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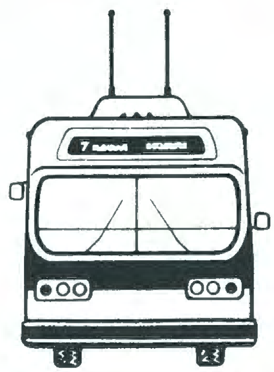
U.S. Department
of Transportation
Urban Mass
Transportation
Administration

TROLLEYBUS PROPULSION EVALUATION



AUGUST 1987 FINAL REPORT

San Francisco
Municipal
Railway

BOOZ, ALLEN & HAMILTON, INC.

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15. Supplementary Notes

16. Abstract

This report documents the findings of a test program conducted on San Francisco Municipal Railway's trolleybus system to evaluate four different types of propulsion systems. Equipment tested in this program was the General Electric switched resistor controller, an air-cooled thyristor chopper made by Westinghouse Electric Corporation, a freon-cooled thyristor chopper made by Alsthom Atlantic, and an AC propulsion system made by Garrett-Stromberg. The report includes a description of each propulsion package supported by schematics and photographs. The data recording equipment (BUSDAC) and the data analysis equipment (PLOTPAC) are described in great detail. The report also includes the test routes, bus loading information, and test schedules. The findings are documented in terms of comparisons of each system's efficiency and ability to regenerate, and a cost analysis comparing switched resistor and advanced propulsion is also presented. The appendices include raw data for each system and example PLOTPAC result forms.

This program was sponsored by UMTA to promote further advancements in trolleybus propulsion systems.

17. Key Words	18. Distribution Statement
Trolleybus propulsion, AC-drive, chopper, regeneration, BUSDAC, PLOTPAC	**Available to the public through the National Technical Information Service Springfield, Virginia 22161**

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NOTICE

NOTICE

PREFACE

The San Francisco Municipal Railway conducted this project to determine the viability of advanced trolleybus propulsion systems in the San Francisco maintenance and operating environment. The work was funded by a Section 6 research, development and demonstration grant from the U.S. Department of Transportation, Urban Mass Transportation Administration (UMTA). The project consisted of two parts. In Part I, a receptivity analysis was conducted. In Part II, demonstration testing of three advanced trolleybus propulsion systems and comparison testing with the existing equipment on MUNI routes was conducted. This report describes the work and results of Part II demonstration testing. This project is one element of UMTA's ongoing efforts to promote advancements in the state-of-the-art for transportation vehicle subsystems.

Technical guidance from UMTA was provided by Mr. P. Sullivan.

The Booz, Allen officer-in-charge of this project was Mr. J. Talley. The work was directed by Mr. D. Turner and technical guidance was provided by Mr. M. McDonald.

The development of testing and data analysis equipment was performed by ACEx who was a subcontractor to Booz, Allen. Mr. J. Cox directed the work for ACEx.

The personnel at MUNI who were instrumental to this project are listed below:

F. Nelson--Program Management
R. Highfill--Engineering Management
D. De Guzman--Technical Assistance
R. Rogers--Maintenance Support
J. Domnigues--Maintenance Support

TABLE OF CONTENTS

LIST OF EXHIBITS

I. SUMMARY

I. SUMMARY

The San Francisco Municipal Railway (MUNI) is one of nine North American transit properties operating electric trolleybuses. MUNI's trolleybuses make up one third of MUNI's transit vehicles, and accommodate about 40 percent of the unlinked passenger trips. MUNI's fleet of trolleybuses are propelled by direct current (DC) motors with switched resistor, or cam, controllers. In view of the expanding transit use of variable voltage DC motor controllers (thyristor choppers) and the quickly developing interest in variable voltage, variable frequency induction motor controllers (AC Drive), MUNI undertook a Trolleybus Propulsion Evaluation Project. The project was conducted for the MUNI by Booz, Allen & Hamilton Inc. of Los Angeles and ACEx (American Computer Exchange Inc.) of Oakland, California.

The project was funded by Section 6 Research, Development and Demonstration grant number CA-06-0147 from the U.S. Department of Transportation, Urban Mass Transportation Administration (UMTA). The project consisted of two parts. In Part I, a receptivity analysis for the trolleybus and light rail traction power distribution system was conducted. In Part II, demonstration testing of three advanced trolleybus propulsion systems and comparison testing with the existing equipment on MUNI routes was conducted. This report describes the work and results of the Part II demonstration testing.

Equipment tested in this program was the General Electric switched resistor controller presently used on the MUNI trolleybus fleet, an air cooled thyristor chopper made by the Transportation Division of Westinghouse Electric Corporation, a freon cooled thyristor chopper made by Alsthom Atlantic, and an AC propulsion system made by Garrett-Stromberg.

The test program was designed to quantify the energy efficiency and performance capabilities of the four trolleybus propulsion systems. The test plan specified that each of the propulsion systems be tested under a broad range of operating conditions such as:

- Empty, seated, and crush passenger loads
- Steep, moderate, and level graded routes.

Test runs were performed for at least two round trips on the three selected routes, with all three loading conditions, for each of the propulsion systems.

The use of advanced trolleybus propulsion systems results in a substantial reduction in net propulsion energy consumption. The energy savings, between stops, ranged between 22 and 53 percent of the baseline propulsion energy required under the same vehicle loading condition on the same routes. Average savings for all the route and loading conditions varied between 35 and 44 percent of the baseline energy consumption, depending on equipment type. The average energy consumption rate of the existing switched resistor equipment was 4.77 kwhr/mi. The combined average energy consumption rate for the advanced equipment was 2.89 kwhr/mi.

Other results of the test program indicated that the use of advanced propulsion systems offered modest performance benefits in terms of improved acceleration control and reduced peak jerk, especially for lightly loaded trolleybuses.

The present value of the projected energy savings ranges from approximately $23,000 to $95,000. The wide range results from variations in the assumed interest rate and the life of the equipment. For an interest rate of 5 percent and an equipment life of 20 years, the present value of the energy savings ranges from $38,000 to $47,700 for the advanced propulsion systems. For an interest rate of 10 percent and an equipment life of 20 years, the present value of energy savings ranges from $26,000 to $32,600.

In future procurements of trolleybus propulsion equipment, any incremental capital costs of advanced propulsion equipment will be able to be evaluated using the data generated from this project.

The remainder of this report is presented in the following chapters and appendices:

- I. Summary
- II. Introduction
- III. Propulsion Systems
- IV. Test Program Results
- V. Findings, Conclusions and Recommendations
- VI. Test Plan
- Appendix A - Test Equipment
- Appendix B - PLOTPAC Results Analysis
- Appendix C - Example PLOTPAC Results

The appendices contain detailed information on the computer-based instrumentation and test results of the MUNI trolleybus propulsion evaluation. The automated data acquisition and analysis tools, developed for MUNI, allowed accurate comparisons of the propulsion systems under test. Similar applications are foreseen for analysis of rail transit propulsion equipment and power distribution systems.

II. INTRODUCTION

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The San Francisco Municipal Railway is one of nine North American transit properties operating electric trolleybuses. MUNI's fleet of trolleybuses is the largest in service, and the number of routes in dense, hilly San Francisco is expanding. Sacramento Street was converted to trolleybus operation in 1981, and Divisadero Street in 1983. MUNI plans to convert at least two more lines in the next five years, and is evaluating the feasibility of converting more than ten others. Preparations are underway to purchase a fleet of articulated trolleybuses, and renewal of the extensive overhead system is continuing.

Trolleybus service is important in San Francisco. In the dense, hilly city, trolleybuses provide quiet, high performance service on major city corridors and residential streets. MUNI's total fleet consists of 345 trolleybuses, 527 diesel buses, 130 light rail articulated vehicles, and 41 cable cars. The trolleybuses make up one third of MUNI's transit vehicles, and they accommodate about 40 percent of the unlinked passenger trips. Exhibit II-1, San Francisco MUNI Trolleybus Operating Statistics Fiscal Year 1983-1984, summarizes the importance of trolleybuses in MUNI's transit service. The trolleybuses provide a disproportionately high percentage of service for a low percentage of operating costs.

EXHIBIT II-1
San Francisco MUNI Trolleybus
Operating Statistics Fiscal Year 1983-84

Trolleybus Fleet Size	345 buses
Percentage of MUNI fleet	33%
Trolleybus passengers	118.6 million
Total passengers	313.1 million
Percentage of passengers	38%
Trolleybus Revenue Miles	7.5 million
Total Revenue Miles	25.2 million
Percentage of Revenue Miles	30%
Trolleybus Revenue Hours	1.0 million
Total Revenue Hours	2.9 million
Percentage of Revenue Hours	36%
Trolleybus Operating Cost	49.7 million
Total Operating Cost	168.8 million
Percentage of Operating Cost	29%

MUNI's fleet of trolleybuses are propelled by DC motors with switched resistor, or cam-controllers. In view of the expanding transit use of variable voltage DC motor controllers (thyristor choppers) and the quickly developing interest in variable voltage, variable frequency induction motor controllers (AC Drive), MUNI undertook a Trolleybus Propulsion Evaluation Project. The project was conducted for the MUNI by Booz, Allen & Hamilton Inc. of Los Angeles and ACEx (American Computer Exchange Inc.) of Oakland, California.

1. THE OBJECTIVES OF THE TROLLEYBUS PROPULSION EVALUATION

The project was funded by Section 6 research, development and demonstration grant number CA-06-0147 from the U.S. Department of Transportation, Urban Mass Transportation Administration (UMTA). The project undertaken by MUNI consisted of two parts. In Part I, MUNI contracted for a receptivity analysis for the MUNI trolleybus and light rail traction power distribution system. In Part II, demonstration testing of three advanced trolleybus propulsion systems, as well as comparison testing of the existing equipment, on MUNI routes was performed.

The receptivity analysis of Part I, as footnoted on the following page, was completed in August 1982, and is the subject of a separate report. This report describes the work and results of the Part II Demonstration Testing.

The objectives of the Part II demonstration testing were to:

- Quantify the cost reductions which can be realized through the use of advanced propulsion controllers, based on their:
  - Increased efficiency
  - Regeneration capability
  - Receptivity of the MUNI traction power network.
- Determine what type routes offer higher cost benefits.
- Observe indications of positive or negative operational impacts, including schedule performance, passenger comfort, acceleration jerk, and gradability.
- Observe indications of positive or negative maintenance impacts, including how effectively the complex assemblies of the propulsion equipment are partitioned into line replaceable units, and the quality of special test equipment and maintenance documentation.

In addition, MUNI developed a general experience base of advanced propulsion equipment and specific experience with the equipment demonstrated. The information derived from the project will aid MUNI in evaluating the application of advanced propulsion equipment for retrofit into the existing fleet, and in incorporating advanced propulsion equipment into future articulated and standard trolleybus procurements.

2. THE BENEFITS OF ADVANCED PROPULSION SYSTEMS

Chopper controlled and AC propulsion systems for transit properties with severe operating profiles and large passenger loads, like the MUNI, have several advantages:

- Advanced propulsion systems use less energy than resistor controlled DC motors when the average travel distance per stop is short. Resistor controlled motors dissipate power in the resistors at low and intermediate speeds. For trolleybuses, as much as 40 percent of the propulsion energy is dissipated in the starting resistors.

- Advanced propulsion systems permit controlled regeneration during braking. In San Francisco, the trolleybus and light rail traction power supplies are coupled together in sections which are extremely receptive to regenerated power. An earlier study predicted that "a weekly average of 93.5 percent of the potentially regenerated power would be received and used in the traction power system. Since up to 25 percent of the propulsion energy can be regenerated, the potential energy savings to the MUNI from general use of advanced equipment would be substantial."*

In addition, a secondary benefit is derived; advanced propulsion systems can provide improved acceleration and jerk performance over resistor controlled motors.

3. THE PROPULSION EQUIPMENT, TEST PROGRAM AND INSTRUMENTATION

In this project, choppers made by Westinghouse Electric Company and Alsthom Atlantic Inc. and an AC drive system made by Garrett-Stromberg were tested in a MUNI trolleybus, and compared to the existing cam-controlled DC motor system. Each propulsion system was tested for energy usage and efficiency, performance, passenger comfort, and regeneration capability.

The test program was designed to highlight the energy efficiency and performance capabilities of the four trolleybus propulsion systems. The test plan specified that each of the propulsion systems be tested under a broad range of operating conditions such as:

- Empty, seated, and crush passenger loads
- Steep, moderate, and level graded routes.

Test runs were performed for at least two round trips on the three selected routes, at all three load conditions, for each of the propulsion systems. More than 150 scheduled test runs were made, in addition to checkout and debugging runs.

To compare the performance of four propulsion systems of unequal ratings, driven under operator control in varying traffic conditions, an intelligent data acquisition and analysis tool was vital. For each trolleybus run over a fixed route, the microprocessor-based data acquisition element, called BUSDAC, was developed. BUSDAC monitored trolleybus speed and acceleration, line, motor, and auxiliary current, voltage and power, trolleybus grade inclination, and test status of the propulsion system.

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* Garrett AiResearch Manufacturing Company, San Francisco Municipal Railway Receptivity Study, Report 82-19078, August 1982.

BUSDAC recorded the data on cartridge tape for off-line analysis. Data are grouped in intervals, called segments. Each segment is the time period between each start and stop of the trolleybus. Exhibit II-2 shows a schematic diagram of BUSDAC connections to the test trolleybus. Exhibit II-3 shows BUSDAC installed on MUNI trolleybus 5161, which was the trolleybus used throughout the project.

Data analysis programs, called PLOTPAC, retrieve the run data from the tape, reorder the data into time sequential records for each parameter, perform selected statistical and analytic functions, and provide the synthesized reports. Using the data, performance of different types of equipment operated under similar but distinct conditions was compared on the basis of statistically validated and selected data.

4. THE PROJECT RESULTS

Exhibit II-4, Example of MUNI Trolleybus Propulsion Test Results, shows an example of the energy measurement results for the four propulsion systems, the average energy consumed by each system, and how the energy was used. Each of these systems was installed on MUNI trolleybus number 5161. For each of the propulsion systems, the energy used was measured on two runs on the #8 - Market Street outbound route, with a ballisted seated load of 50 people at 150 lbs. each. The one-way route is 3.4 miles long, and gradually rises 122 feet over the run.

Some definitions are essential to fully understand Exhibit II-4. They are:

- Cont. = The energy dissipated in the propulsion controls.
- Motor = The net energy used in the motor.
- Dyna. = The energy not regenerated to the traction power system.
- Regen. = The energy regenerated to the traction power system.
- The total energy used by each system = The total height of the three bars above the line.

A complete set of test result summaries is given in Chapter V.

EXHIBIT II-2

Schematic Diagram of BUSDAC Connections to Test Trolleybus

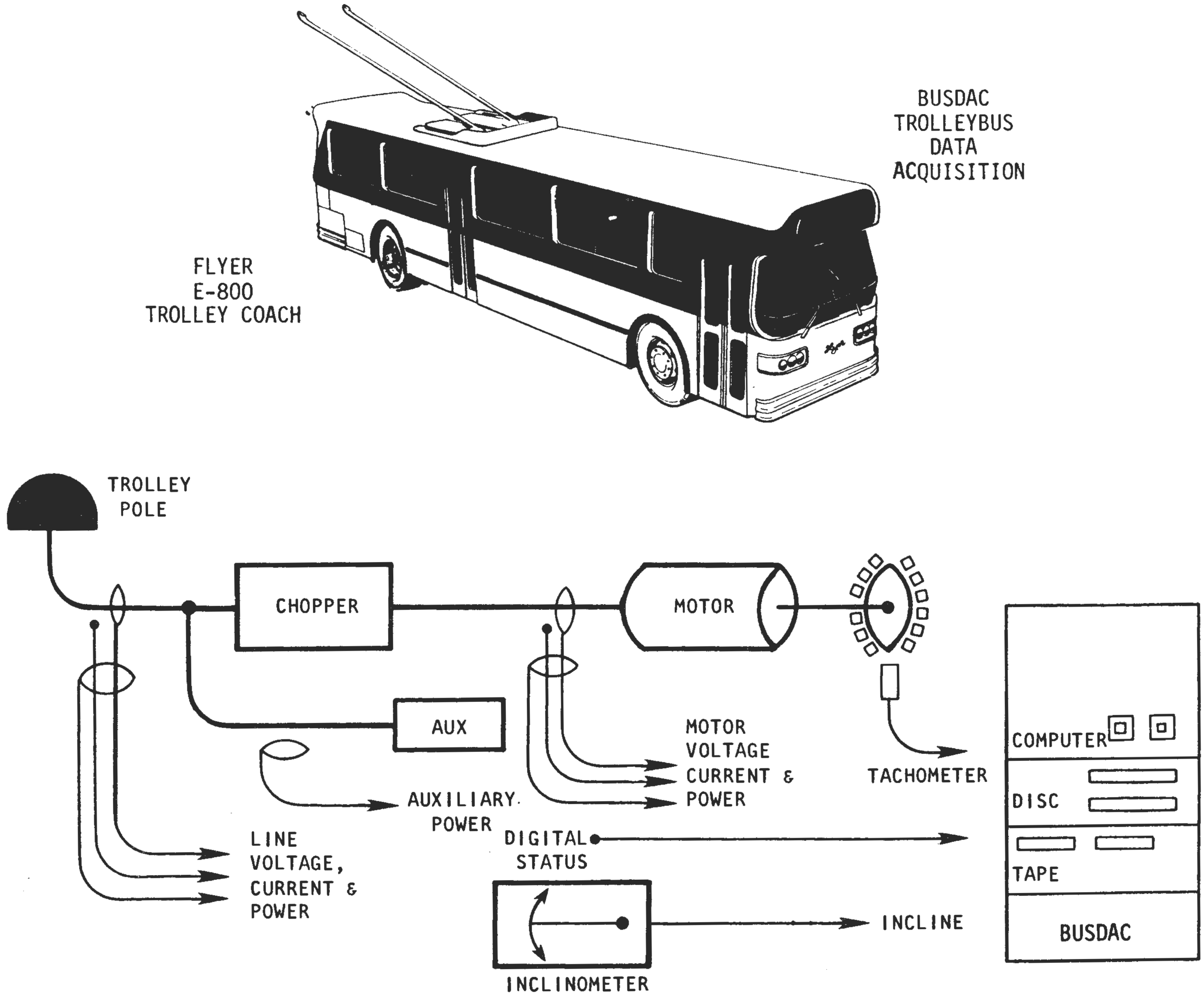
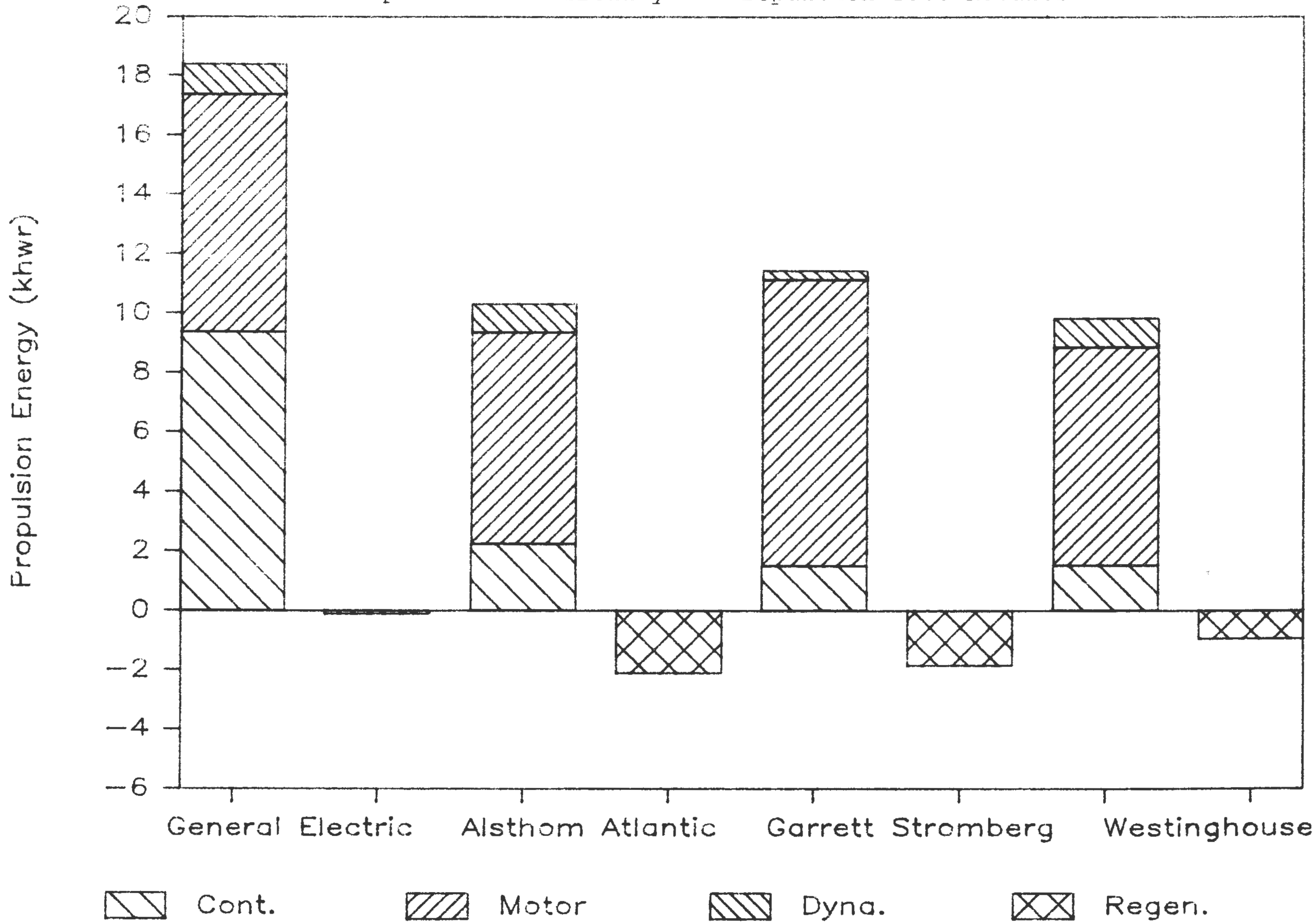


EXHIBIT II-3

BUSDAC Installed on Trolleybus 5161

EXHIBIT II-4

Example of MUNI Trolleybus Propulsion Test Results



III. PROPULSION SYSTEMS

III. PROPULSION SYSTEMS

The Trolleybus Propulsion Evaluation Project tested four propulsion systems: the existing equipment and three advanced systems. They were:

- General Electric DC motor and switched resistor controller
- Garrett-Stromberg 3-phase induction motor and variable voltage, variable frequency AC controller
- Westinghouse DC motor and chopper controller
- Alsthom Atlantic using the existing general electric DC motor chopper controller.

1. SWITCHED RESISTOR - THE BASELINE SYSTEM

The existing General Electric (GE) MRC Cam controller and type 1213 DC motor was considered the baseline system for the comparative analyses. The characteristics of the GE equipment included:

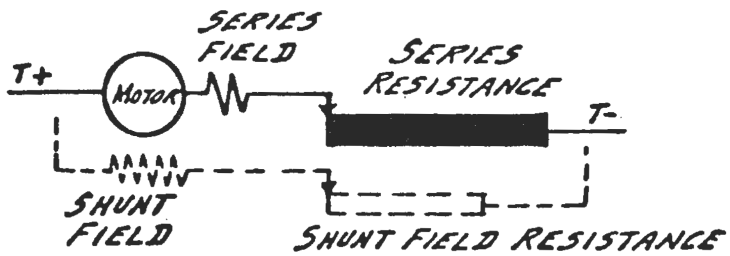
- 155 hp continuous, 214 ampere, compound-wound, 600 vDC, self-ventilated motor.
- 14 steps of resistive and field shunt control in propulsion, with resistive soft-start, current limiting, and dynamic braking.
- Controlled dynamic brake with no control or inhibiting of regeneration to the trolleybus lines. (Uncontrolled regeneration occasionally occurs when rolling downhill.)
- Hill climbing boost button.
- Approximate weight - 1970 lbs.
  - Motor - 1430 lbs.
  - Controller - 540 lbs.

The General Electric switched resistor controller is a pneumatically controlled switching mechanism that provides acceleration control, speed control, and dynamic brake control of the motor. Exhibit III-1, General Electric MRC Motor Controller, illustrates the approach used to control the propulsion system. Fourteen steps of acceleration, five steps of speed control, and five steps of dynamic braking are provided.

EXHIBIT III-1

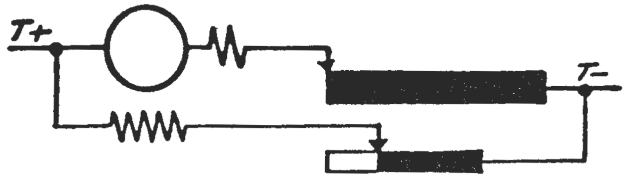
General Electric MRC Motor Controller

ACCELERATION



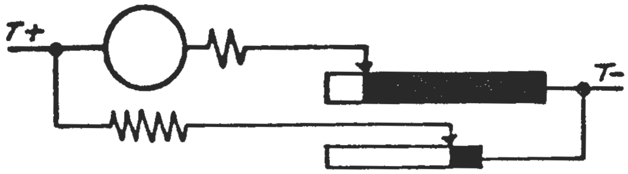
STEP NO. 1

SERIES MOTOR - FULL SERIES RESISTANCE - NO SHUNT FIELD



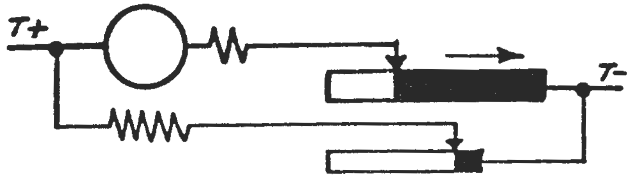
STEP NO. 2

CUMULATIVE COMPOUND MOTOR
FULL SERIES RESISTANCE
PARTIAL SHUNT FIELD RESISTANCE



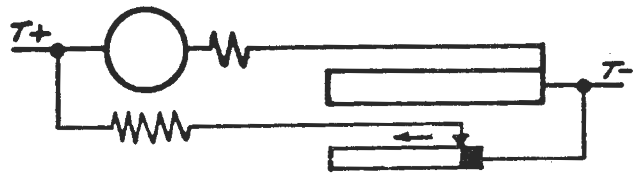
STEP NO. 3

CUMULATIVE COMPOUND MOTOR
PARTIAL SERIES RESISTANCE
PARTIAL SHUNT RESISTANCE



STEPS NO. 4 TO NO. 10 INCLUSIVE

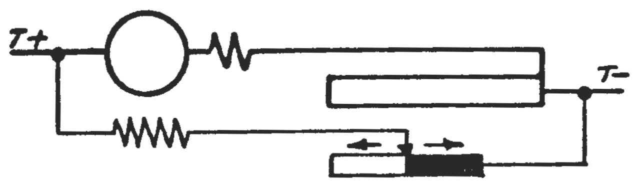
CUMULATIVE COMPOUND MOTOR
SERIES RESISTANCE GRADUALLY CUT OUT, FULL SHUNT FIELD



STEPS NO. 11 TO NO. 14 INCLUSIVE

CUMULATIVE COMPOUND TO SERIES MOTOR
NO SERIES RESISTANCE
SHUNT FIELD GRADUALLY REDUCED TO ZERO

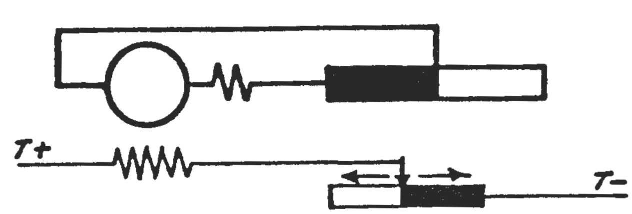
SPEED CONTROL



STEPS NO. 10 TO NO. 14 INCLUSIVE

CUMULATIVE COMPOUND, DIFFERENTIAL COMPOUND OR SERIES MACHINE
NO SERIES RESISTANCE
SHUNT FIELD VARIED

DYNAMIC BRAKING



POSITIONS NO. 1 TO NO. 5 INCLUSIVE

DIFFERENTIAL COMPOUND MACHINE
FIXED SERIES RESISTANCE, SHUNT FIELD VARIED

Adjustable series field and shunt field resistors, in series with the motor armature and shunt field, provide stepwise motor control. In the braking mode the motor is run as a differential compound machine with a fixed series resistor and a variable shunt field. Uncontrolled regeneration can occur when braking on a downhill grade. A hill-climbing boost button control is provided, which permits the overcurrent limit to be temporarily exceeded, providing extra hill climbing power.

Exhibit III-2 shows the switched resistor controller and associated relays located at the rear of the trolleybus. Series and shunt field resistors are mounted on the trolleybus undercarriage, and the motor is mounted almost directly beneath the controller housing.

The motor is rated at 155 hp continuous, with a maximum speed of 3750 rpm. It is a 4-pole, compound-wound commutating pole, DC motor with self-ventilation.

Routine maintenance on the system consists of motor brush replacement and replacement or refinishing of relay and power contactor electrical contacts.

2. GARRETT-STROMBERG AC DRIVE

The Garrett-Stromberg AC drive system uses a three phase induction motor and variable-voltage, variable-frequency inverter. The characteristics of the AC drive include:

- 150 hp continuous, 240 amperes rms, three phase 460 vAC, totally enclosed, force ventilated three phase induction motor.
- Continuous control from zero to full power in propulsion and dynamic braking. Adjustable acceleration and jerk limits.
- Regeneration down to 0 mph.
- Approximate weight - 2,460 lbs.
  - Motor - 1410 lbs.
  - Controller - 1050 lbs.

The Garrett-Stromberg system provides continuous control of trolleybus speed by transforming the 600 vDC line voltage to a variable 3-phase AC voltage at a variable frequency between 0.5 and 115 Hz. The main components of the propulsion system are shown in Exhibit III-3, Garrett-Stromberg AC Drive Schematic. The main components include the inverter, line chopper, braking chopper circuit, LC filter, and control circuits which are not shown.

The line chopper and the inverter control the amplitude and the fundamental frequency of the AC voltage. When supplying tractive power, the inverter operates in two ranges as the trolleybus speed increases: the constant flux and constant torque range, with increasing voltage and frequency; and the field weakening range with increasing frequency and constant voltage. The rated output voltage is 460 vAC in the acceleration mode.

EXHIBIT III-2

General Electric Switched Resistor Controller

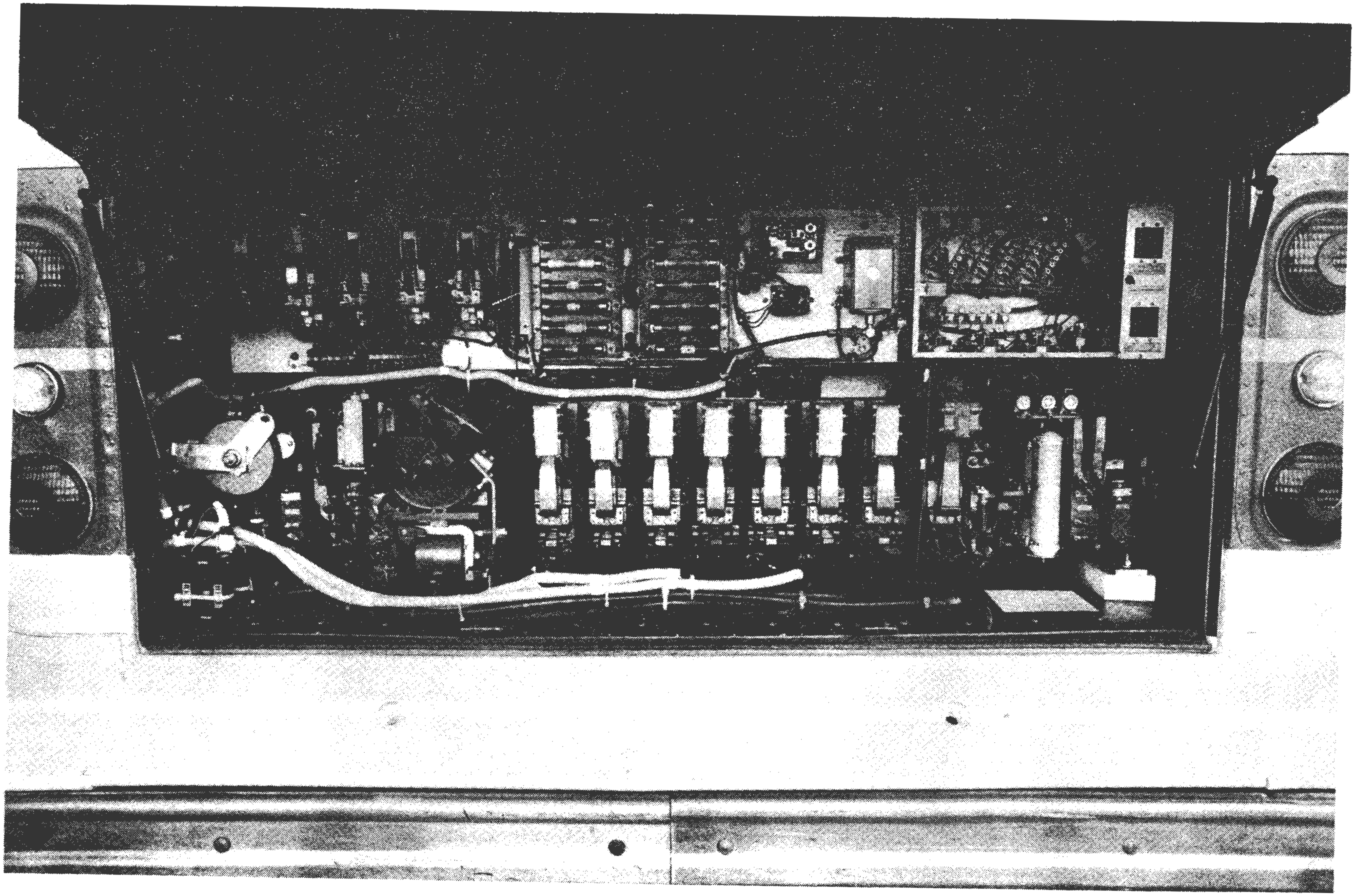
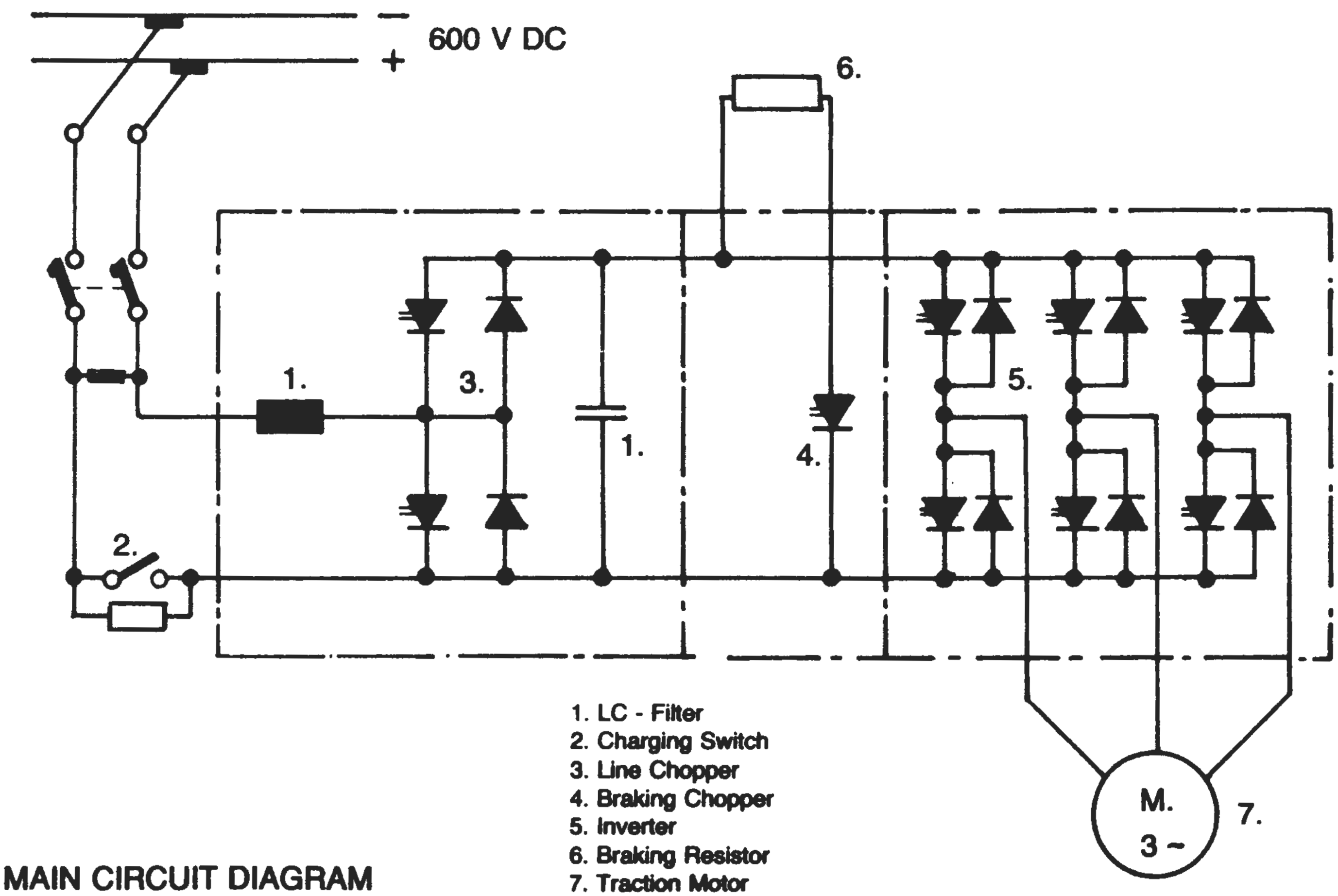


EXHIBIT III-3

Garrett-Stromberg AC Drive Schematic



MAIN CIRCUIT DIAGRAM

In the braking mode, the inverter transfers power from the motor, now acting as a 3-phase generator, to provide either dynamic braking or regenerative braking. The dynamic braking resistor shunts the inverter, as diagrammed in Exhibit III-3, and dynamic braking power is controlled by the braking chopper in series with the resistor. Alternatively, the line chopper can be switched on when the internal DC voltage becomes greater than the line voltage, to maximize power transfer to the line. The inductor capacitor (LC) filter acts to prevent harmonics from appearing in the line and smooths current flow to the motor.

Exhibit III-4, Garrett-Stromberg Chopper-Inverter Unit, shows the inverter as installed underneath the trolleybus, on the curb side, between the front and rear doors.

The Garrett-Stromberg traction motor, shown in Exhibit III-5, is a 3-phase squirrel cage induction motor, type HXUR/E 562 G2. The motor is totally enclosed and is cooled by a shaft mounted fan, which blows air along the internal ribbed surface of the motor. Heat is transferred through the motor case to the external environment. Cooling air does not enter the motor, protecting the motor windings from contamination.

Routine system maintenance includes periodic inspection and renewing of the line switch and charging switch contacts. The AC motor, of course, has no commutator.

The inverter uses conventional thyristors for power switching and generation of the variable voltage, variable frequency output. The inverter control logic consists of numerous analog and digital circuits, contained in an electronics card cage enclosure. A maintenance test set can be connected to a dedicated test connector, to monitor the control signals for maintenance troubleshooting. Automated test equipment was not provided for the MUNI test. However, Garrett-Stromberg indicated that automatic test equipment can be made available.

The equipment provided for the trolleybus test did not include automatic protection against polarity reversal of the overhead lines. Manual provision was made to open the line breaker when the trolleybus approached the few known polarity reversal locations on the test routes. Garrett-Stromberg indicated that the solution to automatic protection is straightforward and the equipment is available.

3. WESTINGHOUSE CHOPPER

The characteristics of the Westinghouse chopper system included:

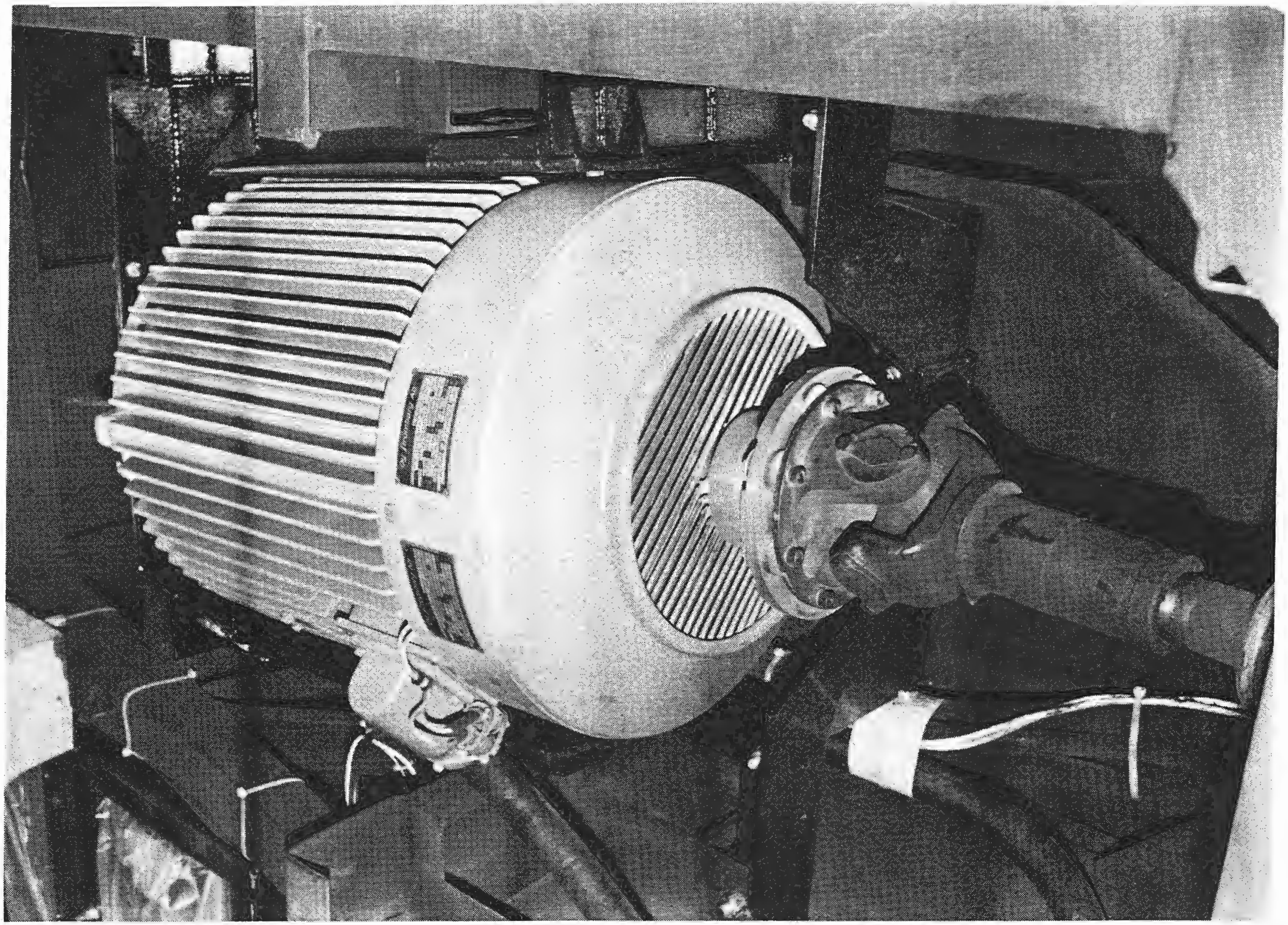
- 140 hp continuous, 194 ampere, series-wound 600 vDC, type 1442, self-ventilated motor.
- Continuous control from zero to full power, in propulsion and dynamic braking, noting that electric brake capability fades at low speeds. Adjustable acceleration and jerk limits. Provision for a battery auxiliary power unit.
- Regeneration provided down to 2.5 mph.
- Approximate weight - 3,254 lbs., including converters for off line operation and auxiliary onboard power conditioning:
  - Motor - 1530 lbs.
  - Controller - 1724 lbs.

EXHIBIT III-4

Garrett-Stromberg Chopper-Inverter Unit

EXHIBIT III-5

Garrett-Stromberg Traction Motor 3-Phase 460 vAC



The Westinghouse chopper achieves continuous control of the DC motor by pulse-width modulating the DC input line voltage. The average voltage across the motor can be varied from zero to full line voltage. The Westinghouse Chopper Schematic, Exhibit III-6, shows the field winding FLD, field shunt FS, motor armature A, input bridge BR, and the main switching circuits: the main chopper T1 & T2; the regenerating switches TB4 & TB5, the regeneration controls TB1, TB2, TB3, R1, R2, and R3, and the brake chopper circuit, T5, T6 and R5.

Braking can be either dynamic or regenerative. Motor power can be transferred back to the line when the motor voltage exceeds the line voltage. Regeneration control is provided by the thyristors TB, TP1, and TPC and resistors R1, R2, and R3. If motor output voltage is insufficient to regenerate or if the line voltage rises to a preset limit, then dynamic braking is provided by the brake resistor R5 and chopper T5, T6.

Exhibit III-7, Westinghouse Chopper Rear View, shows the chopper unit mounted in the test trolleybus. To simplify the test arrangement, the chopper was mounted inside the passenger compartment, rather than in the rear equipment compartment. Westinghouse, however, has installed similar equipment in the rear equipment compartment of a trolleybus made by the same supplier.

The motor used in the test is shown in Exhibit III-8, Westinghouse Traction Motor.

Routine maintenance for the Westinghouse equipment includes inspection and periodic replacement of the traction motor brushes, and maintenance of the line switches.

The chopper is controlled by microprocessor-based control logic, contained in an electronics card cage holding six circuit cards. Extensive built-in self-test diagnostics are provided, operating under microprocessor control. The diagnostics indicate failed components or circuits by a coded display, which is interpreted using a troubleshooting guide.

The equipment includes a built-in provision for off wire operation using a converter energized by a 72 volt battery pack for low speed, limited range operation. The equipment also includes a second converter for charging 12 volt and 72 volt batteries and powering the trolleybus auxiliaries, including heating, lighting, and ventilation. Neither of the auxiliary converters were used in the trolleybus test.

4. THE ALSTHOM ATLANTIC CHOPPER

The characteristics of the Alsthom Atlantic chopper included:

- Full compatibility with the existing GE traction motor.
- Continuous control from zero to full power, in propulsion and dynamic braking. Adjustable acceleration and jerk limits.
- Regeneration down to 2 mph.
- Approximate weight - 2,630 lbs.
    - GE motor - 1,430 lbs.
    - Controller - 2,024 lbs.

EXHIBIT III-6

Westinghouse Chopper Schematic

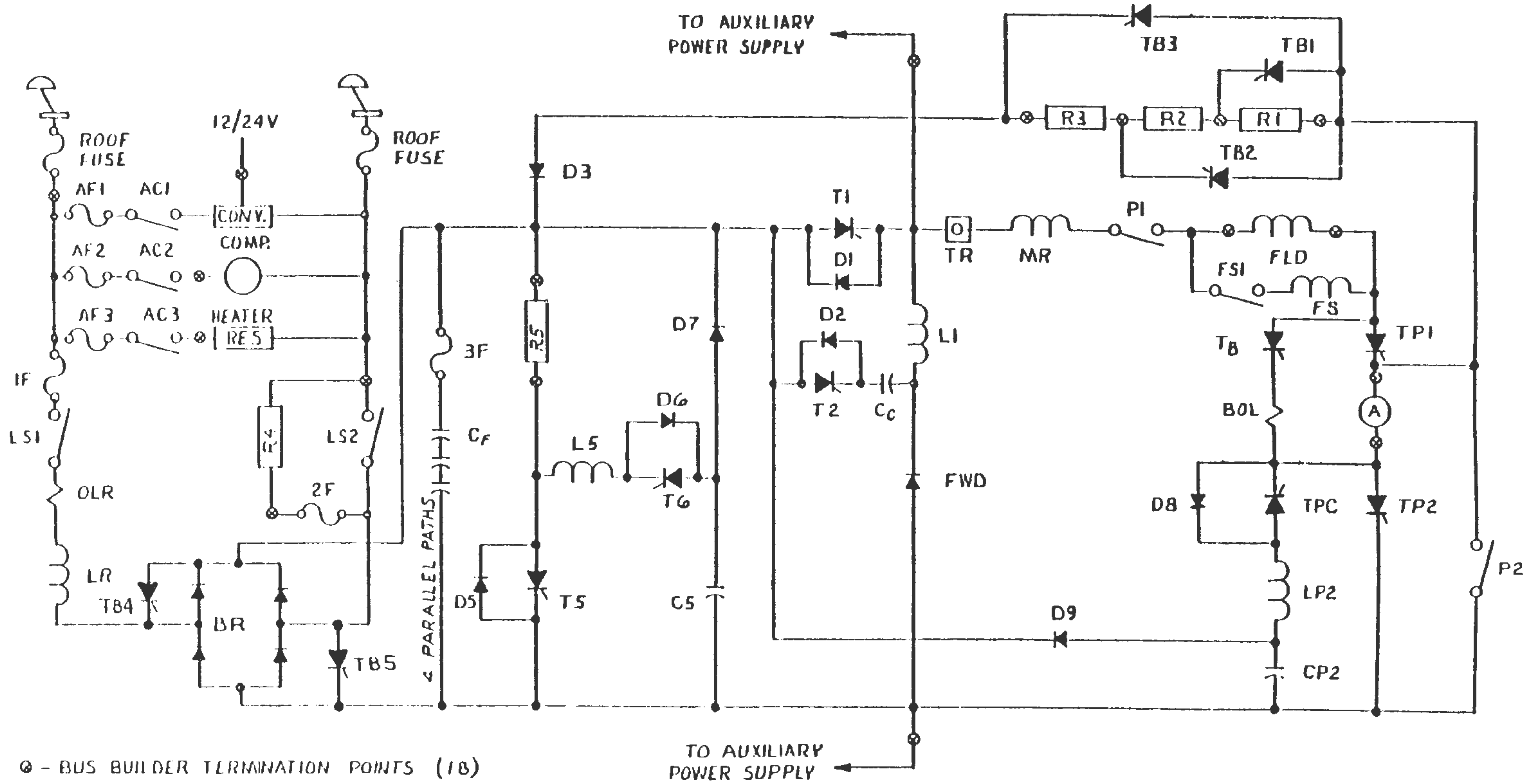


EXHIBIT III-7

Westinghouse Chopper Rear View

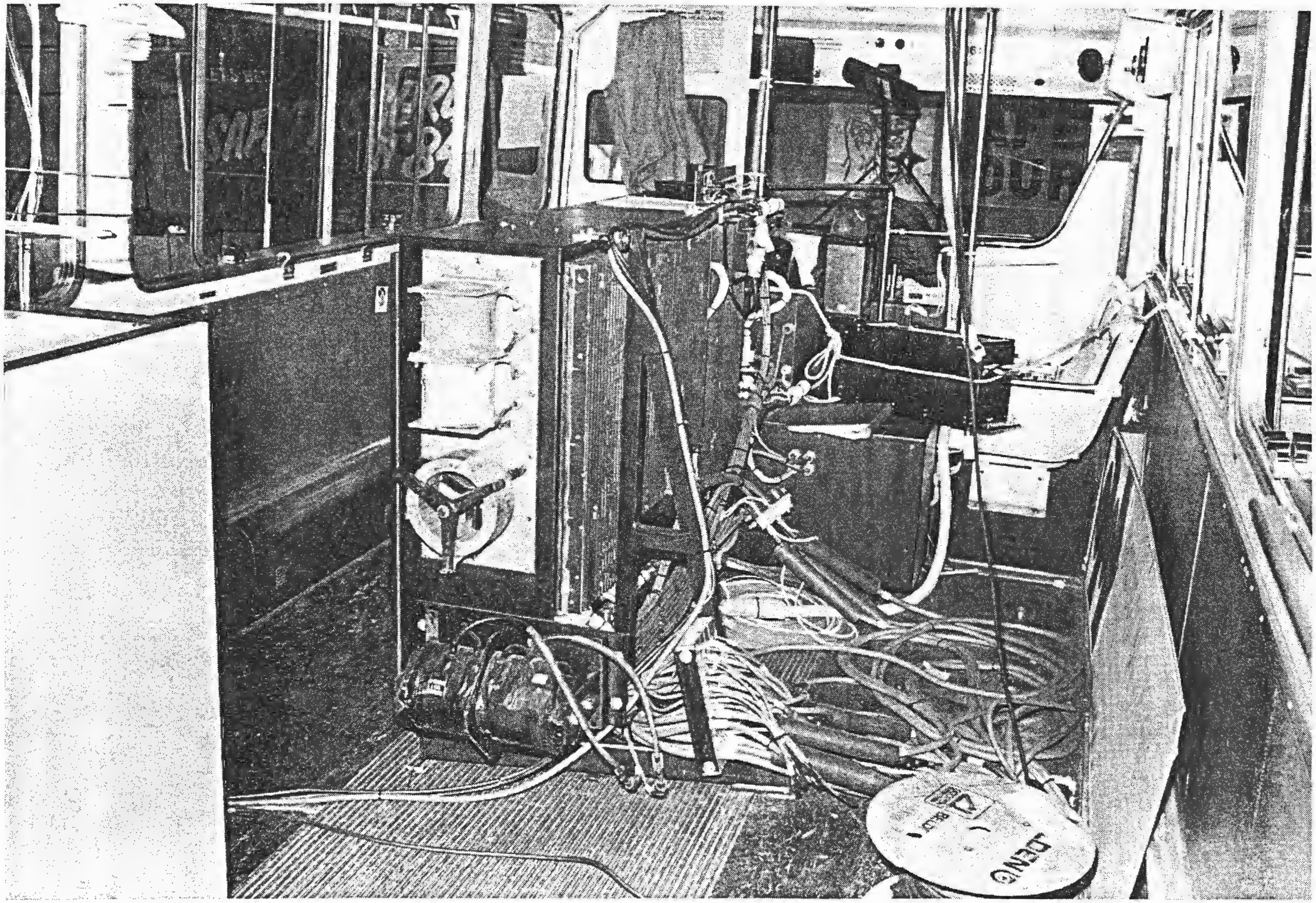
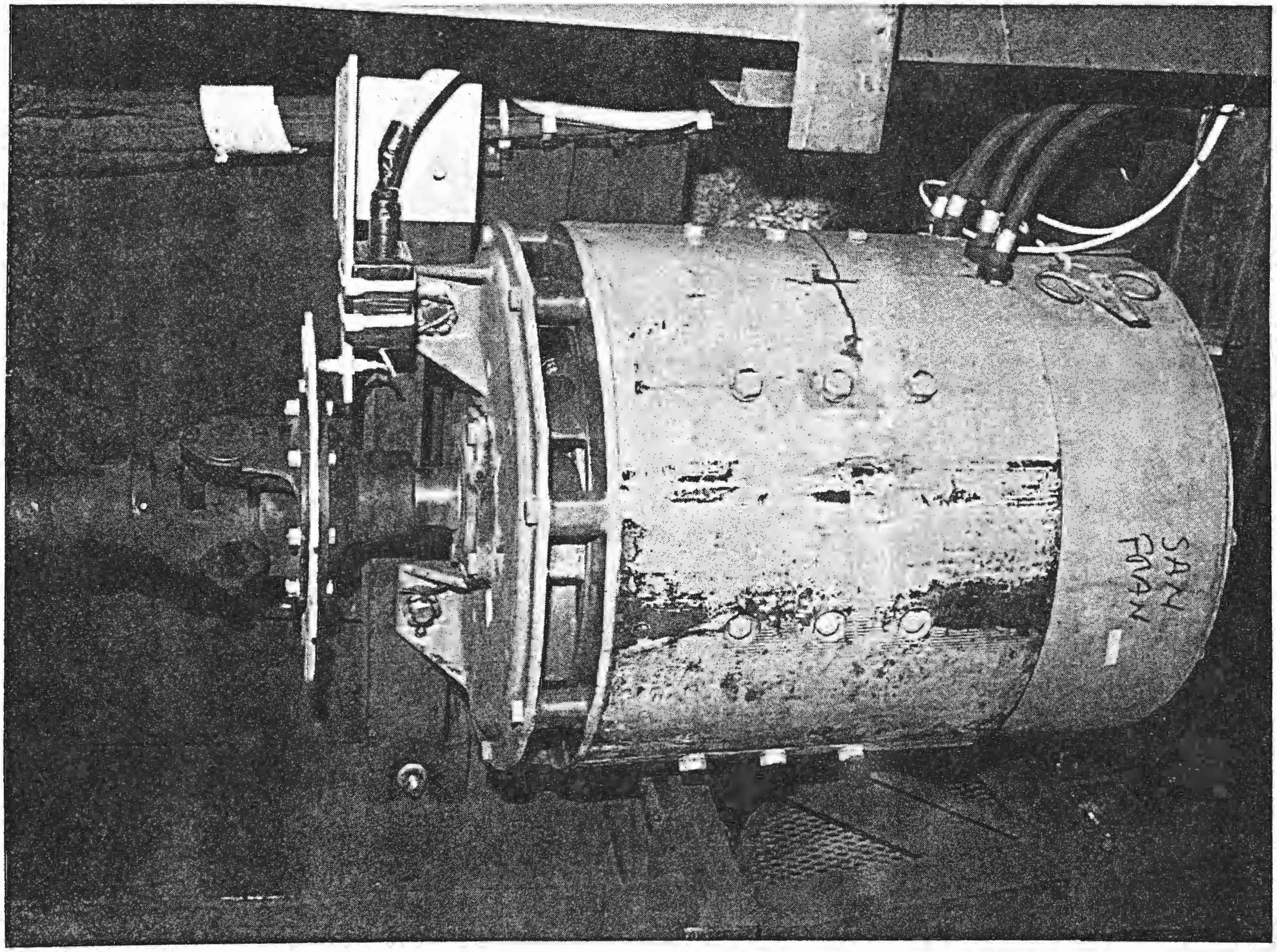


EXHIBIT III-8

Westinghouse Traction Motor



The Alsthom Atlantic controller is a pulse-width modulated voltage chopper, as shown in Exhibit III-9, Alsthom Atlantic Chopper Schematic. The Alsthom Atlantic system provides separate chopper circuits for the traction motor armature and shunt windings, in order to control the compound motor.

A unique feature of the Alsthom Atlantic system is the use of liquid-cooled thyristor assemblies, as shown in Exhibit III-10, Thyristor Unit Removal from the Freon Tank. The thyristors are immersed in a sealed tank of freon. The tank is cooled with external air by natural convection. The freon-cooled thyristor assembly was designed to be mounted on the roof of or underneath the trolleybus. Exhibit III-11 is a photograph of the chopper unit mounted on the test trolleybus roof.

The motor used for the Alsthom Atlantic tests was a GE type 1213, which is presently used on the entire MUNI trolleybus fleet.

The Alsthom Atlantic accelerator and brake pedal assembly used in the test differs from the conventional North American arrangement. The accelerator provides full electrical braking when released. As the accelerator is depressed through the first quarter of its travel, electrical braking is reduced to zero. As the pedal is further depressed, electrical propulsion is applied. Releasing the pedal at any time applies full electrical braking. The brake pedal provides only friction braking. Alternative pedal arrangements which control all braking from the braking pedal are also available.

Routine maintenance requirements for the system include inspection, motor brush replacement, and line switch maintenance.

The inverter control logic consists of numerous analog and some digital circuits, contained in two electronics card cage enclosures. A maintenance test set can be connected to a dedicated connector, and permits monitoring of the control signals for maintenance troubleshooting. A test connector on the freon-cooled thyristor tank allows testing of all the thyristors and power components without disassembling the tank. Automated test equipment was not provided for the propulsion evaluation test.

EXHIBIT III-9

Alsthom Atlantic Chopper Schematic

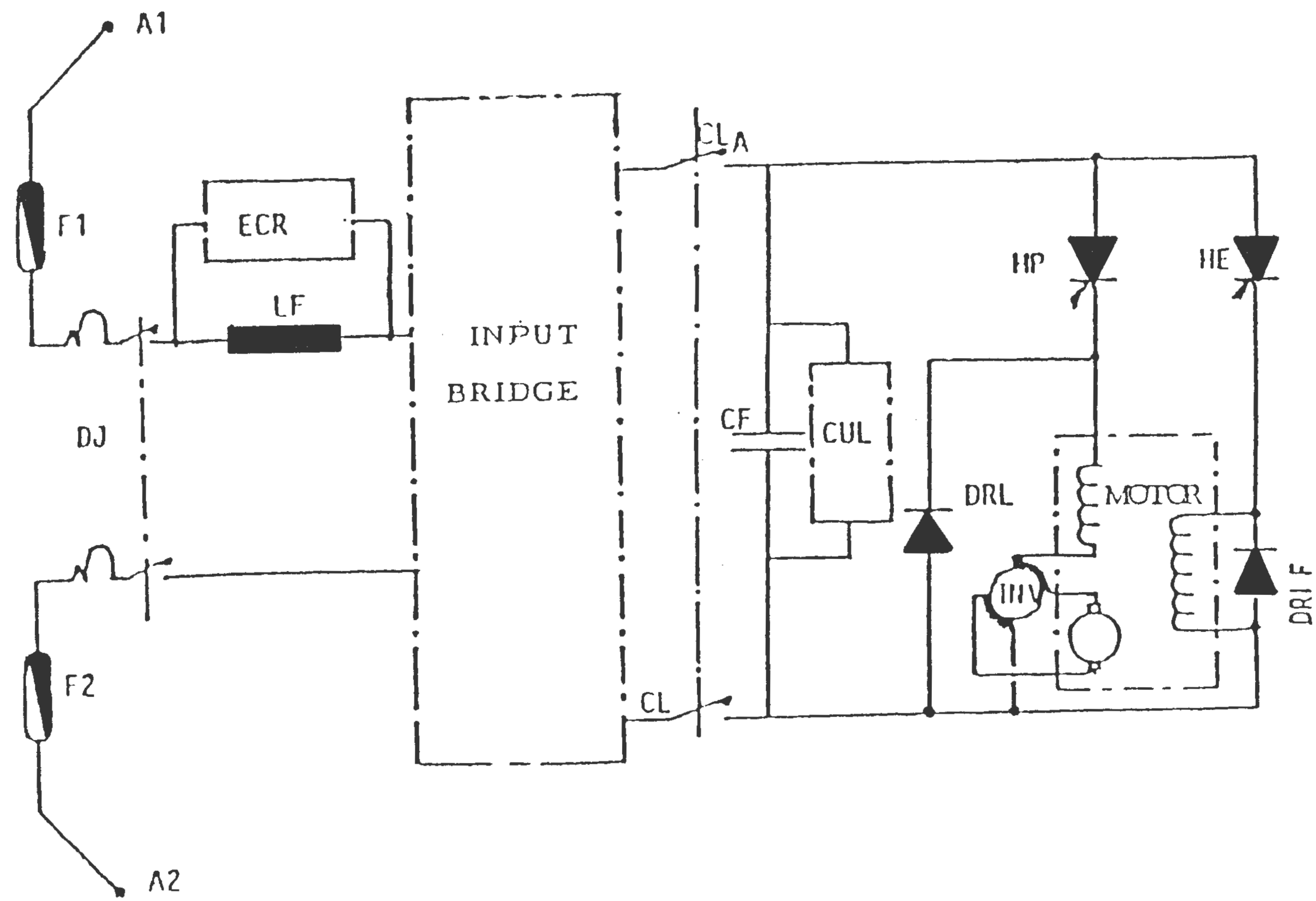


EXHIBIT III-10

Thyristor Unit Removal from the Freon Tank

EXHIBIT III-11

Alsthom Atlantic Chopper Mounted on Test Trolleybus Roof

IV. TEST PLAN

IV. TEST PLAN

The test plan for the project called for comparison tests to be made between the existing equipment and the three advanced propulsion systems, under conditions which corresponded closely to MUNI revenue service. The objectives of the test plan were to:

- Ensure that the test results were objective, complete and accurate
- Structure the testing so that test results would yield information useful for MUNI's equipment engineering and planning
- Deliver test results that provided insight into the efficiency, performance, and operation of the propulsion equipment.

The test plan was designed to achieve the objectives and to highlight the capabilities of the systems under test in two areas. First, provisions were made to quantify the energy consumption, regeneration, and efficiency of the power controllers and motors. Particular attention was paid to the capability of the equipment to regenerate a maximum amount of kinetic energy into a receptive traction power supply. Situations in which the receptivity of the traction power system limited energy savings received close attention. The second capability of interest was the trolleybus performance, measured in terms of acceleration, jerk, and grade ascending and descending performance.

In addition, attention was paid to any feature which impacted operations or maintenance of the equipment. For example, the test program was not extensive enough in scope to permit suppliers to provide equipment specifically designed to a single set of performance criteria. Instead, the program used "off-the-shelf" systems, usually modified slightly from the supplier's most recent trolleybus project. Direct comparison of performance between systems must be conditioned by recognition of differences in system specifications.

In addition, to expedite the test program, the easiest possible means was selected to install the propulsion equipment into test trolleybus 5161. The final arrangements included:

- The Garrett-Stromberg equipment installed beneath the trolleybus, on the curb side. This installation was the closest to revenue readiness.
- The Westinghouse equipment installed inside the passenger compartment.
- The Alsthom Atlantic equipment installed on the trolleybus roof, with power cables and control equipment in the passenger compartment.

No attempt was made to install the equipment in a configuration suitable for revenue service.

1. TEST ROUTES

To assess the capabilities of the equipment in the MUNI operating environment, the test program was established to run the test trolleybus over three routes, which were:

(1) Number 8 - Market Street

The Number 8 - Market Street route is 3.4 miles long. It gradually rises 122 feet in the outbound direction, as it runs from the Stewart Terminal downtown to Collingsworth and 18th streets. Of the 82 MUNI routes, it ranks 11th in terms of passengers per vehicle mile.

(2) Number 5 - Fulton Street

The Number 5 - Fulton Street route is 6.8 miles long. In the outbound direction, it rises from nearly sea level at the Stewart Terminal up to a 10 percent grade to a peak altitude of 334 feet above its starting elevation, and then descends to fourteen feet above its starting elevation, near Cabrillo and La Playa streets. It ranks 41st in passengers per vehicle mile.

(3) Number 41 - Union Street

The Number 41 - Union Street route is 3.4 miles long. In the outbound direction, it rises from Mission and Howard streets up 19 percent grades to a peak altitude of 266 feet above its starting elevation, and then descends to 51 feet above its starting elevation, at Union and Steiner streets. It ranks 15th in passengers per vehicle mile.

The selected routes were considered representative of MUNI grades and duty cycles.

2. WEIGHT AND PASSENGER LOADING

Provision was made to successively install each of the propulsion systems in MUNI's trolleybus 5161, a Flyer E-800 trolleybus typical of the existing in-service fleet. At the start of the test program, trolleybus 5161 weighed 22,880 pounds on a certified public scale.

For each of the routes, round trip runs were made at three simulated passenger loadings. The passenger loadings were:

- Empty
- Seated load
- Crush load.

When empty, the trolleybus carried only the propulsion equipment, the BUSDAC data acquisition system, the driver, the BUSDAC operator, and the propulsion supplier's technician. The BUSDAC system and the staff contributed about 800 pounds to the gross empty weight of the trolleybus. Some seats were removed from the trolleybus, partially offsetting the weight of the BUSDAC equipment.

In the empty condition, compensation was not made for the basic weight differences between the four propulsion systems, since it was assumed that equipment weight differences would result in weight differences in a factory equipped trolleybus. Minor reductions were permitted to compensate for extra equipment used only for the test program, which would not be part of a factory equipped trolleybus.

In the seated load condition, the trolleybus carried the equivalent additional weight of 50 seated passengers of 150 pounds each, or 7500 pounds. The actual added weight was adjusted to compensate for the staff on board and the BUSDAC equipment weight.

In the crush load condition, the trolleybus carried the equivalent additional weight of 50 seated and 25 standing passengers of 150 pounds each, or 11,250 pounds.

Exhibit IV-1, Trolleybus Test Weights, shows the weight of the trolleybus for all three loading conditions for each of the propulsion systems under test.

EXHIBIT IV-1
Trolleybus Test Weights

	Loading		
Equipment	Empty	Seated	Crush
General Electric	23,340 lbs.	30,530 lbs.	34,280 lbs.
Garrett-Stromberg	25,180	32,370	36,120
Westinghouse	26,040	33,230	36,990
Alsthom Atlantic	25,908	32,410	36,160

3. PREPARATIONS

The preparations for each of the propulsion system tests were similar, and are discussed in more detail in the following sections.

(1) BUSDAC Installation

Before the first test, BUSDAC was installed in trolleybus 5161. BUSDAC installation required:

- Bolting two half-height equipment cabinets to the floor, in the middle rear of the trolleybus. The computer cabinet was mounted on vibration isolating mounts. Power for BUSDAC was taken from the trolleybus 12 volt battery.

- Mounting the power sensor panel and fuse assembly on the rear seat, inside the trolleybus.

- Connecting the voltage, current, and power sensors to the motor, trolley line, and auxiliary connection points in the rear equipment compartment.

- Installing the tachometer gear wheel on the drive shaft and mounting the tachometer sensor on the transverse motor mount beam.

- Connecting the digital status indicators to BUSDAC. These included the "air compressor on" and "hill climb boost" button.

- Connecting the BUSDAC cables.

For each of the equipment installations, BUSDAC was connected to the propulsion system by first installing the voltage, current, and power sensors at the proper points. The BUSDAC sensor was configured to measure either AC or DC motor power through the flip of a switch.

(2) Propulsion Equipment Installation

For each of the propulsion systems except the in-service General Electric equipment, the test equipment was installed by equipment supplier engineers and technicians, MUNI project and Presidio shop personnel, and consultants.

(3) Shakedown Demonstration

The trolleybus, with the propulsion equipment and BUSDAC installed, was operated in shakedown testing, under the direction of the equipment supplier's technical staff. Adjustments were made to optimize the equipment for the MUNI trolleybus, and to suppress any propulsion equipment electromagnetic interference impacts on the BUSDAC system.

(4) Sensor Calibration Testing

Before the first use of BUSDAC, the readings and recordings of BUSDAC were subject to a calibration test. Each sensor output was confirmed by comparison to an independent measurement device. Test results demonstrated BUSDAC accuracy of voltage, current, power, and velocity measurements to better than 2 percent of full scale reading.

(5) Trolleybus Calibration

For each propulsion system and trolleybus weight, the BUSDAC calibration tests were run to establish the tachometer calibration constant and the level grade and low speed drag force.

(6) Convergence Testing

For each propulsion system, a convergence run was performed. The trolleybus was run on outer California Street, where the regular block spacings permitted repeated, identical trolleybus movements. The resulting PLOTPAC results were inspected, to ensure that the successive measurements of similar events gave repeating results.

(7) Confirmation Calculation

For several test segments, independent measurements were made with strip chart recorders and other instruments. Calculations were made on the resulting plots and measurements, to ensure that the results generated by BUSDAC and PLOTPAC were confirmed by the independent measurements.

4. TEST RUNS

During testing, provisions were made to ensure the validity of the test results for making comparisons between systems. The provisions consisted of:

- At least two complete, unimpeded round trips on each route, for each propulsion system, and for each weight condition.

- Conducting tests during off-peak, mid-day hours since more off-peak hours were available during the limited test period, and since traffic conditions were most duplicated during those hours.

- Using only three drivers in the test program, with 90 percent of the runs being made by two experienced drivers.

- Eliminating ambient temperature as a large variable; San Francisco weather does not vary widely. The temperature during testing ranged between 45 and 85 degrees F, and between sunny and raining.

Finally, the status of the equipment was checked by MUNI technicians and by the propulsion supplier technicians, to ensure that no failure interfered with the normal operation of the trolleybus.

5. SCHEDULE

Highlights of the project testing schedule were as follows:

- Booz, Allen and ACEx began work on the project in November 1982.

- BUSDAC and PLOTPAC were installed on test trolleybus 5161 in November 1983. Shakedown testing on the General Electric controller began at that time. Testing of the GE equipment was complete in January 1984.

- In February 1984, at the conclusion of testing of the baseline equipment, Garrett began installation of the AC Propulsion system on the trolleybus. Testing was complete in April.

- In June 1984, installation of the Westinghouse chopper began. Testing was complete in September.

- In September, installation of the Alsthom Atlantic equipment began.

- At the end of December 1984, Alsthom Atlantic equipment testing was completed, and the trolleybus propulsion evaluation testing was completed.

In January 1985, trolleybus 5161 was restored to original condition and returned to revenue service.

V. HIGHLIGHTS OF THE TEST PROGRAM RESULTS

V. HIGHLIGHTS OF THE TEST PROGRAM RESULTS

Comprehensive testing of four trolleybus propulsion systems under fixed conditions produced significant information on their energy use and performance. The test program was broad enough in scope to reveal:

- Comparative performance between advanced and conventional equipment
- Differences between the advanced propulsion systems
- Characteristics of each system for alternative operating conditions
- Various aspects of trolleybus propulsion systems in general.

The massive quantity of data collected in this project would have been overwhelming and uninterpretable without careful structuring of the data presentation. The data acquisition and analysis tools, which were developed for this project, provide a hierarchy of structured test reports. Summary reports provide information in a concise fashion, and optional reports made it simple to obtain more detail when needed. These tools, called BUSDAC and PLOTPAC, are described fully in Appendix A.

A one page PLOTPAC run summary describes each one-way test run of the trolleybus. Further analyses combine the results of all one-way test runs for the same test conditions. A top level analysis presents the results for all test runs.

Chapter V presents the trolleybus propulsion test results and is divided into the following sections:

- Top Level Comparisons
  - Energy per mile
  - Average acceleration
- System Comparison
  - Between propulsion systems tested
  - For each route and weight
- Route Comparison
- Route Summary Sheets
  - Combined run summary results
  - One per round trip route and loading
- PLOTPAC Run Summaries
  - One run summary per one-way test run

- PLOTPAC Histograms
  - Distance, speed, acceleration
  - Grade, change in elevation
  - Line, motor, and auxiliary energy
- Segment Reports and Time Plots
  - Segment summary
  - Time plots of:
    - Distance, speed, acceleration, jerk, grade
    - Line and motor energy
    - Line and motor voltage and current
    - Efficiency.

Details are provided in the following sections.

1. TOP LEVEL COMPARISONS

The top level comparisons cover energy consumption per mile and average acceleration.

(1) Energy Per Mile

Exhibit V-1, Trolleybus Propulsion Energy Use, shows the results of the propulsion energy per mile measurements for each of the four trolleybus propulsion systems, at all three weights, on each of the six one-way routes.

The major results are grouped by equipment supplier. The data is presented in a cluster of 24 points for each supplier. Within each cluster, three points on the same vertical line give the empty, seated, and crushed load result for each route. The six vertical sets are ordered by route from left to right. The order is:

- Market Inbound
- Union Inbound
- Fulton Inbound
- Fulton Outbound
- Union Outbound
- Market Outbound.

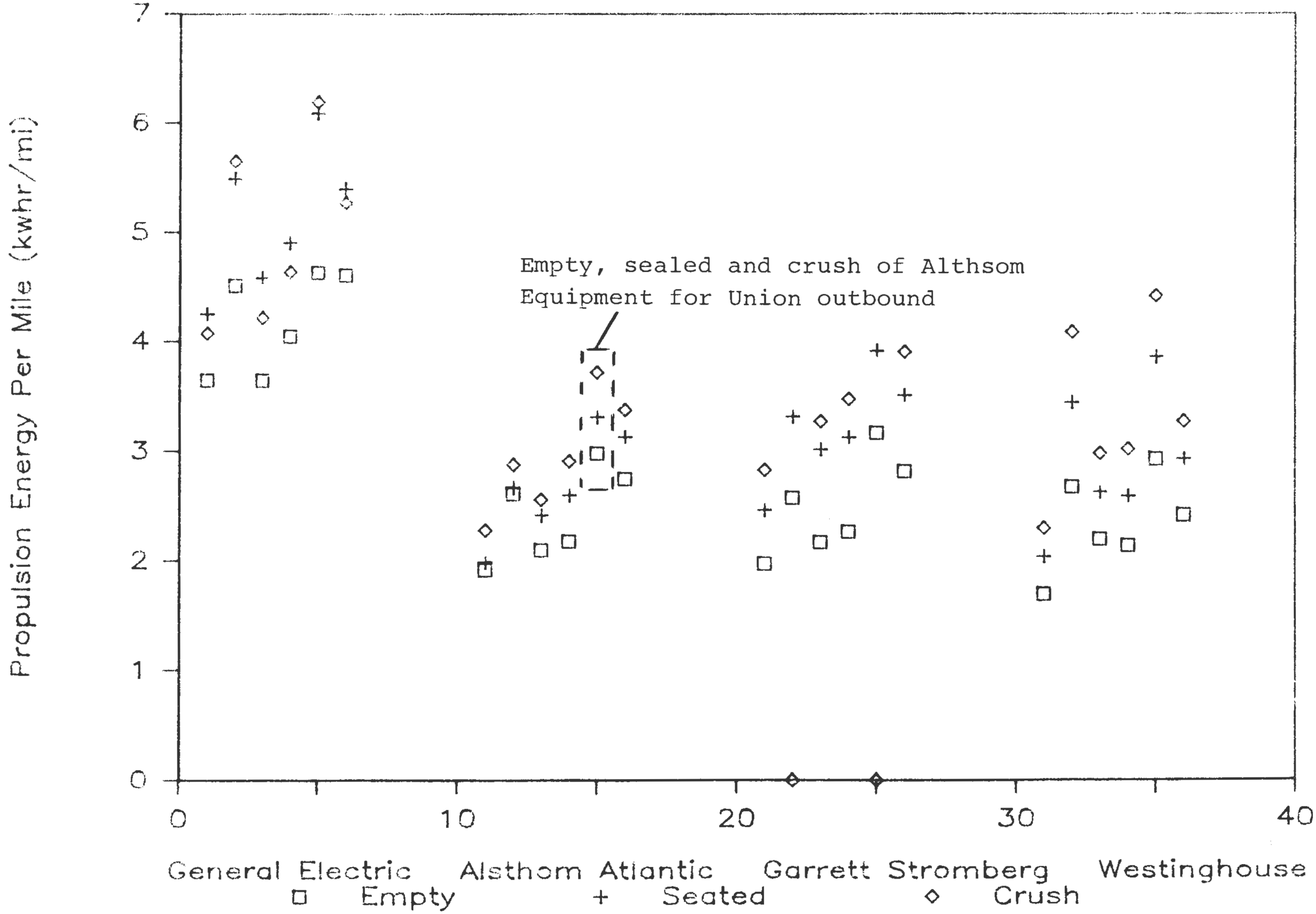
To clarify the groupings a sample is labeled on Exhibit V-1.

For each route, the three data points show the net propulsion energy consumption per mile, in units of kilowatt-hours per mile (kwhr/mi), for runs in the empty, seated load, and crush load conditions. Each data point is the average of two, or occasionally three, test runs.

The data of Exhibit V-1 were averaged together in order to generate equipment average propulsion energy consumption figures. These route averages and loading averages do not represent any single condition, but provide a reasonable yardstick for comparing equipment performance.

EXHIBIT V-1

Trolleybus Propulsion Energy Use



No crush load tests were conducted of the Garrett-Stromberg equipment on the Union Street route. However, for comparison purposes, a projected estimate was made based on Garrett-Stromberg's performance at seated and crush loads on other routes.

The averages by equipment type and loading are shown in Exhibit V-2, All-Test Average Energy Consumption. The exhibit also shows an average for all three advanced systems, and the ratio of the advanced system to the switched resistor (cam) system. The average energy consumption per mile for the three advanced propulsion systems for all routes and weights was 2.89 kwhr/mi, compared to 4.77 kwhr/mi for the switched resistor system. This performance was equivalent to 39 percent lower energy consumption than the switched resistor system. Exhibit V-2 also shows that for a seated load, the advanced systems rating is 57 percent of the switched resistor controller.

EXHIBIT V-2
All-Test Average Energy Consumption
(Kilowatt Hours per Mile)

Load	General Electric	Garrett-Stromberg	Westing-house	Alsthom Atlantic	Average Advanced	Percent of Cam
Empty	4.18	2.50	2.35	2.42	2.42	58%
Seated	5.12	3.23	2.92	2.69	2.94	57%
Crush	5.01	3.61*	3.35	2.96	3.30	66%
Average	4.77	3.11	2.87	2.69	2.89	61%
Percent of Cam	100%	65%	60%	56%	61%	

* Projected.

(2) Average Acceleration

Exhibit V-3, Average Acceleration in Propulsion, shows the results of average calculations for trolleybus acceleration, in miles per hour per second, for each of the four propulsion systems, at all three weights, on each of the six one-way routes. The format is the same as the energy consumption results shown in Exhibit V-1.

Average acceleration is the time average of all positive accelerations greater than 0.5 mphps during a single run. The 0.5 mphps threshold was chosen to eliminate effects of momentary propulsion applications during constant speed running. The average acceleration is a measure which combines the effects of equipment performance, loading, traffic, and driver habits. Positive accelerations were chosen to avoid the influence of friction brakes on the data.

EXHIBIT V-3

Average Acceleration in Propulsion

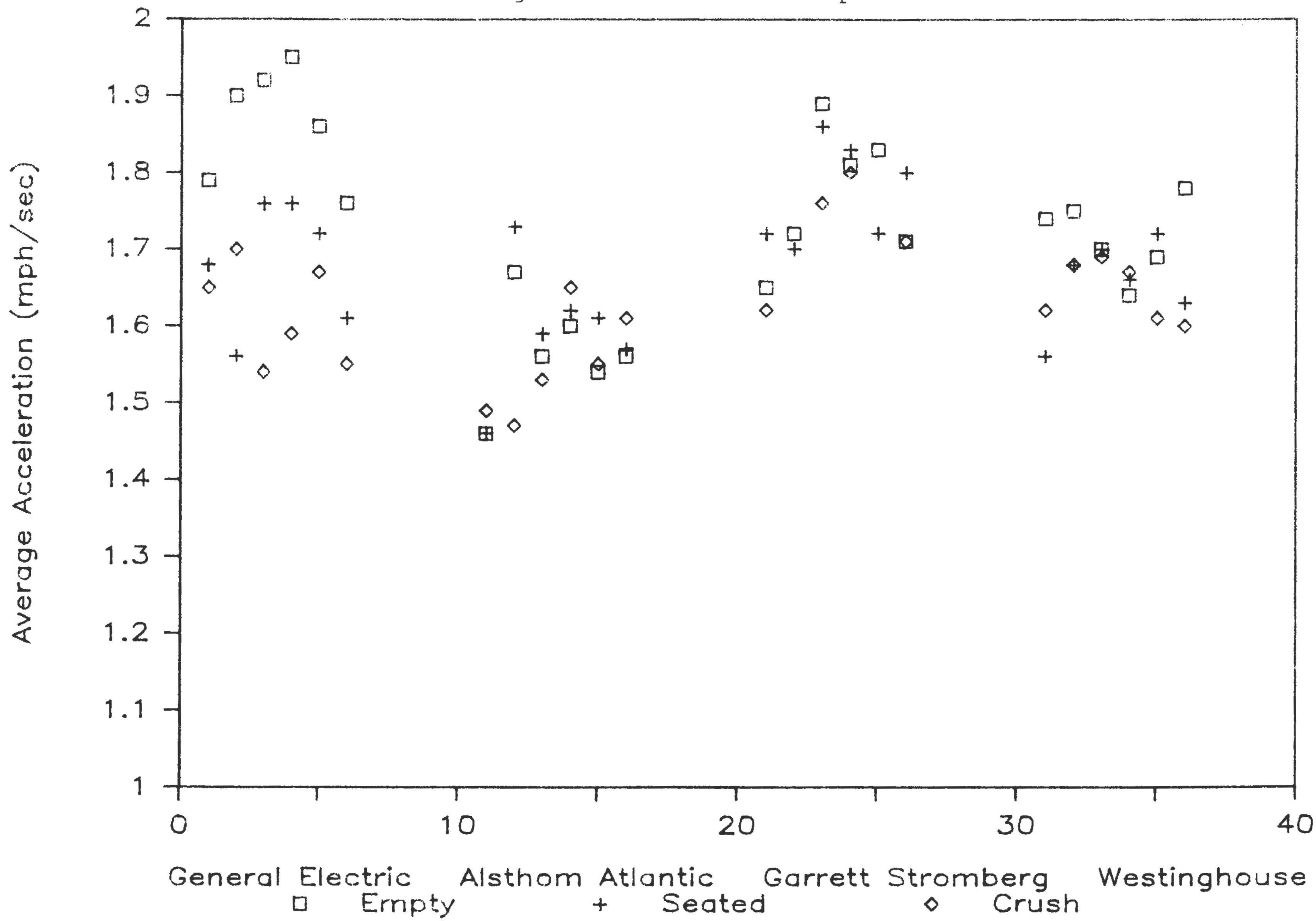


Exhibit V-4, All-Test Average Acceleration, shows the averages of the acceleration calculations by equipment type and weight, as well as the spread between crush load and empty average acceleration. The advanced systems have smaller variations in average acceleration, delivering greater passenger comfort and reduced schedule variance resulting from equipment performance.

EXHIBIT V-4
All-Test Average Acceleration
(Miles per Hour per Second)

Load	General Electric	Garrett-Stromberg	Westing-house	Alsthom Atlantic	Average Advanced	Percent of Cam
Empty	1.86	1.77	1.72	1.57	1.69	91%
Seated	1.68	1.77	1.66	1.60	1.68	100%
Crush	1.62	1.72	1.65	1.55	1.64	101%
Spread Empty to Crush	.24	.05	.07	.05*	.06	25%

* Spread is between Seated and Crush acceleration values.

2. SYSTEM COMPARISON

A discussion of each propulsion system's performance follows.

(1) Energy Usage

Exhibit V-1 previously showed the net propulsion energy consumption per mile for each of the propulsion systems, on all routes, at all loadings. The following set of exhibits shows in greater detail how each of the systems consumes energy. Exhibit V-5, Market Street Results, presents six graphs showing the four propulsion systems on the Market Street runs. The three left hand graphs show the empty, seated and crush load conditions travelling inbound, and the right hand graphs show the energy use travelling outbound. Exhibits V-6 and V-7 show corresponding results on the Union Street and Fulton Street routes.

Each graph in these exhibits shows how the propulsion energy was used, dissipated, and regenerated. All graphs for a single route are plotted on a common energy scale, for ease of comparison between inbound and outbound runs, and different loadings. The graphs show:

- Control Energy: The energy dissipated in the propulsion controls. This is the first bar above the zero line for each of the systems. For this run, the General Electric switched resistor controller consumes 50 percent of the total propulsion energy used in that run - far more energy than any of the advanced systems.

EXHIBIT V-5

Market Street Results

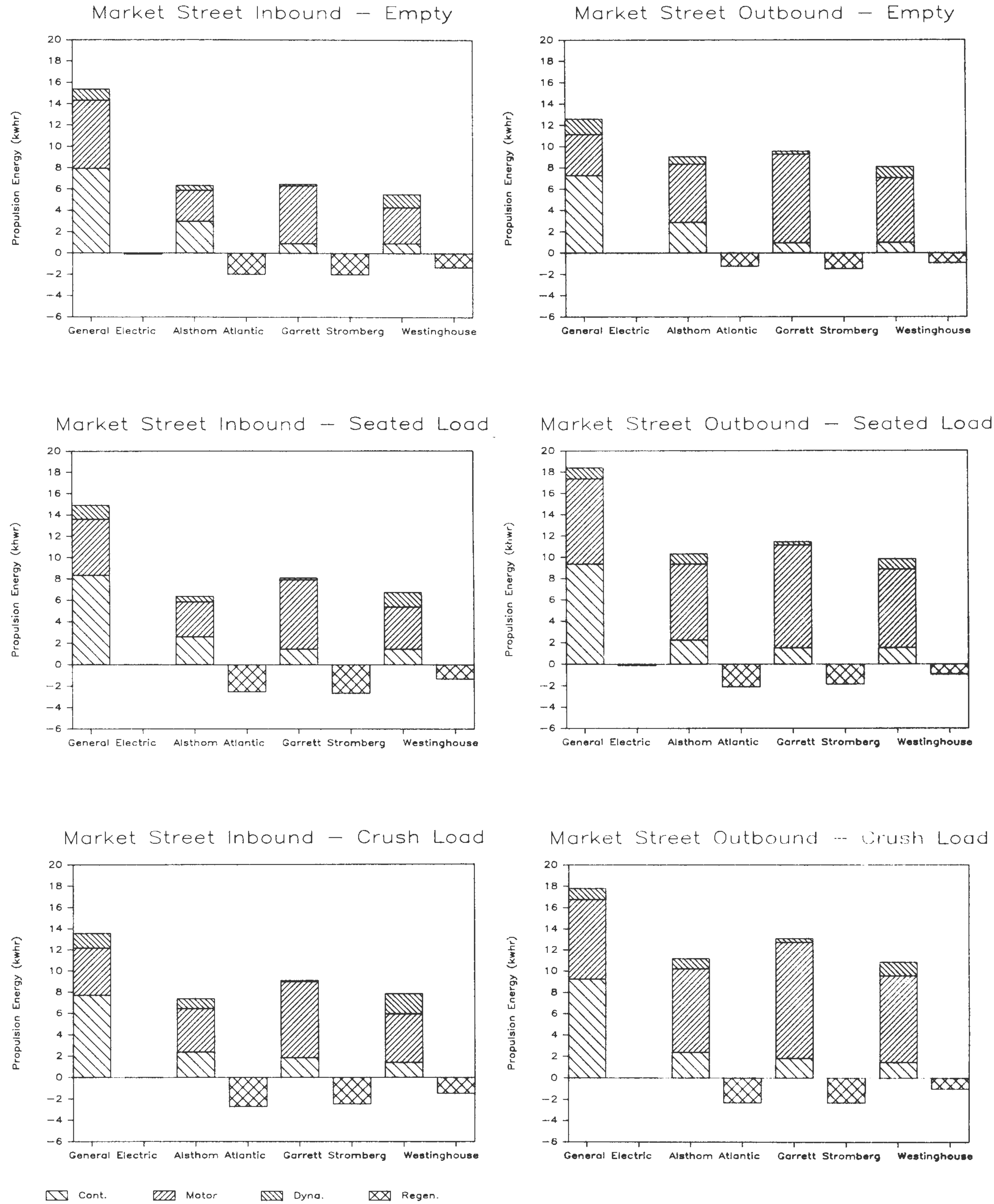


EXHIBIT V-6

Union Street Results

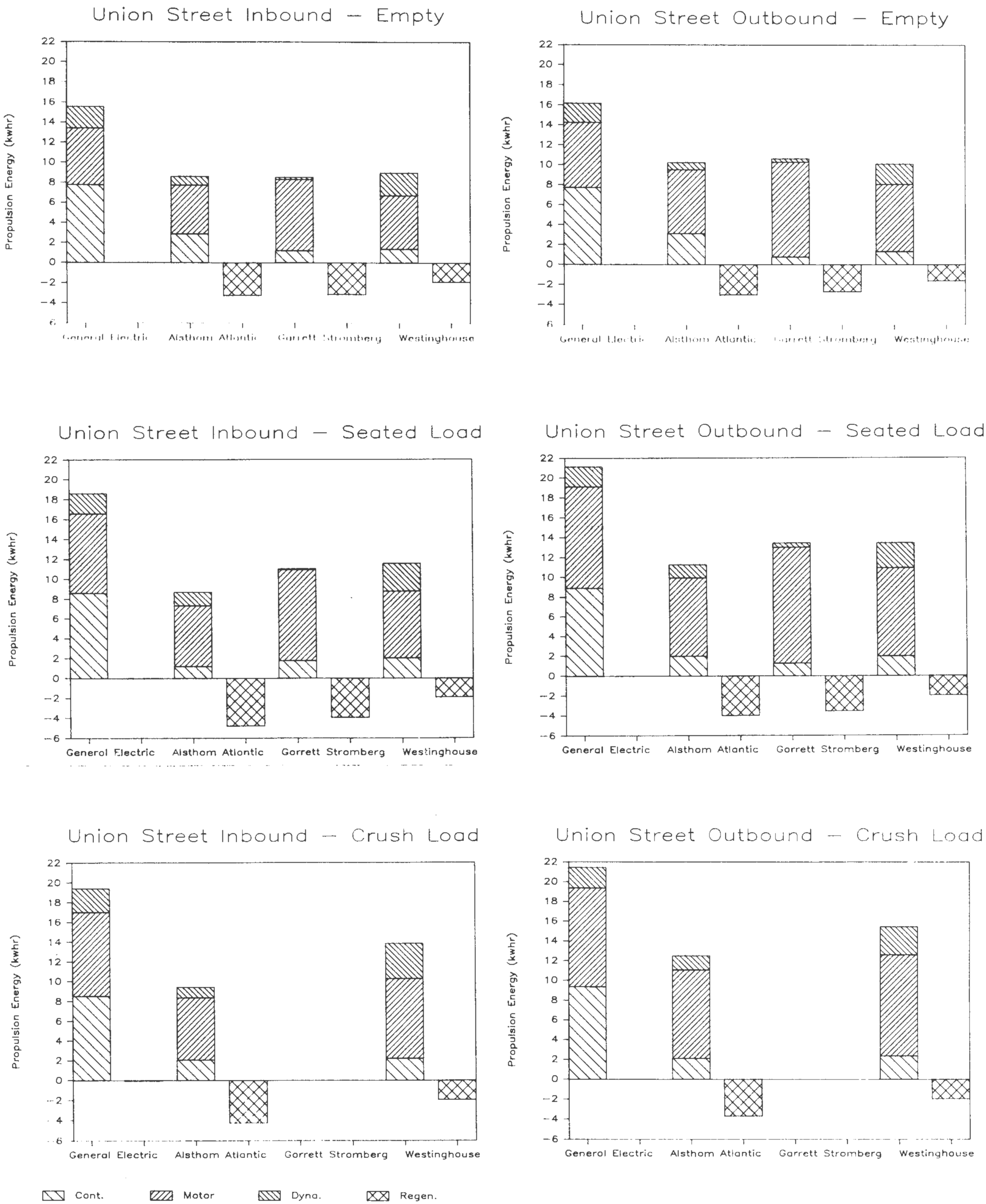
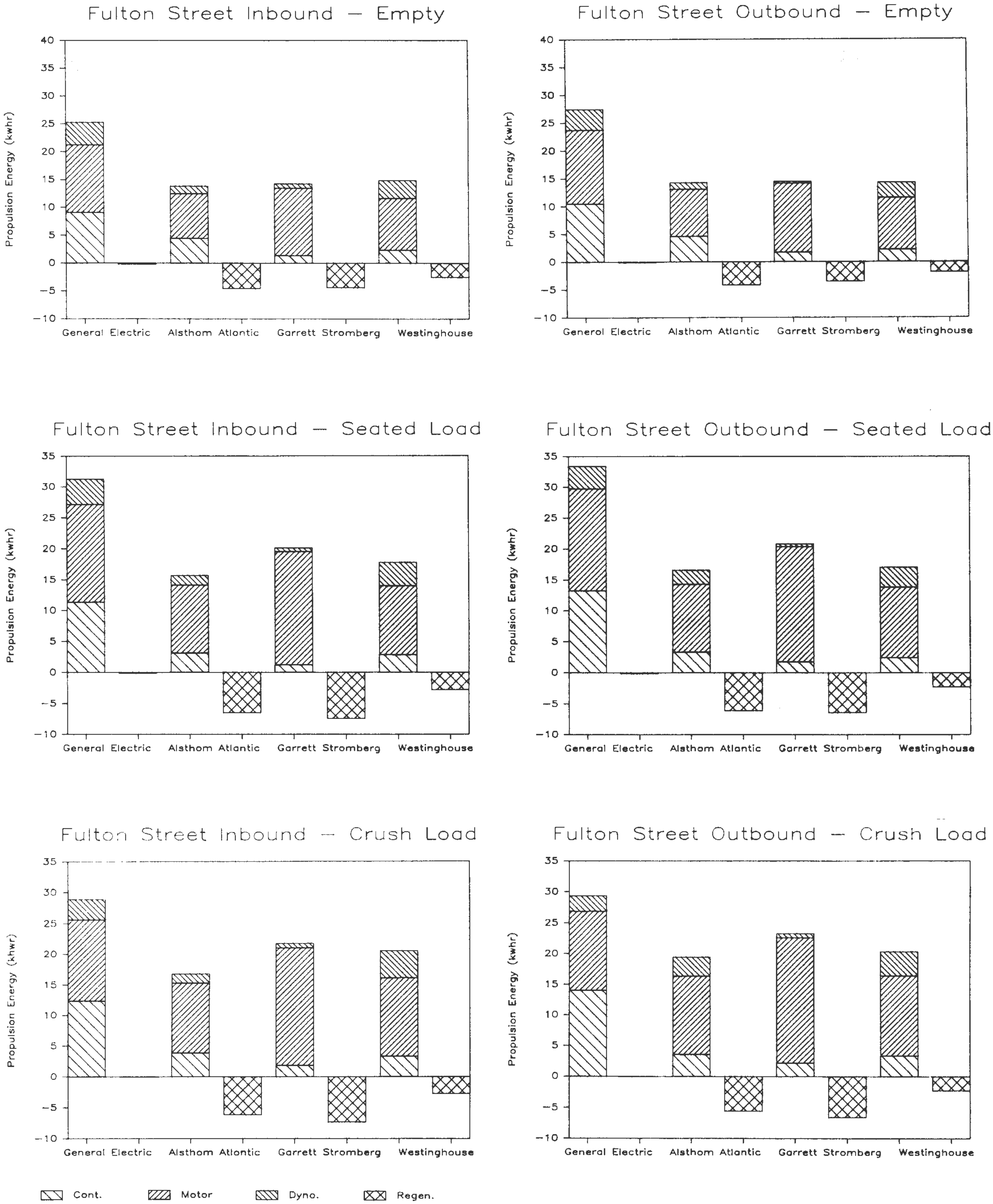


EXHIBIT V-7

Fulton Street Results



- Motor Energy: The net energy used in the motor. The second bar above the line includes the energy used moving the trolleybus, as well as heating losses in the motor. The three DC motors use roughly the same amount of energy in the motor; the AC motor uses somewhat more energy than the DC motors.

- Dynamic Brake Energy: The energy not regenerated to the traction power system. The top bar shows the energy that was generated by the traction motor while the trolleybus was braking that was not sent back to the traction power system. The energy was dissipated in the trolleybus's dynamic brake resistors. The switched resistor controller has no regeneration controls, and dissipates all of the braking energy except for the occasional uncontrolled regeneration.

- Regenerated Energy: The energy regenerated to the traction power system. The bar below the line shows the actual braking energy that was regenerated to the traction power system and then used by another trolleybus. Regenerated energy is a function of line receptivity.

- Net Energy: The total energy used by each propulsion system. The total height of the three bars above the line is the net energy used by that propulsion system for these tests. If the traction power system is nonreceptive, then the total height of the bars would be increased by the amount of regeneration energy below the line. Specifically, the dynamic brake energy would increase by the amount of energy not regenerated.

For the test conditions a single trolleybus was regenerating into a highly receptive traction power system. The average results for each propulsion system are based on the summation of measurements taken over six hundred individual segments, or more. Because of the extensive samples taken it is believed that the average results accurately represent the anticipated energy consumption for each trolleybus on the MUNI system. However, for multiple trolleybuses with regeneration capability, a reduction in receptivity is likely to occur.

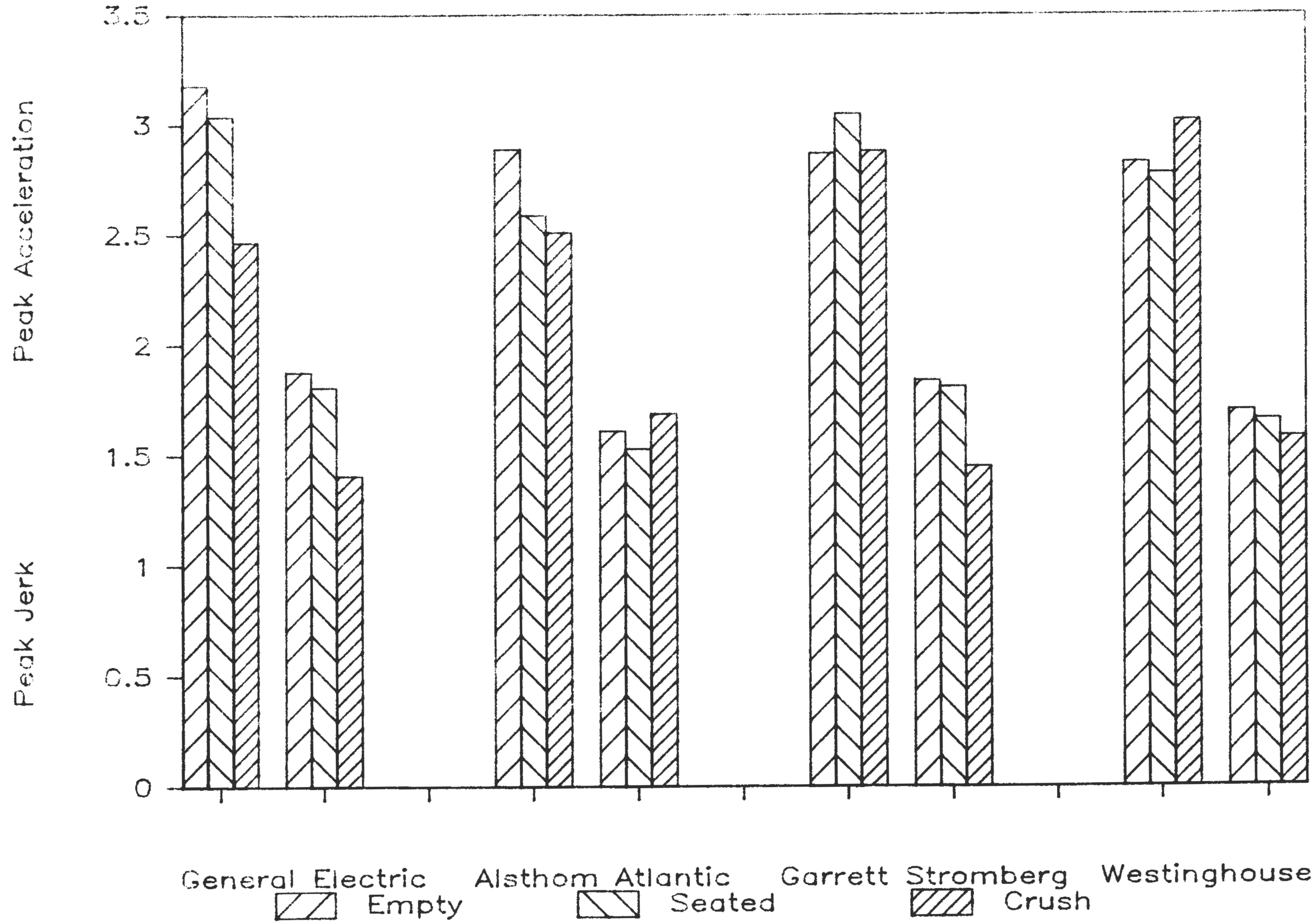
The preceding exhibits provide a straightforward basis for comparing the energy performance of the four propulsion systems under a single set of conditions. The data summarized by the exhibits allow evaluation of the components of energy use, and selection of strategies for operating cost reduction and propulsion system design improvement.

(2) Acceleration and Jerk

Exhibit V-8, Peak Jerk and Acceleration in Propulsion, shows ride performance indicators of peak acceleration and peak jerk, for all four propulsion systems, at all three loadings, on one Market Street Inbound run.

EXHIBIT V-8

Peak Jerk and Acceleration in Propulsion



Market Street, with its gentle downhill slope, was selected because it is the simplest route on which to compare performance. The performance indicators are:

- Peak Acceleration: For each segment, the highest one-second positive acceleration event was selected. The indicator is the average of the peak acceleration values for segments of one run. Peak acceleration is shown on the left hand portions of each of the four equipment groupings.

- Peak Jerk: For each segment, the highest positive one-second jerk, or change in acceleration, while in propulsion was selected. This indicator is the average of the peak jerk values for segments of one run.

As previously mentioned, Exhibit V-4 shows average acceleration, which is the average of all the positive accelerations greater than 0.5 mphps, for all runs. All ride indicators are based on measurements while the trolleybus is in propulsion, so that characteristics of the friction brake system are not combined with those of electric braking by the propulsion system.

3. ROUTE COMPARISON

At the next level of detail, the test program results were used to compare the energy performance of each propulsion system over all three route and weight conditions. The graphs of Exhibit V-9, Trolleybus Propulsion Energy Use, show the energy usage per mile for one of the propulsion systems, for all three loadings and all six one-way routes. Each graph is a visual representation of one system's data from Exhibit V-1. The six groups of bars on each graph correspond to the six one-way routes for Market Street, Union Street and Fulton, both inbound and outbound. For each one-way route, the net energy consumption per mile is shown for the empty, seated, and crush load cases.

4. ROUTE SUMMARY SHEETS

Route summary sheets were generated, to group together PLOTPAC run summary data for similar runs. Each route summary sheet shows the results for all runs in both directions on a single route, at one weight, for one equipment configuration. Exhibit V-10, PLOTPAC Results, shows an example route summary for the General Electric equipment, on Market Street, with a seated load. It combines the results of the two round trip test runs. A complete set of route summary sheets for all tests is contained in Appendix B of this report.

Exhibit V-11, Route Summary Sheet Indicators, gives the definition of terms used to calculate the indicators given in the route summary sheets. The source data are taken from the PLOTPAC run summaries for the test runs. Equipment type, route, change in elevation, one-way run distance, and trolleybus weight are shown in the header of Exhibit V-10, PLOTPAC Results.

EXHIBIT V-9

Trolleybus Propulsion Energy Use

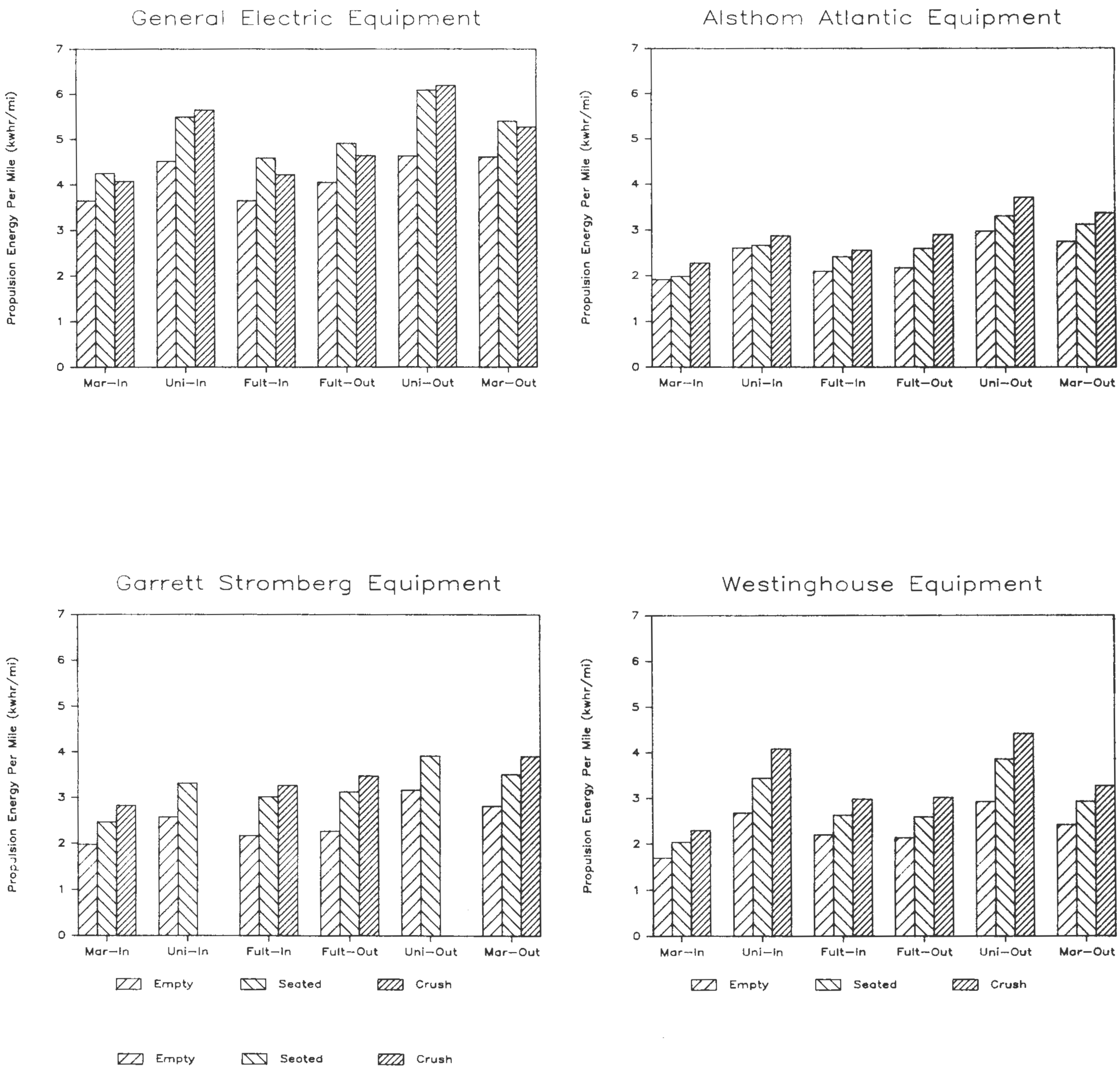


EXHIBIT V-10

PLOTPAC Results

Equipment: General Electric Controller **Route: 8 - MARKET**
Change in Elevation: +122 FEET OUTBOUND **Distance: 3.4 MILES**
Weight: 30,748 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.	Direction:	Inbound		
2.	Run Number:	235	237	
3.	Number of Stops:	47	49	48
4.	Average Accel:	1.80	1.56	1.68
5.	Energy per Mile:	4.51	3.99	4.25
6.	Prop Energy In:	15.18	14.71	14.94
7.	Line Energy Regen:	.00	0.00	.00
8.	Motor Energy In:	8.32	7.25	7.78
9.	Net Motor Energy:	5.71	4.81	5.26
9.1	Auxiliary Energy:	1.92	4.73	3.33
10.	Lost Control Ener:	6.86	7.46	7.16
11.	Motor Regen Ener:	2.61	2.44	2.52
12.	Ener Not Received:	2.61	2.44	2.52
13.	Control Loss %:	45.18%	50.70%	47.94%
14.	Regen Loss %:	17.18%	16.57%	16.87%
15.	Total Loss %:	62.36%	67.26%	64.81%
16.	Control Efficiency	0.55	0.49	0.52
18.	Net Ener Not Rec'd	1.43	1.20	1.31
19.	Ener Not Rec'd %:	99.84%	100.00%	99.92%

	ITEM	RUN DATA		AVERAGE
1.	Direction:	Outbound		
2.	Run Number:	234	236	
3.	Number of Stops:	56	55	56
4.	Average Accel:	1.64	1.59	1.62
5.	Energy per Mile:	5.45	5.35	5.40
6.	Prop Energy In:	18.94	18.11	18.52
7.	Line Energy Regen:	0.22	0.01	0.11
8.	Motor Energy In:	10.52	9.70	10.11
9.	Net Motor Energy:	8.29	7.72	8.00
9.1	Auxiliary Energy:	2.18	2.09	2.13
10.	Lost Control Ener:	8.43	8.41	8.42
11.	Motor Regen Ener:	2.23	1.98	2.10
12.	Ener Not Received:	2.01	1.97	1.99
13.	Control Loss %:	44.48%	46.44%	45.46%
14.	Regen Loss %:	10.61%	10.88%	10.75%
15.	Total Loss %:	55.09%	57.32%	56.21%
16.	Control Efficiency	0.56	0.54	0.55
18.	Net Ener Not Rec'd	0.99	1.05	1.02
19.	Ener Not Rec'd %:	80.35%	99.05%	89.70%

EXHIBIT V-11
Route Summary Sheet Indicators

1. DIRECTION: Inbound or Outbound, the direction of travel for the run. Taken from Run Summary.

2. RUN NUMBER: The PLOTPAC run number identifying the one-way trip. Taken from Run Summary.

3. NUMBER OF STOPS: The number of times the trolleybus speed was less than 0.5 mph for more than one second during the run. Taken from Run Summary.

4. AVERAGE ACCEL: The time-weighted average of all accelerations greater than +0.5 mphps. Taken from Run Summary. (mphps).

5. ENERGY PER MILE: The net propulsion energy consumed during the run, divided by the total distance traveled during the run. Taken from Run Summary. (kwhr/mi).

6. PROP ENERGY IN: The total of all energy coming into the trolleybus during the run, excluding auxiliary energy, and not subtracting energy regenerated to the line. Taken from Run Summary. (kwhr).

7. LINE ENERGY REGEN: The total of all energy flowing from the trolleybus into the traction power system. Taken from Run Summary. (kwhr).

8. MOTOR ENERGY IN: The total of all energy coming into the traction motor during the run, not subtracting energy which flows out of the motor during dynamic braking. Taken from Run Summary. (kwhr).

9. NET MOTOR ENERGY: The total Motor Energy In, minus the energy which flows out of the motor during dynamic braking. Taken from Run Summary. (kwhr).

9.1 AUXILIARY ENERGY: The total of all Auxiliary Energy used during the run. Taken from Run Summary. (kwhr).

10. LOST CONTROL ENER: The energy dissipated in the motor controller, while the motor is in propulsion. (kwhr).
LOST CONTROL ENER = PROP ENERGY IN - MOTOR ENERGY IN.

11. MOTOR REGEN ENER: The energy which flows out of the motor during dynamic brake. (kwhr).
MOTOR REGEN ENER = MOTOR ENERGY IN - NET MOTOR ENERGY.

Route Summary Sheet Indicators

12. ENER NOT RECEIVED: Energy which flows out of the motor during dynamic braking which does not flow out of the trolleybus, and is not received by the traction power system. (kwhr).
ENER NOT RECEIVED = MOTOR REGEN ENER - LINE ENERGY REGEN

13. CONTROL LOSS: The fraction of the total incoming propulsion energy which is dissipated in the controls. (percent).
CONTROL LOSS = 100 * LOST CONTROL ENER / PROP ENERGY IN

14. REGEN LOSS: The fraction of the total incoming propulsion energy which does not flow out of the trolleybus, and is not received by the traction power system. (percent).
REGEN LOSS = 100 * ENER NOT RECEIVED / PROP ENERGY IN

15. TOTAL LOSS: The total fraction of the incoming propulsion energy which is dissipated. (percent).
TOTAL LOSS = CONTROL LOSS + REGEN LOSS

16. CONTROL EFFICIENCY: The efficiency of the propulsion controls in transforming line energy to motor energy, measured while in the propulsion mode. (fraction).
CONTROL EFFICIENCY = (PROP ENERGY IN - LOST CONTROL ENER / PROP ENERGY IN

18. NET ENER NOT REC'D: The energy which was made available for regeneration by the propulsion system but which was not received by the traction power system, considering energy which was absorbed in the auxiliaries. (kwhr).
NET ENER NOT REC'D = (MOTOR REGEN ENER * CONTROL EFFICIENCY)
  - LINE ENERGY REGEN
  - AUXILIARY ENERGY * (LINE ENERGY REGEN / PROP ENERGY IN)

19. ENER NOT REC'D: The fraction of the energy available for regeneration that was not received by the traction power system. (percent).
ENER NOT REC'D = NET ENER NOT REC'D / ((MOTOR REGEN ENER * CONTROL EFFICIENCY) - AUXILIARY ENERGY * (LINE ENERGY REGEN / PROP ENERGY IN))

5. PLOTPAC RUN SUMMARIES

PLOTPAC run summaries are one page reports of analyzed test data results for a single one-way run. PLOTPAC accepts the test data tapes created by BUSDAC, and calculates:

- Elapsed time and distance
- Average velocity, acceleration and jerk
- Grade, and change in elevation
- Peak motor and line power
- Energy used from the line, in the motor, in auxiliaries, and in the wheels
- Energy/mile, energy/hour, and efficiency.

The BUSDAC data for each trolleybus run is analyzed as a set of start-stop-start intervals, called segments. The results for all the segments is presented in the run summary report. An example run summary report for run 214 of the General Electric equipment on a Market Street Inbound run with an empty load is shown in Exhibit V-12.

Appendix A of this report provides more information about PLOTPAC and its reports. Appendix C provides a total set of run summary reports and other PLOTPAC results for each of the propulsion systems, tested under equivalent conditions.

6. PLOTPAC HISTOGRAMS

PLOTPAC run summaries provided a top level view of the trolleybus equipment performance for a single run. PLOTPAC also produced histograms, to allow a close look at performance over shorter travel distances.

As noted previously, each trolleybus run was analyzed as a set of numbered start-stop-start segments. A histogram ranked the segments of a single run by a single performance criterion, such as average velocity, and divided the segments into ten ranges of performance.

PLOTPAC can create histograms of 12 different performance parameters. These include:

- Distance travelled, average speed, and average acceleration
- Change in elevation, average positive grade, and average negative grade
- Line, motor, net, and regenerated energy
- Energy per mile, energy per hour, and system efficiency.

The average and standard deviation of the performance parameter are shown on the histogram.

Exhibit V-13 shows histograms for run 214 of distance travelled, average velocity, change in elevation, net energy, average positive acceleration, and energy per mile for all the segments in run 214. Histograms are useful for selecting individual segments with desired performance characteristics for more detailed analysis. For example, the histograms of Exhibit V-13 could be used to find a segment of 500 to 600 feet, with an average speed of 12.5 to 15 mph, and a change in elevation of 0 to -20 feet. This permits selection and comparison of segments of nearly equivalent performance.

EXHIBIT V-12

Run Summary Statistics and Run Log Report Run Number 214

DATE: 16-DEC-83
TIME: 12:15:26
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
  TYPE: GE RESISTIVE CONTROLLER
COMMENT:8-MARKET-INBOUND-COLLINGSWOOD/18TH...
BUS WEIGHT: 23748.0 LBS
CALIBRATION DATA: TACHOMETER=   12.8 PULSES PER FOOT
                     DRAG=   464.0 POUNDS FORCE

NUMBER OF SEGMENTS	=	46
TOTAL TIME TRAVELING	=	1175.2 SEC
TOTAL TIME STOPPED	=	713.8 SEC
TOTAL TIME	=	1889.0 SEC
TOTAL DISTANCE TRAVELLED	=	17440.1 FT
AVERAGE DISTANCE TRAVELLED	=	379.1 FT
PEAK VELOCITY IN RUN	=	29.1 MPH
AVERAGE VELOCITY	=	10.1 MPH
COMMERCIAL VELOCITY	=	6.3 MPH
TOTAL CHANGE IN ELEVATION	=	-137.7 FT
AVERAGE ASCENDING GRADE	=	2.7 %
FRACTION OF RUN ON ASCENDING GRADE	=	0.17
AVERAGE DESCENDING GRADE	=	-2.7 %
FRACTION OF RUN ON DESCENDING GRADE	=	0.43
PEAK POWER USED	=	216.6 KW
PEAK POWER REGENERATED	=	-33.6 KW
PEAK MOTOR POWER	=	200.3 KW
PEAK MOTOR POWER REGENERATED	=	-115.2 KW
TOTAL POSITIVE LINE ENERGY	=	14.914 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	12.338 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-0.014 KWH
NET LINE ENERGY IN RUN	=	14.900 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	6.421 KWH
NET MOTOR ENERGY IN RUN	=	3.697 KWH
TOTAL AUXILIARY ENERGY	=	1.891 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	3.951 KWH
NET PROPULSION ENERGY PER MILE	=	3.731 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	37.753 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.32
CONTROLS EFFICIENCY IN PROPULSION	=	0.52
MOTOR EFFICIENCY IN PROPULSION	=	0.62
PEAK ACCELERATION IN PROPULSION	=	5.13 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.79 MPH/SEC
PEAK JERK IN PROPULSION	=	4.07 MPH/SEC2

EXHIBIT V-13

Histograms for Run 214

Total Distance Traveled for Run 214

(Feet)	Segment
0 -< 100	4, 5, 7, 13, 14, 23, 33, 45
100 -< 200	2
200 -< 300	1, 20, 30, 34, 35, 37, 39
300 -< 400	9, 11, 16, 21, 24, 25, 26, 27, 29, 38, 41, 44
400 -< 500	3, 6, 12, 18, 19, 22, 28, 36
500 -< 600	10, 17, 42, 43
600 -< 700	31
700 -< 800	8
800 -< 900	15
900 -	32, 40, 46

Average = 379.1 Feet
Std Dev = 258.3 Feet

Average Velocity for Run 214

(Mph)	Segment
0.0 -< 2.5	14, 23, 33
2.5 -< 5.0	2, 4, 5, 7
5.0 -< 7.5	1, 3, 6, 13, 30, 37, 38, 45
7.5 -<10.0	20, 34, 36, 39, 41, 44, 46
10.0 -<12.5	9, 11, 16, 21, 24, 25, 26, 27, 28, 29, 32, 35, 42, 43
12.5 -<15.0	8, 12, 17, 18, 22, 31, 40
15.0 -<17.5	10, 15, 19
17.5 -<20.0	
20.0 -<22.5	
22.5-	

Average = 9.3 Mph
Std Dev = 3.8 Mph

EXHIBIT V-13

Histograms for Run 214

Change in Elevation for Run 214

(Feet)	Segment
-< -80	
-80 -< -60	
-60 -< -40	
-40 -< -20	18, 19
-20 -< 0	1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 17, 20, 21, 22, 29, 30, 31, 33, 34, 35, 36, 41, 42, 43, 44, 45, 46
0 -< 20	5, 7, 15, 16, 23, 24, 25, 26, 27, 28, 32, 37, 38, 39, 40
20 -< 40	6
40 -< 60	
60 -< 80	
80 -	

Average = -3.0 Feet
Std Dev = 8.2 Feet

Energy Net for Run 214

(Watt-Hours)	Segment
0 -< 200	2, 3, 4, 5, 13, 14, 23, 33, 34, 45
200 -< 400	1, 7, 9, 10, 11, 12, 17, 18, 19, 20, 21, 24, 25, 27, 28, 29, 30, 31, 35, 36, 37, 39, 41, 42, 43, 44
400 -< 600	8, 16, 22, 26, 38, 40
600 -< 800	32
800 -< 1000	15, 46
1000 -< 1200	6
1200 -< 1400	
1400 -< 1600	
1600 -< 1800	
1800 -	

Average = 323.9 Watt-Hours
Std Dev = 197.7 Watt-Hours

EXHIBIT V-13

Histograms for Run 214

Average Positive Acceleration for Run 214

(Mph/sec)	Segment
0.0 -< 0.3	33
0.3 -< 0.6	14
0.6 -< 0.9	
0.9 -< 1.2	3, 32
1.2 -< 1.5	2, 11, 16, 23, 29, 34, 37
1.5 -< 1.8	1, 5, 6, 8, 9, 21, 30, 36, 38, 42, 44, 46
1.8 -< 2.1	4, 15, 17, 28, 31, 35, 39, 40, 43, 45
2.1 -< 2.4	7, 12, 13, 18, 19, 26, 41
2.4 -< 2.7	22, 27
2.7-	10, 20, 24, 25

Average = 1.8 Mph/sec
Std Dev = 0.6 Mph/sec

Energy per Mile for Run 214

(Watt-Hrs/mile)	Segment
0 -< 1600	3, 14, 33
1600 -< 3200	10, 12, 17, 19, 31, 32, 36, 40, 41, 42, 43
3200 -< 4800	2, 8, 9, 11, 18, 21, 22, 24, 25, 26, 27, 28, 29, 30, 34, 35, 37, 44, 46
4800 -< 6400	1, 4, 15, 20, 38, 39, 45
6400 -< 8000	13, 16
8000 -< 9600	
9600 -<11200	6
11200 -<12800	
12800 -<14400	
14400 -	5, 7, 23

Average = 5891.2 Watt-Hours/mile
Std Dev = 9029.6 Watt-Hours/mile

7. SEGMENT REPORTS AND TIME PLOTS

When detailed information on a single segment was needed, PLOTPAC provided segment summary reports. An example is shown in Exhibit V-14 for segment 17 of run 214, chosen from the histograms described above. The segment summary report provides the same calculations as the run summary report, but only for the data of a single start-stop-start interval of the trolleybus.

PLOTPAC also created plots for any selected segment of a run, for any of the following variables:

- Input voltage and current
- Motor voltage and current
- Input power and motor power
- Acceleration and jerk
- Grade and velocity
- Instantaneous efficiency
- Position.

Exhibit V-15 shows example plots for segment 17 of run 214. The graphs show input voltage and current, motor voltage and current, input and motor power, acceleration and jerk, and velocity and grade. In a typical run of 50 to 80 segments, the analyst can select any of the hundreds of plots of the trolleybus's operational performance.

EXHIBIT V-14

Segment Summary Report for Run 214, Segment 17

DATE: 16-DEC-83
TIME: 12:15:26
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: GE RESISTIVE CONTROLLER
COMMENT:8-MARKET-INBOUND-COLLINGSWOOD/18TH...
BUS WEIGHT: 23748.0 LBS

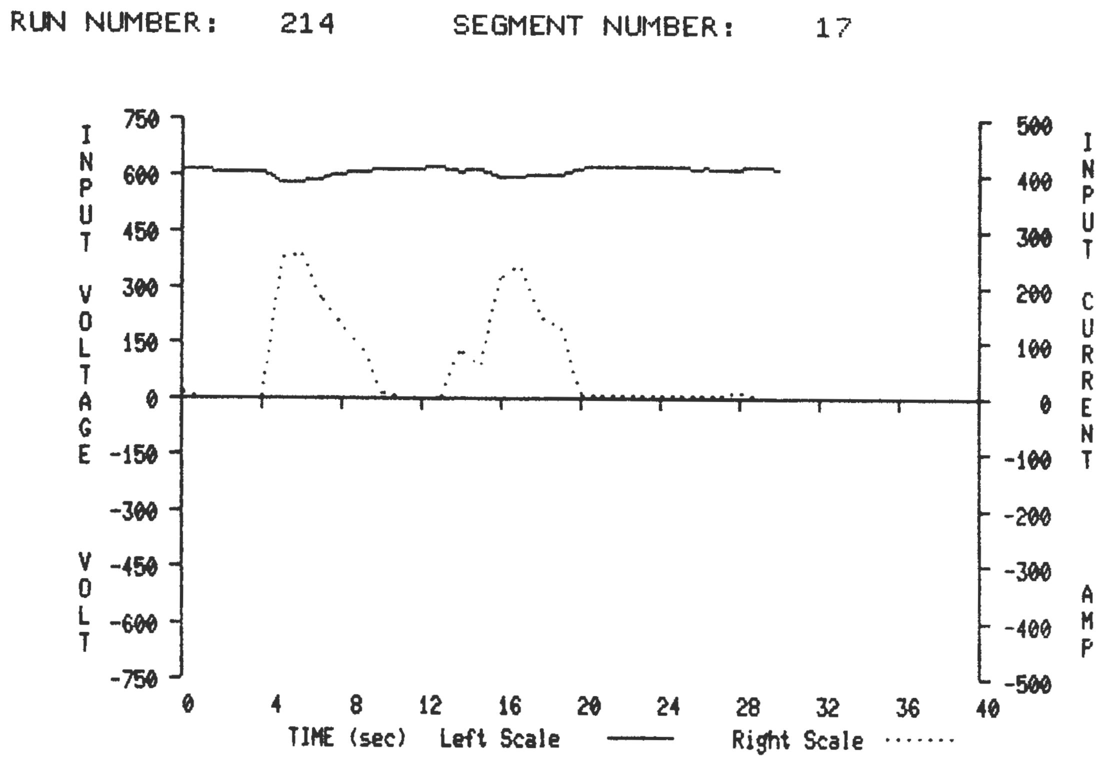
CALIBRATION DATA:	TACHOMETER=	12.8	PULSES PER FOOT
	DRAG=	464.0	POUNDS FORCE

TIME TRAVELING	=	28.6 SEC
TIME STOPPED	=	2.4 SEC
DISTANCE TRAVELLED	=	543.9 FT
MAXIMUM VELOCITY	=	25.1 MPH
AVERAGE VELOCITY	=	13.0 MPH
COMMERCIAL VELOCITY	=	12.0 MPH
CHANGE IN ELEVATION	=	-14.2 FT
AVERAGE ASCENDING GRADE	=	0.0 %
FRACTION OF SEGMENT ON ASCENDING GRADE	=	0.00
AVERAGE DESCENDING GRADE	=	-2.8 %
FRACTION OF SEGMENT ON DESCENDING GRADE	=	0.91
PEAK POWER USED	=	149.0 KW
PEAK POWER REGENERATED	=	0.0 KW
PEAK MOTOR POWER	=	145.2 KW
PEAK MOTOR POWER REGENERATED	=	-115.2 KW
TOTAL POSITIVE LINE ENERGY	=	0.327 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	0.288 KWH
TOTAL ENERGY REGENERATED TO LINE	=	0.000 KWH
NET LINE ENERGY IN SEGMENT	=	0.327 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	0.206 KWH
NET MOTOR ENERGY IN SEGMENT	=	0.079 KWH
TOTAL AUXILIARY ENERGY	=	0.029 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	0.134 KWH
NET PROPULSION ENERGY PER MILE	=	2.792 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	33.403 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.47
CONTROLS EFFICIENCY IN PROPULSION	=	0.72
MOTOR EFFICIENCY IN PROPULSION	=	0.65
PEAK ACCELERATION IN PROPULSION	=	3.75 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.88 MPH/SEC
PEAK JERK IN PROPULSION	=	3.08 MPH/SEC2

12:28:48 * SEGMENT 17

EXHIBIT V-15

Plots for Run 214, Segment 17



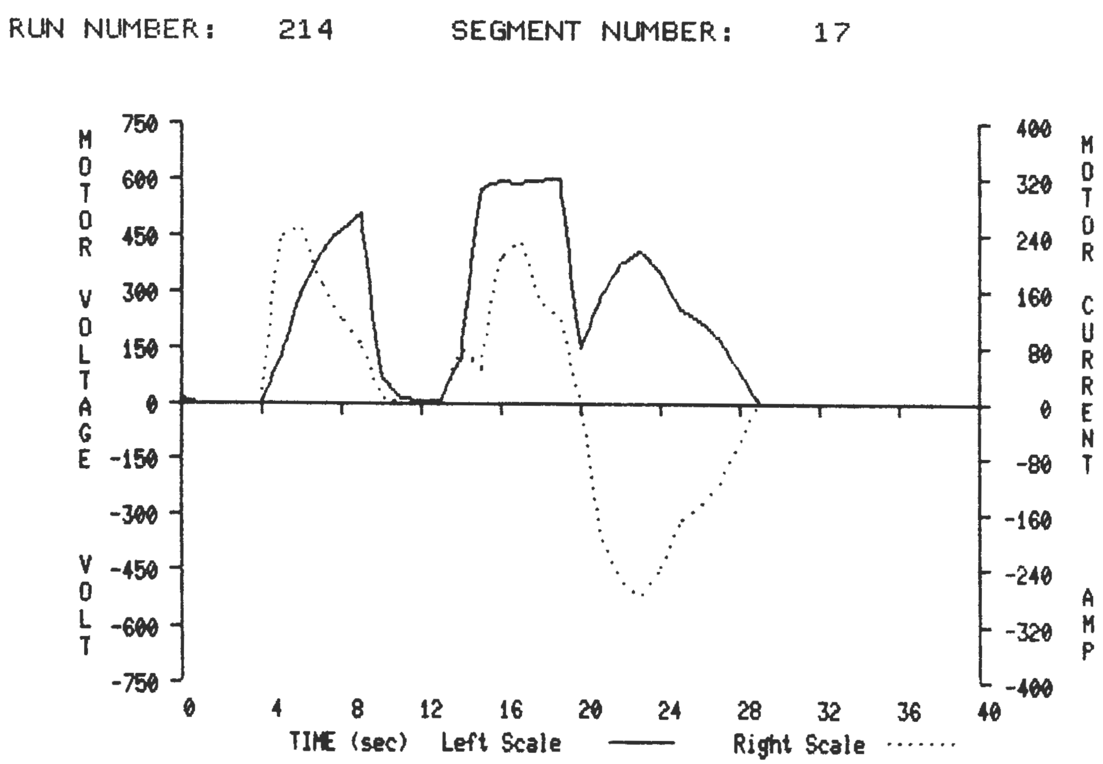
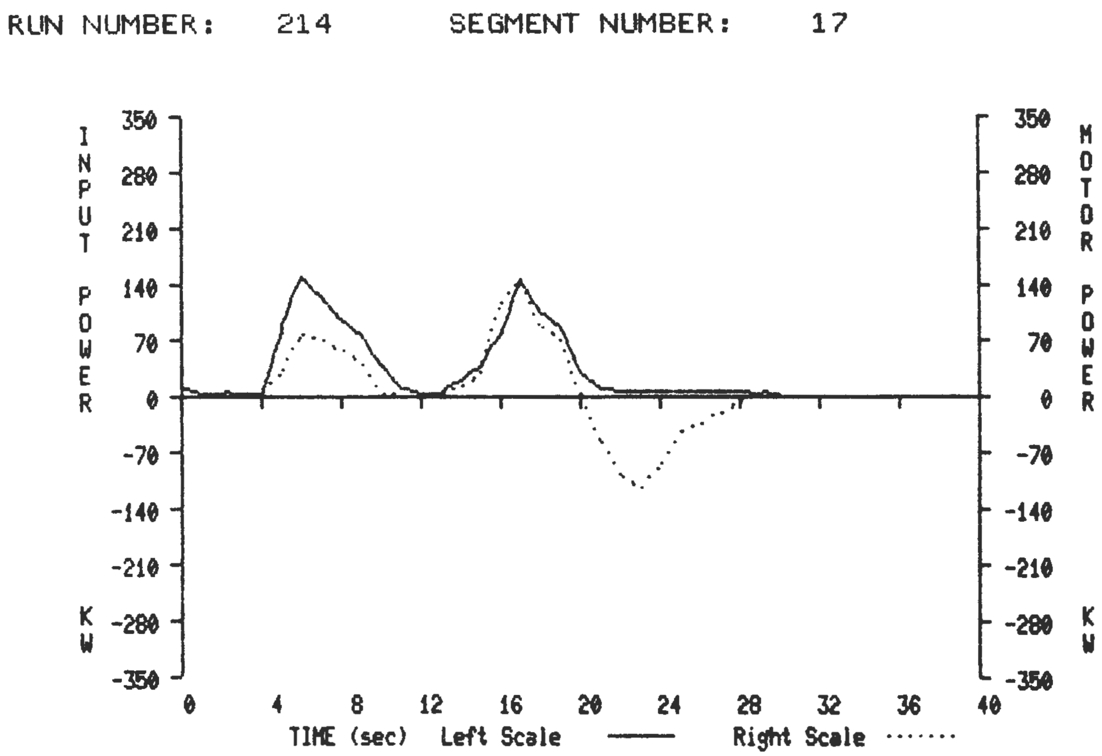


EXHIBIT V-15
Plots for Run 214, Segment 17



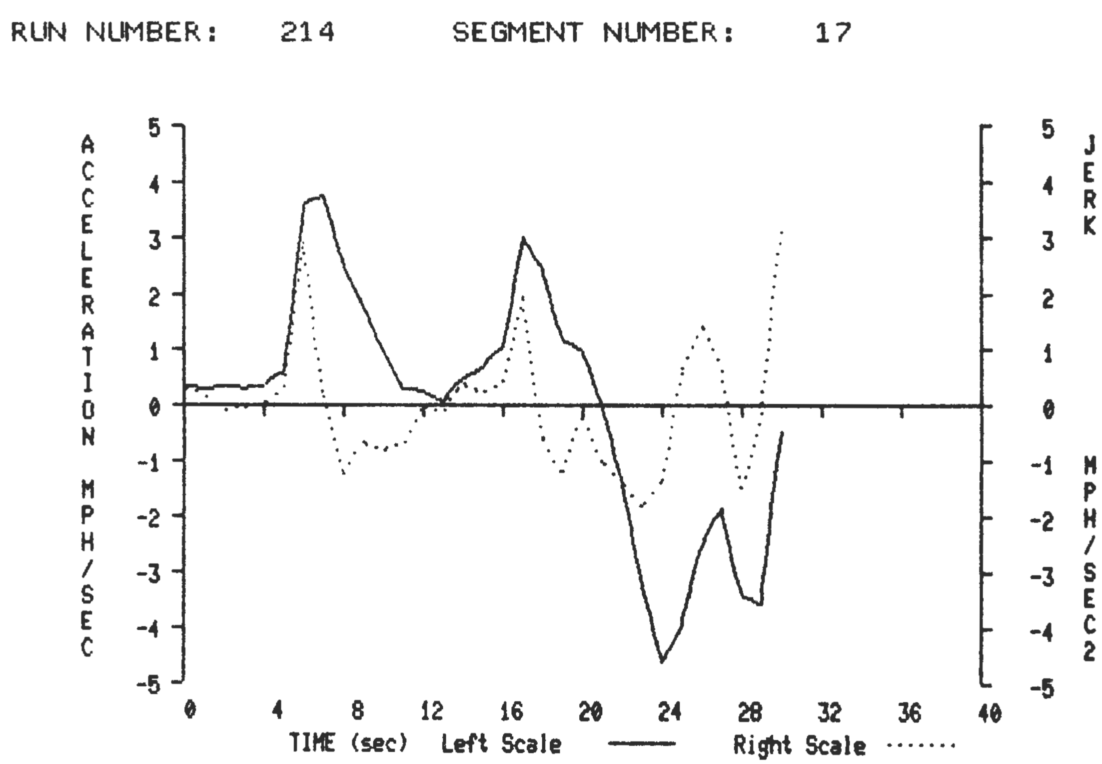
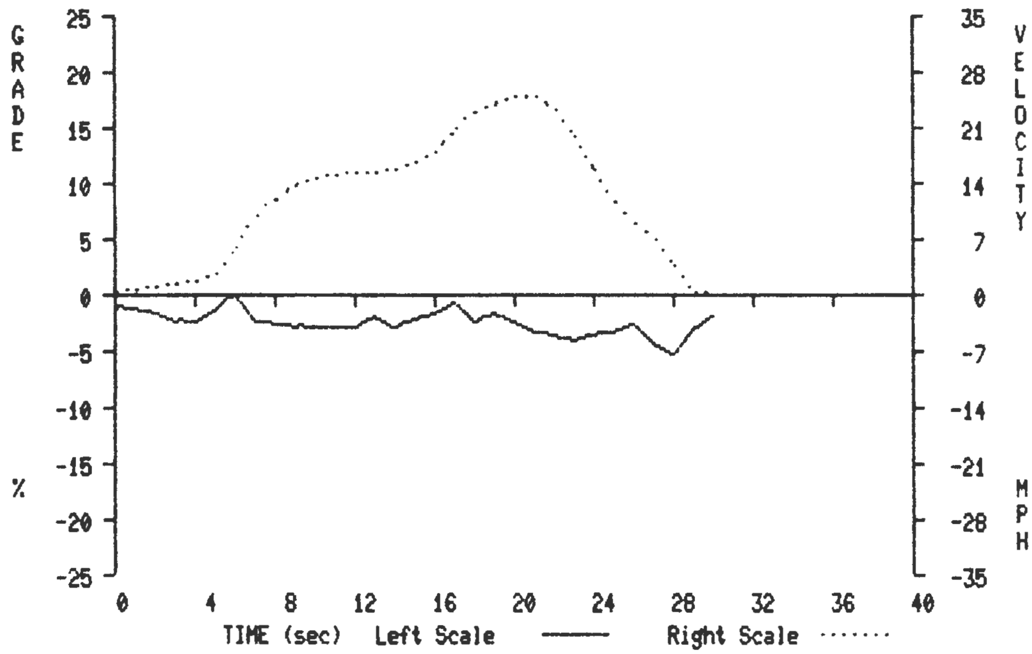


EXHIBIT V-15

Plots for Run 214, Segment 17

RUN NUMBER: 214 SEGMENT NUMBER: 17



VI. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

VI. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The data gathered in the test of the four propulsion systems and the analysis of that data provides useful information for transit operating properties, in addition to the San Francisco MUNI, and for the manufacturers of the propulsion equipment. The findings and conclusions of the evaluation project are presented in four groups:

- General
- Energy
- Performance
- Cost.

Each is discussed in more detail below.

1. GENERAL

Advanced propulsion systems are well suited to trolleybus applications. All of the commercially available systems operated in a satisfactory manner in MUNI service, within the limits of their specified performance. None presented any fundamental technical problems to full scale deployment.

(1) Operations

In general, the advanced equipment exhibited no inherent operational problems, and offered operating benefits. The findings are:

- The advanced systems provide a smoother ride than the switched resistor equipment, especially for lightly loaded trolleybuses.
- Automatic, built in protection must be provided against traction power polarity reversal, to ensure that no operational burden is imposed on the driver.
- The power and brake pedal configuration should conform to the requirements of the MUNI Operations Department, to permit consistent driver reaction and control.
- Interlocks and start-up controls, including any hill start boost feature, should be made as simple as practicable.

(2) Maintenance

The maintenance aspects of the advanced systems offer advantages and disadvantages. They consist of the following:

- Advanced propulsion systems are much more complex than conventional systems. They use solid state power switches, novel component and equipment packages, and analog, digital, and microprocessor control circuits.

- Advanced propulsion systems can provide vastly improved maintenance diagnostics, through plug-in test sets and automated built-in test and diagnostic procedures. Microprocessor based controllers, such as the Westinghouse equipment, can offer highly effective built-in maintenance diagnostic aids.

- None of the systems, as configured, made outstanding use of technology to aid maintenance. All suppliers, including Westinghouse, can and should take further advantage of advanced technologies to assist, simplify and automate equipment maintenance. Such maintenance aids are essential to offsetting the problems associated with maintaining complex solid state electronics.

- Suppliers of advanced systems should design their equipment to make Line Replaceable Units (LRUs) of reasonable size, weight, and complexity. Such steps will permit transit properties to maximize the service availability of their advanced propulsion trolleybuses.

(3) Safety

The advanced equipment appears to offer no safety problems in trolleybus applications that have not been previously addressed in other applications of the advanced propulsion systems. Issues for consideration include:

- Equipment must be designed to eliminate the possibility of equipment failure which would apply more propulsion power than requested by the driver.

- Explicit documentation should be prepared to describe the provisions for detecting and protecting the public against an electrified trolleybus. Statements regarding special maintenance, operating, or traction power systems provisions should be required by the transit property and provided by the trolleybus and propulsion equipment suppliers.

- Equipment must be designed to minimize, or eliminate, hazards to maintenance personnel. For example, the commutating circuits and line filters of the choppers will contain electrolytic capacitors that must be discharged before it is safe to access the equipment boxes. It is recommended that hazard analyses be conducted on new equipment before permitting MUNI maintenance or passenger service.

2. ENERGY

The use of advanced trolleybus propulsion systems results in substantial reduction of net propulsion energy consumption. The energy savings range between 22 and 53 percent of the baseline propulsion energy usage of the switched resistor equipment, under the same conditions of weight and route, as shown in Exhibit VI-1, Relative Energy Savings.

Aggregate energy figures combine equally the contribution of all test cases. They do not represent any single case exactly, but provide an equitable comparison basis for overall performance evaluation. Exact comparisons can be made based on the detailed PLOTPAC data given in Appendix B.

Aggregate energy savings for runs at all three loadings are shown in Exhibit VI-2. Average savings for all the route and loading conditions of the MUNI test vary between 35 and 44 percent of the baseline usage, depending on equipment type. Actual energy savings at MUNI for a fully equipped fleet would fall into that range.

The aggregate average energy rate of the switched resistor equipment is 4.77 kwhr/mi. The aggregate average energy rate for the advanced equipment is 2.89 kwhr/mi, or 39 percent less.

Following is a brief discussion of several findings related to the energy usage of the propulsion systems.

(1) Loading

The percentage of energy savings gained from using advanced equipment is greatest for empty trolleybuses, and is least for crush loaded trolleybuses. For example:

- Switched resistor equipment is least efficient when empty. It becomes relatively more efficient as it is loaded.
- The efficiency of advanced equipment is not heavily dependent on weight. It becomes incrementally less efficient when loaded.

As previously mentioned, Exhibit V-2 shows composite averages for each equipment type and loading condition.

(2) Route

Advanced systems deliver the greatest energy advantages when operating on hilly terrain, because:

- They operate efficiently going uphill.
- Since they can regenerate, they can recover the gravitational potential energy going downhill, if the traction power system is receptive.

EXHIBIT VI-1

Relative Energy Savings

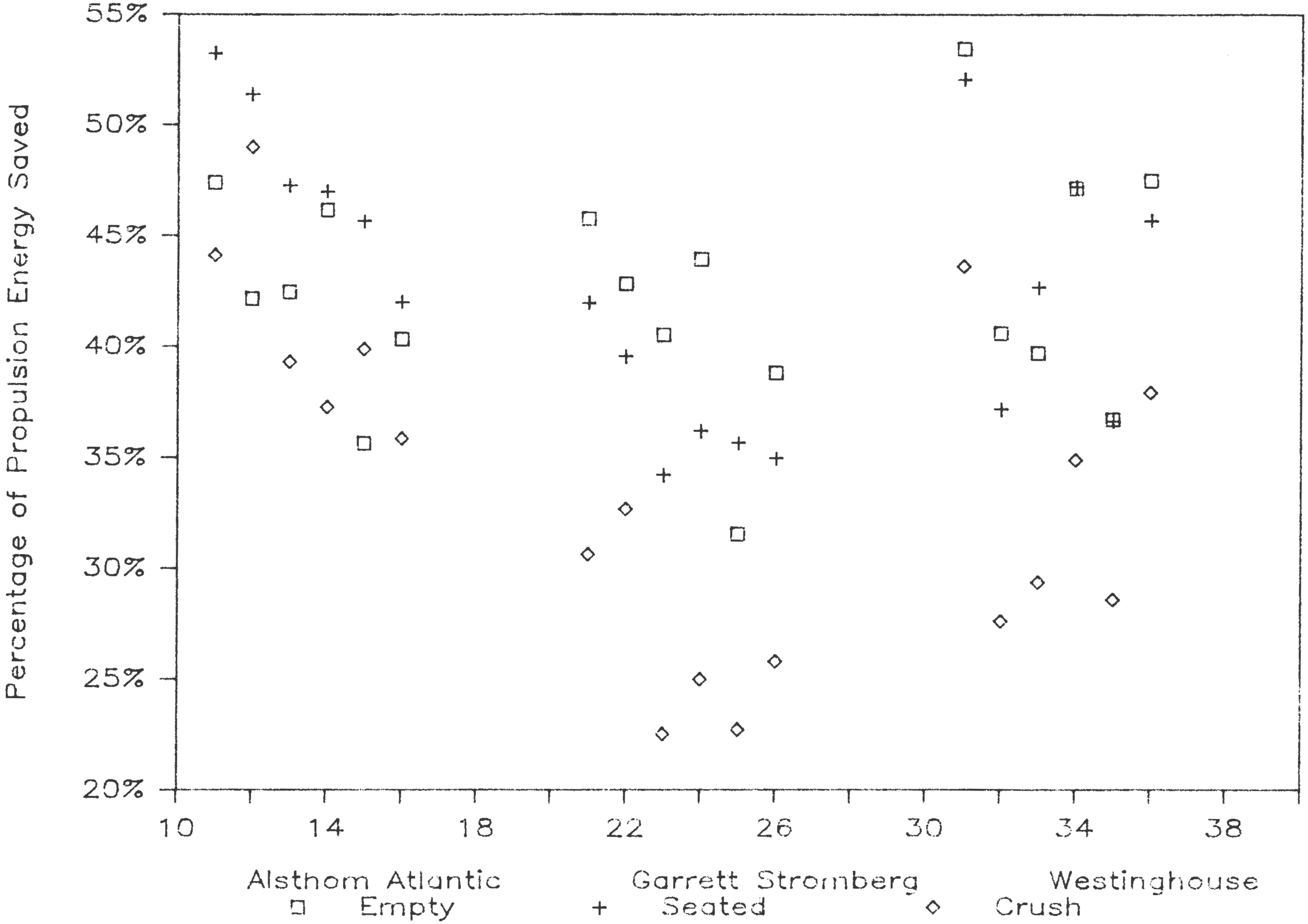
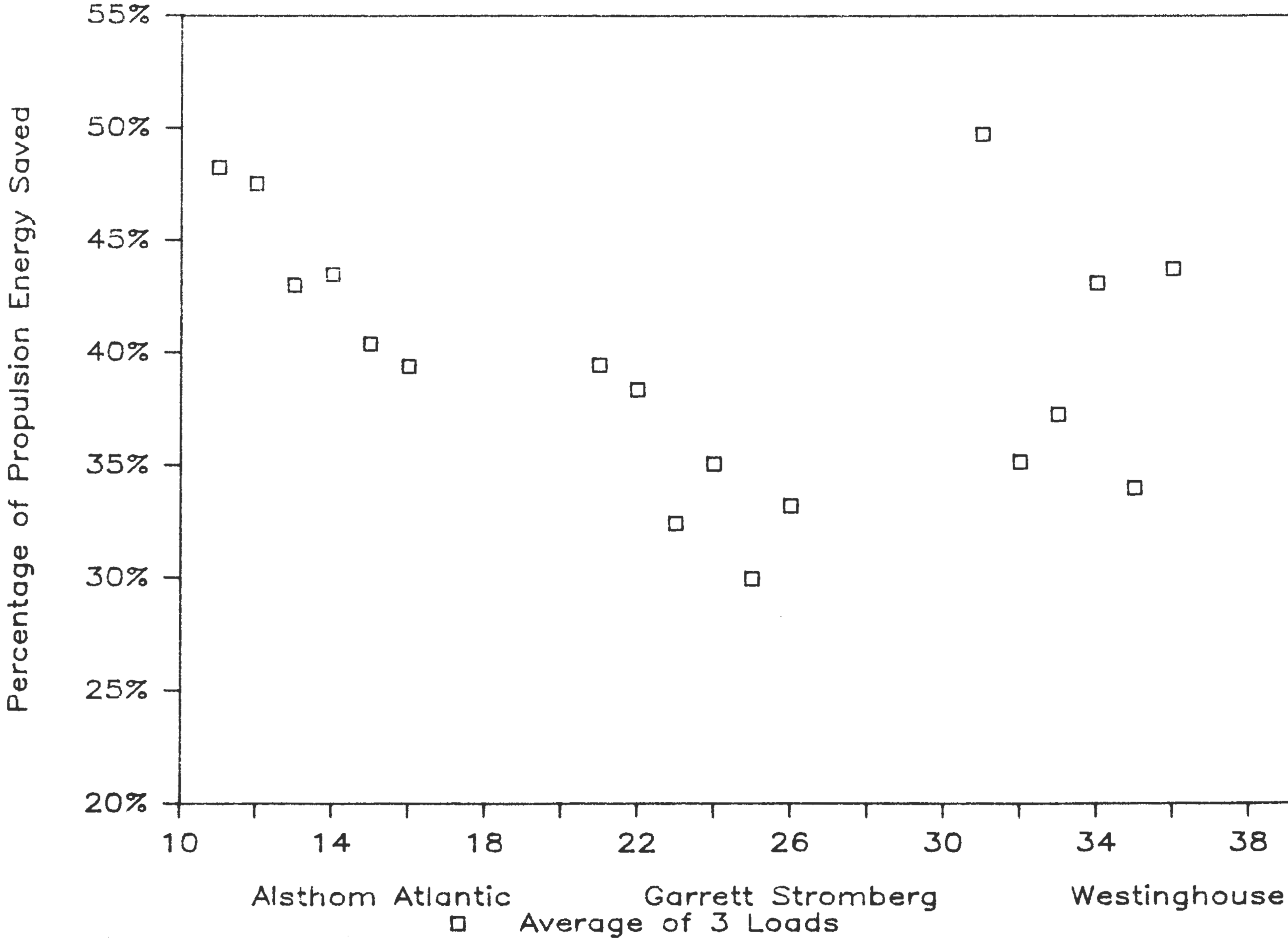


EXHIBIT VI-2

Relative Energy Savings - Average of Three Loads



Advanced systems also deliver energy advantages on level terrain, especially when traffic requires frequent stops, since most of the energy used by the trolleybus in acceleration is converted into kinetic energy which is recoverable by regeneration on subsequent deceleration. Systems with the highest power circuit and motor efficiency perform best on level terrain.

(3) Switched Resistor Equipment Energy Losses

The largest energy loss in switched resistor propulsion equipment is in starting and running the trolleybus. The energy is lost in the switched resistor propulsion controls. The second largest loss is of dynamic braking energy, which is dissipated in the dynamic braking resistors.

Exhibits V-5, V-6, and V-7 presented earlier illustrated the energy dissipated in the controls and the energy dissipated in the dynamic braking resistors for each of the propulsion systems tested, for all routes and loadings. The exhibits in Appendix B list the control and regeneration losses in kilowatt hours and percentages of the total propulsion energy.

The switched resistor system control losses range between 28 and 48 percent of the total propulsion energy use. The aggregate average control loss for the switched resistor equipment is 40 percent. For the aggregate average energy rate of the conventional equipment, that amounts to a loss of 1.91 kwhr/mi.

The switched resistor system regeneration losses range between 11 and 23 percent of the total propulsion use. The aggregate average regeneration loss for the switched resistor equipment is 18 percent. For the aggregate average energy rate of the switched resistor equipment, that amounts to a loss of 0.86 kwhr/mi.

(4) Advanced Equipment Control Losses

Control losses are much lower for advanced propulsion systems in low speed service with frequent stops.

Control losses for advanced equipment would be slightly higher than switched resistor equipment for sustained high speed operation. However, MUNI service does not include any sustained high speed operating routes.

For the tests conducted at the MUNI, control losses in the advanced equipment were between 10 and 76 percent of the losses in the switched resistor equipment for the same runs. The aggregate average control losses were 22 percent of those of the switched resistor equipment. This represents a 1.49 kwhr/mi reduction in losses for the advanced equipment, compared to the aggregate average of 4.77 kwhr/mi for the switched resistor equipment.

(5) Regeneration

Regeneration is an important energy saving capability of the advanced systems. Switched resistor equipment can not control regeneration, and only regenerates a small fraction of the dynamic brake energy to the traction power system. Regeneration impacts include regeneration losses and regeneration savings.

1. Regeneration Losses

Regeneration losses as defined here include all energy created during dynamic brake applications but not regenerated to the traction power system, because of dissipation in the propulsion controls or because of an unreceptive traction power system.

For the test runs of the advanced equipment, regeneration losses were between 8 and 156 percent of the losses of the switched resistor equipment. The aggregate average regeneration losses were 66 percent of those of the switched resistor equipment, or the equivalent of a 0.29 kwhr/mi reduction in energy consumption rate for the advanced equipment.

2. Regeneration Savings

Regeneration savings are the amount of energy returned to the traction power system by the propulsion equipment. This is the dynamic brake energy from the motor, minus dynamic brake resistor losses, traction power circuit losses, and energy used by the trolleybus auxiliary equipment. Regeneration savings of the switched resistor equipment are almost zero.

The advanced propulsion systems regenerate to the traction power system between 6 and 23 percent of the net propulsion energy used by the switched resistor equipment. The aggregate average energy regenerated in these tests by the advanced equipment was 13 percent, or the equivalent of 0.60 kwhr/mi.

(6) Garrett-Stromberg AC Propulsion Equipment

The Garrett-Stromberg equipment provides satisfactory energy performance and savings. The aggregate energy consumption rate for the Garrett-Stromberg equipment was 3.11 kwhr/mi, or 65 percent of the switched resistor equipment rate. Distinguishing characteristics are:

- Superior regeneration capability. The Garrett-Stromberg equipment has the lowest regeneration losses, as can be seen in the size of the top bars presented earlier in Exhibits V-5, V-6, and V-7. It also has the greatest regeneration savings. Indication of this excellent regeneration capability is further illustrated in the segment plots of Appendix C. For the test runs, the aggregate average regeneration losses were 17.8 percent of the switched resistor equipment, compared to the all-equipment average of 66 percent. Regeneration savings for the Garrett-Stromberg equipment was 15.0 percent, compared to the all-equipment average of 12.7 percent.

- Higher motor energy. The Garrett-Stromberg equipment uses substantially more energy in the traction motor than the other systems. The three DC motor systems use roughly equivalent amounts of motor energy. The Garrett-Stromberg equipment may use more motor energy because of the induction motor design and the mode of slip control used in the inverter.

- Good inverter efficiency. The aggregate average control losses for Garrett-Stromberg were 15.4 percent, compared to the all-equipment average of 22 percent.

(7) Westinghouse Chopper

The Westinghouse equipment provides satisfactory energy performance and savings. The aggregate energy consumption rate for the Westinghouse equipment in these tests was 2.87 kwhr/mi, or 60 percent of the switched resistor equipment rate. Distinguishing characteristics are:

- Good chopper efficiency. The Westinghouse chopper control losses were 20.3 percent, compared to the all-equipment average of 22 percent.

- Average motor energy. The net energy used in the traction motor was comparable to the other DC motor systems.

- High regeneration losses. The Westinghouse equipment had high regeneration losses and low regeneration savings, compared to the all-equipment averages. The regeneration losses were 113 percent of those in the switched resistor equipment, compared to the all-equipment average of 66 percent. The regeneration savings were 7.7 percent, compared to the all-equipment average of 12.7 percent.

The Westinghouse equipment controls regeneration both with the main chopper, and with series resistors and bypass thyristors. The high regeneration losses are caused by energy dissipation in the series resistors.

(8) Alsthom Atlantic Chopper Equipment

The Alsthom Atlantic equipment provides satisfactory energy performance and savings. The aggregate energy consumption rate for the Alsthom Atlantic equipment in these tests was 2.69 kwhr/mi, or 56 percent of the switched resistor equipment rate. The overall energy consumption rate of the Alsthom Atlantic equipment, in kilowatt hours per mile, is the lowest of the advanced systems.

Distinguishing characteristics are:

- Moderately low regeneration losses. The Alsthom Atlantic equipment regeneration losses were 58 percent of the switched resistor equipment losses, compared to the all-equipment average of 66 percent. The regeneration savings were 15.5 percent, compared to the all-equipment average of 12.7 percent.

- Moderate control losses. The Alsthom Atlantic equipment control losses were 30 percent, compared to the all-equipment average of 22 percent.

- Moderately low motor energy. The net motor energy used was the lowest of the amounts used by the DC motor systems.

3. PERFORMANCE

The performance test program indicated that the use of advanced propulsion systems offers modest performance benefits in terms of reduced spread in average acceleration, and reduced peak jerk and peak acceleration for empty trolleybuses.

(1) Peak Jerk

Exhibit V-8 presented earlier showed the peak jerk for each of the propulsion systems at each load, for one run. The indicator was the average of the highest one second jerk event in each segment of each run. The aggregate peak jerk for the advanced equipment was 1.65 mphpsps, while the peak jerk for the switched resistor equipment was 1.66 mphpsps.

For an empty trolleybus, the switched resistor equipment peak jerk was 1.88 mphpsps, while the average for the advanced equipment was 1.71 mphpsps. Reduced peak jerk increases passenger comfort.

(2) Peak Acceleration

Exhibit V-8 presented earlier showed the peak acceleration for each of the propulsion systems at each load, for one run. The aggregate peak acceleration for the advanced equipment was 2.82 mphps, while the peak acceleration for the switched resistor equipment was 2.84 mphps.

For an empty load trolleybus, the switched resistor equipment peak acceleration was 3.18 mphps, while the average for the advanced equipment was 2.86 mphps. Reduced peak acceleration increases passenger comfort.

(3) Average Acceleration

Exhibit V-3 discussed earlier showed the average acceleration for each of the propulsion systems at each load, for all runs. Exhibit V-3 also showed aggregate statistics for average acceleration. The aggregate difference between the empty load and crush load average acceleration for the advanced equipment was 0.06 mphps, while the difference between empty and crush load average acceleration for the switched resistor equipment was 0.24 mphps. The findings were:

- The average accelerations of all of the advanced equipment was much more tightly grouped than the switched resistor equipment.

- Garrett-Stromberg's equipment provided the highest aggregate average acceleration. Garrett-Stromberg's equipment also provided the highest peak acceleration and peak jerk. However, the difference between the highest and lowest aggregate average acceleration was less than 0.2 mphps.

Reduced spread in average acceleration may marginally improve schedule adherence capability.

(4) Equipment Differences and Limitations

Several performance considerations are relevant to particular systems. It is important to note that the test program was not extensive enough in scope to permit suppliers to provide equipment specifically designed to a single set of performance criteria. Instead, the program used "off-the-shelf" systems, usually modified slightly from the supplier's most recent trolleybus project. The horsepower rating of the readily available Garrett-Stromberg equipment was insufficient to provide sustained operation at crush loads on the steep grades of the Union Street route. This limitation required interpolation of the data since the Union Street crush load tests were not conducted. For a MUNI specific application, Garrett-Stromberg would supply equipment with a higher horsepower rating.

4. COST ANALYSIS

The value of purchasing an advanced propulsion system for the MUNI trolleybus is a function of the energy savings and the capital costs. In this analysis, the emphasis was placed on the difference between the life cycle costs of the baseline system (General Electric switched resistor controller) and the three advanced propulsion systems. The incremental capital cost of the advanced propulsion systems over a switched resistor controller may be viewed as an investment, the energy savings may be viewed as a return on the investment.

Because the purchase price of each of the propulsion systems is not known, the cost analysis was structured to identify the price differential that would or would not justify the acquisition of each system. Costs were calculated on a per trolleybus basis.

(1) Assumptions

To keep the analysis manageable and at the same time meaningful, simplifying assumptions were made with regard to many of the variables included in the cost analysis:

- Energy Cost - The marginal cost was assumed to be 8.5 cents/kwhr, consistent with the cost used in the MUNI Short Range Transit Plan (SRTP).

- Trolleybus Loading - A loading of 33 1/3 percent empty, 33 1/3 percent fully seated, 33 1/3 percent crush loaded was assumed. A separate sensitivity analysis varied the loading from 100 percent empty to 100 percent crush loaded.

- Annual Miles/Trolleybus - Trolleybus fleet miles of 7,471,000 for FY 1983-84 divided by 345 trolleybuses equaled an average miles/year of 21,655 for each trolleybus.

- Propulsion System Life - The analysis was performed for periods of 15, 20, and 25 years because the exact economic life of the systems was not known.

- Opportunity Cost of Money - Because of the large energy savings, the choice of discount rate has a major impact on the present value of a lifetime of energy savings. Depending on the assumptions made relative to inflation, municipal bond financing, subsidized capital and operating costs, etc, the use of numerous discount rates can be rationalized. To provide wide comparisons, the analysis was performed using discount rates ranging from a low of 0 percent to a high of 10 percent. An analysis in MUNI's Short Range Transit Plan makes a case for an effective discount rate of 0 percent based on historical energy cost, inflation and local financing costs. The 10 percent is based on the recommended Office of Management and Budget circular A-94.

- Maintenance Costs - Maintenance cost differentials between the switched resistor equipment system and the advanced propulsion systems were not included in the analysis. Maintenance cost data was not available for comparison of the systems.

- Salvage Value - The salvage value of the propulsion system at the end of its economic life was considered to be zero.

- Line Receptivity - The test results quantified the actual regeneration of the test trolleybus running on the MUNI system. The previous receptivity study, conducted by Garrett AiResearch in 1982, concluded that 93.5 percent of the energy available for regeneration would be accepted by the traction power system. If the entire trolleybus fleet were retrofitted with regenerative propulsion equipment, the actual regeneration for each trolleybus would be slightly less than the results given in this report. For the purposes of this cost analysis, however, the slight reduction in regeneration has been excluded since exact quantification of the reduction is beyond the scope of this analysis.

(2) Results of the Cost Analysis

The results of the cost analysis are graphically depicted in Exhibit VI-3, Present Value of Energy Savings, and are detailed in the tables of Exhibit VI-4, Energy Life Cycle Cost Analysis for Distributed Loads. For each advanced propulsion system, the present value of 15, 20 and 25 years of energy savings has been plotted using discount rates of 0 , 5 and 10 percent. The present value of the energy savings represents the difference in capital costs that would justify the purchase of each propulsion system. For example, assuming a discount rate of 5 percent, the present value of 20 years of energy savings using the Garrett-Stromberg propulsion system would be $37,998, or in round

EXHIBIT VI-3

Present Value of Energy Savings

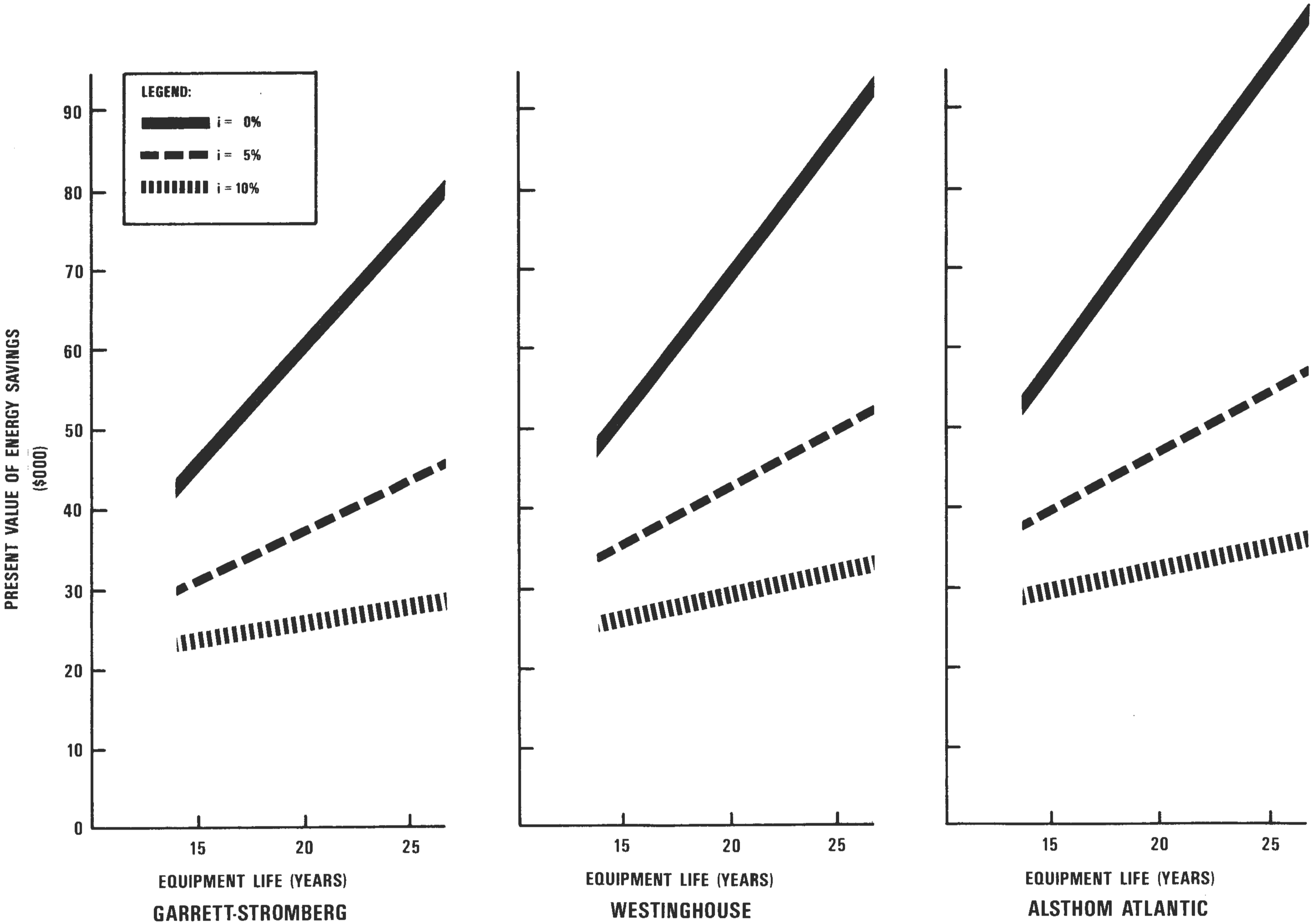


EXHIBIT VI-4

Energy Life Cycle Cost Analysis for Distributed Loads

	% LOADS	General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY(kwh/mile)					
Empty	33.33%	4.18	2.50	2.35	2.42
Seated	33.33%	5.12	3.23	2.92	2.69
Crush	33.33%	5.01	3.61	3.35	2.96
Average		4.77	3.11	2.87	2.69
Savings/Mile/Coach			1.66	1.90	2.08

Trolley*Miles	7471000
Trolleycoaches	345
$$/KWH	0.085
Miles/Year	21655

			General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY COSTS/COACH			$8,779	$5,730	$5,288	$4,951
Savings/Year/Coach				$3,049	$3,491	$3,828
PRESENT VALUE OF SAVINGS	Propulsion Life	Int. Rate				
	25	10.00%		$27,677	$31,686	$34,749
	20	10.00%		$25,959	$29,719	$32,592
	15	10.00%		$23,192	$26,551	$29,118
	25	5.00%		$42,974	$49,199	$53,955
	20	5.00%		$37,998	$43,503	$47,708
	15	5.00%		$31,649	$36,233	$39,736
	25	0.01%		$76,128	$87,157	$95,582
	20	0.01%		$60,918	$69,743	$76,484
	15	0.01%		$45,700	$52,320	$57,378

figures $38,000. From the perspective of capital costs, it would be worthwhile for the MUNI to pay up to $38,000 more for a Garrett-Stromberg propulsion system over switched resistor equipment without regeneration, assuming equal performance and equal maintenance costs.

A similar analysis can be conducted looking at the life cycle cost savings differential between two advanced propulsion systems. For an economic life of 20 years and a discount rate of 5 percent, the present value of the energy savings of the Westinghouse system would be $43,503. From a capital cost perspective, it would be cost effective to spend up to $43,503 - $37,998 = $5,505 more for the Westinghouse system then the Garrett-Stromberg system, other costs and performance being equal.

Exhibit VI-5, Life Cycle Cost Comparison for Advanced Propulsion Systems, provides tables for the comparison of the capital costs between the three advanced propulsion systems. Each propulsion system is compared to the other two in terms of the capital cost differential which would justify its purchase. The positive numbers represent the added capital costs of the alternative that would be justified. The negative numbers represent the reduced capital costs of the alternative that would be required to justify its purchase.

For example, assuming a propulsion system life of 20 years and a discount rate of 5 percent (the arrow), the Garrett system would need to be at least $5,505 less expensive than the Westinghouse system before it would be cost-efficient. Likewise, the Alsthom Atlantic system could be priced up to $4,205 more than the Westinghouse system because of its greater energy savings.

(3) Sensitivity Analysis

A limited amount of sensitivity analysis was performed on the data. It consisted of:

- Trolleybus Loading - The analysis was conducted with 100 percent of the loads empty, and 100 percent of the loads crush to evaluate the impact on energy savings. The detailed results are presented in Exhibit VI-6, Energy Life Cycle Cost Analysis for Empty Trolleybus, and Exhibit VI-7, Energy Life Cycle Cost Analysis for Crush Loaded Trolleybus. Even at these extreme cases, savings did not vary significantly.

- Discount Rates - As is evident in the various exhibits, the selection of the discount rate has a large impact on the results of the analysis. For the intermediate assumption (5 percent), additional capital costs of $30,000 to $50,000 for each advanced propulsion system would be worthwhile, assuming no increase/decrease in maintenance costs.

EXHIBIT VI-5

Life Cycle Cost Comparison for Advanced Propulsion Systems

Economic Life	Discount Rate		Garrett-Stromberg vs. Westinghouse (Dollars)	Garrett-Stromberg vs. Alsthom Atlantic (Dollars)
25 yrs.	10%	BASE	+4,009	+7,072
20	10%	BASE	+3,760	+6,633
15	10%	BASE	+3,359	+5,926
25	5%	BASE	+6,225	+10,981
20	5%	BASE	+5,505	+9,710
15	5%	BASE	+4,584	+8,087
25	0%	BASE	+11,029	+19,454
20	0%	BASE	+8,825	+15,566
15	0%	BASE	+6,620	+11,678

Economic Life	Discount Rate	Westinghouse vs. Garrett-Stromberg (Dollars)		Westinghouse vs. Alsthom Atlantic (Dollars)
25 yrs.	10%	-4,009	BASE	+3,063
20	10%	-3,760	BASE	+2,873
15	10%	-3,359	BASE	+2,567
25	5%	-6,225	BASE	+4,756
→ 20	5%	-5,505	BASE	+4,205
15	5%	-4,584	BASE	+3,503
25	0%	-11,029	BASE	+8,425
20	0%	-8,825	BASE	+6,741
15	0%	-6,620	BASE	+5,058

Economic Life	Discount Rate	Alsthom Atlantic vs. Garrett-Stromberg (Dollars)	Alsthom Atlantic vs. Westinghouse (Dollars)	
25 yrs.	10%	-7,072	-3,063	BASE
20	10%	-6,633	-2,873	BASE
15	10%	-5,926	-2,567	BASE
25	5%	-10,981	-4,756	BASE
20	5%	-9,710	-4,205	BASE
15	5%	-8,087	-3,503	BASE
25	0%	-19,454	-8,425	BASE
20	0%	-15,566	-6,741	BASE
15	0%	-11,678	-5,058	BASE

Exhibit VI-6

Energy Life Cycle Cost Analysis for Empty Trolleybus

	% LOADS	General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY(kwh/mile)					
Empty	100.00%	4.18	2.50	2.35	2.42
Seated	0.00%	5.12	3.23	2.92	2.69
Crush	0.00%	5.01	3.61	3.35	2.96
Average		4.18	2.50	2.35	2.42
Savings/Mile/Coach			1.68	1.83	1.76

Trolley*Miles	7471000
Trolleycoaches	345
$$/KWH	0.085
Miles/Year	21655

		General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY COSTS/COACH		$7,694	$4,602	$4,326	$4,454
Savings/Year/Coach			$3,092	$3,368	$3,240
PRESENT VALUE OF SAVINGS					
Propulsion Life	Int. Rate				
25	10.00%		$28,069	$30,576	$29,406
20	10.00%		$26,327	$28,677	$27,581
15	10.00%		$23,521	$25,621	$24,641
25	5.00%		$43,583	$47,475	$45,659
20	5.00%		$38,537	$41,978	$40,373
15	5.00%		$32,097	$34,963	$33,626
25	0.01%		$77,208	$84,102	$80,885
20	0.01%		$61,782	$67,298	$64,724
15	0.01%		$46,348	$50,486	$48,555

EXHIBIT VI-7

Energy Life Cycle Cost Analysis for Crush Loaded Trolleybus

	% LOADS	General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY(kwh/mile)					
Empty	0.00%	4.18	2.50	2.35	2.42
Seated	0.00%	5.12	3.23	2.92	2.69
Crush	100.00%	5.01	3.61	3.35	2.96
Average		5.01	3.61	3.35	2.96
Savings/Mile/Coach			1.40	1.66	2.05

Trolley*Miles	7471000
Trolleycoaches	345
$$/KWH	0.085
Miles/Year	21655

			General Electric	Garrett Stromberg	Westing house	Alsthom Atlantic
ENERGY COSTS/COACH			$9,222	$6,645	$6,166	$5,448
Savings/Year/Coach				$2,577	$3,056	$3,773
PRESENT VALUE OF SAVINGS	Propulsion Life	Int. Rate				
	25	10.00%		$23,391	$27,735	$34,251
	20	10.00%		$21,939	$26,013	$32,125
	15	10.00%		$19,601	$23,241	$28,701
	25	5.00%		$36,319	$43,064	$53,182
	20	5.00%		$32,115	$38,079	$47,025
	15	5.00%		$26,748	$31,715	$39,167
	25	0.01%		$64,340	$76,289	$94,212
	20	0.01%		$51,485	$61,046	$75,389
	15	0.01%		$38,623	$45,796	$56,556

- Economic Life - The economic life of the propulsion system also impacts the savings. Comparisons were conducted for lives of 15, 20 and 25 years. Caution should be used to always compare alternatives with equal economic lives.

- Energy Costs - No sensitivity analysis was conducted on energy cost. The actual energy costs for MUNI are known. Changes to the 8.5¢/kwh cost would affect the savings proportionally.

APPENDIX A

TEST EQUIPMENT

TEST EQUIPMENT

The test equipment consists of a vehicle carried data acquisition system, called BUSDAC, and an off-vehicle data analysis system, called PLOTPAC. Both systems are computer-based and use the same basic architecture, hardware, operating system, and application language. Exhibit A-1, BUSDAC/PLOTPAC System, provides an illustration of the overall system.

BUSDAC measured and recorded the important operating parameters of the trolleybus and its propulsion system, under dynamic and static conditions. BUSDAC measured and digitized the trolleybus parameters at rates up to 10 times per second, and recorded the data on tape for subsequent analysis by PLOTPAC.

PLOTPAC organized, analyzed, and reported on the data collected by BUSDAC for each run. PLOTPAC operated interactively, under control of the user, and provided a hierarchical data structure, so that the analyst could look at the results of a trolleybus run, starting at the most concise, summarized level, and proceed to the needed level of detail.

The following sections present the BUSDAC and PLOTPAC systems. Sections 1 and 2 describe the capabilities and performance, and operation of BUSDAC. Sections 3 and 4 describe PLOTPAC's capabilities and operation. Sections 5 describes BUSDAC hardware, including computer system, peripherals, transducers and interface equipment. Section 6 is a general discussion of BUSDAC software architecture and the system states. Section 7 describes PLOTPAC hardware, and Section 8 completes the discussion with PLOTPAC software.

1. BUSDAC CAPABILITIES AND PERFORMANCE

BUSDAC measures, displays, and records the trolleybus's operating state. Exhibit A-2, Schematic Diagram of BUSDAC Connections to Test Trolleybus, shows the input measurement system and illustrates the parameters measured, including:

- Input power, line voltage and line current
- Motor power, motor voltage and motor current
- Auxiliary power
- Vehicle speed, from a tachometer, with high resolution
- Vehicle distance
- Vehicle grade and acceleration, from an inclinometer
- Vehicle status, from 16 discrete inputs
- Date and time.

EXHIBIT A-1

BUSDAC/PLOTPAC System

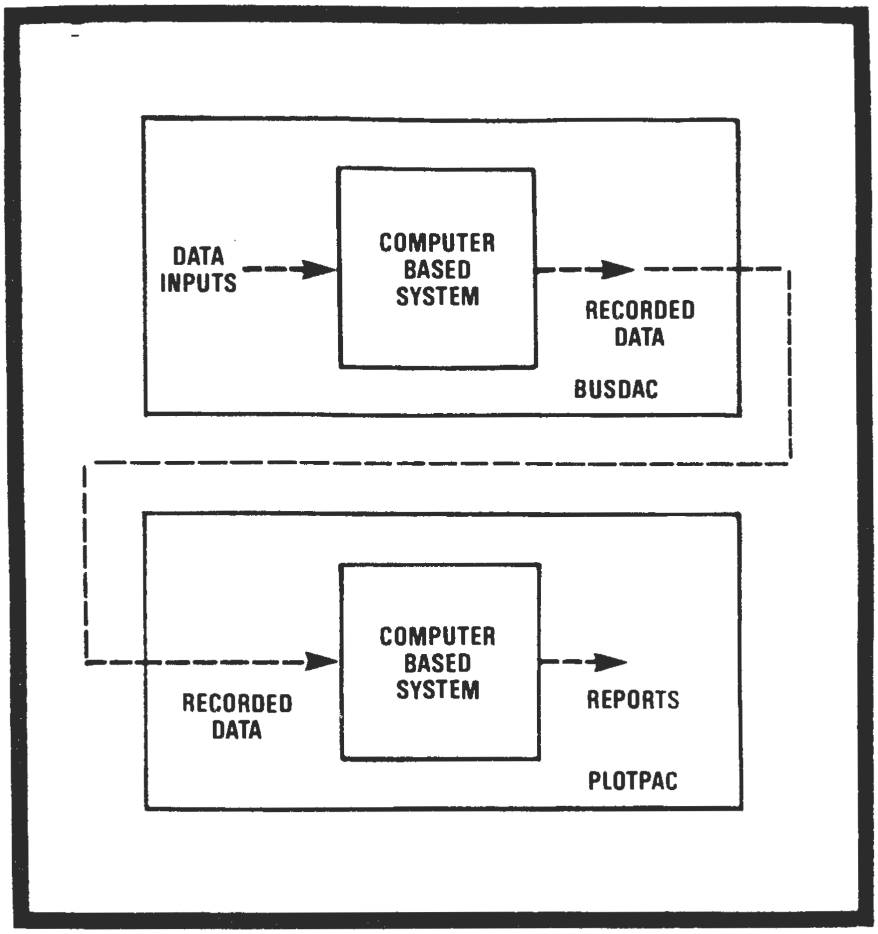
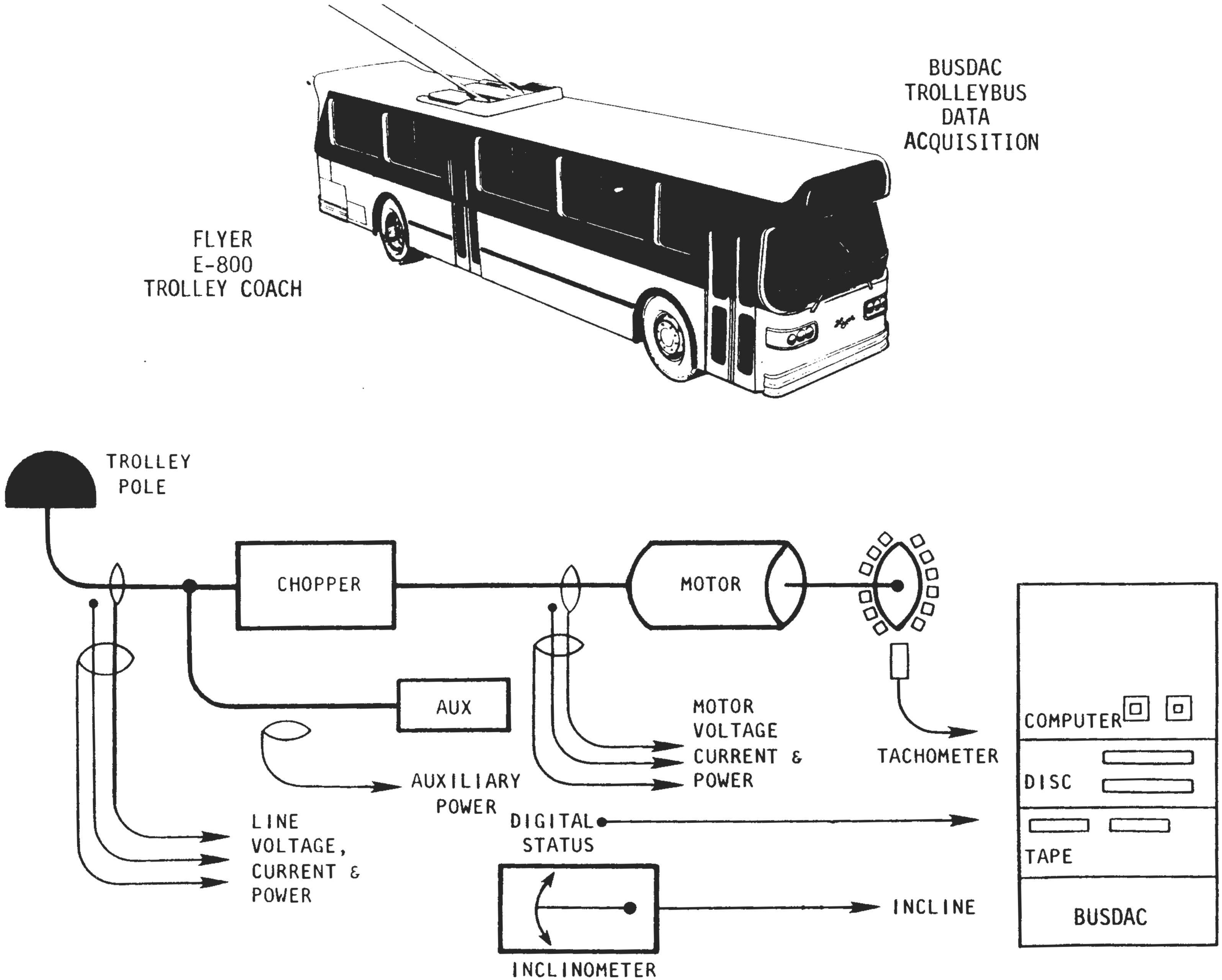


EXHIBIT A-2

Schematic Diagram of BUSDAC Connections to Test Trolleybus



BUSDAC permits the automatic calibration of key parameters, while operating in a calibrate mode. The two parameters are:

- Tachometer pulses per foot, measured by moving the trolleybus a known distance and counting the accumulated tachometer pulses

- Trolleybus drag force, measured by noting the deceleration of the trolleybus on a level grade with no power applied

Tachometer calibration provides for an accurate measure of distance and velocity during a run and the trolleybus drag measurement is used in PLOTPAC for determining the energy applied directly to the wheels of a trolleybus.

BUSDAC records the operator's comments during a run. The operator's comments are time-stamped and become part of the information stored on tape. Significant events during a run can then be noted and easily cross referenced to the trolleybus's operating state in the PLOTPAC reports.

BUSDAC provides a test mode for measuring and displaying the trolleybus's operating state without recording data. This is useful during the shakedown testing when new equipment is being installed and checked for correct operation and measurement of parameters before a run is attempted.

BUSDAC provides a display of the operating state of the trolleybus during testing and data acquisition. Propulsion equipment failures can be easily noted and corrective action taken. A snapshot of the trolleybus operating state can be printed out at any time.

BUSDAC measures the parameters at rates that vary from once per second to 10 times per second. Power, current and voltage measurements are collected at a 1 Hz rate. Velocity and distance are sampled five times every second and the inclinometer 10 times per second. Status is sampled once per second. With BUSDAC's two recording tapes, up to two hours of data can be recorded at one time. Because typical run times on MUNI trolley lines are 40 minutes one way, a single tape was usually sufficient for most runs.

Each run is fully defined on the data tape. BUSDAC requires use of the initialization mode, which records the important run status indicators, including date, time, trolleybus driver, test operator, equipment type, trolleybus weight, and general comments. BUSDAC prompts the operator to supply the data, which is then logged onto the tape along with the data collected.

BUSDAC measurement accuracies are:

- Voltage, current and power: better than 2 percent of the full scale reading

- Time: better than 1 millisecond

- Distance: better than 2 inches

- Incline: better than 0.5 percent.

These accuracies are based on the inherent measuring capabilities of the instruments and the data acquisition equipment. The accuracy of derived values, such as velocity, acceleration, or energy, calculated using floating point arithmetic, depends on the accuracy of the basic measurements.

In addition to errors introduced from accuracy limits of the measuring instruments, certain aspects of BUSDAC connection, programming, and use also introduce errors. They consist of the following:

- BUSDAC was not equipped with a power meter to measure power in the shunt field of the compound motor used in the General Electric and Alsthom Atlantic equipment configurations. This caused the propulsion controls of those two systems to appear less efficient by about 1 percent of the consumed propulsion energy and the motor to appear more efficient by the same amount.

- BUSDAC only measured voltage, current and power once per second. Analog low pass filters on the actual measuring instruments provided suitable averaging, with time constants of about one second. This arrangement provided some time shift in measurements for rapidly varying signals and caused offsets between power and other measurements which lasted for several seconds.

- BUSDAC measured velocity five times per second, and calculated acceleration, jerk, and grade over 0.2 second periods. However, BUSDAC averages the readings and uses a single calculation per second as the reporting basis. This reduces the absolute magnitude of peak jerk and peak acceleration, by averaging them over one second. However, the measurements remain accurate relative to one another.

2. BUSDAC OPERATION

The trolleybus battery supplies power to BUSDAC's power subsystem. Once power is turned on, BUSDAC is a fully operational computer system which only needs its software loaded into the computer to begin operation.

The software is stored on an 8-inch floppy disc. The disc is inserted into the floppy disc subsystem and the front panel switches on the computer are toggled to cause the system to boot. Next, the operating system and the application program are loaded into memory, and the operating system prompt appears on the terminal screen. The floppy is removed from the disc unit and stored. Data storage tapes are then installed in the tape unit.

At the terminal prompt, the operator enters the date and time-of-day and calls up the application program by typing "@BUS". The application program loads and enters the start-up mode. The application program has thirteen modes, as illustrated in Exhibit A-3, BUSDAC System States.

With the first mode entered, start-up automatically transitions into the wait mode. The wait mode displays an operator selection menu on the computer terminal, as shown in Exhibit A-4, Wait Mode Screen Format. The wait mode provides the operator selection of four other modes to enter: tape initialization mode; test mode; calibration mode; or tape erase mode.

EXHIBIT A-3

BUSDAC System States

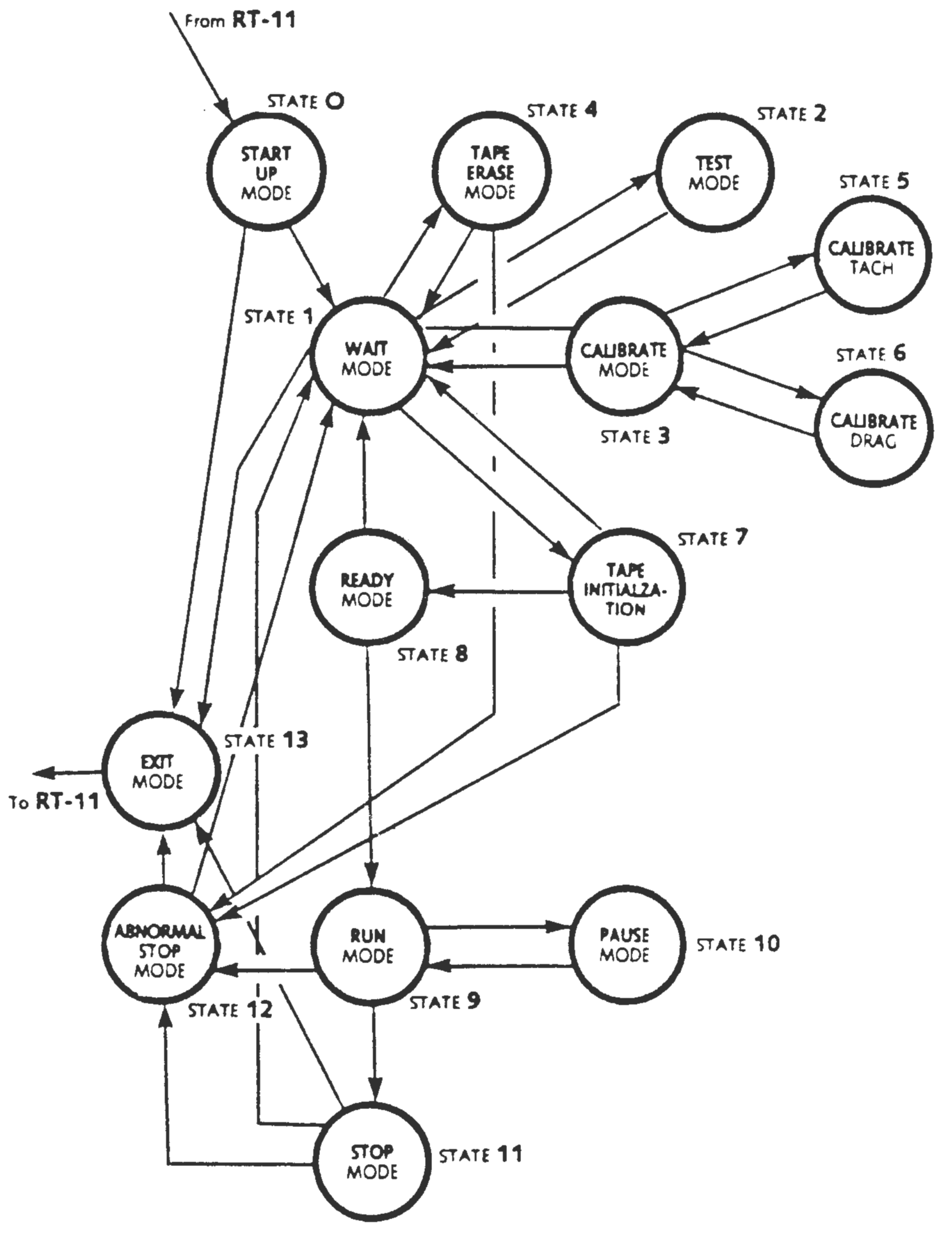


EXHIBIT A-4

Wait Mode Screen Format

```
System entered Wait Mode at 15:14:52 28-NOV-84

Select desired mode:

     1. Tape Initialization Mode.

     2. Test Mode.

     3. Calibration Mode.

     4. Tape Erase Mode.

     9. Exit Mode (Exit to RT-11).

(Run Mode is only accessible from Tape Initialization Mode
to ensure that every tape has a header.)

Enter mode number and type RETURN:
```

The test mode is used in preliminary testing of the equipment before an actual run. It provides a continuous monitor of the trolleybus's operating state as illustrated in the screen of Exhibit A-5, Test Mode Screen Format. The test operator can debug his system before performing an actual run and acquiring data.

The calibration mode is used before a series of runs are undertaken because it is necessary to know what the tachometer and drag force calibrations are in order to do calculations in PLOTPAC, the data analysis system. Also, the tachometer calculation must be known before a drag force can be determined. The operator screens for calibration are shown in Exhibit A-6, Calibration Mode Screen Format. Tachometer calibration is performed by moving the trolleybus a known distance in the tachometer calibration mode and entering the external measurement into the computer. Drag calibration is done by driving the trolleybus faster than 10 miles per hour and letting it coast at least 100 feet or to obtain a velocity of less than 2 miles per hour. The drag force calculation is done automatically by BUSDAC in this mode.

Before a run can begin, the operator must pass through the tape initialization mode. The screen for this mode is shown in Exhibit A-7, Tape Initialization Mode Screen Format. The operator can selectively enter and change the information requested for tape initialization. Choosing option 11, the system writes this information onto a header block of the data tape and enters the ready mode prior to running.

From the ready mode the operator can go into the run mode. A run mode screen is shown in Exhibit A-8. This mode is recording the trolleybus's operating state on tape. The screen display is updated every 3.5 seconds. While in this mode the operator can enter any number of comments during the run and all comments will be stored on the tape with a time stamp. A pause mode is provided to suspend data acquisition; run mode can be reentered and data acquisition operation continues. The run is terminated by the operator by entering the stop mode. The system ends data acquisition, writes any data in its buffer to the tape and does general housekeeping.

If errors in BUSDAC equipment are detected during the run the system will go into the abnormal stop mode and send an error message to the operator.

3. PLOTPAC CAPABILITIES

PLOTPAC was designed to concisely present the results of the analysis, rather than raw data. PLOTPAC analyzes data on the basis of a run, which for this project was defined as one-way operation over a MUNI trolleybus route. For the purpose of data analysis, each run was viewed as a collection of start-stop-start intervals, called segments. PLOTPAC accepts the data tapes created by BUSDAC, and calculates:

- Time
- Distance
- Velocity
- Elevation and grade
- Power
- Energy
- Energy/hour
- Efficiency
- Acceleration and jerk.

EXHIBIT A-5

Test Mode Screen Format

```
System entered Test Mode at 15:22:08 28-NOV-84

velocity =                       0.0 mph
distance =                       0.0 ft
incline =                        0.2 degrees
input voltage =                600.4 volts
input current =                  1.4 amps
input power =                    3.3 kwatts
motor voltage =                  2.7 volts
motor current =                  0.6 amps
motor power =                    0.3 kwatts
aux. power =                     1.7 kwatts
Time: 15:22:09    Date: 28-NOV-84
Status:
  15  14  13  12  11  10   9   8   7   6   5   4   3   2   1   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

To return to Wait Mode type RETURN:
```

EXHIBIT A-6

Calibration Mode Screen Format

```
System entered Calibration Mode at 15:23:18 28-NOV-84

Present calibration values are:
     Tach calibration:  12.90
     Bus weight:  25908.
     Drag force:   200.0

Select desired function:

     1. Execute tachometer calibration.

     2. Input previous tachometer calibration value.

     3. Execute drag force calibration.

     4. Input previous drag force calibration value.

     5. Return to Wait Mode.

Enter function number and type RETURN:
```

```
Execute Tachometer Calibration:

Step 1: Mark starting point accurately; type G and RETURN when ready: G
Step 2: Move bus 50 to 100 feet; stop bus; when complete type S and RETURN: S
Step 3: Measure total distance traveled very accurately;
        Enter distance in feet and inches.
Enter feet (nnn) and type RETURN: 100
Enter inches (nn) and type RETURN: 0
```

```
Execute Drag Force Calibration

Enter bus weight in pounds (nnnnnn) and type RETURN: 25908
Step 2: Bring bus up to a reasonable speed ( > 10 MPH ) on a level grade;
cut off both propulsion and brakes.
Bus must coast 100 feet or slow to less than 2 MPH. Be careful!
Type G and RETURN to start: G
```

EXHIBIT A-7

Tape Initialization Mode Screen Format

```
System entered Tape Initialization Mode at 15:15:16 28-NOV-84
Select item to change or desired function:
     1. Test run number (0 < nnnnn < 32767):    507
     2. Number of tapes to use for this run (1 or 2): 1
     3. Route:
        41-UNION-INBOUND
     4. Driver name:
        STEVEN HO
     5. Busdac Operator name:
        FROILAN "ALAN" I. DE GUZMAN
     6. Bus weight (nnnnnn):  25908.
     7. Equipment type:
        ALSTHOM-ATLANTIQUE DC CHOPPER - AWO
     8. Tachometer Calibration (nn.nn):  12.90
     9. Drag Force Calibration (Must match bus weight!) (nnnn.n):   200.0
    10. Miscellaneous comment line (70 characters maximum!):
        DAVE TURNER OF B.A.H., FOURET & CHAILLOU OF A.A. ON BOARD...
    11. Write tape header(s) and go into Ready Mode.
    12. Bypass Initialization and return to Wait Mode.

Enter item number or function number and type RETURN:
```

EXHIBIT A-8

Run Mode Screen Format

```
System entered Run Mode at 15:42:28 28-NOV-84

velocity =                      0.0 mph
distance =                     22.6 ft
incline =                       0.2 degrees
input voltage =               583.6 volts
input current =                 1.0 amps
input power =                   3.3 kwatts
motor voltage =                 3.1 volts
motor current =                 1.2 amps
motor power =                   0.3 kwatts
aux. power =                    1.7 kwatts
Time: 15:42:29    Date: 28-NOV-84
Status:
  15  14  13  12  11  10   9   8   7   6   5   4   3   2   1   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

Select desired function:
     1. Accept one comment (70 characters max.; terminate with RETURN).
     5. Enter Pause Mode.
     9. Enter Stop Mode.
Enter your comment and type RETURN:
70 Max: THIS IS JUST A TEST OF THE TROLLEY BUS...
```

The results of these calculations are presented in the run summary statistics and run report and for each of the segment calculation reports. Samples of these reports are shown in Chapter V. Besides the calculated values shown in tabular form, each report begins with the conditions and characteristics of the run and the report concludes with a listing of status events and comments. In the segment report only those events and comments pertaining to the segment are recorded.

PLOTPAC graphs histograms of the segments of a run for 12 variables as well as calculating the average and standard deviation for these variables. The variables are:

- Total distance
- Average velocity
- Change in elevation
- Average grade up
- Average grade down
- Energy in
- Energy regenerated
- Energy net
- Average positive acceleration
- Energy per mile
- Energy per hour
- Efficiency of system.

Samples of the histogram outputs are shown in Chapter V, and the histograms are provided with 10 ranges.

PLOTPAC creates plots for each segment of a run for the following variables:

- Input voltage and current
- Motor voltage and current
- Input power and motor power
- Acceleration and jerk
- Grade and velocity
- Instantaneous efficiency
- Position.

Plots of the six variables are available. In a typical run of 50 segments, the analyst has available to him 350 plots of the trolleybus's operational variables. Samples of the plots are given in Chapter V.

PLOTPAC provides a hierarchy of output results proceeding from the run summary statistics and run log report at the highest and most concise level, to plots of selected variables at the most detailed level. The analyst requests the desired level and amount of reports to be produced for a run, iteratively if required. The purpose of this presentation format is to minimize the amount of raw or processed data provided to the analyst while still permitting comparison of equipment performance at the required level of detail.

4. PLOTPAC OPERATIONS

PLOTPAC possesses two application programs: the first, PLPAC1, is a tape processing program for BUSDAC data tapes; the second, PLPAC, is used for interactive report generation.

The first task of the analyst is to process the raw data from BUSDAC. The data, stored on one or two tape cartridges from BUSDAC, is copied to PLOTPAC's hard disk system for processing. The tape processing program 'PLPAC1' is invoked and prompts the operator:

PLOTPAC: PROCESS BUSDAC FILE

READY? Y/N

The analyst replies by typing Y for yes and tape processing begins. The program will request the analyst to enter a new drag force value if so desired. The program then runs automatically to completion and generates five run result files to be used by the report generation program, PLPAC. These are:

- HDRFIL.DAT !file containing header information
- DATFIL.DAT !file containing processed data
- COMFIL.DAT !file containing comments
- SINDEX.DAT !file containing index to segments
- SUMRUN.DAT !file containing summary data

PLPAC is the interactive report generation program and is designed to produce:

- Run summary statistics and run log reports
- Segment calculations
- Histograms
- Plots.

The report generating program PLPAC presents the analyst with the following main menu:

PLOTPAC DATA ANALYSIS SECTION

1 SEGMENT PLOTTING AND HISTOGRAM
2 REPORTS
3 EXIT PLOTPAC

TYPE A NUMBER AND RETURN:

If reports are desired, selection 2 is chosen and a new menu appears.

PLOTPAC REPORT GENERATION MODE

0 EXIT REPORT MODE
1 RUN SUMMARY REPORT
2 SEGMENT ANALYSIS REPORT

TYPE A NUMBER AND RETURN

Choosing option 1 causes the run summary statistics and run log report to be displayed on the terminal, after which the analyst is asked if he wants a printout of the report.

PRINT? Y/N

Segment reports are accessed by choosing option 2,and the analyst is prompted by the system:

PLEASE ENTER THE SEGMENT NUMBER?

The summary report for that segment is displayed and can be printed out.

Exiting the report generation mode, the analyst returns to the main menu. From there he can request segment plotting or histograms and is presented with the following menu:

SELECT ONE OF THE FOLLOWING MODE

1 LINEAR GRAPHS
2 HISTOGRAMS
3 RETURN

ENTER A NUMBER AND RETURN.

Requesting option 1 for linear graphs the analyst is requested to:

ENTER A SEGMENT NUMBER PLEASE?

After which he is presented with a print selection menu:

PLOTS FOR SEGMENT NUMBER #

1 INPUT VOLTAGE AND CURRENT
2 MOTOR VOLTAGE AND CURRENT
3 INPUT POWER AND MOTOR POWER
4 ACCELERATION AND JERK
5 GRADE AND VELOCITY
6 INSTANTANEOUS EFFICIENCY
7 POSITION
8 RETURN

ENTER A NUMBER AND RETURN.

Selection of one of the print options will result in a plot of the variables on the screen for the chosen segment. The screen plot can be printed out. From this menu all the prints for the segment can be viewed and printed.

Returning to the histogram/plot menu, the analyst can choose the histogram mode. He is presented with the following menu:

SELECT ONE OF THE FOLLOWING HISTOGRAMS

1 DISTANCE TRAVELLED
2 AVERAGE VELOCITY
3 CHANGE IN GRADE
4 AVERAGE ASCENDING GRADE
5 AVERAGE DESCENDING GRADE
6 ENERGY DRAWN FROM LINE
7 ENERGY RETURNED TO LINE

8 NET ENERGY USED
9 AVERAGE ACCELERATION
10 ENERGY/MILE
11 ENERGY/HOUR
12 EFFICIENCY OF SYSTEM
0 EXIT HISTOGRAM MODE

ENTER A NUMBER AND RETURN.

Selecting an option will result in the histogram being displayed on the terminal, after which a print can be requested.

The processed files, used by PLPAC, are archived onto a floppy disk. Further analysis of a run can be done using these files and running the PLPAC program.

5. BUSDAC HARDWARE

BUSDAC is based on a Digital Equipment Corporation LSI-11/23 processor, and includes a floppy disc drive for loading the data acquisition program, a dual cartridge tape drive for recording trolleybus data, a terminal for operator commands and data and status display, and a printer for selective hardcopy. The processor chassis contains the processor, memory, serial communication, analog input, digital input, counter timer, real time clock, and tachometer synchronizer cards.

Trolleybus equipment parameters are measured, isolated, protected and converted to suitable signal levels for the computer data acquisition system by transducers and support equipment. Line, motor, and auxiliary voltage, current and power are sensed by wide-band power instruments, which represent 600V, 400A power levels by rms equivalent 0-10 volt signals. The power instruments provide 1 percent accurate indications for inputs from DC to 5000 Hz. Suitable high voltage fusing and transient protection is provided.

Trolleybus grade is measured by a servo inclinometer, mounted with its sensitive axis oriented in the direction of travel. Grade is calculated by subtracting the acceleration computed from the tachometer from the inclinometer reading. The filtered, buffered output of the inclinometer provides a signal between -10v and +10v DC to the analog to digital converter.

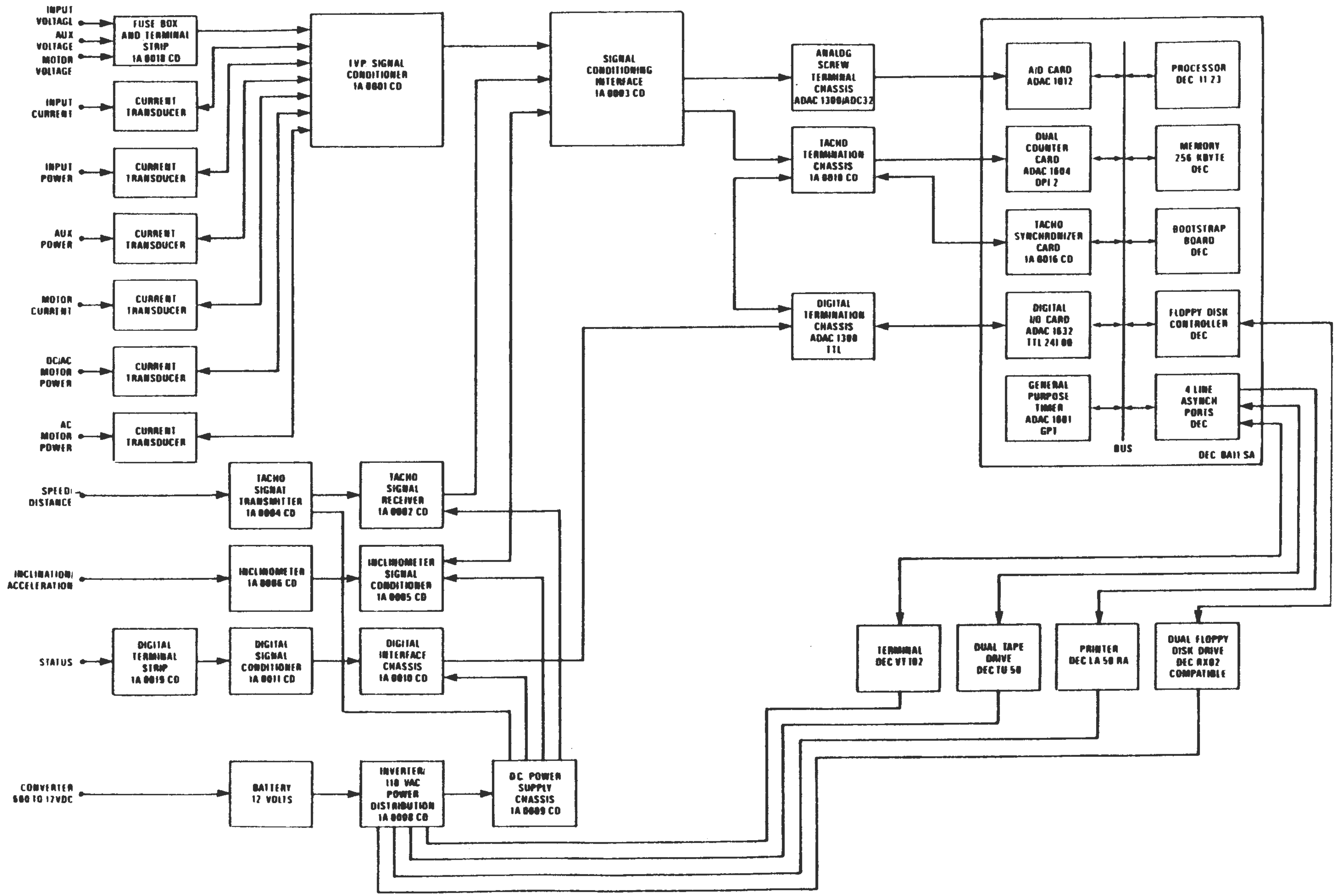
Speed and distance traveled are measured with a tachometer which consists of an eddy current oscillator metal sensor and a 12-toothed wheel mounted to the traction motor drive shaft. The tachometer provides about one pulse per inch of travel. Distance is measured by accumulating tachometer pulses. Velocity is measured by counting 100 khz clock pulses for the period of a single tachometer pulse. This approach provides very accurate measurement of velocity at low speeds as well as at high speeds, and yields exact distance data.

Provision is made for up to 16 discrete digital inputs to be monitored and recorded. Eight 600 vDC inputs and eight 12 vDC inputs are fused, isolated and connected to a digital input card on the computer trolleybus. Suitable low-pass filtering is provided for analog signals.

Exhibit A-9 shows the block diagram of BUSDAC. The following sections describe BUSDAC equipment in terms of its subsystems.

EXHIBIT A-9

BUSDAC Block Diagram



(1) DEC Computer Rack

The Digital Equipment Corporation (DEC) computer rack consists of the processor chassis, dual tape drive, dual disk drive, display terminal with keyboard, printer, analog termination chassis, digital termination chassis, and tachometer termination.

(2) Processor Chassis

The DEC BA11-SA processor chassis is a self-contained unit with a power supply and a bus structure for mounting computing and I/O cards to create a computing system. The cards are:

- Processor card
- 256 kbyte memory
- 8 channel analog to digital converter
- Dual counter
- General purpose timer
- 4 channel serial I/O
- Floppy disk controller
- Tachometer synchronizer
- Digital I/O.

The processor card contains the 16 bit microcomputer, LSI-11/23. The associated 256 kbyte memory card makes up the basic computing unit of BUSDAC. Memory is loaded with the basic RT-11 operating system, utilities and application program.

The I/O cards for the peripheral computer equipment are the 4-channel serial card and the floppy disk controller card. The serial card provides communication between the DEC TU-8 dual tape unit, the DEC VT102 terminal and the DEC LA-50 printer. The floppy disk controller card provides the control and data path between the processor and the dual floppy disc system.

The I/O cards for the measurement of BUSDAC parameters are the 8-channel analog-to-digital converter, the general purpose timer, the dual counter, the digital I/O, and the tachometer synchronizer card. The analog-to-digital convertor is set to convert -10v to +10v signals with a 12-bit resolution at a maximum conversion rate of 35 khz. The dual counter card has two 16-bit registers, one of which accumulates tachometer pulses for a measurement of distance, the other register for a measurement of tachometer period or velocity. The distance counter input comes directly from the tachometer circuits but the velocity counter input comes from the tachometer synchronizer card. This card is controlled by the general purpose timer, which triggers it at a 5 Hz rate as well as control signals via the digital I/O which provide for RESET and DATA VALID signals. The digital I/O card is also used for inputing sixteen status signals.

(3) Dual Tape Drive

The dual tape drive is a DEC TU-8 with the capacity of 262 kbytes per tape. The TU-8 is driven by a serial line at 19.2 kbaud during the run mode of BUSDAC.

(4) Floppy Disks

The dual floppy discs are from Data Systems and are used to load the software for running BUSDAC. Once the software is loaded the discs are not used for other than program development.

(5) Display Terminal and Keyboard

The display terminal and keyboard is a DEC VT100 which provides screen displays for the operator during a BUSDAC run. The attached keyboard is for operator control and input during the testing process. The terminal is connected to a serial line and runs at 9600 baud.

(6) Printer

The printer is a DEC LA-50, and is connected to a serial line and provides for printing capability during the running of BUSDAC.

(7) Termination Chasses

The three termination chasses are for analog and digital interconnection to the processor chassis cards. The analog termination chassis provides a screw terminal strip and a flat cable connection to the Analog-to-Digital card. The digital termination chassis provides a screw terminal for digital signals as well as a flat cable connection to the digital I/O card. A termination chassis is also provided for the tachometer circuits and interconnect the general purpose timer, counter and tachometer synchronizer cards.

(8) I/O and Power Rack

The I/O and power rack consists of the following components: digital interface, analog signal conditioner, DC power supply, AC power mode/isolator, and a 1 KVA inverter.

(9) Digital Interface

The digital interface isolates and conditions the status signals. Eight channels are for high level status signals and eight are for low level, the high level being derived from 600 volt signals and the low level from 12 volts. All 16 circuits use opto-isolators. A low input signal corresponds to a 12 or 600 volt signal input to the digital signal conditioner.

(10) Analog Signal Conditioner Interface

The function of the analog signal conditioner is to provide over voltage protection and filtering for the analog signals: input voltage, current and power; motor voltage, current and power; auxiliary power and inclination. Each circuit has in-line fuses, transient suppressors, and RC filters. In addition, the analog signals can also be monitored at the front panel through an isolated BNC connector. Signal leads are all shielded. A tachometer monitor is also provided.

(11) Power Supply

The +15/-15 volt, +5 volt power supply chassis provides DC power for the tachometer, inclinometer, and status circuits. Four connectors on the chassis distribute power to the tachometer sensor, the tachometer signal conditioner, the inclinometer, and the status circuits. The chassis provides fusing protection as well as monitoring lights.

(12) Inverter and 110 vAC Power Distribution

The function of this circuit is to provide 110 vAC power to all the BUSDAC devices. This includes power supply chassis, IVP signal conditioner, processor chassis, tape unit disc unit, printer and terminal. AC power is provided by a 1 KVA 12 vDC to 120 vAC inverter which is powered by the trolleybus's battery system. This AC power is isolated through a 1 KVA transformer and is distributed to all subsystems from a power distribution strip. An external AC power connection is also provided.

(13) Inclinometer

The inclinometer is a self-contained device from Schaevitz Engineering which measures inclination (+/- 30 degrees) and acceleration (+/- 0.5g) producing an output in the range of +5v to -5v. The device is sensitive along one axis and is mounted on a metal plate with the sensitive axis parallel to the length of the trolleybus. A set screw adjustment is provided for zeroing the output on level ground. Power requirements are +/- 15 volts and a single connector, mounted on the side, provides both power and signal leads.

The output of the inclinometer is conditioned by the inclinometer signal conditioner which provides an amplification of the signal to +/- 10 volts to match the full range of the analog to digital converter as well as providing a low output impedance.

(14) Tachometer

The tachometer system consists of the tachometer, a tachometer transmitter, and a tachometer signal receiver.

The tachometer is a twelve toothed wheel mounted on a flange which is connected to the trolleybus motor shaft. The wheel is 1/4 inch thick steel and ground flat so there is little play in the axial direction.

The tachometer transmitter consists of an all-metals proximity detector mounted in a metal box. The detector and box is mounted next to the tachometer wheel. The detector changes its output when it detects the presence of metal, in this case steel. The distance between tachometer sensor and wheel is less than one-quarter of an inch. The output levels of the sensor switch between 3 volts for no metal to 15 volts for metal.

The tachometer signal receiver input is the output of the tachometer metal proximity detector. The function of this circuit is to isolate the tachometer signal and condition it to a TTL level for measurement by the distance and velocity circuits.

(15) IVP Signal Conditioner

The IVP signal conditioner consists of voltage and watt transducers and current signal conditioners. The actual current transducers are external to the chassis. These transducers and signal conditioners measure the voltage and current levels generated by the trolleybus during operation and convert them to low level analog signals in the +10 to -10 volt range.

There are two voltage transducers, which measure the input line voltage and the motor voltage and produce signal levels of 10 volts DC for a maximum input of 800 volts rms.

There are two signal conditioners, with associated external current transducers, which measure the input line current and the motor current. An input line current of 700 amperes rms will produce an output signal of +10 volts. A motor current of 400 amperes rms will produce an output signal of +10 volts.

There are four watt transducers, each with an external current transducer. These transducers measure both voltage and current and multiply the input signals to produce a measure of wattage. The input watt transducer is rated at 800 volts and 700 amperes producing a maximum +/- 10 volt signal. The two remaining watt transducers are used for measuring the motor power. For DC motors only one transducer is used, for AC motors two transducers are used in the two wattmeter method of measuring power. The rating of the motor power measurement is 800 volts and 400 amperes for a +/- 10 volt output.

The chassis was grounded to the trolleybus frame to prevent high voltage shock and a ground fault interrupter was included in the incoming power circuit.

(16) High Voltage Digital Input

The high voltage digital input was conditioned for status measurement by the digital signal conditioner. The digital signal conditioner isolates and conditions the status signals from the trolleybus system. There are two voltage level inputs, 600 volts and 12 volts DC. The 600 volts is isolated by means of a neon-bulb and photo-resistor circuit. The neon bulb, with a series resistor will regulate at 60 volts and will produce enough light to switch a photo-resistor from the off state of 2 megohms to the on state of 300 ohms. When the photo-resistor switches to 300 ohms the induced current level is detected. The 12 volt inputs are isolated by an opto-isolator circuit.

6. BUSDAC SOFTWARE

BUSDAC software is the computer program that controls the acquisition of data, recording of data, and other functions, such as calibration, initializing of tapes, tape erasing, and test mode.

BUSDAC software was written in Fortran running under the DEC RT-11 operating system and used RT-11 utilities. Software drivers for the I/O cards, provided by ADAC, were incorporated into the program. When the program is running, the operator is offered a series of selection menus on the video screen, and he can request a desired operation by selecting a command using the keyboard. Exhibit A-3, mentioned previously, showed the BUSDAC system states transition diagram.

(1) System States

BUSDAC system states are defined by the following operational modes:

0. STARTUP MODE (AUTOMATIC)
1. WAIT MODE
2. TEST MODE
3. CALIBRATION MODE
4. TAPE ERASE MODE
5. CALIBRATE TACHOMETER MODE
6. CALIBRATE DRAG FORCE MODE
7. TAPE INITIALIZATION MODE
8. READY MODE
9. RUN MODE (WITH SELECTIVE DISPLAYS AND COMMENTS)
10. PAUSE MODE
11. STOP MODE
12. ABNORMAL STOP MODE
13. EXIT MODE (AUTOMATIC)

BUSDAC makes system's state transitions mainly through the operator's mode selection. The mode selection process is implemented through simple menu selection. Following is a description of all of the modes.

Startup Mode - The start-up mode is entered upon invoking BUSDAC. This mode will request the time and date from RT-11, initialize variables, output a message, and then automatically go into the wait mode. If there is no system date or time, or if some fatal condition exists, BUSDAC will exit to RT-11 immediately.

Wait Mode - In this mode, the system displays a menu for selection. The wait mode can transition to the tape initialization mode, test mode, calibration mode, and tape erase mode.

Test Mode - This mode of BUSDAC operation allows an operator to request the BUSDAC computer to read and display all sensors continuously every 3.5 seconds. This mode will permit testing of BUSDAC in the lab environment as well as during the initial checkout of BUSDAC before a run. The test mode enters from and exits to the wait mode on operator command.

Calibration Mode - In this mode, the operator can inform the BUSDAC computer that calibration data will be measured. Data associated with the calibration of the tachometer and dragforce will be displayed and printed in hardcopy form. The calibration mode can execute either the tachometer calibration or the drag force calibration by operator command. Both of these modes will go back to the calibration mode upon completion. The operator can either command BUSDAC to return to the wait mode or continue with calibration.

The calibration mode also allows the operator to input the previously measured tachometer calibration result and/or the previously measured dragforce calibration result and the associated trolleybus weight.

The tachometer calibration must be executed or the previous tachometer calibration result must be inputted before executing the dragforce calibration.

Tape Erase Mode - From the wait mode, the operator can command the system to go into the tape erase mode. The operator can specify whether to erase only the tape in drive 0 or the tape in drive 0 and drive 1. After the tape is erased, the system will issue a message to the operator and will go back into the wait mode. Unrecoverable tape errors will enter the abnormal stop mode.

Calibrate Tachometer Mode - Discussed under Calibration Mode.

Calibrate Drag Force Mode - Discussed under Calibration Mode.

Tape Initialization Mode - From the wait mode, the system can go into the tape initialization mode on operator command. In this mode, the operator can enter or edit the test run number, the number of tapes for this run, the route, the trolleybus driver's name, the BUSDAC operator's name, the trolleybus weight, the equipment type, the tachometer and dragforce calibrations, and an additional comment. This data, along with the date and time, identifies the test run. When the operator has completed the desired input or changes, he can issue a command to log the data to the tape header blocks. After the system has written the tape header, the system will enter the ready mode automatically. Alternatively, the operator can issue a command to bypass the initialization process and return directly to the wait mode.

Ready Mode - When tape initialization is completed, the system enters the ready mode. From the ready mode, the operator can request the system to actually start running or return to the wait mode. Returning to the wait mode deletes the files created by the tape initialization mode since the header data must be rewritten to get back to the ready mode again.

Run Mode and Pause Mode - The run mode is the data acquisition and display mode. It can only be entered from the ready mode. From the run mode the operator can request the pause mode or stop mode at any time. In the run mode, snapshots of the data being collected will be displayed at regular intervals. This data can be sent to the printer for hard copy by the operator using the local printer function of the VT102 terminal.

The BUSDAC operator can enter any comments desired. However, these comments are restricted to less than 70 characters. The comments are time stamped and recorded. From the run mode, the system can go into the pause mode and return back to run mode by operator command. While in the pause mode, data acquisition is suspended.

Stop and Abnormal Stop Modes - From the run mode, the operator can command the system to go into the stop mode. The system will write out the remaining data and add an end-of-data marker to the tape. The system will go into an abnormal stop mode if errors are detected during the run. A message will be given to the operator. Both stop and abnormal stop modes allow the operator to return to the wait mode or exit to RT-11.

Exit Mode - The exit mode is entered by operator command from the wait mode, stop mode, abnormal stop mode, or automatically from start-up mode if start-up fails. The exit mode cleans up any outstanding I/O, turns off interrupts that are active, finishes up any housekeeping, and unconditionally exits to RT-11.

(2) Software Organization

BUSDAC's software architecture consists of a main program, BUSDAC, which calls the various mode subroutines. The mode subroutines are as follows:

WAITM	wait mode subroutine
TESTM	test mode subroutine
CALIBM	calibration mode subroutine
ERASEM	erase mode subroutine
TINITM	tape initialization mode
READY	ready mode subroutine
RUNM	run mode subroutine
PAUSEM	pause mode subroutine
STOPM	stop mode subroutine
ASTOPM	abnormal stop mode subroutine
EXITM	exit mode subroutine

The BUSDAC software map structure is shown in Exhibit A-10. The main subroutines of BUSDAC can be seen in the diagram and correspond to the BUSDAC system states discussed previously.

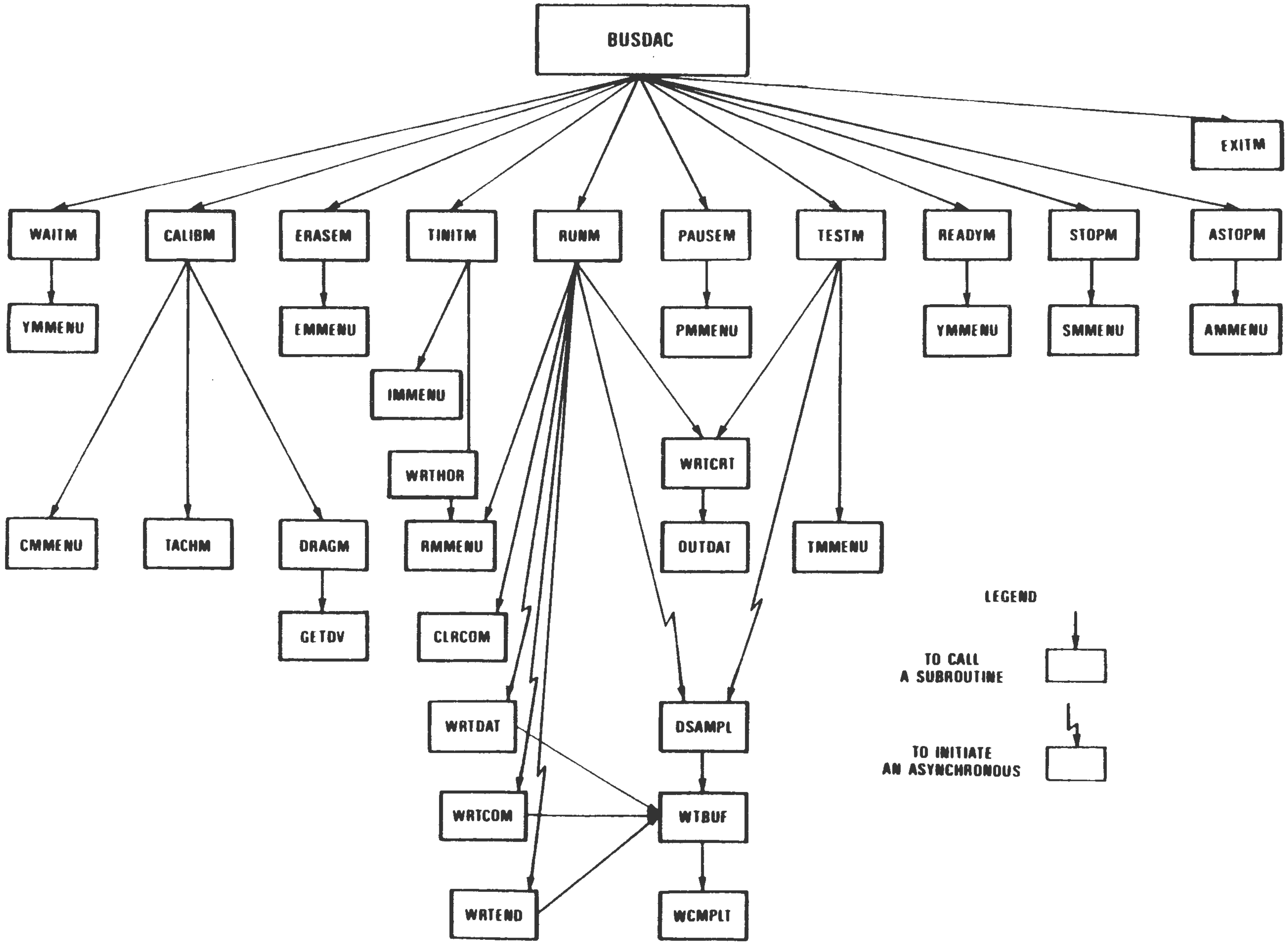
The data collected by BUSDAC is stored as a standard RT-11 file with reserved areas, volume identification, and file directory allocation. The data is structured in the form of 512 byte blocks and contains one header block, data blocks, comment blocks and an end block.

The header block starts with an identification number and continues with test run number, tape number, date, time, trolleybus weight, tachometer and dragforce calibrations, and five character strings for route, name of driver, name of operator, type of equipment, and comment.

The data block starts with an identification number, then follows with the time and seven seconds of data describing the trolleybus system states. Each subsequent ten seconds is also time stamped. A count of valid data is also included in each block.

EXHIBIT A-10

BUSDAC Software Map Structure



The format of the comment block contains the identification number, time, and associated comments. A total of six comments can be packed into one block.

The end block, used to signal the end of run data, contains an identification number followed by a continue flag for signaling the tape analysis system that there is data on a second tape.

7. PLOTPAC HARDWARE

PLOTPAC is based on a Digital Equipment LSI-11/23 processor; a hard disk for file handling; a dual tape drive for copying trolleybus data files; a floppy disk for archiving data files and processed files; a graphics terminal for operator commands and presentation of reports, histograms and graphs; and a printer for selective printing of reports, histograms, and plots.

(1) Processor Chassis

The DEC BA11-SA processor chassis is a self-contained unit with a power supply, card cage, and bus structure for accommodating computing and I/O cards. For PLOTPAC, the cards required in the chassis are:

- Processor card
- 256 kbyte memory
- Floppy disk controller
- Hard disk controller
- 4-channel serial I/O.

The processor card contains the 16-bit microprocessor, the LSI-11/23, and along with the memory card provides the computing capability of the system.

The floppy disk and hard disk controller cards provide control and data communication between the processor and the peripheral floppy and hard disks. The 4-channel serial I/O card provides for communication between the DEC VT-125 graphics terminal, the DEC TU-8 dual tape drive, and the DEC LA-50 printer.

(2) Dual Tape Drive

The dual tape drive is a Digital Equipment Corporation TU-8 which communicates with the processor chassis at 38.4 kbaud. The drive uses pre-formatted tape with a capacity of 262 kbytes each. BUSDAC data files are read by this system and transferred to either the floppy disk for archiving or the hard disk for processing.

(3) Floppy and Hard Disk System

The single floppy and the hard disk system are supplied by Data Systems. The hard disk has a capacity of 10 megabytes formatted and is partitioned into two virtual drives, which emulate a standard DEC RL02 disk system. The operating system, RT-11, and the application are stored on hard disk. Also, data files are transferred to the hard disk for processing. The floppy disk is used for archiving.

(4) Graphics Terminal and Keyboard

The graphics terminal is a Digital Equipment Corporation VT125. Besides providing graphics capability, the VT125 functions as an alphanumeric terminal. The operator controls all tape processing and report generation via the terminal and keyboard system. During report generation, the analyst can view report summaries, histograms, and plots.

(5) Printer

The printer is a Digital Equipment Corporation LA-50. This is a dot-matrix printer with the ability to print in test mode as well as graphics mode. All reports, histograms, and plots generated by PLOTPAC can be printed.

8. PLOTPAC SOFTWARE

PLOTPAC software consists of two main programs, PLPAC1 and PLPAC. These programs were written in FORTRAN and operate under Digital Equipment Corporations RT-11 operating system. Flowcharts of PLPAC1 and PLPAC are shown in Exhibits A-11 and A-12.

PLPAC1 is the tape processing program. Data tapes from BUSDAC are copied into PLOTPAC'S hard disk and stored as a single data file, BUSDAC.DAT PLPAC1 is invoked and uses the data file to generate five separate files to be used in report generation. The files are a header file containing information about the run conditions, a data file containing processed data, a comment file, an index file containing pointers to segments in the data file, and a run summary file containing summary data for the run.

The five files for each run are:

- HDRFIL.DAT
- DATFIL.DAT
- COMFIL.DAT
- SINDEX.DAT
- SUMRUN.DAT

PLPAC is the report generation program and uses the files created by PLPAC1 to generate a summary report for a run, segment summaries, histograms, and plots. The program operates interactively and allows selective viewing and printing of all summaries, histograms, and plots.

The five files created by PLPAC1 are archived onto a floppy disk. Subsequent analysis can be done by copying these files into the hard disk and invoking PLPAC. The data file BUSDAC.DAT is also archived.

(1) Tape Processing

The tape processing state is transparent to the user once PLPAC1 is invoked, where the only analyst option is to enter a new drag force. The program runs to completion and informs the analyst when tape processing is finished.

EXHIBIT A-11

PLPAC$_1$ Flowchart

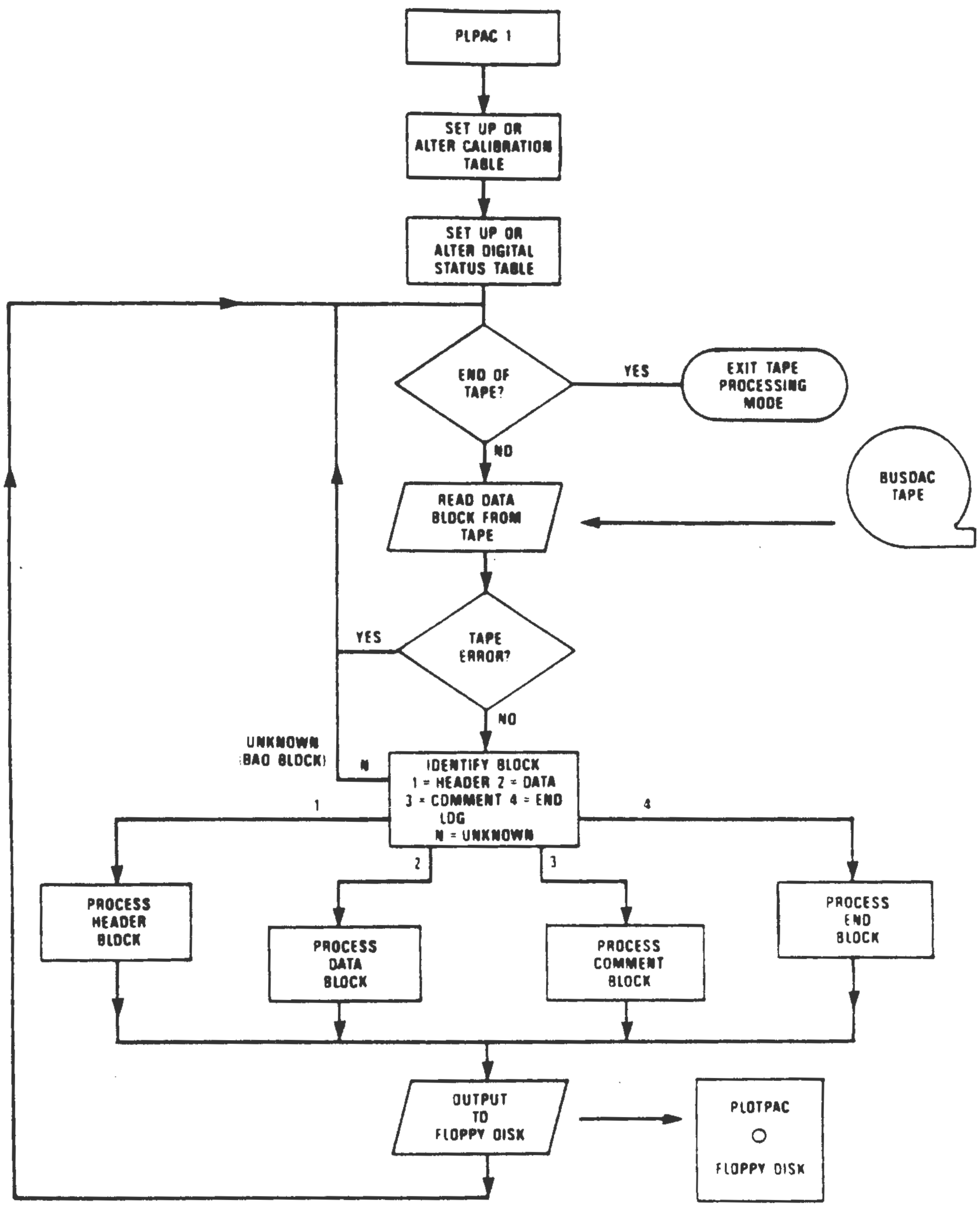
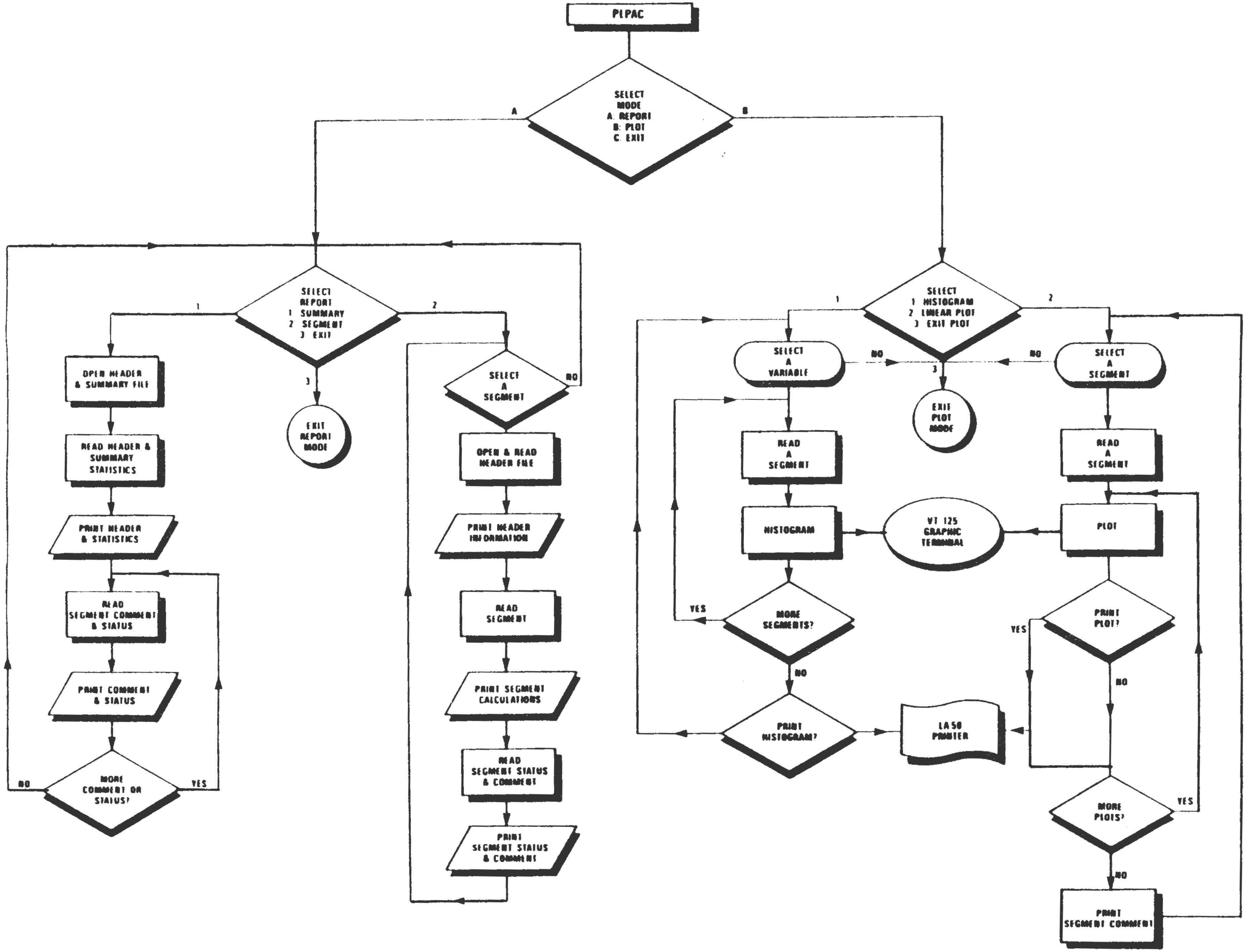


EXHIBIT A-12

PLPAC Flowchart



(2) Report Generation

Report generation can be in several states: data analysis select, select reports; run summary; segment summaries; select segment plots and histograms; plots; and histograms.

The data analysis select state is entered from RT-11 by invoking PLPAC. This state provides for selecting report modes for run or segment summaries, selecting histograms and plotting modes, or returning to RT-11.

The select reports mode provides the analyst the choice of either the run summary mode or segment summary mode or returning to the data select state. In the run summary state the analyst is presented the run summary report on the terminal and can selectively print the report. In the segment summary state the analyst can selectively view a segment report and print the report. This state automatically exits to the select report state on completion.

The select segment plots and histograms state is entered from the data analysis select state. Plots or histograms may be selected. On entering the plot state the analyst can choose a segment and is given a choice of one of eight plots. All plots can be viewed and selectively printed. In the histogram state the analyst can select one of twelve histograms for viewing and selectively printing.

APPENDIX B

PLOTPAC RESULTS ANALYSIS

General Electric Company

MRC SWITCHED RESISTANCE CONTROLLER

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GENERAL ELECTRIC RESISTANCE — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 23,700 lbs. - AWO

	ITEM	RUN DATA			AVERAGE
1.0	Direction:		Inbound		
2.0	Run Number:	206	209	211	
3.0	Number of Stops:	68	66	73	69
4.0	Average Accel:	1.99	1.86	1.91	1.92
5.0	Energy per Mile:	3.87	3.36	3.72	3.65
6.0	Prop Energy In:	27.21	23.15	26.09	25.48
7.0	Line Energy Regen:	0.13	0.29	0.14	0.19
8.0	Motor Energy In:	19.78	16.22	18.38	18.12
9.0	Net Motor Energy:	13.06	10.86	12.59	12.17
9.1	Auxiliary Energy:	2.83	3.03	3.02	2.96
10.0	Lost Control Ener:	7.44	6.93	7.72	7.36
11.0	Motor Regen Ener:	6.72	5.36	5.78	5.95
12.0	Ener Not Received:	6.59	5.06	5.64	5.76
13.0	Control Loss %:	27.33%	29.94%	29.57%	28.89%
14.0	Regen Loss %:	24.21%	21.87%	21.61%	22.62%
15.0	Total Loss %:	51.54%	51.82%	51.18%	51.51%
16.0	Control Efficiency:	0.73	0.70	0.70	0.71
18.0	Net Ener Not Rec'd:	4.74	3.42	3.91	4.02
19.0	Ener Not Rec'd %:	97.08%	91.20%	96.05%	95.16%

1.0	Direction:		Outbound		
2.0	Run Number:	208	210	212	Average
3.0	Number of Stops:	65	67	82	71
4.0	Average Accel:	2.11	1.89	1.86	1.95
5.0	Energy per Mile:	4.27	3.87	4.01	4.05
6.0	Prop Energy In:	28.93	26.36	27.40	27.56
7.0	Line Energy Regen:	0.01	0.15	0.19	0.12
8.0	Motor Energy In:	20.97	17.62	17.98	18.86
9.0	Net Motor Energy:	14.67	12.40	12.64	13.24
9.1	Auxiliary Energy:	2.76	2.80	2.84	2.80
10.0	Lost Control Ener:	7.96	8.74	9.42	8.71
11.0	Motor Regen Ener:	6.30	5.22	5.35	5.62
12.0	Ener Not Received:	6.29	5.07	5.15	5.50
13.0	Control Loss %:	27.52%	33.16%	34.37%	31.59%
14.0	Regen Loss %:	21.72%	19.23%	18.81%	19.96%
15.0	Total Loss %:	49.25%	52.38%	53.17%	51.60%
16.0	Control Efficiency:	0.72	0.67	0.66	0.68
18.0	Net Ener Not Rec'd:	4.55	3.32	3.30	3.72
19.0	Ener Not Rec'd %:	99.69%	95.18%	93.90%	96.92%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 23,748 lbs. - AWO

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	213	215	
3.0	Number of Stops:	58	56	57
4.0	Average Accel:	1.74	1.73	1.74
5.0	Energy per Mile:	4.66	4.32	4.49
6.0	Prop Energy In:	16.29	14.71	15.50
7.0	Line Energy Regen:	0.20	.00	0.10
8.0	Motor Energy In:	8.51	8.49	8.50
9.0	Net Motor Energy:	6.42	6.41	6.41
9.1	Auxiliary Energy:	2.23	2.02	2.12
10.0	Lost Control Ener:	7.78	6.21	6.99
11.0	Motor Regen Ener:	2.09	2.09	2.09
12.0	Ener Not Received:	1.89	2.08	1.99
13.0	Control Loss %:	47.74%	42.25%	45.00%
14.0	Regen Loss %:	11.62%	14.17%	12.89%
15.0	Total Loss %:	59.36%	56.42%	57.89%
16.0	Control Efficiency	0.52	0.58	0.55
18.0	Net Ener Not Rec'd	0.87	1.20	1.03
19.0	Ener Not Rec'd %:	79.41%	99.72%	89.56%
1.0	Direction:	Outbound		
2.0	Run Number:	214	216	
3.0	Number of Stops:	46	48	47
4.0	Average Accel:	1.79	1.77	1.78
5.0	Energy per Mile:	3.73	3.70	3.71
6.0	Prop Energy In:	12.34	12.90	12.62
7.0	Line Energy Regen:	0.01	.00	0.01
8.0	Motor Energy In:	6.42	6.86	6.64
9.0	Net Motor Energy:	3.70	4.02	3.86
9.1	Auxiliary Energy:	1.89	1.95	1.92
10.0	Lost Control Ener:	5.92	6.04	5.98
11.0	Motor Regen Ener:	2.72	2.84	2.78
12.0	Ener Not Received:	2.71	2.84	2.77
13.0	Control Loss %:	47.96%	46.81%	47.38%
14.0	Regen Loss %:	21.96%	22.00%	21.98%
15.0	Total Loss %:	69.92%	68.81%	69.37%
16.0	Control Efficiency	0.52	0.53	0.53
18.0	Net Ener Not Rec'd	1.40	1.51	1.45
19.0	Ener Not Rec'd %:	98.86%	99.77%	99.32%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance:3.4 MILES
Weight: 23,700 lbs. - AWO

	ITEM	RUN DATA			AVERAGE
1.0	Direction:		Inbound		
2.0	Run Number:	200	202	204	
3.0	Number of Stops:	36	48	60	48
4.0	Average Accel:	2.01	1.84	1.84	1.90
5.0	Energy per Mile:	4.27	4.78	4.49	4.51
6.0	Prop Energy In:	14.54	16.51	15.64	15.57
7.0	Line Energy Regen:	.00	0.00	.00	.00
8.0	Motor Energy In:	9.27	9.08	9.40	9.25
9.0	Net Motor Energy:	5.39	5.65	5.93	5.66
9.1	Auxiliary Energy:	1.69	1.97	2.33	2.00
10.0	Lost Control Ener:	5.27	7.43	6.24	6.32
11.0	Motor Regen Ener:	3.88	3.43	3.47	3.59
12.0	Ener Not Received:	3.88	3.43	3.47	3.59
13.0	Control Loss %:	36.26%	45.02%	39.88%	40.39%
14.0	Regen Loss %:	26.66%	20.75%	22.20%	23.21%
15.0	Total Loss %:	62.92%	65.77%	62.08%	63.59%
16.0	Control Efficiency:	0.64	0.55	0.60	0.60
18.0	Net Ener Not Rec'd:	2.47	1.88	2.09	2.15
19.0	Ener Not Rec'd %:	99.86%	100.00%	99.94%	99.94%
1.0	Direction:		Outbound		
2.0	Run Number:	201	203	205	
3.0	Number of Stops:	49	42	58	50
4.0	Average Accel:	1.95	1.86	1.76	1.86
5.0	Energy per Mile:	4.55	4.69	4.65	4.63
6.0	Prop Energy In:	16.09	16.35	16.08	16.17
7.0	Line Energy Regen:	0.05	0.02	0.02	0.03
8.0	Motor Energy In:	10.40	9.69	9.13	9.74
9.0	Net Motor Energy:	6.73	6.48	6.34	6.52
9.1	Auxiliary Energy:	1.72	1.85	2.28	1.95
10.0	Lost Control Ener:	5.70	6.66	6.95	6.43
11.0	Motor Regen Ener:	3.67	3.21	2.79	3.22
12.0	Ener Not Received:	3.62	3.19	2.78	3.19
13.0	Control Loss %:	35.39%	40.74%	43.21%	39.78%
14.0	Regen Loss %:	22.51%	19.49%	17.26%	19.75%
15.0	Total Loss %:	57.90%	60.22%	60.47%	59.53%
16.0	Control Efficiency:	0.65	0.59	0.57	0.60
18.0	Net Ener Not Rec'd:	2.32	1.88	1.57	1.92
19.0	Ener Not Rec'd %:	97.67%	98.83%	98.78%	98.42%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller
Change in Elevation: +14 FEET OUTBOUND
Weight: 30,748 lbs. - AW1

Route: 5 - FULTON
Distance:6.8 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	238	240	
3.0	Number of Stops:	70	81	76
4.0	Average Accel:	1.80	1.71	1.76
5.0	Energy per Mile:	4.80	4.39	4.59
6.0	Prop Energy In:	32.57	30.33	31.45
7.0	Line Energy Regen:	0.18	0.12	0.15
8.0	Motor Energy In:	23.20	20.67	21.93
9.0	Net Motor Energy:	16.42	15.20	15.81
9.1	Auxiliary Energy:	6.20	5.41	5.81
10.0	Lost Control Ener:	9.37	9.66	9.52
11.0	Motor Regen Ener:	6.78	5.48	6.13
12.0	Ener Not Received:	6.60	5.35	5.98
13.0	Control Loss %:	28.78%	31.85%	30.32%
14.0	Regen Loss %:	20.26%	17.65%	18.96%
15.0	Total Loss %:	49.05%	49.50%	49.27%
16.0	Control Efficiency:	0.71	0.68	0.70
18.0	Net Ener Not Rec'd:	4.62	3.59	4.10
19.0	Ener Not Rec'd %:	95.61%	96.09%	95.85%
1.0	Direction:	Outbound		
2.0	Run Number:	239	241	
3.0	Number of Stops:	72	90	81
4.0	Average Accel:	1.83	1.69	1.76
5.0	Energy per Mile:	4.90	4.91	4.91
6.0	Prop Energy In:	33.28	33.89	33.58
7.0	Line Energy Regen:	0.26	0.01	0.14
8.0	Motor Energy In:	23.08	21.39	22.23
9.0	Net Motor Energy:	16.88	16.09	16.49
9.1	Auxiliary Energy:	6.45	4.87	5.66
10.0	Lost Control Ener:	10.20	12.50	11.35
11.0	Motor Regen Ener:	6.19	5.30	5.75
12.0	Ener Not Received:	5.93	5.29	5.61
13.0	Control Loss %:	30.66%	36.89%	33.77%
14.0	Regen Loss %:	17.83%	15.60%	16.71%
15.0	Total Loss %:	48.49%	52.49%	50.49%
16.0	Control Efficiency	0.69	0.63	0.66
18.0	Net Ener Not Rec'd	3.98	3.33	3.66
19.0	Ener Not Rec'd %:	92.77%	99.62%	96.20%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 30.748 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	235	237	
3.0	Number of Stops:	47	49	48
4.0	Average Accel:	1.80	1.56	1.68
5.0	Energy per Mile:	4.51	3.99	4.25
6.0	Prop Energy In:	15.18	14.71	14.94
7.0	Line Energy Regen:	.00	0.00	.00
8.0	Motor Energy In:	8.32	7.25	7.78
9.0	Net Motor Energy:	5.71	4.81	5.26
9.1	Auxiliary Energy:	1.92	4.73	3.33
10.0	Lost Control Ener:	6.86	7.46	7.16
11.0	Motor Regen Ener:	2.61	2.44	2.52
12.0	Ener Not Received:	2.61	2.44	2.52
13.0	Control Loss %:	45.18%	50.70%	47.94%
14.0	Regen Loss %:	17.18%	16.57%	16.87%
15.0	Total Loss %:	62.36%	67.26%	64.81%
16.0	Control Efficiency	0.55	0.49	0.52
18.0	Net Ener Not Rec'd	1.43	1.20	1.31
19.0	Ener Not Rec'd %:	99.84%	100.00%	99.92%
1.0	Direction:	Outbound		
2.0	Run Number:	234	236	
3.0	Number of Stops:	56	55	56
4.0	Average Accel:	1.64	1.59	1.62
5.0	Energy per Mile:	5.45	5.35	5.40
6.0	Prop Energy In:	18.94	18.11	18.52
7.0	Line Energy Regen:	0.22	0.01	0.11
8.0	Motor Energy In:	10.52	9.70	10.11
9.0	Net Motor Energy:	8.29	7.72	8.00
9.1	Auxiliary Energy:	2.18	2.09	2.13
10.0	Lost Control Ener:	8.43	8.41	8.42
11.0	Motor Regen Ener:	2.23	1.98	2.10
12.0	Ener Not Received:	2.01	1.97	1.99
13.0	Control Loss %:	44.48%	46.44%	45.46%
14.0	Regen Loss %:	10.61%	10.88%	10.75%
15.0	Total Loss %:	55.09%	57.32%	56.21%
16.0	Control Efficiency	0.56	0.54	0.55
18.0	Net Ener Not Rec'd	0.99	1.05	1.02
19.0	Ener Not Rec'd %:	80.35%	99.05%	89.70%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 32,748 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	230	232	
3.0	Number of Stops:	50	47	49
4.0	Average Accel:	1.57	1.54	1.56
5.0	Energy per Mile:	5.73	5.26	5.49
6.0	Prop Energy In:	19.48	17.86	18.67
7.0	Line Energy Regen:	0.04	0.04	0.04
8.0	Motor Energy In:	11.42	11.39	11.40
9.0	Net Motor Energy:	7.80	8.15	7.97
9.1	Auxiliary Energy:	7.28	9.09	8.19
10.0	Lost Control Ener:	8.06	6.48	7.27
11.0	Motor Regen Ener:	3.61	3.24	3.43
12.0	Ener Not Received:	3.57	3.20	3.39
13.0	Control Loss %:	41.39%	36.25%	38.82%
14.0	Regen Loss %:	18.34%	17.93%	18.14%
15.0	Total Loss %:	59.73%	54.19%	56.96%
16.0	Control Efficiency:	0.59	0.64	0.61
18.0	Net Ener Not Rec'd:	2.06	2.01	2.04
19.0	Ener Not Rec'd %:	97.34%	97.30%	97.32%
1.0	Direction:	Outbound		
2.0	Run Number:	231	233	
3.0	Number of Stops:	48	60	54
4.0	Average Accel:	1.66	1.77	1.72
5.0	Energy per Mile:	6.00	6.19	6.09
6.0	Prop Energy In:	21.12	21.15	21.13
7.0	Line Energy Regen:	0.02	.00	0.01
8.0	Motor Energy In:	13.36	13.41	13.39
9.0	Net Motor Energy:	9.99	10.38	10.19
9.1	Auxiliary Energy:	3.49	7.17	5.33
10.0	Lost Control Ener:	7.75	7.75	7.75
11.0	Motor Regen Ener:	3.37	3.03	3.20
12.0	Ener Not Received:	3.35	3.02	3.19
13.0	Control Loss %:	36.71%	36.61%	36.66%
14.0	Regen Loss %:	15.88%	14.30%	15.09%
15.0	Total Loss %:	52.60%	50.91%	51.75%
16.0	Control Efficiency:	0.63	0.63	0.63
18.0	Net Ener Not Rec'd:	2.11	1.92	2.01
19.0	Ener Not Rec'd %:	99.07%	99.86%	99.47%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance: 6.8 MILES
Weight: 34,068 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	260	262	
3.0	Number of Stops:	75	73	74
4.0	Average Accel	1.57	1.50	1.54
5.0	Energy per Mile:	4.27	4.17	4.22
6.0	Prop Energy In:	28.98	28.95	28.96
7.0	Line Energy Regen:	0.03	0.03	0.03
8.0	Motor Energy In:	18.72	18.21	18.47
9.0	Net Motor Energy:	13.14	13.44	13.29
9.1	Auxiliary Energy:	3.03	2.93	2.98
10.0	Lost Control Ener:	10.26	10.74	10.50
11.0	Motor Regen Ener:	5.58	4.77	5.17
12.0	Ener Not Received:	5.54	4.74	5.14
13.0	Control Loss %:	35.40%	37.09%	36.25%
14.0	Regen Loss %:	19.13%	16.39%	17.76%
15.0	Total Loss %:	54.53%	53.48%	54.01%
16.0	Control Efficiency:	0.65	0.63	0.64
18.0	Net Ener Not Rec'd:	3.57	2.97	3.27
19.0	Ener Not Rec'd %:	98.99%	99.05%	99.02%
1.0	Direction:	Outbound		
2.0	Run Number:	261	263	
3.0	Number of Stops:	75	75	75
4.0	Average Accel:	1.65	1.53	1.59
5.0	Energy per Mile:	4.52	4.76	4.64
6.0	Prop Energy In:	30.70	28.16	29.43
7.0	Line Energy Regen:	0.06	.00	0.03
8.0	Motor Energy In:	18.94	15.45	17.20
9.0	Net Motor Energy:	13.77	11.96	12.86
9.1	Auxiliary Energy:	2.89	3.57	3.23
10.0	Lost Control Ener:	11.76	12.70	12.23
11.0	Motor Regen Ener:	5.17	3.49	4.33
12.0	Ener Not Received:	5.11	3.49	4.30
13.0	Control Loss %:	38.31%	45.12%	41.71%
14.0	Regen Loss %:	16.65%	12.40%	14.52%
15.0	Total Loss %:	54.96%	57.51%	56.24%
16.0	Control Efficiency	0.62	0.55	0.58
18.0	Net Ener Not Rec'd	3.13	1.91	2.52
19.0	Ener Not Rec'd %:	97.98%	99.76%	98.87%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 34,090 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	269	271	
3.0	Number of Stops:	52	37	45
4.0	Average Accel:	1.55	1.75	1.65
5.0	Energy per Mile:	4.18	3.97	4.08
6.0	Prop Energy In:	14.13	13.08	13.61
7.0	Line Energy Regen:	0.03	.00	0.02
8.0	Motor Energy In:	6.95	7.36	7.15
9.0	Net Motor Energy:	4.37	4.54	4.45
9.1	Auxiliary Energy:	1.96	1.52	1.74
10.0	Lost Control Ener:	7.18	5.72	6.45
11.0	Motor Regen Ener:	2.58	2.82	2.70
12.0	Ener Not Received:	2.55	2.82	2.69
13.0	Control Loss %:	50.82%	43.74%	47.28%
14.0	Regen Loss %:	18.04%	21.58%	19.81%
15.0	Total Loss %:	68.86%	65.32%	67.09%
16.0	Control Efficiency	0.49	0.56	0.53
18.0	Net Ener Not Rec'd	1.23	1.59	1.41
19.0	Ener Not Rec'd %:	97.31%	99.93%	98.62%
1.0	Direction:	Outbound		
2.0	Run Number:	268	270	
3.0	Number of Stops:	52	39	46
4.0	Average Accel:	1.50	1.60	1.55
5.0	Energy per Mile:	5.47	5.07	5.27
6.0	Prop Energy In:	18.38	17.24	17.81
7.0	Line Energy Regen:	0.00	0.00	0.00
8.0	Motor Energy In:	8.83	10.07	9.45
9.0	Net Motor Energy:	7.09	7.90	7.50
9.1	Auxiliary Energy:	2.04	1.73	1.89
10.0	Lost Control Ener:	9.55	7.17	8.36
11.0	Motor Regen Ener:	1.74	2.16	1.95
12.0	Ener Not Received:	1.74	2.16	1.95
13.0	Control Loss %:	51.96%	41.59%	46.78%
14.0	Regen Loss %:	9.47%	12.55%	11.01%
15.0	Total Loss %:	61.43%	54.14%	57.79%
16.0	Control Efficiency	0.48	0.58	0.53
18.0	Net Ener Not Rec'd	0.84	1.26	1.05
19.0	Ener Not Rec'd %:	100.00%	100.00%	100.00%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: General Electric Controller — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance:3.4 MILES
Weight: 34,090 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	264	266	
3.0	Number of Stops:	45	47	46
4.0	Average Accel:	1.62	1.78	1.70
5.0	Energy per Mile:	5.47	5.83	5.65
6.0	Prop Energy In:	18.96	20.01	19.48
7.0	Line Energy Regen:	0.15	0.00	0.08
8.0	Motor Energy In:	11.82	12.94	12.38
9.0	Net Motor Energy:	7.99	8.99	8.49
9.1	Auxiliary Energy:	1.73	1.60	1.66
10.0	Lost Control Ener:	7.14	7.07	7.10
11.0	Motor Regen Ener:	3.83	3.95	3.89
12.0	Ener Not Received:	3.68	3.95	3.81
13.0	Control Loss %:	37.66%	35.34%	36.50%
14.0	Regen Loss %:	19.39%	19.75%	19.57%
15.0	Total Loss %:	57.05%	55.09%	56.07%
16.0	Control Efficiency:	0.62	0.65	0.64
18.0	Net Ener Not Rec'd:	2.22	2.55	2.39
19.0	Ener Not Rec'd %:	93.14%	100.00%	96.57%
1.0	Direction:	Outbound		
2.0	Run Number:	265	267	
3.0	Number of Stops:	50	46	48
4.0	Average Accel:	1.67	1.66	1.67
5.0	Energy per Mile:	6.17	6.21	6.19
6.0	Prop Energy In:	21.56	21.33	21.45
7.0	Line Energy Regen:	0.01	0.02	0.01
8.0	Motor Energy In:	13.41	13.29	13.35
9.0	Net Motor Energy:	10.03	9.95	9.99
9.1	Auxiliary Energy:	1.78	1.66	1.72
10.0	Lost Control Ener:	8.16	8.04	8.10
11.0	Motor Regen Ener:	3.38	3.33	3.36
12.0	Ener Not Received	3.37	3.32	3.34
13.0	Control Loss %:	37.82%	37.70%	37.76%
14.0	Regen Loss %:	15.63%	15.55%	15.59%
15.0	Total Loss %:	53.45%	53.25%	53.35%
16.0	Control Efficiency:	0.62	0.62	0.62
18.0	Net Ener Not Rec'd:	2.09	2.06	2.07
19.0	Ener Not Rec'd %:	99.48%	99.12%	99.30%

Garrett-Stromberg

AC PROPULSION SYSTEM

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 25,740 lbs. - AWO

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	304	306	
3.0	Number of Stops:	50	59	55
4.0	Average Accel:	1.73	2.05	1.89
5.0	Energy per Mile:	2.13	2.21	2.17
6.0	Prop Energy In:	17.80	20.25	19.02
7.0	Line Energy Regen:	3.81	5.02	4.41
8.0	Motor Energy In:	16.79	19.18	17.99
9.0	Net Motor Energy:	11.38	12.89	12.13
9.1	Auxiliary Energy:	1.46	1.39	1.43
10.0	Lost Control Ener:	1.01	1.07	1.04
11.0	Motor Regen Ener:	5.41	6.29	5.85
12.0	Ener Not Received:	1.61	1.27	1.44
13.0	Control Loss %:	5.66%	5.28%	5.47%
14.0	Regen Loss %:	9.03%	6.28%	7.66%
15.0	Total Loss %:	14.69%	11.57%	13.13%
16.0	Control Efficiency:	0.94	0.95	0.95
18.0	Net Ener Not Rec'd:	0.99	0.60	0.79
19.0	Ener Not Rec'd %:	19.35%	9.99%	14.67%
1.0	Direction:	Outbound		
2.0	Run Number:	305	307	Average
3.0	Number of Stops:	54	47	51
4.0	Average Accel:	2.04	1.66	1.85
5.0	Energy per Mile:	2.44	2.10	2.27
6.0	Prop Energy In:	18.86	17.65	18.26
7.0	Line Energy Regen:	3.93	3.13	3.53
8.0	Motor Energy In:	17.57	16.23	16.90
9.0	Net Motor Energy:	12.70	12.27	12.49
9.1	Auxiliary Energy:	1.20	1.28	1.24
10.0	Lost Control Ener:	1.29	1.42	1.36
11.0	Motor Regen Ener:	4.87	3.96	4.41
12.0	Ener Not Received:	0.94	0.83	0.88
13.0	Control Loss %:	6.85%	8.04%	7.45%
14.0	Regen Loss %:	4.96%	4.70%	4.83%
15.0	Total Loss %:	11.82%	12.74%	12.28%
16.0	Control Efficiency:	0.93	0.92	0.93
18.0	Net Ener Not Rec'd:	0.35	0.28	0.32
19.0	Ener Not Rec'd %:	7.76%	7.81%	7.78%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE
Change in Elevation: +122 FEET OUTBOUND
Weight: 25,740 lbs. - AWO

Route: 8 - MARKET
Distance:3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	309	311	
3.0	Number of Stops:	55	44	50
4.0	Average Accel:	1.61	1.69	1.65
5.0	Energy per Mile:	2.12	1.84	1.98
6.0	Prop Energy In:	9.10	8.27	8.68
7.0	Line Energy Regen:	1.93	2.05	1.99
8.0	Motor Energy In:	8.05	7.91	7.98
9.0	Net Motor Energy:	5.50	5.35	5.42
9.1	Auxiliary Energy:	0.98	0.80	0.89
10.0	Lost Control Ener:	1.04	0.36	0.70
11.0	Motor Regen Ener:	2.56	2.56	2.56
12.0	Ener Not Received:	0.63	0.51	0.57
13.0	Control Loss %:	11.47%	4.38%	7.92%
14.0	Regen Loss %:	6.88%	6.18%	6.53%
15.0	Total Loss %:	18.35%	10.55%	14.45%
16.0	Control Efficiency	0.89	0.96	0.92
18.0	Net Ener Not Rec'd	0.13	0.20	0.16
19.0	Ener Not Rec'd %:	5.56%	8.27%	6.92%
1.0	Direction:	Outbound		
2.0	Run Number:	308	310	
3.0	Number of Stops:	44	50	47
4.0	Average Accel:	1.60	1.81	1.71
5.0	Energy per Mile:	2.78	2.87	2.82
6.0	Prop Energy In:	10.43	11.92	11.17
7.0	Line Energy Regen:	1.09	1.88	1.49
8.0	Motor Energy In:	9.21	11.53	10.37
9.0	Net Motor Energy:	7.66	9.04	8.35
9.1	Auxiliary Energy:	0.86	0.98	0.92
10.0	Lost Control Ener:	1.22	0.39	0.80
11.0	Motor Regen Ener:	1.56	2.49	2.02
12.0	Ener Not Received:	0.46	0.61	0.53
13.0	Control Loss %:	11.67%	3.25%	7.46%
14.0	Regen Loss %:	4.43%	5.08%	4.75%
15.0	Total Loss %:	16.10%	8.32%	12.21%
16.0	Control Efficiency	0.88	0.97	0.93
18.0	Net Ener Not Rec'd	0.19	0.37	0.28
19.0	Ener Not Rec'd %:	13.85%	15.36%	14.60%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance:3.4 MILES
Weight: 25,740 lbs. - AWO

	ITEM		RUN DATA			AVERAGE
1.0	Direction:			Inbound		
2.0	Run Number:		315	317	319	
3.0	Number of Stops:		51	52	46	50
4.0	Average Accel:		1.62	1.68	1.87	1.72
5.0	Energy per Mile:		2.58	2.35	2.81	2.58
6.0	Prop Energy In:		11.63	10.99	13.23	11.95
7.0	Line Energy Regen:		2.82	3.01	3.61	3.15
8.0	Motor Energy In:		10.78	10.52	11.80	11.03
9.0	Net Motor Energy:		7.22	6.91	7.19	7.11
9.1	Auxiliary Energy:		0.93	1.12	0.96	1.00
10.0	Lost Control Ener:		0.85	0.47	1.43	0.92
11.0	Motor Regen Ener:		3.56	3.61	4.60	3.92
12.0	Ener Not Received:		0.74	0.60	0.99	0.78
13.0	Control Loss %:		7.32%	4.28%	10.83%	7.48%
14.0	Regen Loss %:		6.33%	5.45%	7.51%	6.43%
15.0	Total Loss %:		13.65%	9.72%	18.35%	13.91%
16.0	Control Efficiency:		0.93	0.96	0.89	0.93
18.0	Net Ener Not Rec'd:		0.25	0.14	0.23	0.21
19.0	Ener Not Rec'd %:		7.56%	4.02%	5.66%	5.75%
1.0	Direction:			Outbound		
2.0	Run Number:		312	318	320	
3.0	Number of Stops:		52	57	51	53
4.0	Average Accel:		1.79	1.83	1.88	1.83
5.0	Energy per Mile:		2.78	3.35	3.39	3.17
6.0	Prop Energy In:		12.48	13.40	14.76	13.55
7.0	Line Energy Regen:		2.71	2.60	2.82	2.71
8.0	Motor Energy In:		12.61	12.93	13.24	12.92
9.0	Net Motor Energy:		9.36	9.68	9.43	9.49
9.1	Auxiliary Energy:		0.96	1.23	1.13	1.11
10.0	Lost Control Ener:	zero	-0.13	0.47	1.53	0.62
11.0	Motor Regen Ener:		3.25	3.24	3.80	3.43
12.0	Ener Not Received:		0.54	0.65	0.98	0.72
13.0	Control Loss %:	zero	-1.01%	3.49%	10.36%	4.28%
14.0	Regen Loss %:		4.33%	4.81%	6.65%	5.26%
15.0	Total Loss %:		3.32%	8.30%	17.01%	9.54%
16.0	Control Efficiency	one	1.01	0.97	0.90	0.96
18.0	Net Ener Not Rec'd		0.36	0.29	0.37	0.34
19.0	Ener Not Rec'd %:		11.11%	9.37%	10.95%	10.48%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE
Change in Elevation: +14 FEET OUTBOUND
Weight: 32,340 lbs. - AW1

Route: 5 - FULTON
Distance: 6.8 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	330	332	
3.0	Number of Stops:	66	81	74
4.0	Average Accel:	1.94	1.77	1.86
5.0	Energy per Mile:	3.07	2.98	3.02
6.0	Prop Energy In:	28.67	27.60	28.14
7.0	Line Energy Regen:	7.85	7.06	7.46
8.0	Motor Energy In:	27.67	26.79	27.23
9.0	Net Motor Energy:	18.39	18.27	18.33
9.1	Auxiliary Energy:	1.58	2.46	2.02
10.0	Lost Control Ener:	1.00	0.81	0.91
11.0	Motor Regen Ener:	9.28	8.53	8.90
12.0	Ener Not Received:	1.43	1.46	1.45
13.0	Control Loss %:	3.50%	2.93%	3.22%
14.0	Regen Loss %:	4.98%	5.30%	5.14%
15.0	Total Loss %:	8.48%	8.24%	8.36%
16.0	Control Efficiency:	0.97	0.97	0.97
18.0	Net Ener Not Rec'd:	0.67	0.58	0.63
19.0	Ener Not Rec'd %:	7.49%	7.06%	7.28%
1.0	Direction:	Outbound		
2.0	Run Number:	331	333	
3.0	Number of Stops:	69	78	74
4.0	Average Accel:	1.92	1.73	1.83
5.0	Energy per Mile:	3.33	2.93	3.13
6.0	Prop Energy In:	29.55	26.09	27.82
7.0	Line Energy Regen:	7.00	5.89	6.44
8.0	Motor Energy In:	28.00	24.89	26.44
9.0	Net Motor Energy:	19.36	17.96	18.66
9.1	Auxiliary Energy:	2.49	1.88	2.19
10.0	Lost Control Ener:	1.55	1.20	1.37
11.0	Motor Regen Ener:	8.64	6.93	7.78
12.0	Ener Not Received:	1.64	1.04	1.34
13.0	Control Loss %:	5.25%	4.59%	4.92%
14.0	Regen Loss %:	5.55%	4.00%	4.78%
15.0	Total Loss %:	10.80%	8.59%	9.69%
16.0	Control Efficiency	0.95	0.95	0.95
18.0	Net Ener Not Rec'd	0.60	0.30	0.45
19.0	Ener Not Rec'd %:	7.30%	4.55%	5.93%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance:3.4 MILES
Weight: 32,340 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	335	337	
3.0	Number of Stops:	46	47	47
4.0	Average Accel:	1.75	1.69	1.72
5.0	Energy per Mile:	2.52	2.42	2.47
6.0	Prop Energy In:	11.17	10.80	10.98
7.0	Line Energy Regen:	2.67	2.62	2.65
8.0	Motor Energy In:	10.01	9.74	9.87
9.0	Net Motor Energy:	6.58	6.38	6.48
9.1	Auxiliary Energy:	1.00	0.90	0.95
10.0	Lost Control Ener:	1.16	1.06	1.11
11.0	Motor Regen Ener:	3.43	3.36	3.40
12.0	Ener Not Received:	0.75	0.75	0.75
13.0	Control Loss %:	10.39%	9.80%	10.10%
14.0	Regen Loss %:	6.73%	6.91%	6.82%
15.0	Total Loss %:	17.12%	16.71%	16.92%
16.0	Control Efficiency:	0.90	0.90	0.90
18.0	Net Ener Not Rec'd:	0.16	0.20	0.18
19.0	Ener Not Rec'd %:	5.09%	6.50%	5.79%
1.0	Direction:	Outbound		
2.0	Run Number:	334	336	
3.0	Number of Stops:	45	46	46
4.0	Average Accel:	1.78	1.81	1.80
5.0	Energy per Mile:	3.43	3.58	3.51
6.0	Prop Energy In:	13.27	13.63	13.45
7.0	Line Energy Regen:	1.77	1.95	1.86
8.0	Motor Energy In:	11.99	12.38	12.18
9.0	Net Motor Energy:	9.51	9.77	9.64
9.1	Auxiliary Energy:	0.99	0.97	0.98
10.0	Lost Control Ener:	1.28	1.25	1.27
11.0	Motor Regen Ener:	2.48	2.61	2.55
12.0	Ener Not Received:	0.71	0.66	0.69
13.0	Control Loss %:	9.68%	9.15%	9.41%
14.0	Regen Loss %:	5.38%	4.86%	5.12%
15.0	Total Loss %:	15.06%	14.01%	14.53%
16.0	Control Efficiency	0.90	0.91	0.91
18.0	Net Ener Not Rec'd	0.34	0.28	0.31
19.0	Ener Not Rec'd %:	15.27%	12.02%	13.64%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance:3.4 MILES
Weight: 32,340 lbs. - AW1

	ITEM	RUN DATA			AVERAGE
1.0	Direction:	Inbound			
2.0	Run Number:	338	342		
3.0	Number of Stops:	50	68		59
4.0	Average Accel:	1.72	1.67		1.70
5.0	Energy per Mile:	3.24	3.40		3.32
6.0	Prop Energy In:	14.99	15.64		15.31
7.0	Line Energy Regen:	3.87	4.00		3.93
8.0	Motor Energy In:	13.76	14.20		13.98
9.0	Net Motor Energy:	9.03	9.37		9.20
9.1	Auxiliary Energy:	1.13	1.55		1.34
10.0	Lost Control Ener:	1.22	1.45		1.33
11.0	Motor Regen Ener:	4.74	4.83		4.78
12.0	Ener Not Received:	0.87	0.82		0.85
13.0	Control Loss %:	8.15%	9.24%		8.70%
14.0	Regen Loss %:	5.81%	5.27%		5.54%
15.0	Total Loss %:	13.95%	14.51%		14.23%
16.0	Control Efficiency	0.92	0.91		0.91
18.0	Net Ener Not Rec'd	0.19	-0.02	zero	0.09
19.0	Ener Not Rec'd %:	4.40%	-0.42%	zero	1.99%
1.0	Direction:	Outbound			
2.0	Run Number:	340	343		
3.0	Number of Stops:	60	49		55
4.0	Average Accel:	1.64	1.80		1.72
5.0	Energy per Mile:	3.78	4.06		3.92
6.0	Prop Energy In:	16.64	17.80		17.22
7.0	Line Energy Regen:	3.25	3.85		3.55
8.0	Motor Energy In:	15.79	16.63		16.21
9.0	Net Motor Energy:	11.68	11.76		11.72
9.1	Auxiliary Energy:	1.25	1.13		1.19
10.0	Lost Control Ener:	0.85	1.17		1.01
11.0	Motor Regen Ener:	4.11	4.87		4.49
12.0	Ener Not Received:	0.86	1.03		0.94
13.0	Control Loss %:	5.09%	6.57%		5.83%
14.0	Regen Loss %:	5.17%	5.76%		5.46%
15.0	Total Loss %:	10.26%	12.33%		11.29%
16.0	Control Efficiency	0.95	0.93		0.94
18.0	Net Ener Not Rec'd	0.41	0.46		0.43
19.0	Ener Not Rec'd %:	10.41%	10.12%		10.26%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 36,090 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	360	362	
3.0	Number of Stops:	71	75	73
4.0	Average Accel:	1.82	1.69	1.76
5.0	Energy per Mile:	3.19	3.34	3.27
6.0	Prop Energy In:	29.65	29.83	29.74
7.0	Line Energy Regen:	7.61	7.11	7.36
8.0	Motor Energy In:	28.59	28.03	28.31
9.0	Net Motor Energy:	19.31	19.08	19.19
9.1	Auxiliary Energy:	1.73	2.78	2.26
10.0	Lost Control Ener:	1.06	1.80	1.43
11.0	Motor Regen Ener:	9.28	8.95	9.11
12.0	Ener Not Received:	1.67	1.85	1.76
13.0	Control Loss %:	3.58%	6.02%	4.80%
14.0	Regen Loss %:	5.62%	6.19%	5.91%
15.0	Total Loss %:	9.20%	12.22%	10.71%
16.0	Control Efficiency:	0.96	0.94	0.95
18.0	Net Ener Not Rec'd:	0.89	0.65	0.77
19.0	Ener Not Rec'd %:	9.95%	7.67%	8.81%
1.0	Direction:	Outbound		
2.0	Run Number:	361	365	
3.0	Number of Stops:	71	75	73
4.0	Average Accel	1.77	1.83	1.80
5.0	Energy per Mile:	3.45	3.52	3.48
6.0	Prop Energy In:	30.29	30.35	30.32
7.0	Line Energy Regen:	6.77	6.45	6.61
8.0	Motor Energy In:	28.67	28.51	28.59
9.0	Net Motor Energy:	20.38	20.54	20.46
9.1	Auxiliary Energy:	1.61	1.64	1.63
10.0	Lost Control Ener:	1.62	1.84	1.73
11.0	Motor Regen Ener:	8.30	7.97	8.13
12.0	Ener Not Received:	1.53	1.52	1.52
13.0	Control Loss %:	5.35%	6.07%	5.71%
14.0	Regen Loss %:	5.04%	5.00%	5.02%
15.0	Total Loss %:	10.39%	11.07%	10.73%
16.0	Control Efficiency:	0.95	0.94	0.94
18.0	Net Ener Not Rec'd:	0.72	0.68	0.70
19.0	Ener Not Rec'd %:	9.19%	9.15%	9.17%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: GARRETT AC DRIVE
Change in Elevation: +122 FEET OUTBOUND
Weight: 36,090 lbs. - AW2

Route: 8 - MARKET
Distance: 3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	366	no test	
3.0	Number of Stops:	47		47
4.0	Average Accel:	1.62		1.62
5.0	Energy per Mile:	2.83		2.83
6.0	Prop Energy In:	12.06		12.06
7.0	Line Energy Regen:	2.46		2.46
8.0	Motor Energy In:	10.62		10.62
9.0	Net Motor Energy:	7.17		7.17
9.1	Auxiliary Energy:	2.30		2.30
10.0	Lost Control Ener:	1.44		1.44
11.0	Motor Regen Ener:	3.45		3.45
12.0	Ener Not Received:	0.99		0.99
13.0	Control Loss %:	11.94%		11.94%
14.0	Regen Loss %:	8.21%		8.21%
15.0	Total Loss %:	20.15%		20.15%
16.0	Control Efficiency:	0.88		0.88
18.0	Net Ener Not Rec'd:	0.11		0.11
19.0	Ener Not Rec'd %:	3.60%		3.60%
1.0	Direction:	Outbound		
2.0	Run Number:	367	369	
3.0	Number of Stops:	51	48	50
4.0	Average Accel:	1.73	1.69	1.71
5.0	Energy per Mile:	4.04	3.78	3.91
6.0	Prop Energy In:	16.19	14.96	15.57
7.0	Line Energy Regen:	2.27	2.33	2.30
8.0	Motor Energy In:	14.44	13.66	14.05
9.0	Net Motor Energy:	11.36	10.50	10.93
9.1	Auxiliary Energy:	1.00	0.98	0.99
10.0	Lost Control Ener:	1.74	1.30	1.52
11.0	Motor Regen Ener:	3.08	3.15	3.12
12.0	Ener Not Received:	0.82	0.82	0.82
13.0	Control Loss %:	10.78%	8.69%	9.74%
14.0	Regen Loss %:	5.05%	5.50%	5.27%
15.0	Total Loss %:	15.83%	14.19%	15.01%
16.0	Control Efficiency:	0.89	0.91	0.90
18.0	Net Ener Not Rec'd:	0.34	0.40	0.37
19.0	Ener Not Rec'd %:	12.53%	13.73%	13.13%

Garrett-Stromberg Equipment

PLOTPAC RESULTS ANALYSIS FOR ROUTE 41 - UNION

Test not performed because of power limitations of equipment.

Westinghouse Electric Corporation
Transportation Division

CHOPPER PROPULSION SYSTEM

PLOTPAC RESULTS ANALYSIS

Equipment: Westinghouse Chopper — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 26.570 lbs. - AWO

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	410	412	
3.0	Number of Stops:	70	72	71
4.0	Average Accel:	1.64	1.75	1.70
5.0	Energy per Mile:	2.22	2.18	2.20
6.0	Prop Energy In:	17.48	17.81	17.64
7.0	Line Energy Regen:	2.36	2.69	2.52
8.0	Motor Energy In:	15.73	16.23	15.98
9.0	Net Motor Energy:	9.42	9.23	9.33
9.1	Auxiliary Energy:	1.80	1.63	1.71
10.0	Lost Control Ener:	1.75	1.57	1.66
11.0	Motor Regen Ener:	6.30	7.01	6.65
12.0	Ener Not Received:	3.95	4.32	4.13
13.0	Control Loss %:	10.03%	8.84%	9.44%
14.0	Regen Loss %:	22.57%	24.23%	23.40%
15.0	Total Loss %:	32.60%	33.07%	32.84%
16.0	Control Efficiency:	0.90	0.91	0.91
18.0	Net Ener Not Rec'd:	3.07	3.45	3.26
19.0	Ener Not Rec'd %:	54.13%	54.03%	54.08%

1.0	Direction:	Outbound		
2.0	Run Number:	411	413	Average
3.0	Number of Stops:	63	68	66
4.0	Average Accel:	1.66	1.62	1.64
5.0	Energy per Mile:	2.15	2.12	2.14
6.0	Prop Energy In:	16.53	16.29	16.41
7.0	Line Energy Regen:	1.90	1.88	1.89
8.0	Motor Energy In:	14.83	14.73	14.78
9.0	Net Motor Energy:	9.52	9.21	9.37
9.1	Auxiliary Energy:	2.15	1.46	1.81
10.0	Lost Control Ener:	1.70	1.56	1.63
11.0	Motor Regen Ener:	5.31	5.51	5.41
12.0	Ener Not Received:	3.41	3.64	3.52
13.0	Control Loss %:	10.29%	9.60%	9.94%
14.0	Regen Loss %:	20.61%	22.32%	21.47%
15.0	Total Loss %:	30.89%	31.92%	31.41%
16.0	Control Efficiency	0.90	0.90	0.90
18.0	Net Ener Not Rec'd	2.61	2.94	2.78
19.0	Ener Not Rec'd %:	54.89%	58.95%	56.92%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 21, 1984

Equipment: Westinghouse Chopper — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance:3.4 MILES
Weight: 26.570 lbs. - AWO

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	406	408	
3.0	Number of Stops:	44	46	45
4.0	Average Accel:	1.71	1.76	1.74
5.0	Energy per Mile:	1.79	1.61	1.70
6.0	Prop Energy In:	7.45	6.70	7.07
7.0	Line Energy Regen:	1.37	1.26	1.31
8.0	Motor Energy In:	6.69	6.17	6.43
9.0	Net Motor Energy:	3.54	3.22	3.38
9.1	Auxiliary Energy:	1.28	1.08	1.18
10.0	Lost Control Ener:	0.76	0.53	0.64
11.0	Motor Regen Ener:	3.16	2.95	3.05
12.0	Ener Not Received:	1.79	1.69	1.74
13.0	Control Loss %:	10.17%	7.93%	9.05%
14.0	Regen Loss %:	24.01%	25.24%	24.62%
15.0	Total Loss %:	34.18%	33.16%	33.67%
16.0	Control Efficiency:	0.90	0.92	0.91
18.0	Net Ener Not Rec'd:	1.23	1.25	1.24
19.0	Ener Not Rec'd %:	43.48%	46.10%	44.79%
1.0	Direction:	Outbound		
2.0	Run Number:	407	409	
3.0	Number of Stops:	46	53	50
4.0	Average Accel:	1.85	1.71	1.78
5.0	Energy per Mile:	2.45	2.38	2.42
6.0	Prop Energy In:	9.29	9.11	9.20
7.0	Line Energy Regen:	0.92	0.98	0.95
8.0	Motor Energy In:	8.42	8.40	8.41
9.0	Net Motor Energy:	6.10	6.07	6.09
9.1	Auxiliary Energy:	1.01	1.22	1.11
10.0	Lost Control Ener:	0.87	0.71	0.79
11.0	Motor Regen Ener:	2.32	2.32	2.32
12.0	Ener Not Received:	1.41	1.34	1.38
13.0	Control Loss %:	9.35%	7.79%	8.57%
14.0	Regen Loss %:	15.14%	14.76%	14.95%
15.0	Total Loss %:	24.48%	22.54%	23.51%
16.0	Control Efficiency:	0.91	0.92	0.91
18.0	Net Ener Not Rec'd:	1.09	1.03	1.06
19.0	Ener Not Rec'd %:	51.70%	48.17%	49.93%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 23, 1984

Equipment: Westinghouse Chopper
Change in Elevation: +41 FEET OUTBOUND
Weight: 26,570 lbs. - AWO

Route: 41 - UNION
Distance:3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	402	404	
3.0	Number of Stops:	44	54	49
4.0	Average Accel:	1.72	1.77	1.75
5.0	Energy per Mile:	2.62	2.73	2.68
6.0	Prop Energy In:	10.84	11.28	11.06
7.0	Line Energy Regen:	1.87	1.94	1.91
8.0	Motor Energy In:	9.88	10.35	10.11
9.0	Net Motor Energy:	5.36	5.32	5.34
9.1	Auxiliary Energy:	1.10	1.04	1.07
10.0	Lost Control Ener:	0.97	0.94	0.95
11.0	Motor Regen Ener:	4.52	5.02	4.77
12.0	Ener Not Received:	2.65	3.08	2.86
13.0	Control Loss %:	8.92%	8.30%	8.61%
14.0	Regen Loss %:	24.41%	27.30%	25.85%
15.0	Total Loss %:	33.32%	35.61%	34.47%
16.0	Control Efficiency:	0.91	0.92	0.91
18.0	Net Ener Not Rec'd:	2.05	2.49	2.27
19.0	Ener Not Rec'd %:	49.93%	53.96%	51.95%
1.0	Direction:	Outbound		
2.0	Run Number:	403	405	
3.0	Number of Stops:	51	56	54
4.0	Average Accel:	1.66	1.72	1.69
5.0	Energy per Mile:	2.85	3.02	2.93
6.0	Prop Energy In:	11.65	12.09	11.87
7.0	Line Energy Regen:	1.63	1.66	1.65
8.0	Motor Energy In:	10.63	11.19	10.91
9.0	Net Motor Energy:	6.70	6.78	6.74
9.1	Auxiliary Energy:	1.12	1.06	1.09
10.0	Lost Control Ener:	1.02	0.90	0.96
11.0	Motor Regen Ener:	3.93	4.41	4.17
12.0	Ener Not Received:	2.30	2.75	2.52
13.0	Control Loss %:	8.77%	7.47%	8.12%
14.0	Regen Loss %:	19.72%	22.70%	21.21%
15.0	Total Loss %:	28.49%	30.17%	29.33%
16.0	Control Efficiency:	0.91	0.93	0.92
18.0	Net Ener Not Rec'd:	1.79	2.27	2.03
19.0	Ener Not Rec'd %:	50.07%	55.70%	52.88%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 29, 1984

Equipment: Westinghouse Chopper — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 33,370 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	430	432	
3.0	Number of Stops:	67	67	67
4.0	Average Accel:	1.72	1.67	1.70
5.0	Energy per Mile:	2.69	2.57	2.63
6.0	Prop Energy In:	21.48	20.14	20.81
7.0	Line Energy Regen:	2.85	2.76	2.81
8.0	Motor Energy In:	19.16	18.31	18.74
9.0	Net Motor Energy:	11.52	10.85	11.18
9.1	Auxiliary Energy:	1.51	1.49	1.50
10.0	Lost Control Ener:	2.31	1.83	2.07
11.0	Motor Regen Ener:	7.65	7.46	7.55
12.0	Ener Not Received:	4.80	4.70	4.75
13.0	Control Loss %:	10.77%	9.11%	9.94%
14.0	Regen Loss %:	22.34%	23.32%	22.83%
15.0	Total Loss %:	33.11%	32.43%	32.77%
16.0	Control Efficiency:	0.89	0.91	0.90
18.0	Net Ener Not Rec'd:	3.77	3.81	3.79
19.0	Ener Not Rec'd %:	55.29%	56.27%	55.78%

1.0	Direction:	Outbound		
2.0	Run Number:	431	433	
3.0	Number of Stops:	65	70	68
4.0	Average Accel:	1.67	1.64	1.66
5.0	Energy per Mile:	2.59	2.58	2.59
6.0	Prop Energy In:	19.88	19.79	19.83
7.0	Line Energy Regen:	2.31	2.29	2.30
8.0	Motor Energy In:	17.74	17.91	17.82
9.0	Net Motor Energy:	11.29	11.65	11.47
9.1	Auxiliary Energy:	1.36	1.64	1.50
10.0	Lost Control Ener:	2.14	1.88	2.01
11.0	Motor Regen Ener:	6.46	6.26	6.36
12.0	Ener Not Received:	4.15	3.97	4.06
13.0	Control Loss %:	10.75%	9.51%	10.13%
14.0	Regen Loss %:	20.88%	20.04%	20.46%
15.0	Total Loss %:	31.62%	29.55%	30.59%
16.0	Control Efficiency:	0.89	0.90	0.90
18.0	Net Ener Not Rec'd:	3.30	3.18	3.24
19.0	Ener Not Rec'd %:	57.25%	56.20%	56.73%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 21, 1984

Equipment: Westinghouse Chopper — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 33,370 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	439	441	
3.0	Number of Stops:	51	45	48
4.0	Average Accel	1.57	1.54	1.56
5.0	Energy per Mile:	2.13	1.96	2.04
6.0	Prop Energy In:	8.56	7.93	8.25
7.0	Line Energy Regen:	1.34	1.31	1.32
8.0	Motor Energy In:	7.35	7.09	7.22
9.0	Net Motor Energy:	4.15	3.70	3.93
9.1	Auxiliary Energy:	1.34	1.09	1.21
10.0	Lost Control Ener:	1.22	0.85	1.03
11.0	Motor Regen Ener:	3.20	3.38	3.29
12.0	Ener Not Received:	1.86	2.08	1.97
13.0	Control Loss %:	14.20%	10.70%	12.45%
14.0	Regen Loss %:	21.71%	26.15%	23.93%
15.0	Total Loss %:	35.91%	36.85%	36.38%
16.0	Control Efficiency:	0.86	0.89	0.88
18.0	Net Ener Not Rec'd:	1.20	1.53	1.37
19.0	Ener Not Rec'd %:	43.67%	50.80%	47.23%
1.0	Direction:	Outbound		
2.0	Run Number:	438	440	
3.0	Number of Stops:	41	52	47
4.0	Average Accel:	1.61	1.65	1.63
5.0	Energy per Mile:	3.00	2.87	2.93
6.0	Prop Energy In:	11.36	10.46	10.91
7.0	Line Energy Regen:	0.97	0.92	0.95
8.0	Motor Energy In:	9.92	9.38	9.65
9.0	Net Motor Energy:	7.59	7.11	7.35
9.1	Auxiliary Energy:	1.24	1.13	1.18
10.0	Lost Control Ener:	1.43	1.08	1.26
11.0	Motor Regen Ener:	2.33	2.27	2.30
12.0	Ener Not Received:	1.36	1.35	1.35
13.0	Control Loss %:	12.62%	10.31%	11.46%
14.0	Regen Loss %:	11.99%	12.88%	12.43%
15.0	Total Loss %:	24.61%	23.19%	23.90%
16.0	Control Efficiency:	0.87	0.90	0.89
18.0	Net Ener Not Rec'd:	0.96	1.01	0.99
19.0	Ener Not Rec'd %:	47.20%	49.87%	48.53%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 30, 1984

Equipment: Westinghouse Chopper | Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND | Distance:3.4 MILES
Weight: 33,370 lbs. - AW1

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	434	436	
3.0	Number of Stops:	56	49	53
4.0	Average Accel:	1.63	1.72	1.68
5.0	Energy per Mile:	3.48	3.42	3.45
6.0	Prop Energy In:	13.82	13.51	13.66
7.0	Line Energy Regen:	1.93	1.86	1.89
8.0	Motor Energy In:	12.26	12.15	12.20
9.0	Net Motor Energy:	6.79	6.68	6.74
9.1	Auxiliary Energy:	1.58	1.34	1.46
10.0	Lost Control Ener:	1.56	1.36	1.46
11.0	Motor Regen Ener:	5.47	5.47	5.47
12.0	Ener Not Received:	3.54	3.62	3.58
13.0	Control Loss %:	11.30%	10.06%	10.68%
14.0	Regen Loss %:	25.61%	26.76%	26.18%
15.0	Total Loss %:	36.91%	36.82%	36.86%
16.0	Control Efficiency:	0.89	0.90	0.89
18.0	Net Ener Not Rec'd:	2.70	2.88	2.79
19.0	Ener Not Rec'd %:	55.71%	58.55%	57.13%
1.0	Direction:	Outbound		
2.0	Run Number:	435	437	
3.0	Number of Stops:	53	54	54
4.0	Average Accel:	1.74	1.70	1.72
5.0	Energy per Mile:	3.90	3.81	3.86
6.0	Prop Energy In:	15.97	15.19	15.58
7.0	Line Energy Regen:	2.11	1.88	2.00
8.0	Motor Energy In:	14.41	13.80	14.10
9.0	Net Motor Energy:	9.21	8.66	8.93
9.1	Auxiliary Energy:	1.41	1.23	1.32
10.0	Lost Control Ener:	1.56	1.39	1.48
11.0	Motor Regen Ener:	5.20	5.14	5.17
12.0	Ener Not Received:	3.10	3.26	3.18
13.0	Control Loss %:	9.79%	9.16%	9.47%
14.0	Regen Loss %:	19.39%	21.46%	20.42%
15.0	Total Loss %:	29.18%	30.62%	29.90%
16.0	Control Efficiency:	0.90	0.91	0.91
18.0	Net Ener Not Rec'd:	2.40	2.64	2.52
19.0	Ener Not Rec'd %:	51.15%	56.44%	53.79%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 29, 1984

Equipment: Westinghouse Chopper — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance:6.8 MILES
Weight: 36,990 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	460	462	
3.0	Number of Stops:	68	65	67
4.0	Average Accel:	1.73	1.65	1.69
5.0	Energy per Mile:	3.10	2.87	2.98
6.0	Prop Energy In:	24.35	22.67	23.51
7.0	Line Energy Regen:	2.75	2.71	2.73
8.0	Motor Energy In:	21.72	20.39	21.05
9.0	Net Motor Energy:	13.25	12.38	12.82
9.1	Auxiliary Energy:	1.91	1.62	1.77
10.0	Lost Control Ener:	2.63	2.28	2.45
11.0	Motor Regen Ener:	8.47	8.00	8.24
12.0	Ener Not Received:	5.72	5.30	5.51
13.0	Control Loss %:	10.80%	10.06%	10.43%
14.0	Regen Loss %:	23.49%	23.36%	23.43%
15.0	Total Loss %:	34.29%	33.42%	33.86%
16.0	Control Efficiency:	0.89	0.90	0.90
18.0	Net Ener Not Rec'd:	4.59	4.30	4.44
19.0	Ener Not Rec'd %:	60.75%	59.70%	60.23%

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Outbound		
2.0	Run Number:	461	no test	
3.0	Number of Stops:	70		70
4.0	Average Accel:	1.66		1.66
5.0	Energy per Mile:	3.02		3.02
6.0	Prop Energy In:	22.79		22.79
7.0	Line Energy Regen:	2.28		2.28
8.0	Motor Energy In:	20.25		20.25
9.0	Net Motor Energy:	13.07		13.07
9.1	Auxiliary Energy:	1.62		1.62
10.0	Lost Control Ener:	2.54		2.54
11.0	Motor Regen Ener:	7.18		7.18
12.0	Ener Not Received:	4.90		4.90
13.0	Control Loss %:	11.14%		0.11
14.0	Regen Loss %:	21.51%		0.22
15.0	Total Loss %:	32.65%		0.33
16.0	Control Efficiency:	0.89		0.89
18.0	Net Ener Not Rec'd:	3.94		3.94
19.0	Ener Not Rec'd %:	61.78%		0.62

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 30, 1984

Equipment: Westinghouse Chopper — Route: 41 - UNION
Change in Elevation: +41 FEET OUTBOUND — Distance:3.4 MILES
Weight: 36,990 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	470	475	
3.0	Number of Stops:	49	50	50
4.0	Average Accel:	1.68	1.75	1.72
5.0	Energy per Mile:	4.02	4.16	4.09
6.0	Prop Energy In:	15.52	16.26	15.89
7.0	Line Energy Regen:	1.84	2.03	1.94
8.0	Motor Energy In:	14.03	14.57	14.30
9.0	Net Motor Energy:	7.97	8.14	8.05
9.1	Auxiliary Energy:	0.95	1.05	1.00
10.0	Lost Control Ener:	1.50	1.69	1.59
11.0	Motor Regen Ener:	6.05	6.44	6.25
12.0	Ener Not Received:	4.21	4.41	4.31
13.0	Control Loss %:	9.64%	10.38%	10.01%
14.0	Regen Loss %:	27.13%	27.10%	27.12%
15.0	Total Loss %:	36.77%	37.48%	37.13%
16.0	Control Efficiency:	0.90	0.90	0.90
18.0	Net Ener Not Rec'd:	3.51	3.61	3.56
19.0	Ener Not Rec'd %:	64.27%	62.53%	63.40%
1.0	Direction:	Outbound		
2.0	Run Number:	469	474	
3.0	Number of Stops:	52	54	53
4.0	Average Accel:	1.65	1.63	1.64
5.0	Energy per Mile:	4.30	4.55	4.42
6.0	Prop Energy In:	17.02	18.06	17.54
7.0	Line Energy Regen:	1.88	2.05	1.96
8.0	Motor Energy In:	15.29	16.19	15.74
9.0	Net Motor Energy:	9.83	10.64	10.23
9.1	Auxiliary Energy:	1.09	1.27	1.18
10.0	Lost Control Ener:	1.73	1.87	1.80
11.0	Motor Regen Ener:	5.46	5.55	5.51
12.0	Ener Not Received:	3.58	3.50	3.54
13.0	Control Loss %:	10.17%	10.37%	10.27%
14.0	Regen Loss %:	21.05%	19.40%	20.23%
15.0	Total Loss %:	31.21%	29.77%	30.49%
16.0	Control Efficiency:	0.90	0.90	0.90
18.0	Net Ener Not Rec'd:	2.91	2.79	2.85
19.0	Ener Not Rec'd %:	59.26%	55.98%	57.62%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS
August 21, 1984

Equipment: Westinghouse Chopper — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance:3.4 MILES
Weight: 36,990 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	466	468	
3.0	Number of Stops:	48	48	48
4.0	Average Accel:	1.69	1.55	1.62
5.0	Energy per Mile:	2.41	2.18	2.30
6.0	Prop Energy In:	9.97	9.01	9.49
7.0	Line Energy Regen:	1.53	1.43	1.48
8.0	Motor Energy In:	8.94	8.06	8.50
9.0	Net Motor Energy:	4.76	4.35	4.55
9.1	Auxiliary Energy:	1.07	0.95	1.01
10.0	Lost Control Ener:	1.02	0.95	0.98
11.0	Motor Regen Ener:	4.19	3.71	3.95
12.0	Ener Not Received:	2.66	2.28	2.47
13.0	Control Loss %:	10.26%	10.49%	10.38%
14.0	Regen Loss %:	26.66%	25.36%	26.01%
15.0	Total Loss %:	36.93%	35.85%	36.39%
16.0	Control Efficiency:	0.90	0.90	0.90
18.0	Net Ener Not Rec'd:	2.06	1.74	1.90
19.0	Ener Not Rec'd %:	54.91%	52.50%	53.71%
1.0	Direction:	Outbound		
2.0	Run Number:	465	467	
3.0	Number of Stops:	45	45	45
4.0	Average Accel:	1.70	1.49	1.60
5.0	Energy per Mile:	3.39	3.15	3.27
6.0	Prop Energy In:	12.38	11.54	11.96
7.0	Line Energy Regen:	1.10	0.92	1.01
8.0	Motor Energy In:	11.08	10.47	10.77
9.0	Net Motor Energy:	8.18	8.13	8.15
9.1	Auxiliary Energy:	0.96	0.96	0.96
10.0	Lost Control Ener:	1.31	1.06	1.19
11.0	Motor Regen Ener:	2.90	2.34	2.62
12.0	Ener Not Received:	1.80	1.43	1.61
13.0	Control Loss %:	10.54%	9.23%	9.89%
14.0	Regen Loss %:	14.51%	12.38%	13.44%
15.0	Total Loss %:	25.05%	21.61%	23.33%
16.0	Control Efficiency:	0.89	0.91	0.90
18.0	Net Ener Not Rec'd:	1.41	1.14	1.27
19.0	Ener Not Rec'd %:	54.24%	53.36%	53.80%

Alsthom Atlantic Inc.

CHOPPER PROPULSION SYSTEM

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom-Atlantic Chopper
Change in Elevation: +14 FEET OUTBOUND
Weight: 25,908 lbs. - AWO

Route: 5 - FULTON
Distance:6.8 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	509	511	
3.0	Number of Stops:	63	68	66
4.0	Average Accel·	1.67	1.45	1.56
5.0	Energy per Mile:	2.09	2.12	2.10
6.0	Prop Energy In:	19.16	18.46	18.81
7.0	Line Energy Regen:	5.06	4.10	4.58
8.0	Motor Energy In:	16.34	14.98	15.66
9.0	Net Motor Energy:	7.98	8.11	8.04
9.1	Auxiliary Energy:	1.63	1.83	1.73
10.0	Lost Control Ener:	2.82	3.49	3.16
11.0	Motor Regen Ener:	8.36	6.87	7.62
12.0	Ener Not Received:	3.30	2.77	3.04
13.0	Control Loss %:	14.74%	18.89%	16.81%
14.0	Regen Loss %:	17.24%	14.99%	16.12%
15.0	Total Loss %:	31.98%	33.88%	32.93%
16.0	Control Efficiency:	0.85	0.81	0.83
18.0	Net Ener Not Rec'd:	1.64	1.06	1.35
19.0	Ener Not Rec'd %:	23.02%	19.09%	21.05%

1.0	Direction:	Outbound		
2.0	Run Number:	508	510	Average
3.0	Number of Stops:	67	64	66
4.0	Average Accel:	1.60	1.60	1.60
5.0	Energy per Mile:	2.14	2.22	2.18
6.0	Prop Energy In:	18.41	19.24	18.82
7.0	Line Energy Regen:	4.14	4.25	4.19
8.0	Motor Energy In:	15.24	15.73	15.48
9.0	Net Motor Energy:	8.40	8.57	8.48
9.1	Auxiliary Energy:	1.58	1.65	1.62
10.0	Lost Control Ener:	3.17	3.51	3.34
11.0	Motor Regen Ener:	6.84	7.16	7.00
12.0	Ener Not Received:	2.70	2.91	2.81
13.0	Control Loss %:	17.22%	18.24%	17.73%
14.0	Regen Loss %:	14.69%	15.12%	14.91%
15.0	Total Loss %:	31.91%	33.36%	32.64%
16.0	Control Efficiency	0.83	0.82	0.82
18.0	Net Ener Not Rec'd	1.17	1.24	1.20
19.0	Ener Not Rec'd %:	20.68%	21.14%	20.91%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper — Route: 8 - MARKET
Change in Elevation: +122 FEET OUTBOUND — Distance: 3.4 MILES
Weight: 25.908 lbs. - AWO

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	505	507	
3.0	Number of Stops:	42	55	49
4.0	Average Accel:	1.47	1.48	1.48
5.0	Energy per Mile:	1.96	1.94	1.95
6.0	Prop Energy In:	8.56	8.63	8.60
7.0	Line Energy Regen:	1.90	2.05	1.97
8.0	Motor Energy In:	6.42	6.58	6.50
9.0	Net Motor Energy:	2.87	2.95	2.91
9.1	Auxiliary Energy:	1.09	1.32	1.21
10.0	Lost Control Ener:	2.13	2.06	2.10
11.0	Motor Regen Ener:	3.55	3.63	3.59
12.0	Ener Not Received:	1.66	1.58	1.62
13.0	Control Loss %:	24.94%	23.81%	24.38%
14.0	Regen Loss %:	19.36%	18.33%	18.85%
15.0	Total Loss %:	44.30%	42.15%	43.23%
16.0	Control Efficiency:	0.75	0.76	0.76
18.0	Net Ener Not Rec'd:	0.53	0.40	0.47
19.0	Ener Not Rec'd %:	19.86%	14.60%	17.23%
1.0	Direction:	Outbound		
2.0	Run Number:	504	506	
3.0	Number of Stops:	44	48	46
4.0	Average Accel:	1.51	1.60	1.56
5.0	Energy per Mile:	2.77	2.73	2.75
6.0	Prop Energy In:	10.22	10.69	10.45
7.0	Line Energy Regen:	1.08	1.41	1.25
8.0	Motor Energy In:	7.83	8.49	8.16
9.0	Net Motor Energy:	5.39	5.57	5.48
9.1	Auxiliary Energy:	1.11	1.15	1.13
10.0	Lost Control Ener:	2.39	2.20	2.29
11.0	Motor Regen Ener:	2.44	2.91	2.68
12.0	Ener Not Received:	1.35	1.50	1.43
13.0	Control Loss %:	23.37%	20.60%	21.98%
14.0	Regen Loss %:	13.23%	14.05%	13.64%
15.0	Total Loss %:	36.61%	34.64%	35.62%
16.0	Control Efficiency:	0.77	0.79	0.78
18.0	Net Ener Not Rec'd:	0.67	0.75	0.71
19.0	Ener Not Rec'd %:	35.64%	32.37%	34.00%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper
Change in Elevation: +41 Feet Outbound
Weight: 25,908 lbs. - AW0

Route: 41 - Union
Distance:3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	500	502	
3.0	Number of Stops:	44	50	47
4.0	Average Accel:	1.66	1.67	1.67
5.0	Energy per Mile:	2.71	2.52	2.61
6.0	Prop Energy In:	12.27	12.02	12.14
7.0	Line Energy Regen:	3.06	3.44	3.25
8.0	Motor Energy In:	10.25	10.06	10.16
9.0	Net Motor Energy:	4.88	4.86	4.87
9.1	Auxiliary Energy:	1.11	1.13	1.12
10.0	Lost Control Ener:	2.02	1.96	1.99
11.0	Motor Regen Ener:	5.37	5.20	5.29
12.0	Ener Not Received:	2.31	1.76	2.03
13.0	Control Loss %:	16.43%	16.28%	16.36%
14.0	Regen Loss %:	18.85%	14.61%	16.73%
15.0	Total Loss %:	35.28%	30.89%	33.09%
16.0	Control Efficiency:	0.84	0.84	0.84
18.0	Net Ener Not Rec'd:	1.15	0.58	0.87
19.0	Ener Not Rec'd %:	25.66%	13.42%	19.54%
1.0	Direction:	Outbound		
2.0	Run Number:	501	503	
3.0	Number of Stops:	53	58	56
4.0	Average Accel:	1.52	1.55	1.54
5.0	Energy per Mile:	3.00	2.96	2.98
6.0	Prop Energy In:	13.38	13.69	13.54
7.0	Line Energy Regen:	2.87	3.20	3.04
8.0	Motor Energy In:	11.12	11.40	11.26
9.0	Net Motor Energy:	6.41	6.38	6.39
9.1	Auxiliary Energy:	1.23	1.30	1.27
10.0	Lost Control Ener:	2.27	2.29	2.28
11.0	Motor Regen Ener:	4.71	5.02	4.86
12.0	Ener Not Received:	1.83	1.83	1.83
13.0	Control Loss %:	16.93%	16.75%	16.84%
14.0	Regen Loss %:	13.68%	13.34%	13.51%
15.0	Total Loss %:	30.61%	30.09%	30.35%
16.0	Control Efficiency:	0.83	0.83	0.83
18.0	Net Ener Not Rec'd:	0.77	0.68	0.73
19.0	Ener Not Rec'd %:	19.72%	16.29%	18.00%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom-Atlantic Chopper
Change in Elevation: +14 FEET OUTBOUND
Weight: 32,410 lbs. - AW1

Route: 5 - FULTON
Distance: 6.8 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	530	532	
3.0	Number of Stops:	67	65	66
4.0	Average Accel:	1.59	1.58	1.59
5.0	Energy per Mile:	2.40	2.45	2.42
6.0	Prop Energy In:	22.78	22.80	22.79
7.0	Line Energy Regen:	6.53	6.50	6.51
8.0	Motor Energy In:	20.41	20.76	20.59
9.0	Net Motor Energy:	10.98	11.05	11.02
9.1	Auxiliary Energy:	1.94	1.74	1.84
10.0	Lost Control Ener:	2.36	2.04	2.20
11.0	Motor Regen Ener:	9.43	9.71	9.57
12.0	Ener Not Received:	2.91	3.21	3.06
13.0	Control Loss %:	10.37%	8.94%	9.66%
14.0	Regen Loss %:	12.76%	14.07%	13.42%
15.0	Total Loss %:	23.13%	23.01%	23.07%
16.0	Control Efficiency:	0.90	0.91	0.90
18.0	Net Ener Not Rec'd:	1.37	1.84	1.61
19.0	Ener Not Rec'd %:	16.22%	20.85%	18.54%

1.0	Direction:	Outbound		
2.0	Run Number:	531	533	Average
3.0	Number of Stops:	61	76	69
4.0	Average Accel:	1.67	1.57	1.62
5.0	Energy per Mile:	2.63	2.57	2.60
6.0	Prop Energy In:	23.92	22.47	23.20
7.0	Line Energy Regen:	6.31	5.92	6.11
8.0	Motor Energy In:	21.63	20.11	20.87
9.0	Net Motor Energy:	11.14	10.86	11.00
9.1	Auxiliary Energy:	1.68	1.86	1.77
10.0	Lost Control Ener:	2.29	2.37	2.33
11.0	Motor Regen Ener:	10.50	9.25	9.87
12.0	Ener Not Received:	4.19	3.32	3.76
13.0	Control Loss %:	9.56%	10.52%	10.04%
14.0	Regen Loss %:	17.53%	14.79%	16.16%
15.0	Total Loss %:	27.09%	25.32%	26.20%
16.0	Control Efficiency	0.90	0.89	0.90
18.0	Net Ener Not Rec'd	2.75	1.86	2.30
19.0	Ener Not Rec'd %:	28.94%	22.48%	25.71%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper
Change in Elevation: +122 FEET OUTBOUND
Weight: 32,410 lbs. - AW1

Route: 8 - MARKET
Distance: 3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	540	542	
3.0	Number of Stops:	43	55	49
4.0	Average Accel:	1.47	1.48	1.48
5.0	Energy per Mile:	2.03	1.94	1.99
6.0	Prop Energy In:	9.80	8.63	9.22
7.0	Line Energy Regen:	2.96	2.05	2.50
8.0	Motor Energy In:	8.31	6.58	7.45
9.0	Net Motor Energy:	3.59	2.95	3.27
9.1	Auxiliary Energy:	1.29	1.32	1.31
10.0	Lost Control Ener:	1.49	2.06	1.77
11.0	Motor Regen Ener:	4.73	3.63	4.18
12.0	Ener Not Received:	1.77	1.58	1.68
13.0	Control Loss %:	15.21%	23.81%	19.51%
14.0	Regen Loss %:	18.05%	18.33%	18.19%
15.0	Total Loss %:	33.26%	42.15%	37.70%
16.0	Control Efficiency:	0.85	0.76	0.80
18.0	Net Ener Not Rec'd:	0.66	0.40	0.53
19.0	Ener Not Rec'd %:	16.50%	14.60%	15.55%
1.0	Direction:	Outbound		
2.0	Run Number:	539	541	
3.0	Number of Stops:	43	43	43
4.0	Average Accel:	1.62	1.52	1.57
5.0	Energy per Mile:	3.26	2.99	3.13
6.0	Prop Energy In:	12.93	12.40	12.67
7.0	Line Energy Regen:	1.95	2.29	2.12
8.0	Motor Energy In:	11.13	10.77	10.95
9.0	Net Motor Energy:	7.32	6.94	7.13
9.1	Auxiliary Energy:	1.42	1.14	1.28
10.0	Lost Control Ener:	1.80	1.63	1.72
11.0	Motor Regen Ener:	3.81	3.83	3.82
12.0	Ener Not Received:	1.86	1.54	1.70
13.0	Control Loss %:	13.93%	13.16%	13.55%
14.0	Regen Loss %:	14.37%	12.45%	13.41%
15.0	Total Loss %:	28.31%	25.61%	26.96%
16.0	Control Efficiency:	0.86	0.87	0.86
18.0	Net Ener Not Rec'd:	1.11	0.83	0.97
19.0	Ener Not Rec'd %:	34.02%	24.90%	29.46%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper
Change in Elevation: +41 Feet Outbound
Weight: 32,410 lbs. - AW1

Route: 41 - Union
Distance: 3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	535	537	
3.0	Number of Stops:	41	38	40
4.0	Average Accel:	1.80	1.66	1.73
5.0	Energy per Mile:	2.49	2.85	2.67
6.0	Prop Energy In:	13.48	14.19	13.84
7.0	Line Energy Regen:	5.04	4.54	4.79
8.0	Motor Energy In:	13.34	12.74	13.04
9.0	Net Motor Energy:	6.24	5.98	6.11
9.1	Auxiliary Energy:	1.08	1.03	1.06
10.0	Lost Control Ener:	0.13	1.45	0.79
11.0	Motor Regen Ener:	7.11	6.76	6.93
12.0	Ener Not Received:	2.07	2.22	2.14
13.0	Control Loss %:	1.00%	10.24%	5.62%
14.0	Regen Loss %:	15.35%	15.64%	15.50%
15.0	Total Loss %:	16.35%	25.88%	21.12%
16.0	Control Efficiency:	0.99	0.90	0.94
18.0	Net Ener Not Rec'd:	1.59	1.20	1.40
19.0	Ener Not Rec'd %:	22.65%	19.73%	21.19%
1.0	Direction:	Outbound		
2.0	Run Number:	534	538	
3.0	Number of Stops:	44	45	45
4.0	Average Accel:	1.72	1.51	1.62
5.0	Energy per Mile:	3.27	3.36	3.31
6.0	Prop Energy In:	15.78	15.39	15.58
7.0	Line Energy Regen:	4.33	3.65	3.99
8.0	Motor Energy In:	14.46	13.86	14.16
9.0	Net Motor Energy:	8.17	7.72	7.94
9.1	Auxiliary Energy:	1.17	1.36	1.27
10.0	Lost Control Ener:	1.32	1.53	1.42
11.0	Motor Regen Ener:	6.29	6.14	6.22
12.0	Ener Not Received:	1.96	2.49	2.23
13.0	Control Loss %:	8.34%	9.94%	9.14%
14.0	Regen Loss %:	12.44%	16.19%	14.32%
15.0	Total Loss %:	20.78%	26.14%	23.46%
16.0	Control Efficiency:	0.92	0.90	0.91
18.0	Net Ener Not Rec'd:	1.12	1.56	1.34
19.0	Ener Not Rec'd %:	19.38%	28.17%	23.77%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom-Atlantic Chopper — Route: 5 - FULTON
Change in Elevation: +14 FEET OUTBOUND — Distance: 6.8 MILES
Weight: 36,160 lbs. - AW2

	ITEM	RUN DATA		AVERAGE
1.0	Direction:		Inbound	
2.0	Run Number:	564	566	
3.0	Number of Stops:	bad data	70	70
4.0	Average Accel:		1.53	1.53
5.0	Energy per Mile:		2.56	2.56
6.0	Prop Energy In:		23.50	23.50
7.0	Line Energy Regen:		6.16	6.16
8.0	Motor Energy In:		20.73	20.73
9.0	Net Motor Energy:		11.41	11.41
9.1	Auxiliary Energy:		1.99	1.99
10.0	Lost Control Ener:		2.77	2.77
11.0	Motor Regen Ener:		9.32	9.32
12.0	Ener Not Received:		3.16	3.16
13.0	Control Loss %:		11.79%	0.12
14.0	Regen Loss %:		13.43%	0.13
15.0	Total Loss %:		25.22%	0.25
16.0	Control Efficiency:		0.88	0.88
18.0	Net Ener Not Rec'd:		1.54	1.54
19.0	Ener Not Rec'd %:		18.70%	0.19

1.0	Direction:		Outbound	
2.0	Run Number:	565	567	Average
3.0	Number of Stops:	68	64	66
4.0	Average Accel:	1.64	1.66	1.65
5.0	Energy per Mile:	2.84	2.99	2.91
6.0	Prop Energy In:	25.08	25.68	25.38
7.0	Line Energy Regen:	5.52	5.63	5.57
8.0	Motor Energy In:	22.42	23.27	22.84
9.0	Net Motor Energy:	12.59	13.02	12.81
9.1	Auxiliary Energy:	1.76	1.61	1.69
10.0	Lost Control Ener:	2.65	2.42	2.54
11.0	Motor Regen Ener:	9.83	10.24	10.04
12.0	Ener Not Received	4.31	4.62	4.46
13.0	Control Loss %:	10.58%	9.42%	10.00%
14.0	Regen Loss %:	17.19%	17.97%	17.58%
15.0	Total Loss %:	27.77%	27.39%	27.58%
16.0	Control Efficiency	0.89	0.91	0.90
18.0	Net Ener Not Rec'd	2.88	3.30	3.09
19.0	Ener Not Rec'd %:	32.80%	35.55%	34.18%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper
Change in Elevation: +122 FEET OUTBOUND
Weight: 36,160 lbs. - AW2

Route: 8 - MARKET
Distance: 3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:	Inbound		
2.0	Run Number:	569	571	
3.0	Number of Stops:	49	49	49
4.0	Average Accel	1.49	1.48	1.49
5.0	Energy per Mile:	2.33	2.23	2.28
6.0	Prop Energy In:	10.69	10.20	10.44
7.0	Line Energy Regen:	2.78	2.65	2.72
8.0	Motor Energy In:	9.13	8.50	8.81
9.0	Net Motor Energy:	4.26	3.93	4.10
9.1	Auxiliary Energy:	1.24	1.29	1.26
10.0	Lost Control Ener:	1.56	1.70	1.63
11.0	Motor Regen Ener:	4.87	4.57	4.72
12.0	Ener Not Received:	2.08	1.92	2.00
13.0	Control Loss %:	14.61%	16.68%	15.64%
14.0	Regen Loss %:	19.50%	18.81%	19.16%
15.0	Total Loss %:	34.11%	35.49%	34.80%
16.0	Control Efficiency:	0.85	0.83	0.84
18.0	Net Ener Not Rec'd:	1.05	0.82	0.94
19.0	Ener Not Rec'd %:	25.28%	21.63%	23.45%
1.0	Direction:	Outbound		
2.0	Run Number:	568	570	
3.0	Number of Stops:	39	47	43
4.0	Average Accel:	1.59	1.62	1.61
5.0	Energy per Mile:	3.44	3.32	3.38
6.0	Prop Energy In:	13.44	13.98	13.71
7.0	Line Energy Regen:	2.04	2.58	2.31
8.0	Motor Energy In:	11.51	12.22	11.87
9.0	Net Motor Energy:	7.65	8.08	7.86
9.1	Auxiliary Energy:	1.18	1.29	1.23
10.0	Lost Control Ener:	1.93	1.75	1.84
11.0	Motor Regen Ener:	3.87	4.14	4.01
12.0	Ener Not Received:	1.83	1.57	1.70
13.0	Control Loss %:	14.33%	12.54%	13.43%
14.0	Regen Loss %:	13.62%	11.20%	12.41%
15.0	Total Loss %:	27.95%	23.74%	25.85%
16.0	Control Efficiency:	0.86	0.87	0.87
18.0	Net Ener Not Rec'd:	1.10	0.81	0.95
19.0	Ener Not Rec'd %:	33.12%	22.36%	27.74%

Booz, Allen & Hamilton, Inc. / American Computer Exchange
PLOTPAC RESULTS ANALYSIS

Equipment: Alsthom Atlantic Chopper
Change in Elevation: +41 Feet Outbound
Weight: 36,160 lbs. - AW2

Route: 41 - Union
Distance:3.4 MILES

	ITEM	RUN DATA		AVERAGE
1.0	Direction:		Inbound	
2.0	Run Number:	560	562	
3.0	Number of Stops:	bad data	46	46
4.0	Average Accel:		1.47	1.47
5.0	Energy per Mile:		2.88	2.88
6.0	Prop Energy In:		14.05	14.05
7.0	Line Energy Regen:		4.26	4.26
8.0	Motor Energy In:		12.63	12.63
9.0	Net Motor Energy:		6.28	6.28
9.1	Auxiliary Energy:		1.26	1.26
10.0	Lost Control Ener:		1.42	1.42
11.0	Motor Regen Ener:		6.35	6.35
12.0	Ener Not Received:		2.09	2.09
13.0	Control Loss %:		10.13%	0.10
14.0	Regen Loss %:		14.88%	0.15
15.0	Total Loss %:		25.02%	0.25
16.0	Control Efficiency:		0.90	0.90
18.0	Net Ener Not Rec'd:		1.07	1.07
19.0	Ener Not Rec'd %:		18.69%	0.19

1.0	Direction:		Outbound	
2.0	Run Number:	561	563	
3.0	Number of Stops:	54	58	56
4.0	Average Accel:	1.52	1.57	1.55
5.0	Energy per Mile:	3.72	3.71	3.72
6.0	Prop Energy In:	16.53	16.49	16.51
7.0	Line Energy Regen:	3.74	3.63	3.68
8.0	Motor Energy In:	14.90	15.02	14.96
9.0	Net Motor Energy:	8.88	9.02	8.95
9.1	Auxiliary Energy:	1.40	1.53	1.47
10.0	Lost Control Ener:	1.63	1.46	1.55
11.0	Motor Regen Ener:	6.03	6.00	6.01
12.0	Ener Not Received:	2.29	2.37	2.33
13.0	Control Loss %:	9.87%	8.88%	9.38%
14.0	Regen Loss %:	13.84%	14.39%	14.11%
15.0	Total Loss %:	23.71%	23.27%	23.49%
16.0	Control Efficiency:	0.90	0.91	0.91
18.0	Net Ener Not Rec'd:	1.38	1.50	1.44
19.0	Ener Not Rec'd %:	25.35%	27.47%	26.41%

APPENDIX C

EXAMPLE PLOTPAC RESULTS FORMS

General Electric Company

MRC SWITCHED RESISTANCE CONTROLLER

RUN SUMMARY STATISTICS AND RUN LOG REPORT
RUN NUMBER 235

DATE: 09-JAN-84
TIME: 02:30:04
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: GE RESISTIVE CONTROLLER - AW1
COMMENT:GE / AW1 / 8-MARKET-INBOUND / COLD WEATHER
BUS WEIGHT: 30748.0 LBS
CALIBRATION DATA: TACHOMETER= 12.9 PULSES PER FOOT
DRAG= 464.0 POUNDS FORCE

NUMBER OF SEGMENTS	=	47	
TOTAL TIME TRAVELING	=	1213.6	SEC
TOTAL TIME STOPPED	=	655.4	SEC
TOTAL TIME	=	1869.0	SEC
TOTAL DISTANCE TRAVELLED	=	17754.2	FT
AVERAGE DISTANCE TRAVELLED	=	377.7	FT
PEAK VELOCITY IN RUN	=	27.7	MPH
AVERAGE VELOCITY	=	10.0	MPH
COMMERCIAL VELOCITY	=	6.5	MPH
TOTAL CHANGE IN ELEVATION	=	-96.1	FT
AVERAGE ASCENDING GRADE	=	2.6	%
FRACTION OF RUN ON ASCENDING GRADE	=	0.20	
AVERAGE DESCENDING GRADE	=	-2.8	%
FRACTION OF RUN ON DESCENDING GRADE	=	0.37	
PEAK POWER USED	=	209.7	KW
PEAK POWER REGENERATED	=	-4.1	KW
PEAK MOTOR POWER	=	197.8	KW
PEAK MOTOR POWER REGENERATED	=	-122.2	KW
TOTAL POSITIVE LINE ENERGY	=	17.637	KWH
TOTAL POSITIVE PROPULSION ENERGY	=	15.175	KWH
TOTAL ENERGY REGENERATED TO LINE	=	-0.002	KWH
NET LINE ENERGY IN RUN	=	17.636	KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	8.319	KWH
NET MOTOR ENERGY IN RUN	=	5.710	KWH
TOTAL AUXILIARY ENERGY	=	1.922	KWH
ENERGY USED AT WHEELS IN PROPULSION	=	5.396	KWH
NET PROPULSION ENERGY PER MILE	=	4.513	KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	45.011	KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.36	
CONTROLS EFFICIENCY IN PROPULSION	=	0.55	
MOTOR EFFICIENCY IN PROPULSION	=	0.65	
PEAK ACCELERATION IN PROPULSION	=	6.10	MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.80	MPH/SEC
PEAK JERK IN PROPULSION	=	6.10	MPH/SEC2

02:30:04 RUN STARTS

Total Distance Histogram for Run 235

(Feet)	Segment
0 -< 100	3, 4, 7, 9, 10, 21, 28, 36
100 -< 200	6, 8, 18, 26, 34, 43, 44, 45
200 -< 300	5, 23, 25, 30, 39, 46
300 -< 400	2, 14, 17, 19, 22, 27, 29, 40
400 -< 500	16, 20, 24, 35
500 -< 600	1, 15, 33, 37, 41, 42
600 -< 700	11, 31
700 -< 800	38
800 -< 900	12
900 -	13, 32, 47

Average = 377.7 Feet
Std Dev = 320.3 Feet

Average Velocity Histogram for Run 235

(Mph)	Segment
0.0 -< 2.5	3, 7, 9, 21
2.5 -< 5.0	4, 6, 8, 10, 28, 36
5.0 -< 7.5	1, 5, 25, 26, 30, 44
7.5 -<10.0	2, 14, 18, 22, 23, 27, 34, 35, 37, 39, 43, 45, 46
10.0 -<12.5	24, 33, 38, 40, 42, 47
12.5 -<15.0	11, 13, 16, 17, 19, 20, 29, 32
15.0 -<17.5	12, 15, 31, 41
17.5 -<20.0	
20.0 -<22.5	
22.5-	

Average = 9.0 Mph
Std Dev = 4.1 Mph

Change in Elevation Histogram for Run 235

(Feet)	Segment
-< -80	
-80 -< -60	
-60 -< -40	
-40 -< -20	16, 17
-20 -< 0	1, 2, 3, 4, 11, 12, 13, 15, 18, 19, 20, 28, 29, 30, 31, 33, 34, 39, 40, 41, 42, 43, 44, 45, 46
0 -< 20	5, 6, 7, 8, 9, 10, 14, 21, 22, 23, 24, 25, 26, 27, 32, 35, 36, 37, 38, 47
20 -< 40	
40 -< 60	
60 -< 80	
80 -	

Average = -2.0 Feet
Std Dev = 6.8 Feet

Average Positive Acceleration Histogram for Run 235

(Mph/sec)	Segment
0.0 -< 0.3	3
0.3 -< 0.6	
0.6 -< 0.9	
0.9 -< 1.2	1, 4, 5, 7, 9, 21
1.2 -< 1.5	6, 25, 30, 36, 42, 44
1.5 -< 1.8	2, 8, 10, 11, 14, 24, 27, 32, 37, 38, 46, 47
1.8 -< 2.1	12, 13, 15, 17, 22, 28, 29, 35, 43
2.1 -< 2.4	16, 23, 26, 33, 34, 39, 41
2.4 -< 2.7	18, 19, 20, 31, 40
2.7-	45

Average = 1.8 Mph/sec
Std Dev = 0.5 Mph/sec

Energy per Mile Histogram for Run 235

(Watt-Hrs/mile)	Segment
0 -< 1600	3
1600 -< 3200	2, 11, 12, 16, 17, 20, 32, 33, 41, 42
3200 -< 4800	13, 15, 23, 27, 30, 31, 35, 37, 38, 39, 40, 43, 46, 47
4800 -< 6400	1, 14, 19, 22, 24, 25, 29, 44
6400 -< 8000	4, 5, 18, 34
8000 -< 9600	26
9600 -<11200	21, 36, 45
11200 -<12800	
12800 -<14400	
14400 -	6, 7, 8, 9, 10, 28

Average = 13469.7 Watt-Hours/mile
Std Dev = 45736.5 Watt-Hours/mile

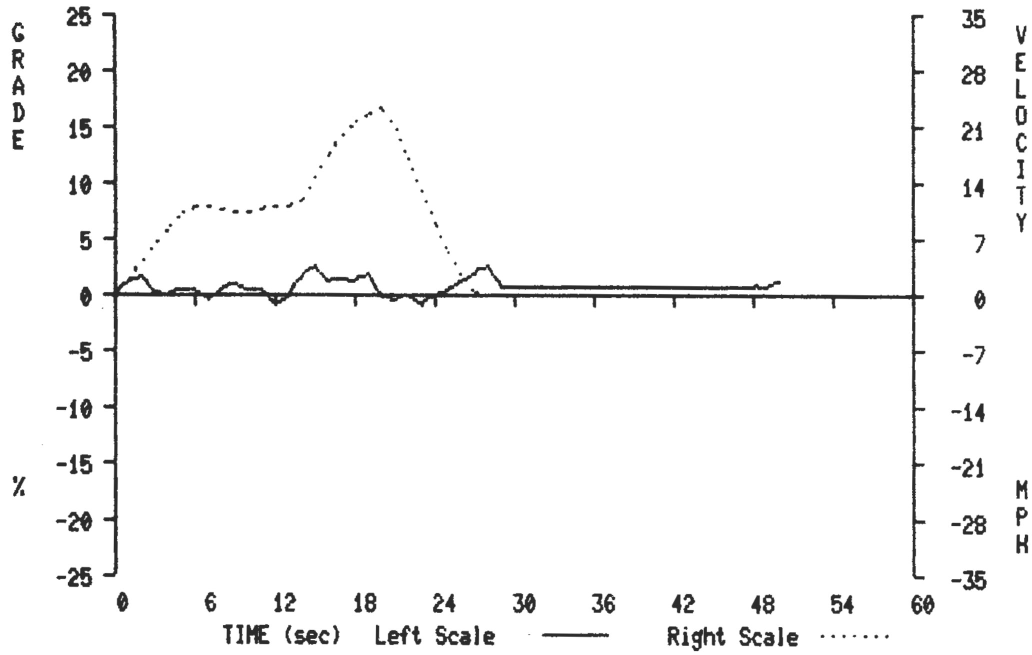
SEGMENT CALCULATIONS REPORT
RUN 235 SEGMENT 24

DATE: 09-JAN-84
TIME: 02:30:04
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
  TYPE: GE RESISTIVE CONTROLLER - AW1
COMMENT:GE / AW1 / 8-MARKET-INBOUND / COLD WEATHER
BUS WEIGHT: 30748.0 LBS
CALIBRATION DATA: TACHOMETER= 12.9 PULSES PER FOOT
DRAG= 464.0 POUNDS FORCE

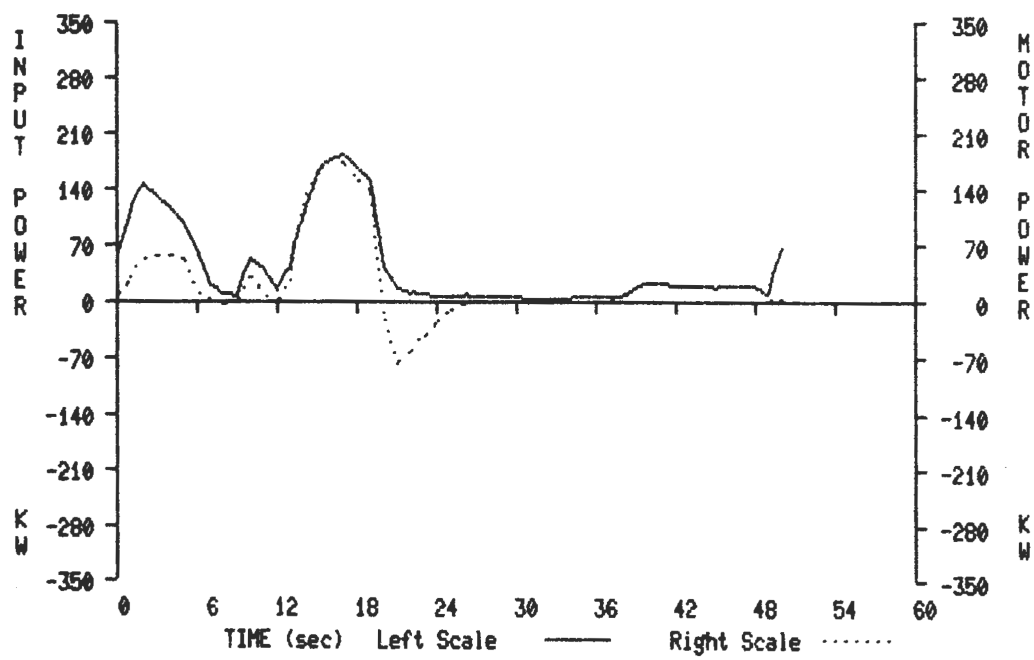
TIME TRAVELING	=	26.8 SEC
TIME STOPPED	=	24.2 SEC
DISTANCE TRAVELLED	=	465.7 FT
MAXIMUM VELOCITY	=	23.4 MPH
AVERAGE VELOCITY	=	11.8 MPH
COMMERCIAL VELOCITY	=	6.2 MPH
CHANGE IN ELEVATION	=	2.6 FT
AVERAGE ASCENDING GRADE	=	1.7 %
FRACTION OF SEGMENT ON ASCENDING GRADE	=	0.36
AVERAGE DESCENDING GRADE	=	-1.2 %
FRACTION OF SEGMENT ON DESCENDING GRADE	=	0.07
PEAK POWER USED	=	184.6 KW
PEAK POWER REGENERATED	=	0.0 KW
PEAK MOTOR POWER	=	176.3 KW
PEAK MOTOR POWER REGENERATED	=	-76.1 KW
TOTAL POSITIVE LINE ENERGY	=	0.637 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	0.492 KWH
TOTAL ENERGY REGENERATED TO LINE	=	0.000 KWH
NET LINE ENERGY IN SEGMENT	=	0.637 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	0.347 KWH
NET MOTOR ENERGY IN SEGMENT	=	0.280 KWH
TOTAL AUXILIARY ENERGY	=	0.096 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	0.231 KWH
NET PROPULSION ENERGY PER MILE	=	5.581 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	34.749 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.47
CONTROLS EFFICIENCY IN PROPULSION	=	0.71
MOTOR EFFICIENCY IN PROPULSION	=	0.66
PEAK ACCELERATION IN PROPULSION	=	2.87 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.68 MPH/SEC
PEAK JERK IN PROPULSION	=	1.98 MPH/SEC2

02:49:39 * SEGMENT 24
02:50:28 !STATUS BITS ENABLED: 1
02:49:45 !STATUS BITS DISABLED: 1

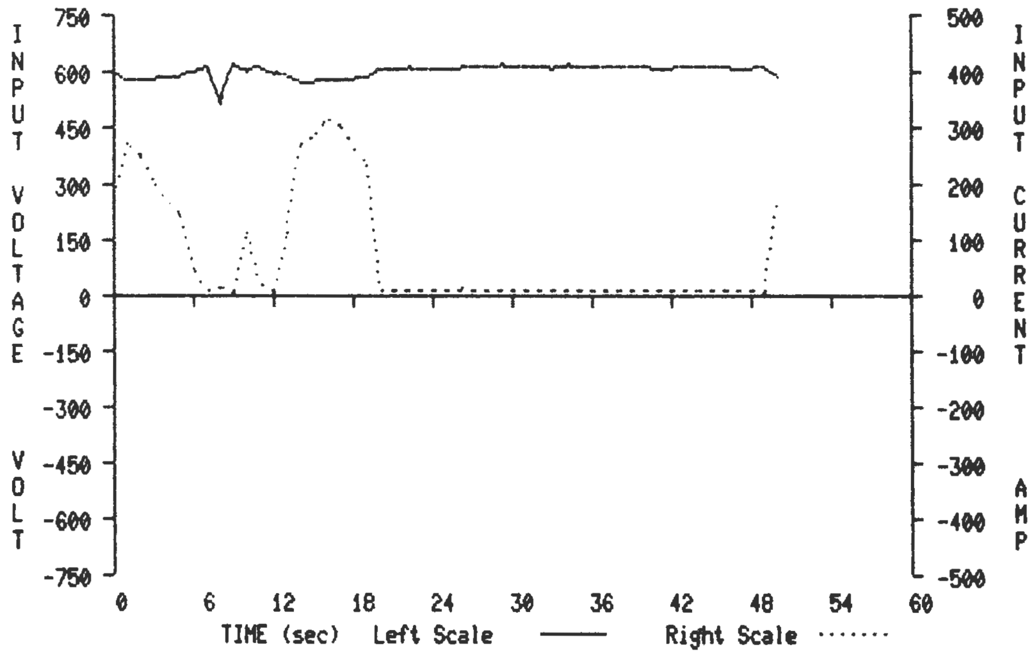
RUN NUMBER: 235 SEGMENT NUMBER: 24



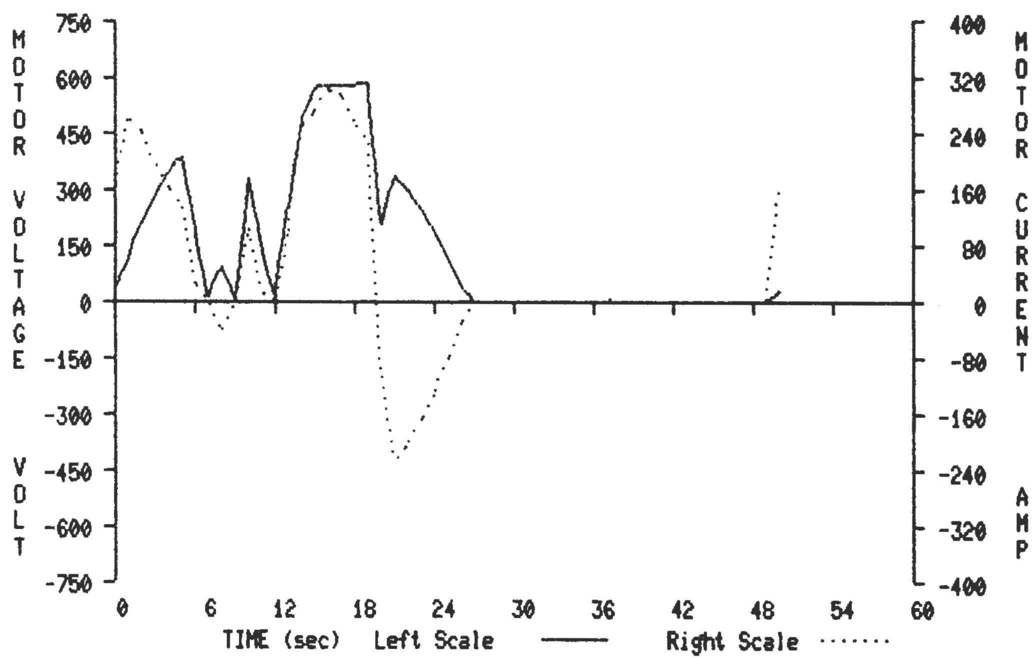
RUN NUMBER: 235 SEGMENT NUMBER: 24



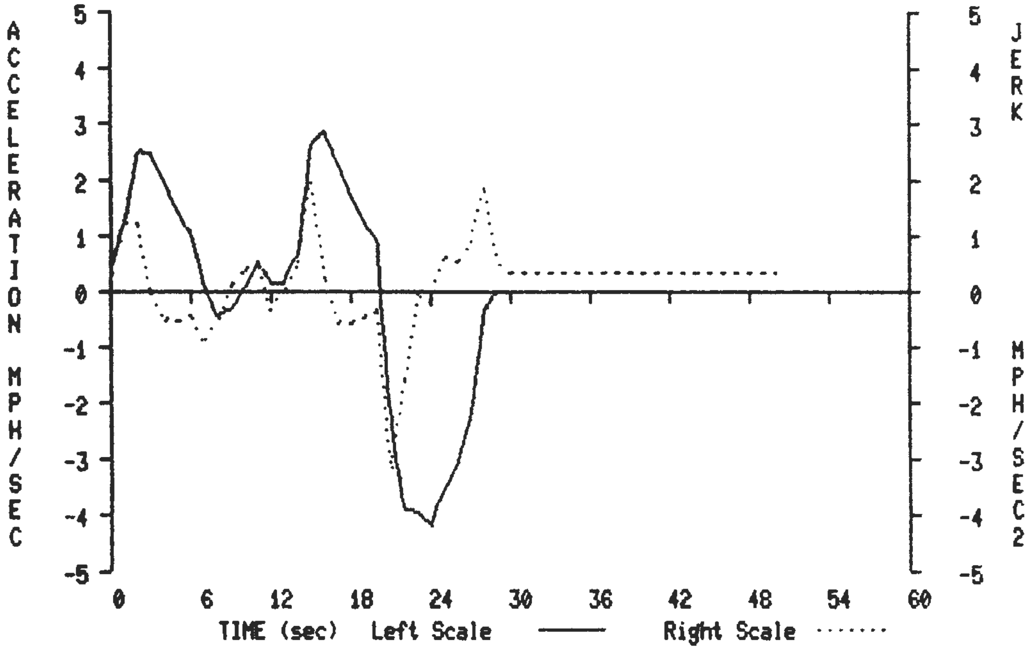
RUN NUMBER: 235 SEGMENT NUMBER: 24



RUN NUMBER: 235 SEGMENT NUMBER: 24



RUN NUMBER: 235 SEGMENT NUMBER: 24



Garrett-Stromberg

AC PROPULSION SYSTEM

RUN SUMMARY STATISTICS AND RUN LOG REPORT
RUN NUMBER 335

DATE: 19-APR-84
TIME: 10:21:53
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN / JIM SIMPSON OF GARRETT ON BOARD
EQUIPMENT
TYPE: GARRETT - STROMBERG AC PROPULSION / AW1
COMMENT:T = 72 F / H = 52 % / SUNNY BUT OVERCAST / COOL
BUS WEIGHT: 32340.0 LBS
CALIBRATION DATA: TACHOMETER= 13.1 PULSES PER FOOT
DRAG= 272.0 POUNDS FORCE

NUMBER OF SEGMENTS	=	46
TOTAL TIME TRAVELING	=	1180.2 SEC
TOTAL TIME STOPPED	=	659.8 SEC
TOTAL TIME	=	1840.0 SEC
TOTAL DISTANCE TRAVELLED	=	17820.9 FT
AVERAGE DISTANCE TRAVELLED	=	387.4 FT
PEAK VELOCITY IN RUN	=	29.6 MPH
AVERAGE VELOCITY	=	10.3 MPH
COMMERCIAL VELOCITY	=	6.6 MPH
TOTAL CHANGE IN ELEVATION	=	-31.6 FT
AVERAGE ASCENDING GRADE	=	2.5 %
FRACTION OF RUN ON ASCENDING GRADE	=	0.25
AVERAGE DESCENDING GRADE	=	-2.8 %
FRACTION OF RUN ON DESCENDING GRADE	=	0.29
PEAK POWER USED	=	209.2 KW
PEAK POWER REGENERATED	=	-150.7 KW
PEAK MOTOR POWER	=	202.7 KW
PEAK MOTOR POWER REGENERATED	=	-164.7 KW
TOTAL POSITIVE LINE ENERGY	=	12.067 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	11.166 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-2.674 KWH
NET LINE ENERGY IN RUN	=	9.393 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	10.006 KWH
NET MOTOR ENERGY IN RUN	=	6.580 KWH
TOTAL AUXILIARY ENERGY	=	1.002 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	5.953 KWH
NET PROPULSION ENERGY PER MILE	=	2.516 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	25.902 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.53
CONTROLS EFFICIENCY IN PROPULSION	=	0.90
MOTOR EFFICIENCY IN PROPULSION	=	0.59
PEAK ACCELERATION IN PROPULSION	=	4.39 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.75 MPH/SEC
PEAK JERK IN PROPULSION	=	4.65 MPH/SEC2

10:21:53 RUN STARTS

Total Distance Histogram for Run 335

(Feet)	Segment
0 -< 100	5, 9, 15, 17, 19, 38, 39, 43
100 -< 200	14, 31, 34, 45
200 -< 300	1, 18, 23, 26, 28, 36, 42
300 -< 400	7, 13, 20, 21, 22, 24, 25, 37
400 -< 500	33
500 -< 600	2, 3, 16, 30, 32, 40, 41
600 -< 700	8, 10, 27, 44
700 -< 800	4, 35, 46
800 -< 900	6, 11, 12, 29
900 -	

Average = 387.4 Feet
Std Dev = 262.5 Feet

Average Velocity Histogram for Run 335

(Mph)	Segment
0.0 -< 2.5	5, 9, 15, 17, 38, 39
2.5 -< 5.0	19, 34, 43
5.0 -< 7.5	1, 7, 26, 37, 44
7.5 -<10.0	2, 3, 8, 18, 20, 24, 31, 36, 42, 45
10.0 -<12.5	13, 14, 16, 21, 22, 23, 27, 28, 33, 35, 40, 41, 46
12.5 -<15.0	4, 6, 25, 29, 30, 32
15.0 -<17.5	10, 11, 12
17.5 -<20.0	
20.0 -<22.5	
22.5-	

Average = 8.9 Mph
Std Dev = 4.3 Mph

Change in Elevation Histogram for Run 335

(Feet)	Segment
-< -80	
-80 -< -60	
-60 -< -40	
-40 -< -20	8, 12
-20 -< 0	1, 2, 4, 5, 6, 7, 9, 11, 13, 14, 25, 26, 27, 30, 31, 36, 37, 38, 39, 40, 41, 42, 45
0 -< 20	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 28, 29, 32, 33, 34, 35, 43, 44, 46
20 -< 40	3, 10
40 -< 60	
60 -< 80	
80 -	

Average = -0.7 Feet
Std Dev = 9.6 Feet

Average Positive Acceleration Histogram for Run 335

(Mph/sec)	Segment
0.0 -< 0.3	5, 9, 38, 39
0.3 -< 0.6	15
0.6 -< 0.9	17, 43
0.9 -< 1.2	1, 2, 44
1.2 -< 1.5	3, 27, 37
1.5 -< 1.8	6, 7, 10, 11, 12, 24, 33, 34, 35, 36, 40, 42, 46
1.8 -< 2.1	4, 13, 16, 18, 19, 20, 26, 32, 41
2.1 -< 2.4	8, 21, 22, 25, 29
2.4 -< 2.7	14, 23, 28, 30, 31, 45
2.7-	

Average = 1.6 Mph/sec
Std Dev = 0.7 Mph/sec

Energy per Mile Histogram for Run 335

(Watt-Hrs/mile)	Segment
0 -< 1600	2, 8, 11, 12, 40, 41
1600 -< 3200	1, 4, 6, 7, 16, 20, 22, 24, 25, 26, 27, 29, 30, 33, 35, 36, 37, 42, 44, 46
3200 -< 4800	10, 13, 14, 18, 21, 28, 32, 34, 43
4800 -< 6400	3, 19, 23, 31, 45
6400 -< 8000	5
8000 -< 9600	
9600 -<11200	
11200 -<12800	
12800 -<14400	
14400 -	9, 15, 17, 38, 39

Average = 9488.0 Watt-Hours/mile
Std Dev = 25221.8 Watt-Hours/mile

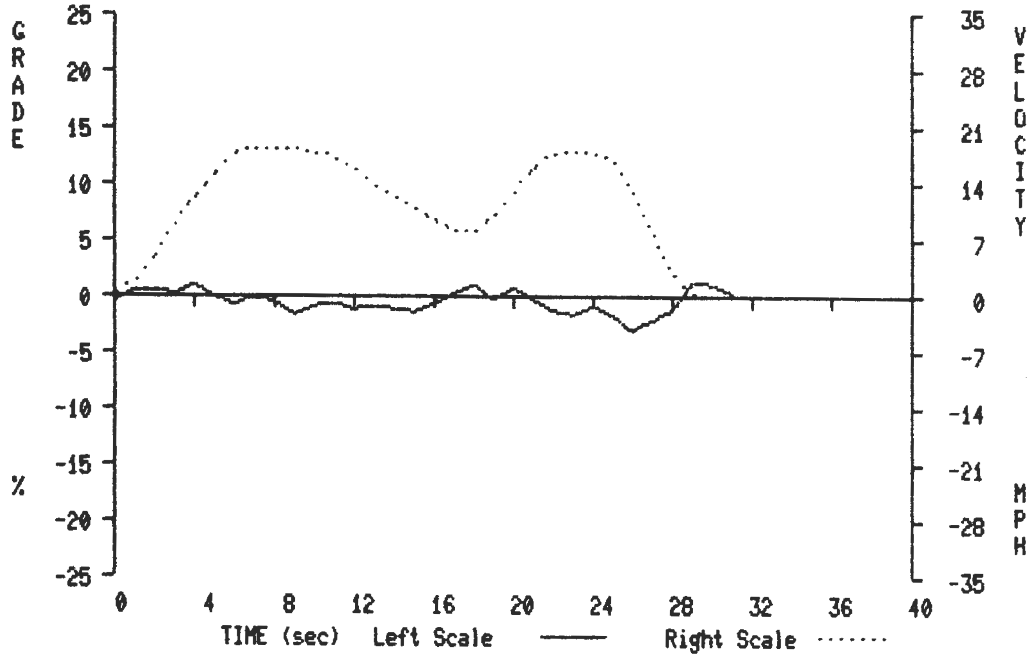
SEGMENT CALCULATIONS REPORT
RUN 335 SEGMENT 30

DATE: 19-APR-84
TIME: 10:21:53
ROUTE: 8-MARKET-INBOUND
DRIVER: WEST HATCH
OPERATOR:FROILAN "ALAN" I. DE GUZMAN / JIM SIMPSON OF GARRETT ON BOARD
EQUIPMENT
TYPE: GARRETT - STROMBERG AC PROPULSION / AW1
COMMENT:T = 72 F / H = 52 % / SUNNY BUT OVERCAST / COOL
BUS WEIGHT: 32340.0 LBS
CALIBRATION DATA: TACHOMETER= 13.1 PULSES PER FOOT
DRAG= 272.0 POUNDS FORCE

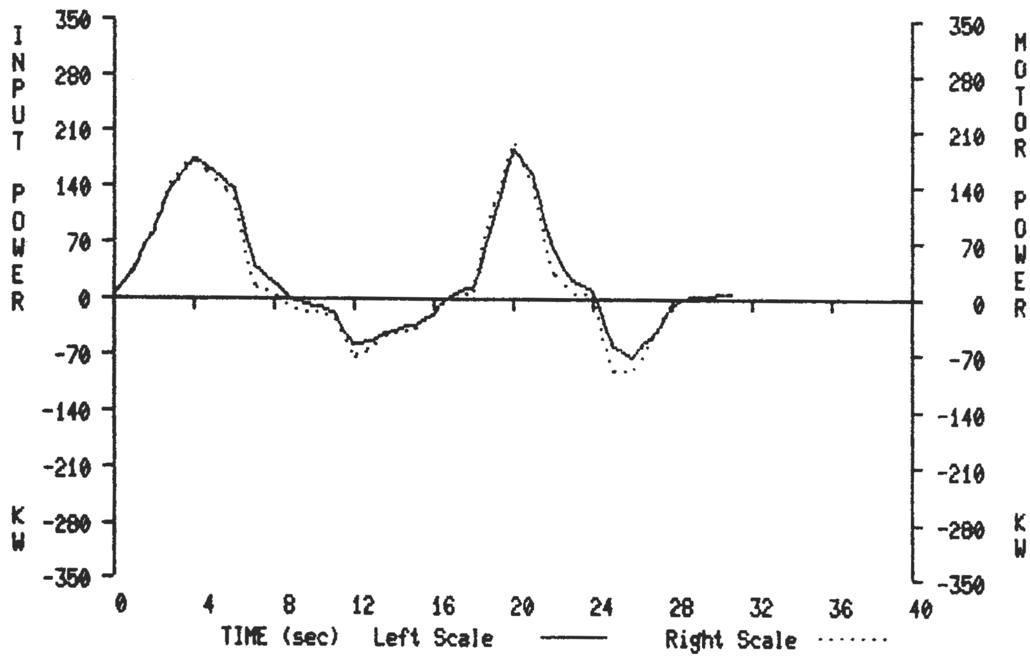
TIME TRAVELING	=	28.8 SEC
TIME STOPPED	=	3.2 SEC
DISTANCE TRAVELLED	=	535.4 FT
MAXIMUM VELOCITY	=	18.4 MPH
AVERAGE VELOCITY	=	12.7 MPH
COMMERCIAL VELOCITY	=	11.4 MPH
CHANGE IN ELEVATION	=	-4.0 FT
AVERAGE ASCENDING GRADE	=	1.2 %
FRACTION OF SEGMENT ON ASCENDING GRADE	=	0.06
AVERAGE DESCENDING GRADE	=	-1.7 %
FRACTION OF SEGMENT ON DESCENDING GRADE	=	0.39
PEAK POWER USED	=	188.1 KW
PEAK POWER REGENERATED	=	-74.6 KW
PEAK MOTOR POWER	=	197.5 KW
PEAK MOTOR POWER REGENERATED	=	-90.8 KW
TOTAL POSITIVE LINE ENERGY	=	0.379 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	0.370 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-0.118 KWH
NET LINE ENERGY IN SEGMENT	=	0.261 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	0.351 KWH
NET MOTOR ENERGY IN SEGMENT	=	0.202 KWH
TOTAL AUXILIARY ENERGY	=	0.019 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	0.217 KWH
NET PROPULSION ENERGY PER MILE	=	2.486 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	28.358 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.59
CONTROLS EFFICIENCY IN PROPULSION	=	0.95
MOTOR EFFICIENCY IN PROPULSION	=	0.62
PEAK ACCELERATION IN PROPULSION	=	3.93 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	2.49 MPH/SEC
PEAK JERK IN PROPULSION	=	2.63 MPH/SEC2

10:43:02 * SEGMENT 30
10:43:27 !STATUS BITS DISABLED: 1

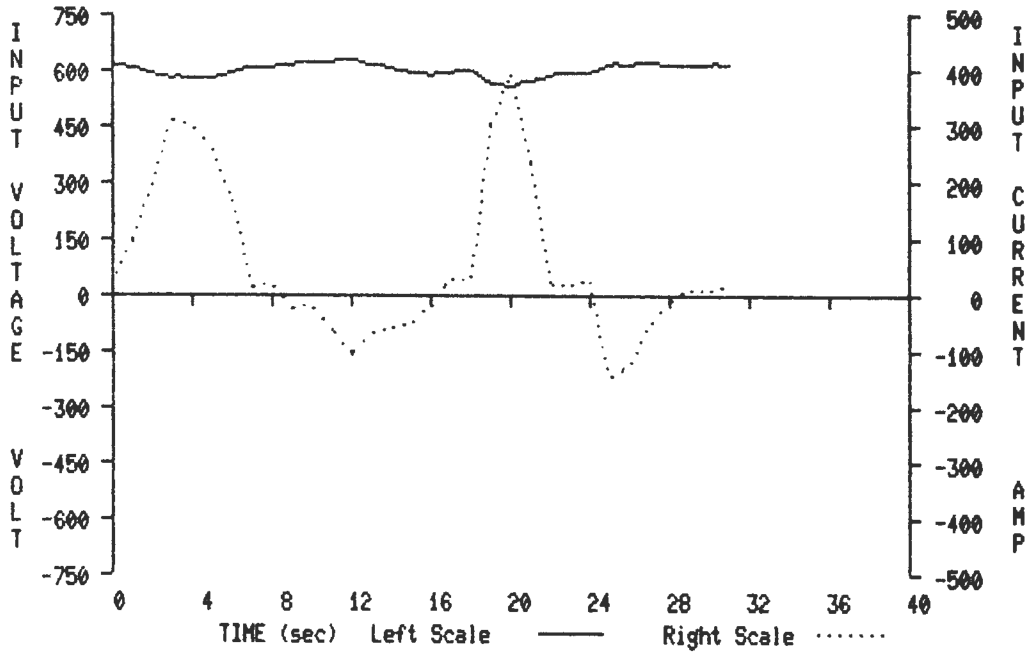
RUN NUMBER: 335 SEGMENT NUMBER: 30



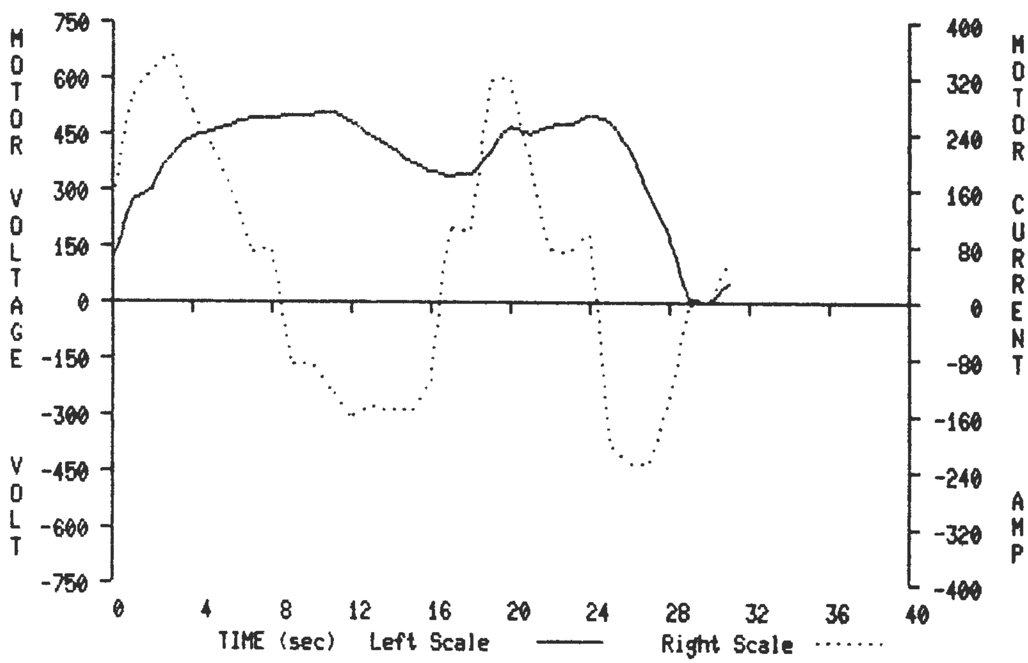
RUN NUMBER: 335 SEGMENT NUMBER: 30



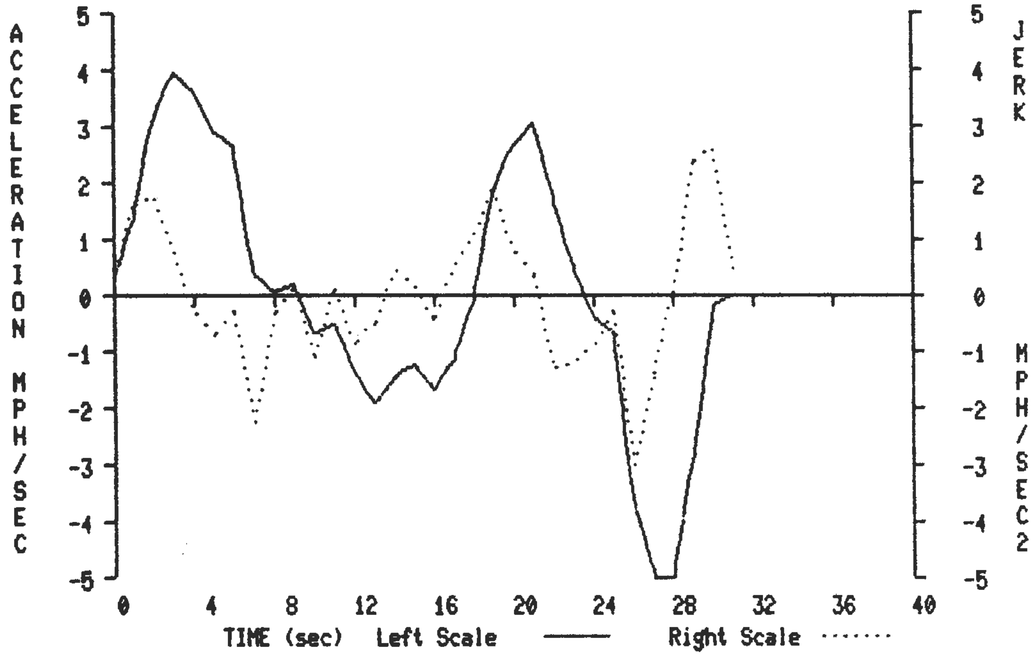
RUN NUMBER: 335 SEGMENT NUMBER: 30



RUN NUMBER: 335 SEGMENT NUMBER: 30



RUN NUMBER: 335 SEGMENT NUMBER: 30



Westinghouse Electric Corporation
Transportation Division

CHOPPER PROPULSION SYSTEM

RUN SUMMARY STATISTICS AND RUN LOG REPORT
RUN NUMBER 439

DATE: 31-AUG-84
TIME: 11:01:42
ROUTE: 8-MARKET-IN
DRIVER: STEVEN HO
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: WESTINGHOUSE DC CHOPPER
COMMENT:**UNDEFINED**
BUS WEIGHT: 33370.0 LBS
CALIBRATION DATA: TACHOMETER= 13.0 PULSES PER FOOT
DRAG= 339.7 POUNDS FORCE

NUMBER OF SEGMENTS	=	51
TOTAL TIME TRAVELING	=	1326.0 SEC
TOTAL TIME STOPPED	=	837.0 SEC
TOTAL TIME	=	2163.0 SEC
TOTAL DISTANCE TRAVELLED	=	17935.0 FT
AVERAGE DISTANCE TRAVELLED	=	351.7 FT
PEAK VELOCITY IN RUN	=	22.1 MPH
AVERAGE VELOCITY	=	9.2 MPH
COMMERCIAL VELOCITY	=	5.7 MPH
TOTAL CHANGE IN ELEVATION	=	-67.8 FT
AVERAGE ASCENDING GRADE	=	2.6 %
FRACTION OF RUN ON ASCENDING GRADE	=	0.22
AVERAGE DESCENDING GRADE	=	-2.7 %
FRACTION OF RUN ON DESCENDING GRADE	=	0.35
PEAK POWER USED	=	176.4 KW
PEAK POWER REGENERATED	=	-43.2 KW
PEAK MOTOR POWER	=	169.4 KW
PEAK MOTOR POWER REGENERATED	=	-115.8 KW
TOTAL POSITIVE LINE ENERGY	=	9.788 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	8.563 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-1.336 KWH
NET LINE ENERGY IN RUN	=	8.452 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	7.347 KWH
NET MOTOR ENERGY IN RUN	=	4.152 KWH
TOTAL AUXILIARY ENERGY	=	1.335 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	4.637 KWH
NET PROPULSION ENERGY PER MILE	=	2.128 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	19.622 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.54
CONTROLS EFFICIENCY IN PROPULSION	=	0.86
MOTOR EFFICIENCY IN PROPULSION	=	0.63
PEAK ACCELERATION IN PROPULSION	=	3.87 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.57 MPH/SEC
PEAK JERK IN PROPULSION	=	3.22 MPH/SEC2

11:01:42 RUN STARTS

Total Distance Histogram for Run 439

(Feet)	Segment
0 -< 100	1, 2, 6, 18, 33, 34, 40
100 -< 200	16, 39, 44, 46, 49
200 -< 300	3, 10, 20, 25, 28, 29, 31, 32, 35, 36, 38, 42, 45, 48
300 -< 400	12, 15, 19, 21, 22, 24, 47, 50, 51
400 -< 500	30, 37, 41
500 -< 600	4, 5, 13, 17, 23, 43
600 -< 700	11, 26
700 -< 800	7
800 -< 900	8, 9, 14
900 -	27

Average = 351.7 Feet
Std Dev = 240.6 Feet

Average Velocity Histogram for Run 439

(Mph)	Segment
0.0 -< 2.5	2, 6, 33
2.5 -< 5.0	18, 34, 39, 40
5.0 -< 7.5	1, 3, 5, 24, 31, 32, 38, 43, 44, 46, 49
7.5 -<10.0	4, 10, 15, 16, 19, 20, 21, 22, 23, 25, 35, 36, 41, 42, 45, 47, 48, 50, 51
10.0 -<12.5	7, 9, 13, 27, 28, 29, 30, 37
12.5 -<15.0	12, 14, 17, 26
15.0 -<17.5	8, 11
17.5 -<20.0	
20.0 -<22.5	
22.5-	

Average = 8.4 Mph
Std Dev = 3.4 Mph

Change in Elevation Histogram for Run 439

(Feet)	Segment
-< -80	
-80 -< -60	
-60 -< -40	14
-40 -< -20	4, 9
-20 -< 0	3, 7, 8, 10, 13, 15, 16, 24, 25, 26, 28, 29, 38, 39, 40, 41, 42, 43, 44, 45, 46, 48, 51
0 -< 20	1, 2, 6, 11, 12, 17, 18, 19, 20, 21, 22, 23, 27, 30, 31, 32, 33, 34, 35, 36, 37, 47, 49, 50
20 -< 40	5
40 -< 60	
60 -< 80	
80 -	

Average = -1.3 Feet
Std Dev = 9.5 Feet

Average Positive Acceleration Histogram for Run 439

(Mph/sec)	Segment
0.0 -< 0.3	
0.3 -< 0.6	
0.6 -< 0.9	2, 6, 33
0.9 -< 1.2	4, 5, 32, 34, 39, 42, 43
1.2 -< 1.5	1, 7, 9, 15, 18, 24, 26, 30, 38, 40, 49
1.5 -< 1.8	3, 8, 12, 14, 23, 25, 27, 28, 31, 41, 45, 46, 47, 50
1.8 -< 2.1	11, 13, 16, 19, 21, 35, 36, 37, 44, 48
2.1 -< 2.4	10, 17, 20, 22, 29, 51
2.4 -< 2.7	
2.7-	

Average = 1.6 Mph/sec
Std Dev = 0.4 Mph/sec

Energy per Mile Histogram for Run 439

(Watt-Hrs/mile)	Segment
0 -< 1600	4, 9, 10, 13, 14, 26, 39, 41, 43, 44, 45
1600 -< 3200	3, 7, 8, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31, 32, 35, 38, 40, 42, 46, 47, 48, 50
3200 -< 4800	11, 12, 34, 36, 37, 49, 51
4800 -< 6400	5
6400 -< 8000	2, 33
8000 -< 9600	
9600 -<11200	1, 18
11200 -<12800	
12800 -<14400	
14400 -	6

Average = 4898.5 Watt-Hours/mile
Std Dev = 15503.6 Watt-Hours/mile

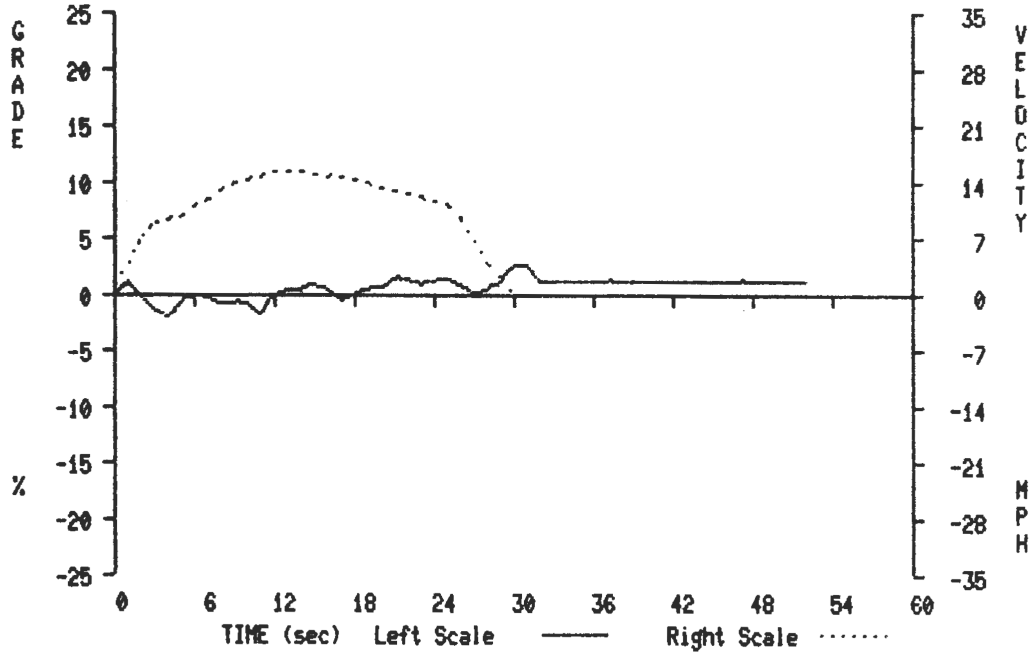
SEGMENT CALCULATIONS REPORT
RUN 439 SEGMENT 30

DATE: 31-AUG-84
TIME: 11:01:42
ROUTE: 8-MARKET-IN
DRIVER: STEVEN HO
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: WESTINGHOUSE DC CHOPPER
COMMENT:**UNDEFINED**
BUS WEIGHT: 33370.0 LBS
CALIBRATION DATA: TACHOMETER= 13.0 PULSES PER FOOT
DRAG= 339.7 POUNDS FORCE

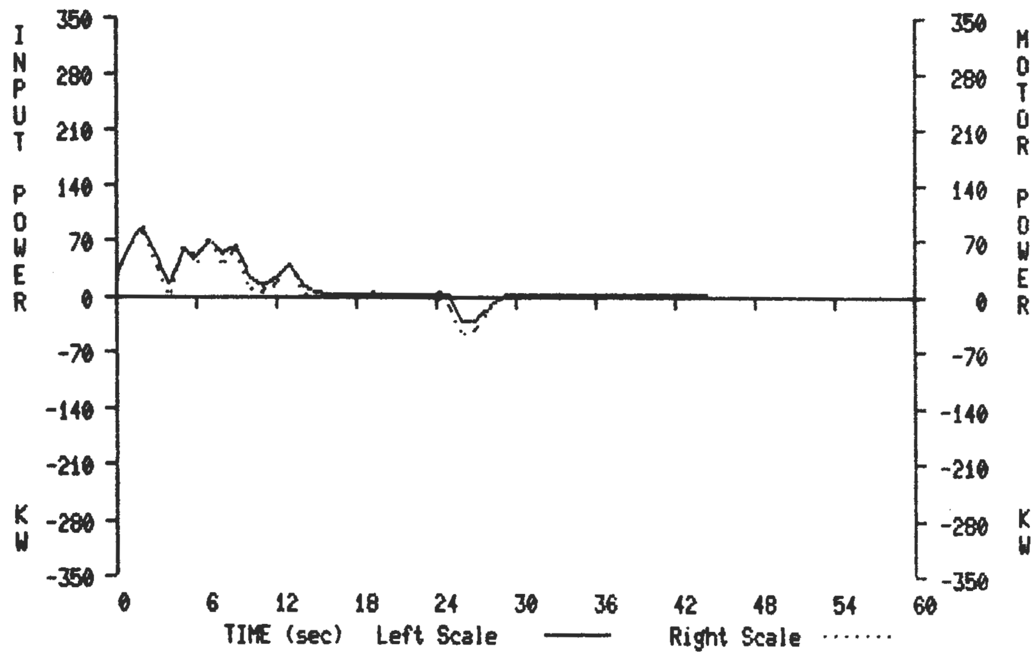
TIME TRAVELING	=	30.0	SEC
TIME STOPPED	=	23.0	SEC
DISTANCE TRAVELLED	=	490.6	FT
MAXIMUM VELOCITY	=	15.2	MPH
AVERAGE VELOCITY	=	11.1	MPH
COMMERCIAL VELOCITY	=	6.3	MPH
CHANGE IN ELEVATION	=	0.6	FT
AVERAGE ASCENDING GRADE	=	1.4	%
FRACTION OF SEGMENT ON ASCENDING GRADE	=	0.19	
AVERAGE DESCENDING GRADE	=	-1.7	%
FRACTION OF SEGMENT ON DESCENDING GRADE	=	0.12	
PEAK POWER USED	=	85.0	KW
PEAK POWER REGENERATED	=	-31.4	KW
PEAK MOTOR POWER	=	80.6	KW
PEAK MOTOR POWER REGENERATED	=	-49.1	KW
TOTAL POSITIVE LINE ENERGY	=	0.208	KWH
TOTAL POSITIVE PROPULSION ENERGY	=	0.186	KWH
TOTAL ENERGY REGENERATED TO LINE	=	-0.022	KWH
NET LINE ENERGY IN SEGMENT	=	0.187	KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	0.157	KWH
NET MOTOR ENERGY IN SEGMENT	=	0.123	KWH
TOTAL AUXILIARY ENERGY	=	0.024	KWH
ENERGY USED AT WHEELS IN PROPULSION	=	0.082	KWH
NET PROPULSION ENERGY PER MILE	=	1.769	KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	11.164	KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.44	
CONTROLS EFFICIENCY IN PROPULSION	=	0.84	
MOTOR EFFICIENCY IN PROPULSION	=	0.52	
PEAK ACCELERATION IN PROPULSION	=	3.34	MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.41	MPH/SEC
PEAK JERK IN PROPULSION	=	1.89	MPH/SEC2

11:25:37 * SEGMENT 30
11:26:15 5TH...

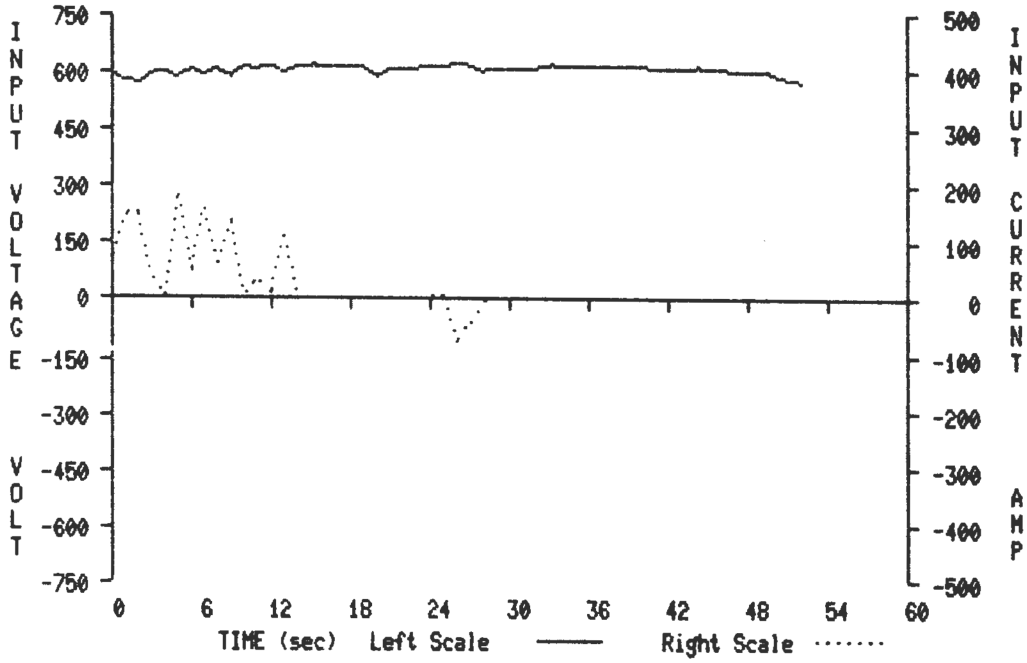
RUN NUMBER: 439 SEGMENT NUMBER: 30



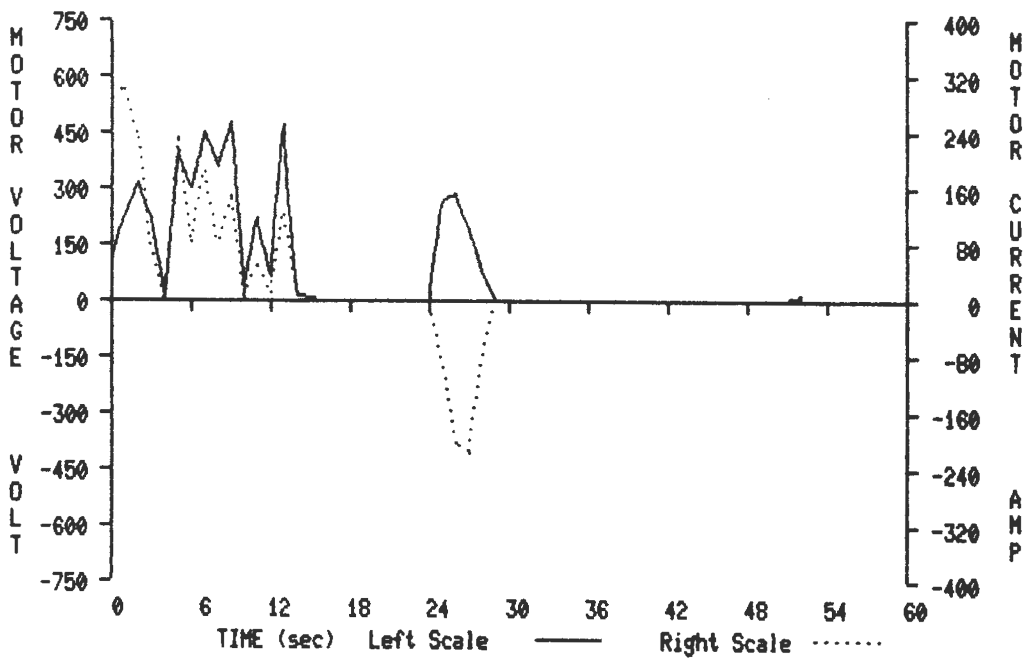
RUN NUMBER: 439 SEGMENT NUMBER: 30



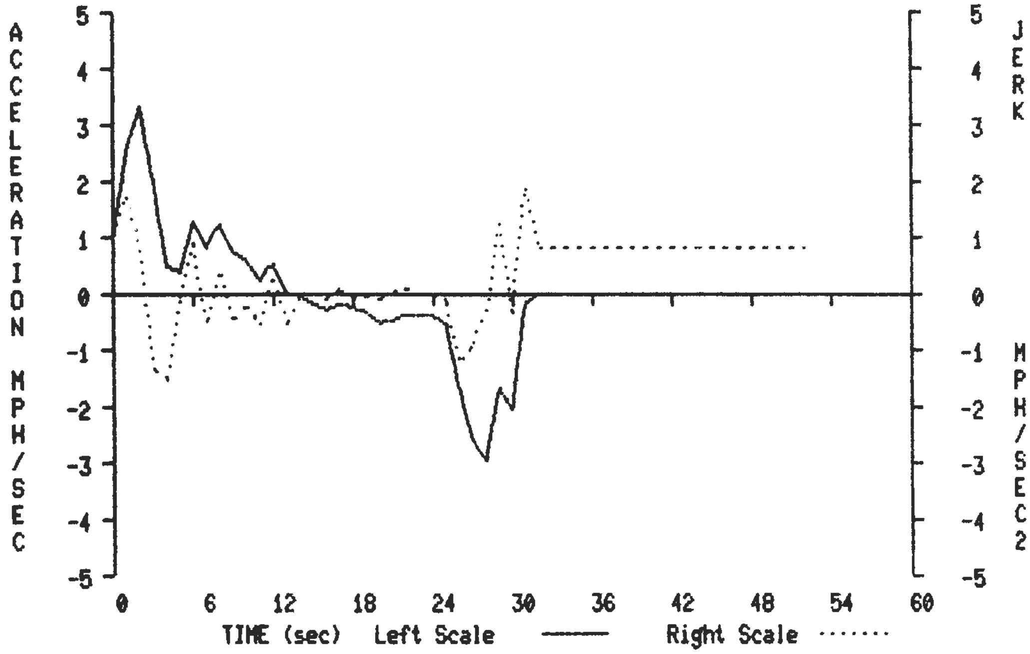
RUN NUMBER: 439 SEGMENT NUMBER: 30



RUN NUMBER: 439 SEGMENT NUMBER: 30



RUN NUMBER: 439 SEGMENT NUMBER: 30



Alsthom Atlantic Inc.

CHOPPER PROPULSION SYSTEM

RUN SUMMARY STATISTICS AND RUN LOG REPORT
RUN NUMBER 540

DATE: 10-DEC-84
TIME: 10:53:59
ROUTE: 8-MARKET-IN
DRIVER: STEVEN HO
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: ALTHOM-ATLANTIQUE DC CHOPPER - AW1
COMMENT:FREDERIC FOURET & ALAIN CHAILLOU OF AA ON BOARD...
BUS WEIGHT: 32410.0 LBS
CALIBRATION DATA: TACHOMETER= 13.0 PULSES PER FOOT
DRAG= 339.7 POUNDS FORCE

NUMBER OF SEGMENTS	=	43
TOTAL TIME TRAVELING	=	1335.0 SEC
TOTAL TIME STOPPED	=	732.0 SEC
TOTAL TIME	=	2067.0 SEC
TOTAL DISTANCE TRAVELLED	=	17784.7 FT
AVERAGE DISTANCE TRAVELLED	=	413.6 FT
PEAK VELOCITY IN RUN	=	22.5 MPH
AVERAGE VELOCITY	=	9.1 MPH
COMMERCIAL VELOCITY	=	5.9 MPH
TOTAL CHANGE IN ELEVATION	=	-68.3 FT
AVERAGE ASCENDING GRADE	=	2.6 %
FRACTION OF RUN ON ASCENDING GRADE	=	0.21
AVERAGE DESCENDING GRADE	=	-2.7 %
FRACTION OF RUN ON DESCENDING GRADE	=	0.35
PEAK POWER USED	=	180.5 KW
PEAK POWER REGENERATED	=	-140.3 KW
PEAK MOTOR POWER	=	170.6 KW
PEAK MOTOR POWER REGENERATED	=	-163.8 KW
TOTAL POSITIVE LINE ENERGY	=	11.197 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	9.803 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-2.958 KWH
NET LINE ENERGY IN RUN	=	8.239 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	8.312 KWH
NET MOTOR ENERGY IN RUN	=	3.585 KWH
TOTAL AUXILIARY ENERGY	=	1.288 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	5.339 KWH
NET PROPULSION ENERGY PER MILE	=	2.032 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	18.458 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.54
CONTROLS EFFICIENCY IN PROPULSION	=	0.85
MOTOR EFFICIENCY IN PROPULSION	=	0.64
PEAK ACCELERATION IN PROPULSION	=	3.93 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.47 MPH/SEC
PEAK JERK IN PROPULSION	=	3.70 MPH/SEC2

10:53:59 RUN STARTS

Total Distance Histogram for Run 540

(Feet)	Segment
0 -< 100	8, 11, 17, 31
100 -< 200	4, 7, 9, 28, 29, 38, 41
200 -< 300	18, 22, 23, 33, 36, 40
300 -< 400	1, 13, 19, 20, 21, 24, 27, 34, 35
400 -< 500	3, 39
500 -< 600	2, 14, 30, 32, 37
600 -< 700	6, 42
700 -< 800	5, 43
800 -< 900	10, 12, 15
900 -	16, 25, 26

Average = 413.6 Feet
Std Dev = 283.0 Feet

Average Velocity Histogram for Run 540

(Mph)	Segment
0.0 -< 2.5	8, 11, 17, 31
2.5 -< 5.0	4, 7, 41
5.0 -< 7.5	1, 2, 9, 13, 22, 24, 28, 29, 32, 35, 36, 39, 40
7.5 -<10.0	3, 18, 19, 20, 21, 23, 33, 34, 38, 42
10.0 -<12.5	5, 15, 16, 25, 27, 30, 37, 43
12.5 -<15.0	6, 10, 12, 14, 26
15.0 -<17.5	
17.5 -<20.0	
20.0 -<22.5	
22.5-	

Average = 8.0 Mph
Std Dev = 3.4 Mph

Change in Elevation Histogram for Run 540

(Feet)	Segment
-< -80	
-80 -< -60	
-60 -< -40	15
-40 -< -20	10
-20 -< 0	1, 2, 5, 6, 7, 8, 9, 11, 14, 24, 25, 27, 28, 29, 36, 37, 38, 39, 40, 41, 42
0 -< 20	3, 4, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 26, 30, 31, 32, 33, 34, 35, 43
20 -< 40	
40 -< 60	
60 -< 80	
80 -	

Average = -1.6 Feet
Std Dev = 9.7 Feet

Average Positive Acceleration Histogram for Run 540

(Mph/sec)	Segment
0.0 -< 0.3	8
0.3 -< 0.6	
0.6 -< 0.9	11, 17, 31
0.9 -< 1.2	3, 4, 5, 7, 24, 26, 35, 41
1.2 -< 1.5	1, 2, 6, 12, 19, 25, 30, 33, 34, 37, 43
1.5 -< 1.8	9, 10, 14, 15, 16, 20, 22, 23, 28, 29, 32, 36, 38, 39
1.8 -< 2.1	13, 18, 21, 40, 42
2.1 -< 2.4	27
2.4 -< 2.7	
2.7-	

Average = 1.4 Mph/sec
Std Dev = 0.4 Mph/sec

Energy per Mile Histogram for Run 540

(Watt-Hrs/mile)	Segment
0 -< 1600	1, 2, 6, 10, 14, 15, 21, 25, 36, 37
1600 -< 3200	5, 7, 9, 12, 16, 18, 19, 20, 23, 24, 26, 27, 28, 29, 30, 35, 38, 39, 40, 41, 42, 43
3200 -< 4800	8, 11, 13, 22, 32, 33, 34
4800 -< 6400	3
6400 -< 8000	4, 17, 31
8000 -< 9600	
9600 -<11200	
11200 -<12800	
12800 -<14400	
14400 -	

Average = 2594.7 Watt-Hours/mile
Std Dev = 1829.1 Watt-Hours/mile

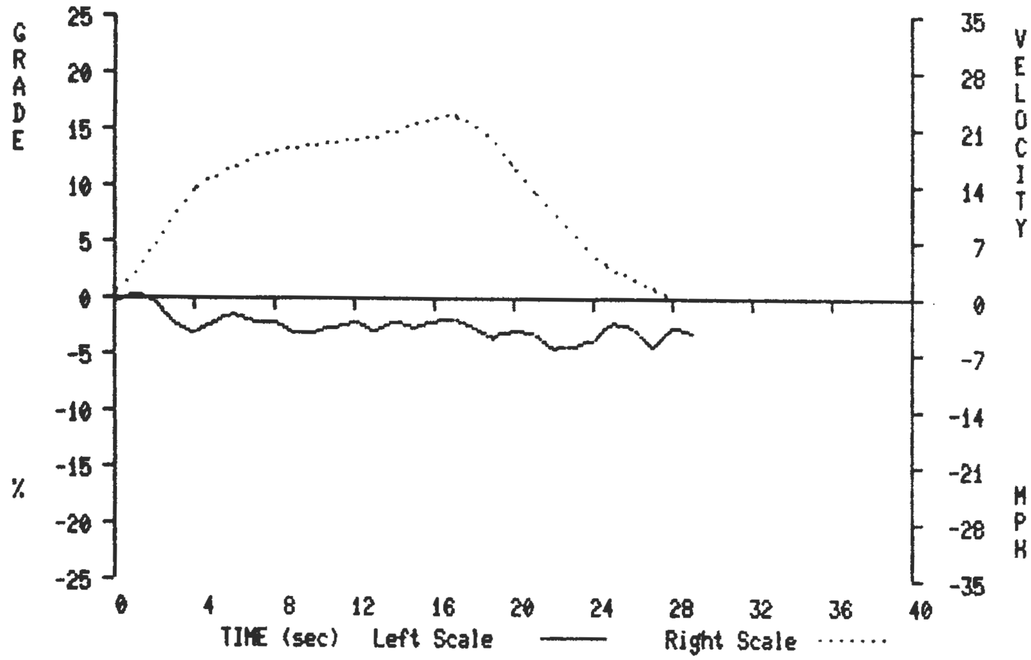
SEGMENT CALCULATIONS REPORT
RUN 540 SEGMENT 14

DATE: 10-DEC-84
TIME: 10:53:59
ROUTE: 8-MARKET-IN
DRIVER: STEVEN HO
OPERATOR:FROILAN "ALAN" I. DE GUZMAN
EQUIPMENT
TYPE: ALTHOM-ATLANTIQUE DC CHOPPER - AW1
COMMENT:FREDERIC FOURET & ALAIN CHAILLOU OF AA ON BOARD...
BUS WEIGHT: 32410.0 LBS
CALIBRATION DATA: TACHOMETER= 13.0 PULSES PER FOOT
DRAG= 339.7 POUNDS FORCE

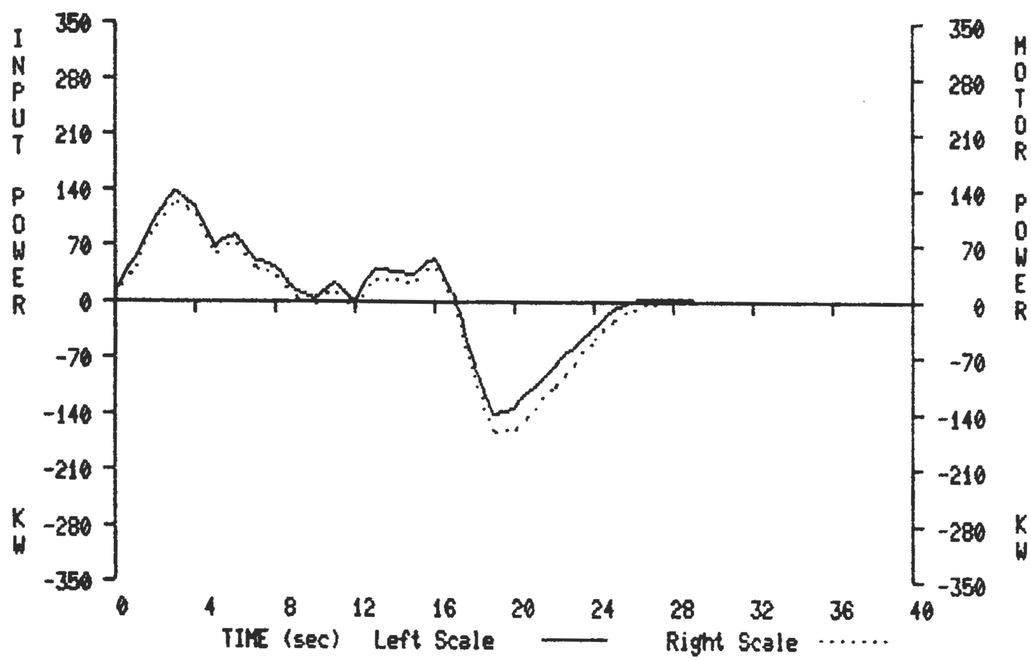
TIME TRAVELING	=	27.6 SEC
TIME STOPPED	=	2.4 SEC
DISTANCE TRAVELLED	=	563.2 FT
MAXIMUM VELOCITY	=	22.5 MPH
AVERAGE VELOCITY	=	13.9 MPH
COMMERCIAL VELOCITY	=	12.8 MPH
CHANGE IN ELEVATION	=	-14.3 FT
AVERAGE ASCENDING GRADE	=	1.2 %
FRACTION OF SEGMENT ON ASCENDING GRADE	=	0.00
AVERAGE DESCENDING GRADE	=	-2.6 %
FRACTION OF SEGMENT ON DESCENDING GRADE	=	0.97
PEAK POWER USED	=	138.1 KW
PEAK POWER REGENERATED	=	-140.3 KW
PEAK MOTOR POWER	=	123.8 KW
PEAK MOTOR POWER REGENERATED	=	-163.8 KW
TOTAL POSITIVE LINE ENERGY	=	0.246 KWH
TOTAL POSITIVE PROPULSION ENERGY	=	0.234 KWH
TOTAL ENERGY REGENERATED TO LINE	=	-0.178 KWH
NET LINE ENERGY IN SEGMENT	=	0.068 KWH
TOTAL MOTOR ENERGY IN PROPULSION	=	0.198 KWH
NET MOTOR ENERGY IN SEGMENT	=	-0.036 KWH
TOTAL AUXILIARY ENERGY	=	0.015 KWH
ENERGY USED AT WHEELS IN PROPULSION	=	0.108 KWH
NET PROPULSION ENERGY PER MILE	=	0.526 KWH/MILE
NET PROPULSION ENERGY PER HOUR	=	6.729 KW
SYSTEM EFFICIENCY IN PROPULSION	=	0.46
CONTROLS EFFICIENCY IN PROPULSION	=	0.84
MOTOR EFFICIENCY IN PROPULSION	=	0.54
PEAK ACCELERATION IN PROPULSION	=	3.93 MPH/SEC
AVERAGE ACCELERATION IN PROPULSION	=	1.62 MPH/SEC
PEAK JERK IN PROPULSION	=	1.75 MPH/SEC2

11:05:51 * SEGMENT 14

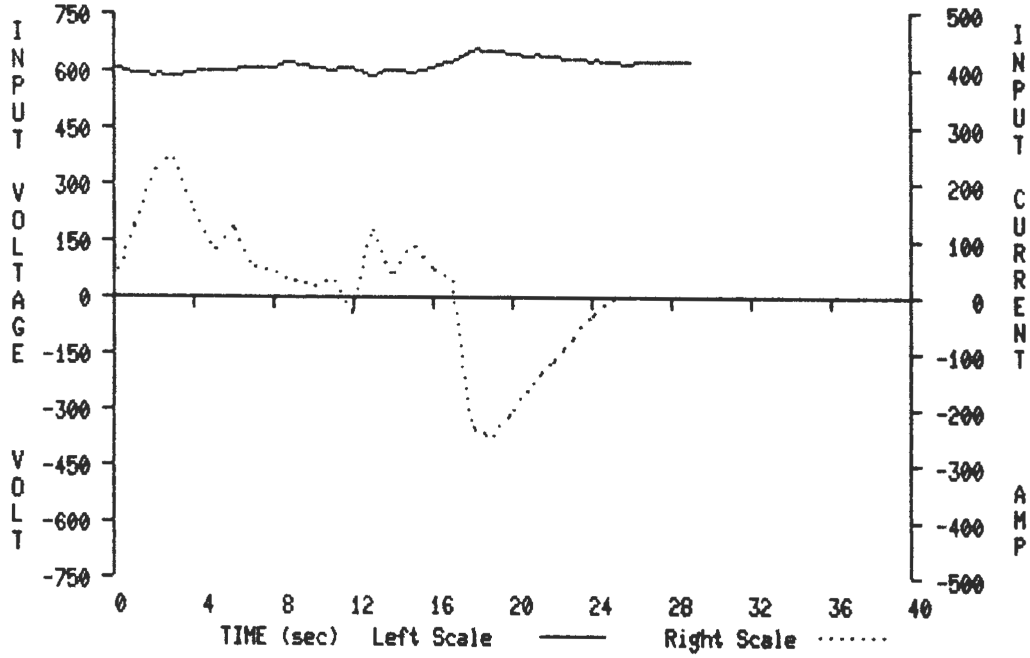
RUN NUMBER: 540 SEGMENT NUMBER: 14



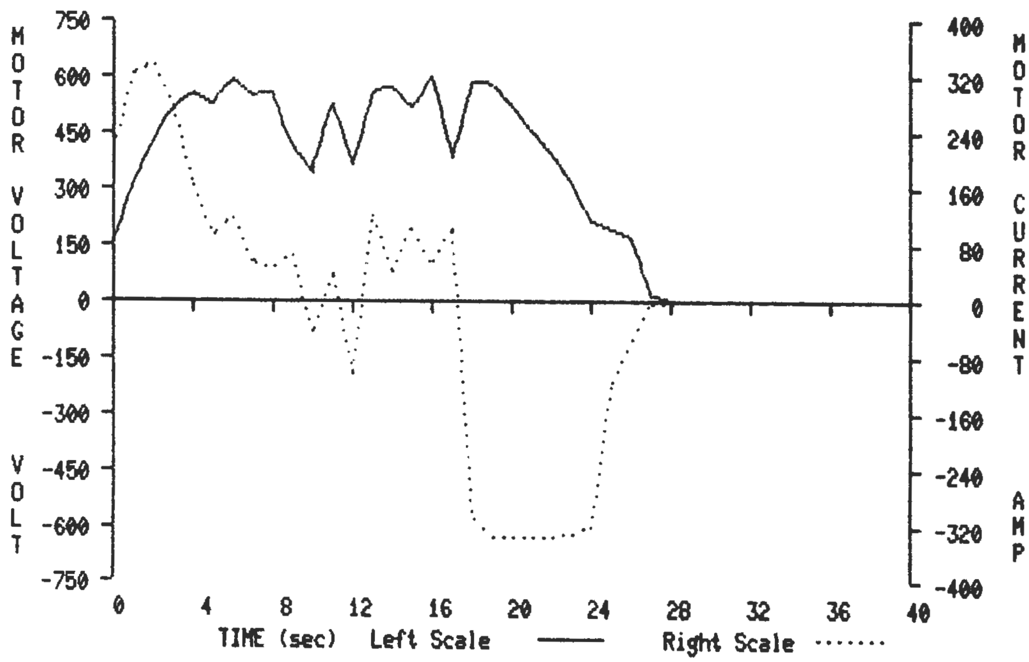
RUN NUMBER: 540 SEGMENT NUMBER: 14



RUN NUMBER: 540 SEGMENT NUMBER: 14



RUN NUMBER: 540 SEGMENT NUMBER: 14



RUN NUMBER: 540 SEGMENT NUMBER: 14