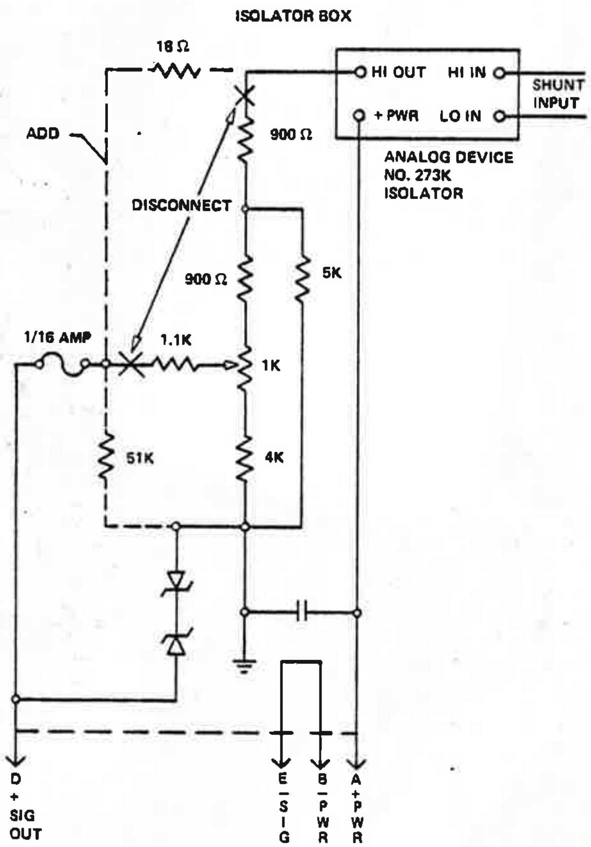


FIGURE 4–7. MODIFICATION TO TSC ISOLATION AMPLIFIERS.

armature currents (two were recorded). No field current was recorded during the PATCO test. The 2000 amp Janco shunt was installed at the knife switch for measurement of line current. On the Silverbird, a 1000 amp Janco shunt was added to the car circuitry to measure field current. The Westinghouse cam control current shunt was used for the armature current. The installation of the 2000 amp Janco shunt for line current measurement was made at the input to the main breaker in the cam controller box. The car's accessories wiring had to be changed so that the accessories current was drawn from the "low" side of the current shunt.

4.3.5 Driver's Command

Driver's command was monitored by recording the "P-Signal" during the SOAC test. Cam control cars, however, do not have a "P-Signal" which covers both braking and acceleration modes. For this reason, a linear displacement transducer was connected to the control handle for measurement of the driver's command to the propulsion system. A sketch of the Silverbird installations is shown in Figure 4-8.

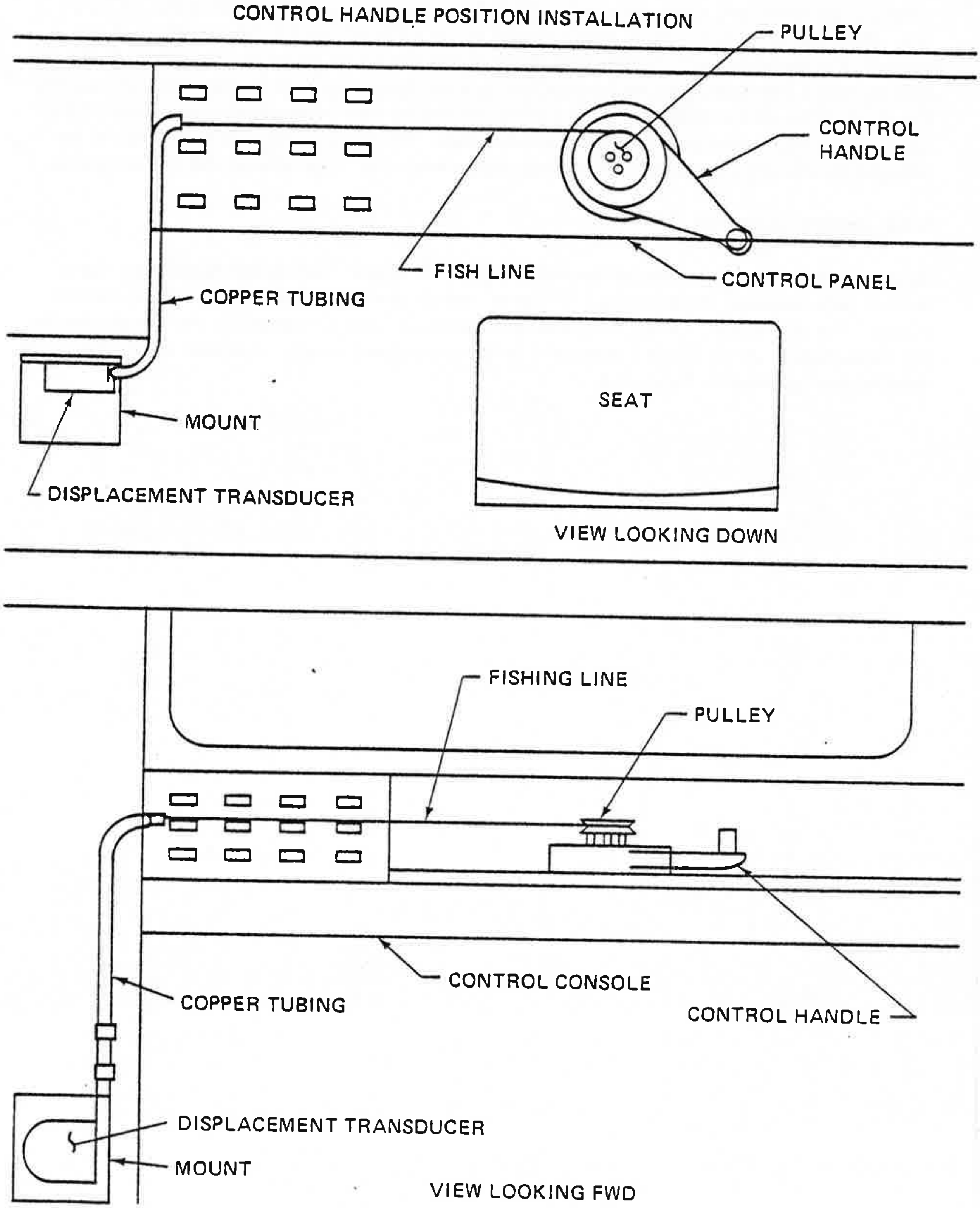


FIGURE 4–8. SILVERBIRD "DRIVER'S COMMAND" INSTALLATION.

5. TEST PROCEDURE

5.1 DETAILED TEST LOG

A detailed log of the test program run in New York City is attached as Appendix A to this report. It covers the test effort from the shipment of equipment to New York to its return to Boeing Vertol. It is included in this report as a guide for planning and estimating future property test programs with similar requirements. It also demonstrates the rather wide range of problems that can be experienced during property tests.

5.2 TEST CREW AND JOB DESCRIPTIONS

In Boston and New York, six people were required to conduct the DATTIS test. The property supplied the motorman, conductor, and an engineer/liaison person, and the DATTIS test personnel were the test engineer and two instrumentation technicians. The duties for each during the test are described in the following sections. PATCO has less union restrictions on its personnel and is able to combine the taks of conductor and motorman. PATCO also chose not to provide an engineer/liaison person during the test, reducing the total crew to four.

5.2.1 Motorman

The motorman's task throughout the test was to drive the test train. In particular he was instructued to drive the train as if it were carrying passengers, and he was on a normally scheduled revenue service run. In all cases, he was to obey block controls and speed limits. He was instructed to stop in those stations designated by the property liaison person, and to leave the station as quickly as possible following door closure, block controls permitting.

5.2.2 Conductor

The conductor's only duty during the test was to open and close the doors as directed by the test engineer. In the case of Boston and New York, this task was accomplished from the cab of the second car of the two-car test train. In each station the doors on the side of the car opposite the platform were opened.

5.2.3 Property Liaison Person

In New York a supervisor from New Car Engineering Department was provided as the single point of communications between the test team and the property operations and maintenance staff. In Boston, an engineer from the Car Engineering Department was provided to perform this task. In addition to this communication task, the liaison officer inspected the instrumentation and wiring installations and approved them as adequate for testing. Prior to the test, the test engineer and liaison officer discussed the routing of the test train, and the station stop requirements. During the test, the liaison officer rode in the cab with the driver and maintained constant radio communication with the line controllers. The liaison officer obtained clearance from the controllers for the train, monitored the driver's performance, and kept the test engineer informed of problems along the line via the cab-to-cab intercom.

5.2.4 Test Engineer

Prior to each test run the test engineer informs the property liaison person of the test route and station stop requirements. Following this conference, he prepares data log sheets and schedule for the instrumentation technicians, and briefs them on the test. When the motorman and conductor are assigned, the test engineer briefs them on the test, and their tasks during the test. During the test, the test engineer rides in the cab of the second car and instructs the conductor when to open and close the doors in each station. From the second cab, the test engineer is in constant communication with the liaison person in the motorman's cab by intercom.

5.2.5 Instrumentation Technicians

Two instrumentation technicians are required to operate the SOAC instrumentation system during property tests. Prior to the test run, the entire system is zeroed, balanced, and calibrated. During the test run, the two technicians maintain tape logs for each tape recorder, and monitor the oscillograph output for bad data, or lost channels. At each station, the technicians record station name and an event on the magnetic tape edge track.

5.3 TEST PROCEDURE

The following sequence of events was followed for each test:

a. The installation of all test equipment is checked.

b. A coordination meeting between the test engineer and the property liaison official is held.

c. Test engineer prepares data sheets for the test.

d. Test engineer briefs instrumentation engineers on the test route.

e. The motorman and conductor are briefed by the test engineer.

f. The train leaves the maintenance area and proceeds to the first station on the test route.

g. During traverse to the first station, noise meter levels and speed/distance measurement are verified.

h. Ten minutes prior to arrival at first station, all recording equipment is turned on, and all members of the test crew assume their stations.

i. When the train enters the first test station, the motorman stops the train.

j. The conductor opens the door.

k. While the doors are open, the two instrumentation technicians record the tape footage and time on the data sheets and on the voice track. The kilowatt-hour meter data is also recorded on the data sheets.

l. The conductor closes the door at the test engineer's instruction.

m. As soon as the doors close, the instrumentation technicians place an event on tape to mark the beginning of a station-to-station block.

n. As soon as the doors close and a clear signal is shown in the cab, the motorman proceeds to drive the test train to the next station.

o. When the train stops in the next station (and all the succeeding stations on the test route), the test engineer starts a stop watch to time the length of time in the station and tells the conductor to open the doors.

p. The instrumentation technicians perform step k.

q. The test engineer compares elapsed time in the station with the recorded SOAC station stop times, and instructs the conductor to close the doors at the appropriate time.

r. The conductor closes the doors.

s. The event is placed on the tape recorder.

t. The driver accelerates out of the station when he gets the clear signal from the door circuit.

u. At first sensed car motion, the test engineer stops the stop watch and records the elapsed time on his data sheets.

v. The test train proceeds to the next station and repeats steps o. through u. until the last station is cleared.

6. DATA REDUCTION

6.1 GENERAL

All machine reduction of recorded data is performed at Garrett AiResearch Company in Torrance, California. Using techniques developed during the SOAC data reduction, the data is first inspected for unwanted high frequency spikes, and if found, an R-C circuit is applied to eliminate them prior to the digitizing process. The horizontal and vertical ride roughness filters, Root Mean Square (RMS) filters, multiplying filters, and low pass filters are all applied to the data prior to the digitizing. The output of the digitizer is then sampled at 1/4 sec intervals to produce a data base. This data base contained approximately 14,000 discrete data points for each channel of the Silverbird testing, 10,000 for the PATCO, and over 31,000 for the R-46 test. This mass of data is then processed and arranged by a Digital Scientific Meta-4 computer into three different output formats. The Fortran listings of the computer programs used during this data reduction are shown in Appendix B. The three output formats are station summary, frequency distribution, and tabular values.

6.2 STATION SUMMARIES

The data included in each summary (see Figure 7-2 for an example) can be divided into two broad groups; test conditions and car response. Included in the test conditions is a list of the station stops made during the test, a measurement of distance, the recorded block time, the recorded station stop time, and the maximum speed recorded between stations. Included in the car response data is the third rail power consumption for each car of the two-car test train, and the recorded armature current for a single traction motor.

6.2.1 Station Name

The list of stations on each route is available from each property schedule. However, care must be taken to delete stations skipped during SOAC and DATTIS testing. The number of stations used varied from 35 on the southbound "A" line in New York to 11 for the Lindenwold test.

6.2.2 Distance

Three distances are reported on each station summary. The first is the property surveyed distance between each station. This distance is considered correct and it is used to correct the distances recorded during the SOAC and DATTIS tests. Table 6-1 shows the correction calculations for the SOAC data recorded while at PATCO. The distance between each station measured during the test varies depending on where in the station the test train was stopped, but the total distance can be considered accurate. On this basis, the average error is used to correct the test data. The third distance reported is the DATTIS measured distance.

6.2.3 Block Time

Block time for this report is measured from the door closing and train start in one station until the door closing and train start in the next station. The first time reported is the scheduled time that the property allows for each train to traverse from station to station, including the

TABLE 6–1. CORRECTION OF DISTANCE DATA

STATION	SURVEYED DISTANCE	SOAC	DIFF	%	CORRECTED DISTANCE
Lindenwold	0	0	0	0	0
Ashland	1.79	1.97	+.18	10.0	1.78
Haddonfield	3.19	3.49	+.30	9.4	3.16
Westmont	0.87	0.99	+.12	13.8	0.90
Collingswood	1.05	1.17	+.12	11.4	1.06
Ferry Avenue	1.61	1.69	+.08	5.0	1.53
Broadway	2.16	2.42	+.26	12.0	2.19
City Hall – Camden	0.25	0.25	0	0	0.23
8th & Market Streets	2.35	2.61	+.26	11.1	2.36
12th & Locust Streets	0.65	0.74	+.09	12.2	0.67
15th & Locust Streets	0.28	0.31	+.03	10.7	0.28
		Average 9.56% High			
Total Distance	14.20				14.16

time spent loading passengers. The second block time reported is from the SOAC test conducted at the property. The third block time is that recorded during the DATTIS testing at the three properties.

6.2.4 Station Stop Time

The station stop time is the amount of time spent stationary in each station for the purpose of loading and unloading passengers. The SOAC data was previously reported in Reference 2. The DATTIS data was manually recorded by the test engineer during the test using a stop watch. It is important that the SOAC and DATTIS stop times be equal to facilitate comparison of energy consumption and noise levels.

6.2.5 Maximum Speed

The maximum speed for the SOAC train in each station-to-station block is reported in the first column under the heading "Max Speed". The DATTIS speed for each test train is reported adjacent to the SOAC maximum speeds.

6.2.6 Power Consumption

Power consumption is reported in two units; kilowatt-hours, and kilowatt-hours/miles. The kilowatt-hour measurement is obtained by instantaneously multiplying the third rail current and voltage recorded values in the digitizing process. The SOAC data is obtained from Reference 2 and the DATTIS data is reduced from magnetic tapes recorded during the property test. The kilowatt-hour/mile number is obtained by dividing the kilowatt-hours by the corrected test mileage for each train.

6.2.7 Armature Current

The current required by the test train during a station-to-station traverse is an indication of the duty cycle requirements for the motor and its cooling system. Since the current flow changes direction during dynamic braking, the recorded shunt data must be run through the RMS filter prior to the digitizing to ensure that all of the data has a positive sign associated with it. The SOAC data is again drawn from Reference 2. The DATTIS data was reduced for each station-to-station traverse.

6.3 FREQUENCY DISTRIBUTION

The most convenient way to compare large blocks of data is to sort them into groups and plot the number of occurrences within each group against the group's range. This normally results in bar graphs. The additional requirement of allowing easy comparison between the DATTIS and SOAC data forces a different plotting arrangement. For this report, the midpoint of the group's range was used to locate the x-axis position of the plotted data points. The y-axis was the frequency of occurrence of data in that group's range. These data points are then connected to form a continuous line representing the trains performance for a given sensor. Frequency distributions comparing SOAC and DATTIS data were prepared for the following parameters: car acceleration, car speed, interior noise, longitudinal ride quality, forward car vertical and horizontal ride quality, and mid-car vertical and horizontal ride quality. Insufficient SOAC data exists for the comparison of roll, pitch and yaw, but the DATTIS data is plotted for use in future comparisons. Exterior noise levels were recorded for the SOAC during some simulated revenue service test, but not reduced, so no direct comparisons are possible. The DATTIS exterior noise levels are plotted on a cumulative distribution basis to allow comparison with the interior noise levels.

6.4 TABULAR COMPARISONS

Tabular values are calculated for most parameters for simple comparisons not involving plotted data. Ride quality data is compared at certain cumulative percentiles, at the maximum value, and as a weighted average. The noise data is compared at different cumulative percentiles, at the maximum value, and at an equivalent noise level. Power consumption requires values for the total distance, average block distance, total run time, average block time, average station stop time, average block speed, maximum speed, average maximum speed, total kilowatt-hours, average kilowatt-hours/mile, and the average armature current (RMS). A short explanation for each is found in the following paragraphs.

6.4.1 Cumulative Percentiles

The 50th and 95th cumulative percentiles are reported for the ride quality data. The convention for the noise data is to report the 50th and 99th percentile. In each case, the data is read as "the specified percent of the data occurs at this value or lower". The 50th percentile represents the median of the data distribution, and the 95th and the 99th their respective levels.

6.4.2 Maximum Value

The maximum value for a given parameter is determined during the sorting of the data group. It is the largest recorded value.

6.4.3 Equivalent Sound Level

The Equivalent Sound Level (L_{eq}) provides a single number measure of the time varying noise, not only of the transit cars, but of all noises recorded at a specific location. It is calculated separately for each time period that the noise data is sampled. L_{eq} is determined using the following equation:

$$L_{eq} = 10 \text{ Log } \frac{\sum_{i=1}^{N} \text{antilog } \frac{AL_i}{10}}{N}$$

For this equation AL_i = the instantaneous A-level for sample i

N = the number of samples of AL in a specified time period.

These equations are drawn from Reference 3.

6.4.4 Weighted Average

Weighted average is a measure of the central tendency of a distribution. It is more frequently called an arithmetic mean. It is the single value most representative of the entire distribution, much like the Equivalent Sound Level. For a continuous variable, x, with a probability density function F (x), the weighted average is defined as:

$$A_{weighted}(x) = \int_{-\infty}^{\infty} x\,F(x)\,dx$$

For ride quality distributions in this report, the weighted average may be approximated by:

$$A_W(x) = \sum_i x_i p_i$$

where x_i = mid-point value of a distribution group range

p_i = frequency of occurrence within a distribution group

and the summation is performed over the entire distribution. These calculations are performed during the computer data reduction and may be found in the computer program listing in Appendix B.

6.4.5 Total Distance

The total distance for each transit line is available as surveyed by the properties. The test total distance is calculated by adding up the individual block distances.

6.4.6 Average Block Distance

The average block distance is found by dividing the total distance by the number of stations minus one. It is the distance most often used in the computer simulation of transit car performance.

6.4.7 Total Run Time

Total run time is the scheduled run time for each of their lines. The test total run time is found by adding the individual block times recorded during the test. It is an important indication that the duty cycle requirements for any two separate test programs were the same.

6.4.8 Average Block Time

The average block time is calculated by dividing the total run time by the number of stations less one. This parameter is used in computer projection of transit car performance for each property.

6.4.9 Average Station Stop

The average station stop is found by averaging the station stop times recorded during the test. It is important that the average station stop times be approximately equal to avoid distorting the ride quality and noise data.

6.4.10 Average Block Speed

The average block speed is calculated for the time the test train is in motion. The distance used in the distance versus time calculation is the average block distance. The time is the average block time less the average station stop time. In other words,

$$\text{Average Block Speed} = \frac{\text{Average Block Distance (miles)} \times 3600}{(\text{Average Block Time (Min)} \times 60) - \text{Average Station Stop (Sec)}}$$

6.4.11 Maximum Speed

The maximum speed is found by inspection of the station summary data. The largest value in the maximum speed column is used for the tabular comparisons.

6.4.12 Average Maximum Speed

The average maximum speed is calculated by averaging the maximum speed recorded for each block. This number is then used in computer simulation of transit car performance for the property.

6.4.13 Total Kilowatt-Hours

The total power consumption in kilowatt-hours is obtained by adding the kilowatt-hours recorded for each block. This allows immediate comparison between SOAC and the transit property test train, but not between properties, or different lines, since the mileage involved is different for each.

6.4.14 Average Kilowatt-Hours

The average kilowatt-hours expended per block is found by dividing the total kilowatt-hours by the number of stations less one. This value is used to check the computer simulation of transit cars on an average block for each of the transit lines.

6.4.15 Average Kilowatt-Hours/Mile

The average kilowatt-hour/mile is calculated by dividing the total kilowatt-hours for the test by the total mileage recorded in the test. This is the value most commonly used for comparison of transit car energy consumption peformance.

6.4.16 Average Armature Current

The average armature current is calculated by averaging the RMS armature current recorded for each block during the test.

7. TEST RESULTS

7.1 INTRODUCTION

The test results are divided into two groups within this section. The first group presents the results in two-way comparisons between the SOAC and each of the transit property vehicles. The PATCO data is presented first, followed by the NYCTA R-46, and finally the MBTA Silverbird data. The second group presents the same data in a format which allows comparison between all four transit cars.

7.2 PATCO TRANSIT CAR VERSUS SOAC

7.2.1 Summary

The State-of-the-Art Car in simulated revenue service on the Lindenwold High Speed Line provides a reduced interior noise level, and improved ride quality in the lateral mode. The PATCO transit car has superior ride quality in the vertical and longitudinal modes in similar simulated revenue service. Although the PATCO transit car traction motors consume 12% less current than the SOAC, total power consumption for the PATCO car was 5% higher than the SOAC. Summaries of the test data are shown in Figure 7-1 and Figure 7-2.

7.2.2 Noise

Figure 7-3 shows the interior noise level distribution for the SOAC and the PATCO transit car in simulated revenue service on the Lindenwold High Speed Line. The shift of the SOAC noise data to lower levels is readily apparent. Although the SOAC train did record noise above 80 dBA, the reduction of noise in the 70 to 80 dBA range is significant in comparison to the PATCO transit car. This is reflected in the lower equivalent sound level of 74 dBA for the SOAC versus 78.5 for the PATCO train.

Figure 7-4 shows the relationship between the interior noise levels recorded in the SOAC and PATCO tests, and the exterior noise level recorded during the PATCO test. The equivalent exterior noise level of 108.0 dBA means that the PATCO construction and sound proofing result in a 29.5 dBA reduction in noise level for the seated passenger. The equivalent exterior noise data is not available for the SOAC.

7.2.3 Ride Quality

Figure 7-5 is a comparison of the longitudinal ride quality of the two trains. Both trains recorded 82% of their data below the 0.1g level, and the data is best discussed in terms of what occurs above and below this vibration level. Below 0.01g the SOAC out performs the PATCO car by virtue of the smoother acceleration and braking available from the chopper control system. Above .01g the PATCO car performs better than the SOAC train. Since the performance of the car at the higher vibration levels is more important than the lower vibration level performance, the PATCO car provides the better longitudinal ride quality.

The SOAC train provides improved lateral ride quality in comparison to the PATCO transit car. The forward car lateral ride quality is shown in Figure 7-6, and the mid-car in Figure 7-7.

RIDE QUALITY	CUMULATIVE PERCENTILE 50% SOAC	CUMULATIVE PERCENTILE 50% PATCO	CUMULATIVE PERCENTILE 95% SOAC	CUMULATIVE PERCENTILE 95% PATCO	MAXIMUM SOAC	MAXIMUM PATCO
JOURNAL BOX VERTICAL ACCEL (g)	±0.6	±1.5	±1.88	±1.1	±4.0	±14.5
JOURNAL BOX LATERAL ACCEL (g)	±1.0	±0.18	±1.94	±1.0	±4.50	± 9.0
LONGITUDINAL RIDE ROUGHNESS (GRMS)	0.005	0.0050	0.018	0.0125	0.058	0.0725
FORWARD CAR VERTICAL RIDE ROUGHNESS	0.019	0.0138	0.044	0.0343	0.140	0.0875
MID-CAR VERTICAL RIDE ROUGHNESS (GRMS)	0.019	0.0120	0.041	0.0270	0.040	0.0575
FORWARD CAR LATERAL RIDE ROUGHNESS (GRMS)	0.012	0.0196	0.029	0.0475	0.083	0.0975
MID-CAR LATERAL RIDE ROUGHNESS (GRMS)	0.006	0.0095	0.015	0.0225	0.035	0.525
PITCH (RAD/SEC-SEC)	±0.140	±0.013	±0.190	± 0.084	0.285	0.335
ROLL (RAD/SEC-SEC)	±0.108	±0.048	±0.190	±0.225	0.315	0.550
YAW (RAD/SEC-SEC)	±0.103	±0.012	±0.190	±0.055	0.141	0.205
NOISE	50%		99%		EQUIVALENT	
INTERIOR NOISE LEVEL (dBA)	66	73.3	89	89.2	74	78.5
EXTERIOR NOISE LEVEL (dBA)	–	103.0	–	115.0	–	108.0

FIGURE 7–1. PATCO RIDE QUALITY AND NOISE DATA SUMMARY

STATION		DISTANCE (MILES)			BLOCK TIME (MIN.)			STATION STOP TIME (SEC)		MAX SPEED (MPH)		POWER CONSUMPTION				ARMATURE CURRENT (AMPS-RMS)	
												KWHR		KWHR/MILE			
NO.	NAME	SCHEDULED	SOAC	PATCO	SCHEDULED	SOAC	PATCO	SOAC	PATCO	SOAC	PATCO	SOAC	PATCO	SOAC	PATCO	SOAC	PATCO
1	LINDENWOLD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	ASHLAND	1.79	1.78	1.79	3.0	2.40	2.85	14.4	16.6	70	76.4	12.39	12.53	6.96	7.00	441.1	343.5
3	HADDONFIELD	3.19	3.16	3.15	3.0	3.75	3.33	18.0	20.6	70	77.0	19.44	18.56	6.15	5.89	416.8	333.0
4	WESTMONT	0.87	0.90	0.87	1.0	1.55	1.50	16.8	16.6	68	69.6	9.58	9.54	10.64	10.96	498.8	445.2
5	COLLINGSWOOD	1.05	1.06	1.04	1.0	1.75	1.50	10.8	10.6	70	75.8	11.08	10.30	10.45	9.90	510.7	459.1
6	FERRY AVENUE	1.61	1.53	1.58	2.0	1.87	1.98	10.8	10.4	70	77.0	8.92	11.98	5.83	7.58	406.9	404.5
7	BROADWAY	2.16	2.19	2.16	3.0	3.15	2.98	12.0	12.8	70	76.3	12.74	14.81	5.81	6.86	365.0	339.0
8	CITY HALL – CAMDEN	0.25	0.25	0.23	1.0	1.24	1.03	14.4	14.9	20	24.2	1.68	2.17	6.72	9.43	248.6	243.4
9	8TH & MARKET ST	2.35	2.36	2.38	5.0	4.95	4.68	12.0	12.2	40	43.4	15.17	15.84	6.42	6.66	311.4	294.6
10	12TH & LOCUST ST	0.65	0.67	0.69	2.5	1.92	1.83	13.2	14.1	37	41.6	5.23	5.77	7.81	8.36	349.5	309.2
11	15TH & LOCUST ST	0.28	0.28	0.26	1.0	0.99	1.04	13.2	21.8	29	32.9	2.62	2.70	9.35	10.38	413.3	304.9
	TOTALS	14.2	14.18	14.15	22.5	23.57	22.72	135.6	150.6			98.85	104.2				
	AVG	1.42	1.42	1.41	2.25	2.36	2.27	13.6	15.0					6.97	7.36	396.2	347.6

FIGURE 7–2. STATION SUMMARY FOR PATCO TRANSIT CAR TEST.

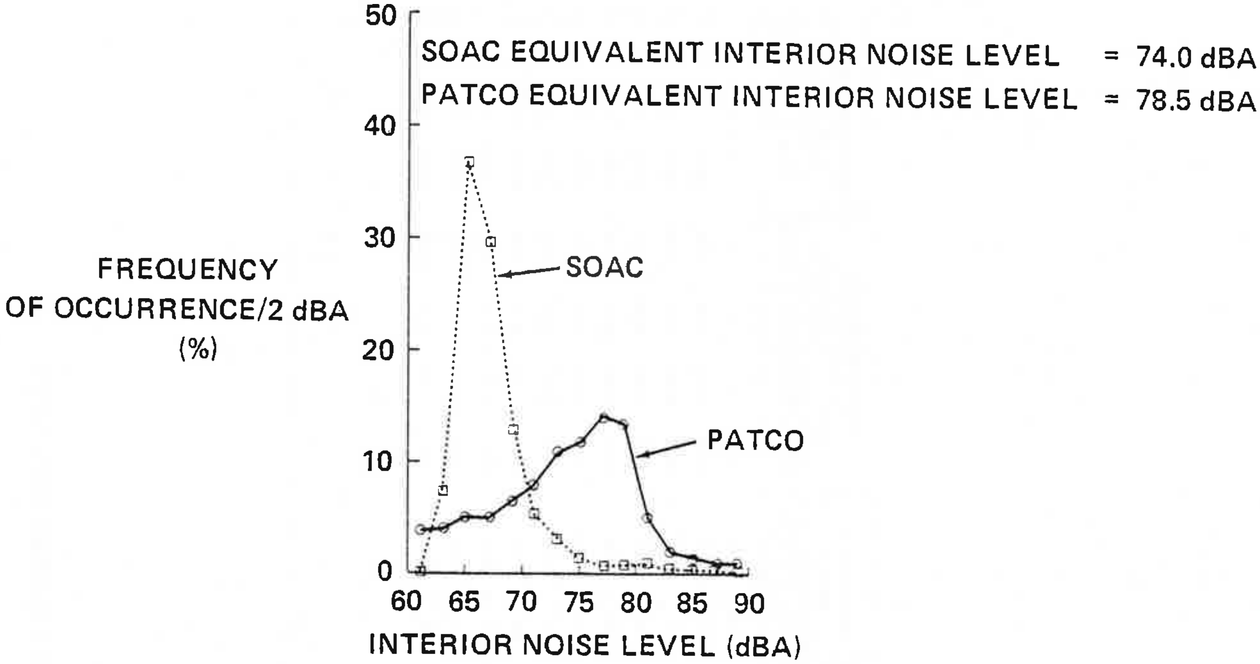
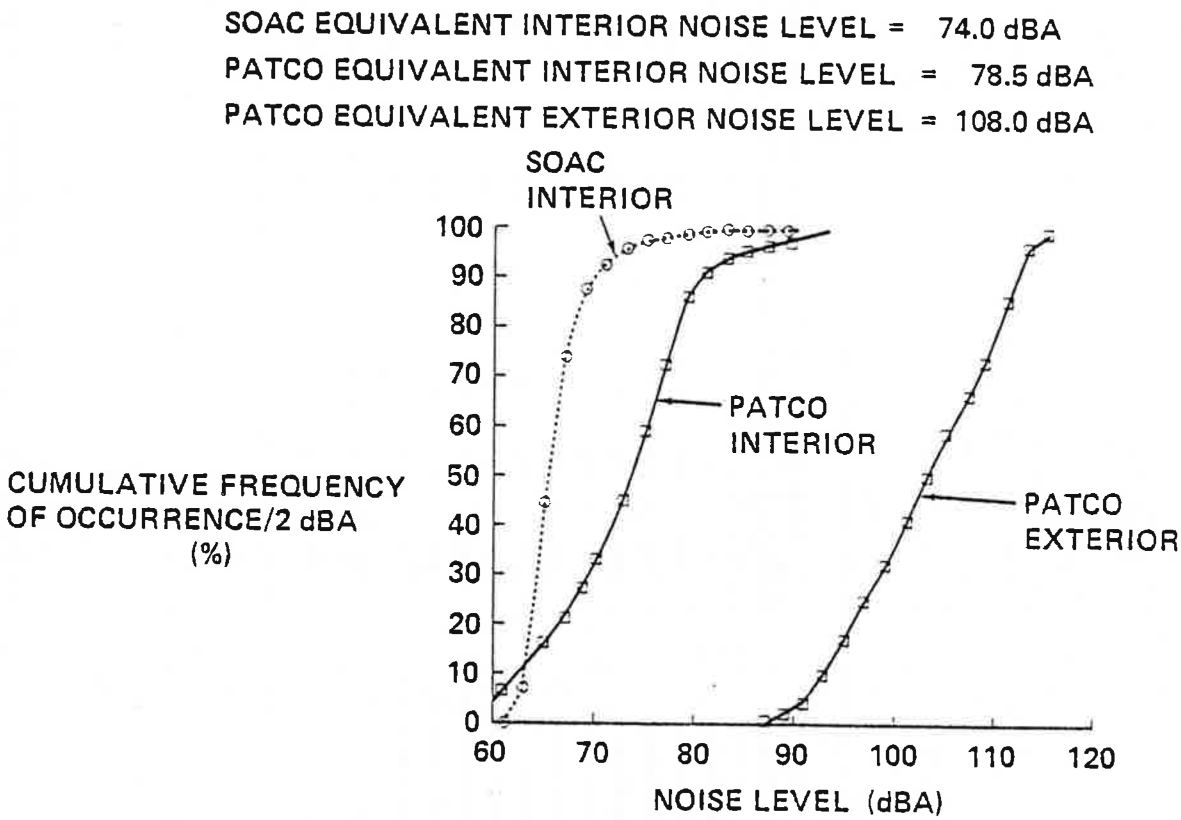


FIGURE 7–3. INTERIOR NOISE LEVEL COMPARISON SOAC VS PATCO



SIMULATED REVENUE SERVICE ON LINDENWOLD HIGH-SPEED LINE

NOTE: EQUIVALENT EXTERIOR NOISE DATA NOT RECORDED DURING SOAC TESTS

FIGURE 7–4. NOISE LEVEL COMPARISON.

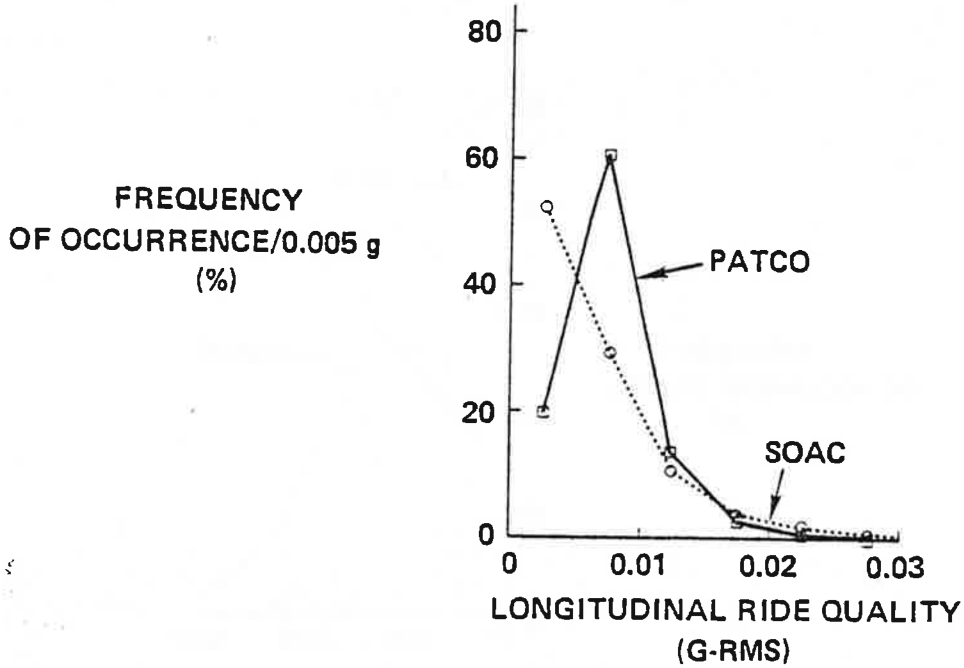


FIGURE 7–5. LONGITUDINAL RIDE QUALITY COMPARISON PATCO VS SOAC.

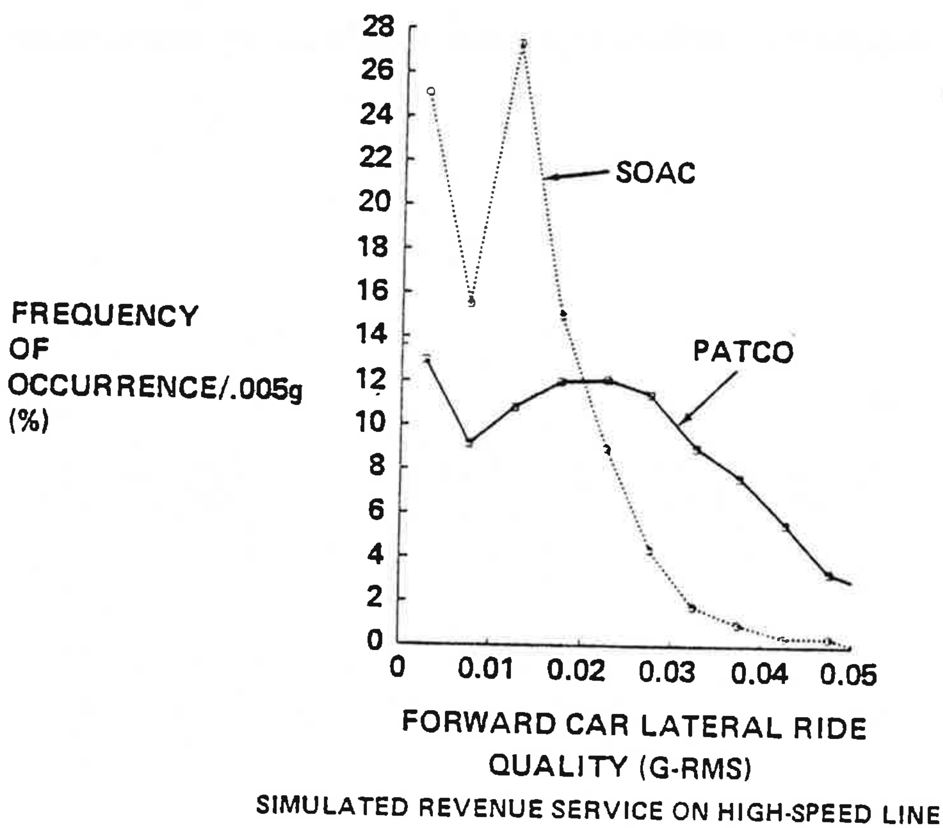
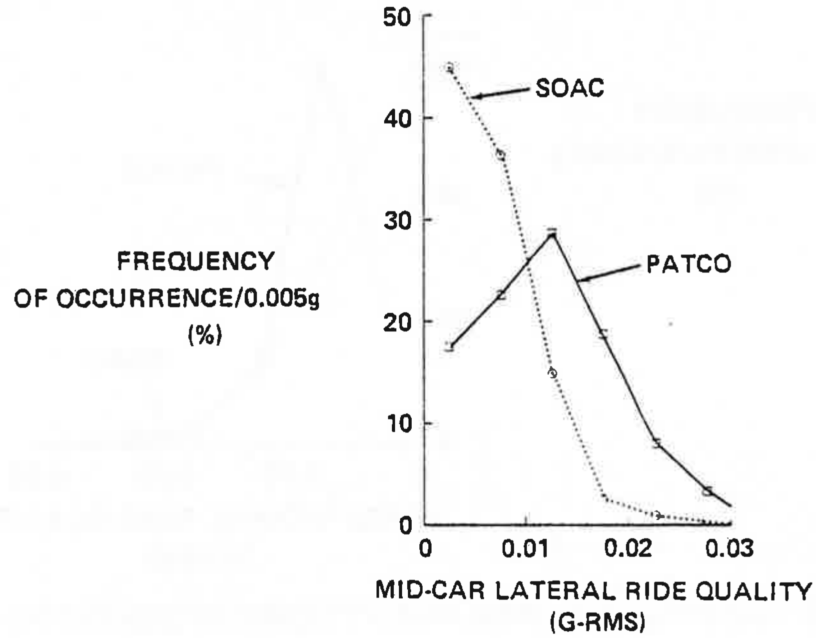


FIGURE 7–6. FORWARD CAR LATERAL RIDE QUALITY COMPARISON PATCO VS SOAC.



SIMULATED REVENUE SERVICE ON THE LINDENWOLD HIGH-SPEED LINE

FIGURE 7–7. MOD-CAR LATERAL RIDE QUALITY COMPARISON PATCO VS SOAC.

Both figures show the SOAC reducing the time spent in the mid and upper lateral vibration levels with a corresponding increase in the time spent in the lower ranges.

The PATCO transit car demonstrates superior vertical ride quality at the forward and mid-car positions. Figure 7-8 is a plot of the data recorded at the forward car position, and Figure 7-9 represents the mid-car data.

Data reduction reveals the PATCO transit car pitches and yaws less than the SOAC, but rolls more. The pitch, roll, and yaw data recorded during the DATTIS program is plotted in Figures 7-10, 7-11, and 7-12.

The measurement of journal box accelerations proved ineffective in showing similar vibration inputs for the PATCO train test and the SOAC test. The PATCO gearbox-mounted accelerometers provided data which had shifted to a lower g value than that recorded during the SOAC test. The SOAC vertical accelerometer data included accelerations as high as ± 1.88g's in its cumulative 95th percentile. The comparable PATCO figure is only ± 1.1g. The lateral data recorded by SOAC included ± 1.94g in its cumulative 95th percentile. Comparable data shows 95% of the PATCO lateral data below ± 1g.

7.2.4 Power Consumption

The power consumption data is summarized in Figure 7-2. The data reveals the PATCO car spent more time in station, reached higher speeds in transit between stations, and completed the route in less time than the SOAC train. The distribution of the speed data is shown in Figure 7-13, and the acceleration data in Figure 7-14. Although the PATCO transit car completed the route more quickly than the SOAC, it consumed only 5% more power. It is interesting to note that the PATCO traction motor consumed 12% less current than the SOAC traction motor. The additional current required by the SOAC results from the modulation of the field current and motor voltage by the Garrett AiResearch designed chopper control system.

7.3 NYCTA R-46 VERSUS SOAC

7.3.1 Summary

The State-of-the-Art Car in simulated revenue service on the NYCTA "A" line provides a reduced interior noise level, and improved ride quality in comparison to a NYCTA R-46 under similar conditions. A summary of the vibration and noise data is shown in Table 7-1. However, the SOAC train uses 40% more power than the R-46 to accomplish its primary purpose of carrying people from point A to point B. A summary of the pertinent power consumption data is shown in Table 7-2.

7.3.2 Noise

Figure 7-15 shows the interior noise level distribution for the SOAC and R-46 in simulated revenue service on the NYCTA "A" line. The shift of SOAC noise data to lower levels is readily apparent. Although the SOAC train did record noise above 80 dBA, the reduction of noise in the 70 to 80 dBA range is significant in comparison to the R-46. This is reflected in the lower equivalent sound level of 72 dBA for the SOAC versus 77.1 for the R-46.

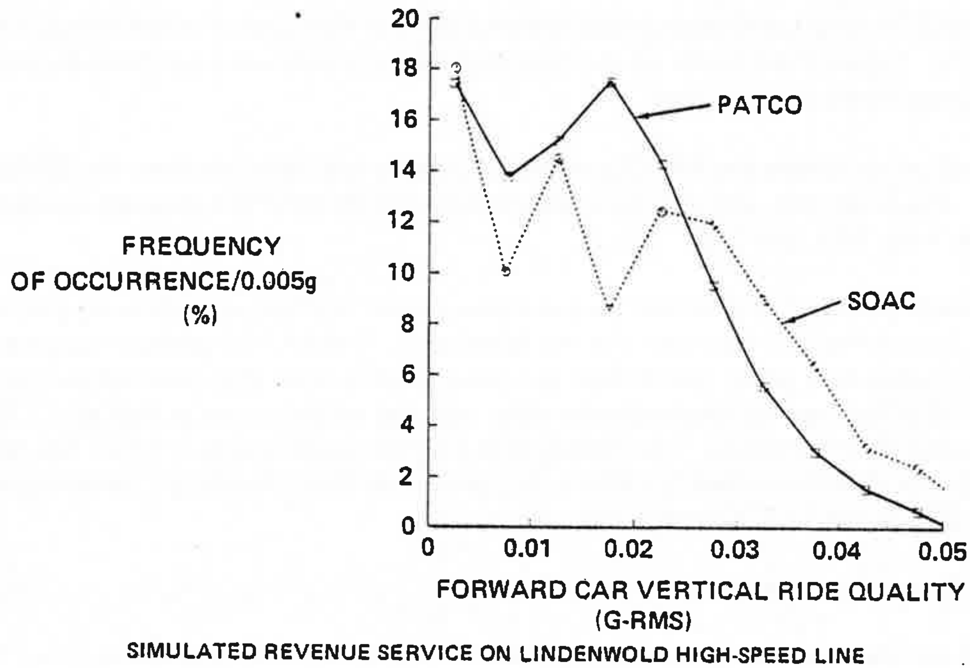
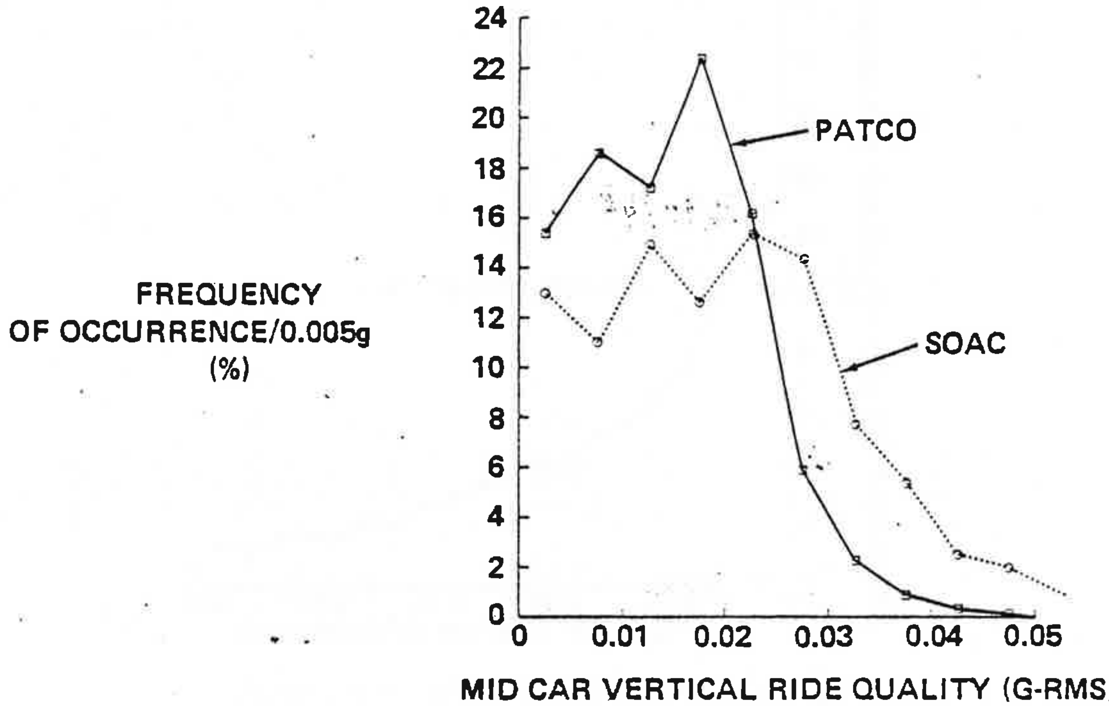
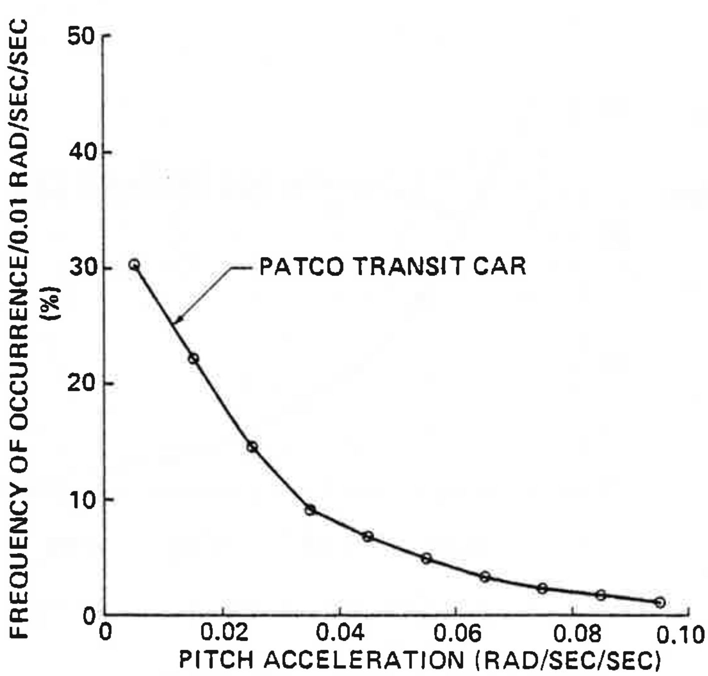


FIGURE 7–8. FORWARD CAR VERTICAL RIDE QUALITY COMPARISON PATCO VS SOAC



SIMULATED REVENUE SERVICE ON LINDENWOLD HIGH-SPEED LINE

FIGURE 7–9. MID-CAR VERTICAL RIDE QUALITY COMPARISON PATCO VS SOAC.



SIMULATED REVENUE SERVICE ON LINDENWOLD HIGH-SPEED LINE

FIGURE 7–10. PATCO PITCH DATA.

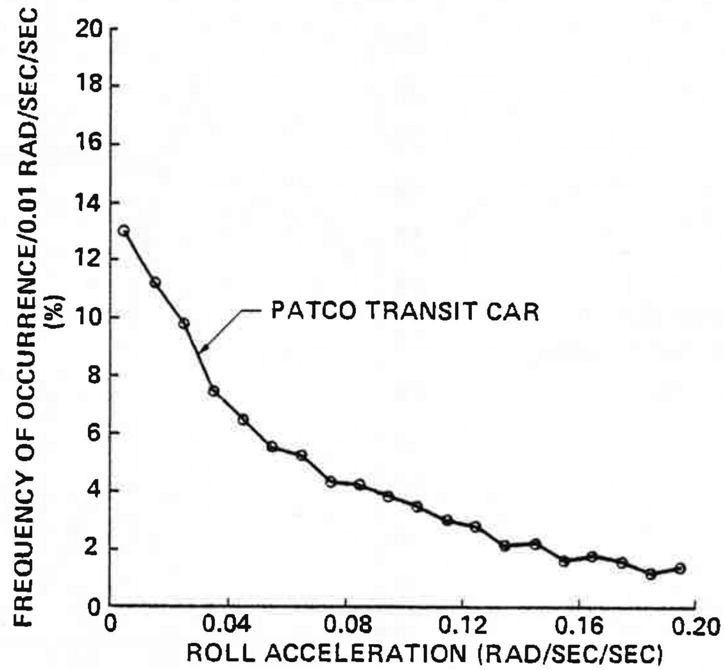


FIGURE 7–11. PATCO ROLL DATA.

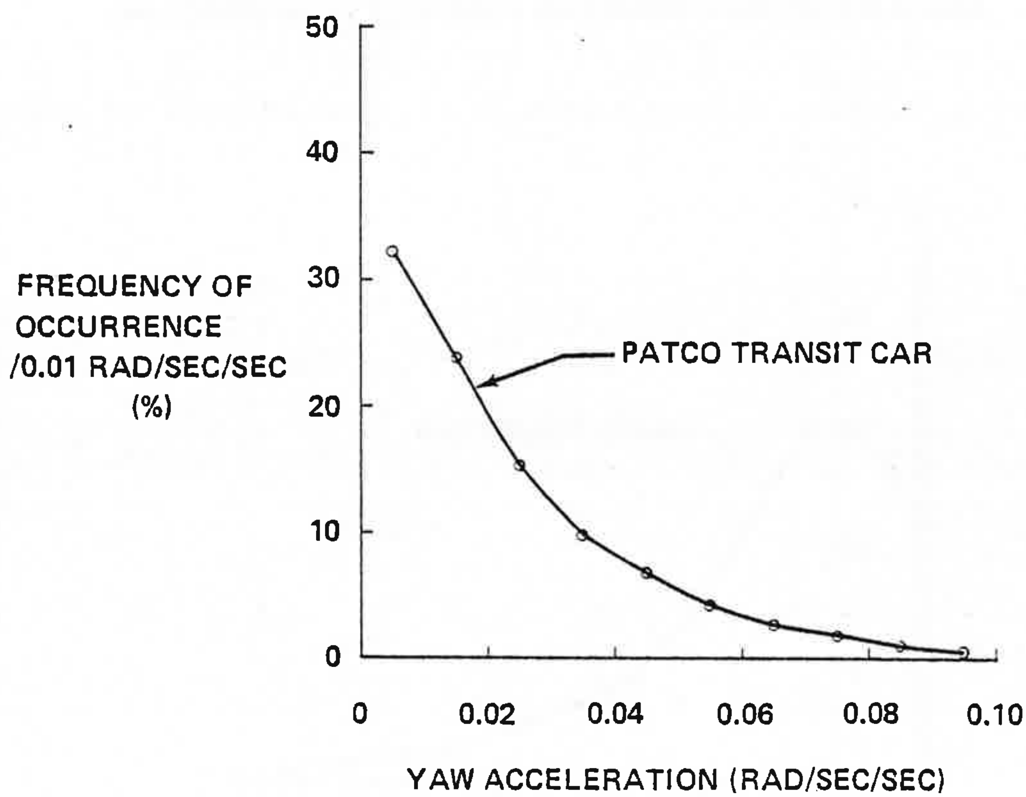


FIGURE 7–12. PATCO YAW DATA.

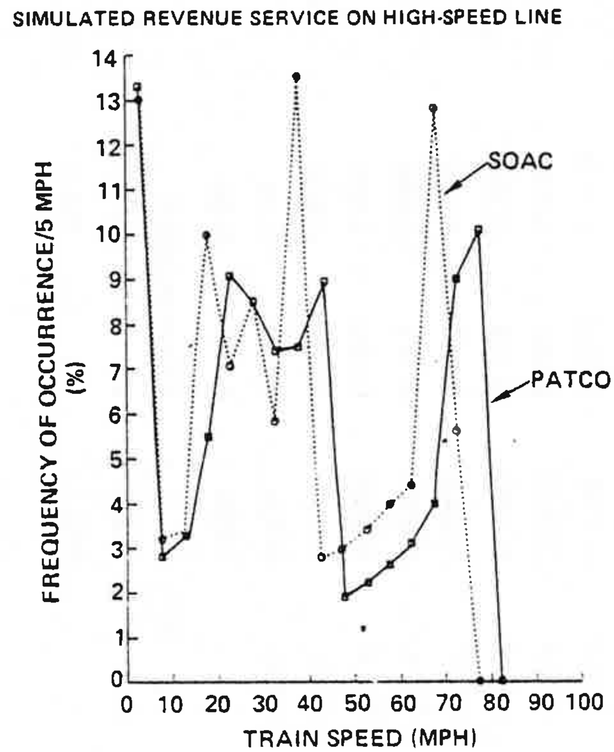
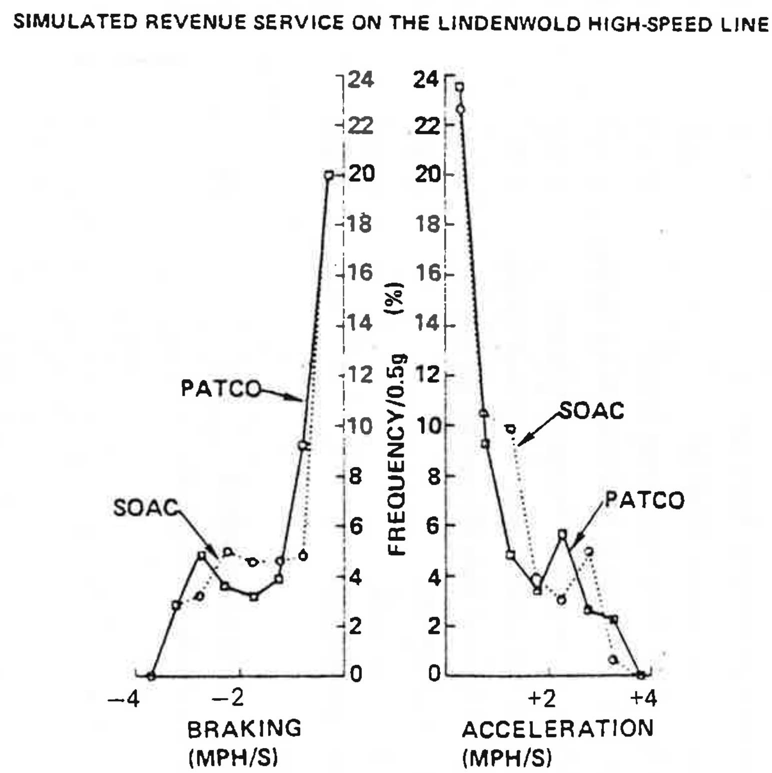


FIGURE 7–13. TRAIN SPEED COMPARISON PATCO VS SOAC.



;URE 7–14. TRANSIT CAR ACCELERATION COMPARISON STATE-OF-THE-ART CAR VS PATCO TRANSIT CAR.

TABLE 7–1. NYCTA R-46 RIDE QUALITY AND NOISE SUMMARY

	CUMULATIVE PERCENTILE					
	50%		95%		MAXIMUM	
RIDE QUALITY	SOAC	R-46	SOAC	R-46	SOAC	R-46
Journal Box Vertical Accel (g)	± 1.1	± 0.15	± 4.5	± 0.9	± 15.0	± 15.0
Journal Box Lateral Accel (g)	± 3.2	± 0.21	± 15.4	± 1.05	± 20.0	± 14.0
Longitudinal Ride Roughness (grms)	0.003	0.0023	0.010	0.0103	0.050	0.050
Forward Car Vertical Ride Roughness (grms)	0.007	0.0133	0.026	0.0407	0.118	0.300
Mid-Car Vertical Ride Roughness (grms)	0.006	0.0086	0.027	0.0258	0.145	0.115
Forward Car Lateral Ride Roughness (grms)	0.007	0.0091	0.028	0.0332	0.113	0.080
Mid-Car Lateral Ride Roughness (grms)	0.004	0.0056	0.018	0.0196	0.085	0.045
Pitch (rad/sec-sec)	0.050	0.005	0.095	0.042	0.167	0.600
Roll (rad/sec-sec)	0.060	0.026	0.180	0.195	0.656	0.70
Yaw (rad/sec-sec)	0.085	0.008	—	0.045	0.198	0.60
NOISE	50%		99%		EQUIVALENT	
Interior Noise Level (dBA)	68	70.3	81	89	72	77.1
Exterior Noise Level (dBA)	—	99.5	—	113	—	113.3

TABLE 7–2. SUMMARY OF R-46 TEST ON 'A' LINE SOUTHBOUND

SUMMARIZED ITEM	SCHEDULED	SOAC	R-46
Total Distance	22.11	22.02	21.87
Avg Block Distance	0.65	0.65	0.64
Total Run Time	64.0	62.39	63.82
Avg Block Time	1.88	1.84	1.88
Avg Station Stop		17.9	18.0
Avg Block Speed		25.30	24.30
Max Speed		52.0	49.0
Avg Max Speed		38.89	36.43
Power Consumption			
Total kwhr		181.98	129.54
Avg kwhr		5.35	3.81
Avg kwhr/mile		8.26	5.92
Avg Armature Current		301.93	187.10

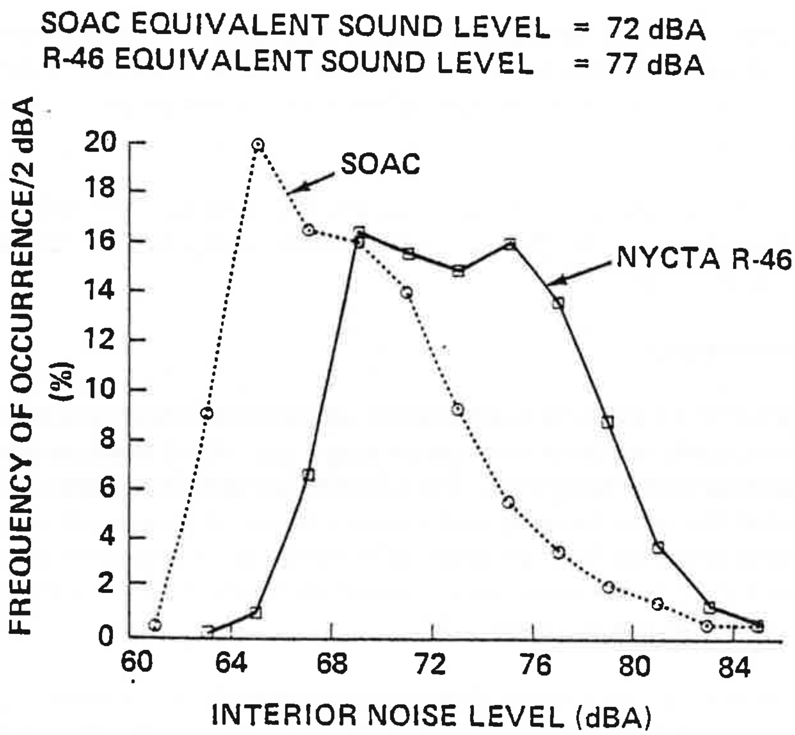


FIGURE 7–15. INTERIOR NOISE LEVEL COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46 SIMULATED REVENUE SERVICE ON THE NYCTA 'A' LINE.

Figure 7-16 shows the relationship between the interior noise levels recorded in the SOAC and R-46 tests, and the exterior noise level recorded during the R-46 test. The equivalent exterior sound level of 103.3 dBA means that the R-46 construction and soundproofing result in a 26.2 dBA reduction in noise level for the seated passenger. The equivalent exterior noise data is not available for the SOAC.

7.3.3 Ride Quality

The measurement of journal box accelerations proved ineffective in showing similar vibration inputs for the R-46 and the SOAC. The R-46 gearbox mounted accelerometers showed a large shift to lower g values. The SOAC vertical accelerometer data included accelerations as high as 4.5g to encompass 95% of the data, while the R-46 recorded 96% of its vertical data below .9g. The R-46 recorded 95% of its lateral accelerometer data below 1.05g, but the SOAC data includes ± 15.4g in its cumulative 95th percentile.

Figure 7-17 is a comparison of the longitudinal ride quality of the two trains. The SOAC reduced the frequency of occurrence of the mid-range vibration levels (.005g to .0125g), but failed to reduce the higher level amplitudes (.0125g to .03g).

The SOAC train provides improved lateral ride quality in comparison to the R-46. The forward car lateral ride quality is shown in Figure 7-18, and the mid-car in Figure 7-19. Both figures show the SOAC reducing the time spent in the mid and upper lateral vibration levels with a corresponding increase in the time spent in the lower ranges.

SOAC demonstrates improved vertical ride quality throughout its range at the forward car position. This is shown in Figure 7-20. Mid-car data is mixed however. Figure 7-21 shows the SOAC ride quality improved in the mid-range vertical vibration environment, and equivalent to the R-46 above .0275g's.

Data reduction of roll, pitch, and yaw data indicates the R-46 rolls the same as the SOAC, but yaws and pitches far less than the SOAC. The R-46 roll, pitch and yaw data is presented in Figures 7-22, 7-23, and 7-24.

7.3.4 Power Consumption

Power consumption of a transit car is affected by all the parameters involved in a description of the route: time, speed, distance, and station stop time. All of these parameters are shown in the detailed summary of Figure 7-25. The summary of this data appears in Figure 7-16. Both trains traveled the same distance, in the same amount of time, spent equal amounts of time in the stations, averaged the same speed over the route, and reached the same maximum speeds. The distribution of the speed data is shwon in Figure 7-26. The distribution of the car acceleration data is shown in Figure 7-27.

Despite the fact that all of the test variables came out essentially the same, the SOAC used 40% more power than the R-46 to complete a simulated revenue service round trip on the NYCTA "A" line. Since the car weights are the same, only differences in the propulsion and drive system can account for the poor power consumption of the SOAC. The SOAC chopper control system was by design more efficient than a cam controller system. Of the

SOAC EQUIVALENT INTERIOR NOISE LEVEL = 72 dBA
R-46 EQUIVALENT INTERIOR NOISE LEVEL = 77 dBA
R-46 EQUIVALENT EXTERIOR NOISE LEVEL = 113 dBA

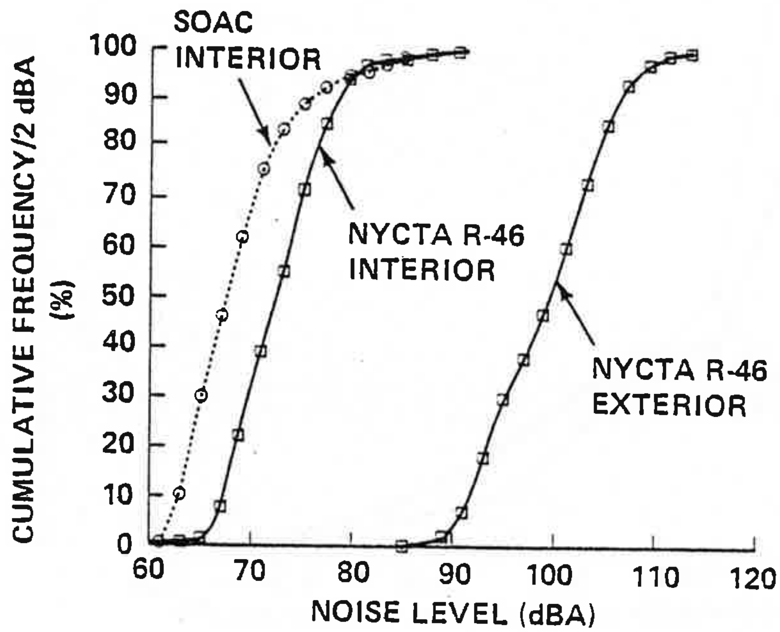


FIGURE 7–16. NOISE LEVEL COMPARISON NYCTA 'A' LINE.

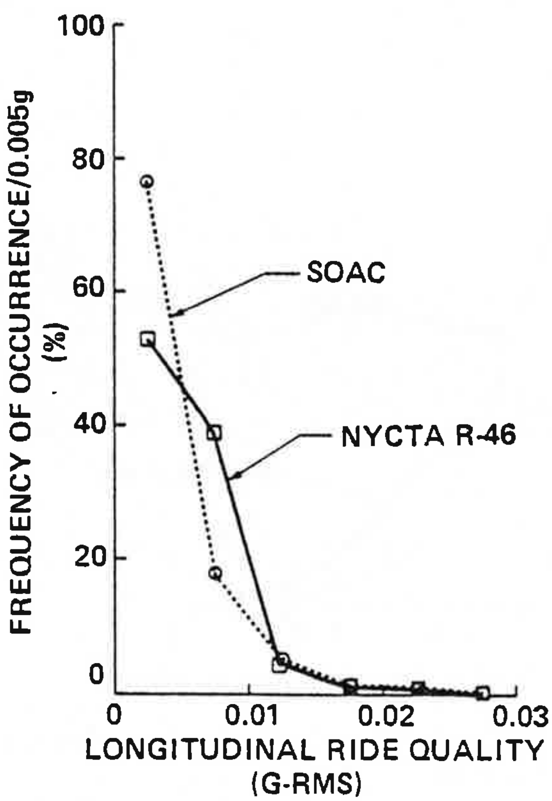


FIGURE 7–17. LONGITUDINAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

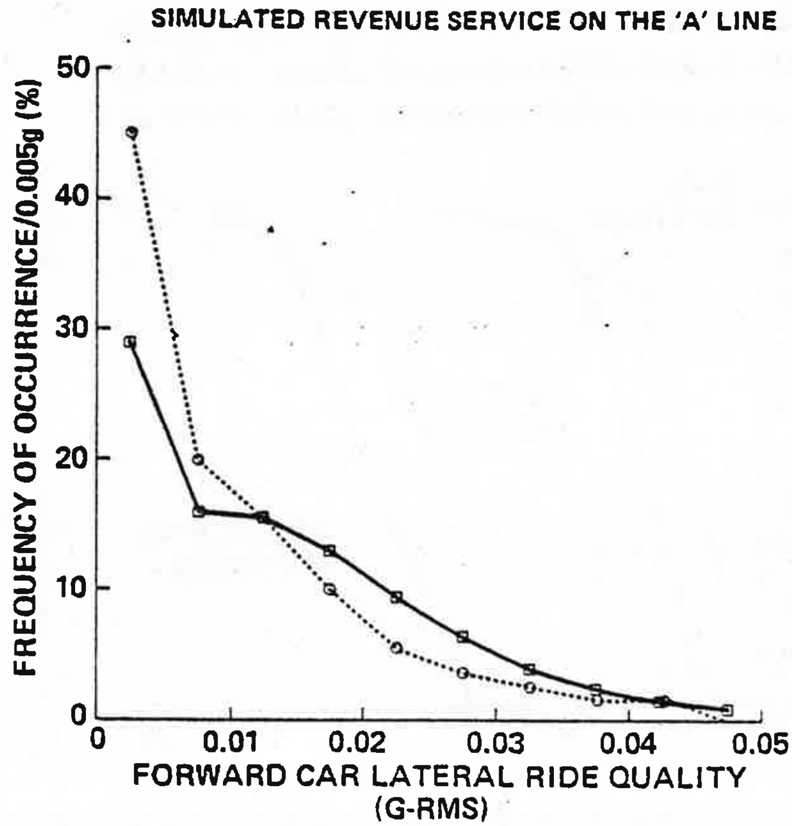


FIGURE 7–18. FORWARD CAR LATERAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

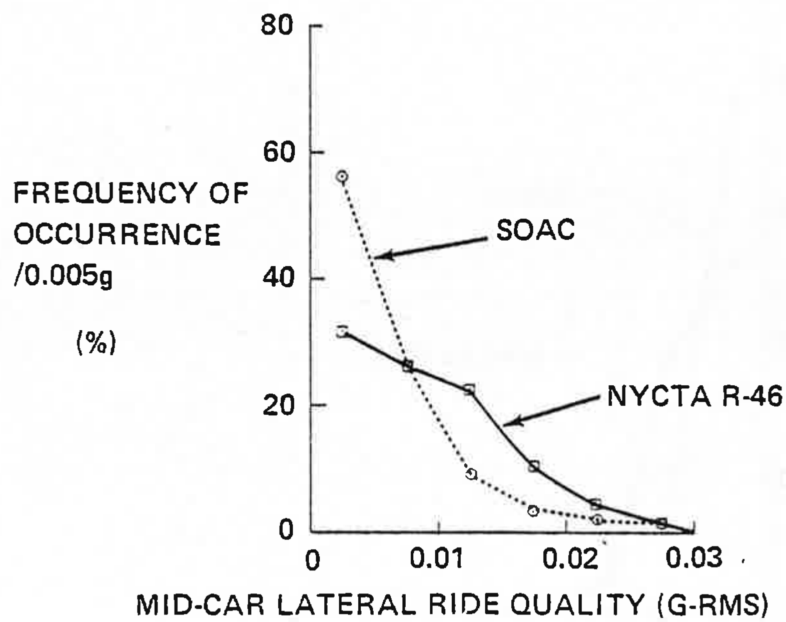


FIGURE 7–19. MID-CAR LATERAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

SIMULATED REVENUE SERVICE ON THE 'A' LINE

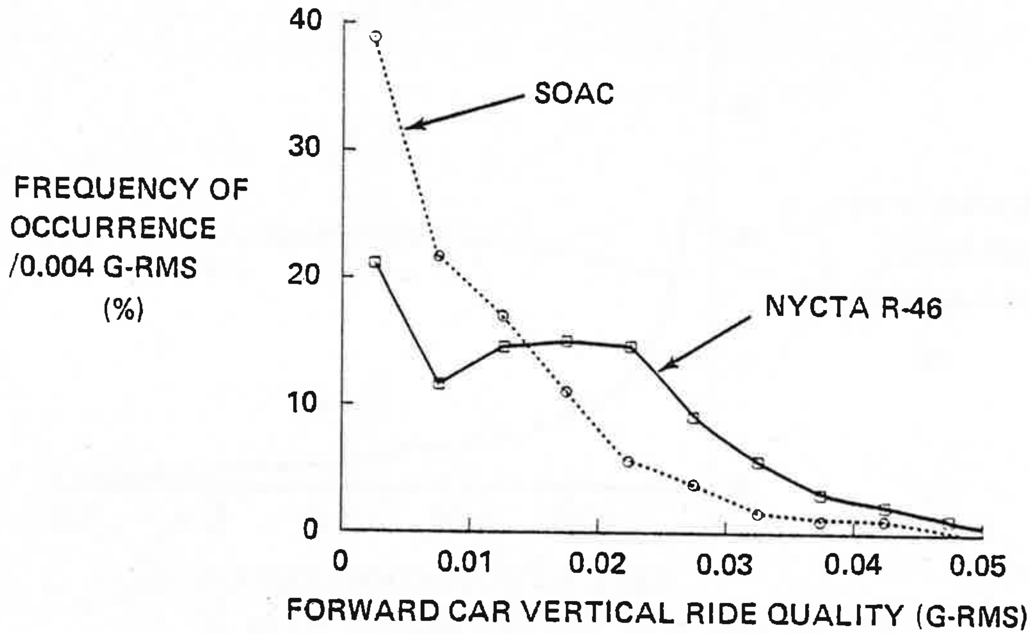


FIGURE 7–20. FORWARD CAR VERTICAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

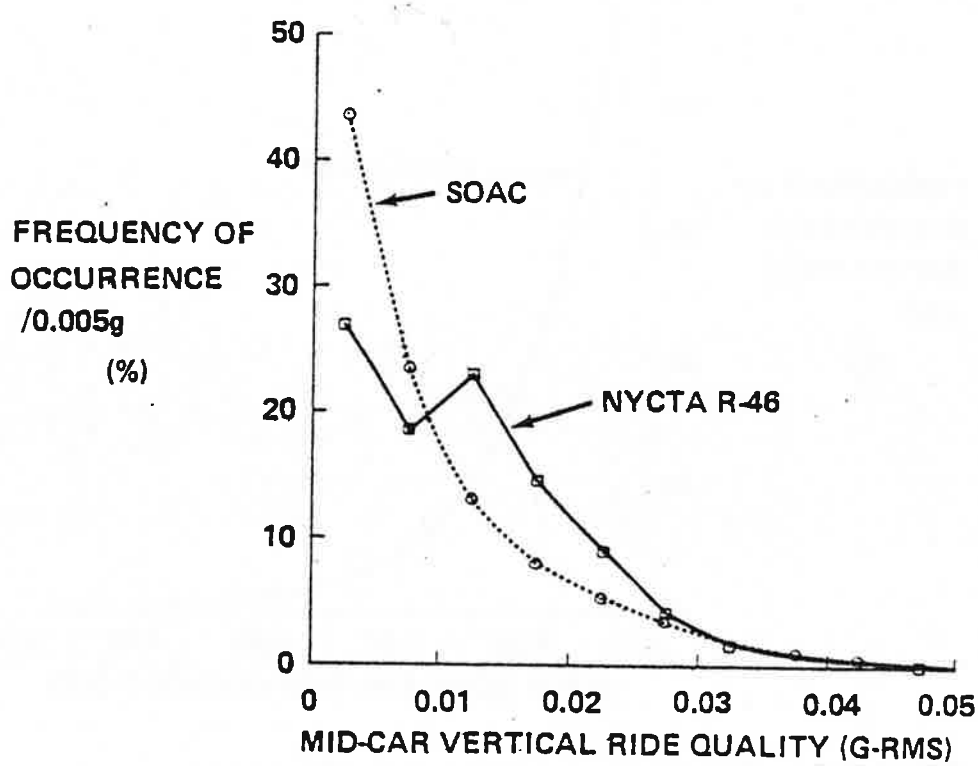


FIGURE 7–21. MID-CAR VERTICAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

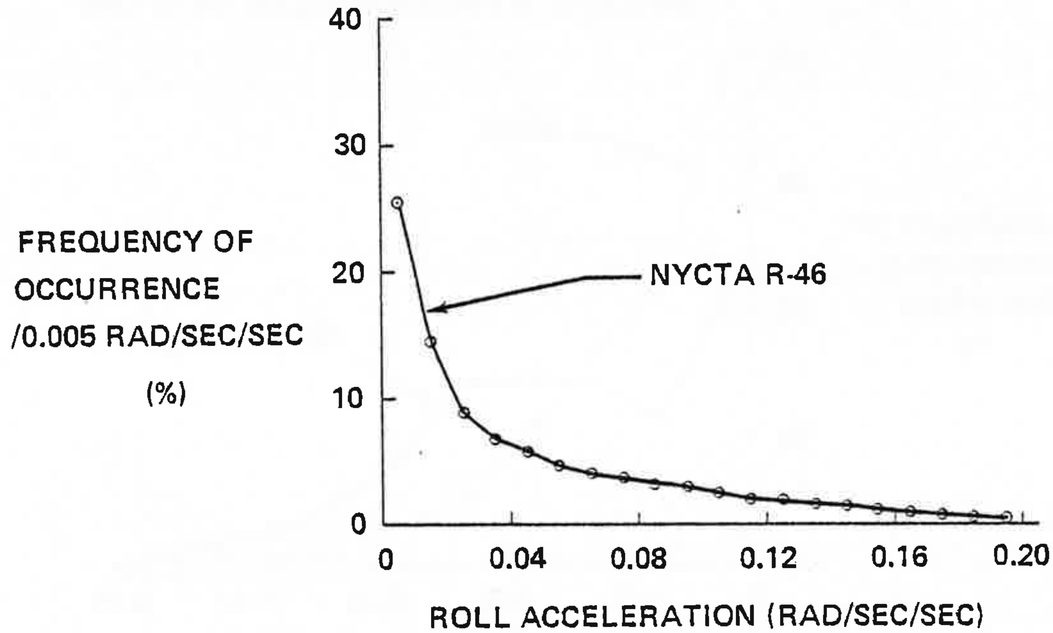


FIGURE 7–22. NYCTA R-46 ROLL DATA.

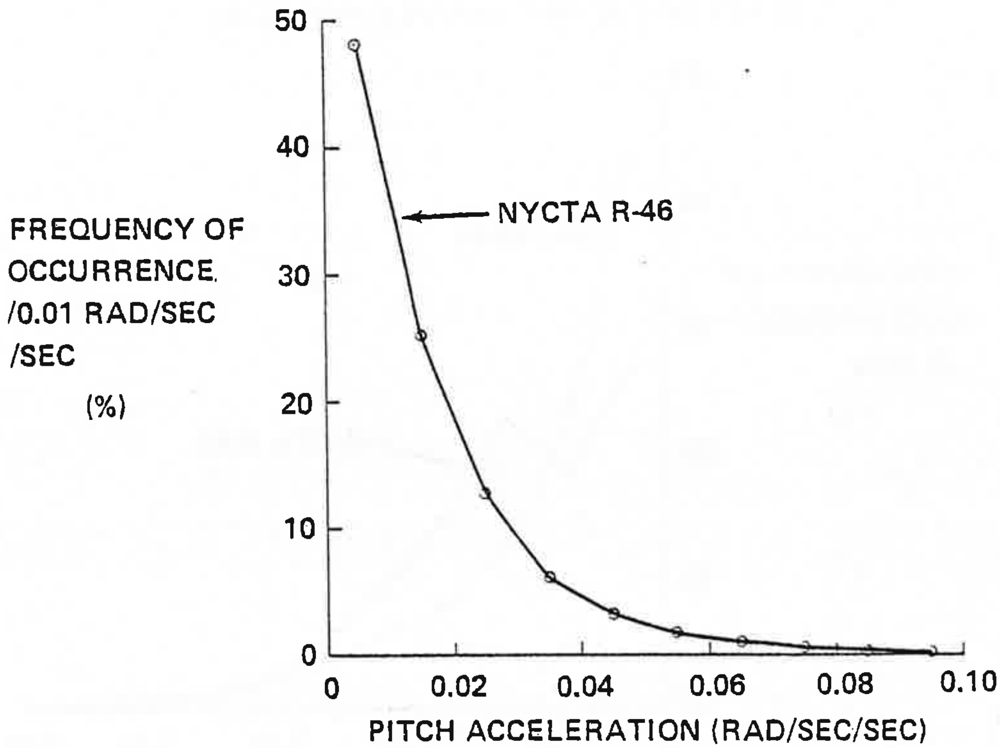


FIGURE 7–23. NYCTA R-46 PITCH DATA.

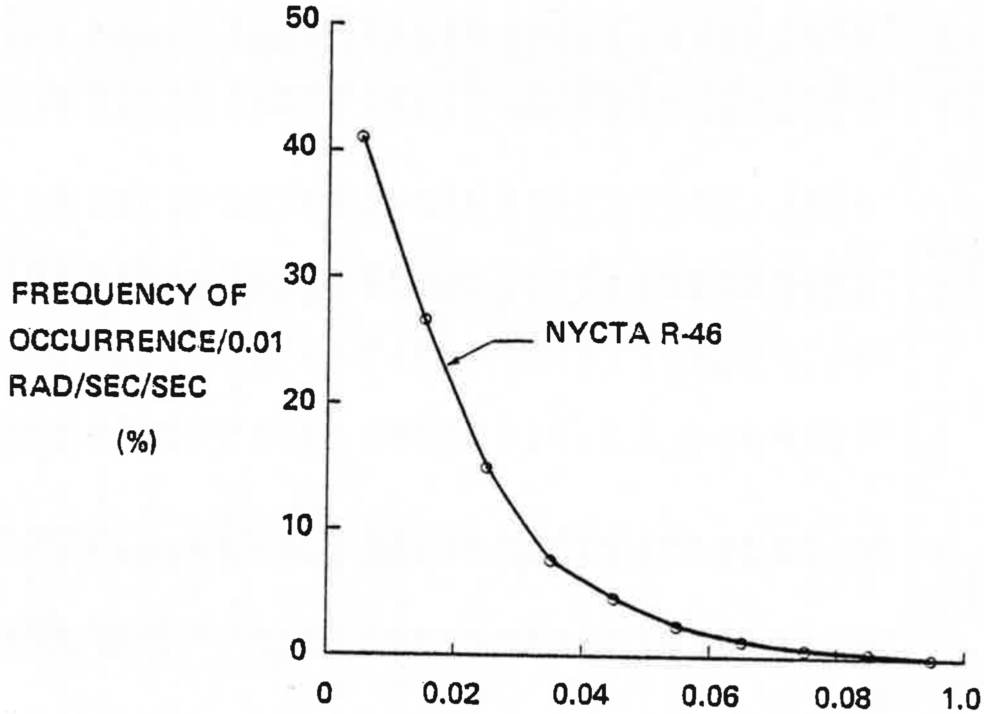


FIGURE 7–24. NYCTA R-46 YAW DATA.

NO.	STATION NAME	DISTANCE (MILES)			BLOCK TIME (MIN)			STATION STOP TIME (SEC)		MAX SPEED (MPH)		POWER CONSUMPTION KWHR		POWER CONSUMPTION KWHR/MILE		ARMATURE CURRENT (AMP-RMS)	
		SURVEYED	SOAC	R-46	SCHEDULED	SOAC	R-46	SOAC	R-46	SOAC	R-46	SOAC	R-46	SOAC	R-46	SOAC	R-46
1	207TH ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	200TH ST	0.42	0.42	0.39	1.5	1.60	1.99	16.8	17.0	40	38.3	4.14	3.08	9.86	7.83	275.6	175.5
3	190TH ST	0.59	0.58	0.58	1.5	1.32	1.77	16.8	17.2	50	31.2	9.09	5.71	15.67	9.77	514.7	210.8
4	181ST ST	0.51	0.51	0.52	1.5	1.28	1.70	19.2	18.8	50	31.3	8.37	5.24	16.41	10.10	512.7	204.8
5	175TH ST	0.34	0.32	0.34	1.5	1.04	1.32	16.8	21.0	46	30.6	5.82	3.65	18.19	10.72	486.2	214.5
6	168TH ST	0.49	0.50	0.47	2.0	1.78	1.66	18.0	16.0	30	31.0	3.64	2.70	7.28	5.72	227.7	166.5
7	145TH ST	1.15	1.11	1.13	3.0	2.86	2.61	21.6	21.7	40	44.9	5.87	4.17	5.29	3.70	256.4	166.4
8	125TH ST	1.04	1.07	1.03	3.0	2.70	3.21	19.2	16.5	50	34.9	8.54	3.76	7.98	3.63	331.7	139.0
9	59TH ST	3.35	3.31	3.30	7.0	5.82	6.49	18.0	17.1	52	45.5	17.75	13.55	5.36	4.11	229.5	133.8
10	42ND ST	0.92	0.92	0.90	2.5	1.82	1.95	14.4	14.8	49	49.0	6.02	4.23	6.54	4.69	348.2	193.9
11	34TH ST	0.35	0.33	0.34	1.5	1.28	1.30	16.8	16.3	37	31.0	3.78	2.43	11.45	7.18	339.0	181.8
12	14TH ST	0.89	0.90	0.93	2.0	2.02	2.11	18.0	18.2	48	47.0	7.27	4.44	8.08	4.78	337.8	183.8
13	4TH ST	0.65	0.64	0.61	2.0	1.92	1.71	18.0	19.0	43	42.0	4.72	3.63	7.38	5.99	222.1	186.0
14	CANAL ST	0.82	0.81	0.81	2.5	2.46	2.46	49.2	48.2	50	41.8	6.73	4.61	8.31	5.70	286.0	169.7
15	CHAMBERS ST	0.53	0.53	0.53	1.5	1.42	1.62	15.6	15.9	44	35.6	5.63	4.17	10.62	7.88	345.3	202.7
16	BROADWAY STS	0.36	0.37	0.35	1.5	1.34	1.43	14.4	14.2	30	24.8	3.37	1.95	9.11	5.66	323.6	149.9
17	BROOKLYN BRIDGE	1.22	1.22	1.21	2.5	2.62	2.70	14.4	14.6	50	44.3	10.08	5.91	8.26	4.90	325.6	169.5
18	JAY ST	0.61	0.62	0.60	1.5	1.72	1.72	18.0	18.6	36	39.2	5.15	4.58	8.31	7.70	310.4	205.6
19	HOYT ST	0.37	0.36	0.38	1.5	2.14	1.54	19.2	19.5	24	28.3	3.55	1.69	9.86	4.41	202.7	167.4
20	LAFAYETTE AVENUE	0.60	0.61	0.62	1.5	2.24	2.03	16.8	16.2	32	37.0	5.02	4.18	8.23	6.70	224.6	178.8
21	CLINTON AVENUE	0.48	0.48	0.49	1.5	1.36	1.48	16.8	16.3	36	37.5	4.51	3.84	9.40	7.83	364.0	216.4
22	FRANKLIN AVENUE	0.49	0.49	0.50	1.5	1.34	1.43	16.8	16.5	38	41.2	3.66	2.81	7.47	5.66	335.5	201.3
23	NOSTRAND AVENUE	0.36	0.34	0.31	1.0	1.16	1.15	19.2	20.3	37	38.8	2.93	2.22	8.62	7.11	325.0	219.1
24	THROOP AVENUE	0.49	0.49	0.47	1.5	1.56	1.41	18.0	18.1	34	39.1	3.75	3.42	7.65	7.32	198.1	212.2
25	UTICA AVENUE	0.53	0.54	0.54	1.5	1.54	1.44	14.4	14.2	37	43.7	4.18	3.70	7.74	6.83	317.5	229.0
26	RALPH AVENUE	0.52	0.52	0.52	1.5	1.68	1.49	16.8	15.1	36	40.4	4.35	3.62	8.37	6.96	224.6	215.1
27	ROCKAWAY AVENUE	0.47	0.49	0.46	1.0	2.28	1.50	19.2	19.6	33	33.1	5.52	4.37	11.27	9.57	191.8	211.5
28	E. NEW YORK ST	0.35	0.35	0.36	1.0	1.32	1.54	15.6	15.9	38	25.3	3.34	2.02	9.54	5.65	264.5	161.2
29	LIBERTY AVENUE	0.61	0.60	0.62	2.5	2.16	2.08	15.6	14.9	26	30.3	2.70	1.76	4.50	2.84	142.2	130.3
30	VAN SICIEN AVENUE	0.45	0.46	0.43	1.5	1.40	1.42	19.2	20.4	33	35.3	3.09	2.48	6.72	5.75	273.6	200.4
31	SHEPARD AVENUE	0.51	0.51	0.51	1.5	1.40	1.48	18.0	19.0	38	43.2	4.00	3.49	7.84	6.85	345.2	221.5
32	EUCLID AVENUE	0.44	0.49	0.50	1.5	1.48	1.76	18.0	23.4	37	31.2	3.82	2.66	7.80	5.36	294.7	157.4
33	GRANT AVENUE	0.44	0.38	0.35	2.0	1.60	1.71	18.0	17.4	25	22.4	3.49	2.51	9.18	7.12	255.1	141.9
34	HUDSON ST	0.36	0.37	0.37	2.0	1.30	1.34	20.4	19.1	36	32.0	4.42	4.01	11.95	10.71	336.3	224.8
35	BOYD AVENUE	0.40	0.38	0.40	1.0	1.34	1.27	18.0	20.0	37	38.1	3.68	2.95	9.68	7.46	297.6	218.82

FIGURE 7–25. STATION SUMMARY FOR R-46 ON NYCTA "A" LINE.

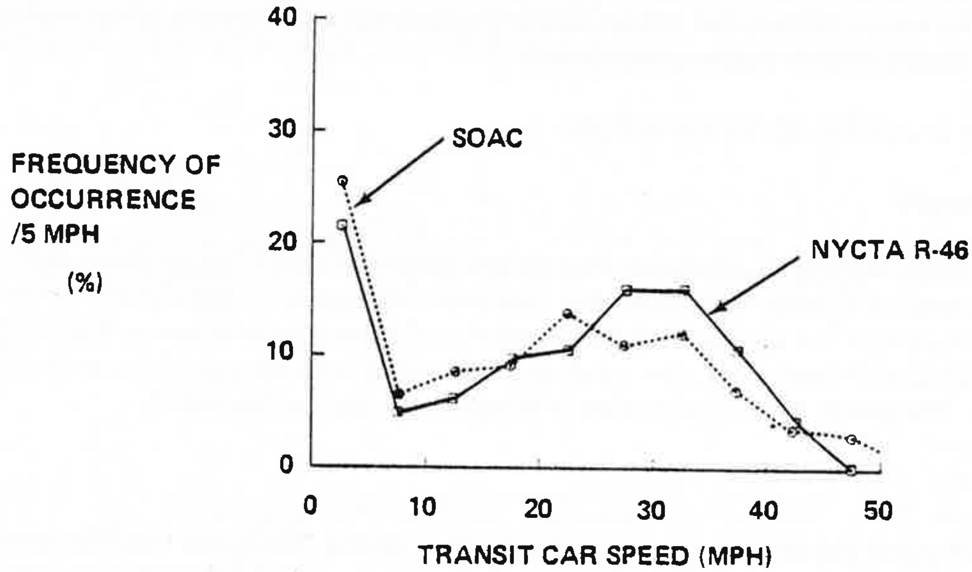


FIGURE 7–26. TRANSIT CAR SPEED COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

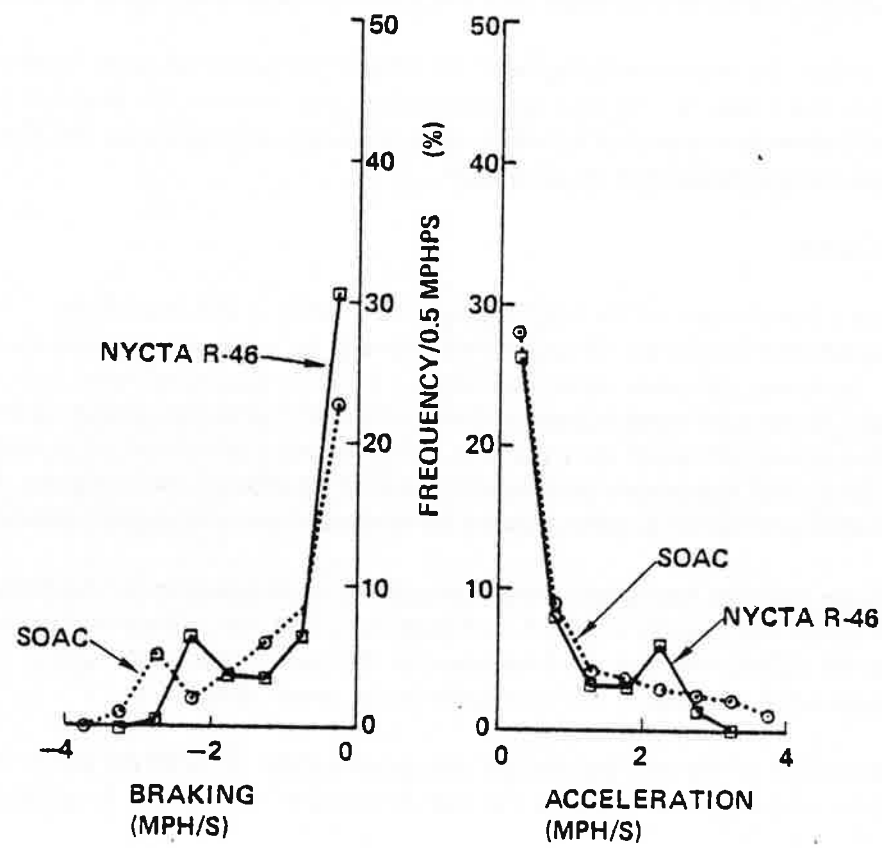


FIGURE 7–27. TRANSIT CAR ACCELERATION COMPARISON STATE-OF-THE-ART CAR VS NYCTA R-46.

remaining components of propulsion, the motors were significantly different for the two trains. The R-46 used motors rated at 115 hp, while the SOAC had motors 52% larger at 175 hp. This motor differential, the accompanying gearing, and different wheel sizes contribute to the SOAC's higher power consumption.

7.4 MBTA SILVERBIRD VERSUS SOAC

7.4.1 Summary

The State-of-the-Art Car in simulated revenue service on the MBTA South Shore Red Line provides a reduced interior noise level, and improved ride quality in comparison to the MBTA Silverbird transit car. A summary of the vibration and noise data is shown in Table 7-3. However, the SOAC train used more than twice as much power to complete the route as did the Silverbird. The power consumption data is shown in the Station Summary.

7.4.2 Noise

Figure 7-28 shows the interior noise level distribution for the SOAC and the Silverbird in simulated revenue service on the MBTA "Red" Line. A majority of the SOAC data occurs between 66 and 70 dBA, while the Silverbird data is more uniformly spread. The equivalent sound level for the SOAC data was 72.7 dBA, but the Silverbird equivalent noise level was 76.0 dBA.

Figure 7-29 shows the relationship between the interior and exterior noise levels recorded during the Silverbird testing. No equivalent exterior noise data for the SOAC is available. The equivalent exterior noise level of 108.4 for the Silverbird means that the Silverbird reduces the noise level for the passengers by 22.4 dBA.

7.4.3 Ride Quality

Figure 7-30 is a comparison of the longitudinal ride quality of the two trains. The Silverbird data shows a reduced frequency of occurrence above 0.1g, with a corresponding increase below .01g. However, the peak value recorded by the Silverbird was higher than that recorded by the SOAC. On at least three occasions during the test, the Westinghouse cam controller hung up at the wrong contactor during a stop. This caused a severe jolt when acceleration was next called for by the motorman, and resulting loss of balance by the test crew. Because of this phenomenon the SOAC is rated a better performed in the longitudinal mode.

The SOAC train provides improved lateral ride quality in comparison to the Silverbird. The forward car lateral ride quality is shown in Figure 7-31, and the mid-car in Figure 7-32. Both figures show the SOAC reducing the time spent in the middle and upper lateral vibration levels with a corresponding increase in the time spent in the lower ranges.

Figure 7-33 is a plot of the mid-car vertical ride quality data. The SOAC performance is clearly superior in the vertical mode at the mid-car position, and in the forward car as well, as is shown in Figure 7-34.

Data reduction of roll, pitch, and yaw data indicates that the Silverbird yaws less than the SOAC, rolls more than the SOAC, and pitches more than the SOAC. The roll, pitch, and yaw data is presented in Figures 7-35, 7-36, and 7-37.

TABLE 7–3. MBTA RIDE QUALITY AND NOISE SUMMARY

	CUMULATIVE PERCENTILE					
	50%		95%		MAXIMUM	
RIDE QUALITY	SOAC	SILVERBIRD	SOAC	SILVERBIRD	SOAC	SILVERBIRD
Journal Box Vertical Accel (g)	± 0.75	± 0.30	± 5.5	± 2.65	± 20.0	± 13.5
Journal Box Lateral Accel (g)	± 1.50	± 0.17	± 8.5	± 1.00	± 17.5	± 5.0
Longitudinal Ride Roughness (grms)	0.006	0.0037	0.017	0.0120	0.050	0.0775
Forward Car Vertical Ride Roughness (grms)	0.015	0.0272	0.060	0.0559	0.150	0.1725
Mid-Car Vertical Ride Roughness (grms)	0.011	0.0408	0.054	0.0810	0.120	0.1275
Forward Car Lateral Ride Roughness (grms)	0.009	0.0088	0.030	0.363	0.075	0.0875
Mid-Car Lateral Ride Roughness (grms)	0.006	0.0062	0.019	0.0203	0.035	0.0475
Pitch (rad/sec-sec)	0.054	0.024	0.098	0.125	0.239	0.35
Roll (rad/sec-sec)	0.055	0.055	0.160	0.265	0.420	0.850
Yaw (rad/sec-sec)	0.050	0.015	0.095	0.055	0.100	0.450
NOISE	50%		99%		EQUIVALENT	
Interior Noise (dBA)	68.8	69.7	81.5	84.2	72.7	76.0
Exterior Noise Level (dBA)	–	102.4	–	116.48	–	108.4

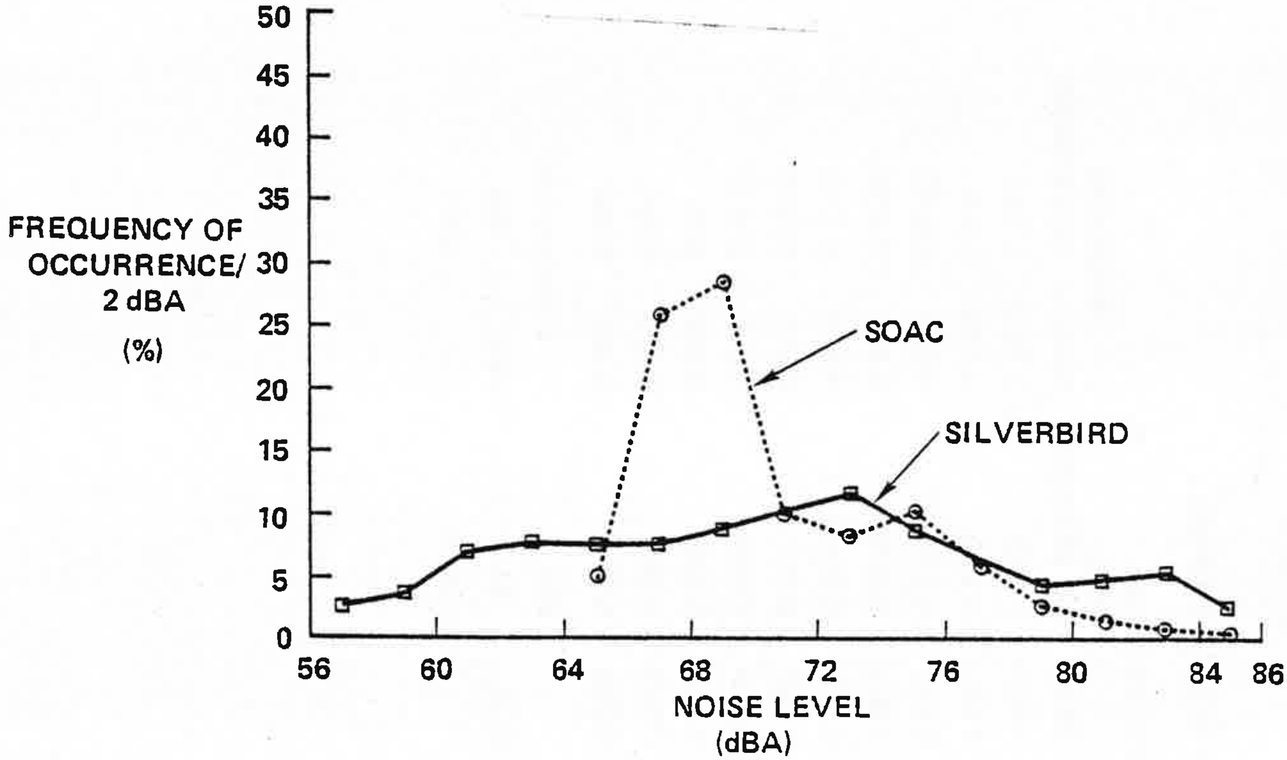


FIGURE 7–28. INTERIOR NOISE LEVEL COMPARISON SOAC VS SILVERBIRD.

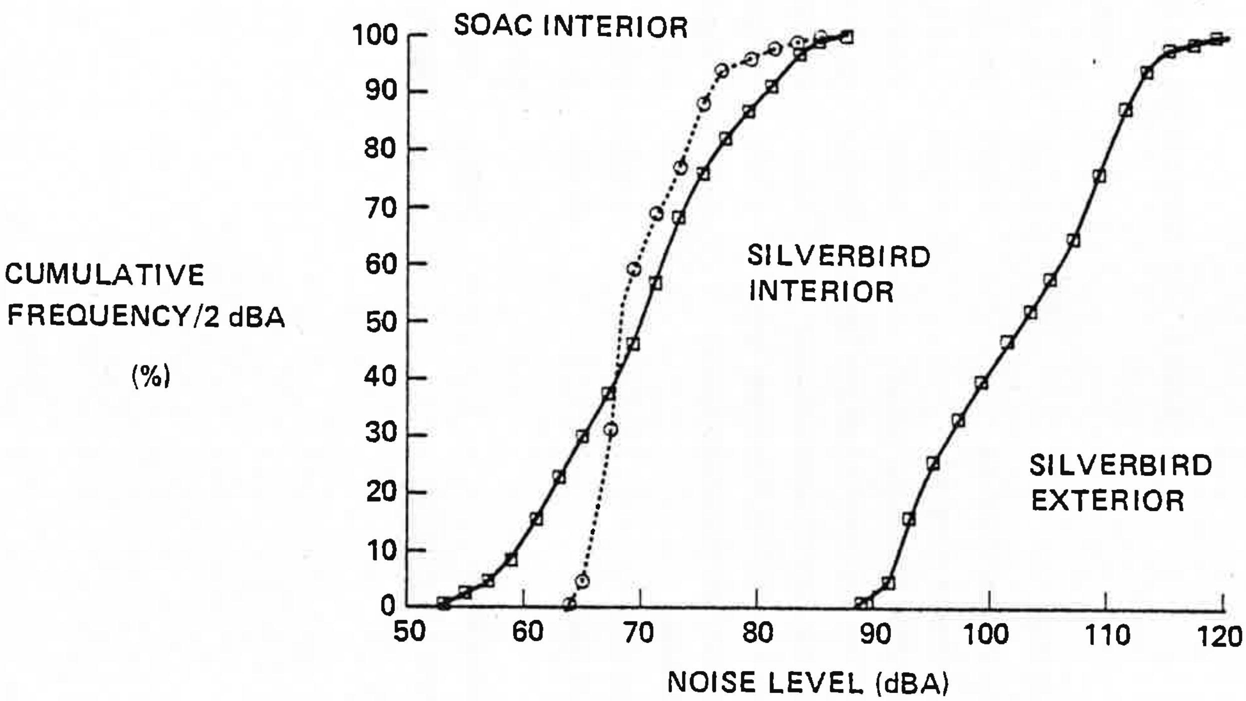


FIGURE 7–29. NOISE LEVEL COMPARISON.

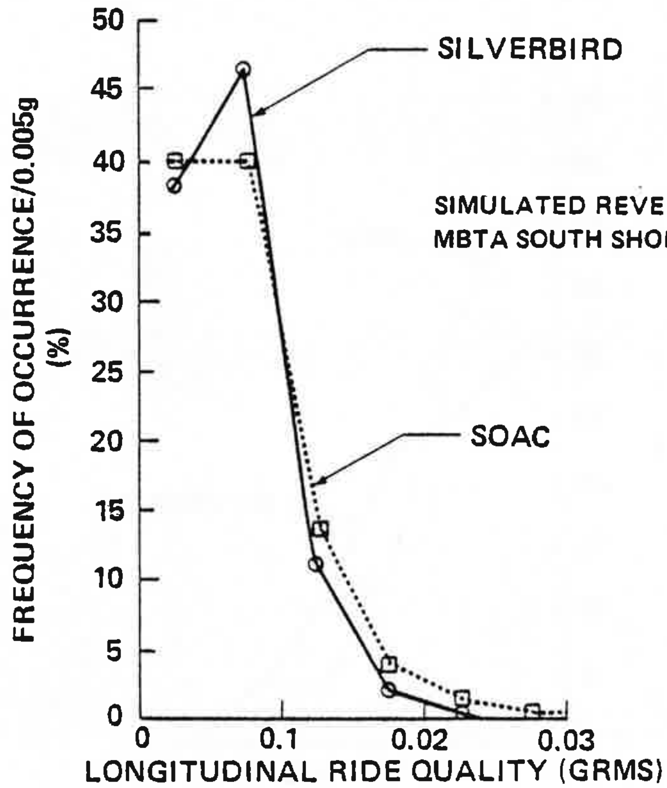


FIGURE 7–30. LONGITUDINAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS SILVERBIRD TRANSIT CAR.

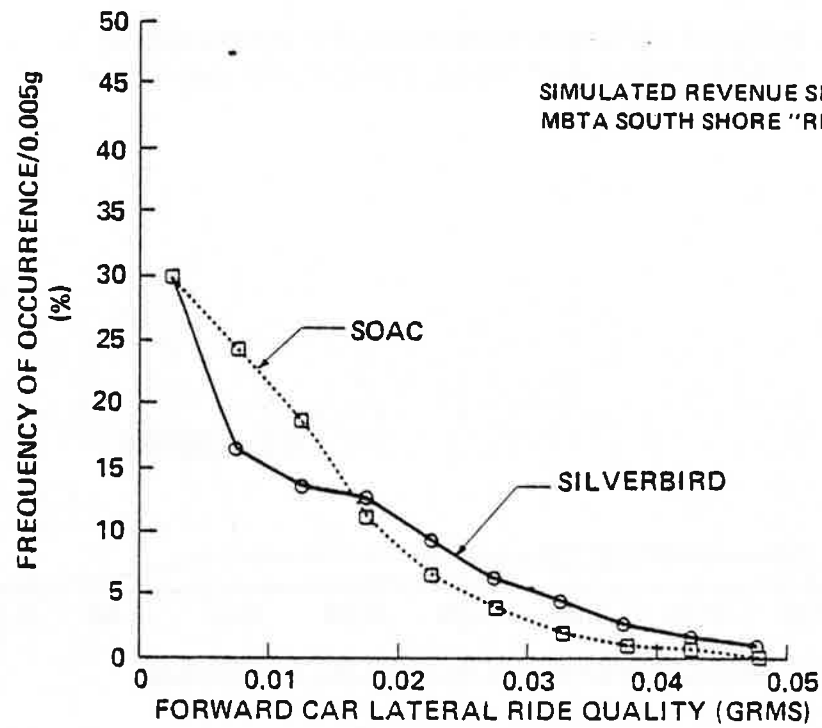


FIGURE 7–31. FORWARD CAR LATERAL RIDE QUALITY COMPARISON STATE-OF-THE ART CAR VS SILVERBIRD TRANSIT CAR.

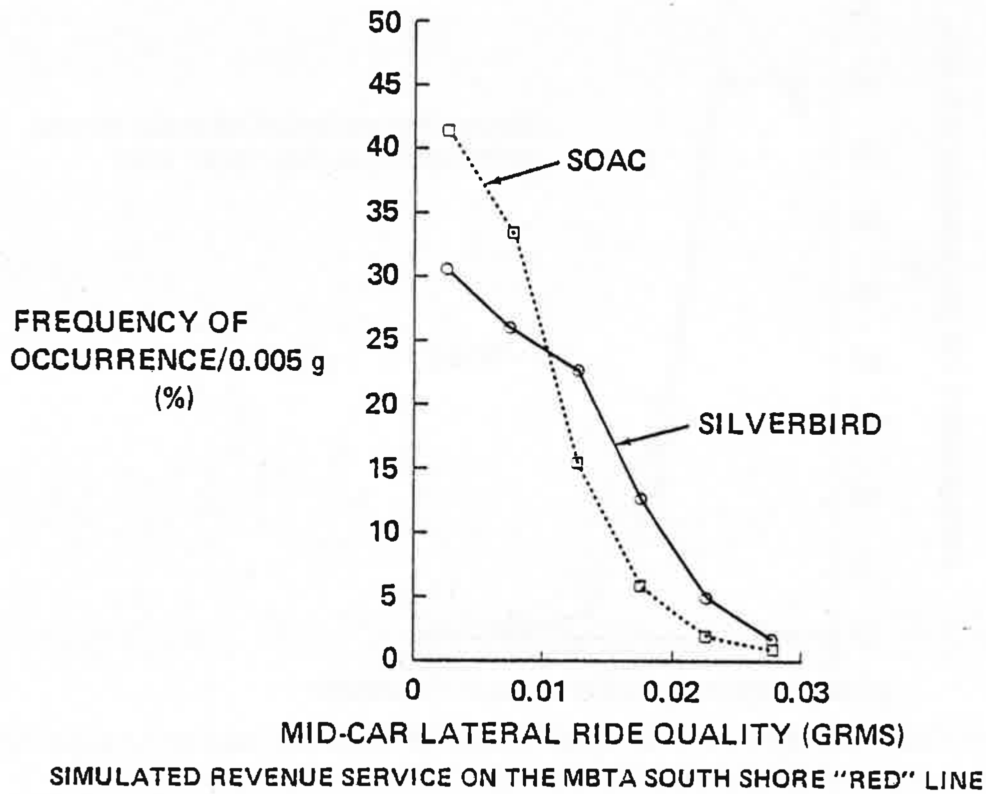


FIGURE 7–32. MID-CAR LATERAL RIDE QUALITY COMPARISON STATE-OF-THE-ART VS SILVERBIRD TRANSIT CAR.

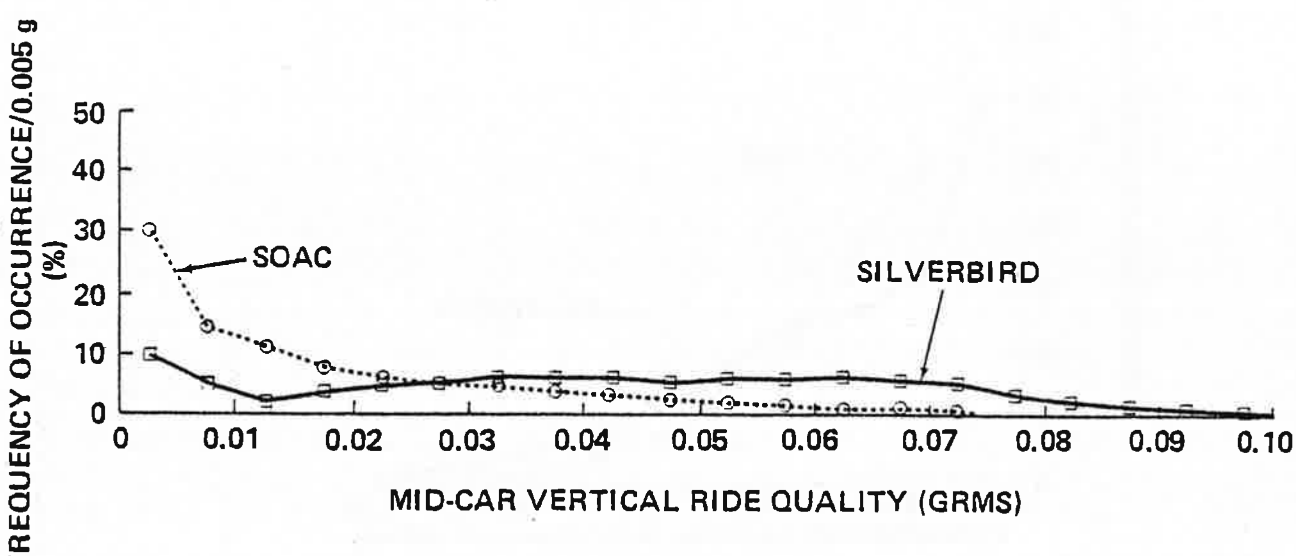


FIGURE 7–33. MID-CAR VERTICAL RIDE QUALITY COMPARISON SOAC VS SILVERBIRD.

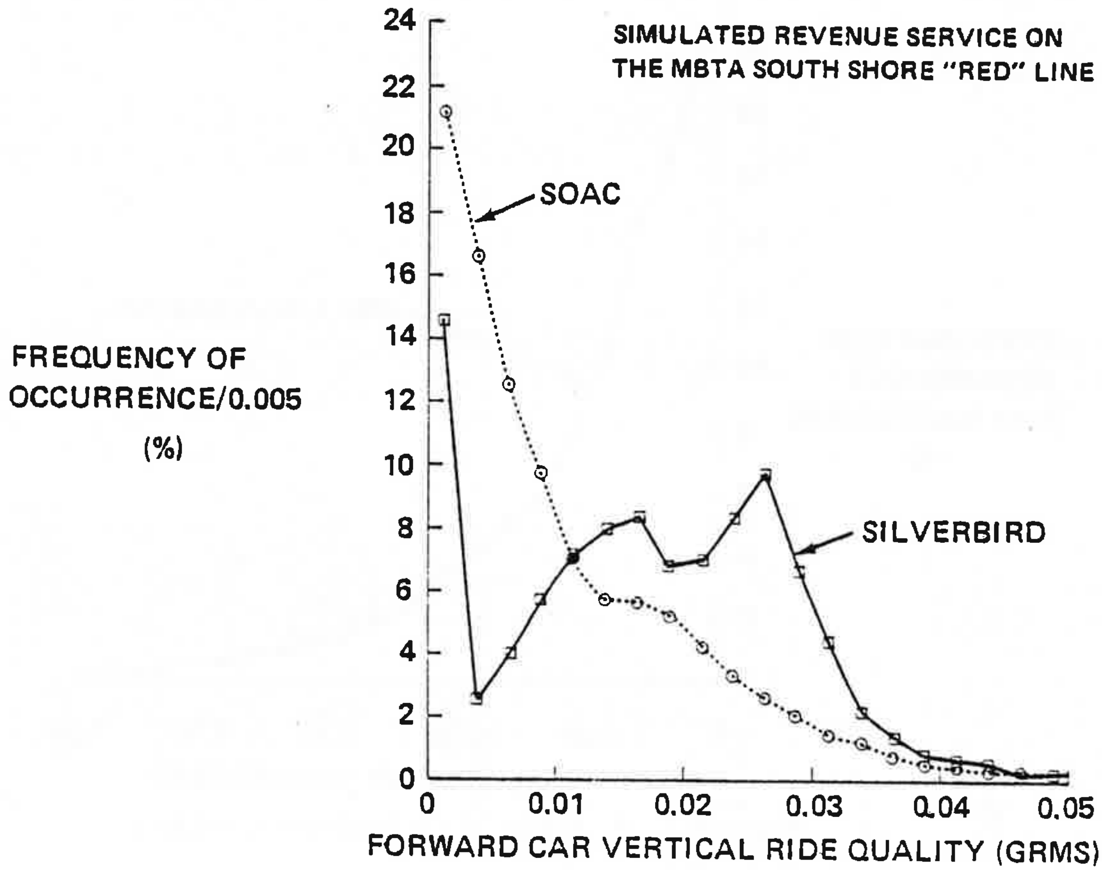


FIGURE 7–34. FORWARD CAR VERTICAL RIDE QUALITY COMPARISON STATE-OF-THE-ART CAR VS SILVERBIRD TRANSIT CAR.

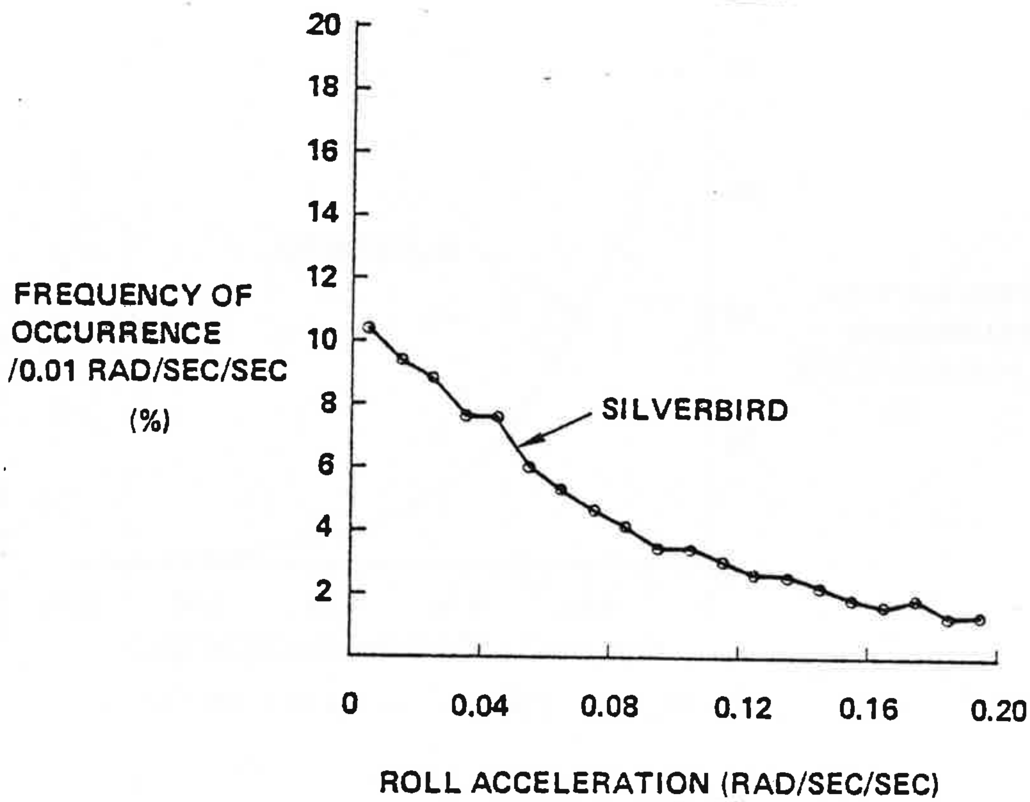


FIGURE 7–35. MBTA SILVERBIRD ROLL DATA.

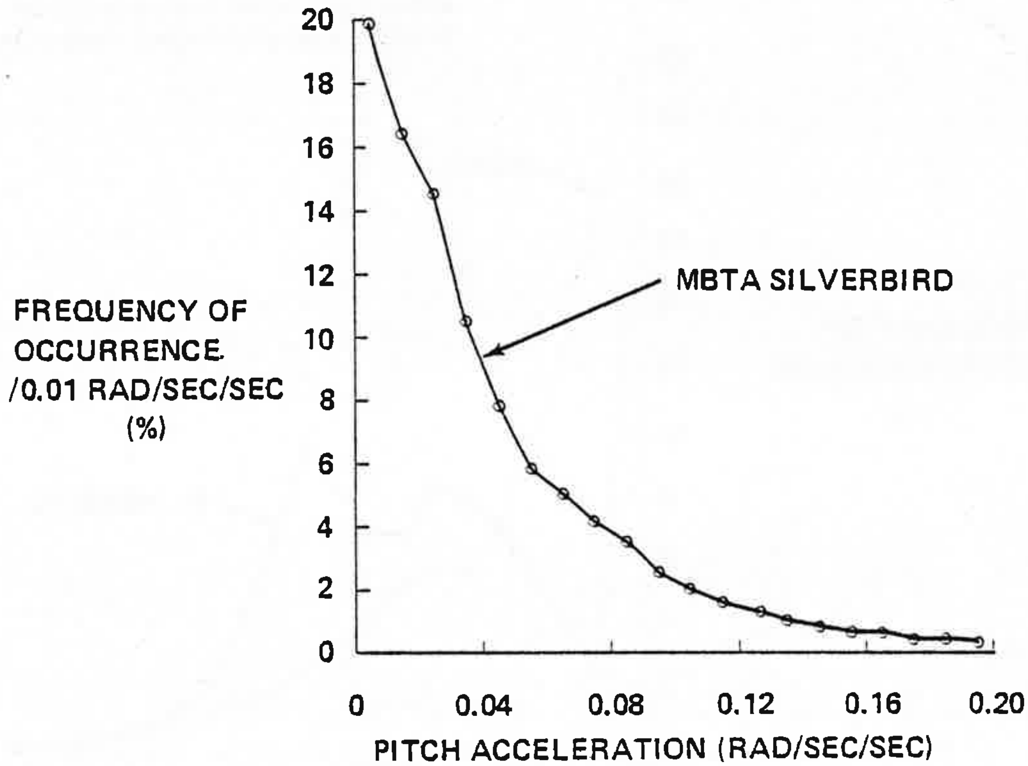


FIGURE 7–36. MBTA SILVERBIRD PITCH DATA.

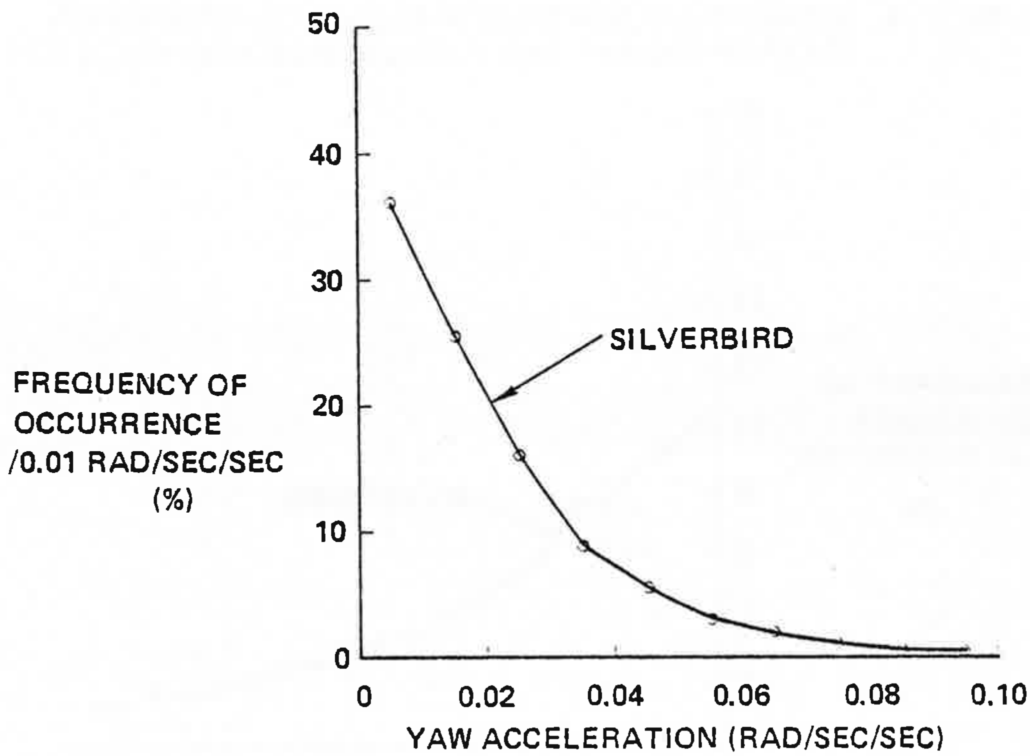


FIGURE 7–37. MBTA SILVERBIRD YAW DATA.

The measurement of "journal box" accelerations proved ineffective in showing similar vibration inputs for the Silverbird and the SOAC. The Silverbird "gearbox mounted" accelerometers showed a large shift to lower g values.

7.4.4 Power Consumption

Power consumption of a transit car is effected by all of the parameters involved in a description of the route: time, speed, distance, and station stop time. The data recorded for each of these parameters is shown in the Station Summary in Figure 7-38. Both trains traveled the same distance. The Silverbird completed the route more quickly than the SOAC, spent slightly longer in station than the SOAC, and reached almost the same maximum speeds during its test. The distribution of acceleration data for the two tests is shown in Figure 7-39. The figure reveals that the Silverbird spent 60% of its total time accelerating, while SOAC spent only 46% of its time under acceleration. This is due to the lower acceleration rates of the Silverbird causing more time to be used to reach the block speed. Figure 7-40 shows the distribution of speed data. Despite the fact that the Silverbird total block time was less than the SOAC, its power consumption was only 49% of the SOAC. Some of this saving results from its more favorable horsepower-to-weight ratio of .0060, compared to the SOAC is .0079. The Silverbird offers more efficient operation on the MBTA Red Line than does the SOAC.

7.5 BEST AVAILABLE RIDE

Since the same instrumentation, same test procedures, same test procedures, same test conditions, and the same data reduction was used for all four trains operating on the three properties, direct comparison of a typical ride on each is possible. Figure 7-41 is a bar graph representation of the weighted averages for the five primary measures of ride quality. As was explained in Section 6, the weighted average is the single value most representative of the distribution of data points recorded during the test. Figure 7-41 clearly shows that the best ride was on the State-of-the-Art Car operating on the NYCTA "A" line in New York City during its demonstration period. The best available ride on one of the three in-service trains is on the R-46 operating on the "A" line in New York City. The R-46 ride is superior to that available at the other properties in four of the five comparisons. Of the three in-service trains, only PATCO, and only in the lateral acceleration mode, is superior to the R-46. Figure 7-42, a bar graph, confirms the NYCTA R-16's superior ride.

7.6 ACOUSTIC COMPARISONS

The quietest available ride would have been aboard the SOAC train during its demonstration period. As shown in Figure 7-43, the SOAC was quieter than existing trains, regardless of which property it was run on. Of the three in-service trains, the MBTA Silverbird has the quietest interior. This is achieved despite the fact that its environment, as shown in Figure 7-43, is the loudest of the three tested. The Silverbird's acoustic materials and design provided the largest reduction in sound level for the passengers, and New York's R-46 the least.

7.7 POWER CONSUMPTION EFFICIENCY

Normally the power consumption between lines, and properties, is compared on a kilowatt-hours per mile basis to eliminate the effect of different route lengths. Dividing the power consumption by the maximum number of passengers eliminates the variable of different

STATION		TEST CONDITIONS										POWER CONSUMPTION				MOTOR ARMATURE CURRENT	
		DISTANCE			BLOCK TIME			STATION STOP		MAX SPEED		KWHR		KWHR/MILE			
NO.	NAME	SURVEYED	SOAC	SILVERBIRD	SCHEDULED	SOAC	SILVERBIRD	SOAC	SILVERBIRD	SOAC	SILVERBIRD	SOAC	SILVERBIRD	SOAC	SILVERBIRD	SOAC	SILVERBIRD
1	HARVARD ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	CENTRAL ST	0.96	0.95	0.92	2.17	2.18	1.98	14.4	15.6	49	49.5	7.10	4.04	7.47	4.38	289.4	198.71
3	KENDALL ST	0.95	0.93	0.90	2.33	2.80	2.52	57.6	56.2	49	52.2	6.62	3.93	7.12	4.38	233.7	161.86
4	CHARLES ST	0.72	0.71	0.69	2.10	2.28	1.84	16.8	16.5	37	46.1	6.46	3.76	9.10	5.45	243.9	182.98
5	PARK	0.56	0.53	0.53	1.65	2.26	1.83	15.6	17.0	38	37.5	4.78	2.01	9.02	3.76	251.5	136.16
6	WASHINGTON ST	0.21	0.20	0.23	1.17	1.12	1.11	16.8	16.3	24	28.2	2.00	1.17	10.00	5.05	271.9	155.33
7	SOUTH ST	0.27	0.28	0.26	1.08	1.30	1.04	15.6	14.6	26	34.7	2.36	1.39	8.43	5.32	268.1	168.40
8	BROADWAY ST	0.83	0.79	0.79	2.42	2.00	2.15	24.0	24.6	49	47.3	6.21	3.14	7.86	3.96	286.3	142.07
9	ANDREW ST	0.83	0.83	0.81	2.25	2.00	1.94	18.0	17.8	50	46.2	7.12	3.98	8.58	4.92	295.6	175.28
10	N. QUINCY ST	4.43	4.14	4.10	5.00	8.50	6.84	32.4	32.8	64	54.7	30.90	12.79	7.46	3.12	296.6	146.52
11	WOLLASTON ST	0.76	0.81	0.76	1.08	2.64	1.66	19.2	21.3	52	52.3	9.16	2.86	12.30	3.79	352.6	215.11
12	QUINCY CENTER	1.27	1.24	1.29	1.09	3.20	5.49	16.8	16.8	56	53.2	10.02	6.82	8.08	5.29	327.1	137.11
	TOTAL	11.79	11.41	11.28	23.15	30.38	28.4	247.20	249.50			93.53	45.89				
	AVG	1.07	1.04	1.03	2.10	2.76	2.58	22.47	22.68					8.20	4.07	290.0	165.41

FIGURE 7–38. MBTA STATION SUMMARY

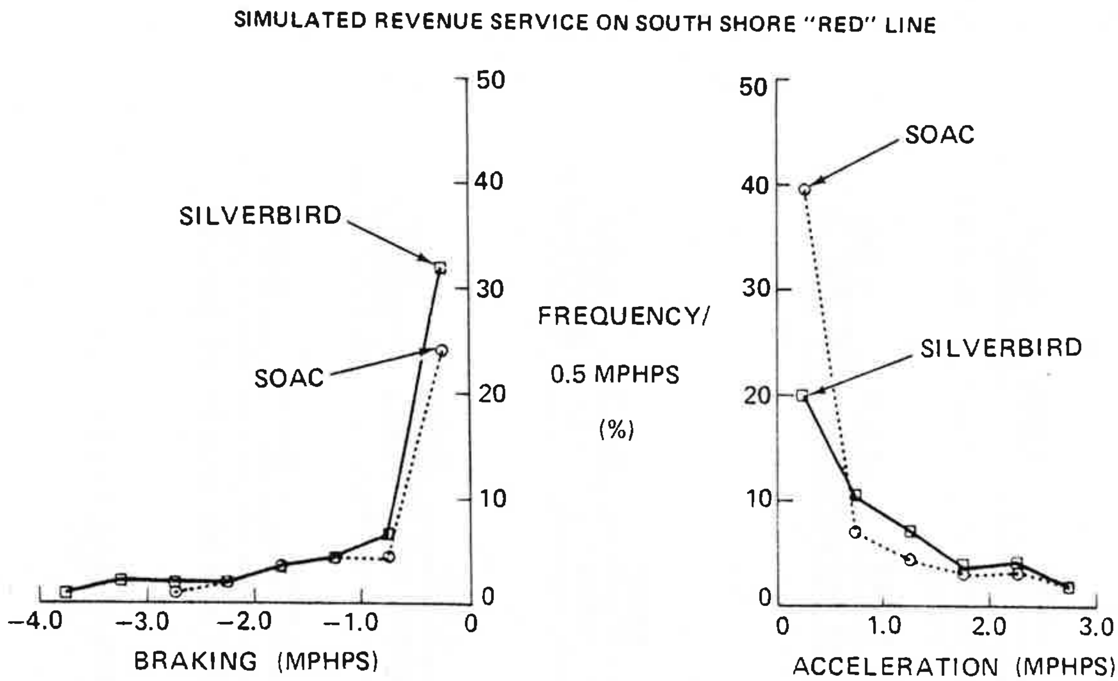


FIGURE 7–39. TRANSIT CAR ACCELERATION COMPARISON STATE -OF-THE-ART CAR VS SILVERBIRD TRANSIT CAR.

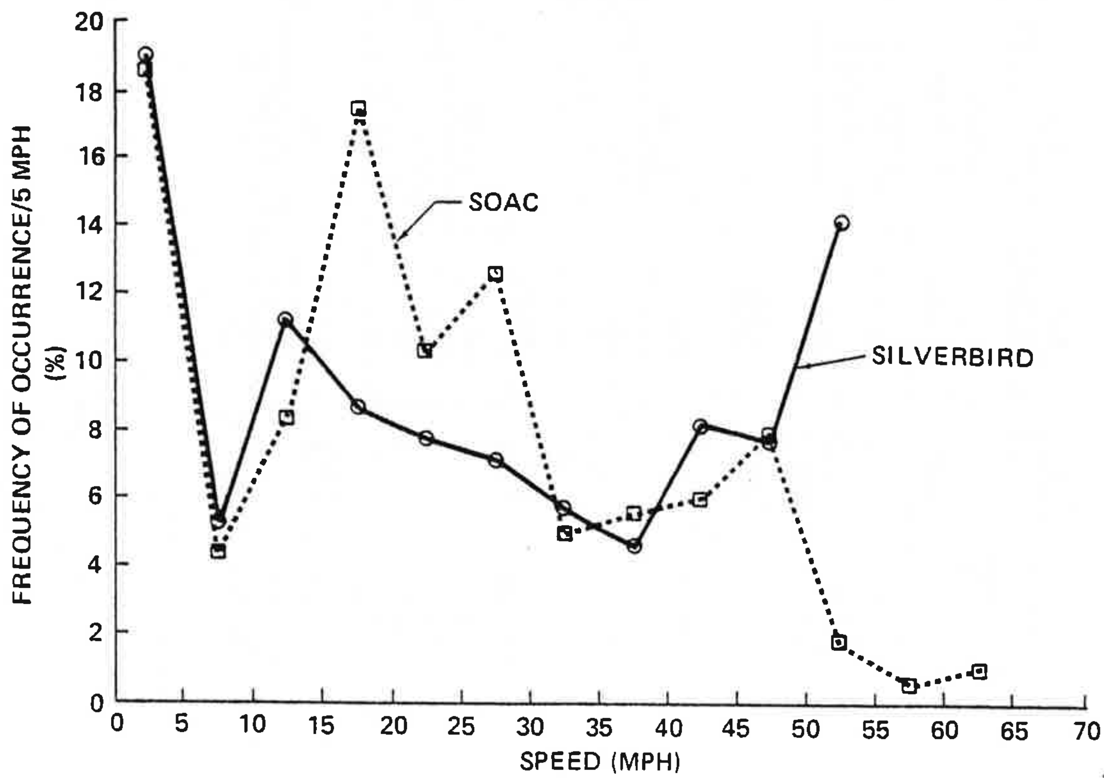


FIGURE 7–40. SPEED DISTRIBUTION COMPARISON SOAC VS SILVERBIRD.

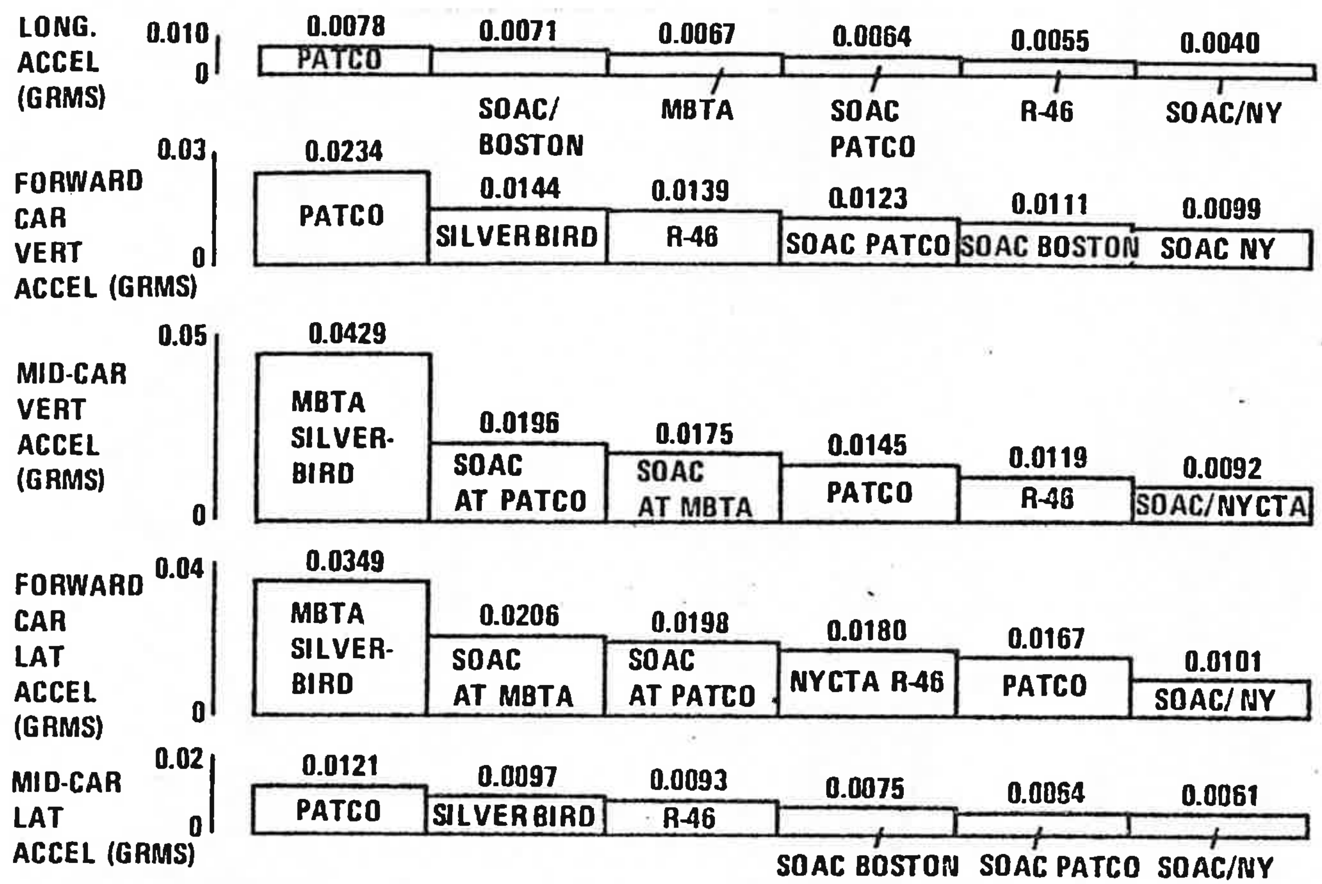


FIGURE 7–41. RIDE QUALITY COMPARISON WEIGHTED AVERAGES.

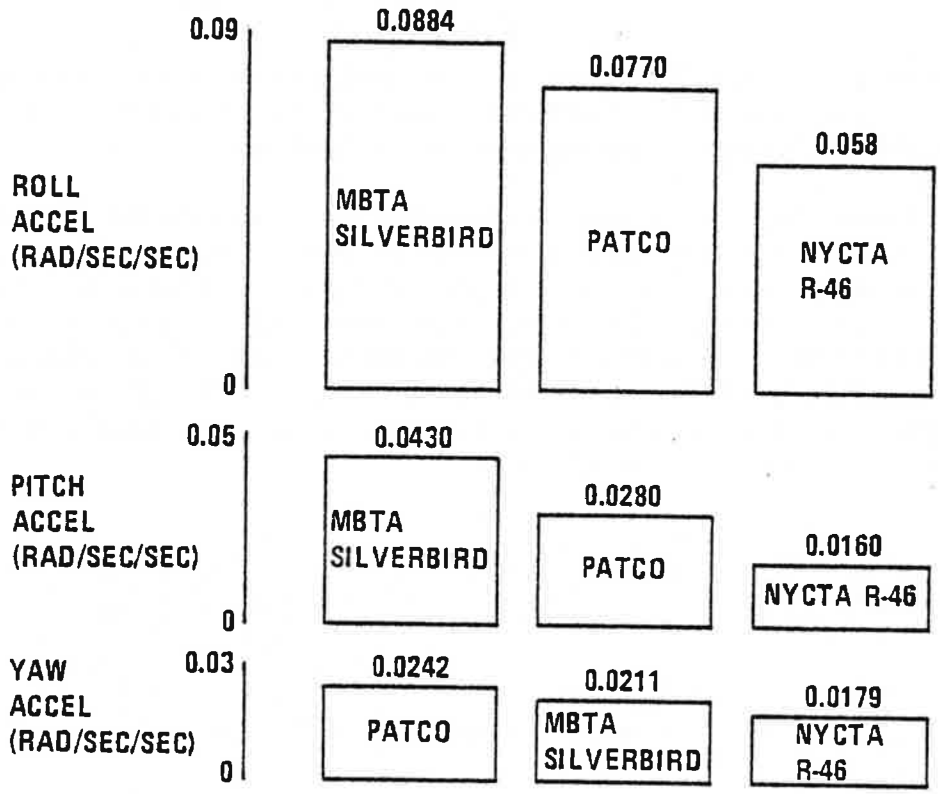


FIGURE 7–42. ROLL, PITCH, YAW COMPARISON, WEIGHTED AVERAGES.

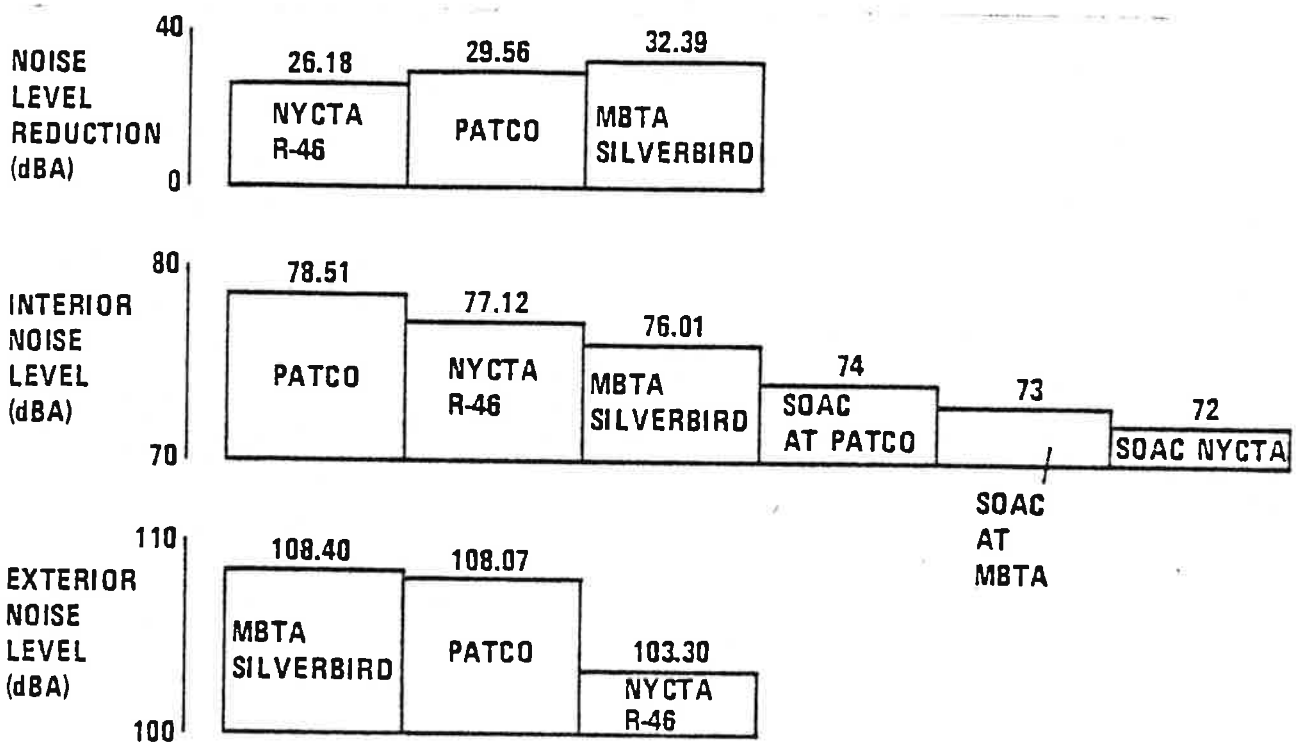


FIGURE 7–43. NOISE LEVEL COMPARISON, EQUIVALENT NOISE LEVELS AND DIFFERENTIALS.

passenger loads and permits comparisons on a per passenger basis. Figure 7-44 shows an expanded summary table of power consumption data and the compilation of the power consumption efficiency number in watt hours per mile per passenger.

Figure 7-45 shows this data rearranged to allow easier use. Clearly the MBTA Silverbird and the NYCTA R-46 are more efficient vehicles than the SOAC. The most efficient, and least expensive to operate, vehicle/route combinations are the Silverbird operating on the Harvard to Quincy Center route (Power Consumption Efficiency = 17.72 for the round trip), the NYCTA R-46 on the "E" Line (PCE = 19.02), the MBTA Silverbird on the Harvard to Ashmont route (PCE = 19.40), and the R-46 on the "A" Line (PCE = 20.42). PATCO's poor performance is due to its high speeds and low passenger volume. The SOAC suffers from an inefficient drive system in this comparison.

	TEST LINE	TRAIN	POWER CONSUMP KILOWATT HOURS	DISTANCE* MILES	POWER CONSUMP KWHR/MILE/CAR	PASSENGER LOAD 2 CAR TRAIN MAX	POWER CONSUMPTION EFFICIENCY NO. MAX LOAD WHR/MILE/PASS
1	PATCO – WESTBOUND	SOAC	98.85	14.1	7.01	520	26.96
		PATCO	104.5	↕	7.41	300	49.40
2	PATCO – EASTBOUND	SOAC	105.85	↕	7.51	520	28.88
		PATCO	100.0	14.1	7.09	300	47.26
3	'N' LINE – NORTHBOUND	SOAC	139.1	15.36	9.06	520	34.84
		R-46	88.6	15.36	5.77	600	19.24
4	'E' LINE – EASTBOUND	SOAC	109.76	16.20	6.78	520	26.08
		R-46	95.9	↕	5.92	600	19.74
5	'E' LINE – WESTBOUND	SOAC	113.91	↕	7.03	520	27.04
		R-46	89.0	16.20	5.49	600	18.30
6	'A' LINE – SOUTHBOUND	SOAC	181.98	23.13	7.87	520	30.26
		R 46	135.7	↕	5.87	600	19.56
7	'A' LINE – NORTHBOUND	SOAC	196.31	↕	8.49	520	32.66
		R-46	147.5	23.13	6.38	600	21.26
8	'D' LINE – NORTHBOUND	SOAC	190.12	25.06	7.59	520	29.20
		R-46	156.2	25.06	6.23	600	20.76
9	ASHMONT TO HARVARD	SOAC	69.95	9.02	7.75	520	29.80
		MBTA	36.9	9.02	4.09	478	17.12
10	HARVARD TO QUINCY CENTER	SOAC	93.53	11.79	7.93	520	30.50
		MBTA	45.5	↕	3.86	478	16.16
11	QUINCY CENTER TO HARVARD	SOAC	99.14	↕	8.41	520	32.34
		MBTA	54.3	11.79	4.61	478	19.28
12	HARVARD TO ASHMONT	SOAC	70.64	9.02	7.83	520	30.12
		MBTA	46.5	8.97	5.18	478	21.68

*DISTANCE IS SCHEDULED DISTANCE FOR THIS TABLE

FIGURE 7–44. POWER CONSUMPTION SUMMARY TABLE.

PCE RANGE	PCE VALUE (watt-hours/ mile/ passenger)	TRAIN	ROUTE
15→19.99	16.16	SILVERBIRD	HARVARD TO QUINCY CENTER
	17.12	SILVERBIRD	ASHMONT TO HARVARD
	18.30	R-46	"E" LINE - WESTBOUND
	19.24	R-46	"N" LINE - NORTHBOUND
	19.28	SILVERBIRD	QUINCY CENTER TO HARVARD
	19.56	R-46	"A" LINE - SOUTHBOUND
	19.74	R-46	"E" LINE - EASTBOUND
20→24.99	20.76	R-46	"D" LINE - NORTHBOUND
	21.26	R-46	"A" LINE - NORTHBOUND
	21.68	SILVERBIRD	HARVARD TO ASHMONT
25→29.99	26.08	SOAC	"E" LINE - EASTBOUND
	26.96	SOAC	PATCO - WESTBOUND
	27.04	SOAC	"E" LINE - WESTBOUND
	28.88	SOAC	PATCO - EASTBOUND
	29.20	SOAC	"D" LINE - NORTHBOUND
	29.80	SOAC	ASHMONT TO HARVARD
30→34.99	30.12	SOAC	HARVARD TO ASHMONT
	30.26	SOAC	"A" LINE - SOUTHBOUND
	30.50	SOAC	HARVARD TO QUINCY CENTER
	32.34	SOAC	QUINCY CENTER TO HARVARD
	32.66	SOAC	"A" LINE - NORTHBOUND
	34.84	SOAC	"N" LINE - NORTHBOUND
35→39.99			
40→44.99			
45→49.99	47.26	PATCO	EASTBOUND
	49.40	PATCO	WESTBOUND

FIGURE 7–45. POWER CONSUMPTION EFFICIENCY.

8. CONCLUSIONS

8.1 SOAC

As shown in the 15 car-to-car comparisons in Figure 7-44, the SOAC ride quality performance is exceeded in only three cases. Figure 7-46 shows the acoustic performance of the SOAC exceeds the other cars tested, and represents a goal for future trains. The SOAC propulsion system, however, did not optimize the sizing of the motors and gearing for the routes tested. Indeed, were it not for the small passenger load carried by the PATCO transit car, the SOAC would be rated the least efficient of the four trains tested.

8.2 THREE TRAINS IN SERVICE

The PATCO transit car came closest to equaling the SOAC in ride comfort. However, the best available ride of the three trains is aboard the R-46 in New York due to the more favorable environment. The quietest ride was found on the MBTA Silverbird operating on the Red Line. The most efficient is the MBTA Silverbird, with the NYCTA R-46 propulsion system a close second.

9. LIST OF REFERENCES

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3. Assessment of Urban Rail Noise Climates and Abatement Options, Noise Assessment Report

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   R. Spencer and E. Hinterkeuser

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   Report No. UMTA-MA-06-0025-75-14
   September 1975
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APPENDIX A
NYCTA R-46 TEST LOG

The following is a log of the NYCTA R-46 test effort from shipment of equipment to New York through its return to Boeing Vertol. It is included in this report as a guide for planning and estimating future programs with similar requirements. It demonstrates a rather wide range of unexpected problems.

MONDAY, OCTOBER 18, 1976

8 A.M.	—	Test engineer arrived at PATCO. Lindenwold, N.J. and began banding of test equipment for shipment to New York.
9 A.M.	—	Banding of test equipment completed. Quaker Van Lines truck arrives and loading of equipment begins.
10 A.M.	—	Loading of test equipment is completed. Garrett technician arrived for trip to New York. Test engineer and Garrett technician began trip to New York in rent-a-car with Quaker Van following to avoid getting lost.
1 P.M.	—	Arrival of test team near 207th Street Maintenance shops in N.Y. Quaker Van truck became lodged under the structure for the elevated IRT No. 1 lines only 4 blocks from destination. Effort began to dislodge and reroute truck.
2 P.M.	—	Arrival of test equipment and team at 207th Street. Effort begins to position truck and secure fork truck for unloading.
3 P.M.	—	Unloading of test equipment started.
3:30 P.M.	—	All equipment unloaded. NYCTA Police contacted to provide guard for equipment during the night. Fork truck scheduled for 9 A.M. October 19 for loading of test equipment on train. NYCTA officials are requested to review the 4 car train requirement again.
4 P.M.	—	Test crew departs 207th Street.

TUESDAY, OCTOBER 19, 1976

8 A.M.	—	Test crew arrived at 207th Street. Because of construction inside the shops, the test R-46 train has been moved from the engineering pit near the wall to the center of the building. This necessitates the movement of equipment on a long very rough route to the car. Because the fork is a large, non-suspended model, the test engineer elects to push and/or carry as much equipment as possible to the trains.
9 A.M.	—	Fork truck arrives and moves the last pieces of test equipment to the train. Fork truck unable to turn in aisle between trains. Test engineer requests a smaller, more movable fork or movement of train to easier loading position.

10 A.M.	–	Unable to obtain smaller fork or move train. Loading of equipment began.
11 A.M.	–	Loading complete. During loading operation outside car paint was scratched and the divider inside the door was damaged. Unpacking of equipment begins.
12 A.M.	–	Lunch
1 P.M.	–	Installation of sensors begins.
2 P.M.	–	NYCTA agrees to use of two 'A' car train and begins removing the two 'B' cars from the test train.
3 P.M.	–	'B' cars are removed and the two 'A' cars recoupled. The gearbox accelerometer brackets require modification before installation. They are given to NYCTA for modification in their machine shops. The planned insertion of shunts in the field and armature cables prove physically impossible. Using cables from the PATCO test a new installation is fabricated. Steel banding equipment is used to hold the isolation amplifier and voltage divider boxes in place. All test instrumentation cables are tyrapped in place.
5 P.M.	–	End of day.

WEDNESDAY, OCTOBER 20, 1976

8 A.M.	–	Arrival at 207th Street shops. One Garrett technician begins checkout and tuning of console and amplifiers. B-V test engineer installs interior sensors. One Garrett technician completes insulation of field and armature current shunts.
10 A.M.	–	Installation of gearbox accelerometer mounts completed and all cables connected except line current. Console and system checkout continue.
12 A.M.	–	Lunch
1 P.M.	–	Knife switch modification for line current measurements proves a disaster. R-46 cables are far stiffer than expected. Water tight fittings were designed for installations not removal. Proper tools are unavailable. Alternatives are sought, but prove unavailable. Finally, 3 people, B-V test engineer, Garrett technician, and NYCTA maintenance man working together during the next 3 hours are able to remove the R-46 cables from the knife switch. Then using cables from the PATCO test, a new installation of the line current shunt is made.
4 P.M.	–	All sensors installed and system checkout complete. A request is made to schedule test runs on a siding for Thursday afternoon. A crew is scheduled for first test Thursday night at 8 P.M.

THURSDAY, OCTOBER 21, 1976

8 A.M. — Arrival at 207th Street. NYCTA requires additional insulation on all three shunt installations. B-V test engineer and one Garrett technician begin this rework while one technician checks out the console and the rest of the sensors.

10 A.M. — Rework of shunt insulation completed and approved by NYCTA. A full system calibration is started.

11:30 A.M. — Lunch

1 P.M. — Test train pulls out of repair building and onto siding for rolling check of instrumentation. Rolling tests reveal no armature voltage during dynamic braking. Problem is incorrect location of lead for return line from motors.

Rolling test reveals wrong polarity on line current shunt. Rolling test reveals insufficient range on vertical ride quality accelerometers. Investigation of this shows considerable forward car body vibration due to compressor operation. Rolling tests show 25g range too large for journal box accelerometers.

2:30 P.M. — Rolling tests complete. Inspection of undercar and correction of problems begins.

5 P.M. — Armature voltage problem solved by relocating wire from car body ground to armature current return line in cam controller box. Line current polarity corrected by switching instrumentation wires on shunt. Close examination of data reveals mid-car vertical accelerometer range adequate at .25g, but forward car is raised to .50g. Gearbox accelerometer range is lowered to ± 10g. Data sheets are prepared and distributed to the test crew. Route and test procedure discussed with NYCTA.

5:30 P.M. — Dinner break and coordination meeting for test crew.

6:30 P.M. — AC power problem becomes critical. Location of test train in center of building instead of along the wall forces use of a weak AC power circuit for powering the instrumentation system and battery charger. Using the battery charger draws the line below the minimum voltage needed to power the instrumentation console. Since both are needed in the period just before test, an extension cord is stretched from the test train across the three adjacent pits to the wall of the building. A final calibration of all test equipment is made. A final charge is made to the battery system.

8 P.M. — NYCTA motorman and conductor arrive for test. Both are briefed on their required tasks and all extension cords are retracted.

8:15 P.M.	–	R-46 test train leaves 207th Street. The two Garrett technicians will operate the instrumentation system and monitor it for problems. NYCTA's New Car Engineering representative will ride in the cab with the motorman to aid in route clearance and problem solving. B-V test engineer and NYCTA conductor operate the doors from the cab of the second car. The two cabs are in communication by intercom. Driver and conductor are directed not to use PA system.
8:43 P.M.	–	Arrival of R-46 test train at Brooklyn Bridge. During transit period to this point both interior and exterior microphone ranges have been checked. At this point all instrumentation is turned on. On the other side of the bridge is Dekalb Station, first stop on the southbound test of the 'N' line. Crossing of the Brooklyn bridge is extremely slow and rough.
8:51 P.M.	–	Start of 'N' line test Southbound – Dekalb Station.
8:55 P.M.	–	Between Pacific and 36th Street Stations, 4 stations are skipped. All 4 were skipped by the SOAC and represent an express schedule.
9:12 P.M.	–	Interior Noise Meter set too high. During stop at 18th Avenue Station, it was reset to 80 dBA scale.
9:30 P.M.	–	Completion of Southbound portion of 'N' line test at Stillwell Station. Crews from the two cabs switch ends and test continues.
9:32 P.M.	–	Start of Northbound run on 'N' line, starting at Stillwell. R-46 test train leaves immediately behind a passenger train. This forces strict speed control of train by motorman to avoid stopping at 'red' signals.
9:47 P.M.	–	R-46 test train stopped in tunnel for 'red' signal.
9:54 P.M.	–	R-46 test train stopped in tunnel for 'red' signal.
10:04 P.M.	–	R-46 test train stopped in tunnel for 'red' signal.
10:27 P.M.	–	End of northbound test on 'N' line, at 57th Street. Cab crews again exchange ends.
10:30 P.M.	–	Southbound test on 'N' line resumes. First station 57th Street.
10:49 P.M.	–	R-46 test train completes test on 'N' line at Dekalb St. Station. Begin transit to 207th Street maintenance shops.
11:30 P.M.	–	Returned to maintenance building. Battery charger started for a twelve hour cycle. Initial undercar inspection reveals no problems.
12 P.M.	–	End of day.

FRIDAY, OCTOBER 22, 1976

10 A.M.	–	Phone calls to Boeing Vertol, Garrett, TSC, and MBTA occupy morning hours. Garrett technicians purchase new batteries for noise meters and get data sheets copied.
12 A.M.	–	Luncheon coordination meeting for test crew.
1 P.M.	–	Arrival to 207th Street. Begin detailed check of each parameter.
2 P.M.	–	Detailed analysis shows marginal clearance of data on 5 channels. All three journal boxes were increased in range to 15g. The mid-car vertical was raised to .5g and the forward car to 1.0g.
3 P.M.	–	A fresh system calibration is recorded. B-V test engineer and NYCTA discuss route and station stop times for the test of the 'E' line. Data sheets are written and copies at 207th Street.
5 P.M.	–	Dinner break and test crew coordination meeting.
6 P.M.	–	Garrett technicians disassemble one of the NOVA inverters in an effort to reduce its extreme noise and vibration. They find all fasteners loose in bottom of box and the transformer and other components connected to the case by wiring. Repairs are made but do not noticeably improve things.
8 P.M.	–	Motorman and conductor arrive and are briefed by B-V test engineer. R-46 test train then leaves for Hudson terminal.
8:39 P.M.	–	R-46 in Hudson Terminal, start of northbound test on 'E' line.
9:30 P.M.	–	R-46 at 179th Street Station, end of northbound test on 'E' line.
9:35 P.M.	–	R-46 test train leaves 179th Street Station for southbound test on 'E' line.
9:46 P.M.	–	R-46 test train stops at 75th Avenue Station for 134.6 seconds. This is a duplication of the SOAC stop at this station.
10:12 P.M.	–	R-46 test train skips 23rd Street Station. This is a duplication of the SOAC route on the 'E' line.
10:16 P.M.	–	R-46 test train skips Spring Station. This is a duplication of the SOAC route.
10:19 P.M.	–	R-46 test train stops in tunnel to await permission to enter Hudson Terminal.
10:24 P.M.	–	R-46 in Hudson Terminal-end of southbound test on the 'E' line.
11 P.M.	–	R-46 test train in 207th Street shops. Battery charger started. Play back of all channels reveals no problem.
11:30 P.M.	–	End of day.

MONDAY, OCTOBER 25, 1976

12 A.M. – Test crew arrives at 207th Street shops. Detailed review of data from Friday night is begun.

1 P.M. – Detailed review of data reveals no problems. System checkout begins.

2 P.M. – NYCTA insists on copies of all raw data at end of tests. B-V test engineer tries to convince NYCTA that the raw data is of extremely limited use, but to no avail. Garrett technicians begin taping out the data from the 'N' and 'E' lines. B-V test engineer and NYCTA discuss route and scheduling for the 'A' line. B-V test engineer prepares data sheets for the evening.

4 P.M. – Tape out of first two lines complete. New tapes are placed on the recorders for the 'A' line. System calibration begins.

6 P.M. – Dinner break

8 P.M. – NYCTA motorman and conductor arrive and are briefed for the test. All extension cords are retracted and the test train leaves the maintenance building.

8:06 P.M. – Arrival of the R-46 test train at 207th Street Station, first station of southbound test on the 'A' line.

9:09 P.M. – Arrival of the R-46 at Boyd Avenue Station. This is the last stop on the southbound test of the 'A' line. The next four stations are not recorded, just as they were not during the SOAC test.

9:12 P.M. – R-46 test train at Lefferts Blvd Station, first station on northbound leg of 'A' line test.

9:52 P.M. – Between Broadway and Chambers extremely high wheel noise is recorded because of a turn in the tunnel.

10:24 P.M. – R-46 test train in 200th Street Station, last station to be recorded during northbound test on the 'A' line.

10:30 P.M. – R-46 test train in maintenance building. Battery charger turned on. Initial review of data reveals no problems.

11 P.M. – End of day.

TUESDAY, OCTOBER 26, 1976

10 A.M. – Morning hours spent talking on phone with Garrett, TSC, MBTA, and Boeing Vertol.

1 P.M. – Took a trip to south Manhattan in search of special insulation tape for R-46 end of test rework. Upon arrival supplier denied any knowledge of special tape.

2 P.M.	—	Arrival of test team at NYCTA 207th Street. Detailed check of all parameters reveal no problems. Tape out of 'A' line data for NYCTA begins. Car clean-up and preparation for end of test packaging of equipment started.
4 P.M.	—	Tape-out of data complete for 'A' line. Car clean-up complete. 'A' line tapes removed from recorders and the 'N' line tapes put back on. System calibration begins. Data sheets are prepared for the 'D' line. B-V test engineer and NYCTA briefly discuss route and scheduling.
6 P.M.	—	Dinner Break
7 P.M.	—	NYCTA motorman and conductor arrive and are briefed.
7:30 P.M.	—	R-46 test train pulls out of shops. Train proceeds outh on 'A' line until it joins the 'D' line at 125th Street.
8:05 P.M.	—	R-46 test train arrives at 125th Street. Circumstances place the test team immediately between 2 southbound 'D' trains. This results in strict speed control southbound with delays throughout the 'D' line test. The following train is visible from the test train almost constantly from 125th to Parkside where it passes on the express track. This is the starting station for the southbound test of the 'D' line.
8:22 P.M.	—	R-46 test train held in West 4th Station by 'red' signal.
8:44 P.M.	—	High roll rates and lateral accelerations occur between Parkside and Church St. Station.
8:51 P.M.	—	High lateral accelerations occur between Ave. J and Ave. M.
8:59 P.M.	—	R-46 test train unable to leave Sheepshead St. Station because of 'red' signal.
9:07 P.M.	—	R-46 arrives at Ocean Street Station, last station to be recorded during southbound test. The next two stations, Coney Island and Stillwell, are not recorded since they weren't recorded during the SOAC test.
9:15 P.M.	—	R-46 leaves Stillwell Station on the northbound leg of the 'D' line test.
9:37 P.M.	—	R-46 stops for 96 seconds at Prospect Street Station.
9:41 P.M.	—	R-46 test train stops in tunnel before entering Dekalb Station to await permission to enter station.
9:47 P.M.	—	Leaving Dekalb Station the R-46 was switched to a parallel track. During this maneuver an extremely high lateral shock occurred.

10:03 P.M.	–	R-46 test train stops at 34th Street Station for 162 sec.
10:37 P.M.	–	R-46 arrives at Bedford Street Station and stops for 75 sec. This is the end of the northbound test on the 'D' line because 205th Street was not included in the SOAC test.
10:43 P.M.	–	R-46 test train leaves 205th Street and starts southbound on 'D' line.
11 P.M.	–	While R-46 test train at 145th Street Station with doors open, a passenger train entered the station on the same rail. After leaving 145th Street, the R-46 test train was stopped in the tunnel to await clearance to enter 125th Street.
11:05 P.M.	–	R-46 enters 125th Street Station. End of test effort.
11:30 P.M.	–	R-46 returns to 207th Street. Initial inspection of data reveals 1 broken accelerometer and one malfunctioning tape recorder.
12 P.M.	–	End of day.

WEDNESDAY, OCTOBER 27, 1976

8 A.M.	–	Test crew arrives at NYCTA. Tape out of 'D' line data begins for NYCTA. Detailed review of data shows one vertical journal box accelerometer took a large zero shift during test. One tape recorder (No. 2) is adding high frequency spikes to all data recorded on it. Removal of test equipment begins.
10 A.M.	–	Tape out of data complete. All undercar test equipment removed from train. Train moved to open doorway and interior equipment is unloaded by fork lift.
12 A.M.	–	All test equipment removed from train. R-46 train returned to normal condition as a 4 car train. Lunch Break.
1 P.M.	–	NYCTA requests reinsulation of two wire junctions using fiberglass preparation. B-V test engineer begins this work. Garrett technician completes packaging of test equipment fork shipment to Philadelphia.
3 P.M.	–	R-46 test train returns to service. Packaging of equipment is completed. Test crew departs for day. Quaker Van Lines truck is scheduled for 9 A.M. Thursday. Forktruck is requested for loading on Thursday.
5 P.M.	–	Test crew meets for final coordination at dinner.
7 P.M.	–	Boeing Vertol test engineer and one Garrett technician fly to Boston to inspect Silverbird transit cars on Thursday.

THURSDAY, OCTOBER 28, 1976

9 A.M.	—	Garrett technician supervises loading and shipment of test equipment to Philadelphia.
10 A.M.	—	Test program completed.

APPENDIX B
DATTIS DATA REDUCTION PROGRAMS

```
// JOB    ZERO ONE  TWO  THREEFOUR FIVE SIX
// FOR DTHIS
*LISTALL
*IOCS(1443PRINTER)
*IOCS(CARD)
C
C
C        DATTIS HISTOGRAM PROGRAM.  (DATA DISTRIBUTION)
C
      REAL  NHSUM, NHITS
      DIMENSION AHDR1(5)
      DIMENSION UNITS(3,14)
      DIMENSION XHIT(100)
      DIMENSION           XMIN(20),DDX(20),NINTV(20)
      DIMENSION KBUFF(151),IDATA(15,10),TCAL(6,13)
      DIMENSION KARD(40)
C
      EQUIVALENCE (KBUFF(1),IDATA(1,1))
C
      DATA AHDR1 / 'DIST', 'RIBU', 'TION', ' DAT', 'A.  ' /
      DATA UNITS/ 'M.P.','H.  ','    ','M.P.','H./S','EC.','G''S','    ',
     1'  ','G''S','    ',' ','G''S','RMS',' ','G''S','RMS',' ','G''S','RMS
     2',' ','G''S','RMS',' ','G''S','RMS',' '           ,'RAD.','2*'/SEC'
     3,'RAD.','2*'/SEC','RAD.','2*'/SEC','DECI','BELS','    ','DECI','BELS'
     4,'    ' /
      DATA SMFRM / 0.0 /
      DATA SUMOC/ 0.0 /
      DATA NCPYS,ICPY / 1,0 /
      DATA NTAPE/ 0 /
      DATA SUM/ 0.0 /
      DATA THITS/ 0.0 /
      DATA XHIT/100*0.0 /
      DATA XMIN/
     * 0.0,-5.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,50.0,
     * 70.0 /
      DATA DDX/
     * 5.0, 0.5, 1.0, 2.0,.005,.005,.005,.005,.005, 0.1, 0.1, 0.1, 2.0,
     * 2.0 /
      DATA NINTV/
     *  20,  20,  50,  25,  20, 100,  40,  20,  20,  10,  10,  10,  25,
     *  70 /
      DATA NHSUM / 0.0 /
      DATA ICHK / 0 /
C
C
C   GET CALIBRATIONS.
      READ(2,20)TCAL
   20 FORMAT(2X,6E13.6)
C  GET PARAMETER, CHANNEL, FIRST FILE NUMBER, NUMBER OF FILES
      READ(2,27)NPARM,NCHAN,IFILE,NFILS,NTAPE,NCPYS,ICHK
   27 FORMAT(7I10)
C  GET COMMENT CARD
      CALL UMAG(KBUFF,150,5,NTAPE,IERR,IRECL)
      READ(2,21)KARD
   21 FORMAT(40A2)
      CMIN = XMIN(NPARM)
      DX = DDX(NPARM)
      IN = NINTV(NPARM)
   26 IFILE = IFILE - 1
      IF ( IFILE ) 420, 30, 29
   29 CALL UMAG ( KBUFF, 150, 1, NTAPE, IERR, IRECL )
      IF ( IERR - 4 ) 29, 26, 29
```

```
 30 CONTINUE
    CALL CNVDT(IMON,IDAY,IYR)
    IYR = IYR-100*(IYR/100)
350 CONTINUE
    WRITE(3,24)IMON,IDAY,IYR
 24 FORMAT('1'/20X,'* * DATTIS PROPERTY TEST * *'//
   *     25X,'DATE PROCESSED',I4,'/',I2,'/',I2)
    WRITE(3,22)KARD
 22 FORMAT(/ 5X,40A2)
    CMAX = IN
    CMAX = CMIN + CMAX*DX
    GO TO (101,102,103,104,105,106,107,108,109,110,111,112,113,114),
   *      NPARM
101 WRITE ( 3, 31 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 31 FORMAT ( // T10, 'SPEED '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
102 WRITE ( 3, 32 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 32 FORMAT ( // T10, 'VEHICLE ACCELERATION '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
103 WRITE ( 3, 33 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 33 FORMAT ( // T10, 'R.H. REAR J.B. VERT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
104 WRITE ( 3, 34 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 34 FORMAT ( // T10, 'R.H. REAR J.B. LAT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
105 WRITE ( 3, 35 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 35 FORMAT ( // T10,  'MID-CAR C/L LONG. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
106 WRITE ( 3, 36 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 36 FORMAT ( // T10, 'FWD. CAR C/L VERT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
107 WRITE ( 3, 37 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 37 FORMAT ( // T10, 'MID-CAR C/L VERT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
108 WRITE ( 3, 38 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 38 FORMAT ( // T10, 'FWD. CAR C/L LAT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
109 WRITE ( 3, 39 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 39 FORMAT ( // T10, 'MID-CAR C/L LAT. ACC. '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
110 WRITE ( 3, 40 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 40 FORMAT ( // T10, 'PITCH ACCELERATION '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
111 WRITE ( 3, 41 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 41 FORMAT ( // T10, 'ROLL ACCELERATION '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
112 WRITE ( 3, 42 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
 42 FORMAT ( // T10, 'YAW ACCELERATION '
   *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4  )
    GO TO 115
113 WRITE ( 3, 43 ) AHDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
```

```
   43 FORMAT ( // T10, 'INTERIOR NOISE LEVEL '
     *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4   )
      GO TO 115
  114 WRITE ( 3, 44 ) ANDR1,CMIN,CMAX,(UNITS(I,NPARM),I=1,3)
   44 FORMAT ( // T10, 'EXTERIOR NOISE LEVEL '
     *,5A4,' RANGE = ',F4.1,' TO ', F5.1, 2X, 3A4   )
  115 WRITE ( 3, 116 ) IN, DX,
     1    ( UNITS(I,NPARM), I=1,3   )
  116 FORMAT (1H ,T15, '( ', I3,
     1      ' INTERVALS, ',F5.3,2X,3A4 ' PER INTERVAL )' )
C
C
      IF ( ICPY ) 100, 100, 340
  100 CONTINUE
      CALL UMAG(KBUFF,150,1,NTAPE,IERR,IRECL)
C  IF EOF, LOOK FOR NEXT FILE OR QUIT.
      IF(IERR-4)99,300,99
   99 CONTINUE
      IF ( ICHK ) 97, 97, 96
   96 WRITE ( 3, 98 )
   98 FORMAT ( 1H , 10('-----',5X))
   97 CONTINUE
C
      DO 200 I=1,150,15
      SMFRM = SMFRM + 1.0
      CALL PING(KBUFF(I),13)
      II = I+NCHAN-1
C FETCH DATA WORD.
      IF ( NPARM -2 ) 93, 91, 93
   91 ATA = FLOAT( KBUFF(II))
      GO TO 95
   93 ATA = FLOAT( IABS( KBUFF(II) ) )
   95 CONTINUE
      CALL CU(ATA,1,TCAL,NCHAN,0.0,1.0)
      IF (NPARM-2) 92, 94, 92
   92 ATA = ABS( ATA )
      GO TO 977
C     CONVRT G'S TO M.P.H./SEC./SEC. USING G= 32.1380 AT 33 DEG. LATITUDE
C      ( REF. HANDBOOK CHEM. & PHYSICS , 49TH EDITION )
   94 ATA = ATA*((3600.0/5280.0)*32.1380)
  977 CONTINUE
C  SELECT INTERVAL.
      L = IFIX( (ATA-CMIN)/DX + 1.0 )
C  CHECK IF INTERVAL IS IN RANGE.
      IF(L-IN)51,51,52
   51 IF ( L ) 52,52,53
   53 XHIT(L) = XHIT(L)+1.0
      THITS = THITS+1.0
   52 CONTINUE
      IF ( ICHK ) 58, 58, 57
   57 WRITE ( 3, 59 ) NPARM,NCHAN,KBUFF(II),ATA,L
   59 FORMAT ( 1H , 'PARAM. NO.= ', I2, '  CHANNEL= ', I2,
     *      '  COUNTS= ', I6, '  PARAM.= ',F13.6, '  INTERVAL NO.= ',I4 )
   58 CONTINUE
      SUMOC = SUMOC + 1.0
  200 CONTINUE
C
      GO TO 100
C
C
C        END OF DATA---NOW SUMMARIZE.
C
```

```
  300 CONTINUE
      NFILS = NFILS - 1
      IF ( NFILS ) 320, 320, 100
  320 CONTINUE
C  REWIND TAPE.
      CALL UMAG(KBUFF,150,5,NTAPE,IERR,IRECL)
  340 CONTINUE
      WRITE(3,28)
   28 FORMAT(  //T11,'INTERVAL', T27,'OCCURRENCES',T44,'FREQUENCY',
     *            T61,'MIDPOINT', T79,'PRODUCT'/' ')
      CSTEP = CMIN
C
      DO 400 I=1,IN
      CMAX = CSTEP+DX
      PMAX = CMAX - 0.00006
      CALL PLACE ( PMAX,4 )
      CAVG = (CMAX+CSTEP)/2.0
      PAVG = (CMAX+CSTEP)/2.0 + 0.00004
      CALL PLACE ( PAVG,4 )
      HITS = XHIT(I)/THITS
      PROD = CAVG*HITS
      PROD = PROD*10.0
      CALL PLACE ( PROD,4 )
      PROD = PROD/10.0
      SUM = SUM+PROD
      NHITS  = XHIT(I)
      NHSUM = NHSUM + NHITS
      HITS = HITS*10.0
      CALL PLACE ( HITS,4 )
      HITS = HITS/10.0
      PSTEP = CSTEP + 0.000004
      CALL PLACE (PSTEP,4 )
      WRITE(3,25)PSTEP,PMAX,NHITS,HITS,PAVG,PROD
   25 FORMAT ( T4,F9.4,' TO ',F9.4, T31,F8.0,T46, F7.5, T60, F9.4, T74,
     *      F12.5  )
      CSTEP = CMAX
  400 CONTINUE
C
      SUM = SUM*10.0
      CALL PLACE ( SUM,4 )
      SUM = SUM/10.0
      WRITE(3,23) NHSUM, SUM
   23 FORMAT(//T11,  'TOTAL OCCURRENCES = ',   F8.0,
     *           T56,'EXPECTED VALUE =',F14.5///' ')
C
C
      ICPY = 1
      NCPYS = NCPYS - 1
      SUM = 0.0
      NHSUM = 0.0
      IF ( NCPYS ) 420, 420, 350
  420 CONTINUE
      WRITE ( 3, 923 ) THITS, SUMOC, SMFRM
  923 FORMAT ( //1H1,'THITS=',F15.8,'SUMOC=',F15.8,'SMFRM=',F15.8 )
      CALL EXIT
      END
*DELET              5 DTHIS *****
*STORECIP           5 DTHIS DTHIS
*CCEND
// END

// END   13 JAN 77 07.993 HRS
```

```
// JOB   ZERO                            FIVE SIX   11 JAN 77 09.231 HRS
// FOR DTILS   11 JAN 77 09.231 HRS
*IOCS(1443PRINTER)
*IOCS(TYPEWRITER)
*IOCS(CARD)
*LISTALL
C
C        DATTIS STATION SUMMARY PROGRAM.
C            DATE----20 SEPTEMBER, 1976.
C
      INTEGER          OLDEM, NEWEM, FRST1
      DIMENSION KBUFF(151),IDATA(15,10),TCAL(6,13),ITIT(40)
C
      EQUIVALENCE (KBUFF(1),IDATA(1,1))
C
      DATA CK/ 0.3068376     /
      DATA BIAS/ 65536.0 /
      DATA STIME/ 0.0 /
      DATA AIRMS/ 0.0 /
      DATA SIARM/ 0.0 /
      DATA SKWHR/ 0.0 /
      DATA RTIML/ 0.0 /
      DATA SDIST/ 0.0 /
      DATA XBIAS/ 0.0 /
      DATA DIST/ 0.0 /
      DATA PRMS/ 0.0 /
      DATA PKWM/ 0.0 /
      DATA SPMX/ 0.0 /
      DATA RREC/ 0.0 /
      DATA NTAPE/ 2 /
      DATA NSTAT/ 1 /
      DATA IFILN  / 0 /
      DATA IPAGE  / 1 /
      DATA LINES  / 1 /
      DATA  K   / 1 /
      DATA FRST1 / 0 /
C
C
C        READ CALIBRATIONS.
      READ(2,20)TCAL
   20 FORMAT(2X,6E13.6)
C        TITLE CARD.
      READ(2,17)ITIT
   17 FORMAT(40A2)
C       IFILN  = FILE NUMBER OF FILE TO BE USED
      READ(2,19) NTAPE, IFILN
   19 FORMAT(2I10)
      CALL UMAG(KBUFF,150,5,NTAPE,IERR,IRECL)
C
C
      NEOF = IFILN  - 1
      IF (IFILN ) 999,999,60
   60 CALL SKEF7(NTAPE,NEOF)
      WRITE(3,30)ITIT, IPAGE
   30 FORMAT(1H1//T10,40A2,' PAGE NO. ',I2//T50, 8('-'),' POWER CONSUMPT
     1ION ', 8('-'),//
     2   /T 3,'STATION', T17, 'DISTANCE', T33, 'TIME', T51, 'KWHR',
     3   T65, 'KWHR/', T80, 'I-ARM', T93, 'MAX SPEED'
     4   /T4,'NUMBER',   T18, '(MILES)',  T31, '(MIN.)', T45, ' ',
     5   T66, 'MILE',  T76, '(AMP-RMS)', T94, '(M.P.H.)'            )
      DT = 0.248/3600.0
C
C
```

```
  100 CONTINUE
C        READ A RECORD FROM DRIVE NTAPE
      CALL UMAG(KBUFF,150,1,NTAPE,IERR,IRECL)
C          IF EOF, QUIT.
      IF(IERR-4)12,300,12
   12 CONTINUE
C
      DO 200 I=1,10
      NEWEM = IDATA(14,I)
      IF ( FRST1 ) 36, 38, 36
   36 IF ( NEWEM ) 40, 300, 40
   38 IF ( NEWEM ) 200, 200, 40
   40 CONTINUE
      IF ( FRST1 ) 44, 42, 44
   42 FRST1 = 1
      OLDEM = NEWEM
   44 CONTINUE
      CALL PING(IDATA(1,I),13)
C      CHECK EVENT COUNTER.
      IF ( NEWEM - OLDEM ) 70, 120, 70
C
   70 NSTAT = NSTAT+1
      IF(NSTAT-2 )74,74,72
   72 RREC = 1.0 + RREC
   74 CONTINUE
      RTIME = RREC
      TDIST = TDIST+XBIAS
      DIST = CK*TDIST/5280.0
      XBIAS = 0.0
      RREC = 0.0
      K = NSTAT
      OLDEM = NEWEM
      GO TO 190
C
C   RUNNING.
  120 CONTINUE
      IF ( NEWEM ) 128, 300, 128
  128 IF ( IERR-4 ) 110, 300, 110
  110 CONTINUE
      RREC = RREC+1.0
      IF(RREC-1.1)121,121,122
  121 IF(NSTAT-1)126,126,125
C    FIRST RECORD RUNNING---FINALIZE SUMMATIONS + PRINT OUT.
  125 RECS = RTIME
      AIRMS = SQRT(AIRMS/RECS)
      RTIME = 0.248*RTIME/60.0
      PKWM = 0.0
      PKWM = PRMS/DIST
      SKWHR = SKWHR+PRMS
      SIARM = SIARM+AIRMS
      X1 = DIST
      X2 = RTIME
      X3 = PRMS
      X4 = PKWM
      X5 = AIRMS
      X6 = SPMX
      CALL PLACE ( X1, 3 )
      CALL PLACE ( X2, 3 )
      CALL PLACE ( X3, 3 )
```

```
      CALL PLACE ( X4, 3 )
      CALL PLACE ( X5, 2 )
      CALL PLACE ( X6, 1 )
      WRITE ( 3, 29 ) K, X1, X2, X3, X4, X5, X6
   29 FORMAT ( /T2, I6, T15, F11.3, T30, F8.3, T45, F11.3, T60,F11.3,
     *         T75, F11.2, T90, F12.1 )
      LINES = LINES + 1
      IF ( LINES-25 )1126,1125,1125
 1125 IPAGE = IPAGE + 1
      WRITE ( 3,30 ) ITIT,IPAGE
      LINES = 1
 1126 CONTINUE
      SDIST = SDIST+DIST
      STIME = STIME+RTIME
      GO TO 127
C        STATION =1----PRINT ALL ZEROES.
  126 WRITE(3,29)K,DIST,RTIME, PRMS,PKWM,AIRMS,SPMX
  127 CONTINUE
      AIRMS = 0.0
      PRMS = 0.0
      SPMX = 0.0
  122 ATA = IDATA(7,I)
C        CHECK SPEED AGAINST MAX SPEED.
      CALL EU(ATA,1,TCAL,7,0.0,1.0)
      IF(ATA-SPMX)150,150,145
  145 SPMX = ATA
  150 IDIST = IDATA(15,I)
      TDIST = FLOAT(IDIST)
      IF(TDIST)21,25,25
C       IF TDIST GOES NEGATIVE, GENERATE BIAS TO ADD IN NEXT TIME.
   21 XBIAS = BIAS
   25 CONTINUE
C
  190 VOLT = IDATA(3,I)
C       LINE VOLTAGE.
      CALL EU(VOLT,1,TCAL,3,0.0,1.0)
      CURR = IDATA(4,I)
C        LINE CURRENT.
      CALL EU(CURR,1,TCAL,4,0.0,1.0)
      IF(CURR)192,193,193
  192 CURR = 0.0
  193 AI = IDATA(5,I)
C        ARMATURE CURRENT.
      CALL EU(AI,1,TCAL,5,0.0,1.0)
C        CALCULATE RMS (KWHR) TERM.
      PRMS = PRMS+(DT*VOLT*CURR/1000.0)
C        CALCULATE RMS (AI) TERM.
      AIRMS = AIRMS+AI*AI
  200 CONTINUE
C
C
C
C
C
      GO TO 100
  300 CONTINUE
C        REWIND TAPE.
      CALL UMAG(KBUFF,150,5,NTAPE,IERR,IRECL)
C        CALCULATE FINAL AVERAGE VALUES.
```

```
      SKWHM = SKWHR/SDIST
      STAT = FLOAT(NSTAT-1)
      SIARM = SIARM/STAT
      IF ( 20-LINES ) 310,320,320
  310 WRITE ( 3, 311 )
  311 FORMAT ( 1H1 )
  320 CONTINUE
      WRITE(3,22)       SDIST
   22 FORMAT(///11X,'TEST RUN SUMMARY'//
     *       3X,'DISTANCE',       F15.3)
C    *       3X,'DISTANCE',       F14.2)
      WRITE(3,23)       STIME
C  23 FORMAT(3X,'TIME ',             F19.2,F14.2)
   23 FORMAT(3X,'TIME ',             F19.3,F14.2)
      WRITE(3,32)SKWHR
C  32 FORMAT(/3X,'TOTAL KWHR',F24.2)
   32 FORMAT(/3X,'TOTAL KWHR',F24.3)
      WRITE(3,33)SKWHM
C  33 FORMAT(3X,'AVE. KWHR/MILE',F20.2)
   33 FORMAT(3X,'AVE. KWHR/MILE',F20.3)
      WRITE(3,34)SIARM
   34 FORMAT(3X,'AVE. I-ARM',F24.2)
      WRITE(3,27)
   27 FORMAT(//15X,'END OF DATA'/'1'//////////' ')
C
      CALL EXIT
  999 WRITE ( 3, 998 )
  998 FORMAT ( 1H1, 20('*'), ' RUN ABORTED BECAUSE INPUT FILE NO. WAS OM
     *ITTED. ', 20('*'))
      CALL EXIT
      END

VARIABLE ALLOCATIONS
 KBUFF(I )=0096-0000 IDATA(I )=0096-0001  TCAL(R )=0132-0098    DT(R )=0134      RRECC(R )=0136     RTIME(R )=0138
 TDIST(R )=013A       XBIAS(R )=013C       DIST(R )=013E        CK(R )=0140      RECS(R )=0142      AIRMS(R )=0144
  PKWM(R )=0146        PRMS(R )=0148      SKWHR(R )=014A     SIARM(R )=014C        X1(R )=014E         X2(R )=0150
    X3(R )=0152          X4(R )=0154         X5(R )=0156        X6(R )=0158      SPMX(R )=015A      SDIST(R )=015C
 STIME(R )=015E         ATA(R )=0160       DIAS(R )=0162      VOLT(R )=0164      CURR(R )=0166         AI(R )=0168
 SKWHM(R )=016A        STAT(R )=016C       IIIT(I )=0197-0170 OLDEM(I )=0198     NEWEM(I )=0199     FRST1(I )=019A
 NTAPE(I )=019B       IFILN(I )=019C       IERR(I )=019D     IRECL(I )=019E      NEOF(I )=019F      IPAGE(I )=01A0
     I(I )=01A1       NSTAT(I )=01A2          K(I )=01A3     LINES(I )=01A4     IDIST(I )=01A5

STATEMENT ALLOCATIONS
 20   =01C3  17   =01C7  19   =01CA  30   =01CD  29   =023F  311  =024F  22   =0252  23   =0269  32   =0271  33   =0278
 34   =0286  27   =028F  998  =02A8  60   =02F5  100  =0308  12   =0316  36   =0327  38   =032D  40   =0331  42   =0335
 44   =033D  70   =0351  72   =035D  74   =0363  120  =0387  128  =0388  110  =0391  121  =039E  125  =03A4  1125 =041F
 1126 =0432  126  =0440  127  =0452  122  =045E  145  =0477  150  =0478  21   =048E  25   =0492  190  =0492  192  =04BB
 193  =04DF  200  =04E5  300  =04F0  310  =0515  320  =0519  999  =053D

FEATURES SUPPORTED
 ONE WORD INTEGERS
 IOCS

CALLED SUBPROGRAMS
 UMAG    SKEF7   PING    FSORT   PLACE   EU      FADD    FSUB    FMPY    FDIV    FLD     FSTO    FLOAT   LDFAC   MRED
 MWRT    MCOMP   MIOAI   MIOAF   MIOF    MIOI    SUBSC   TYPEN   HOLEB   PRNTN   EAPRT   CARDN

REAL CONSTANTS
```

```
 .248000E 00=01A8   .360000E 04=01AA   .100000E 01=01AC   .528000E 04=01AF   .000000E 00=01B0   .110000E 01=01B2
 .600000E 02=01B4   .100000E 04=01B6

INTEGER CONSTANTS
     2=01B8   150=01B9     5=01BA     1=01BB     3=01BC     4=01BD    10=01BE    13=01BF    25=01C0     7=01C1
    20=01C2

CORE REQUIREMENTS FOR DTILS
 COMMON       0  INSKEL COMMON       0
  VARIABLES     424  PROGRAM     924


END OF COMPILATION
```

APPENDIX C
REPORT OF INVENTIONS

The contract, TSC-DOT-580, required the contractor, Boeing Vertol Company, to collect transit car comparative data and compare performance characteristics according to a research design specified by TSC. A project overview is presented in the report's first section; conclusions appear on pages 8-1.

A diligent review of work performed under this contract has revealed no innovations, discoveries, or improvements of inventions.

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