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TRANSIT CAR DEMONSTRATION TEST PROGRAM ON THE ROLL DYNAMICS UNIT

Volume II

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16. Abstract

This report documents two separate studies aimed at verifying and demonstrating the capabilities of the Roll Dynamics Unit (RDU). The RDU is part of the Rail Dynamics Laboratory (RDL), located at the Transportation Test Center (TTC), in Pueblo, Colorado. During testing, the RDU's potential for simulating actual track conditions was explored and results were correlated with measurements taken during in-track testing. Other efforts focused on the RDU's use as a laboratory instrument, by which selected performance parameters can be varied, and the responses of a single rail vehicle measured, under controlled conditions.

Sponsored by the Urban Mass Transportation Administration (UMTA), testing involved use of the Number One SOAC (State-of-the-Art Car), one of two such vehicles developed under UMTA's Urban Rail Vehicle and Systems Program (URRVS). The 90,000-pound intra-city, rapid transit vehicle, configured as an "A" Car (capable of independent or two-car operation), was operated on the TTC's Transit Test Track (TTT) to provide in-track data. It was then installed on the RDU for the testing described in this report. Information on SOAC technical/historical development and URRVS Program highlights are presented as background for the discussion of the results.

The first study was conducted by TTC personnel under the technical counsel of University of Arizona and Clemson University personnel and concerned itself with rail vehicle stability. Test methodology and software requirements were developed and analytical models evaluated. RDU mechanical characteristics were assessed in terms of their influence on measured vehicle responses during studies of hunting, creep forces, and forced sinusoidal responses.

The other study involved separate testing, done by TTC personnel, in such traditional performance areas of transit vehicle operation as traction, acceleration/deceleration, energy consumption, and spin/slide performance. In-track results were compared to RDU measured responses and the resulting excellent correlation demonstrated the feasibility of RDU testing.

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TRANSIT CAR DEMONSTRATION TEST PROGRAM
ON THE ROLL DYNAMICS UNIT

Volume II

Demonstration of a Transit Car Performance Test on the Roll Dynamics Unit

G. Arnold, S. Nelson

February 11, 1982

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SUMMARY

The results of a successful performance test of a transit car on a roller unit are presented, and the advantages and disadvantages of this method of testing are discussed. The tests, acceleration, deceleration, spin/slide and power-consumption, although of limited scope in comparison to the track tests performed on the same transit car, did show the feasibility of roller testing.

Of the tests, power consumption was very successful, but spin/slide testing was of limited success. An alternative method of spin/slide testing has been proposed which could improve this deficiency.

Emergency braking produced a severe flat on one wheelset of the transit car, but did not damage the rollers. For future testing, an effective roller adhesion control device is required to both clean the rollers and also apply lubrication if required to produce consistent low adhesion. Also an improved speed/acceleration method of recording and analysis is required.

It is concluded that the RDU is most suited for developmental testing of transit car systems, particularly for power consumption and for cars with non-standard wheel gage. Tests should be of such scope as to justify the cost of car setup on the RDU.

The following two tests are recommended:

1. A power consumption study for a standard/non-standard gage transit car which investigates methods of reducing power consumption.
2. A non-standard gage full performance test.

1.0 INTRODUCTION

This report contains the results, conclusions, and recommendations of the first performance test of a transit car on the Roll Dynamics Unit (RDU), at the Department of Transportation (DOT), Transportation Test Center (TTC), Pueblo, Colorado. The main objective of the test was to use a previously track tested experimental transit car, (the State of the Art Car (SOAC)) as a means to evaluate the feasibility and effectiveness of roller-rig testing of transit cars.

This report is limited to performance tests, although creep and stability tests were also conducted and are published under a separate report.

The concept of performance testing on rollers is that the transit car wheels should operate in the same dynamic environment on the rollers as on the track, even though the vehicle does not move longitudinally. The major advantage of roller testing is the opportunity to control parameters, under laboratory conditions, that cannot be controlled in track testing. However, offset against the advantages, are disadvantages applicable to the particular roller design, and other general disadvantages such as a lack of forward airflow over power system heat sources.

The objective of this report is to identify advantages and disadvantages of performance testing on the rollers of the RDU as highlighted by the SOAC test.

Following the setup of the four drive trains of the RDU to accept the SOAC, see Figure 1.1, the car was mounted on the rollers, restrained longitudinally and against excessive roll, and powered by a 600 volt D.C. supply, See Figure 1.2.

Because the SOAC did not move longitudinally on the rollers, the longitudinal inertia of the moving car on the track, was simulated on a per axle basis by the addition of rotational inertia to the drive trains, such that the total simulated inertia matched that of the actual SOAC car weight on the rollers of 90,840 lbs.

By the use of an electrical negative torque input at the motor of each drive train, the overall tractive resistance/speed characteristic of the SOAC on the track was approximated, in order that power consumption, acceleration, and deceleration characteristics produced on the rollers would be valid.

The roller tests, all at a representative car weight, voltage, and direction, covered the following performance characteristics:

acceleration
deceleration
power consumption
spin/slide

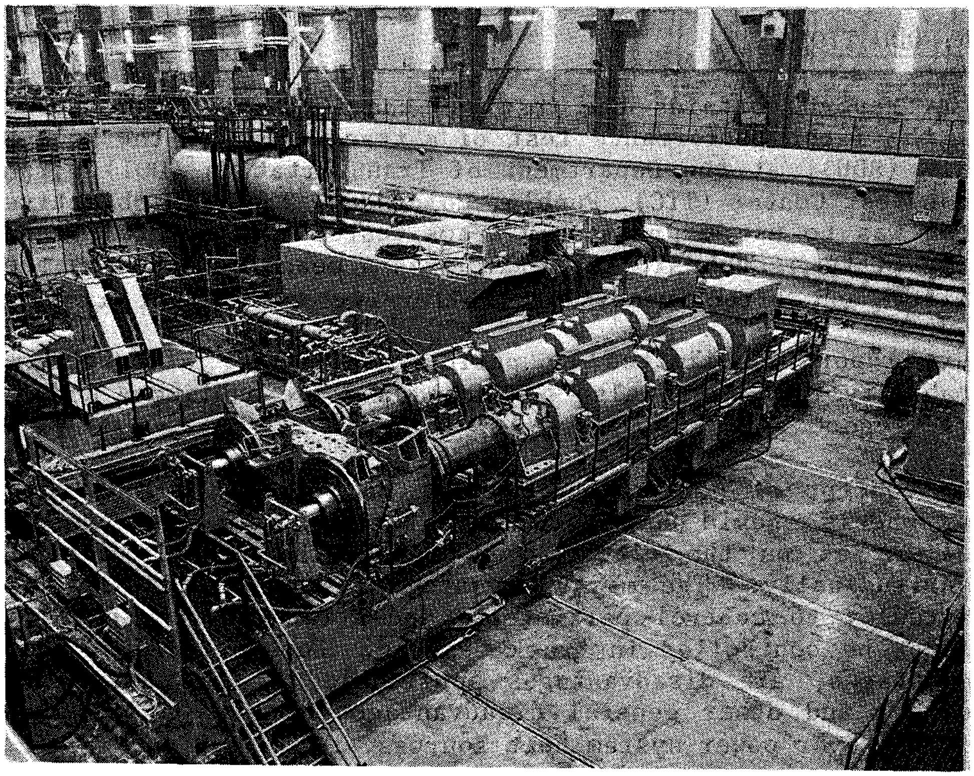


FIGURE 1.1. RDU DRIVE TRAIN SETUP.

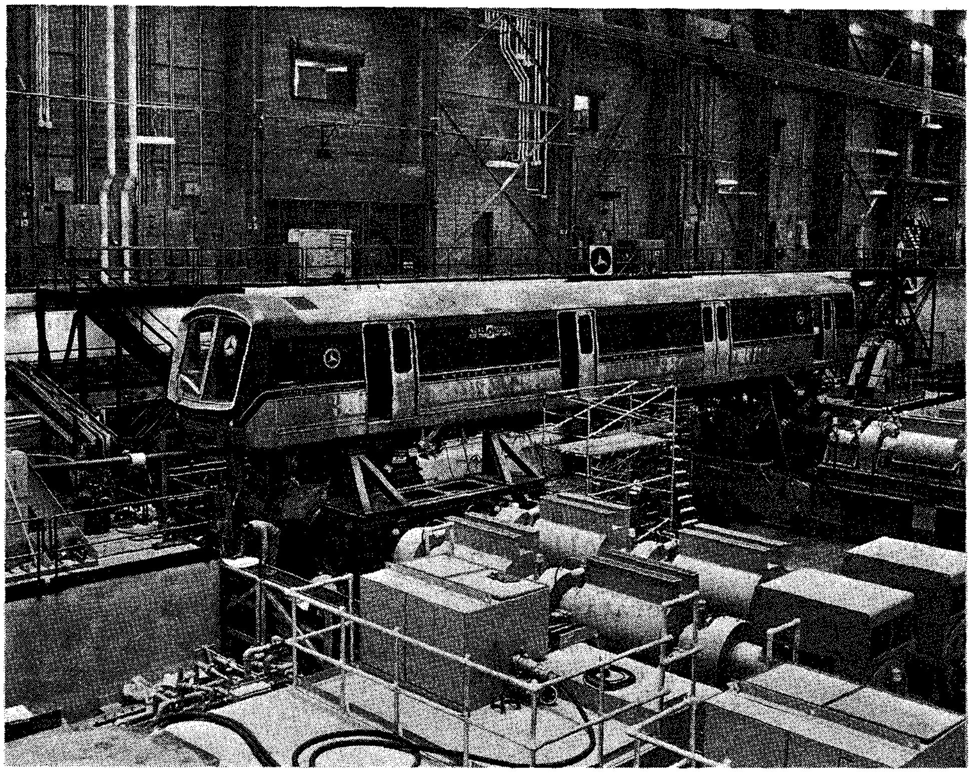


FIGURE 1.2. SOAC CAR ON RDU.

Actual performance testing covered a period of four days, the 11th, 12th, 13th, and 18th of March 1981. Although only a partial matrix of test runs was made in comparison to the matrix of track tests, sufficient data were taken to evaluate the RDU suitability as an alternative to track testing.

This report addresses each performance characteristic and accesses the effectiveness of the RDU. Also the mode of operation of the rollers is detailed and the method used to simulate SOAC track running elaborated.

The report summarizes the main conclusions and makes recommendations for future testing.

2.0 BACKGROUND TO THE RDL

2.1 Introduction

The Rail Dynamics Laboratory (RDL) at the Transportation Test Center (TTC) near Pueblo, Colorado was developed by the Federal Railroad Administration (FRA) to provide a facility to perform dynamic tests of fullscale locomotive, passenger and freight cars, transit vehicles and advanced track systems.

The laboratory can be utilized by railroad and transit industry researchers in dynamics studies such as: passive and active suspension characteristics; vehicle rock and roll tendencies; component stress analysis; component and vehicle natural frequencies; adhesions; ride comfort; acceleration; braking; lading responses; hunting and analytical model validation as well as support causes of derailment.

2.2 RDL History

Today's RDL facility is considerably different from that originally planned by the FRA. Prior to the development of DOT's TTC, no test facility was available in the United States to extensively evaluate and determine the solutions to dynamic operation problems. Just before 1970, FRA contractor studies recommended a fullscale roller rig (a rail dynamics simulator) with capability to handle cars and locomotives at full speed and power, with vibrations applied through the wheels to simulate track conditions. Representatives of railroads and suppliers assisted FRA in preparing performance specifications for the simulator.

FRA engineers opened communications with experts in other countries who had operated similar facilities, using their experience in preparation of the specifications. In order to leave options open for testing advanced high speed systems, such as the tracked air cushion vehicles, the simulator speed capability was designed for approximately 300 mph (483 km/h). The Urban Mass Transportation Administration joined in funding part of the RDL project so that transit vehicles could also be tested in the laboratory and agreed to locate the rail dynamics simulator (RDS) in a laboratory at the Transportation Test Center.

During the development of some of the RDS subsystems, unforeseen technical problems arose which resulted in severe schedule delays and associated risks of great concern to DOT.

In mid-1975 a DOT task force review resulted in the redirection of the RDL program so that it could be completed in a timely manner, relatively free of technical risk, and with minimum cost. The RDS was replaced by the Vibration Test Unit (VTU) designed to vibrate a railcar to simulate the effects of perturbed track on a rail vehicle, and the Roll Dynamics Unit (RDU) designed to simulate forward vehicle motion on rollers.

2.3 Rail Dynamics Laboratory Facilities

The laboratory is a steel and reinforced concrete structure located in the main area of the Test Center. It consists of a high bay, the testing area, and a low bay, a two story structure which contains offices, a control room and other facility support areas.

Two railroad spurs allow access into the building which has an interior height of 77 feet (23.5m) from the RDU pit to the roof supports. With the aid of two 100-ton traveling bridge cranes, test vehicles can easily be lifted from the rail spurs to the test machines.

Additional support functions include the 128-channel data acquisition system, closed circuit television, an intercommunications system, a calibration laboratory, electronic shop, and clean rooms. Office space is also included to accommodate engineers who plan, conduct, and evaluate the tests.

2.4 VTU and RDU

Enclosed in the RDL high bay area are the Vibration Test Unit (VTU) and the Roll Dynamics Unit (RDU) which constitute the laboratory capabilities. Both machines recreate the effects of rails under a vehicle and excite the wheels at the wheel/rail interface. In order to test a variety of railcars, both the VTU and the RDU are constructed in modular configurations to accommodate different car lengths, axle spacings, truck spacings and rail gages.

2.5 RDU Capability

Through a system of drive motors, flywheels and rollers, the RDU is capable of simulating relative motion for both unpowered vehicles, such as boxcars and passenger cars, and for absorbing power produced by selfpropelled vehicles, including locomotives and transit cars.

Each test vehicle wheel rests on and is driven by a supporting roller. Each pair of rollers, mounted on a common shaft, is attached to a drive train which provides inertia. This interface between the vehicle wheelset and the roller pair simulates the vehicle traveling over track. The roller rotation simulates vehicle velocities on tangent track having no lateral or vertical irregularities. Through its flywheels, the RDU is able to simulate resistive forces associated with accelerating or braking of a vehicle.

The RDU will support and drive the wheelsets of a four-axle rail vehicle or locomotive truck. Six or eight-axle locomotives and cars can be tested with the use of auxiliary support stands. The laboratory is equipped to duct off the exhaust produced during locomotive tests and can supply direct current electrical power for testing transit vehicles.

The RDU is equipped with a reaction frame which provides a mounting base for two hydraulic actuators. These actuators can be positioned to apply lateral forces to the side frame of a truck. The forces can be either steady or vibratory, and the pair of forces can be applied either in or out of phase. The following table summarizes the capabilities of the RDU:

RDU CAPABILITY	
Vehicle Length (max)	108.0 ft. (32.92m)
Vehicle Width (max)	12.0 ft. (3.66m)
Vehicle Weight (max)	400,000 lb. (181,437 kg)
Axle Load (max)	100,000 lb. (45,360 kg)
Truck Center Distance	
(min)	69.0 in. (1.75m)
(max)	80.0 ft. (24.38 kg)
Truck Axle Spacing	
(min)	69.0 in (1.75m)
(max)	110.0 in. (2.79m)
Gage	
(min)	56.5 in. (1.44m)
(max)	66.0 in. (1.68m)
Powered Axles	Four (600 hp)

3.0 DESCRIPTION OF THE STATE-OF-THE-ART-CAR (SOAC)

3.1 Introduction

The vehicle tested on the RDU was SOAC number 1 (see Figure 1.2), one of two State-of-the-Art-Cars, designed and constructed as part of the Urban Rapid Rail Vehicle and Systems Program (URRVS).

The URRVS program was inaugurated with the contract award to Boeing Vertol Company. The URRVS program was sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) Office of Research and Development, Rail Technology Division. As Systems Manager, Boeing Vertol was responsible to UMTA for the overall planning and integration as well as the technical and management aspects of the program as defined by UMTA.

The main objective of the program was to make rapid rail transportation more attractive to the urban traveler by providing existing and proposed transit systems with service that is comfortable, reliable, safe, and as economical as possible. The short-range goal was the demonstration of the state-of-the-art in rapid rail vehicular technology; the long-range goal was the development and demonstration of improved vehicles.

The program involved six separate tasks, of which the SOAC program was Task 3; State-of-the-Art Cars (SOAC) - Design, construction, test, and 5-city demonstration of two cars incorporating existing, proven technology.

Procurement of the SOAC was initiated in June 1971 with a survey to determine industry interest that culminated in July 1971 in requests for proposals to five companies; The Budd Company, Pullman Standard, Rohr Industries, St. Louis Car, and Vought Aeronautics. Evaluation of the three proposals received from Pullman, Rohr, and St. Louis Car resulted in Boeing's recommending and UMTA's approving of the subcontract in September 1971 to St. Louis Car Division of General Steel Industries for two cars.

The cars were designed, fabricated, functionally tested, and delivered to the Pueblo, Colorado, Transportation Test Center (TTC) in August 1972, 11½ months after the subcontract award.

Following a preliminary test and adjustment phase, the SOAC vehicles underwent extensive testing at the TTC. In addition to confirming vehicle performance characteristics, the SOAC tests established an engineering data baseline for future programs and for comparing various transit property track characteristics to the Rail Transit Test Track. A delay in testing and evaluation was caused by a collision in August 1973, necessitating major repairs to one of the two cars. After these repairs were completed in December 1973, systems testing was partially repeated and completed in April 1974. Testing included 10,219 miles of simulated demonstration operation; 4,197 car miles before and 6,022 car miles after the accident.

The operational demonstration and evaluation phase of the SOAC program started when the cars arrived in New York City on April 18, 1974, and ended with the completion of the Philadelphia demonstration on April 30, 1975. The phase covered 5 cities: New York (NYCTA), Boston (MBTA), Cleveland (CTS), Chicago (CTA), and Philadelphia (SEPTA).

An extension of the SOAC demonstration program to provide approximately 9 months of revenue service on the Port Authority Transit Corporation (PATCO) High-Speed Line between Lindenwold, New Jersey, and Philadelphia, Pennsylvania, was arranged at PATCO's suggestion. Initiation of the services was delayed until August 12, 1976, due to necessary vehicle modifications and a protracted negotiation for liability coverage. Several problems resulted in only 23 days of intermittent service and subsequent termination on January 24, 1977. The vehicles were then stored by Boeing Vertol awaiting introduction into the Advanced Subsystem Development Program, (Task 5, of URRVS).

In May 1979, SOAC number 2 was shipped to the Budd Company for modification to incorporate the ASDP truck, brake system and truck mounted propulsion components. SOAC number 1 remained unmodified and was shipped to the TTC for use as a tow-vehicle for the modified SOAC number 2. Ride quality, wayside-vibration and brake testing was performed under Contract DOT-UT-90056 with the Budd Company at the TTC.

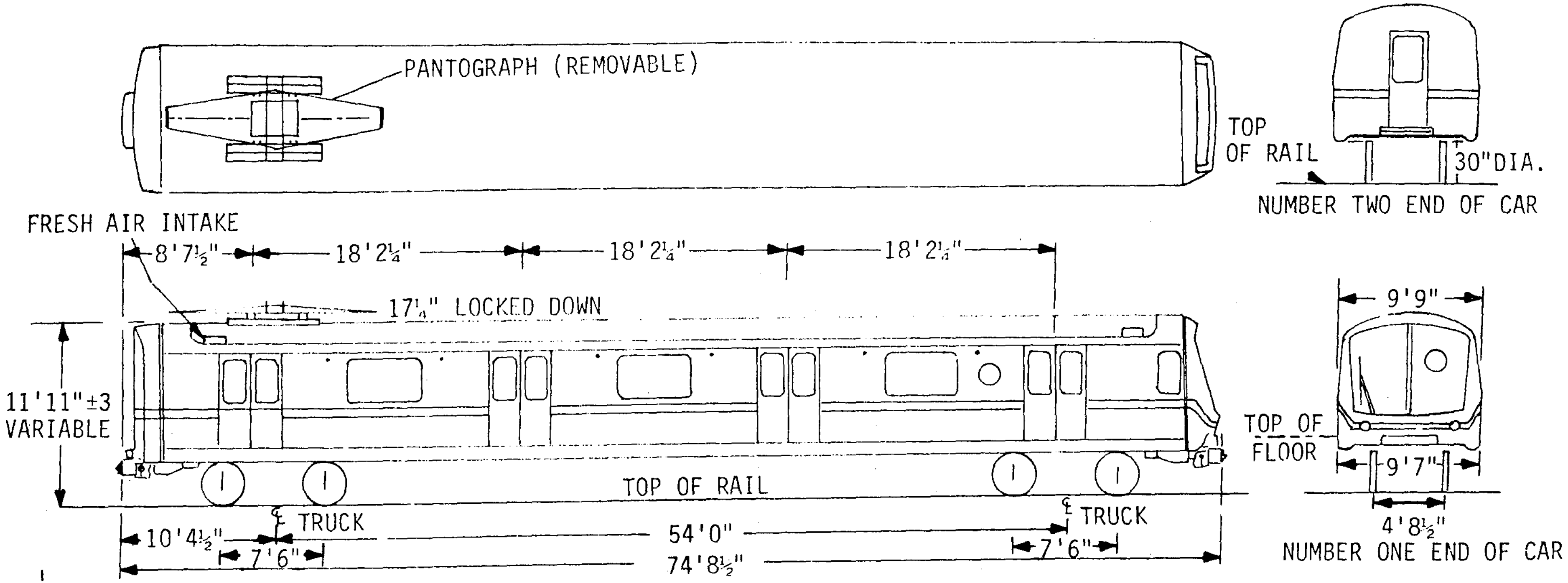
The un-modified SOAC number 1 was mounted on the rollers of the RDU in the RDL at the TTC on February 26, 1981 and testing was completed March 18, 1981. At this point the two SOAC cars are both at the TTC.

3.2 Design and Performance

3.2.1 General

The 90,000 pound SOAC cars were designed for use in frequent-stop, high-speed, intra-city mass transportation. They were both configured as "A" cars, (i.e., may be operated independently or as a two-car unit), and are powered by 600 volts dc which may be picked up with either third rail collectors or a pantograph. Passenger comfort and operating efficiency are featured in the car design.

Figure 3.1 details the SOAC performance and design characteristics. The car's 75-foot length and 9.75-foot width are the maximum outside dimensions compatible with prevailing subway clearances (tunnels, platforms). The cars are capable of 80 mph speeds with an initial acceleration rate of 3.0 mph/sec., (as shown in Figure 3.2, the SOAC can achieve 80 mph in 60 to 65 seconds). Braking from 80 mph may be accomplished with either dynamic or friction braking (or a blended combination) and is accomplished in under 1700 feet. A unique feature of the SOAC is its ability to brake from 80 mph using dynamic braking only. In high-speed, frequent-stop service this would save brake shoe wear, and reduce maintenance costs.



LENGTH.	75 FEET
WIDTH	9.75 FEET
MINIMUM TRACK CURVE RADIUS	145 FEET
SPEED	80 FEET
ACCELERATION, INITIAL .	3.0 MPH/SEC
JERK RATE	2.5 MPH/SEC^2
POWER	600 VDC NOMINAL
NOISE LEVEL, INTERIOR SPEC.	75 dBA @50MPH
ACTUAL	63 dBA @50MPH
NOISE LEVEL, 50 FT WAYSIDE	78 dBA @50MPH
ACTUAL	73 dBA @50MPH

PASSENGER CAPACITY (NO.1 CAR)	
SEATED	62
NOMINAL	100
MAXIMUM	220

PASSENGER CAPACITY (NO.2 CAR)	
SEATED	72
NOMINAL	100
MAXIMUM	300

FIGURE 3.1. SOAC PERFORMANCE AND DESIGN CHARACTERISTICS

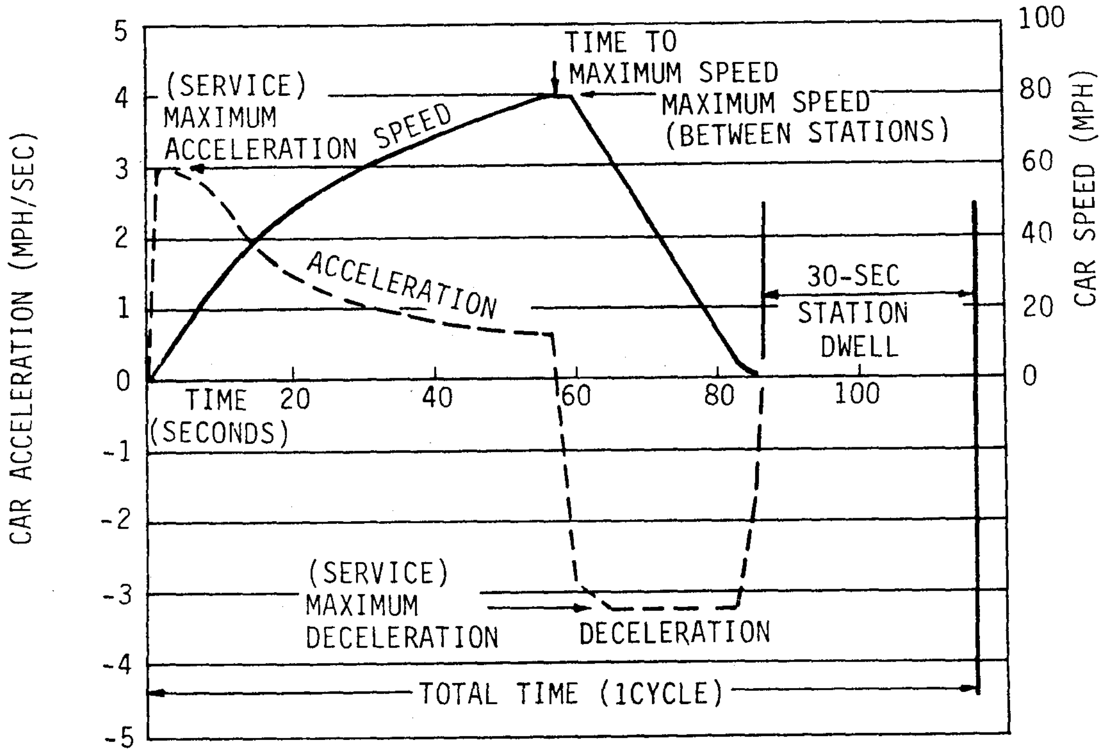


FIGURE 3.2. SOAC OPERATING PROFILE

The cars are adaptable to test and operate in New York, Boston, Cleveland, Chicago and Philadelphia by raising or lowering the car body up to 5 inches from the top of the truck, by the use of shims.

In addition, the third-rail collectors may be raised or lowered to suit various third rail heights. When necessary, the SOAC is equipped with a pantograph, and an automatic power changeover device to change power sources between overhead and third rail "on the fly".

The vehicles depict two types of interiors. The vehicle referred to as SOAC number 1 features "low-density" seating. It contains 64 cushioned, upholstered seats in four different arrangements. SOAC number 2 contains 72 seats of molded fiberglass with padded cushions and, more standing space, designed for "high-density" operation. SOAC number 2 was the instrumented test vehicle.

A brief description of the vehicle subsystems pertinent to the RDU tests is included below. A detailed description may be found in the SOAC State-of-the-Art Car Development Program Report, Volume 1, Design, Fabrication and Test, UMTA-IT-06-0026-71-1, April 1974.

3.2.2 Propulsion System

The propulsion system consists of traction motors, gearboxes, high and low voltage power supplies, and the control systems necessary to provide operations in both driving and braking modes. The motors are mounted two to a truck and are connected electrically in series. The two truck assemblies are connected electrically in parallel. The motors are fully compensated DC, with separately excited fields. The motors have a continuous rating of 175 hp at 1560 rpm (460 amps).

Control of the traction motors is by force commutated DC-DC chopper in the armature circuit and by AC-DC phase-delay rectifiers (thyristors) in the separate field circuits. AC power is supplied by the auxiliary power motor-alternator set. DC power to the armatures is supplied by the third rail shoes (or pantograph) through the input inductor-filter capacitor. Control subsystems provide for load weight, jerk rate and wheel spin/slide compensation, as well as dynamic-friction brake blending.

The SOAC gearbox is double-reduction parallel drive unit using helical gears. The overall gear ratio is 4.781 to 1. Magnetic pickup per axle is provided on the input gear to supply information for the car speedometer and spin/slide detection systems.

Two brake resistor grids are mounted on the SOAC, and provide the electrical load for the traction generators during dynamic braking.

The control of tractive and braking effort is achieved using a tractive effort program which accepts input commands, car weight, etc., and controls the motor torque developed to the desired values. Closed-loop control of motor armature current is the primary method utilized. A P-generator receives input commands from three sources:

master controller, speedometer (speed limiter system), or car hostler, and produces an analog signal from 0.0 to 1.0 amps which is trainlined. P-signal sensing is interpreted for braking, coasting, or propulsion modes (0.0 to 0.45 amps is braking, 0.45 to 0.55 is coasting, and 0.55 to 1.0 amps is propulsion). The P command is modified by car weight as sensed by air suspension pressure. A Tractive Effort Program (TEP) operates on the P command and provides a Tractive Effort Command (TEC) which is proportional to the position of the Master Controller (i.e., 100 percent of available tractive effort for P = 1.0 amps, master controller full foward). Jerk Rate Limiting and Spin/Slide protection are provided by monitoring the time rate of change of each of the four axle speedometers and altering the TEC when the 2.5 mph/sec-sec is exceeded.

3.2.3 Braking System

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

3.2.4 Trucks and Suspension

The truck and suspension system is designed for improved ride quality and reduced noise. The truck has a 7.5-foot wheelbase for standard gage track with inside wheel-axle bearing supports. Assembled weight of the cast alloy nickel steel truck is 14,500 pounds.

The truck frame is isolated from the axles by rubber chevron primary springs. Air bellows control car body leveling and provide car body to truck isolation.

Rubber bumpers are used to limit the deflections. Variable dampers are provided for all axles and can be adjusted during test to optimize ride quality.

3.2.5 Wheels

Resilient wheels were used during some of the SOAC track tests, but for the RDU test only solid wheels were used.

4.0 SOAC PERFORMANCE TESTS ON THE TTC TRANSIT OVAL

4.1 Background

The two SOAC's have undergone extensive track testing both at the TTC and at transit properties. Testing has been directed towards providing "baseline" data for comparing the SOAC capability to other vehicles. The controlled manner of the performance testing on the TTC oval provides a good base for comparison to the performance on the Roll Dynamics Unit. For the comparison, data contained in Report No. UMTA-MA-06-0025-75-2, "SOAC-STATE-OF-THE-ART-CAR ENGINEERING TESTS AT THE DEPARTMENT OF TRANSPORTATION HIGH SPEED GROUND TEST CENTER FINAL REPORT, VOLUME II - PERFORMANCE TESTS" have been used.

4.2 Transit Test Track

The SOAC engineering tests were performed between April and July 1973 on the Transit Test Track at the Transportation Test Center, a 9.1 mile oval of track designed for sustained 80 mph vehicle operation.

The majority of performance tests were carried out on a 4,000 foot tangent part of the loop constructed of 119 lb. rail on concrete ties. For the tests power was supplied by a General Electric model U30C diesel electric locomotive and two auxiliary generators through a third rail distribution system. Because of the power demand, the system could not respond fast enough for maximum acceleration tests with two vehicles. The track now has permanent power.

The power supply was of a "soft" nature. The nominal 600 volt testing actually had a potential of 700 volts at zero current, falling to 600 volts at full acceleration.

The performance tests were carried out at four car weights: 90,000, 105,000, 113,000 and 130,000 lbs. The data relating to a car weight of 105,000 lbs. was mainly addressed in the report.

5.0 SIMULATION OF TRACK RUNNING BY THE RDU FOR THE SOAC

5.1 General

The Roll Dynamics Unit (RDU) is capable of simulating track conditions such that the performance characteristics obtained on the rollers should follow closely those obtained in the field. To simulate track conditions each track input must be addressed. This can be accomplished comprehensively because each drive train of the RDU consists of an inactive element in the form of rotating masses, and an active element in the form of an electrical simulation of inertia and also a torque of any desired value at any instant.

The RDU has four independent roller drive train units each with two rollers. The RDU was able to accept all four axles of the SOAC car tested; two drive trains per truck. The drive trains were configured with each drive train parallel, with its roller pair exactly beneath the axle of the SOAC car.

For this test the drive trains were set up in an identical manner so that each drive train accepted 1/4 of the dynamic loads.

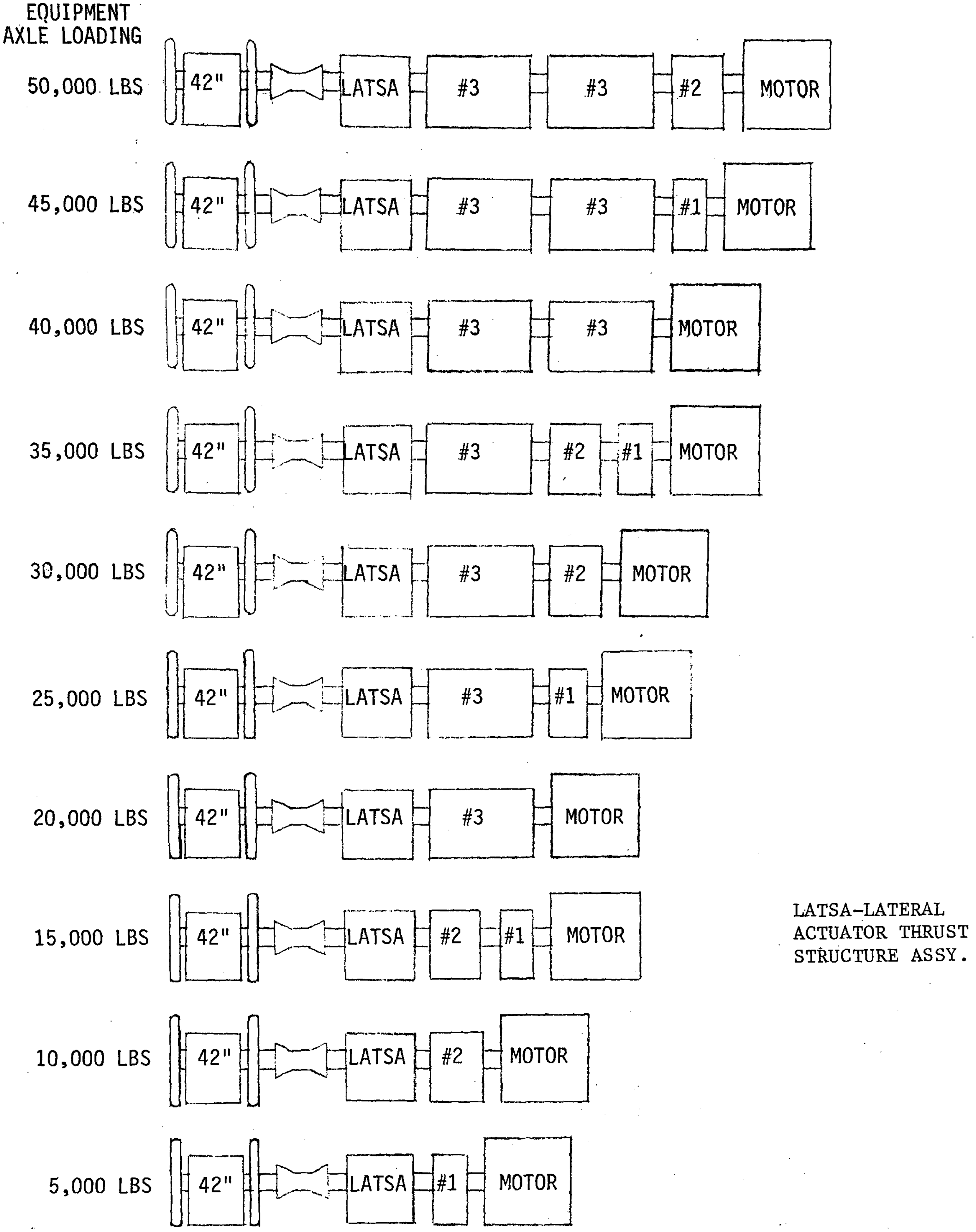
5.2.1 Drive Train Configuration

As designed by General Electric Company each drive train could employ either 42" diameter rollers or 60" diameter rollers in a number of standard configurations. With 42" diameter rollers, the rollers are directly coupled to the motor, but with 60" diameter rollers a gear unit is normally to be used between the rollers and motor, such that one revolution of the rollers produces 2.86 revolutions of the motor. The range of simulated longitudinal inertia for the 60" rollers covers 10,000 to 100,000 lbs. per axle, but the range for the 42" rollers is half this, at 2,500 to 50,000 lbs. per axle. The standard configurations are shown in Figures 5.1 and 5.2.

Because of technical and budgetary restraints, only the 60" rollers were available for the SOAC test, the 42" diameter rollers remaining at this moment in an unfinished condition. Hence, the standard configurations available are those shown in Figure 5.2. For the SOAC test, the standard 20,000 lb. axle loading employing the gear unit and a #1 passive inertia flywheel could have been used, however, a nonstandard configuration was employed without the gear unit. Because of the relative slower speed of the motor without the gear, 8 times more passive inertia was required; namely two #3 units. The configuration used is shown in Figure 5.3. The configuration does have the advantage of direct coupling between motor and rollers.

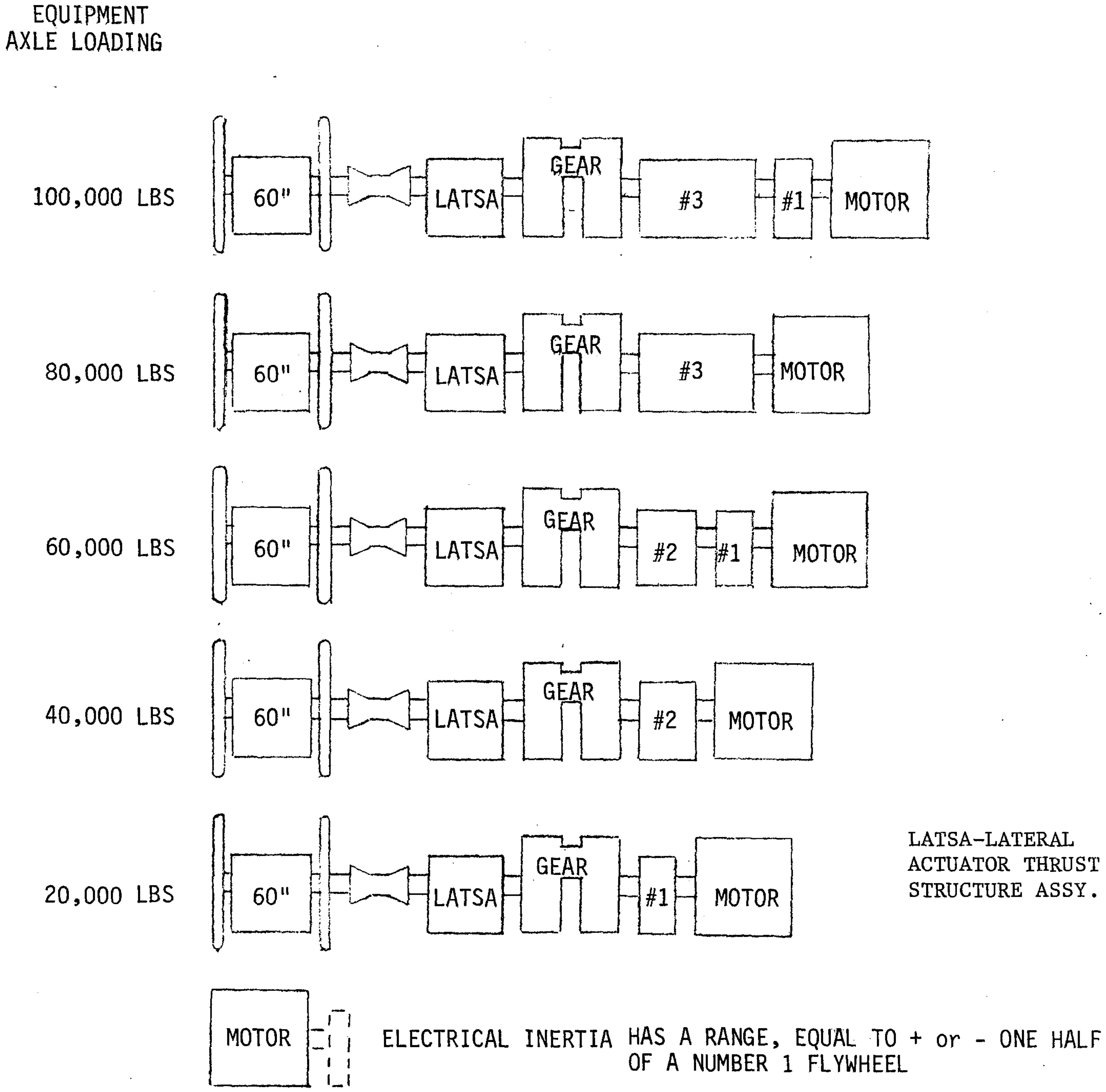
The use of 60" rollers in a directly coupled condition sets the relationship between the peripheral speed of the roller to the speed of the drive train and motor:

peripheral speed (miles per hour) = roller speed (RPM) x 0.1785
peripheral speed (miles per hour) = roller speed (Rad/sec) x 1.7045



#1 FLYWHEEL SIMULATES 5,000 LB LONGITUDINAL INERTIA
#2 FLYWHEEL SIMULATES 10,000 LB LONGITUDINAL INERTIA
#3 FLYWHEEL SIMULATES 20,000 LB LONGITUDINAL INERTIA

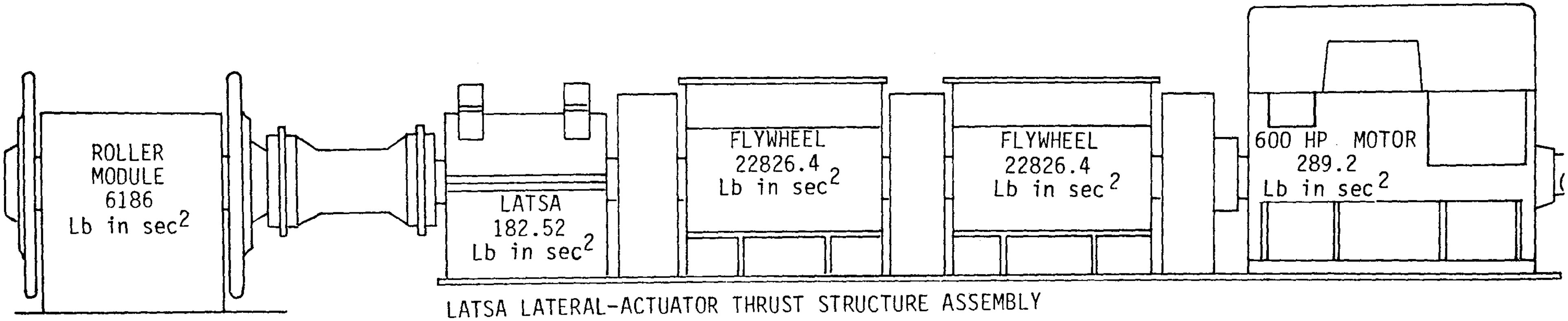
FIGURE 5.1 DRIVE TRAIN CONFIGURATION OPTIONS/42" ROLLERS (0 to 50,000 LBS)



#1 FLYWHEEL SIMULATES 20,000 LBS LONGITUDINAL INERTIA
#2 FLYWHEEL SIMULATES 40,000 LBS LONGITUDINAL INERTIA
#3 FLYWHEEL SIMULATES 80,000 LBS LONGITUDINAL INERTIA

GEARBOX RATIO IS 2302/805

FIGURE 5.2 DRIVE TRAIN CONFIGURATION OPTIONS/60" ROLLERS (0 to 100,000 LBS)



LATSA LATERAL-ACTUATOR THRUST STRUCTURE ASSEMBLY

FIGURE 5.3 RDU DRIVE TRAIN CONFIGURATION FOR SOAC TEST

5.2.1 Drive Train Passive Inertia

Because the SOAC car has no forward velocity when running on rollers (however motors and axle sets are spinning), the longitudinal inertia was simulated by the addition of flywheels.

Although the drive train can be configured to give any desired longitudinal inertia independent of the actual weight of the car on the rollers, it was desired in this case that the longitudinal simulated inertia, match that of the axle load in order that contact patch conditions be as close as possible to actual running values.

The SOAC car was weighed on a per truck basis prior to mounting on the rollers. The truck weights were:

END A	END B	BOTH
45,980 lbs	44,860 lbs	90,840 lbs

Dividing the required longitudinal inertia equally among each of the four drive trains, gives 22,710 lbs per drive train.

The following formula gives the relationship between the rotating inertia and simulated longitudinal inertia and is obtained by equating longitudinal and rotating kinetic energy:

$$J_m = \frac{WR^2}{g}$$

Where J_m = Polar Moment of Inertia (lb-ft-sec^2)
W = Weight of Vehicle (lbs)
R = Roller Diameter (ft)
g = Gravitational Constant (ft/sec^2)

From the equation, the polar moment of inertia required on directly coupled 60" rollers is 4413.5 lb-ft-sec^2 or 52,961 lb-in-sec^2. The configuration used and shown in Figure 5.3 has an inertia of 52,309 lb-in-sec^2. This was 652 lb-in-sec^2 short of the requirement which was adjusted by the use of the electrical capability of the motor.

5.2.2 Electrical Inertia Simulation

The control system of the motor of the drive train is such that a positive or negative torque can be applied proportional to the rate of change of drive train speed. This has the characteristic of inertia. The motor is capable of supplying electrical inertia equivalent to 1/2 the value of a #1 flywheel, sufficient to bridge the gaps between the passive inertia values shown in the configurations of Figure 5.1 and 5.2.

The feature of electrical inertia simulation of the drive train is such that in the case of the standard 60" roller configurations large ranges of simulated weight can be made without reconfiguration. With the gear unit fitted to 60" rollers the electrical longitudinal inertia simulation can be varied between ±10,000 lbs.

For the SOAC tests, only longitudinal inertia was modeled, so that the electrical inertia was set at only one value.

The values of passive and electrical inertia are shown as follows:

		PASSIVE	ELECTRICAL
Total Longitudinal Inertia	Longitudinal Inertia Per Drive Train	Longitudinal Inertia Simulated Per Drive Train	Longitudinal Inertia Simulated Per Drive Train
90,840 lb.	22,710 lb.	22,430 lb.	279.5 lb.
		Actual Rotational Polar Moment of Inertia	Actual Rotational Polar Moment of Inertia
		52,309 lb-in-sec^2	652 lb-in-sec^2
		Total Rotational Polar Moment of Inertia per Drive Train	
		52,961 lb-in-sec^2	

The electrical inertia was added by adjusting thumb switches at the front panel of the master control unit. The value entered at the panel is entered by the control system to each drive train equally. In this case, however, the electrical inertia simulated only represented 1.2% of the total longitudinal inertia. Prior to the tests, the control electrical inertia system was calibrated for the 60" diameter rollers with direct coupling.

5.2.3 Electrical Simulation of Aerodynamic Drag and Other Forces

The motor of the drive train can output a desired torque at any instant and thus can be used to simulate aerodynamic forces, grade forces, curving resistances, etc. This feature is available when the drive train is under full computer control. However, full computer control was not available for the SOAC test, but control of torque was obtained in a limited manner by analog electrical circuitry connected into the control circuits of the master control panel. It was not intended that the circuitry be a permanent fixture, but only to demonstrate torque control for the SOAC tests.

For the track test, the SOAC cars are subjected to the following energy losses:

1. Aerodynamic losses acting on the car body.
2. Aerodynamic losses acting inside the motors (windage).
3. Motor bearing losses.
4. Gearing losses.
5. Rolling losses due to contact patch and due to track flexibility.
6. Flange contact losses.
7. Energy losses in suspension components, couplers, etc.

On the rollers the motor and gearing losses are present because the wheels are turning. However, Aerodynamic Losses on the car body are absent and because the car runs very steadily there are no flanging losses or suspension component losses. Also, the rollers are of a harder material than rail and do not have the soft track flexibility. The rolling losses on the rollers are less than those on track.

There are losses present on the roller not present for track testing, namely the natural losses of the drive trains.

The objective of the torque control of the motor is to bring the energy loss characteristic with speed to match as closely as possible that obtained from track testing or predicted in the absence of track testing.

From the track testing data available from the SOAC tests, Traction Resistance/Speed Characteristics are available. Figure 5.4 shows the Traction Resistance/Speed Characteristic for one car at the Test Track altitude of 4,900 ft. The tractive resistance has been divided by 4 to give traction resistance per axle. Also shown on Figure 5.4 is the natural losses of the drive train. This characteristic was obtained from the curve of speed versus time obtained by allowing one drive train to coast down in speed from 80 mph. The two graphs in figure 5.4 show that the losses of the drive train, at 80 mph, are 54% of the tractive resistance of the SOAC car at the same speed.

The overall tractive resistance with the SOAC car mounted, is addressed in Section 7.0 Traction Resistance.

The manual speed mode allows the control system to maintain a constant speed set by speed reference thumb switches on the control panel. In this mode, electrical inertia circuits are inactive.

Figure 5.5 shows a view of the master control panel and the four drive train control panels.

In manual torque mode, electrical inertia circuits are active and the motor provides additional torque equal to the value set on the torque reference thumb switches. In this mode, the drive train speed will "float" dependent on drag values, transit car input, etc.

In the computer modes, full computer control can be used to control either speed or motor torque, but because full computer control was not available, (due to software limitations) the tests were run in the manual torque mode. The front panel torque reference thumb switches were set to zero, but tests were conducted with a torque reference signal supplied by an electronic circuit as a function of speed, in order to obtain overall correct tractive resistance values.

5.2.4 Operation Mode of the Drive Trains

Each drive train can be operated individually or by master control. For the SOAC tests the operation was by master control. The master control can be in one of the following modes:

1. Manual Speed
2. Manual Torque
3. Computer Speed
4. Computer Torque

The Manual Torque mode was used for the SOAC tests.

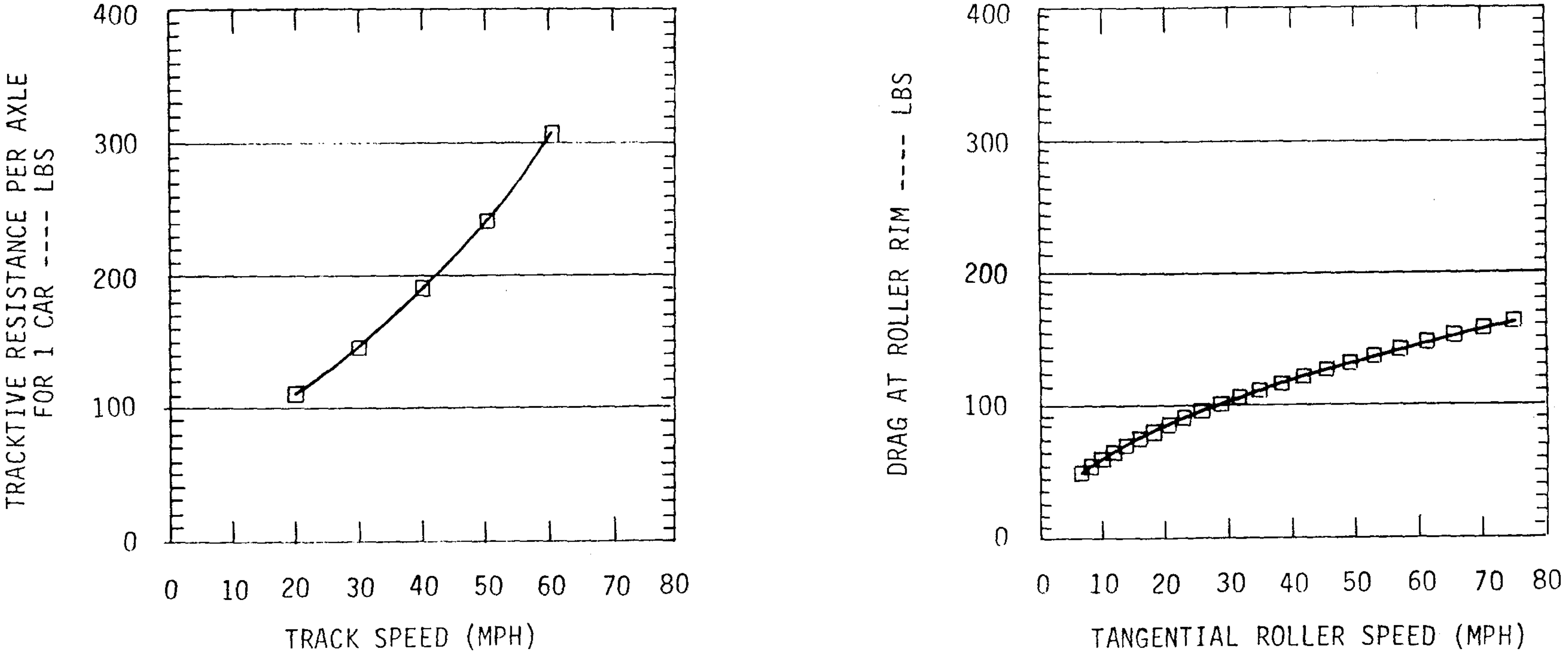


FIGURE 5.4 SOAC CAR TRACTIVE RESISTANCE/SPEED AND DRIVE TRAIN DRAG/SPEED

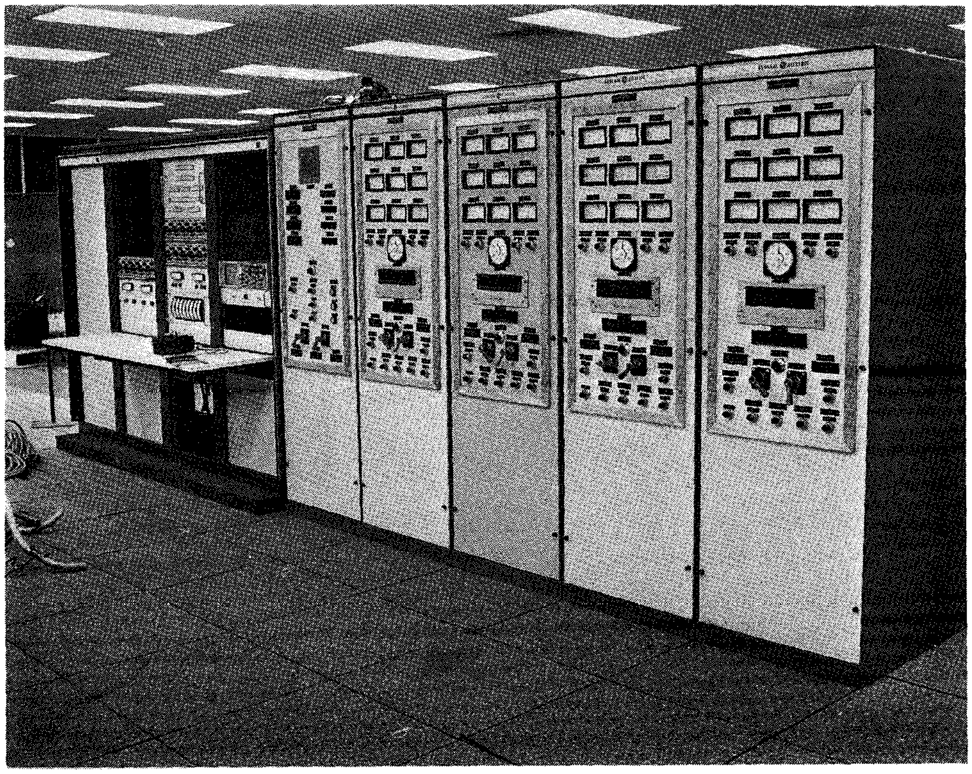


FIGURE 5.5 RDU MASTER PANEL AND 4 DRIVE TRAIN CONTROL PANELS

6.0 INSTRUMENTATION

6.1 General

The SOAC was instrumented for a number of major parameters and the data stored in the RDL data collection system.

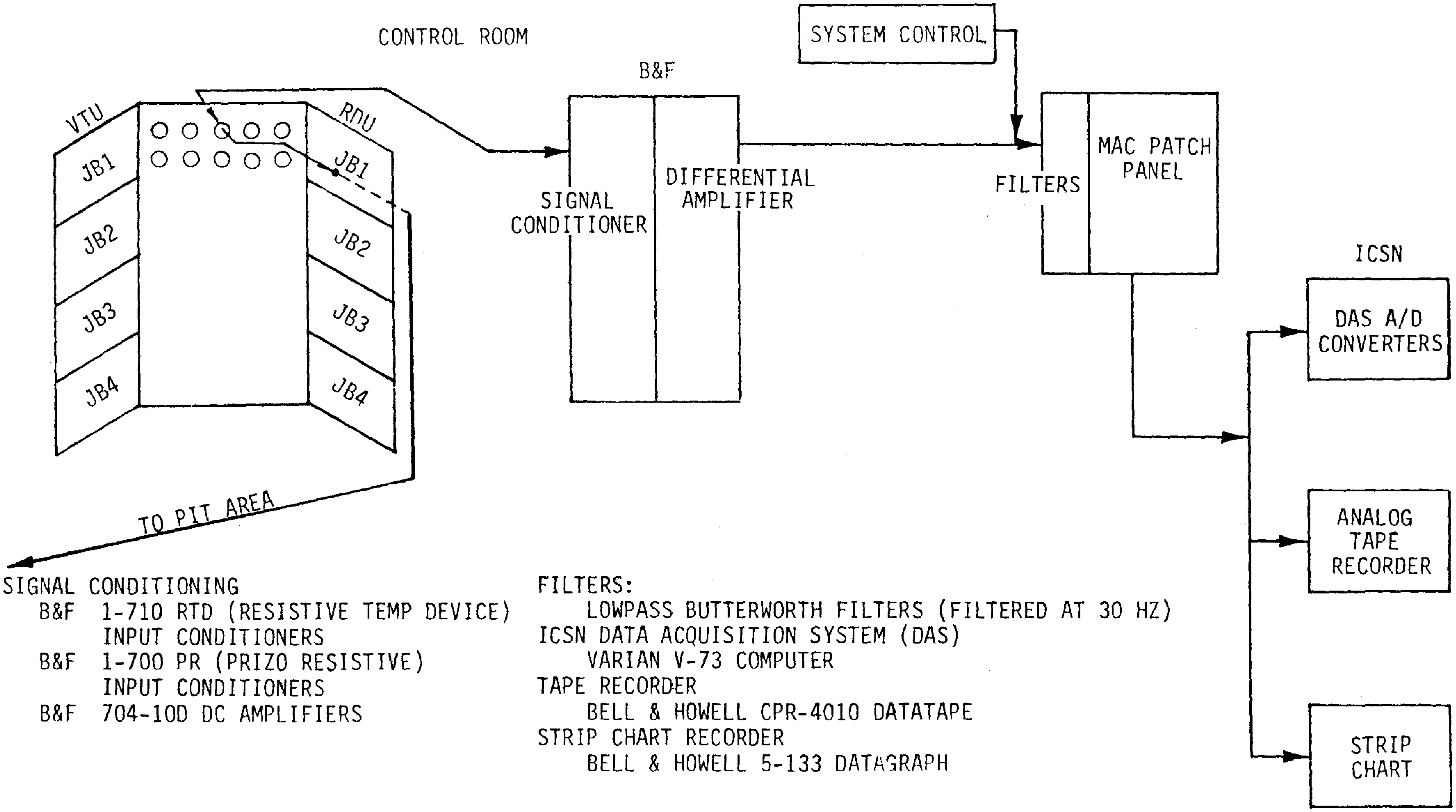
The RDL data collection system is a hybird system, collecting data via signal conditioning onto digital and analog tape. The data flow is shown in Figure 6.1. For the performance tests, 54 parameters were simultaneously recorded onto a multiplex FM recorder or onto an A to D system (ICSN, Integrated Computer System Network). Twelve of the channels were viewed on '0' graph.

Data for this report has been produced almost exclusively from the analog tape, although the digital data would have been available for an in-depth study.

The parameters recorded are listed in detail in the Appendix and consist of the following measurements:

25	temperature
3	voltage
7	current
9	speed
1	pressure
4	torque
2	loads

RAIL DYNAMICS LABORATORY
DATA ACQUISITION SYSTEM



SIGNAL CONDITIONING
  B&F 1-710 RTD (RESISTIVE TEMP DEVICE)
      INPUT CONDITIONERS
  B&F 1-700 PR (PRIZO RESISTIVE)
      INPUT CONDITIONERS
  B&F 704-10D DC AMPLIFIERS

FILTERS:
  LOWPASS BUTTERWORTH FILTERS (FILTERED AT 30 HZ)
ICSN DATA ACQUISITION SYSTEM (DAS)
  VARIAN V-73 COMPUTER
TAPE RECORDER
  BELL & HOWELL CPR-4010 DATATAPE
STRIP CHART RECORDER
  BELL & HOWELL 5-133 DATAGRAPH

FIGURE 6.1 RDL DATA ACQUISITION SYSTEM FLOW DIAGRAM

7.0 TRACTION RESISTANCE

7.1 Objective

The objective of this test was to check if the overall traction resistance/speed characteristic of the SOAC car on the RDU rollers was a good approximation to that produced from track testing. The correct simulation of tractive resistance is required to obtain accurate acceleration and braking characteristics.

7.2 Test Method

With the master control system set in the "Manual Torque Mode", the SOAC car was run up under its own power to a target speed at which the SOAC control was set to "COAST". The speed was allowed to drift freely down.

To prevent any large differences in roller speed developing between each drive train, the tests were conducted with target speeds in 10 mph increments and concluded after a loss of approximately 15 mph.

The speed/time histories were plotted on an XY plotter and the slope of the curve produced the deceleration rate at any velocity.

7.3 Results

The total rotary inertia of the drive train and SOAC car axle set was known, thus the drag torque and hence tractive resistance at the roller rim could be calculated from the deceleration rates.

The following table lists the traction resistance at the roller rim for one drive train.

SPEED (MPH)	TRACTION RESISTANCE AT RIM (LBS)	
	(PER AXLE)	(PER CAR)
5	104	416
10	131	524
15	153	612
20	173	692
30	222	888
40	274	996
50	323	1292
60	410	1640
70	468	1872

Figure 7.1 shows the tractive resistance/speed curve for SOAC taken from the roller unit and also for SOAC taken from track tests.

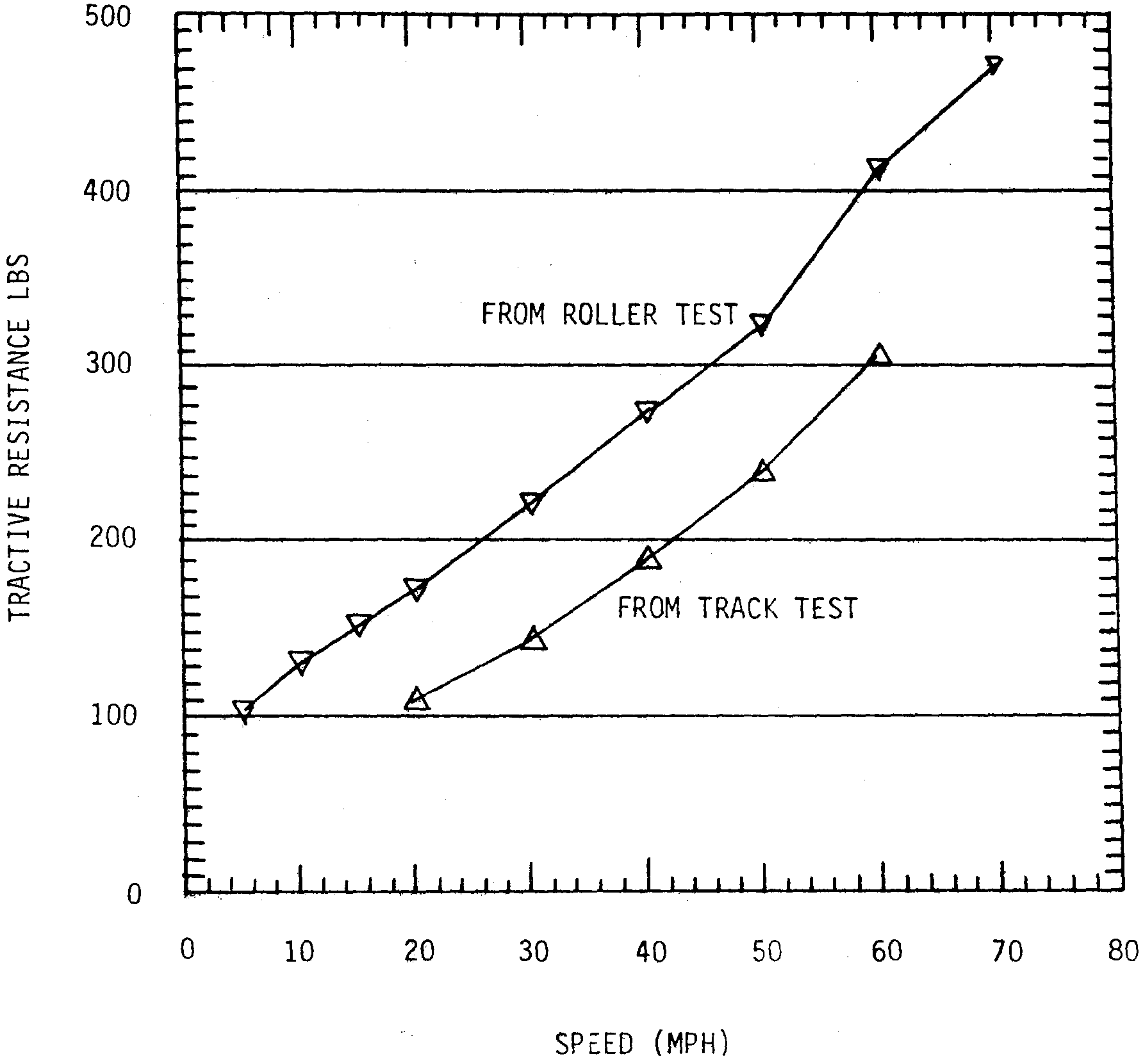


FIGURE 7.1. SOAC TRACK AND RDU TRACTIVE RESISTANCE/SPEED CHARACTERISTIC (PER AXLE).

7.4 Discussion

From Figure 7.1 the roller unit produced approximately 25% greater tractive resistance than was required. It follows that the combination of the drive train losses and applied drag torque was too high. Had testing time been greater (restricted by funding constraint), the applied drag torque could have been adjusted to give closer approximation between the roller tractive resistance and the track tractive resistance.

The effect of higher tractive resistance on the rollers than on the track should have small impact on performance evaluation.

Although close agreement between track and rollers was not obtained, the capability of active variable torque input was amply demonstrated.

8.0 ACCELERATION

8.1 Objective

The objective was to obtain acceleration characteristics on the rollers and compare with track data. Funding restraints prevented tests run at other than the nominal 600 volts.

8.2 Method

With the master control in Torque Mode, the SOAC car was accelerated under its own power using varying P-signals (AMPS). In this instance acceleration rates were obtained from speed/time curves produced on an XY plotter from the recorded roller speed signal.

Distance data was produced from a roller revolution counter and is accurate to 12 feet.

8.3 Test Results

The acceleration/speed characteristics obtained on the RDU for four P wire signals are shown in Figure 8.1. For comparison with track tests, the track characteristics are shown in Figure 8.2 and acceleration/speed data for both the RDU and the track tests is presented in the table on page 34. The Speed/Time/Distance characteristic obtained on the RDU for P = 1 amp is shown in Figure 8.3 and the corresponding track characteristic is shown in Figure 8.4. The control linearity under acceleration at 10 mph for the four P wire signals is shown in Figure 8.5.

8.4 Discussion

At full acceleration of P wire = 1 amp, the car showed close agreement between track tests and roller tests except at high speeds. However, at other P wire values there is less agreement; with the roller test, accelerations in general were lower than those of the track. Also, the control linearity, Figure 8.5, shows that two P wire currents of 0.75 amp and 0.875 amp to be out of the specification tolerance of ± 10% (full scale). It is not thought that this is a result of incorrect roller performance, but rather poor adjustment of the SOAC control.

It should be noted that there were differences between track and roller conditions. Two important areas being that of car weight and voltage current characteristic. The track car weight was 105,000 lbs, but roller car weight was 90,840 lbs. The track voltage supply was very "soft", being 700 volts at zero speed and falling to 600 volts at full power. The roller voltage supply was 600 volts at zero power and remained at that voltage throughout acceleration. Close agreement, therefore, cannot be expected.

In conclusion, the RDU successfully demonstrated its capability to obtain acceleration control characteristics. Such features as off-nominal voltage, variable car weights and forward/reverse directions were not evaluated because of funding restraints, but indications are that they could be readily tested.

(continued on page 34)

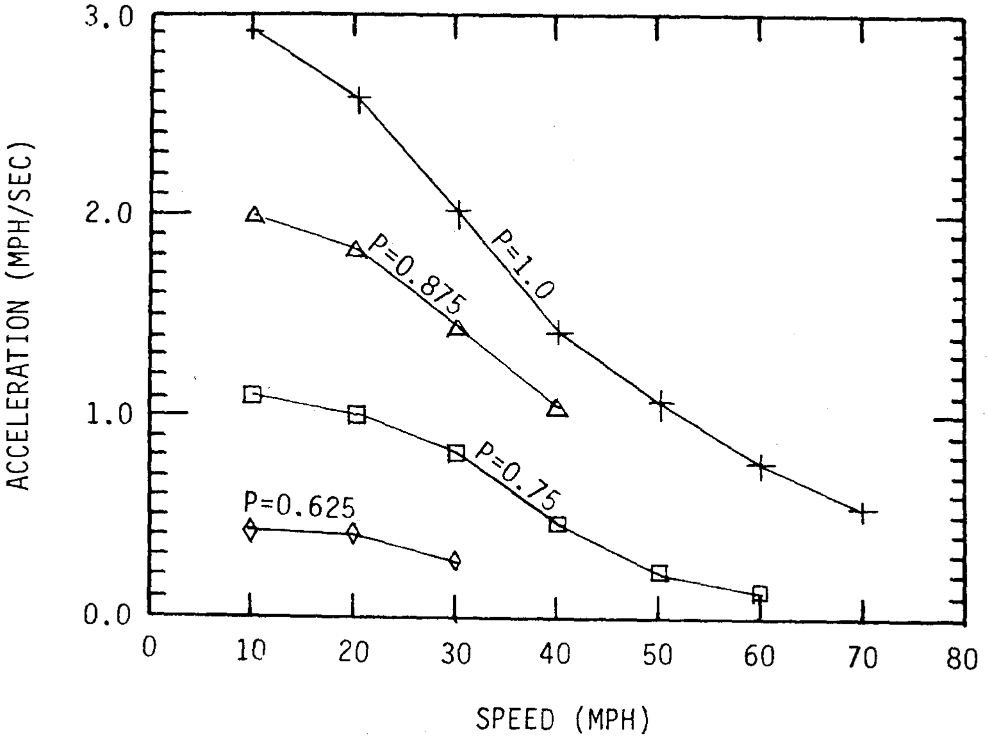


FIGURE 8.1. SOAC RDU ACCELERATION CONTROL CHARACTERISTICS.

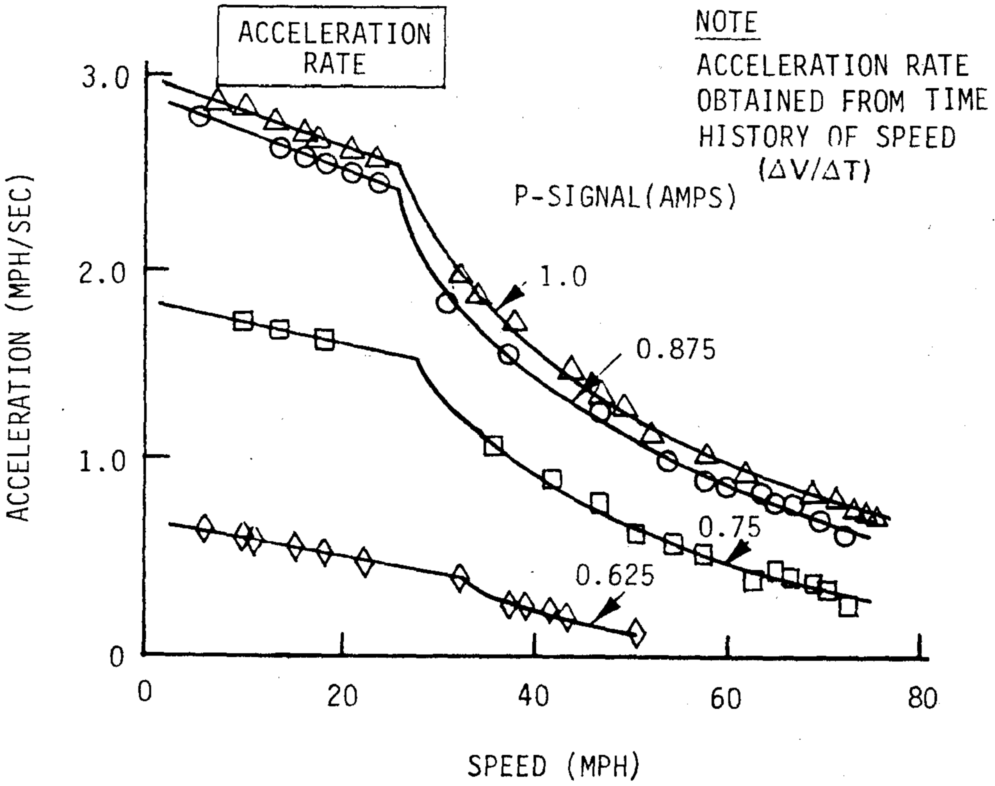


FIGURE 8.2. SOAC TRACK ACCELERATION CONTROL CHARACTERISTICS.

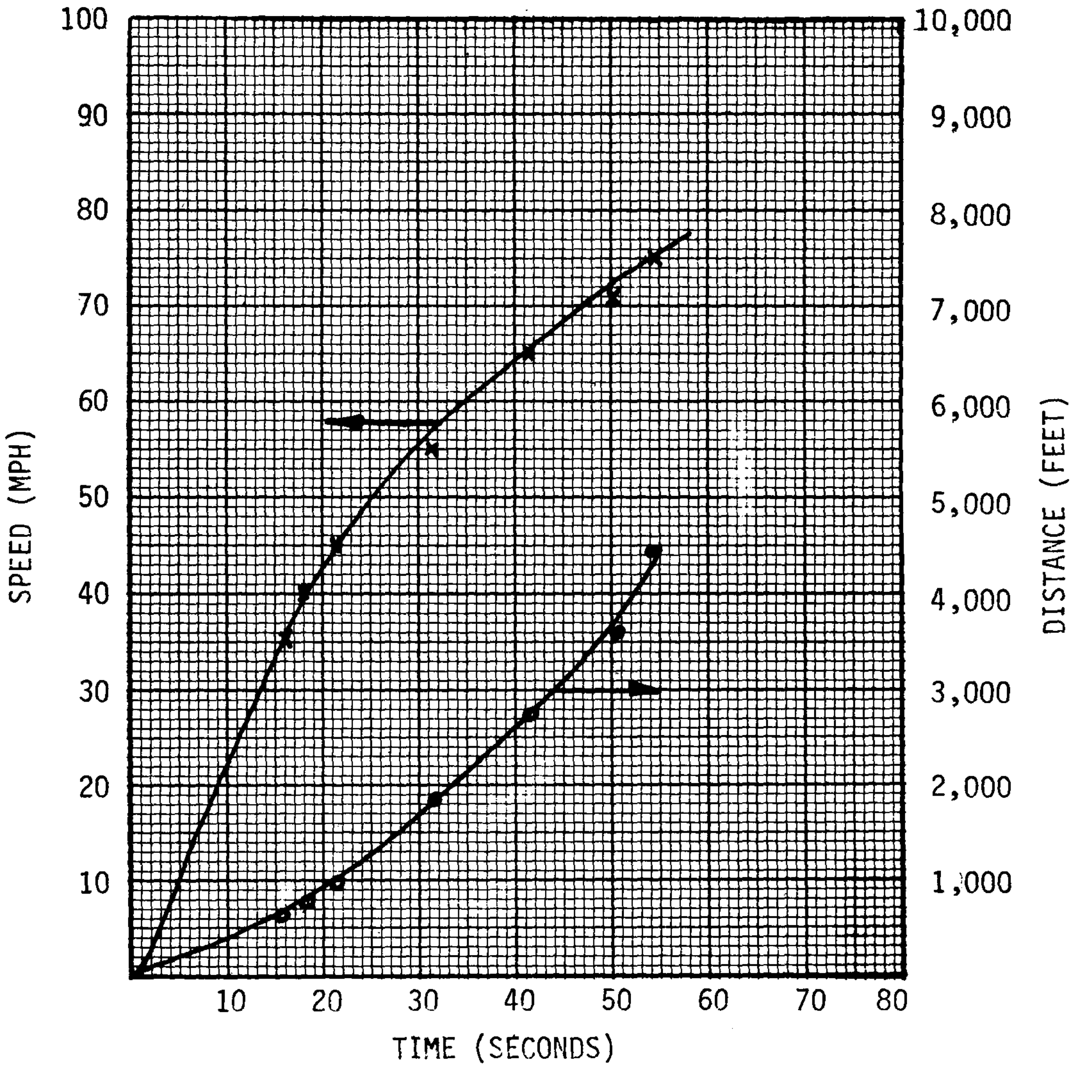


FIGURE 8.3 SPEED AND DISTANCE VS TIME ON RDU AT P = 1.0 AMP

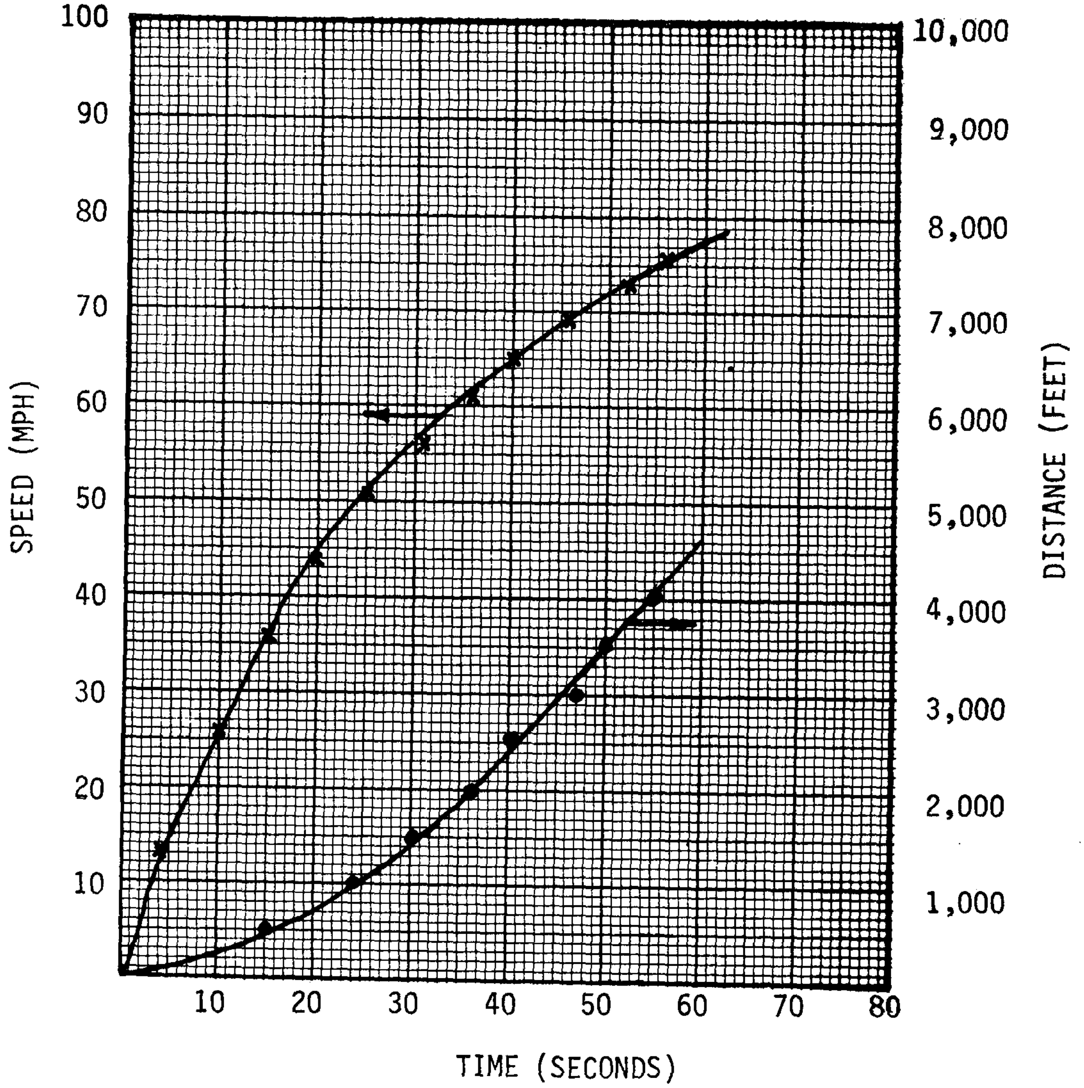


FIGURE 8.4 SPEED AND DISTANCE VS TIME ON TRACK AT P = 1.0 AMP

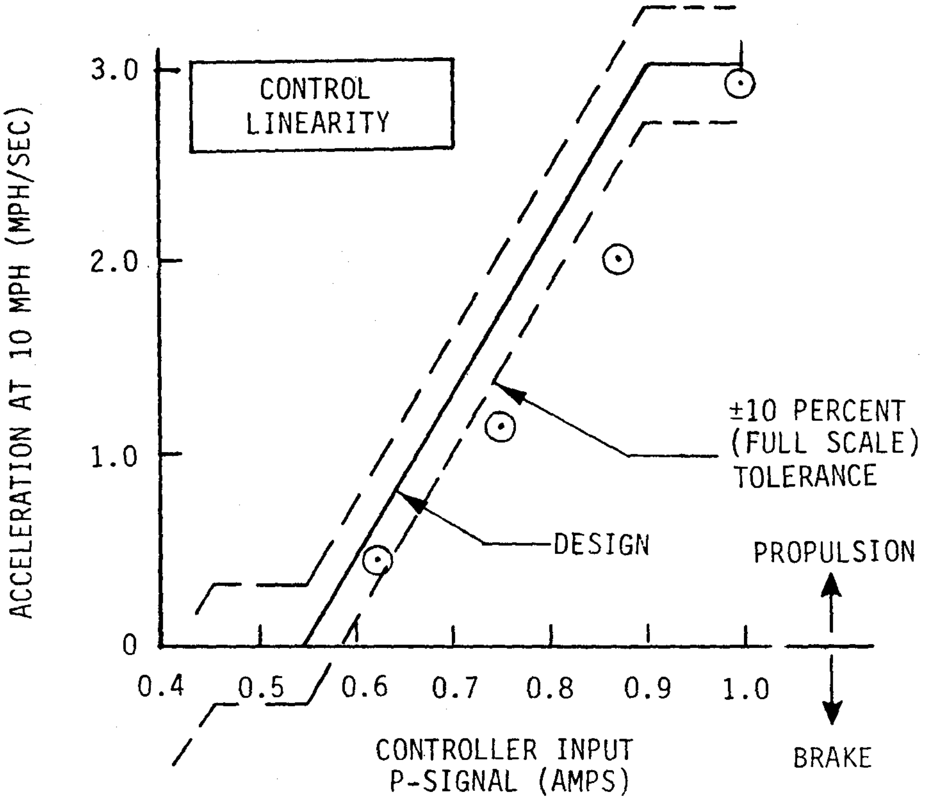


FIGURE 8.5 ACCELERATION CONTROL LINEARITY CHARACTERISTIC ON RDU

ACCELERATION/SPEED CHARACTERISTICS

COMPARISON OF TRACK DATA AND RDU DATA

SPEED MPH	P wire = 0.625 AMP		P wire = 0.75 AMP		P wire = 0.875 AMP		P wire = 1.0 AMP	
	ACCEL MPH/SEC		ACCEL MPH/SEC		ACCEL MPH/SEC		ACCEL MPH/SEC	
	RDU	TRACK	RDU	TRACK	RDU	TRACK	RDU	TRACK
10	0.434	0.6	1.103	1.72	2.0	2.71	2.91	2.81
20	0.414	0.5	1.010	1.61	1.835	2.52	2.58	2.64
30	0.28	0.41	0.819	1.32	1.446	2.02	2.02	2.11
40	0.0	0.22	0.465	0.91	1.046	1.41	1.42	1.56
50	0.0	0.10	0.225	0.65	---	1.10	1.07	1.22
60	0.0	---	0.128	0.46	---	0.86	0.77	0.98
70	0.0	---	---	0.36	---	0.67	0.54	0.79

(continued from page 29)

Recording of other parameters such as armature currents and control signals was also successful on the RDL data acquisition system and would be available for future in depth analysis. From analog signals available at the time of testing, speed/time and speed/acceleration characteristics could have been produced in real time on XY plotter equipment so that the control equipment of one SOAC car could be adjusted and/or modified.

9.0 DECELERATION

9.1 Objective

The objective of the deceleration tests was to obtain the major characteristics of the four brake modes - blended, dynamic only, service friction only, and emergency; and compare to the track test data. The characteristics were to be obtained in good adhesion conditions.

9.2 Method

The SOAC was run to target speed under its own power. Target speed was maintained for a few seconds, then the brake mode was initiated. Speed/time histories provided deceleration rates and distance to stop was provided by the number of roller revolutions taken to stop. The RDU control system was in "Torque Mode" with the reference torque set to zero and tractive resistance feed-back activated.

9.3 Results

9.3.1 Blended Mode

The blended braking mode, which corresponds to normal operation was operated at the following four P wire signals: 0.0, 0.125, 0.250, and 0.375 amp.

For control linearity comparison, the average deceleration rate from 75 mph was computed for each P wire signal by the relationship:

$$\text{average deceleration} = \frac{\text{initial speed (mph)}}{\text{time to stop (seconds)}}$$

Figure 9.1 shows the results plotted against the design criterion, and shows that there was poor linearity in this mode. Two of the four values fell outside the tolerance levels.

The deceleration/speed characteristics obtained on the RDU for each P wire signal from an initial speed of 75 mph are shown in Figure 9.2. The corresponding track characteristics are shown in Figure 9.3. The track data shows steadier deceleration rates than those obtained on the roller test.

The time and distance taken to stop from an initial speed of 75 mph for each P wire is shown in tabular form along with the corresponding track values in the table on page 37.

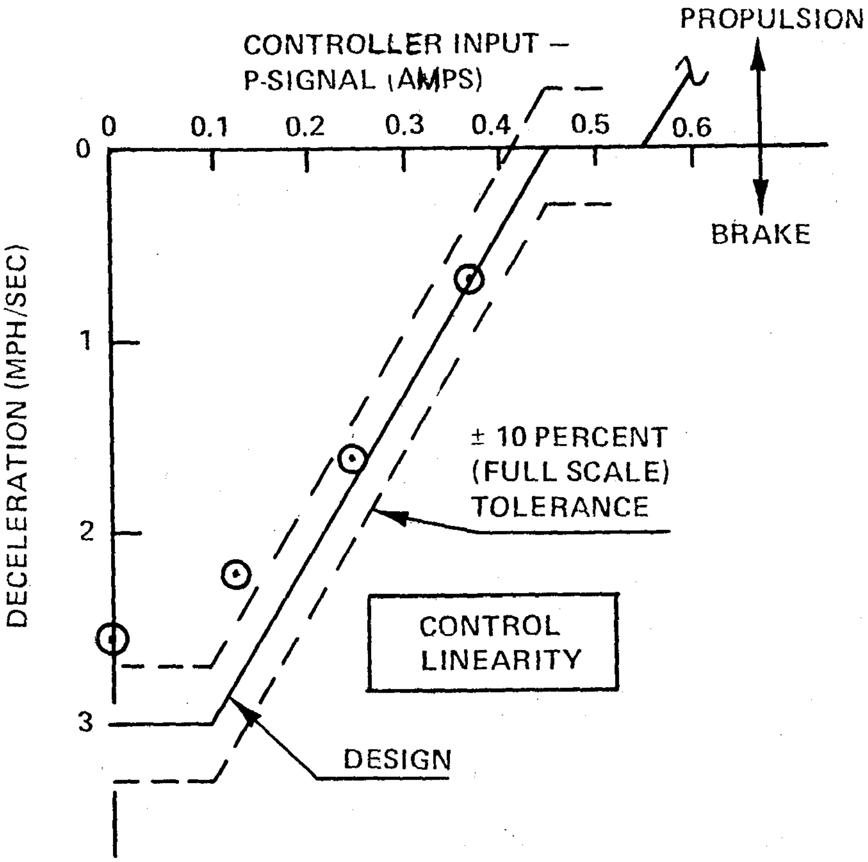


FIGURE 9.1 BLENDED DECELERATION CONTROL LINEARITY CHARACTERISTIC ON RDU

BLENDED BRAKE CONTROL INITIAL SPEED = 75 MPH CONTROLLER INPUT P-SIGNAL, DC (AMPS)	P=0.0	P=0.125	P=0.250	P=0.375
Stopping Time: (Seconds)				
Track:	27.9	31.0	44.2	92.5
Roller:	29.8	34.7	44.9	107.5
Stopping Distance: (Feet)				
Track:	1667	1800	2467	4883
Roller:	1477	2058	2466	5608

The time and distance to stop versus initial speed characteristics for P wire = 0.0 amp (full brake) is shown graphically in Figure 9.4 and the corresponding track data in Figure 9.5. The data shows fair agreement.

9.3.2 Service Friction Mode

The Service Friction Mode, which corresponds to a dynamic brake system failure, was operated at the same four P wire signals as those of the Blended Brake Tests.

For control linearity comparison, the deceleration rate at 10 mph following deceleration from 80 mph is shown in Figure 9.6. The data shows marginal agreement with the design specification. The deceleration speed characteristic for each P wire signal from an initial speed of 70 mph is shown in Figure 9.7 and the corresponding track characteristic is shown in Figure 9.8. The roller test shows a steady deceleration rate as the speed fell.

The distance to stop and time to stop for each P wire from an initial speed of 70 mph is shown in the following table, along with the corresponding track data.

SERVICE FRICTION BRAKE CONTROL INITIAL SPEED = 70 MPH CONTROLLER INPUT P-SIGNAL, DC (AMPS)	P=0.0	P=0.125	P=0.250	P=0.375
Stopping Time: (Seconds)				
Track:	27.5	30.2	47.9	142.5
Roller:	28.5	31.2	46.3	99.0
Stopping Distance: (Feet)				
Track:	1667.7	1770.8	2708.3	7487.0
Roller:	No Data	1743.6	2686.1	6942.9

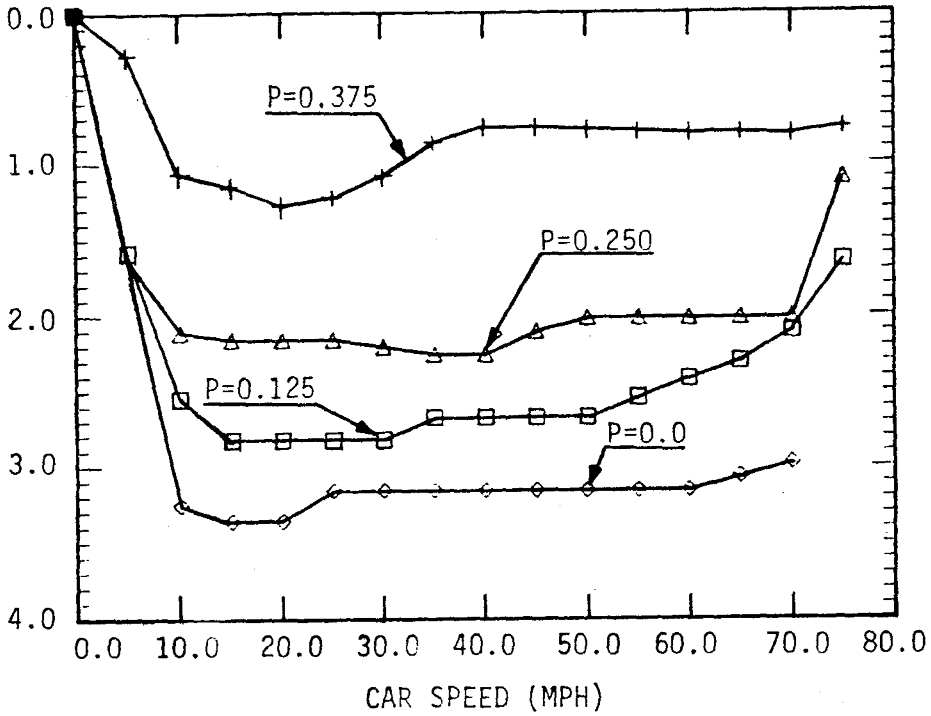


FIGURE 9.2. SOAC RDU BLENDED BRAKING CONTROL CHARACTERISTICS.

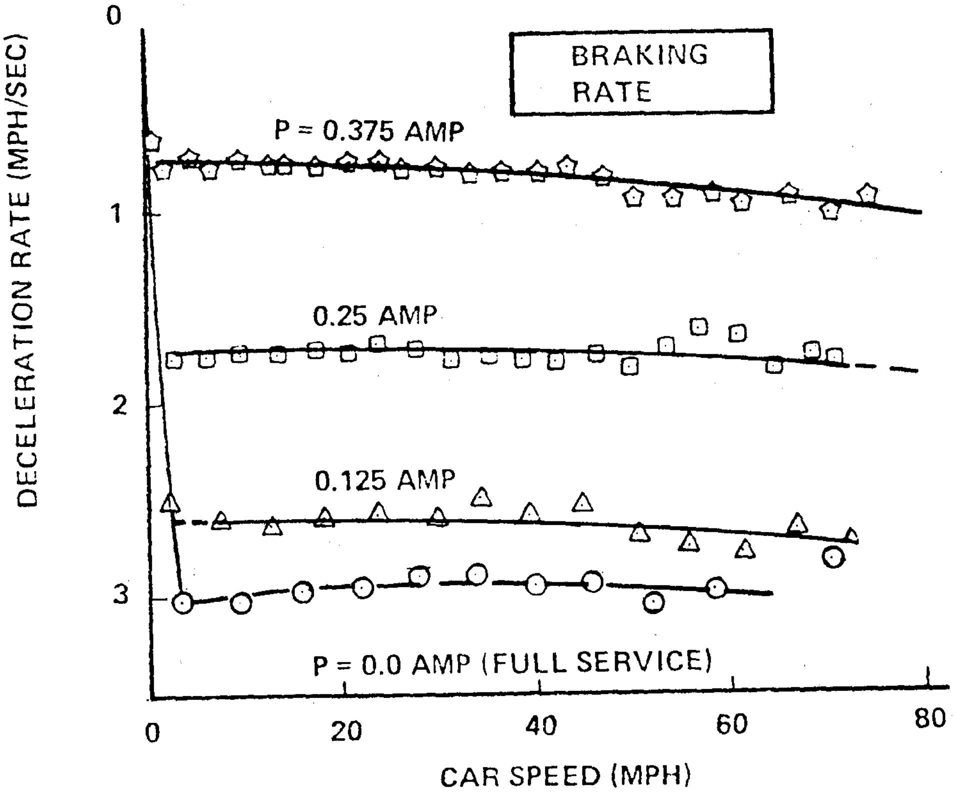


FIGURE 9.3. SOAC TRACK BLENDED BRAKING CONTROL CHARACTERISTICS.

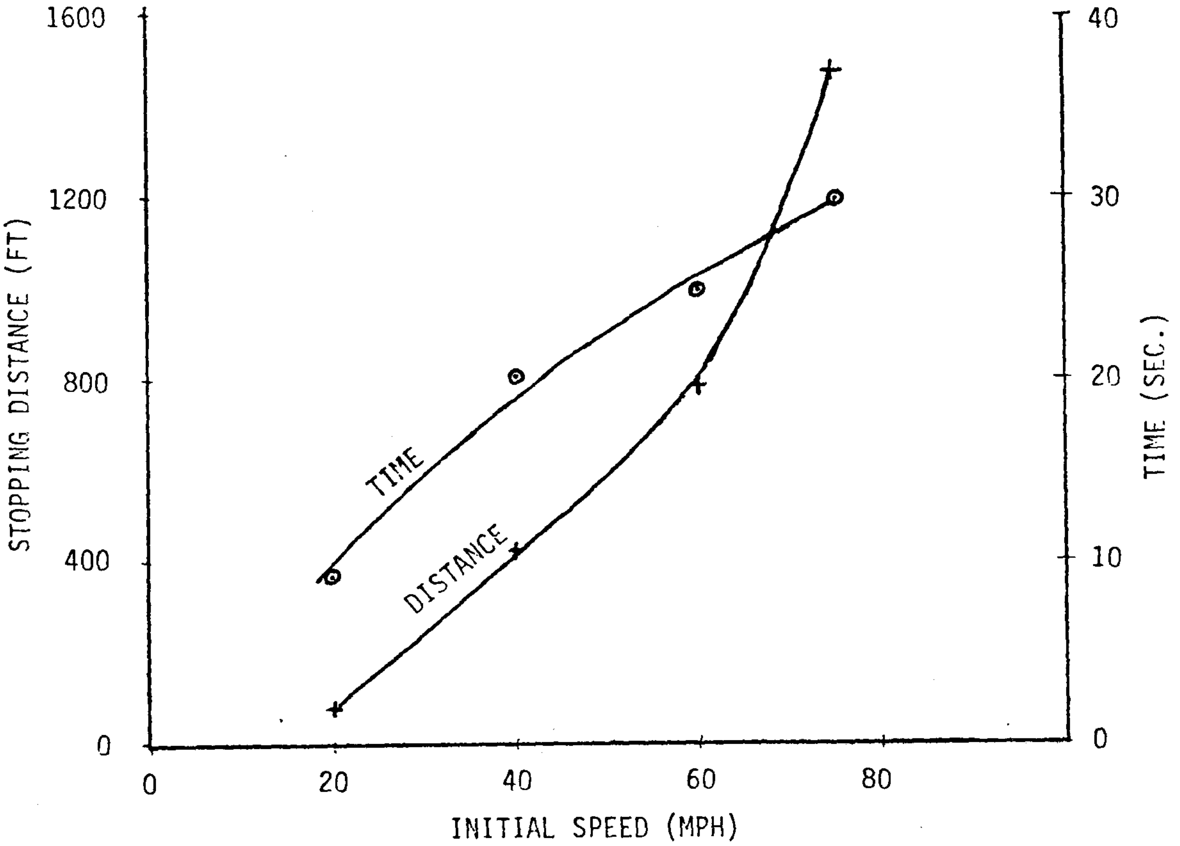


FIGURE 9.4. SOAC RDU BLENDED BRAKING STOPPING DISTANCE.

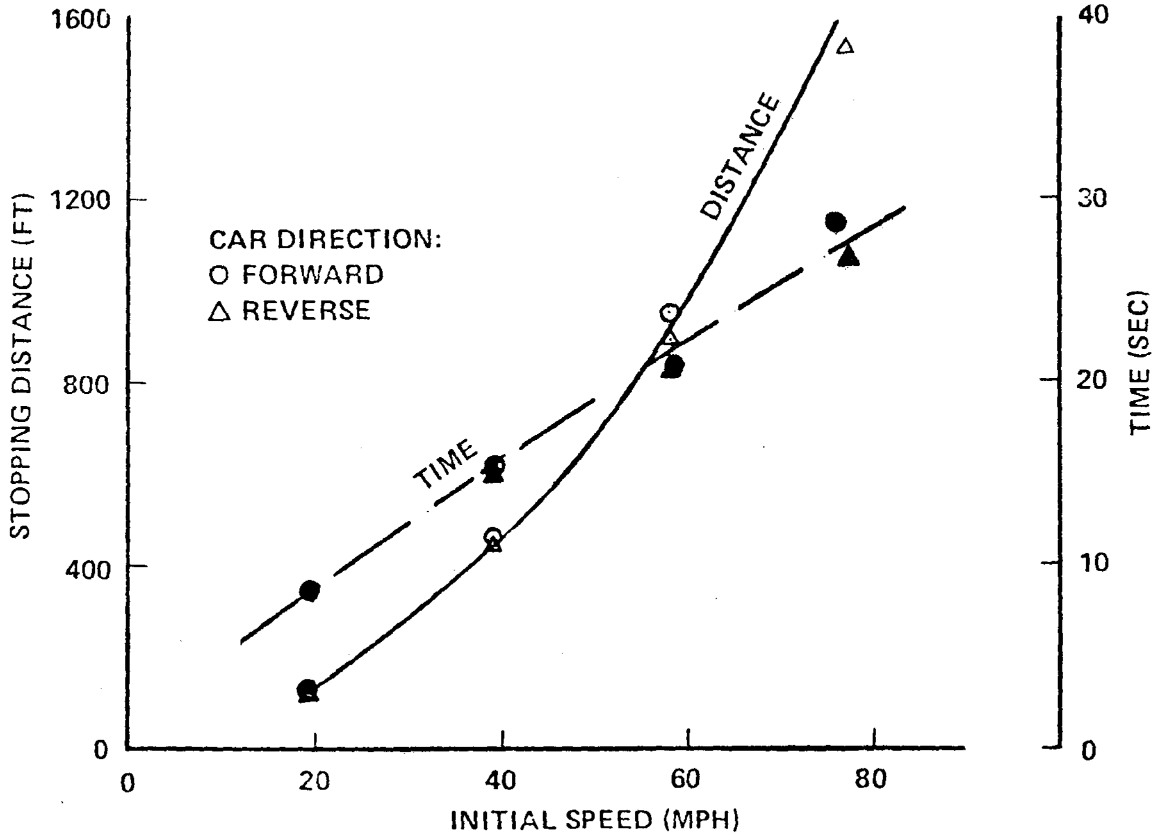


FIGURE 9.5. SOAC TRACK BLENDED BRAKING STOPPING DISTANCE.

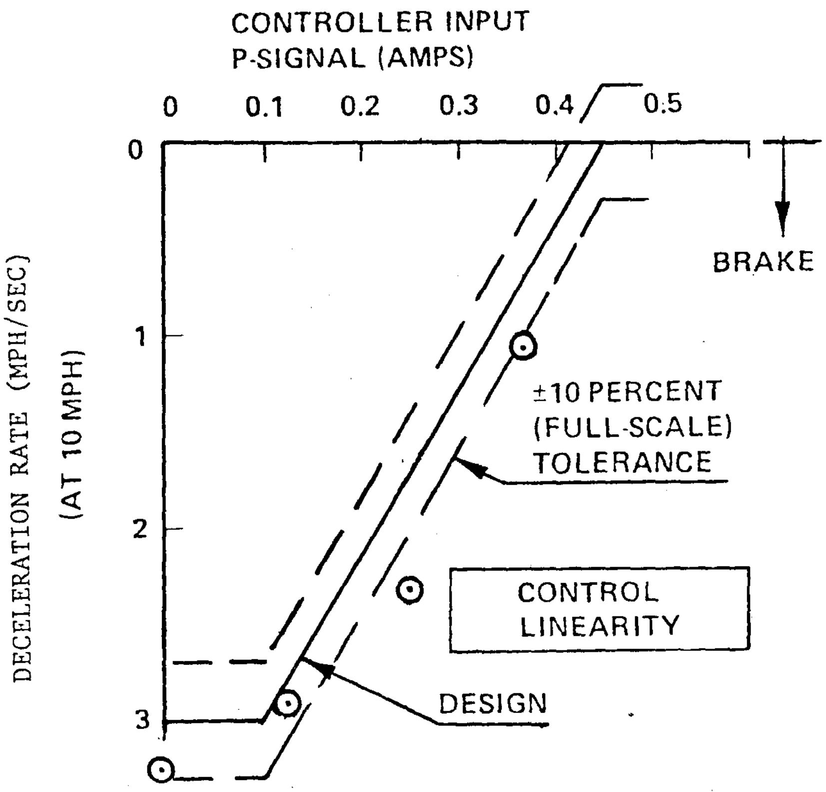


FIGURE 9.6. SOAC SERVICE FRICTION DECELERATION CONTROL LINEARITY CHARACTERISTIC ON RDU.

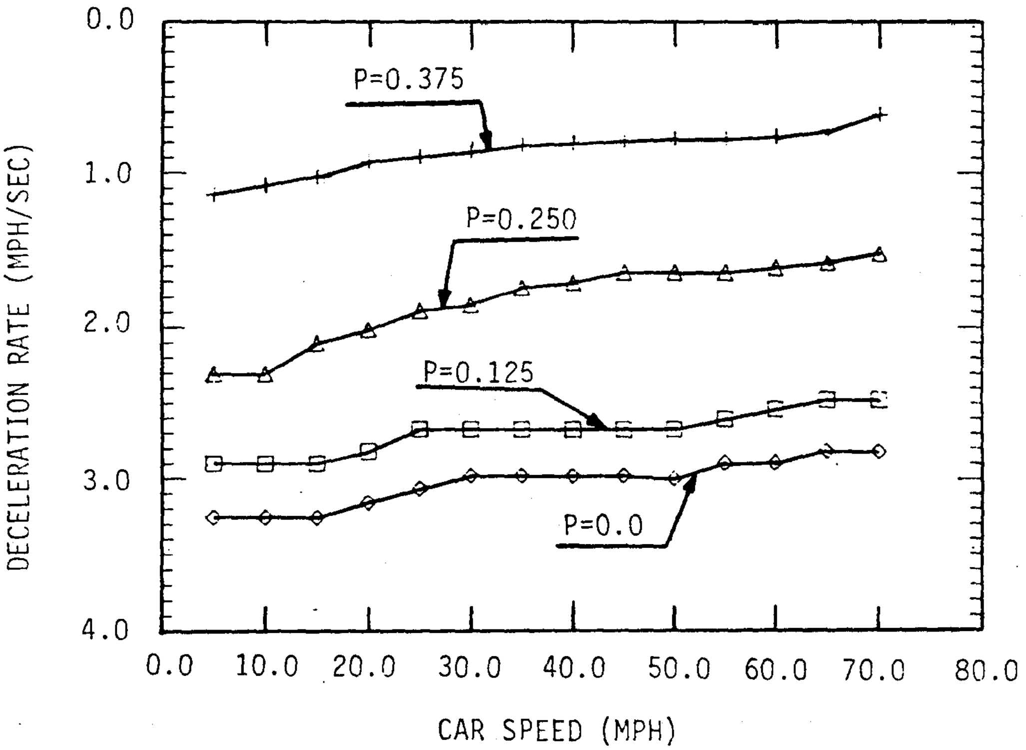


FIGURE 9.7. SOAC RDU SERVICE FRICTION BRAKING CONTROL CHARACTERISTICS.

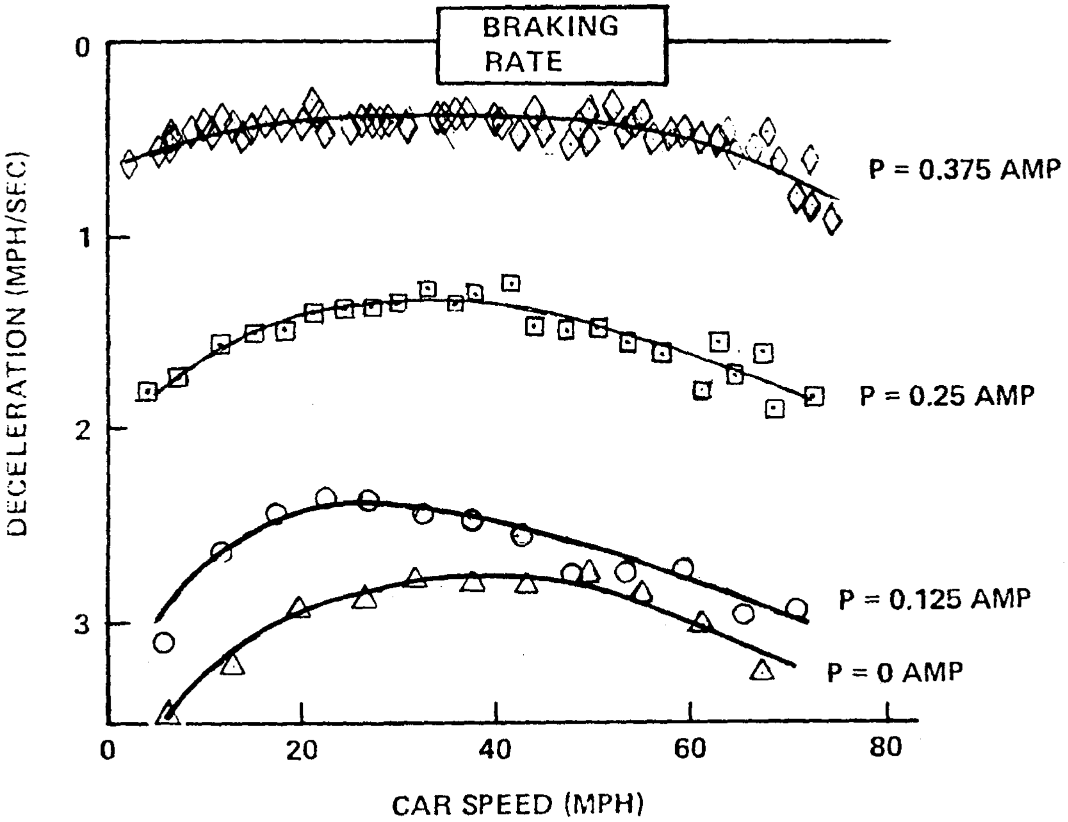


FIGURE 9.8. SOAC TRACK SERVICE FRICTION BRAKING CONTROL CHARACTERISTICS.

9.3.3 Dynamic Braking Only Mode

In this mode all friction brake application is removed and the characteristic of the dynamic brake can be evaluated. Because of time restraints only P = 0.0 amp (Full Service) was tested from four initial speeds. The following table lists the initial speed and the average deceleration over the period of braking. After the SOAC braking effort became zero, the rollers were brought to a stop by the roller regenerative brake.

INITIAL SPEED (MPH)	* DECELERATION MPH/SECOND
76	2.58
64	2.58
41	2.54
16.4	2.56

* typical deceleration rate from the slope of speed/time curve.

This corresponds to 2.9 mph/second for a full service application from 70 mph for the track test.

9.3.4 Emergency Friction Mode

In this mode only friction brakes are used, activated by the emergency stop button on the motormans console.

Only three initial speeds were tested. The following table shows the major characteristics.

INITIAL SPEED (MPH)	DISTANCE TO STOP (Feet)	TIME TO STOP (SEC)	* DECELERATION (MPH/SEC)
59.2	784.4 (780)	20.48 (16.4)	3.27
38.3	314.2 (300)	12.88 (9.3)	3.15
21.3	110.0 (80)	9.17 (5)	3.00

* typical deceleration rate from the slope of speed/time curve.

Figures in parenthesis are for the corresponding track test data. The last run of 75 mph (not shown above) produced a flat on wheelset number two with dimensions 1/2" long 2-3/4" wide by 3/16" deep. Further testing on rollers 1 and 2 was discontinued and the final test, the spin/slide test, was completed using rollers 3 and 4 only.

9.4 Discussion

In general the RDU deceleration data showed agreement with track data. The major differences can be explained by SOAC setup differences rather than by any intrinsic errors of the RDU. Also, the speed data obtained on replay from the multiplex FM recording system was such as to give inaccurate acceleration values and speed data subject to large drift errors. The lack of true acceleration data hampered good comparison.

Funding constraints prevented more complete testing other than in the Blended Brake Mode.

The flat produced by drive train 2 is cause for concern and shows one of the drawbacks to RDU testing. The RDU rollers during the test run became contaminated by oil and other materials which tended to build up on the circumference of the rollers. In the absence of a continuous roller surface scrubbing system, the likelihood of severe slides produced by the emergency brake mode is great. During track tests a severe flat can be removed by a trip to the wheel truing machine at small cost, but for an RDU test this would involve removing and remounting the car. At the moment, without further study, emergency brake operation with spin/slide protection inoperative cannot be accommodated on the RDU.

10.0 SPIN/SLIDE PROTECTION SYSTEM TESTS

10.1 Objective

The objective was to evaluate the SOAC spin/slide protection system on the RDU and compare to track data. However, it was known that because of RDU control restraints this objective would only partially be investigated with the available funds.

The RDU at the time of test could only give identical roller speeds in the "constant speed" mode of operation. In the torque mode, roller speeds are free to float to any value, and thus only systems that operate on a per axle basis can be evaluated. The SOAC spin/slide system operates on a rate of change of axle speed and a differential speed basis.

On a track test, if power or brake is removed from a spinning or sliding wheel set, the wheelset will readjust its speed to match that of the train's forward speed. However, in the case of a wheel on the rollers in torque mode, wheel speed will readjust to the particular roller speed it is on, which may not be identical with other rollers. Testing was attempted in order to ascertain in what capacity the RDU could perform spin/slide system testing.

10.2 Method

Because truck 1 was inoperative with the wheel flat, testing was limited to truck 2 (rollers 3 and 4).

Power was removed from truck #1 and the control system modified so that armature current from truck 1 and 2 were "balanced". Unfortunately, the soap/water spray system had been set up prior to testing on rollers 1 and 2 only, which limited the roller lubrication on rollers 3 and 4 to an application of a grease film prior to the test. This did not generate results comparable with track data where a soap solution was used, but was the only expedient thing to do to comply with time and budget restrictions.

The SOAC car was accelerated and braked under its own power control with the rollers in "torque" mode. Indication of slip or slide was available at the motorman console.

10.3 Results

Two acceleration and fifteen deceleration runs were made. During both acceleration runs (at full power) spin was observed on axle 4. During some of the deceleration runs (those in the service friction mode) slides occurred. Changes in armature current and brake pressure confirmed the operation of the spin/slide control system, see Figure 10.1. Unfortunately, the recorded speed signal from axle 4 was of such poor quality as to make analysis impracticable.

The grease produced unsteady adhesion conditions and badly contaminated the friction brake shoes.

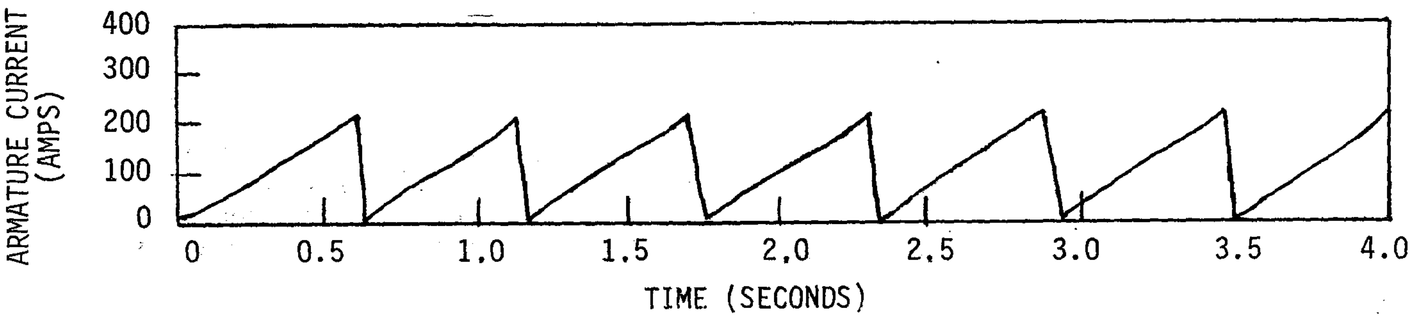


FIGURE 10.1 TRACTION MOTOR ARMATURE CURRENT LEVELS DURING SLIP

During deceleration under blended or dynamic only modes, the SOAC control system on the onset of braking went into "TE pause" and continued to coast.

No damage to the rollers was noticed during the tests.

10.4 Discussion

In general, the test was only partially successful. The tests did show the operation of spin/slide on rollers without damage to the rollers, but the combination of several problems such as:

Testing only one truck.
Grease for roller lubrication.
Poor speed recording.

severely limited the test value.

It is concluded that the torque mode is not a suitable mode for spin/slide testing because of the loss of roller speed synchronization. However, had time permitted, spin/slide testing would have been evaluated in constant speed mode which may have advantages over track testing.

In the constant speed mode, speed regulation is within 0.1%, maintaining close speed to all drive trains. Spin/slide testing could be performed where in effect the car would not accelerate or decelerate. By the maintenance of controlled low adhesion levels on the rollers using a suitable wetting apparatus and by the use of the Hemmelstein torque meter between motor and rollers, data on maximum available adhesion and average adhesion may be available directly, values not available directly in track testing.

For a slide test in constant speed mode, a speed would be selected, say 50 mph, and the drive trains run for a few minutes to stabilize adhesion levels. Braking would be initiated at a gradually increasing rate until a slide occurred. The torque readout at this instant would give the true maximum available adhesion, and the average torque readout over a few slide cycles would give the average braking rate. The test would then be repeated at a range of speeds to give an efficiency/speed characteristic. A similar approach would be used for a spin test.

In conclusion, although the spin/slide test in the torque mode was of limited value, a future test in the constant speed mode may well be very productive and should be explored; although the test would require the construction of apparatus to produce and maintain low adhesion values on the rollers. There was no data available to support any quantification of a spin/slide efficiency or an adhesion level. A separate section on adhesion will not be addressed.

11.0 ENERGY CONSUMPTION AND UNDERCAR TEMPERATURE TESTS

11.1 Objective

The objective of this test was to determine the energy consumption of the SOAC by following a simulated route profile and compare the data to the track energy consumption tests. In addition, the temperatures of undercar equipment were monitored for their peak values in a powered stationary car.

11.2 Method

With the RDU in "manual torque" mode and with torque input applied to simulate tractive resistance, the SOAC was powered without auxiliaries to follow a speed/distance profile. A station stop of 30 seconds was used. The sequence is shown in the table on page 49.

A typical acceleration/time and speed/time section of the profile is shown in Figure 11.1.

Distance for brake application was taken from a roller revolution counter. The energy consumed was found by a watt/hour meter applied to the RDU power supply. The total distance traveled was 9.62 miles, which was one half the distance of the track test.

11.3 Results

The energy consumed between station stops on the RDU is listed on page 50. The average energy consumption was 6.14 kw-hr/car mile which compares to the track figure of 6.7 kw-hr/car mile.

The table on page 51 compares the undercar equipment temperatures taken on the track to that on the rollers.

11.4 Discussion

The agreement between track and roller power consumption shows the effectiveness of power consumption evaluation on the RDU. However, the track used a heavier car than the roller test and the roller test modeled a slightly higher tractive resistance.

The capacity of the RDU to model grades, off-nominal voltage, and a range of vehicle weights was not evaluated. The ability to evaluate power consumption characteristics is an attractive feature of the RDU.

No problems were encountered in conducting energy consumption tests because of lack of forced air flow over brake resistors. These were cooled by locally applied external fans.

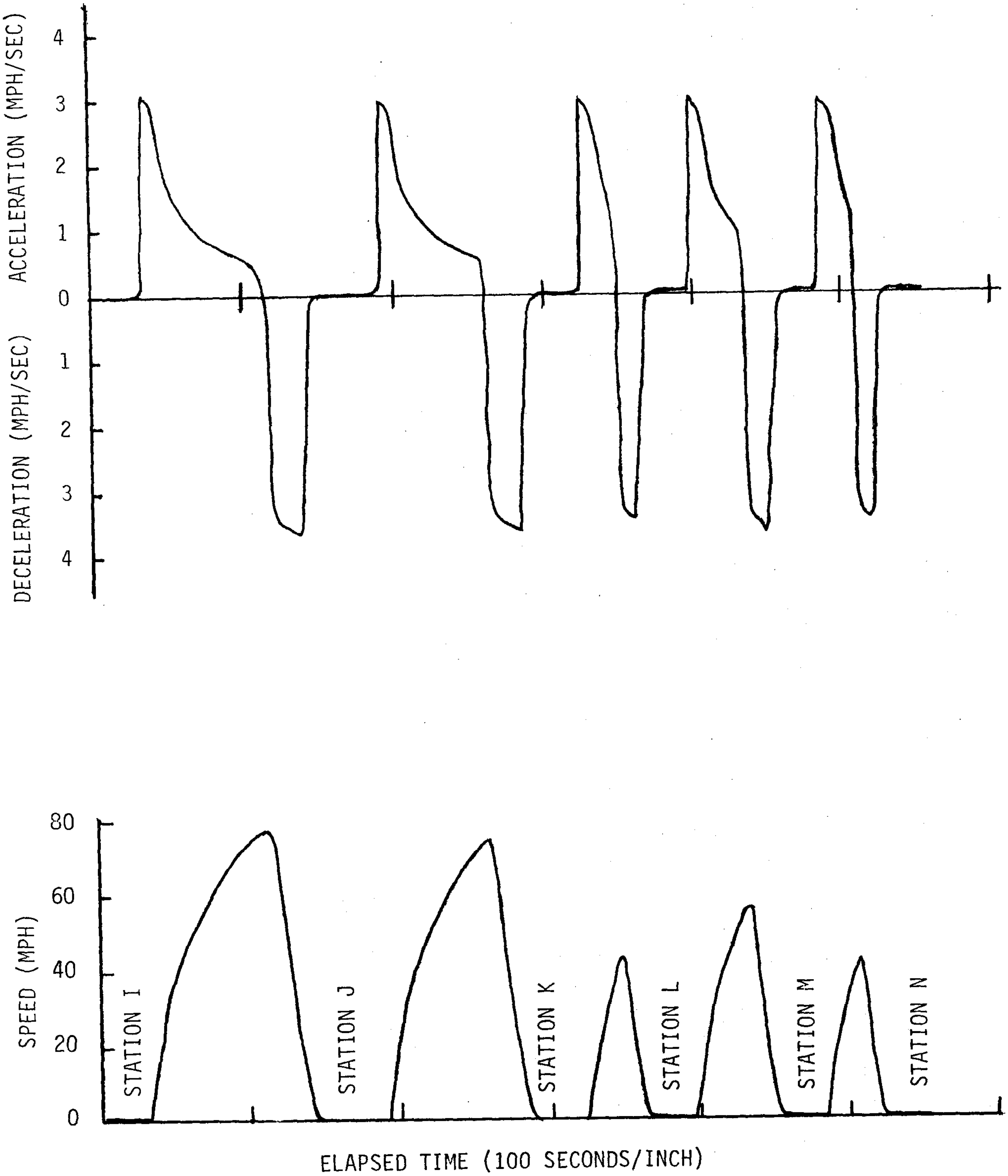


FIGURE 11.1 POWER CONSUMPTION PROFILE SECTION ON RDU

POWER CONSUMPTION TEST SEQUENCE

STATION	SPEED (MPH)	DISTANCE (MILES)	ROLLER REVS	STATION STOP TIME (SECS)	APPLICATION OF BRAKE MARKER (APPROX. REVS)
A to B	60	0.75	252.12	30	191
B to C	70	1.00	336.16	30	250
C to D	50	0.50	168.08	30	126
D to E	60	0.75	252.12	30	191
E to F	50	0.50	168.08	30	126
F to G	40	0.25	84.04	30	55
G to H	40	0.25	84.04	30	55
H to I	50	0.50	168.08	30	126
I to J	80	1.50	504.23	30	402
J to K	80	1.25	420.19	30	315
K to L	40	0.25	84.04	30	55
L to M	50	0.50	168.08	30	126
M to N	40	0.25	84.04	30	55
N to O	70	1.00	336.16	30	250

ENERGY CONSUMED BY SOAC ON THE RDU

ENERGY BETWEEN STATION STOPS (kw-hr)	NUMBER OF REVOLUTIONS	DISTANCE (mi)	ENERGY CONSUMPTION (kw-hr/car mi)
3.8	254	0.76	5.03
5.9	343	1.02	5.78
2.6	170	0.51	5.14
5.0	267	0.79	6.29
3.0	181	0.54	5.57
1.7	84	0.25	6.80
1.5	82	0.24	6.15
2.8	171	0.51	5.50
8.7	515	1.53	5.68
7.8	439	1.31	5.97
2.1	96	0.29	7.35
3.9	187	0.56	7.01
2.1	95	0.28	7.43
6.5	348	1.03	6.28
57.4		9.62	85.98

AVERAGE ENERGY CONSUMPTION = $\frac{85.98}{14}$ = 6.14 kw-hr/car mi

LENGTH OF RUN = 23 min 32 sec

SCHEDULE OF SPEED = 9.62/0.3922 hr = 24.53 mi/hr

SUMMARY OF SOAC UNDERCAR EQUIPMENT TEMPERATURES ON RDU AND TRACK

PARAMETER	PEAK TEMPERATURE (°F)	
	RDU	TRACK
Propulsion blower, Outlet air	119	140
Chopper box, Interior air	122	145
Chopper box, Outlet air	110	145
Traction motor, No. 3 frame	136	151
PCU, Interior air	148	152
PPCU, Interior air	164	177
APCU, Interior air	143	160
Motor smoothing reactor	224	167
Brake grid air *	1332	835
Motor-alternator, Outlet air	147	168
Air conditioner, Condenser, Input air	108	159
Test ambient air	85	77

NOTES:

Performance level-duty cycle: 1-hour rating

PCU = Power Control Unit

PCCU = Propulsion Power Control Unit

APCU = Auxiliary Power Control Unit

* Peak recorded temperatures during brake applications.

12.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

12.1 Discussion

The running of the SOAC car on the RDU successfully demonstrated both the suitability and unsuitability of the RDU for transit car performance evaluations and thus the main test objective was satisfied. The RDU was not built as a performance test rig however, and thus it has inherent drawbacks and limitations although these are in part compensated by additional features not available in track work.

The RDU consists of 4 independent drive trains, each one containing a proportional inertia and torque feed-back. The system is only suited for investigations of parameters which can be divided on a per axle basis. For instance, if a vehicle had say two axles powered and four axles braked, the RDU as it stands could not run a profile, since inertia assigned to the drive trains would be different in either brake or power mode. Also during acceleration the unpowered rollers would remain stationary.

The independent operation of the drive train also is evident should any of the brakes or power systems be in a state of unbalance. In the brake mode, this can cause one axle to stop rolling on the drive train before another axle, or, in the power mode, to reach target speed before the other axle. In a two car performance test on the track, a single out-of-balance motor does not have a dominant effect on performance characteristics. On the rollers it does.

The above difficulty could be resolved somewhat by the use of computer control of drive train speed, torque, etc. This would involve difficulty, since for correct simulation the energy balance must be correct at any instance. Such a balance would be maintained if the rollers were mechanically linked together, in which case the inertia could be added as a single unit.

Although the RDU has limitations because the rollers are not mechanically linked together, the feature of the system to add both electrical inertia and torque input is very useful. In the configurations with 60" rollers and 2.81:1 gear box, the electrical inertia has a range of ± 10,000 lbs. simulated longitudinal inertia per drive train. This gives the ability to vary the effective car weight without drive train reconfiguration. It must be remembered though, that the RDU cannot simulate weight transfer during acceleration or braking, and that the control system can only apply equal electrical inertia to the drive trains.

A very useful feature of the RDU not available at the TTC test track is the ability to change gage of the drive trains in the range 4' 8½" to 5' 6". The RDU could accept transit vehicles from: BART (5' 6"), SEPTA (5' 2½"), Pittsburgh (5' 2½"), Toronto (4' 10").

Under computer control, which would provide positive or negative torque input, a grade profile can be followed including simulation of head winds, curve resistance, etc. The method of simulation of tractive resistance used in the SOAC test is not recommended since fine adjustments are not possible, and the values cannot be varied at will throughout a test sequence. The use of a desk-top computer for computer control of the RDU would provide such housekeeping tasks as oil pressure monitoring leaving the computer only responsible for speed/torque control.

A significant drawback to performance test on the RDU is the lack of a longitudinal accelerometer data available in track testing. Acceleration has to be deduced from speed time characteristic of the rollers. To obtain acceleration in this way required accurate speed values, and it was found that the multiplex analog recording of speed used for the SOAC test was not of sufficient accuracy, was too noisy, and drifted, to give good acceleration data.

For this report, acceleration was calculated by hand measurement of the slope of the speed/time curve of the rollers, which did not produce data points closer than 5 mph increments. Considerable time was spent in an attempt to produce acceleration by the electrical differentiation of the speed signal. However, the signal was far too noisy to produce accurate acceptable results.

Each drive train does produce a pulse tachometer signal from the motor speed sensor and at the LATSA. This signal, if fed to an electronic counter with output in ASC11 form, could provide speed data with extreme accuracy and thus accurate acceleration computed from it. In addition, the counter could provide accurate distance data which could be measured from a trigger set by the controller movement.

It is recommended, from the above, that the distance/speed/acceleration measurement and computation, of the drive trains and of the wheels, be improved.

Of the SOAC tests performed on the RDU, the power consumption tests illustrated the most useful ability of the RDU. The control on such parameters as - voltage, car weight, grade, adhesion, tractive resistance, etc. makes the RDU an effective development tool for the optimization of power consumption versus operating profiles, etc. Such a program would justify the more costly set-up expense versus track testing, which would offset against the ease of variable control. It was unfortunate that due to funding restraints this feature of the RDU was not more fully explored for the SOAC tests.

Of the SOAC tests performed on the RDU, the spin/slide tests were the least successful. Spin/slide testing in the torque mode is not recommended, but it is concluded that testing in the constant speed mode may provide data that is in some respects better than track testing. This mode of operation should be explored for future work. There is a need to build roller cleaning and controlled lubrication equipment for future work in low adhesion conditions.

Because of the severe wheel flat likelihood when operating in the emergency brake mode, it is not recommended that the RDU be used in this mode without further study to find a method which would reduce wheel damage.

The SOAC tests did show that although a severe flat was produced, that at the axle weight of approximately 25,000 lbs. no damage to the rollers was produced. This result is important since there is only one spare set of 60" rollers and the expense of manufacturing would probably preclude any more replacements.

A major cost of the RDU testing is the drive train reconfiguration cost, absent in track testing. With such a cost burden, transit car testing of significant extent is required unless the reconfiguration cost can be reduced.

A major difficulty experienced during SOAC testing on the RDU was contamination of the roller surface by oil and other contaminants. Unlike track testing in which the leading wheelset is always presented with clean rail (particularly so at the TTC where adhesion conditions are very good). Once contaminated, the rollers tend to remain so. It is recommended that a continuous roller scrubbing system be made to maintain roller surface conditions at high adhesion levels.

12.2 Conclusions

- The SOAC test successfully demonstrated the performance evaluation capabilities of the RDU.
- The RDU performance data matched that of the track data given the weight differences, adjustment differences, etc.
- The most successful test conducted was the power consumption test.
- The most unsuccessful test conducted was the spin/slide test.
- Emergency brake testing resulted in a severe flat spot on one axle which made truck #1 inoperative for further testing.
- The rollers do not maintain a steady surface condition during testing, in general the surface becomes contaminated.

12.3 Recommendations

- Speed and distance data from a pulse counter with an ANSI Standard MC 1.1 interface to either a desk-top or main frame must be set up for future roller work to provide good speed, acceleration data.
- The tractive resistance/speed input to each roller drive train should be provided from desk-top or main frame and not from an analog circuit board.
- Simulation of grade/distance can also come from a desk-top without the expense of total control of the drive trains from a computer.

- For all transit car tests a 60" roller, a 2.86:1 gear configuration with a #1 flywheel and electrical inertia should be suitable.

- The resistance/speed characteristic for each of the four drive trains for the above configuration should be determined.

- The use of the RDU for a long term test of power consumption/ speed profile/work should be investigated particularly for wide gage stock such as BART.

- The use of the RDU for straight forward performance characteristic tests cannot be recommended over track tests (unless the wheel gage is not standard) because of the higher set up costs.

- The electrical "tying together" of roller speeds should be investigated.